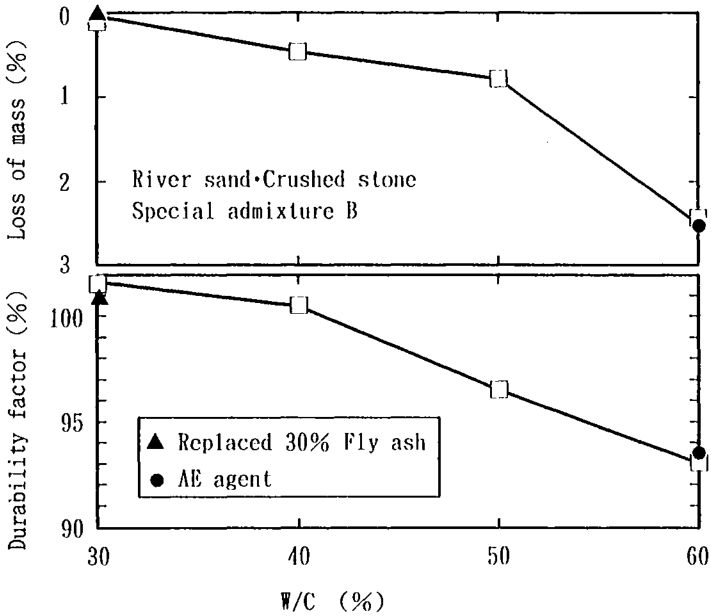

Fig. 11—Relationship between water-cement ratio, loss of mass, and the durability factor

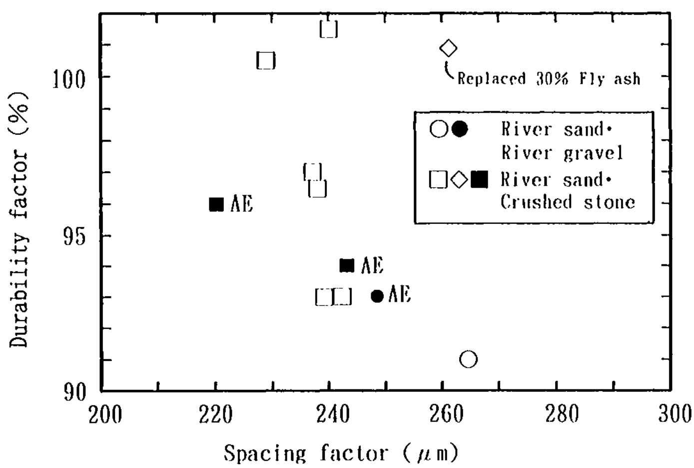

Fig. 12—Relationship between spacing factor and durability factor

An Experimental Construction of Model Structure with Flowing Concrete

by N. Nishiyama, Y. Kasai, N. Yuasa, and Y. Nakata

Synopsis: Flowing concrete is characterized by high flowability, requiring only slight consolidation by vibrating and easy control in a plant. An experimental model structure using flowing concrete was constructed. This paper deals with placing capability on site and properties of hardened flowing concrete in the structure.

Pumpability, flowability, and capability to fill forms were investigated for the fresh flowing concrete and distribution of compressive strength, carbonation depth, cement content, air permeability, and water absorption were measured for the hardened flowing concrete.

Compressive strength of core samples taken from the model structure and standard cylinder specimens from the plant mixture were approximately 24 MPa. The average estimated cement content was 333 kg/m^3 and the standard deviation was 15 Kg/m^3 within a wall of 3 x 4.2 m. Measured carbonation depth was smaller in the freely flowed parts than those in the upper portion of vibrated parts.

