A STUDY ON A TESTING METHOD OF PUMPABILITY BY USING A MODEL OF CONCRETE PUMP

By Shun-ichi TAKAYAMA* : Assistant,
Sandra RESENDE* : Master's Student,
Akira WATANABE* : Professor,
Takashi IDEMITSU* : Assistant Professor,
Yoshifumi SAKAMOTO** : Director.

*Concrete Laboratory, Civil Engineering Department,
Kyushu Institute of Technology (KIT).
(804, Japan, Kitakyushu City, Tobata Ward, Sensui 1-1)

**Department of Architecture,
Chemical Nippon Steel Limited Company.
(804, Japan, Kitakyushu City, Tobata Ward, Saki no Hama)

ABSTRACT

In recent years after most of the concrete mixings are executed, a concrete pump is generally used on the construction site; but, unfortunately, as blockages happen in the pipeline, it becomes necessary to make the concrete more plastic than the required plasticity in the original construction. The reason for this is that there is not a measuring method to accurately express the concrete pumpability.

The authors produced, by some trials, a simulate model of concrete pump having two hydraulic jacks at both ends of a steel pipe. The jacks can act simultaneously keeping the pressure in the pipe at desired values as the oil pressure system is connected with both of them. The authors made sure that the model of the pumping system behaved like truck-mounted pumps used in construction sites, and then investigated several causes that influence the pumpability in this testing apparatus. It was inferred that, with the model pump, loss of pressure in the pipe, segregation of fresh concrete under high pressure and influence of tapered pipe could be obtained.

From the results, it was concluded that this apparatus could be used in the experiments as the pumping properties of the model concrete-pump were almost the same as the ones of a normal truck-mounted pump.

1. INTRODUCTION

For the researches concerning the concrete pumpability, as there is not a simple testing method to determine the pumpability, experiments are generally executed at the construction sites of large projects. The estimation of time required for the concrete pumping and the inference of occurrence or not of blockage in the pipeline depend on the experiences and sense of the technicians in the construction sites. Like this, a method of quantitative judgement of pumpability has not yet been sufficiently and clearly done, especially experiments or researches concerning the pumpability of low slump concretes. Finally in July of 1985, the

Japanese Ministry of Construction chose "Development of Pumps for Low Slump Concrete" as the theme for the project of overall technical development; after that, researches on this subject started all over Japan.

Considering this present situation, the authors developed a model of concrete pumping system that made experiments in laboratories possible. Then, some experimental researches concerning the causes of influences on the concrete pumpability were put in operation in the laboratory in similar conditions to the truck-mounted pumps in construction sites.

2. MODEL OF A CONCRETE PUMPING SYSTEM

In most of the cases of concrete pumping models used in experiments up to now, a method of pressing the jack from only one end of a short pipeline had been adopted. In this method, as one of the ends of the pipeline is open, it is impossible in the laboratory to reproduce the high pressure of about 10 ~ 30 kgf/cm^2 that acts in the pipeline during the actual concrete pumping in the construction sites. That is why the authors devised a model of concrete pumping system like the one shown in Fig. 1 with jacks on both ends of the pipeline. In this system, due to the relief valve, the pressure of the passive jack can be kept constant. Therefore a high pressure of about 30 kgf/cm^2 can indeed be reproduced in the pipeline, and it is believed that the concrete behavior is similar to when it is pumped by truck-mounted pumps in the construction sites.

Every investigated item of the experimental apparatus is indicated below.

2.1. Pipeline

A pipe that can endure high pressures with inner diameter of 70 mm and thickness of 5 mm was used in the pipelines. After blueing the inner surface of both ends of the pipeline (300 mm from the end), a hard chrome plating (thickness: 0.05 mm) was applied. Considering that the pumping experiment is executed several times in sequence, the reason was in order to diminish the wear of the pipeline and piston, and to avoid the leakage of water or cement paste. Pressure transducers to measure the pressure in the pipeline were attached in three places:

- 2 places 400 mm from each end of the pipe
- 1 place half the pipeline length from the end.

2.2. Piston

A hard chrome plating was also applied on the piston whose diameter is 70 mm and length is 62 mm. And a piston seal (urethane gum) was applied on the front surface of the piston, that is, the surface that touches the concrete. In order to remove the air from the pipeline after it is filled with concrete, an air-remove-hole was provided to the piston.

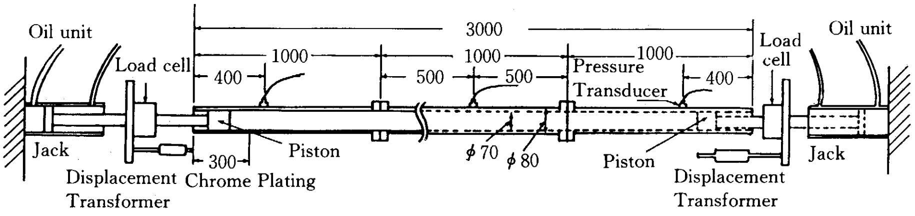

Fig. 1 Model of a Concrete Pump

2.3. Oil Pressure Unit and Oil Pressure Jack

The velocity of concrete flow in truck-mounted concrete pumps has to be adjusted according to the quickness of concrete placing in each specific construction site. Also, the pressure in the pipeline changes depending on the flow velocity and on the length of the pipeline. Therefore, in order that the present apparatus can be provided with the same capabilities as a truck-mounted pump, it was made possible to freely change both the flow velocity and the pressure in the pipeline.

