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BASIC RESEARCH ON HIGHLY WORKABLE CONCRETE WITH LOW HEAT TYPE CEMENT AND LARGE AMOUNT OF LIMESTONE POWDER

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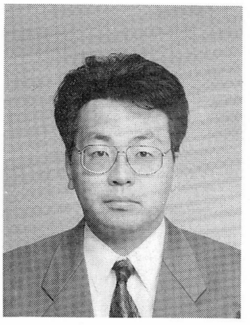
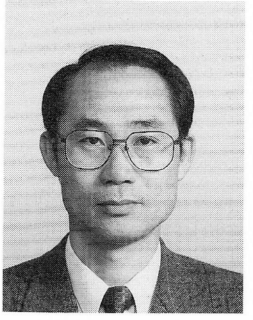

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SYNOPSIS

This report describes experimental results on a highly workable concrete for mass concrete purpose, which is made from a ternary-blended low-heat cement, large amount of limestone powder and air-entraining high-range water-reducing agent. The report also refers to applicability of this type of concrete to mass concrete structures, and its suitability was confirmed through full-size field casting.

Keywords: highly workable concrete, mass concrete, ternary blended low-heat cement, limestone powder, air-entraining high-range water-reducing agent.

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1. INTRODUCTION

The Akashi-Kaikyo Bridge, which is a suspension bridge under construction as a part of the Honshu-Shikoku Bridges, has huge concrete structures of both main piers and anchorages which are unprecedented scale.

The authors have already carried out a research from the viewpoints of materials and mix in an effort reduce hydration heat of concrete; this is one method of suppressing thermal cracking on such mass concrete structures as bridge foundations. Achievements of this work, for example, are discovering that the hydration heat can be substantially lowered by using low-heat generating cement containing a large amount of pulverized blast furnace slag (and fly ash in some cases); and that concrete with good plasticity can be produced by adding pulverized pure limestone powder (simply referred to as "limestone powder") even when the unit cement content is small [1,2].

In conventional mass concrete structures, a concrete with stiff consistency and lean mix of low unit cement content, a type of concrete which needs careful compaction work, has been widely used to reduce the hydration heat wherever this allows designated quality to be maintained. Casting and compaction of such concrete requires a lot of manpower, the supply of which has, however, been gradually diminishing in recent years. In addition, the time available for such work has been often limited because of various legal restrictions. The authors believe it would be technically very valuable to make concrete self-flowing and thus to raise the efficiency of casting work while securing required quality as mass concrete. This would improve the reliability of concrete structures. Although in recent years a great deal of researches have been enthusiastically conducted for the concrete with self-flowing properties and thus requiring no compaction work (referred to as "highly workable concrete"), investigations have not so far covered the case of mass concrete purpose.

This report describes experimental results for low-heat generating highly workable concrete for use in mass concrete structures of bridge foundations. The first step in our study was to determine the mix of highly workable concrete, which was to be made by suitably adding AE (air-entraining) high-range water-reducing agent (simply referred to as "SPA") to conventional mass concrete with a maximum coarse aggregate of 40 mm and with ternary-blended low-heat cement. Next, our study entailed investigating the applicability of this new concrete by casting it into a regular-size foundation.

2. OUTLINE OF EXPERIMENT

2.1 General

The study was roughly divided into two parts as described below:

Experiment 1: Study of the influence of change of mix on various characteristics of the fresh and hardened concrete, and

Experiment 2: Investigation on the applicability of the concrete to real work.

The mixing conditions for the highly workable concrete are as shown in Table 1. The unit cement content was made a constant of 260 kg/m³, because we have thought this might be the minimum from the viewpoint of long-term durability of concrete though a smaller value is generally advantageous for mass concrete purposes. Slump-flow was selected as the index for measuring the self-flowing capacity of the concrete, and the target value was set at 55 cm.

Table 1 Mix design of highly workable concrete

Maximum size of aggregate (mm)	Design strength (91day) (MPa)	Unit content of cement (kg/m³)	Slump flow (cm)	Air content (%)
40	24	260	55± 5	4± 1

2.2 Used materials

Tables 2 to 5 show general characteristics of the used materials. The cement is a ternary-blended low-heat cement consisting of 25% portland cement, 55% blast furnace slag and 20% fly ash, and type of the portland cement used in this study is moderate heat portland cement. As for pulverized mineral material, limestone powder of three different particle size distributions was individually used. Crushed stone was used as the coarse aggregate, and mixture of desalted sea sand and crushed sand was used as the fine aggregate. In order to make the concrete highly workable, three kinds of SPA with different primary components were added in varying amounts so as to maintain the slumpflow. The volume of air was adjusted by adding an AE agent, and an AE water-reducing agent (main component: lignin sulfonate complex and a polyole) was at first used to determine the unit water content.

Table 2 Properties of ternary low-heat generating cement

Specific gravity	Fineness (Blaine) (m²/kg)	Compressive strength (MPa)			Hydration of cement (J/g)		
		7day	28day	91day	7day	28day	91day
2.80	524	17.5	33.1	43.2	176	209	230

Table 3
Series of limestone powder

Note	Specific gravity	Fineness (Blaine) (m²/kg)
LF40	2.71	400
LF55		550
LF75		750

Table 5
Proterties of high range water reducing AE agents

Note	Specific gravity	Main ingredient
N S	1.15	Compound composed of modified lignin, alkylaryl-sulfonate, and a continuous, activation polymer
PO (I)	1.04	Compound of poly-carboxylic ether
PO (II)		

Table 4 Properties of aggregates

Type	Producing district	Kind of aggregate	Specific gravity of saturated surface dry	Absorption (%)	Fineness modulus
Fine aggregate	Hiroshima	Sea sand	2.55	1.98	2.56
	Nishijima	Crushed sand	2.55	2.11	2.97
Coarse aggregate	Akoh	Crushed stone of size 20mm ~ 5mm	2.63	0.58	6.24
		Crushed stone of size 40mm ~ 20mm	2.63	0.54	7.96

2.3 Outline of each experiment

In the experiment 1, which aimed to determine how various elements of the mix affect characteristics of the highly workable concrete, the mix was varied as shown in Table 6. Table 7 gives a summary of the concrete mixes used in this experiment. As for the unit water content, a value (140 kg/m^3) which yielded the slump of about 5 cm with the standard quantity of the AE water-reducing agent was selected as the reference. This small unit water content, as having been used in ordinary stiff consistency concrete, was chosen in order to reduce volume change of the hardened concrete as much as possible. For comparison purpose, a concrete having the slump of about 11 cm (called the conventional mix) was also examined. The limestone powder added in this study has been treated as part of the fine aggregate. The test was basically carried out at 20 deg.C., but some mixes were also tested at low temperature (target: 10 deg.C.).