Keywords: Absorption; carbonation; compressive strength; flowability; models; nondestructive tests; permeability; tests

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INTRODUCTION

Reflecting demands for higher productivity, mechanization of construction works for reinforced concrete structures has been increasing during the past 25 years. As was seen in the change from a bucket and a buggy to a pump truck, labor saving have been mainly realized by mechanization, and that the concrete itself shows no advance except for those of superplasticizers. Development of a new concrete to meet the requirement for simplification and higher quality without consolidation has been studied in the flowing concrete technical committee. Flowing concrete is characterized by high flowability and sufficient durability without increasing the unit amount of water, which was made possible by a newly developed superplasticizer.

The present paper deals with an experimental construction of full-scale model structure with flowing concrete, the results of test for properties of hardened concrete, and discussion of the applicability to practical constructions.

Quality control techniques, pumping capability, rapid measurement in the construction of a full-scale structure are described, and compressive strength evaluation using core samples, estimation of cement content, rapid measurement techniques for carbonation depth, air permeability, and water absorption are applied to confirm the quality of hardened concrete in the model structure.

METHOD OF EXPERIMENTS

Construction of full-scale model structure with flowing concrete

1-- The full-scale model structure

The full-scale reinforced concrete structure comprises two columns with dimensions of 700 x 700 x 3000 mm and walls with thickness of 150 mm as shown in Fig.1 and 2. Reinforcing steel bars for the column were 4-D22 for the main reinforcement and D22 with a pitch of 100 mm for the hoop reinforcement, and D13 for vertical and D10 for horizontal reinforcement each with a pitch of 200 mm were arranged for the wall reinforcement keeping 30 mm for a cover thickness. An internal partition was set at the center of the opening to test two different mixtures, and the form was made of semi-transparent resin to be able to observe the flow behavior of concrete.

2--Mixture proportions of flowing concrete

The mixture proportions of flowing concrete are shown in Table-1. A preliminary batch using two admixtures was executed to determine the mixture proportions for the full-scale construction.

3--Manufacture and transportation of flowing concrete

The flowing concrete was mixed by a tandem forced mixer with a capacity of 3 m^3 in a concrete plant, and the admixture was manually batched. Transportation was made by agitating trucks with 6 m^3 capacity, and took 30 minutes from mixing to placing.

4--Test of quality for flowing concrete

Slump, flow, air content, temperature of concrete, and box test described below were executed to confirm the quality of fresh flowing concrete on arrival of the agitating truck. Sampling was made both at discharge and at the discharge of a pump truck. A concrete specimen of approximately 10 litres was set in a half of 150 x 150 x 400 mm of box test apparatus shown in Fig.3, then the shutter was opened up and the differential height between two parts was measured. Control of compressive strength was made for specimens both under the standard curing and on-site curing at the age of 28 days.

5--Placing of flowing concrete

Flowing concrete was placed, as shown in Photo.1, by the squeeze-type concrete pump truck at points indicated in Fig.1. Pumping capability, angles of repose and lateral pressure against formwork were examined. The lateral pressure against formwork was measured primarily using strain gauges attached to the separators shown in Fig.1 , and then converted into pressure.

Properties of hardened concrete taken from the structure

1--Compressive strength of cores and estimation of cement content

Cores were taken from the points in the model structure as indicated in Fig.4, and compressive strength was measured according to JIS A 1107 at the age of 28 days. These specimens were also subjected to the estimation of cement content by the method using sodium gluconic acid.

The test procedure is, as shown in Fig.5, that a 2.000 g of powdered concrete (So) is dissolved in a 15 %, 300 mL of sodium gluconic acid for 30 minutes under constant temperature of 60 °C and the amount of residue (R) is measured. An estimated cement content is then calculated by a following formula,

$$Co = \frac{So - R}{So/(1 - \frac{Wc}{100})}, \qquad \text{------} \quad (1)$$

and

$$Cm = \frac{Co \bullet Sd}{100 \bullet V}, \quad \text{------} \quad (2)$$

where Co is a dissolution rate of powdered concrete in %, Wc is a loss of powdered concrete at 500 °C, So is a mass of powdered concrete after heating to 500 °C, R is a residue of powdered concrete, Sd is an absolute dry mass of concrete, V is a volume of specimen and Cm is an estimated cement content.