As the jack is connected with the oil pressure unit, and as relief valves and solenoid valves are part of the oil pressure unit of the present apparatus, the pushing force and velocity of the jack can be freely controlled.

The specifications of the oil pressure unit are:

*maximum pushing force: 5,000 kgf,
*maximum velocity: 30 cm/s,
*maximum stroke: 200 mm.

As for the passive jack, the pressure in the pipeline can be adjusted in the range of 2～20 kgf/cm^2 by the relief valve. And as for the active jack, the jack velocity can be adjusted in the range of 5～30 cm/s by the flow control valve. By a simple operation of the changeover switches on the operating board of the oil pressure unit, the pressure in the pipeline can be adjusted in six different values: 2, 5, 8, 10, 15, or 20 kgf/cm^2, and the jack velocity can be adjusted in five different values: 5, 10, 15, 20 or 30 cm/s. Moreover, it is possible to move both jacks simultaneously or to move only one jack at a time by use of the switches.

It is considered that all the above items of the concrete pump model (2.1 ～ 2.3) have almost the same concrete pumping properties of the truck-mounted pumps in construction sites.

3. EXPERIMENT METHOD:

3.1. Measuring Machines and Measured Items

The specifications of measuring machines are shown in Table 1; and Fig. 2 indicates the connections among sensors and measuring machines.

(1) Load Cells: The load cells are attached on the ends of pistons of both oil pressure jacks. The load cell on the active part measures the pushing force of the piston and of concrete, and the load cell on the passive part measures the force transmitted to the pumped concrete by the active jack. It is concluded that the resistance between concrete and the pipe wall that appears when the concrete is pumped is indicated by the difference between the values measured by both load cells and then recorded by the data recoder.

(2) Displacement Transformers: The didplacement transformers measure the didtance the jacks move. Each of the displacement transducers is attached on an H-shaped steel bar. This bar is connected to the pipeline in a way that the end of the displacement transducer touches a steel plate united with the load cell as a single body. The displacement transformers measure the displacement of both active and passive parts and then these values are recorded on a data recorder.

(3) Pressure Transducers; The pressure transducers measure the concrete pressure acting in the pipeline. The pressure used as reference value is the one measured by the pressure transducer nearest the active jack. Two of the pressure transducers are attached on

TABLE 1: Specification of Machinery

MACHINE	SPECIFICATIONS
Load Cell	Maximum Load: 5000kg Non-linearity: 0. 02%
Pressure Transducer	Maximum Pressure: 30kgf/cm^2 Flash Diagram Type Non-linearity: 0. 3~0. 5%
Displacement Transformer	Measurement Range: 200mm Sensibility: 100×10^{-6}/mm Gauge Bridge with Pressure Spring
Jack	Stroke of Piston: 200mm Speed of Piston: 5, 10, 15, 20, 30cm/s Pressure in the Pipeline: 2, 5, 8, 10, 15, 20kgf/cm^2
Oil Pressure Unit	Electric Motor: 15kW, 4p, 200V Maximum Pressure: 170kgf/cm^2 Flow Volume: 55. 4ℓ/min

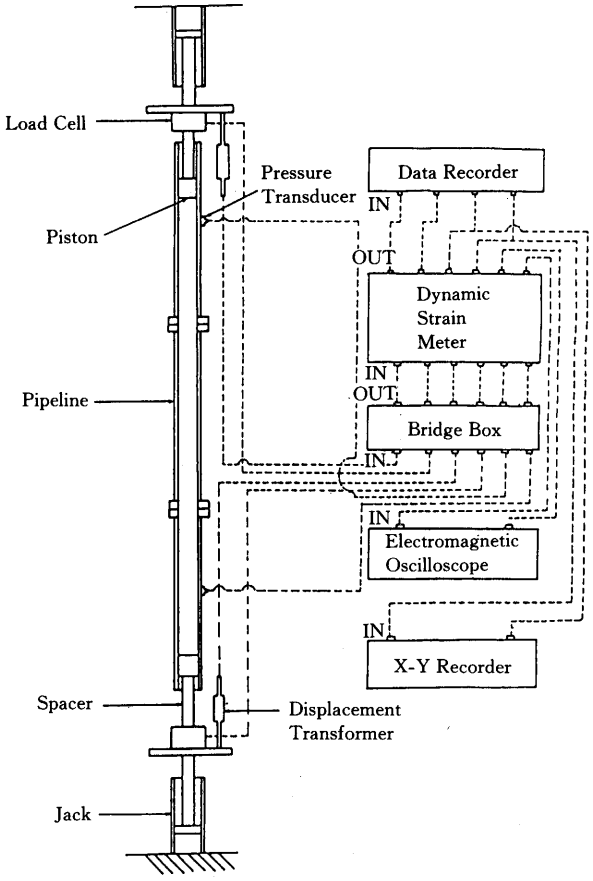

Fig. 2 Connections among Sensors and Measuring Machines

a place 400 mm distant from each end of the pipeline. And the other one is attached on the central point of the pipeline. The measured values are recorded by an electromagnetic oscilloscope.

