PROC. OF JSCE
No. 310, June 1981

EFFECTIVE USE OF RETARDERS AT HORIZONTAL CONSTRUCTION JOINTS OF CONCRETE STRUCTURES

*By Yasuhiko YAMAMOTO**

1. INTRODUCTION

Construction joints are unavoidable not only in massive concrete but also in relatively small concrete structures. They are, undoubtedly, potential planes of weakness and the most vulnerable parts of structures. Every effort has been made and various methods suggested to improve the bond strength at joints. For instance, Concrete Manual[1)] and other workers[2),3)] recommend the use of "wet sandblasting method" to remove the laitance in the surface of concrete. The sandblasted surface is later washed with air-water jet before joining a new concrete on it. ACI Committee 614[4)] suggests a method so-called "green cut cleanup" which consists of cleaning the joining surface of concrete with air plus water jet of high velocity after the concrete has gained the strength to such an extent that only inferior portions in the vicinity of the surface can be removed. "Wire brushing", "chiseling" and "hammering" are other methods that are considered to be effective. Kokubu[5)] reported that the placement of a layer of quality cement paste or mortar on thus treated surface improved the strength significantly. However, it should be noted that all of the traditional methods require a certain form of surface treatment which is usually time-consuming and costly.

Setting retarders have been often used in the various methods mentioned above mainly for the purpose of making the surface treatment easier. They have been added in concrete at a dosage recommended by each manufacturer because the addition of retarders beyond the recommended dosage had been believed to cause deterimental effects to the qualities of concrete. Recently the author found, however, that all mortars recovered their strengths in a short period of time once they had started to harden within 10 days even when an extraordinarily large amount of retarder was added in them.[6)] This observation has led to another way of using retarders for improving the joint strength in concrete structures. The idea is that almost monolithic members or structures could be made if a layer of extraordinarily but properly set-retarded concrete is cast for the last lift of old concrete and new concrete is placed on it, perhaps the day after or later, while the set-retarded concrete is still soft enough to be compacted, thus allowing sufficient vibration to be provided at the boundaries of the three concretes. If this method is proven to be adoptable, many problems related to construction joints in concrete structures or even those of concrete practices would be eased or solved. It should be mentioned here that, after the completion of this work, the author was informed that the same idea as above had been already patented for sliding form method[7)] and its application in a practice reported.[8)] However, these papers describe the adoptability of the idea simply as "very good" and no quantitative evaluation on the strength at the joints is shown.

Present paper discusses the results of experimental work undertaken to examine the feasibility of placing a layer of extraordinarily set-retarded concrete between two horizontal concretes to be joined to improve their bond strength at the joint. The bond strengths in the two boundary planes were tested by splitting tensile strength test. The main variables examined include water-cement ratio and consistency level of concrete, dosage of retarders, and joining time. The results were compared with the inherent strengths of the concretes joined together.

2. MATERIALS

(1) Admixtures

Two kinds of water-reducing and retarding type admixtures (ASTM Type D) were used to extraordinarily retard the setting time of con-

* Member of JSCE, Dr. Eng., Ph. D., Associate Professor, Institute of Structural Eng., University of Tsukuba.

Table 1 Properties of Cement.

Specific Gravity	Fineness, Blaine (cm²/g)	Setting Time (hr-min)		Compound Composition (%)						Compressive Strength (kg/cm²)			
		Initial	Final	C_3S	C_2S	C_3A	C_4AF	$C\bar{S}$	Ig. Loss	1 day	3 days	7 days	28 days
3.15	3 450	2-03	3-10	59.4	17.2	8.5	8.9	2.9	0.8	43	126	196	362

crete. They are commercially available admixtures A and B, and are lignosulfonate type and hydroxycarboxylic acid type, respectively. Reagent-grade citric acid and sucrose were also used in some parts of the experiments as retarders.

No admixture was added to old concrete for the purpose of testing the joint strength under the worst joining condition. However, a normal type lignosulfonate water-reducing admixture C was ingrediented at its recommended dosage in new concrete when its joint strength with set-retarded concrete was tested.

All the admixtures were used by dissolving them thoroughly in mixing water. The dosage of the admixtures was expressed in terms of their weight per unit weight of cement in concrete.

(2) Cement

An ordinary Portland cement (ASTM Type I) was used throughout the work. The properties of the cement are shown in **Table 1**.

(3) Fine Aggregate

The fine aggregate used was natural river sand that passed through a 5 mm sieve. Specific gravity, fineness modulus and absorption of the sand were found to be 2.59, 2.75 and 1.40, respectively. The sand was stored in moist condition and its free surface water was counted as a part of mixing water.

(4) Coarse Aggregate

Crushed limestone aggregate, the maximum size of which being 20 mm, was used in this study. Its absorption and specific gravity were measured to be 0.58% and 2.69, respectively. It was used in the saturated surface dry condition.

(5) Mixing Water

Ordinary tap water that was taken in plastic containers and kept in a temperature-controlled room at 21°C for 24 hrs was used for mixing mortar or concrete.