A pug-mill type forced-mixing mixer with dual axes was used to produce the concrete, and each batch was 0.1 m^3. The mixing was done as the following way; the materials were dropped into the mixer in the sequence of cement, limestone powder and aggregate; dry mixing without water was then carried out for 60 sec.; water including dissolved SPA was added; and finally the concrete was wet-mixed for 120 sec.

Table 6 Examination factor and level

Item	Factor	Level
Material	Air entraining high-range water reducing agent	NS, PO (I), PO (II)
	Blaine of limestone powder	400, 550, 750 m^2/kg
Mix proportion	Sand percentage	34, 37, 40, 43, 48 %
	Unit content of water	130, 135, 140, 145, 150 kg/m^3
	Unit weight of limestone powder	120, 150, 180, 220 kg/m^3

Table 7 Mix proportion of concrete

Type of concrete	Type of LF	Type of SPA	W/C (%)	s/a (%)	Unit weight(kg/m³) W	C	LF
Conventional concrete	LF55	NS, PO	53.8	43	140	260	30
Highly workable concrete	LF55	NS	53.8	34～48	140	260	150
	LF40 LF55 LF75	NS, PO	57.7 ～ 50.0	40	150 ～ 130	260	150
	LF55		53.8	40	140	260	120 ～ 220

Table 8 Testing methods of concrete

Test items	Test methods
Slump	JIS A 1101
Slump flow	JSCE-1990
Air content	JIS A 1128
Concrete temperature	Alcoholic thermometer
Rate of bleeding	JIS A 1123
Setting time	JIS A 6204
Compressive strength	JIS A 1108
Tensile strength	JIS A 1113
Young's modulus	JSCE-1988
Adiabatic temperature rise	
Carbonized depth	CO_2 Concentration: 5% 30℃, 55% RH Measurement: Phenol-phtharein solution
Depth of chloride ion penetration	Cl^- Concentration: 1.8% Measurement: Fluorescein sodium solution

Test items and methods are as shown in Table 8. Test pieces were made by tapping softly with wooden hammer instead of by applying compaction with a rod. The apparatus shown in Fig.1 was used to measure the time needed for a certain volume of the concrete to flow out (called the funnel flow test).

In the experiment 2, we tested at first production method of the concrete whose mix had been determined in the experiment 1. For this, regular on-site plant (dual-axis forced-mixing type with variable speed: capacity : 6 m^3/batch) was used, and then applicability of the highly workable concrete was confirmed through casting real volume (330 m^3) into a foundation (area : 220 m^2, thickness : 1.5 m) of a temporary facility as shown in Fig.2. Two concrete pump cars with capacity of 110 m^3/hour were used to send the concrete, and the diameter of the two concrete pipes was decided to be 20 cm based on a previous experiment. One of the pipes had long horizontal extent of 350 m.

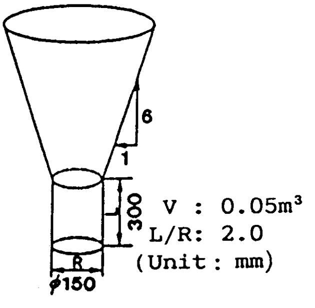

Fig.1 Concrete flow test apparatus

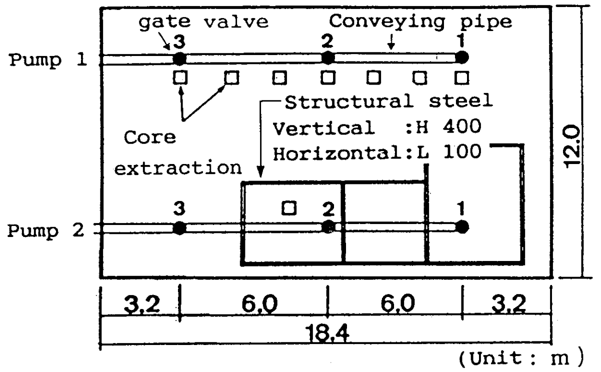

Fig.2 Base of reinforced concrete

The highly workable concrete was at first cast from the extremity of each pipe into the foundation without compaction by vibrators, and the concrete flowed mainly along one direction. After a while, the concrete was reciprocally cast from each gate valve attached along the pipes. Experimental factors other than those shown in Table 8 are: ability to mix the concrete, pumpability, characteristics of flow, lateral pressure acting on form, and so on.

3. RESULTS OF EXPERIMENTS AND CONSIDERATION

3.1 Influence of mix on various characteristics of fresh and hardened concrete

As the various elements of the mix were varied, the amount of SPA was adjusted to give the concrete the designated slumpflow.

(1) Quantity of SPA

The amount of SPA needed was observed to rise slightly as s/a (the fine aggregate percentage) or the fineness of the limestone powder increased, but this amount still remained within harmless range, namely the range free from hardening defects etc.. However, the required amount of SPA seemed to vary with temperature according to the primary chemical components. As shown in Fig.3, the amount of naphthalene sulfonate SPA added at low temperature was kept same or slightly increased, while that of polycarboxilate SPA was decreased.

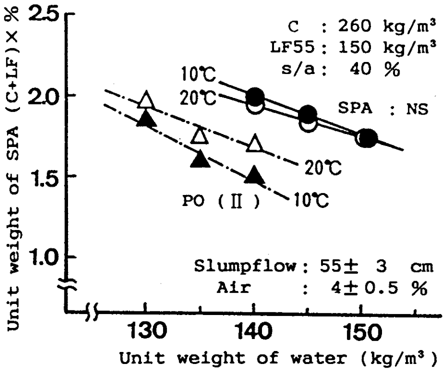

Fig.3 Unit weight of water and SPA

(2) Plasticity of highly workable concrete

Plasticity of the concrete was examined visually. Items checked were; how the concrete was stirred on a mixing plate; whether segregation of the coarse aggregate took place; and how the concrete spread out during the slumpflow test. The plasticity was also judged with the funnel flow test.