(4) X-Y Pen Recorder: The X-Y pen recorder records the load-displacement curved line of the active jack, so that the performances of the pumping experiment can be visually checked from time to time.

3.2. Used Materials

The cement used was ordinary portland cement with specific gravity of 3.15. A sea sand from "Ashiya, Japan" was used as fine aggregate. And crushed stones (maximum size: 15 mm) made from a hard sandstone were used as coarse aggregate. Some physical properties of the aggregates are shown in Table 2. A super-plasticizer was added to the high-strength concrete, and an air-entraining agent (AE agent) was partially added to the ordinary concrete. Table 3 shows the properties of the admixtures used.

3.3. Mix Proportions of Concrete

The usually used ordinary concrete, and a high-strength concrete with compression strength greater than 600 kgf/cm^2 at 28 days of age were the two kinds of concrete used during the experiments.

As shown in Table 4, ordinary concrete with 40 and 50% of water-cement ratio (w/c), and high-strength concrete with w/c ratio of 28% were adopted. Table 4 shows some examples of concrete mix proportions. Although it is considered that the sand percentage (s/a) influences pumpability, in these research studies it is considered almost constant.

3.4. Steps of the Concrete Pumping Test and Methods of Consistency Tests

After mixing the concrete, the experiment is done according to the following order:

TABLE 2: Physical Propertise of Aggregates

TYPE OF AGGREGATE	PLACE OF PRODUCTION	QUALITY OF AGGREGATE	MAXIMUM SIZE	SPECIFIC GRAVITY	SOLID VOLUME (%)	FINENESS MODULUS
Fine Aggregate	Ashiya	Sea Sand	—	2.25	62.6	2.74
Goarse Aggregate	Kokura Minami Ward	Crushed Stone	15mm	2.74	57.9	6.41

TABLE 3: Properties of Admixtures

ABBREVIATION	MAIN CONPONENTS	SPECIFIC GRAVITY	EXTERNAL APPEARANCE	pH
M	β −naphitaline-sulfonic Acid Formaline Condensated Product	1.213±0.01	Dark Brown	9 ± 1
V	Natural Resinuous Acid Chloride Special Surface Active Agent	1.06±0.01	Dark Brown	11.5± 1

TABLE 4: Example of Mix Proportions of Concrete

KIND OF CONCRETE	TARGET SLUMP (cm)	WATER CEMENT RATIO (%)	SAND PERCENTAGE (%)	TAGET AIR CONTENT (%)	UNIT CONTENT (kgf/m^3)				
					WATER	CEMENT	FINE AGGREGATE	COARSE AGGREGATE	ADMIXTURES
Ordinary	18	50	48	4	185	370	805	937	V : 74g
	10	50	48	4	177	354	821	956	V : 35.4g
	10	40	48	4	175	443	769	932	M : 2.66kg V : 89g
High Strength	20	28	45	2	153	571	733	963	M : 8.57kg

(1) The pipeline is composed of three pipes of 1 meter connected in lilne. One of its end is leaned on a vibration table and the other end is put on a ladder that is higher than the vibration table with about 20 degrees of inclination. One of the pistons was already affixed on the lower end of the pipeline before this operation. Concrete is inserted into the pipeline from its upper end until half the pipeline is full. This corresponds to the first of two layers. Simultaneously, some blows are given on the pipeline with a wood hammer so that the concrete moves smoothly to the lower part of the pipeline.

(2) In both layers the compaction of the concrete in the pipeline is done by piercing it 10 times with a round steel bar of 6 mm of diameter, and then by vibrating it for 20 seconds with the vibration table.

(3) After vibration is over, the pipeline is vertically erected, some concrete is added until a fixed mark on the pipeline is reached, and then the other piston is affixed to the pipeline. There is a hole in the center of the piston so that air can be removed from the pipeline. After certifying that the piston has touched the concrete, the air-remove-hole is plugged up with a screwed lid.

(4) The pipeline is set up horizontally on an H-shaped steel bar as shown in Photo 1. Then, the pumping test itself can be started.

(5) The consistency tests are done simultaneously with the pumping test. The consistency tests executed were slump, slump flow, as well as "Propeller Drop Test" and "Concrete Passing Through a Reinforced-bar-grid Test" devised by the authors.

The propeller and its guide are shown in Fig. 3. "Penetration Depth" is the depth that the propeller penetrates in the concrete previously put in the test container when dropped from a point 10 cm higher than the concrete surface.