3. EXPERIMENTAL WORK

(1) General Remark

In studying the new joining method, there are two boundaries to be examined for their joint

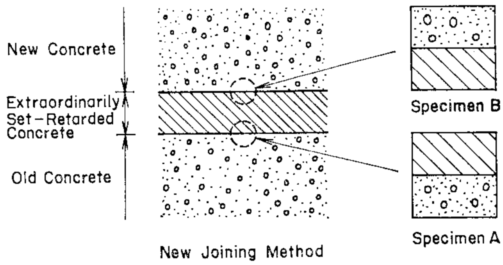

Fig. 1 New Joining Method and Test Specimens.

strengths; one between old concrete and set-retarded concrete and the other between set-retarded concrete and new concrete. The strengths at these boundaries were examined separately by preparing two kinds of specimens as shown in **Fig. 1**.

(2) Determination of Dosage of Retarders

Each of the four retarders was tested for its effect of dosage on the setting time of directly mixed mortars by means of the penetration resistance test (ASTM C 403). Water-cement ratio and flow value of the mortar mixtures were fixed at 0.50 and (180±5) mm, respectively.

Fig. 2 shows the results of the test. Using the results, the dosage which brought the penetration resistance level of mortar to 100 to 200 psi in 15 to 24 hrs was selected for each of the retarders. Such resistance level was tentatively chosen because almost no additional bleeding water was observed to come out of the mortar specimens at the level and the specimens were still sufficiently soft enough to be consolidated for a considerable period of time. The elapsed time of 15 to 24 hrs was set considering both the daily practice of concrete casting at job sites and results of preliminary experiments which showed that mortars sieved from a concrete set 2 to 5 hrs earlier than directly mixed mortar of the same mix proportions. The dosage thus determined was 0.625 or 0.75% of cement by weight for retarder A, 0.35% for retarder B, 0.15% for sucrose, and 0.30% for citric acid. These dosages were changed to 0.50 and 0.825% for retarder A, and 0.25 and 0.50% for retarder B in the part of study where the effect of dosage was examined. Although there was a tendency that richer concrete set in

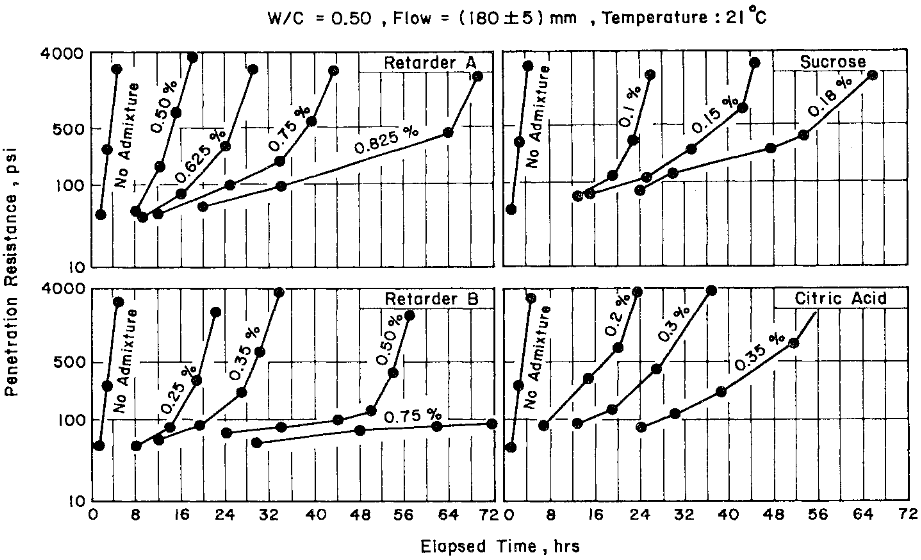

Fig. 2 Effect of Dosage of Retarders on the Setting Time of Mortar.

a shorter period of time at a constant dosage, these dosages were used regardless of water-cement ratio.

(3) Mix Proportion of Concrete

In preparing specimens for testing the joint strength between old concrete and set-retarded concrete (Specimen A), their water-cement ratio was kept constant at 0.50 by weight. Consistency of the mixes was also fixed at (10±1) cm expressed in slump in most cases of this part of the study. It was changed to (5±1) and (15±1) cm when the effect of consistency level was examined. Even in the latter cases, however, the initial slumps of the two concretes joined together were kept equal each other.

Water-cement ratio and slump value of concretes that were used to test the joint strength between set-retarded concrete and new concrete (Specimen B) were mostly 0.40 and (5±1) cm, respectively. In a part of the experiments where the effect of water-cement ratio was examined, the ratio was increased to 0.55 and 0.70. The effect of the consistency of concrete was also examined to some extent in the other part by changing the slump to (2.5±1) and (10±1) cm.