Fig.4 shows the relationship between fine aggregate percentage and flow-through time. When the percentage was within 37% - 45% range, the plasticity and self-flowing characteristics of the concrete were good, which fact was confirmed by shorter flow-through time. A concrete with smaller s/a value of up to 34% showed some segregation that its mortar advanced and much coarse aggregate stayed at the center of slumpflow test, and this concrete was observed to have longer flow-through time due to temporary blocking of the funnel by aggregate. On the other hand, a concrete with higher s/a up to 48% exhibited sedimentation of the coarse aggregate. These results allow us to conclude that s/a of 45% is most suitable because it leads to no blocking nor sedimentation.

When the unit content of limestone powder is compared, as shown in Table 7, a concrete having 120 kg/m³ and the slumpflow of 55 cm showed slight segregation of the coarse aggregate, which fact was made clear by some remaining aggregate at the center of slumpflow test. But, a concrete containing 150 kg/m³ or more of limestone powder showed no substantial segregation. Plasticity in general improved as the limestone powder was made finer. It may thus be concluded that amount of fine particles governs plasticity at first and that the particle size distribution has some effect on it too.

As long as the yield value is held constant, plasticity is generally influenced by plastic viscosity, and the viscosity of concrete is strongly governed by the amount of water included in it. Decrease in the viscosity associated with increasing water content is shown Fig.5 where flow-through time is seen to fall. In addition, the viscosity of concrete was also observed to vary with the type of used SPA, i.e., the polycarboxilate SPA reduced the viscosity when compared with effect by the naphthalene sulfonate SPA. This contrast is concluded to be equivalent to difference of the unit water content by about 10 kg/m³, if viscosity is evaluated in terms of the flow-through time.

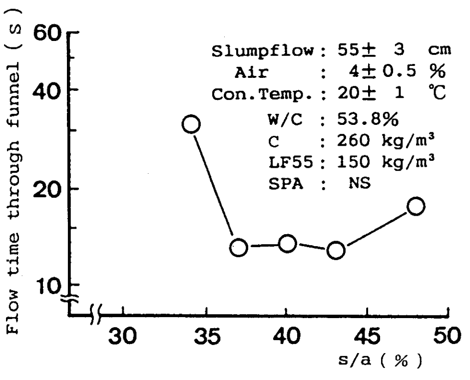

Fig.4 s/a and flow time of rote

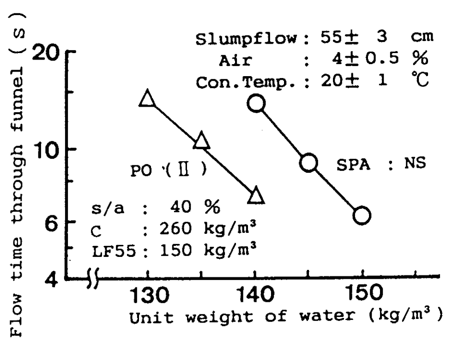

Fig.5 Unit weight of water and flow time of rote

(3) Change of slumpflow with elapsed time

Fig 6 shows change of the slumpflow of concretes mixed with a few SPAs related with elapsed time. When the naphthalene sulfonate SPA was used, the slumpflow did not fall at all even 90 minutes after the mixing, but it began to drop immediately after the mixing even at low temperature of 10 deg.C. when the normal type of polycarboxylate SPA (PO I) was used. This loss in slumpflow by the polycarboxylate SPA could be improved up to the same level as by the naphthalene sulfonate SPA, if the chemical composition was adjusted (PO II). Fig.7 shows influence of temperature on the elapsed time change of slumpflow when PO II is used. At each test temperature, the loss in slumpflow was found to be nearly zero for up to 60 minutes after mixing. However, it was found that increment of the slumpflow after mixing became larger when the test temperature was lower probably because of delayed chemical reaction of the SPA.

The results described above tell that the time, during which the concrete must keep its self-flowing capacity as needed for casting work, can be controlled by adjusting the chemical composition of the SPA, and that consideration must be given not only to the influence of temperature on elapsed time change of the slumpflow but also to increase of the slumpflow after mixing.

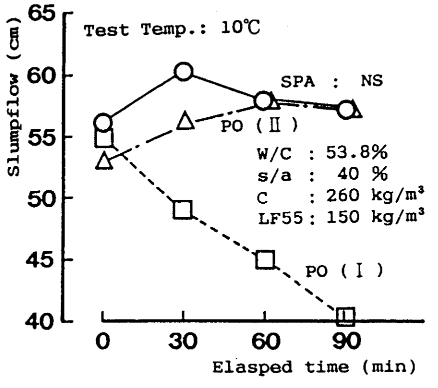

Fig.6 Results of slumpflow test

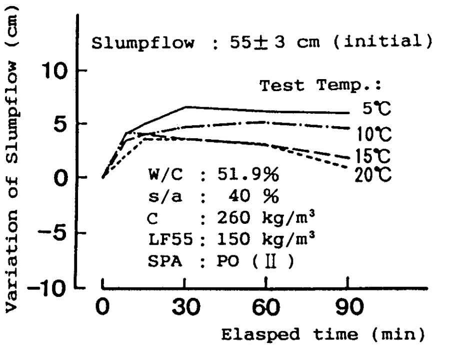

Fig.7 Results of slumpflow test

(4) Bleeding and setting characteristics

All mixes had bleeding ratios less than 3% when the test temperature was 20 deg.C., but this rose larger (in some mixes, substantially) at 10 deg.C.. The degree of this rise was influenced by level of the used SPA as shown in Fig.8, and was also governed by fineness of the limestone powder as shown in Fig.9. Higher fineness was judged to lessen the bleeding under low-temperature conditions.

Setting characteristics were found to have relationship with the amount of SPA as the bleeding do, and the setting time was greatly delayed when more SPA was used. According to Fig.10, which displays result under low-temperature condition, the combination of the type of cement used in this study and the naphthalene sulfonate SPA delays the setting substantially, which fact in turn seems to be one reason for the high bleeding ratio.

Fig.11 shows the relationship between two kinds of maturity (accumulated temperature) one of which was obtained at 20 deg.C. and the other was at 10 deg.C.. Strong correlation is clear despite the difference in mix, so it is thought possible to estimate relatively accurately the setting time at other temperature conditions by calculation with the maturity.