The apparatus of the "Concrete Passing Through a Reinforced-bar-grid Test" is indicated in Fig. 4 . The container is round with a diameter of 24.5 cm and a 49 cm height, and is made of polyvinyl chloride (PVC). Some reinforcing bars are attached to its wall keeping equal distance intervals between them. This container is placed on a vibration table before the test itself starts. The container is filled with two layers of concrete. After each of the layers is put into the container, a round steel bar is vertically pierced 50 times in it. Then immediately after the copper plate is pulled out of the con-

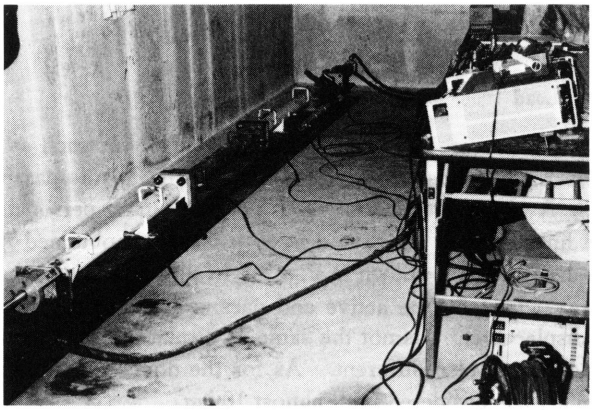

Photo. 1 : Set up of the Pipeline

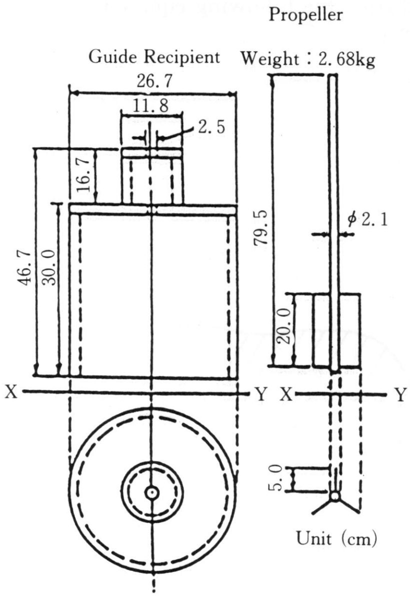

Fig. 3 Apparatus of the "Propeller Drop Test"

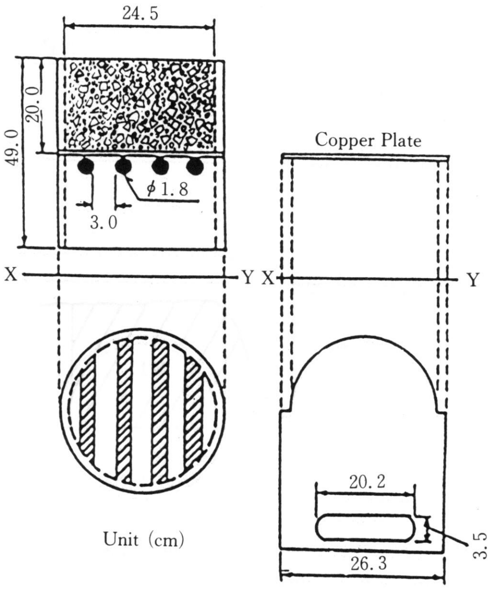

Fig. 4 Apparatus of the "Concrete Passing Through a Reinforced-bar-grid Test"

tainer, a vibration of frequency 3,400 VPM is started. The time elapsed from then until the concrete finishes passing through the clearances of reinforced bars is measured in seconds and termed as "Passing Time". The shorter the concrete passing time in this test, and the deeper the penetration depth in the Propeller Drop Test, the higher the plasticity of the concrete.

4. METHOD OF DATA ANALYSIS

4.1. Displacement and Load

The analogue data that were recorded by the data recorder, such as displacement 1 and load 1 of the active jack as well as displacement 2 and load 2 of the passive jack, were transformed by using an Average Deviation (AD) Program in a personal computer. Load-displacement curved lines of both active and passive jacks are obtained from the tansformed data. These lines are like those shown in Fig. 5. In the same figure, hatched areas E1 and E2 indicate the energy added by the active and passive jacks respectively. Considering on equal time interval, displacement 1 is not the same as displacement 2, therefore the domain of integration of E1 and E2 are also different. As for the domain of integration, the displacement of the active jack was considered until almost 10 cm.