(4) Mixing of Concrete

20 to 30 *l* of concretes were mixed in a 50 *l* capacity revolving-pan type mixer. The mixing procedure adopted was as follows. First, cement and aggregates were placed in the mixer and mixed for half a minute. Mixing water, in which admixture was thoroughly dissolved when necessary, was next added to the mixture and the mixing was continued for another 1 minute. The mixing operation was then stopped for 1 minute and resumed for an additional half minute to complete the mixing.

(5) Preparation and Curing of Specimens

Regular 10×10×50 cm steel molds were utilized in making the 10×10×10 cm cube specimens for testing the joint strength. Four steel plates were inserted in the machined slits of each mold so that four specimens per mold could be made.

a) Joining of Old Concrete and Set-Retarded Concrete (Specimen A)

Plain concrete was first placed in the molds to a half depth with sufficient compaction provided by means of an internal rod-type vibrator. The surface was next lightly leveled with a trowel. After a scheduled period of time, mostly 30 minutes after the mixing of the first concrete, the molds were filled with another concrete that was set-retarded extraordinarily. The compaction of the second concrete was made using the same vibrator by inserting it gradually at the center into the specimens to a depth about 1 cm below the surface of the old concrete. Then, the specimens were finished and covered with wet burlaps and plastic sheets to prevent moisture loss during the curing which was carried out in the laboratory air. About 3 days after the casting, the specimens were demolded and placed in a fog room where the humidity and temperature were controlled at (95±5) % R.H. and (21±1) °C, respectively.

b) Joining of Set-Retarded Concrete and New Concrete (Specimen B)

A half depth of the molds was filled with extraordinarily set-retarded concrete. The concrete was compacted, finished and, then, cured in the laboratory air with wet burlaps and plastic sheets provided on it. Mostly at 15 hrs after the mixing of the first concrete, the second concrete was mixed and placed in the molds to fill the rest of the depth. The compaction of the second concrete and the later procedures for preparing the specimens were made in exactly the same ways as mentioned previously except that the specimens were demolded at about 60 hrs after the casting of the second concrete.

(6) Method of Testing Joint Strength

The joint strength between the two layers of concrete was measured by performing the splitting tensile strength test at the joint. The cube specimen was placed in a universal testing machine and loaded at a rate of about 10 kg/cm^2 per minute through two straight steel bars of 12 mm diameter that were placed between the loading plates of the machine and the specimen. The joint strength, σ_j, was calculated by the equation

$$\sigma_j = \frac{2P}{\pi BL}$$

where B and L are average width and height of a specimen measured on the splitted cross-section, respectively. P is the load at failure.

The values of joint strength shown in this paper are the average of four measurements.

The relation between splitting tensile strength determined by the present method and compressive strength of corresponding cylindrical specimens is shown in **Fig. 3**.

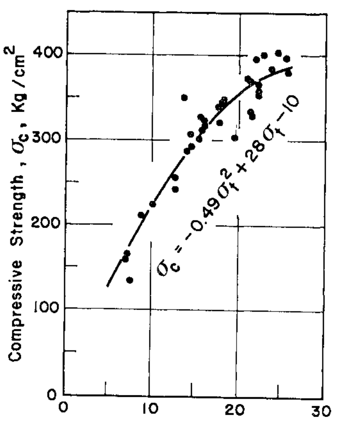

Fig. 3 Relation between Splitting Tensile Strength of Cube Specimens and Compressive Strength of Cylindrical Specimens.

4. JOINT STRENGTH BETWEEN OLD CONCRETE AND SET-RETARDED CONCRETE

(1) Effect of Time Delay of Joining

When extraordinarily set-retarded concrete is cast on ordinary concrete, the joint strength is expected to reduce to some extent because they do not set simultaneously. This effect would be more pronounced if the joining is made at a later time. To examine this effect, set-retarded concrete were cast on plain concretes at various elapsed times and their joint strengths were tested at 7 and 28 days. The test results are shown in **Table 2** along with those of the cases where two plain concretes were joined in the same way.

It is observed in **Table 2** that the strength at joint decreases as joining time is delayed as expected. A close examination of these specimens before the strength test revealed that the exact locations of the joints were relatively difficult to be detected when set-retarded concretes were joined within 30 min, while the boundaries were fairly clearly observed by the color difference of the two concretes in the cases where the joining was made at 1 or 2 hrs of time delay. The clear appearance of the boundaries is supposed to be a sign of insufficient intermixture of the two concretes.

It should be recalled that a rod-type vibrator was inserted only 1 cm below the joining boundary at the center of specimen in this study so that the boundary plane was not disturbed so much for the purpose of the strength test. As the results, almost the same percentage of reduction in joint strength was also observed in all cases even when two plain concretes were joined together as can be seen in **Table 2**. In this connection, it should be mentioned that the underlying concrete was still soft enough to be compacted even at 2 hrs after the mixing. Therefore, considerably higher joint strengths than those shown in this study could be obtained if enough consolidation is provided in practice so that the two concretes are intermixed each other sufficiently and inferior portion of old concrete in the vicinity of the boundary is removed or, at least, scattered.