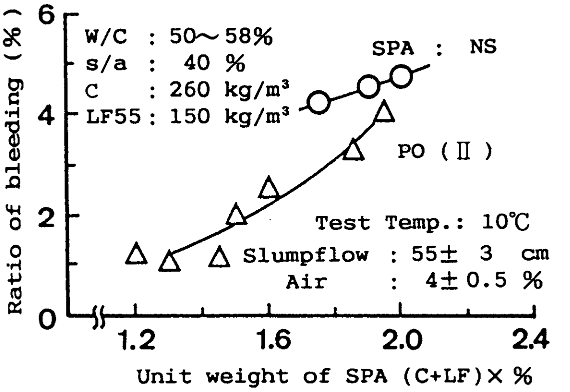

Fig.8 Unit weight of SPA and ratio of bleeding

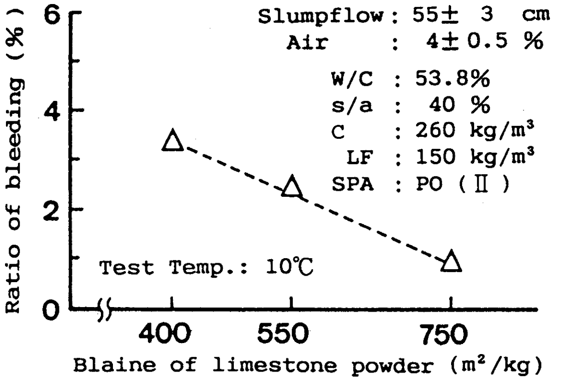

Fig.9 Blaine of limestone powder and ratio of bleeding

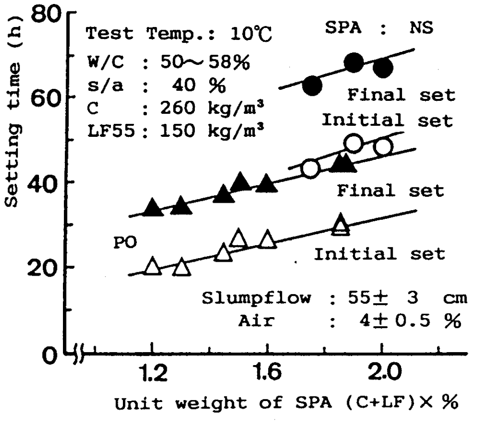

Fig.10 Unit weight of SPA and setting time

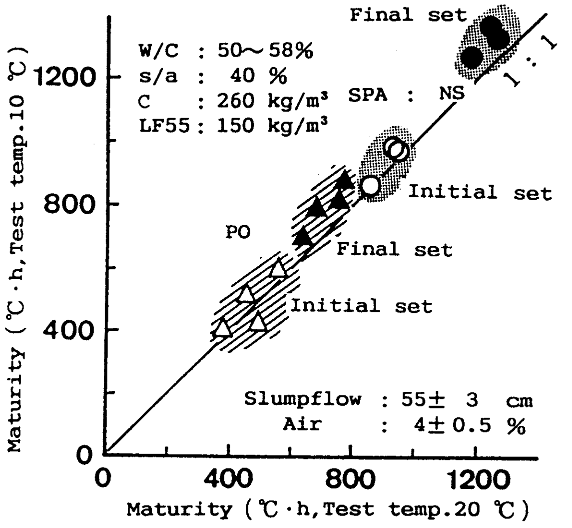

Fig.11 Results of concrete setting test

(5) Development of strength and adiabatic temperature rise

Figs.12 to 15 show the development of compressive strength of the concrete by individual mix element. These results confirm certain common knowledge; that changing the fine aggregate percentage has very little effect on strength; that compressive strength at any age has liner relation with the cement/water ratio, and so on.