4.2. Pressure in the Pipeline

Fig. 6 shows the wave shape of the pressure in the pipeline that was recorded by the electromagnetic oscilloscope. As indicated in the same figure, the pressures in the pipeline P1 and P2 were measured on the position when the pressure became almost constant. Obviously the pressure loss P1 - P2 exists and as the pressure transducers are separated by 2.2 m, the pressure loss per meter ΔP can be calculated from the following equation.

$$\Delta P = (P1 - P2) / 2.2$$

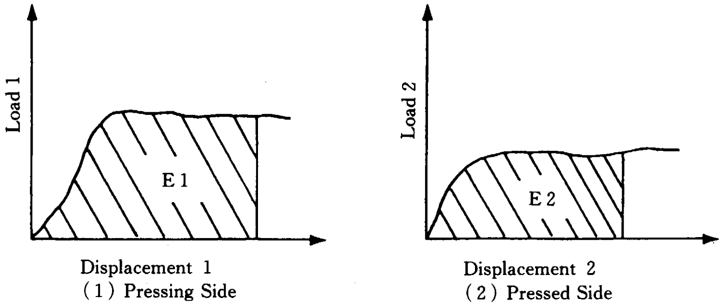

Fig. 5 Load-displacement Curved Line

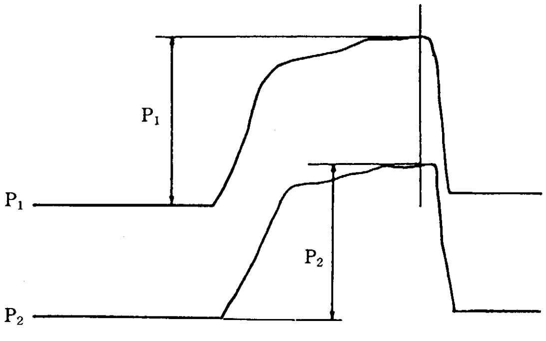

Fig. 6 An Exmple of the Shape of Wave of the Pressure in the Pipeline

5 . RESULTS AND CONSIDERATIONS

As pressure loss, pumping energy and friction loss are indexes of pumpability. Therefore they were measured and examined but as the data of pumping energy and friction loss were very scattered, explanations will be done considering mainly pressure loss.

5. 1. Load-displacement Curved Lines

Fig. 7 shows load-displacement curved lines for different air contents. The solid lines represent load-displacement curved lines of active jack. As the air content increases, the displacement before the load becomes constant gets longer. The reason is that the larger the air content, the more the quantity of compressed air increases and consequently it becomes difficult for the load to be transmitted to the end of concrete plug flow.

5. 2. Air Content and Pressure Loss

At present, as for the truck-mounted concrete pumps, the pumping distance of ordinary concrete is calculated from the pressure loss. Pressure loss is defined as the amount of decrease in the pressure per meter of pipeline. Pressure loss is generally related to the concrete slump and its velocity in the pipeline. The smaller the slump and the faster the speed, the more the pressure loss incrreases.

The relationship between pressure loss and air content is indicated in Fig. 8 and Fig. 9. Considering Fig. 8, it can be clearly seen that the pressure loss of high-strength concrete is larger than 0.3 kgf/cm^2/m but, on the contrary, for the ordinary concrete it is smaller than 0.25 kgf/cm^2/m. As the air content increases, the pressure loss of ordinary concrete has a tendency to decrease. It was concluded that as the air content increases, slump, flow and other consistency indexes also increase; and consequently as the flow characteristics in the pipeline improve, the pressure loss becomes smaller. According to the Japan Society of Civil Engineers, the standard air content for ordinary concrete is supposed to be in the range 3 ~ 6%. From the point when it becomes easy to pump the concrete, it is still desired that it has greater air content to an extent that segregation does not occur, and the concrete has enough strength, water tightness and durability.

By comparing Fig. 8 to Fig. 9, it can be inferred that in the case that the pressure in the pipeline was doubled, the maximum pressure loss of high-strength concrete became almost three times larger reaching 1.7 kgf.cm^2/m; but for the ordinary concrete it almost did not change compared to the case that the pressure in the pipeline was 10 kgf/cm^2. Therefore, it is concluded that in the case of concretes that have exorbitant cohesion like high-strength concretes, with the enlargement of the pressure in the pipeline, the pressure loss also increases.

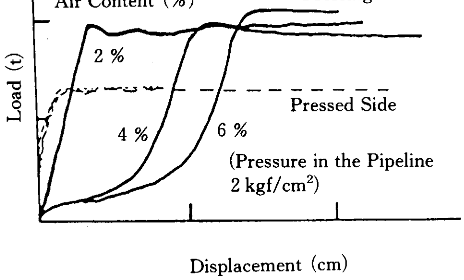

Fig. 7 Load-displacement Curved Line

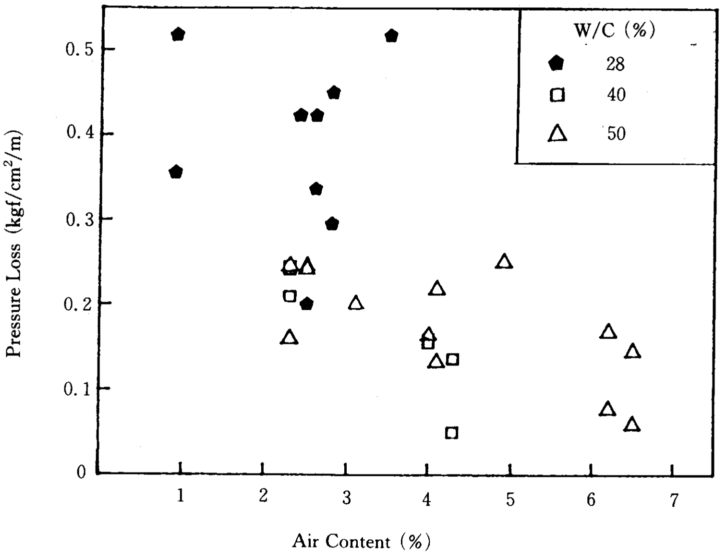

Fig. 8 Relationship between Pressure Loss and Air Content
(Pressure in the Pipeline: 10kgf/cm^2, Flow Velocity: 20cm/s)