2--Rapid tests for carbonation depth, air permeability, and water absorption

Rapid tests for carbonation depth, air permeability and water absorption were executed at 5 months after placing to confirm the quality of hardened concrete. Sampling points were determined to have sufficiently small distance for both column and wall as shown in Fig.1, and drilled to have a hole, which was 10 mm in diameter and shared for every tests.

Rapid test for carbonation depth was made by using concrete powder produced by drilling. A filter paper with phenolphthalein solution was put on a plastic substrate, and slid so as to accept new concrete powder. When the powder first showed red, the drilling was stopped to measure the depth of the hole by a slide calipers as shown in Fig.6.

Rapid test for air permeability was executed with the same hole as used in the carbonation test as shown in Fig.7. The hole with a diameter of 10 mm and a depth of 80 mm was sealed by a cap of silicon rubber, and evacuated by a vacuum pump down to x_1 Pa through a needle for injection set in the rubber cap. Subsequently , a time T (sec.) for x_1 (Pa) to reach an equilibrium pressure x_2 (Pa) by incoming air through the wall of the hole was measured. A rapid air permeability K (Pa/sec.) could be calculated by the following formula (3) , representing the permeability of concrete to air.

$$K = \frac{x_2 - x_1}{T}, \quad \text{------} \quad (3)$$

where x_1 and x_2 were typically 2.1 x10^4 and 2.5 x 10^4 Pa respectively while 1.3 and 3.3 x 10^4 Pa were used when T was as short as 10 second.

Rapid test for water absorption was executed immediately after the air permeability test making use of the rubber cap as shown in Fig.8. The second injection needle was put into the cap and connected to a measuring pipette. Water was introduced to the drilled hole through the first injection needle used for the air permeability test, and a time required for the subsequent decrease of the water for 0.01 mL in the measuring pipette due to absorption from the concrete wall was measured as T in second. The amount of absorption W (mL) can be set for 0.03 ml when T was as short as 10 second. The rapid water absorption rate Q (mL/sec) can be calculated by the following formula (4), and taken for representing the permeability of concrete to water.

$$Q = \frac{W}{T}. \quad \text{------} \quad (4)$$

RESULTS AND DISCUSSIONS

Construction of full-scale model structure with flowing concrete

1--Test of quality for flowing concrete

Quality of fresh flowing concrete tested at the plant, at discharge on site, and at the discharge of pump is shown in Table-2. Regardless of an effect of transportation, slump, air content, and box differential height remained within the acceptable range of specified quality of flowing concrete with slump from 24 to 26 cm, flow from 50 to 60 cm, air content of 4±1%, and box differential height as low as 8 cm, though a slight increase in slump-flow at the discharge was observed. Difference in compressive strength at the age of 28 days was not observed regardless of tests executed in plant, at discharge on site and at the discharge of pump. These results show that flowing concrete can be produced in the conventional concrete plant.

2--Placing of flowing concrete

The angles of repose of flowing concrete exhibited gently sloped shape in general and became more gentle as they approached to an end point as shown in Fig.4 and Photo.2, though a slight difference between mixtures of A and B was observed. No vibrator was needed in the placing for a height up to 2 m owing to an excellent flowability of admixtures A and B. The time taken for placing concrete of one step (375 mm in the height of wall) without vibration was 4 - 6 minutes. The distribution of lateral pressure on the formwork as shown in Fig.9 was changing linearly along with the vertical direction, and exhibited sufficient flowability of flowing concrete. Pumping was also successfully done without an excessive charge in the same way as that of conventional concrete with a slump of 180 mm.

Properties of hardened flowing concrete taken from the structure

1--Compressive strength of cores and estimation of cement content

Results of compressive strength of cores and estimation of cement content are shown in Table-3. Average compressive strength of A and B wall was 26.0 MPa and 22.3 MPa respectively, which was nearly equal to that of standard cured specimens. The difference in compressive strength between A and B may be attributed to an effect of solar radiation. The estimated cement content showed good agreement with the designed value (312 kg/m^3), and no substantial difference along with the height. Flowing concrete in the test walls was proven to flow without segregation.