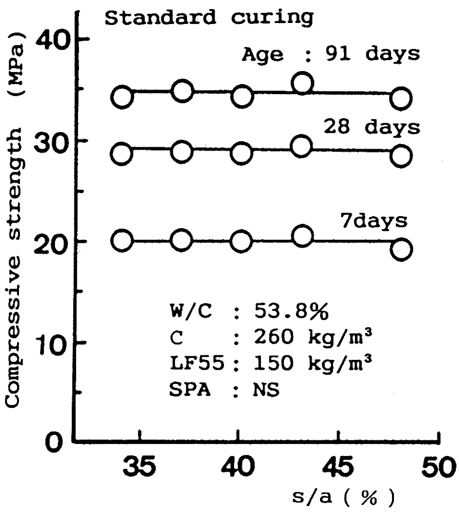

Fig.12
s/a and compressive strength

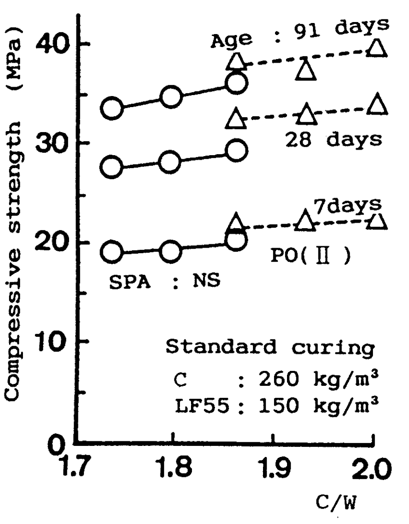

Fig.13
C/W and compressive strength

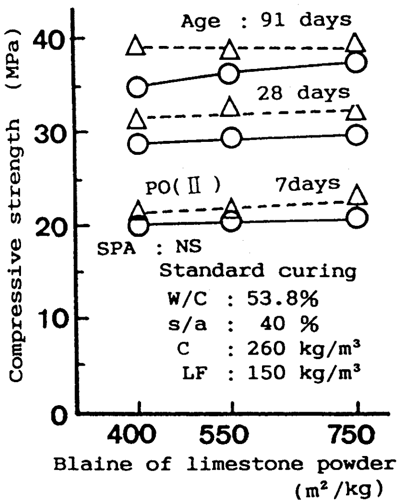

Fig.14 Blaine of limestone powder and compressive strength

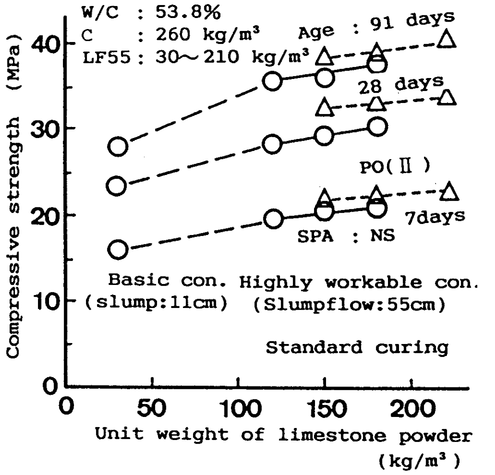

Fig.15 Unit weight of limestone powder and compressive strength

The ultimate strength of the highly workable concrete, however, has tendency to be higher than that of the conventional mix even when both have the same unit water and cement contents (and thus the same water/cement ratios). This tendency was enhanced when the unit content of limestone powder was higher or when the polycarboxylate SPA was used in stead of the naphthlene sulfonate SPA. A farther observation was that finer limestone powder brought slightly higher strength. These tendencies were confirmed only for compressive strength; in contrast the ratio of tensile strength to compressive strength of the highly workable concrete was slightly smaller than that of the conventional mix concrete when the water/cement ratio was the same. The relationships between the compressive strength, tensile strength and static Young's modulus are as shown in Figs.16 and 17.

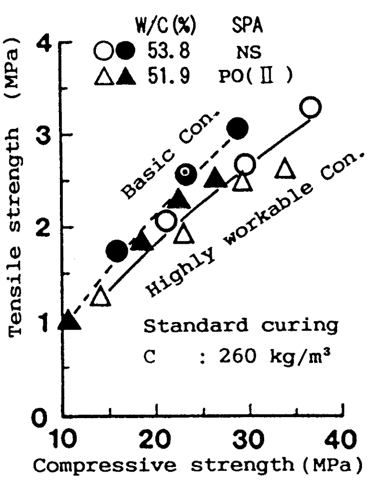

Fig.16 Compressive and tensile strength of concrete

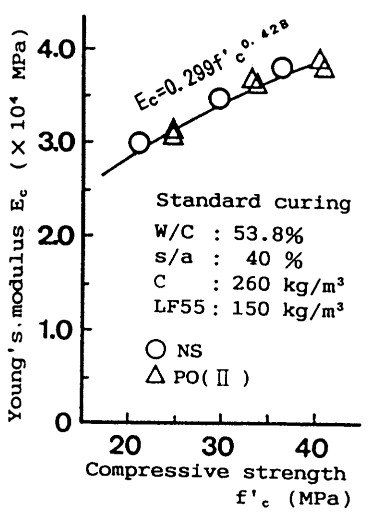

Fig.17 Compressive strength and Young's modulus

Result of adiabatic temperature rise measurements is as shown in Fig.18. The final temperature rise was 25 to 27 deg.C., a value judged acceptable for mass concrete purposes and low enough for this concrete to be called low-heat type. Although the highly workable mix, which contains more SPA than the basic mix, delays the moment at which the temperature rise begins and results in slightly higher final temperature, its thermal characteristics are not different enough to explain the contrast in the development of strength mentioned above.

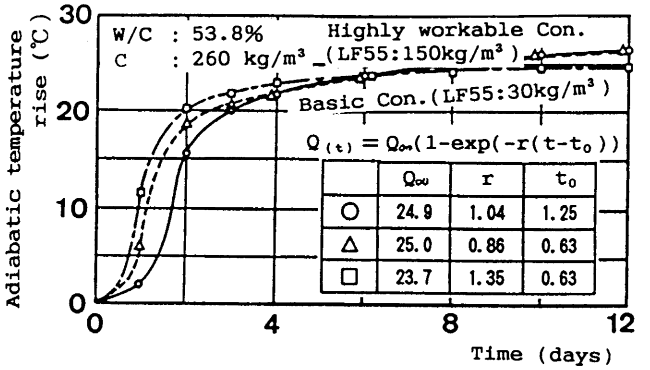

Fig.18 Results of adiabatic temperature rise test

It may be concluded from the above results that the higher strength of the highly workable concrete is a result of the greater dispersion of cement particles during mixing. Namely in the highly workable concrete, which contains more limestone powder and SPA than the conventional mix, these two contribute to disperse the cement particles more effectively during mixing, and this effect in turn enhances hydration and thus the strength. The degree of this dispersion enhancement probably differs according to type of SPA, but the authors have thought that this point be more investigated.

(6) Anti-carbonation and salt-penetration resistance

Fig.19 shows the result of accelerated carbonation test. In every mix, the depth of carbonation is approximately proportional to the square root of the exposure time. The highly workable concrete received less depth of the carbonation by about 30% than the conventional mix because of its increased strength.

Fig.20 shows the penetration depth of chloric iron as determined from the depth of color change inside the concrete by reaction with fluorescein sodium and dissolved silver-nitrate, which concrete had been immersed in artificial seawater. The penetration is less in the highly workable concrete than other concretes which have low water/cement ratio of 35.5% with normal portland cement or B-type blast furnace slag cement both specified in JIS.

Judging from these results, it can be concluded that the addition of large amount of limestone powder, which has been confirmed to have almost no chemical reaction to cement in other tests, introduce no adverse effect on the carbonation nor penetration of chloric iron.

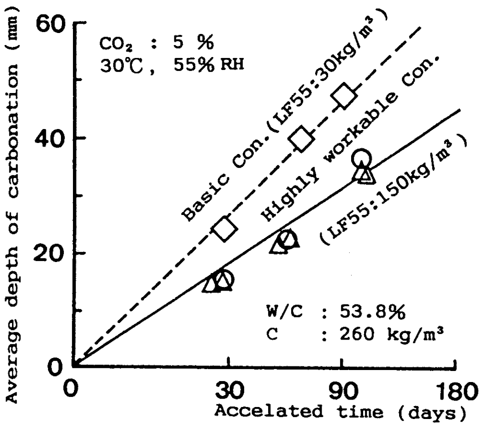

Fig.19 Results of accelated carbonation test

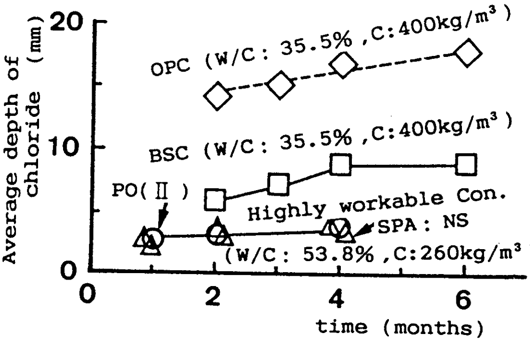

Fig.20 Results of chloride content test

3.2 Applicability of highly workable concrete to actual work

In the experiment 2, applicability of the highly workable concrete is investigated for the mix decided as shown in Table 9. This mix is based on the results of tests on the self-flowing property, bleeding, setting, development of strength and so on.