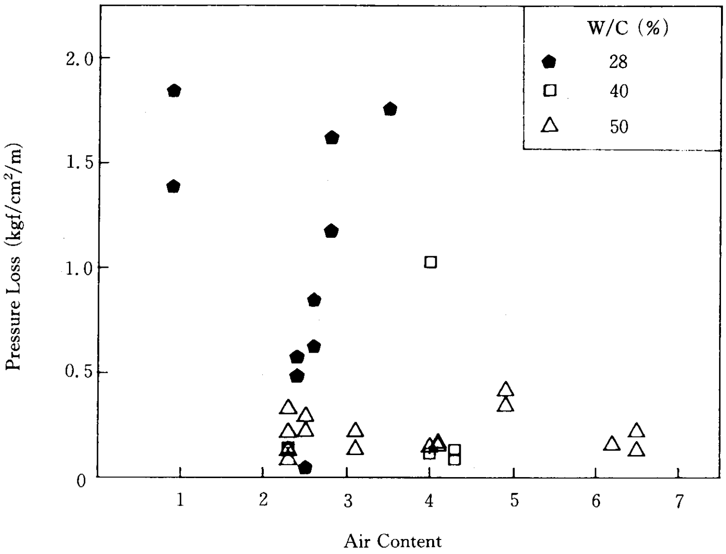

Fig. 9 Relationshin between Pressure Loss and Air Content
(Pressure in the Pipeline: 20kgf/cm^2, Flow Velocity: 20cm/s)

5.3. Velocity of Concrete Flow and Pumping Energy

Fig. 10 indicates the relationship between unit pumping energy and flow velocity. Unit pumping energy is the value obtained by dividing flow energy by displacement. From the same figure, for both ordinary and high-strength concretes, the higher the flow velocity, the higher the pumping energy becomes. As compared to normal concretes, the pumping energy of high-strength concretes (w/c = 28%) is 10~15 kgf·cm/cm larger; moreover, with the increase of velocity, there is a super rapid increase in the pumping energy. This tendency is similar to the results the authors obtained from concrete pumpability experiments held in a certain construction site using a truck-mounted concrete pump. Fig. 11 shows the results of concrete pumpability experiments done using a truck-mounted pump. According to Fig. 11, the pressure loss of exorbitant cohesive high-strength concretes (w/c = 28%) becomes larger super fast as the pumping velocity increases from 40 cm/s to 80 cm/s, and it reaches 4 to 5 times the value of ordinary concrete. Therefore, as for concretes that have exorbitant cohesion like high-strength concretes, it is inferred that when the flow velocity increases the friction resistance between concrete and the pipe wall also becomes larger and the flow resistance increases rapidly.

5.4. Pressure Loss and Consistency

Figs. 12 and 13 show the relationships between pressure loss and flow value or penetration depth respectively, for flow velocity of 5 cm/s and pressure in the pipeline of 20 kgf/cm^2. It is inferred from both figures that the pressure loss of high-strength concrete is larger when compared to the values of ordinary concrete; and the more plastic the concrete becomes, the more the pressure loss tends to decrease. But as the data of pressure loss in the case of ordinary concrete is quite scattered, this tedency can not be clearly seen. Figs. 14 and 15, respectively, show the relationships between pressure loss and flow value or penetration depth considering flow velocity as 20 cm/s and pressure in the pipeline as 2 kgf/cm^2. Similarly to Figs. 12 and 13 for a smaller flow velocity, both Figs. 14 and 15 show the tendency of the pressure loss of high-strength concrete being larger than the one of ordinary concrete. It is

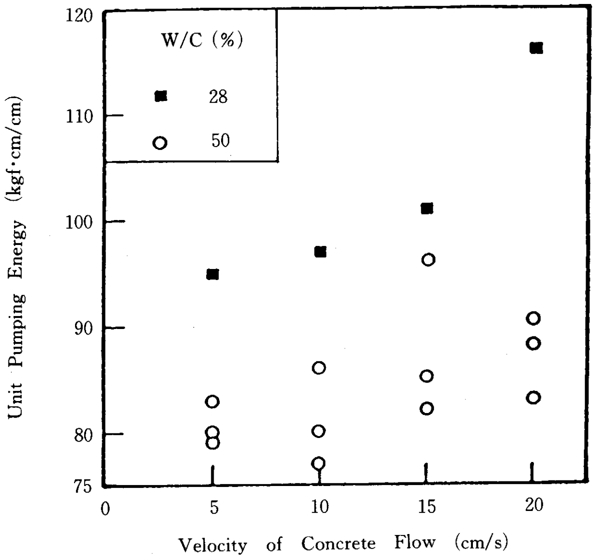

Fig. 10 Relationship between Pumping Energy and Flow Velocity
(Pressure in the Pipeline: 2kgf/cm^2)