Another observation that can be made in **Table 2** is that the use of retarder B resulted in somewhat lower joint strength compared with the other cases. The reason for the tendency is not clear at this stage. However, the joint strength was much improved at 28 days when the strength of

Table 2 Effect of Time Delay of Joining on Joint Strength between Old Concrete and Set-retarded Concrete.

Joined Concrete*				Splitting Tensile Strength** (kg/cm²)									
Retarder		Mix Proportion		Age (days)	Time Delay (min)								Companion Plain Concrete*
					10		30		60		120		
Name	Dosage (%)	Cement (kg/m³)	Water (kg/m³)		Without Joint	At Joint	Without Joint	At Joint	Without Joint	At Joint	Without Joint	At Joint	
A	0.625	286	143	7	13.2	12.3(93)	13.1	11.4(87)	13.0	10.9(84)	13.4	9.6(72)	15.9
				28	18.0	15.8(88)	17.6	15.2(86)	18.9	14.3(76)	18.2	12.9(71)	18.9
B	0.350	380	190	7	12.8	10.8(84)	12.9	10.3(80)	12.7	9.2(72)	13.1	7.5(57)	15.3
				28	17.4	15.0(86)	17.8	14.6(82)	17.6	12.6(72)	18.5	12.2(66)	18.2
No Admixture		406	203	7	14.0	13.1(94)	14.5	12.7(88)	14.0	12.2(87)	14.2	11.3(80)	14.6
				28	19.6	17.6(90)	19.7	16.9(86)	20.1	15.1(75)	20.1	13.5(67)	20.0

* $W/C=0.50$, Slump $=(10\pm1)$ cm.
** The number in parenthesis is a relative percentage to the inherent splitting tensile strength of joined concrete.

the set-retarded concrete became nearly equal to that of the companion plain concrete. Therefore, it seems that, practically speaking, the joining of extraordinarily set-retarded concrete on ordinary concrete could be made as effectively as that between ordinary concretes provided that the set-retardation is recoverable within a desired period of time. In fact, the failure pattern at these joints was not a type of simple boundary-separation of the two concretes but was quite similar to that of specimens without any joint as shown in **Fig. 4**.

(2) Effect of Dosage of Retarders

The results in the previous section implied that almost complete joining of concretes could be made eventually even when retarders were added in the second layer concrete at a considerably high concentration, if the joining was made properly. To investigate this observation further, similar experiments were carried out by changing the dosage of retarders. The time delay for joining was fixed at 30 min in this series of test. The results of the test are shown in **Table 3**.

It can be seen in **Table 3** that the relative strength at joint to the inherent splitting tensile strength of set-retarded concrete is nearly equal in magnitude to that observed in the previous section regardless of the dosage and kind of retarders, although the absolute joint strength at 7 days was reduced when the dosage was relatively high. However, the strength was recovered to almost the same level at 28 days in all cases. It should be noted that the highest concentration of the retarders tested in this part of the experiments can delay the setting time to reach the proctor resistance level of 100 psi by more than 30 hrs. Therefore, the results obtained in this section are considered to promise that the joining of set-retarded concrete on ordinary concrete can be successfully made even when the set-retardation of the former concrete is extended to considerable extent provided that the concrete

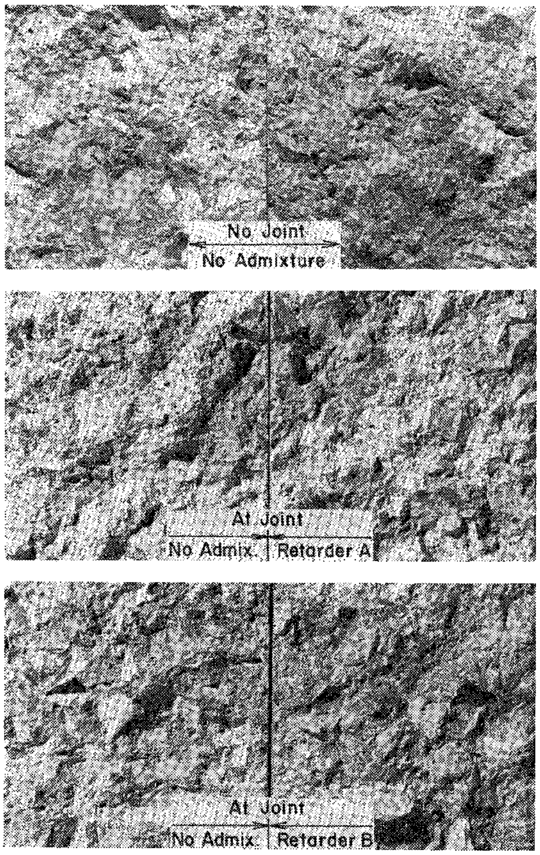

Fig. 4 Appearance of Broken Interface between Old Concrete and Set-retarded Concrete (Age: 28 days).

Table 3 Effect of Dosage of Retarders on Joint Strength between Old Concrete and Set-retarded Concrete.