2--Rapid test for carbonation depth, air permeability, and water absorption

Results of rapid test for carbonation depth, air permeability, and water absorption are shown in Fig.10, 11, and 12, and the numerical data are shown in Table.4. Evolution of carbonation in A wall was slower in a part where the concrete flowed by itself than the other part where the vibrator was applied. Air permeability and water-absorption rate showed higher value at the central part of wall where the concrete flowed by itself.

CONCLUSIONS

A full-scale model structure with the flowing concrete was experimentally constructed. The followings conclusions can be drawn.

(1) Quality of flowing concrete can be controlled sufficiently in the conventional concrete plants.
(2) Capability of flowing concrete was proven to be so satisfactory as to fill a double reinforcement wall with a thickness of 150 mm.
(3) Surface finishing was easier than normal concrete with a slump of 180 mm owing to its low viscosity and high flowability.
(4) Flowing concrete can be placed solely with a slight vibration.
(5) Flowing concrete can be conveyed by the conventional pumps with less pumped load than for normal concrete with a slump of 180 mm.
(6) Quality of hardened flowing concrete showed little variance and was stable.

An experimental construction of full-scale model structure with the flowing concrete has proven its promising future and feasibility using existing plant facilities, site facilities, and quality control techniques.

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TABLE 1 — MIXTURE PROPORTIONS AND PROPERTIES OF CONCRETE

No.	Mixture-proportions								Results								
	M.s. c.a.	W/C	s/a	Unit weight (kg/m^3)					Slump	Flow	Box differential height	Air	Bleeding	Compressive strength (MPa)			
				W	C	S	G	Chemical admixture						1D	3D	7D	28D
	(mm)	(%)	(%)						(cm)	(cm)	(cm)	(%)	(mℓ/cm^2)				
1	20	0.60	53.3	187	312	932	835	Adm B 2.50	24.0	50×50	3.0	4.5	0.16	3.4	12.1	20.9	28.6
2	20	0.60	53.3	187	312	932	853	Adm A 4.99	25.0	55×54	1.0	4.1	0.14	3.6	14.8	22.9	31.1

*Portland cement, Sagami river sand(s.g.2.60, absorption 2.11%, F.M.2.71), c.a.(s.g.2.65, absorption 1.01%, F.M.6.87)

TABLE 2 — PROPERTIES OF CONCRETE IN FIELD

No.	Chemical admixture	Results									
		Place of sampling	Properties of fresh concrete				Concrete temp.	Compressive strength (28D) (MPa)			
			Slump	Flow	Box differential height	Air		Standard curing		Field curing	
			(cm)	(cm)	(cm)	(%)	(℃)	Before pumping	After pumping	Before pumping	After pumping
1	A	Plant Field(discharge) Field(nozzle)	25.0 24.0 25.0	53×51 52×50 57×55	2.0 3.0 1.0	4.0 3.5 3.7	12.0 11.0 11.0	23.3	25.1	27.5	26.1
2	B	Plant Field(discharge) Field(nozzle)	24.0 25.0 25.5	51×50 56×54 59×58	3.0 2.0 2.0	3.4 3.6 3.2	12.0 11.0 11.0	24.9	24.3	23.5	23.2

TABLE 3 — RESULTS OF COMPRESSIVE STRENGTH OF CORES AND CEMENT CONTENT TESTS

Wall	Core sample No.	Height (mm)	Compressive strength (MPa)	Estimated cement content (kg/m³)
A	①	2830	23.3	320
	②	1500	27.1	329
	③	700	23.3	307
	④	2750	28.5	348
	⑤	1470	25.6	315
	⑥	720	26.6	323
	⑦	2690	24.2	352
	⑧	1550	27.1	304
	⑨	470	28.4	349
B	①	2630	20.2	307
	②	1450	21.9	324
	③	660	20.6	356
	④	2610	19.7	320
	⑤	1440	24.7	319
	⑥	650	23.5	339
	⑦	2550	22.6	306
	⑧	1450	24.9	329
	⑨	640	22.6	332