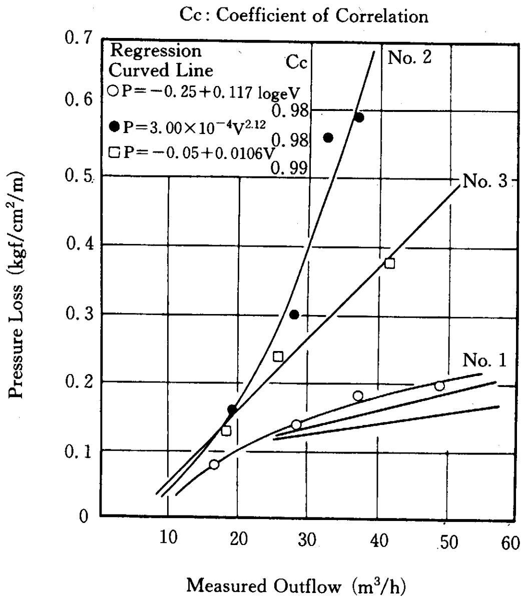

Fig. 11 Relationship between Pressure loss and Measured Outflow

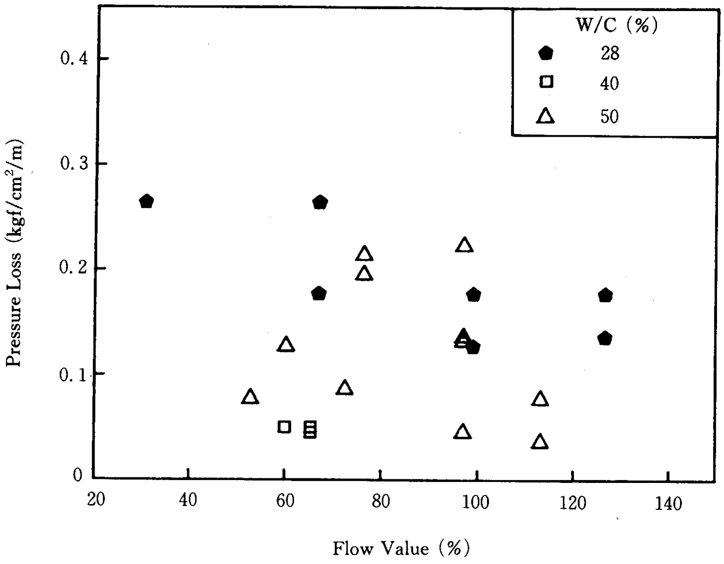

Fig. 12 Relationship between Pressure loss and Flow Value
(Pressure in the Pipeline: 20kgf/cm^2, Flow Velocity: 5cm/s)

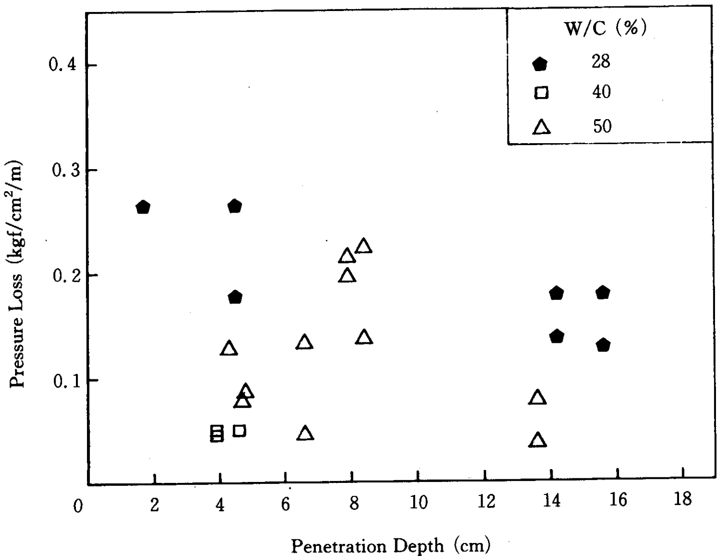

Fig. 13 **Relationship between Pressure loss and Penetration Depth**
(Pressure in the Pipeline: 20kgf/cm^2, Flow Velocity: 5cm/s)