Joined Concrete*				Splitting Tensile Strength** (kg/cm²)					
Retarder		Mix Proportion		7 days			28 days		
Name	Dosage (%)	Cement (kg/m³)	Water (kg/m³)	Without Joint	At Joint	Companion Plain Concrete*	Without Joint	At Joint	Companion Plain Concrete*
A	0.500	302	151	12.7	10.5 (85)	14.5	18.6	15.6 (84)	19.1
	0.625	286	143	13.1	11.4 (87)	15.9	17.6	15.2 (86)	18.9
	0.750	268	134	11.9	9.5 (80)	14.3	17.3	14.1 (82)	18.3
	0.825	252	126	7.4	5.8 (78)	14.2	17.6	14.4 (82)	18.8
B	0.250	385	192	10.8	10.0 (93)	13.7	18.3	14.9 (81)	17.7
	0.350	380	190	12.9	10.3 (80)	15.3	17.8	14.6 (82)	18.2
	0.500	375	188	11.3	7.8 (69)	13.7	19.8	16.8 (85)	20.8

* $W/C=0.50$, Slump=(10±1) cm.
** The number in parenthesis is a relative percentage to the inherent splitting tensile strength of joined concrete. Time delay of joining is 30 min.

recovers its design strength in a desired period of time.

(3) Effect of Consistency of Concrete

In previous sections, the slump value of concretes was fixed at 10 cm. A further investigation was made to examine the effect of consistency of concrete on the joint strength. Slump values selected were 5, 10 and 15 cm. The joining was made at 30 min after the mixing of the first concrete. The test results are shown in **Fig. 5**.

It is observed in **Fig. 5** that, practically speaking, there is quantitatively no significant difference in the relative joint strength regardless of the test ages and the kind of retarders. These results would verify that the discussions so far made can be equally applied, at least, to concrete of these consistency levels.

(4) A Method of Improving Joint Strength

As mentioned previously, some reduction in joint strength may be anticipated if sufficient vibration is not provided in joining concretes. Then, it would be meaningful to consider a practical method to overcome such a problem.

Water-reducing type retarders not only delay the setting time of cement but also reduce a required amount of mixing water in concrete. As the result, when they are used at a high dosage for the purpose of joining concretes, a large amount of mixing water would be reduced. This implies that, in such a case, water-cement ratio of set-retarded concrete can be decreased and, therefore, its joint strength with old concrete will increase, if the cement contents of over-all concretes are maintained the same. This effect was examined by keeping the cement content equal to 406 kg/m³ which had been mainly used for the companion plain concrete. **Fig. 6** shows the results in which the strength at joint is expressed

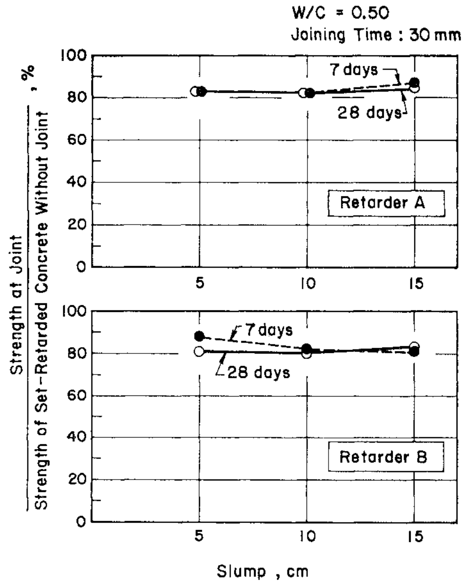

Fig. 5 Effect of Consistency of Concrete on Joint Strength between Old Concrete and Set-retarded Concrete.

in terms of relative percentage to the inherent splitting tensile strength of the companion plain concrete. The previous results that were obtained by fixing the water-cement ratio at 0.50 are also shown in the figure for a comparative purpose.

The experiment showed that retarder A reduced the water-cement ratio remarkably to 0.35 while retarder B decreased the ratio to less extent from 0.50 to 0.47 to yield a concrete of 10 cm slump. As the result of the reductions in water-cement ratio, not only the strength of concrete but also the strength at joint were improved to fairly large extent as expected. For example, the inherent strengths of the two set-retarded concretes were nearly equal to the strength of plain

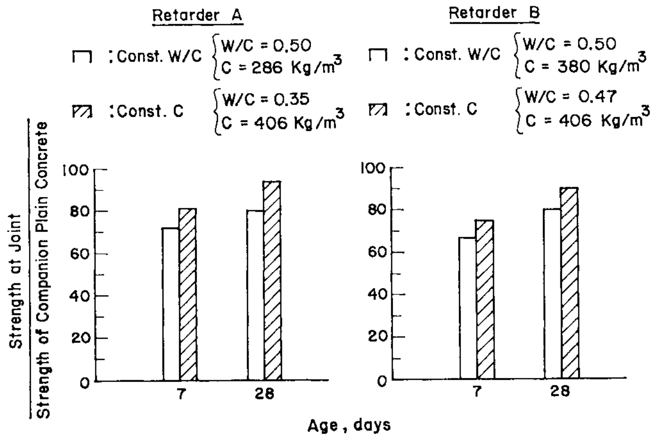

Fig. 6 Effect of Cement Content of Concrete on Joint Strength between Old Concrete and Set-retarded Concrete.