Table 9 Mix proportion of highly workable concrete

W/C (%)	s/a (%)	Unit weight (kg/m³)					
		W	C	LF*	S	G	SPA**
53.8	45	140	260	150	774	972	6.8～7.2

*LF55, **PO(II)

(1) Production method of highly workable concrete

Fig.21 shows the relation between slumpflow and elapsed time by different mixing times in a real mixer for the actual work. The final slumpflow converges approximately to the same value in spite of difference in mixing time, but the slumpflow of a concrete mixed for only a short while was observed to be small at first and then to increase rapidly.

Fig.22 shows the coefficient of variation for each characteristic of the fresh concretes taken from the four opposite corners in the mixer. The variance in weight per unit volume of mortar and weight of coarse aggregate per unit volume are within the allowable range specified in JIS for all mixing times. However, the coefficients of variation for weight of coarse aggregate per unit volume and slumpflow tend to increase as the mixing time is reduced. When mixing is for only 90 sec, absolute value of compressive strength becomes also lower by about 10% . On the other hand, no substantial difference in concrete quality was observed as shown in Table 10, when the mixing time was a constant of 110 sec. but only the sequence of material drop was changed as shown in Fig.23.

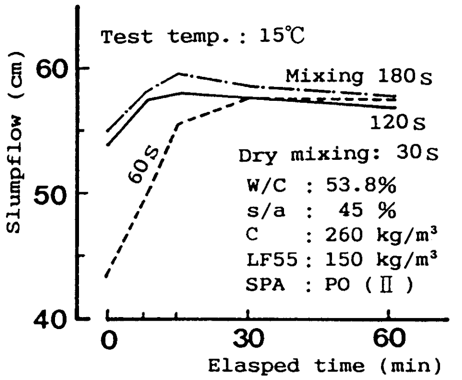

Fig.21 Results of slumpflow test

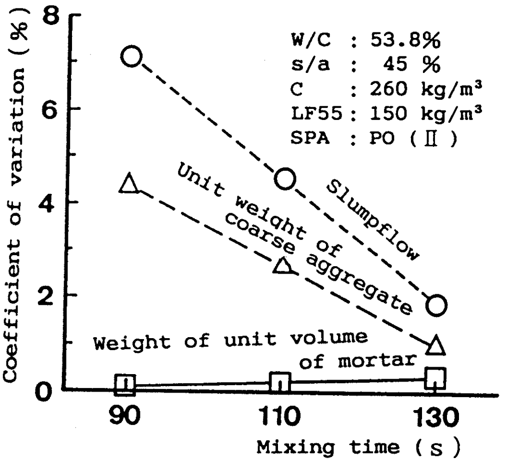

Fig.22 Coefficient of variation on concrete test

Table 10 Various test results of concrete

Mixing pattern	Mixing time (s)	Slump flow (cm)	Air content (%)	Rate pf bleeding (%)	Compressive strength (MPa) 7 day	Compressive strength (MPa) 28 day
1	110	53.5	4.7	0.20	24.9	34.6
2		53.0	4.4	0.31	24.8	34.9
3		54.5	4.6	0.41	25.0	34.2

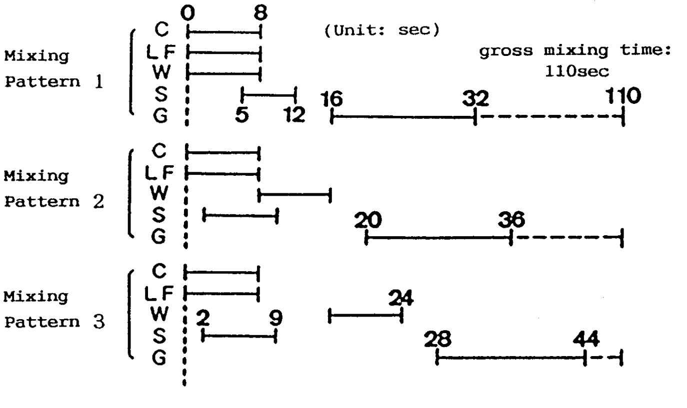

Fig.23 Mixing methods of concrete

From these results, it is concluded necessary to choose a long enough mixing time in order to produce good highly workable concrete with its materials homogeneously dispersed and small variance, but not necessary to take a special method such as dry-mix and so on.

(2) Results of quality control test

The result of the quality control test is as shown in Table 11. The concrete was produced with the real mixer (volume of a batch : 5.5 m^3) to be cast into the RC foundation of temporary facility shown in Fig.2. Average value of slumpflow just after mixing was about 50 cm, and the variation was kept approximately within 5 cm. Almost no variance was observed in the compressive strength of test pieces after standard curing.

Table 11 Results of quality control of concrete

Item	Sample number	Average	Maximum	Minimum	Standard deviation
Slump flow (cm)	30	49	57	44	3.3
Air content (%)	9	3.3	5.2	2.3	0.9
Concrete temperature (℃)	22	14.1	15.5	12.5	0.9
Compressive strength 28-day (MPa)	3	35.5	36.5	34.2	3.4

(3) Pumpability

The pumpability of the concrete was examined with a concrete pipe of the diameter 20 cm and of horizontal real length about 350 m. Fig.24 shows the relationship between pumping pressure and pumping rate. The pressure loss per unit length, as determined from measurement of concrete pressure inside the pipe, is displayed in Fig.25. Generally speaking, very high viscous concrete such as anti-washout under-water concrete made with water-soluble high-molecular admixtures often shows remarkable pumping pressure rise as the pumping rate is increased. In this study of the highly workable concrete, however, it was confirmed for this range of the pipe length that pumping rate as much as about 45 m^3/hour was possible at the maximum pumping pressure. Observed pressure loss per unit length was roughly 70% of that ordinary concrete having the slump of 12 cm was pumped through 15 cm pipe.