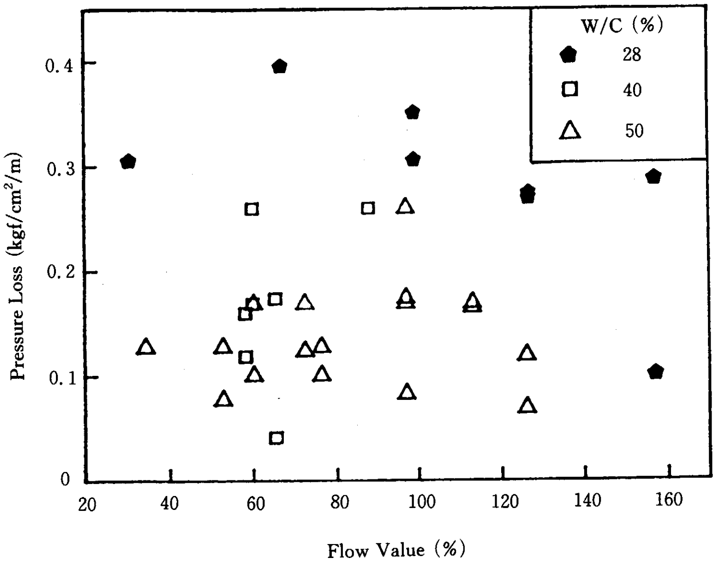

Fig. 14 **Relationship between Pressure loss and Flow Value**
(Pressure in the Pipeline: 2kgf/cm^2, Flow Velocity: 20cm/s)

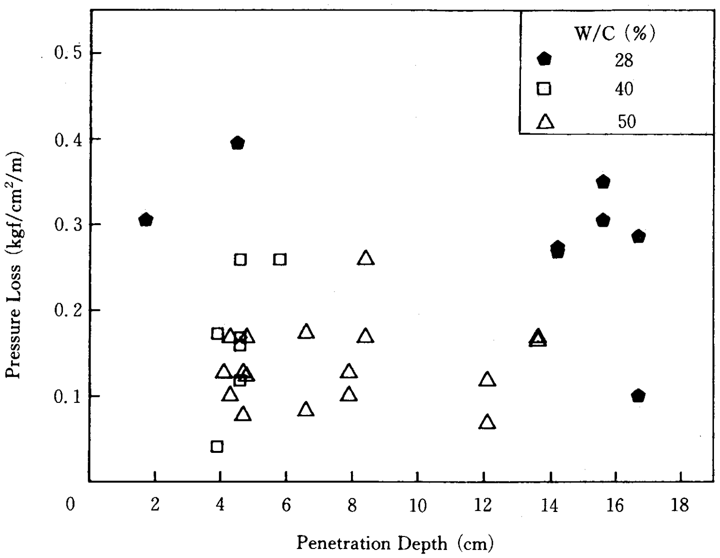

Fig. 15 Relationship between Pressure loss and Penetration Depth
(Pressure in the Pipeline: 2kgf/cm^2, Flow Velocity: 20cm/s)

considered that the reason is that as the flow velocity becomes larger, the pressure loss of high-strenght concrete also increases, but the one of ordinary concrete almost does not become larger.

As the data obtained from the pumping experiments until now are not enough yet and are quite scattered, it was impossible to fulfill one of the purposes of these research studies, that is to select the instrumentation to measure pumpability. But one key point could be perceived to some extent: the relationship betweeen the pressure loss and flow value of high-strenght concrete does exist.

6. CONCLUSIONS

The following are the results obtained from these research studies put together:

(1) Considering the model of the concrete pumping system devised by the authors, similarly to the real truck-mounted pumps, the faster the flow velocity becomes, the more the resistance between concrete and the pipe wall tends to increase. Therefore, it was concluded that this pumping system can be used to do pumpability experiments.

(2) From the indexes that express pumpability, pressure loss, pumping energy and friction loss were considered in the tests, but as the measured values were rather scattered they can not yet be discussed clearly. Concerning these research studies, the pressure loss data seem to be suitable.

(3) It is extremely difficult to select instrumentation to measure consistency that can accurately express pumpability. The authors consider that, as slump test is not suitable enough for pumping experiments, it is better to increase the use of dynamic consistency tests. It is thought that by analyzig the relationship between flow and pressure loss the tendency of high-strength concretes could only be understood to some extent. Therefore in order to infer if flow tests are suitable enough to be used for pumpability experiments,

from now on much more tests should be done.

7. ACKNOWLEDGEMENTS

Finally, the authors wish to express their thanks to the Master's student Hiroyuki Uchida who cooperated extensively with these research studies done in Kyushu Institute of Technology. Thanks are also due to the help obtained from the chief researcher Tomio Tamura who works in the Technical Research Institute of Mitsui Construction Limited Company. The authors also wish to express their deep gratitude to the manufacturer company "Kokura Giken," mainly to its employee Akiroo Wada who has been doing the maintenance works of the pumping system.

8. REFERENCES

(1) Japan Society of Civil Engineers; Symposium about behaviours and measurements of physical properties of fresh concrete; March 1983; (in Japanese).

(2) Japan Society of Civil Engineers; Schematic Norm on execution works of concrete-pumps; Concrete Library, volume 57; November 1985; (in Japanese).

(3) Shun-ichi TAKAYAMA, Takashi IDEMITSU, Yosiaki MURATA; Basic Researches About Pumpability of High-Strength Concretes; Review of the 36th General Meeting of the Cement Association of Japan (CAJ); pp. 194~195; December 1982; (in English).