TABLE 4 — RESULTS OF CARBONATION DEPTH, AIR-PERMEABILITY SPEED AND WATER-ABSORPTION SPEED

No.	X	Y	Carbonation depth (mm)	Air-permeability speed (mmHg / sec)	Water-absorption speed $\times 10^{-4}$ (ml / sec)
1	15	289	2.2	0.526	9.10
2	15	275	3.0	9.677	21.93
3	15	225	3.1	1.422	13.85
4	15	175	1.5	6.383	14.27
5	15	130	2.3	0.946	11.31
6	15	75	1.3	0.826	11.55
7	15	25	0.6	0.667	11.95
8	15	10	0.4	0.365	4.12
9	75	289	2.0	0.564	9.11
10	75	275	2.6	0.730	11.27
11	75	225	1.6	0.532	17.15
12	80	175	1.2	1.395	3.16
13	80	130	0.8	0.744	16.61
14	80	75	1.2	1.875	18.38
15	80	25	1.7	0.567	7.75
16	80	10	1.5	0.704	9.57
17	135	289	2.0	0.691	10.03
18	135	270	2.5	0.459	13.42
19	125	225	2.2	1.538	19.16
20	125	175	0.4	2.098	10.26
21	125	130	0.5	1.038	17.92
22	125	75	1.6	1.282	14.99
23	125	25	1.0	0.530	10.83
24	175	10	0.0	0.831	9.09
25	175	289	1.5	0.374	13.97
26	175	270	2.2	0.682	15.67
27	170	225	1.0	2.239	23.09
28	170	175	0.0	—	13.61
29	170	130	0.1	0.574	6.71
30	170	70	0.0	0.485	7.83
31	170	30	1.3	0.806	13.61
32	170	10	1.1	0.244	4.56
33	235	289	0.6	0.530	10.62
34	235	270	0.6	1.224	11.04
35	235	225	0.8	1.478	3.53
36	225	170	0.4	0.507	11.98
37	225	125	0.3	1.195	13.89
38	225	75	2.0	1.060	8.83
39	225	25	0.7	0.651	10.22
40	225	10	0.6	0.449	4.96
41	275	289	0.7	0.198	3.43
42	275	270	0.5	0.432	7.15
43	275	225	1.0	0.493	4.72
44	280	170	0.9	—	11.04
45	280	125	1.1	1.579	0.00
46	280	75	1.9	1.351	19.96
47	280	25	0.6	0.693	9.40
48	280	10	0.8	0.450	3.44
49	335	289	0.2	0.920	8.58
50	335	270	0.3	0.458	9.02
51	335	225	0.6	1.230	7.32
52	340	170	0.9	1.685	14.73
53	340	125	0.6	0.815	8.86
54	340	75	1.2	0.785	8.47
55	340	25	0.0	1.042	12.36
56	340	10	0.5	0.339	0.00
57	375	289	0.5	0.501	7.11
58	375	270	0.4	1.240	8.34
59	375	225	1.0	1.456	11.49
60	380	170	0.1	0.620	8.79
61	380	125	0.0	1.563	15.48
62	370	75	0.6	1.786	11.48
63	360	75	0.0	0.680	9.19
64	380	25	0.8	0.806	12.36
65	380	10	1.1	0.502	4.14
66	425	289	0.1	1.299	9.27
67	425	270	0.6	0.562	4.47
68	415	235	1.4	1.261	7.86
69	425	170	0.0	0.759	7.07
70	425	125	0.9	0.785	8.47
71	425	75	1.2	1.463	16.98
72	425	25	0.7	1.714	13.40
73	425	10	0.9	0.609	10.22