Changes which were found in the quality of concrete pumped through the 350 m long horizontal pipe were increment of about 5 cm of the slumpflow, 1.0 to 1.5 % of the air content and 2 deg.C.. It is thought that the air content and slumpflow increased as a result of the entrapped air by pumping and the delayed chemical reaction of the SPA, respectively.

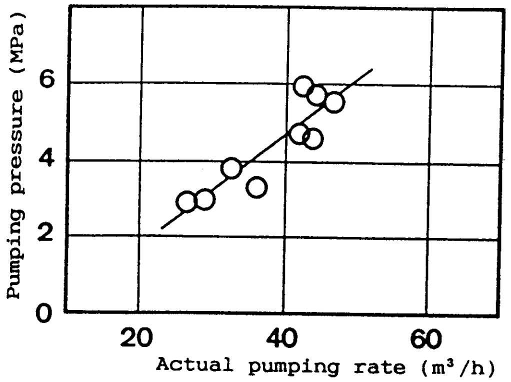

Fig.24 Actual pumping pressure and pumping rate

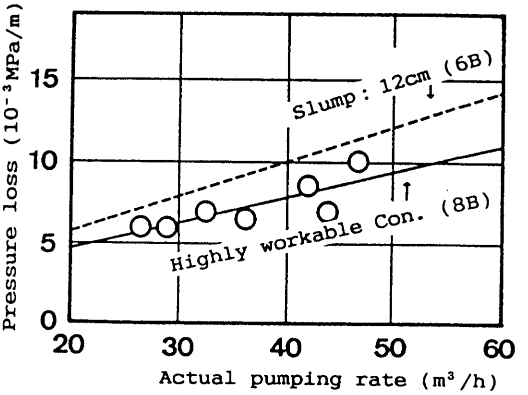

Fig.25 Actual Pressure loss and pumping rate

(4) Self-flowing characteristics

Figs.26 and 27 show the measured gradient of concrete surface as it was cast continuously from the extremity of each pipe. The gradient of flowing concrete through few steel and re-bar obstacles was observed to be 1/20 to 1/30, but this increased to roughly 1/10 where there were more obstacles (horizontal re-bars of D25 @ 150 mm, angle steels). It is thus obvious that dense arrangement of many horizontal re-bars offers more resistance against flowing than sparsely placed steels with larger cross section.

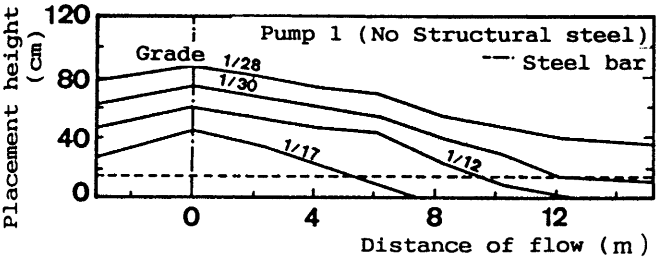

Fig.26 Results of flowing grade (No.1)

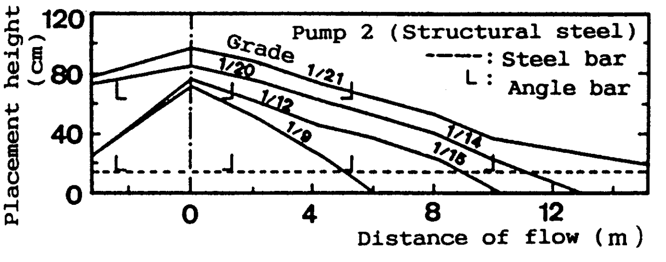

Fig.27 Results of flowing grade (No.2)

(5) Quality of concrete hardened after flowing

Figs.28 and 29 show the compressive strength and unit weight at age of 28 days of test pieces cored from the foundation after hardening. The average strength is about 85% of that of the standard cured test pieces. The variance in strength depending on core location is small in both the horizontal and vertical directions. For flow distance less than 10 m in particular, no tendency for the strength to decrease was observed. On the other hand, some difference in weight per unit volume was found in the vertical direction, and cores taken from lower portion were apt to have larger unit weight. This difference became remarkable when the flow distance exceeded about 10 m.

Regarding the air content in the hardened concrete, entrapped air which was probably brought into at the moment of dropping was found in cores taken from directly beneath the gate valves. The amount of entrapped air was observed to decrease as the flow distance increased, so it can be concluded that the air gradually moved upward as the concrete flowed and this may explain why upper portion of the concrete tended to reduce its unit weight.

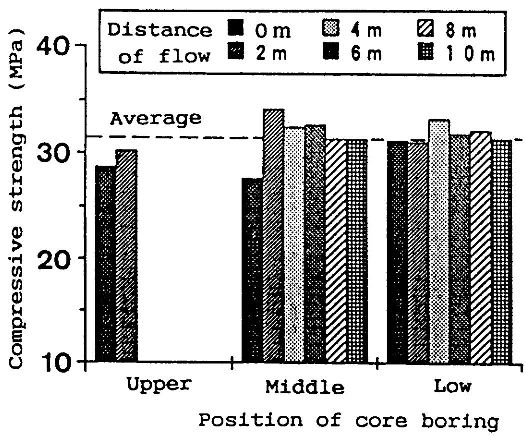

Fig.28 Compressive strength of concrete core

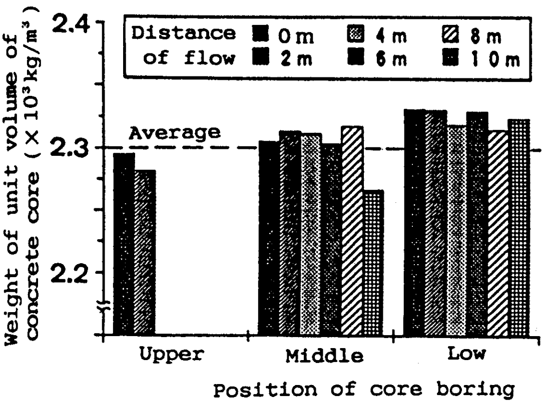

Fig.29 Weight of unit volume of concrete core

These experimental results indicate that it is important to cast the concrete homogeneously into thin layer so as to avoid excessive both flow distance and flow gradient when huge volume of the highly workable concrete is to be cast in wide area. This manner is also required to reduce the unevenness of surface of cast concrete.