concrete at 7 days. At 28 days, retarder A increased the inherent strength by 27% and retarder B by 5% compared with the strength of plain concrete. These improved inherent strengths led to about 10 to 15% higher joint strength in all cases as compared with the results obtained by fixing the water-cement ratio (See **Fig. 6**). These results are supposed to indicate that the method considered in this section would help to improve the joint strength in actual constructions. The use of retarders of high water-reducing ability is, of course, preferable for the purpose.

It should be noted that the increased joint strength of concrete in which retarder A was added was not so large as could be expected from its extremely reduced water-cement ratio. This is because retarder A is lignosulfonate type and entrained 9 to 11% of air in the concretes. However, the results in **Fig. 6** indicate that the increase in strength due to lowered water content was not completely canceled out by the amount of air. In fact, there was no harmful effect observed with retarder A even in previous sections as far as the magnitude of joint strength was concerned. Therefore, it is conceivable that air-entraining type retarders could be equally used for the new joining method unless they entrain extraordinarily large amount of air, say, more than 10%, at higher dosages.

5. JOINT STRENGTH BETWEEN SET-RETARDED CONCRETE AND NEW CONCRETE

(1) Effect of Existence of Laitance

When one concrete is joined on another concrete that had been placed for several hours or more, it would be considered to be a good practice to remove the laitance in the surface to improve the joint strength. The effect of the surface treatment was, therefore, briefly examined before going into the series tests of this Chapter. Retarder A was used at the concentration of 0.625% in the test.

Table 4 Effect of Laitance Removal on Joint Strength between Set-retarded Concrete and New Concrete.

Specimen*		Splitting Tensile Strength, kg/cm²
Without Joint	Set-Retarded Concrete	12.8
	New Concrete**	18.7
With Joint	Laitance Removed	13.8
	No Treatment	14.7

* W/C=0.45, Slump=(5±1) cm.
** Water-reducing admixture C was ingrediented.

At 15 hrs after the casting of set-retarded concrete, a layer of about 2 mm thick was removed by a knife edge from the surface of the specimens and newly mixed plain concrete was cast on the surface. The joint strength was tested at 6 days after the joining and the result was compared with that of another set of specimens that were joined without any surface treatment. The results are shown in **Table 4** together with the inherent strengths of the two concretes.

It is seen in the table that the surface treatment did not improve the strength at joint and the removal of laitance affected rather adversely than expected. The reason is not clear, although it is conceivable that the bond between cement paste and aggregate particles might have been loosened during the laitance removal from such a soft mixture. At any rate, the above result is beneficial because it implies no need for surface treatment when the new technique under study is employed. Based on this result, no surface treatment was made for the rest of the specimens in this work.

Another noteworthy result observed in **Table 4** is that the magnitude of the strength at joint is in-between the inherent strengths of the two concretes joined together in contrast with the results in Chapter 4 which showed a smaller strength at joint compared with the inherent strengths. A part of the reason may be that the strength of the new concrete is about 50% higher than that of the companion concrete. The extremely reduced water content in the underlying concrete through the use of retarder A could be also attributed to the higher joint strength because of the resultant less bleeding water.

(2) Effect of Consistency of Concrete

Since bleeding water increases the water-cement ratio of concrete near the joining surface, it is expected that the joint strength may be reduced when the new method is applied to wetter concretes which release larger amount of bleeding water. On the contrary, the strength is also expected to reduce when the mixtures are very stiff because enough intermixing of concretes may not be attained at the boundary. To examine these effects, another series of tests were conducted by changing the consistency of concrete. The slump values selected were 2.5, 5 and 10 cm. The water-cement ratio was kept constant at 0.40. The results are summarized in **Fig. 7**.

When the retarder A was used for the set-retardation of initially cast concrete, the same results as those observed in Section **5.(1)** were obtained regardless of the difference in consistency or test age of concrete; that is, the strength at the joint was in-between the inherent strengths of the two concretes joined together.

When citric acid was used, on the other hand, the joint strength became smaller than the inherent strength of either one of the two concretes in most cases, although stiffer mixtures showed more or less the same tendency as the above case at 7 days. In this connection, it should be noted that the mixtures in which citric acid was ingrediented required about 25% more mixing water compared with those in which water-reducing type retarder A was added. As the result, a considerable amount of bleeding water was observed to remain on the surface of the specimens even at the time of joining. Therefore, it is conceivable that the existence of the excess amount of bleeding water was responsible for the reduction in the joint strength. This will indicate that the use of water-reducing type retarders in set-retarded concrete is preferable also in view of joining a new concrete on it if the moisture loss of set-retarded concrete is effectively prevented during the curing. However, it should be noted that retarders which cause a relatively large amount of bleeding water in concrete may be rather preferable in actual construction because full avoidance of the loss and/or evaporation of bleeding water is impractical due to, for example, the existence of reinforcing bars, thus the drying of set-retarded concrete being prevented. Presumably, the most satisfactory joining will be attained in such a case where a negligible amount of surface water remains at the time of joining. No further work has been made in this regard. But, at any rate, the results in this section would assure the applicability of the new joining method to concrete of various consistency levels because the observed reduction in joint strength due to the existence of bleeding water is not so significant.