In order to check the quality of joints which result from casting in thin layer, horizontal cores for compressive strength test were taken from a joint portion which was formed by 1.5 hours intermission of casting. This result is as shown in Table 12. Irrespective of the use of vibrators or not, compressive strength and unit weight were found to be roughly equal to those of the cores vertically taken from solid portion.

Table 12 Results of concrete core

Vibration	Core Location distance from Surface (cm)	Compressive strength (MPa)		Surface-dry specific gravity ($\times 10^3$ kg/m^3)	
Yes	20	30.5	31.2* (97)	2.25	2.24* (100)
	50	31.2		2.24	
	80	32.0		2.25	
No	20	30.9	31.5* (98)	2.21	2.22* (99)
	50	31.7		2.23	
	80	31.9		2.23	

(6) Lateral pressure on form

The lateral pressure acting on form during the casting process is generally influenced by such factors as the dimensions of form, arrangement of reinforcement, casting speed, etc.. In the experiment 2, highly workable concrete was poured into a steel pipe (inner diameter : 2,360 mm, thickness of the plate : 22 mm and height : 5.5 m) in such a manner that eight layers with a lift of 50 cm each were cast every 30 minutes without vibrating work, and measurement of the lateral pressure was kept. Such casting conditions (4 m lift per day) were thought parallel to actual construction work. The temperature of the concrete at casting and the averaged ambient temperature were both about 13 deg.C., and the initial setting time was 11 hours.

The observed pressure distribution in the vertical direction at the end of each casting is shown in Fig.30. For about 2 hours after casting, the lateral pressure was found to be roughly equivalent to liquid pressure distribution. Thereafter, the increase in lateral pressure was very small and the pressure was constant after 6 hours. While this measurement was carried out, a series of slumpflow tests were repeated on concrete samples which had been left undisturbed after poring into slumpcones. The result of this showed that the moment at which the lateral pressure began to drop corresponded with the moment at which the slumpflow suddenly fell. Similarly, the time during which a liquid-like pressure acted on form was equivalent to the period for which the undisturbed concrete retained its self-flowing property (in this study: about 2 hours).

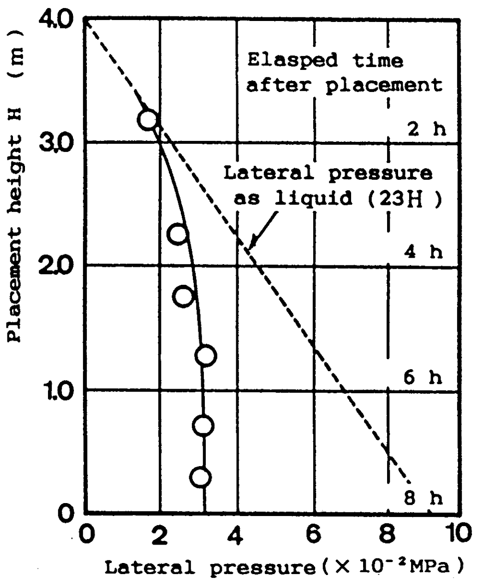

Fig.30 Lateral pressure against formwork of concrete

4. CONCLUSION

The following conclusions can be drawn from the results mentioned above:

(1) Production of highly workable concrete of low-heat type is possible by the use of pulverized limestone powder and SPA (air-entraining high-range water-reducing agent). The resulting concrete, which is made of a maximum coarse aggregate size of 40 mm and a unit cement content of 260 kg/m^3 of a ternary blended low-heat cement, can be sufficiently for mass concrete purpose.

(2) A highly workable concrete made with large quantity of SPA must have a relatively high proportion of fine particles such as cement if good plasticity is to be achieved in a case where special admixtures like water-soluble high-molecular components are not used. From the viewpoint of reducing hydration heat of concrete, an effective way to do this is to use pulverized limestone powder which is chemically inert to cement. No adverse effects were found when this was added in large quantity up to around 150 kg/m^3. Moreover, long term durability was seen to be improved by using it.

(3) The viscosity of the fresh concrete is strongly governed by variations in the unit water content, and the viscosity is decreased with increasing unit water content. The viscosity is also influenced by the type of SPA. With the same unit water content, the viscosity of a concrete containing polycarboxylate SPA tends to be lower than one containing naphthlene-sulfonate SPA.

(4) The retention of slumpflow differs according to the combination of cement and SPA, but it is possible to secure self-flowing property long enough for casting work by adjusting the amount of chemical component. The slumpflow in this case, however, tends to increase after mixing, and the change becomes significant if the concrete temperature is low or if the mixing is insufficient.

(5) Setting of the highly workable concrete is apt to be delayed in proportion to the amount of SPA used. Influence of temperature change on setting, however, can be estimated through calculation of the maturity. When naphthlene-sulfonate SPA is used, setting is postponed larger than by polycarboxylate SPA, and bleeding especially at low temperature condition tends to increase because of this delayed setting.

(6) When the unit contents of water and cement are same and thus the water/cement ratio is also equal between the highly workable mix and the conventional mix, the former concrete containing a large amount of limestone powder and SPA, develops greater strength, though the amount of hydration heat generated is almost the same. The degree of this improvement varies with the type of SPA, and the reason for this may be that dispersing effect of the SPA on cement particles during mixing is different.

(7) When highly workable concrete is produced in an actual mixer for real work, it is important to allow sufficient mixing time so as to ensure that all materials are homogeneously mixed. Changing the order of material addition into the mixer is found to have almost no effect.

(8) Regarding pumpability, relatively low pumping pressure is enough if a pipe of 20 cm diameter is used. A pumping rate of about 45 m^3/hour can be achieved when resistance of pumping is equivalent to horizontally arranged pipe 350 m in length.

(9) The gradient of the surface of highly workable concrete during flowing which has slumpflow around 50 cm is roughly 1/15 to 1/20. Resistance against the flowing concrete becomes stronger by repeatedly-arranged horizontal obstacles like re-bars than sparse obstacles with bigger cross section.

(10) No adverse effects are found in hardened concrete which flowed during the fresh concrete stage.

(11) The lateral pressure on a form immediately after casting is almost equivalent to a liquid pressure distribution, and the moment at which the lateral pressure begins to drop corresponds with the time for the concrete to lose its self-flowing property.

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