The appearances of the broken sections of the

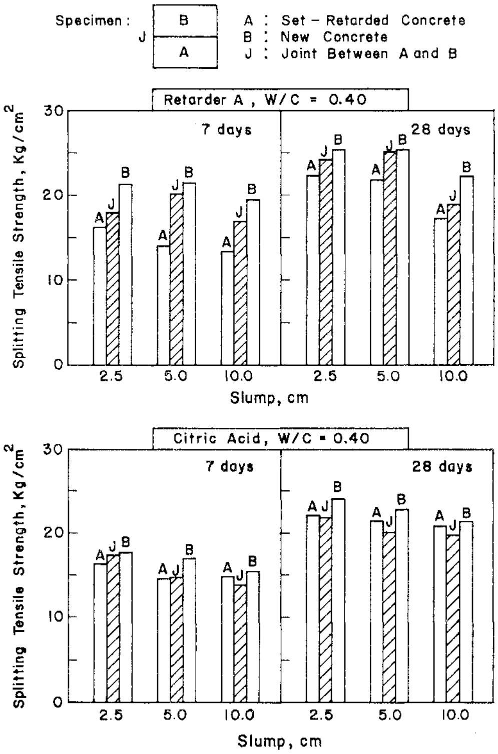

Fig. 7 Effect of Consistency of Concrete on Joint Strength between Set-retarded Concrete and New Concrete.

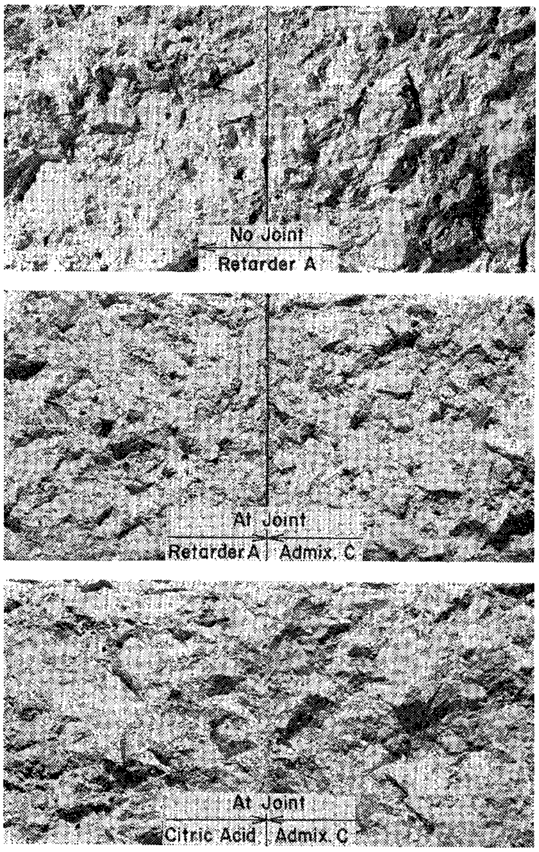

Fig. 8 Appearance of Broken Interface between Set-retarded Concrete and New Concrete (Age: 28 days).

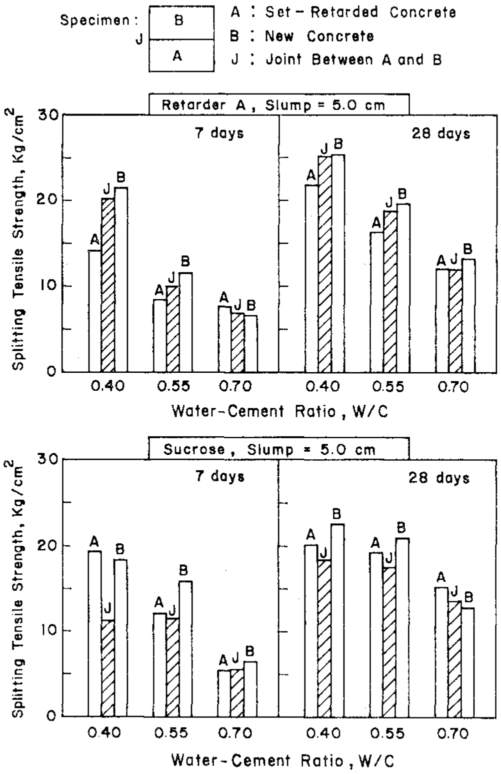

Fig. 9 Effect of Water-cement Ratio of Concrete on Joint Strength between Set-retarded Concrete and New Concrete.

specimens were very similar to those already shown in **Fig. 4** as can be seen in **Fig. 8**

(3) Effect of Water-Cement Ratio of Concrete

In addition to the variables already mentioned, the effect of water-cement ratio, therefore strength level, on the joint strength was examined. The water-cement ratios tested were 0.40, 0.55 and 0.70. Instead of using citric acid, sucrose was added for the set-retardation of concrete in this test to further make sure the effect of bleeding water, because it was found in preliminary experiments that sucrose had no water reducing ability and induced a strong tendency of water-bleeding in concrete. Retarder A was also used as a representative of commercial retarders. Slump values of all the concretes in this series of tests were kept constant at 5 cm. The results are shown in **Fig. 9**.

As was expected, it is seen in **Fig. 9** that the strength at joint is weaker than the inherent strengths of joined concretes in four cases out of six when sucrose was added. This tendency can be observed to increase as water-cement ratio decreases. This may indicate that the effect of bleeding water becomes more prominent when the strength level of concrete is higher. On the contrary, the strength at joint is rather close to the higher inherent strength of joined concretes regardless of water-cement ratio and age when water-reducing type retarder A was added. These results would confirm the importance of reducing the amount of existing bleeding water in the set-retarded concrete at the time of joining. They also indicate that the strength at the joint thus made will not be impaired even when water-cement ratio of concrete is changed as far as proper retarders and their dosages are selected for the set-retardation.

(4) Effect of Joining Time

It would be almost impossible to cast a concrete exactly at a scheduled time at job sites. Then, a considerable reduction in joint strength may take place especially when the joining is delayed to a large extent. This effect was examined by preparing many set-retarded concrete

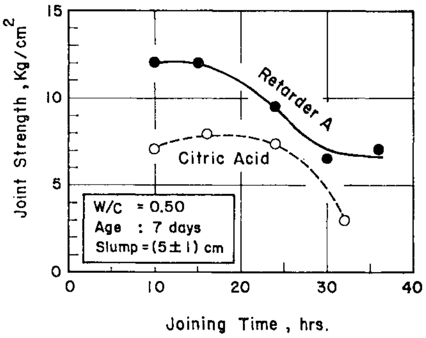

Fig. 10 Effect of Joining Time of New Concrete on Its Joint Strength with Set-retarded Concrete.

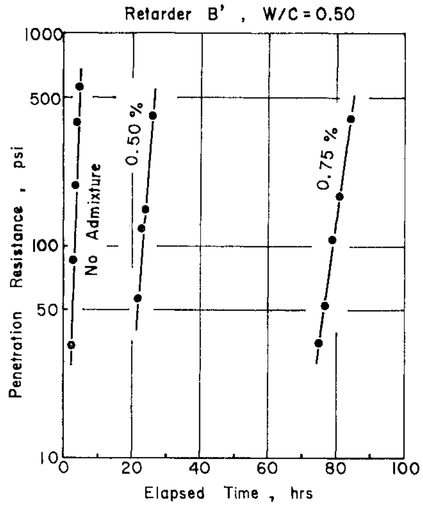

Fig. 11 Effect of Increased Dosage of Retarder on the Setting Time of Mortar.

specimens at one time and joining new concretes on them at various times ranging from 10 to 36 hrs. Retarder A and citric acid were used in this part at the concentrations of 0.625 and 0.3%, respectively.

Although the elapsed time of 15 to 20 hrs was felt to be adequate for joining at the dosages, the results in **Fig. 10** shows that the same or even higher joint strength can be obtained when the joining is made 5 to 10 hrs earlier than the predetermined time. On the other hand, the insertion of a rod-type vibrator into the underlying concrete became harder at or after 24 hrs, presumably because the initial setting time of the concrete was reached soon after the time. Therefore, it is conceivable that earlier joining is preferable and assures a better joint with less effort of compaction, although too early joining may affect adversely because of the existence of bleeding water on the joining surface. However, it should be noted that there is still a plenty of time interval, for example, about 10 hrs in the case of the results in **Fig. 10**, during which a new concrete can be joined successfully.

Sliding form method would be a good example to which the results obtained in this work can be almost directly applied because casting of new concrete is usually made within 1 day. Problems of frequent crack formation along the joints between side walls and top slab of large box elements for submerged tunnel may be solved by joining the slab portion half a day or one day after the casting of the side walls. When heavily-reinforced circular tunnel lining is constructed by traveling form method, difficulty of placing homogeneous concrete near the bottom of the lining will be eased by casting the bottom half and top half on different day using a specially made rotative form of hemicircular section. In many other construction sites, however, the joining of new concrete is often made at later ages than 1 day because of arrangements for construction, problem of heat evolution in concrete and other reasons. The applicability of the new method in these cases is out of scope of the present work, but is under study together with the problems related to the method. The results so far obtained suggest that the joining method could be extended to such cases by increasing the dosage of retarders and that the same concepts as those shown in this work may be equally applicable. **Fig. 11** is an example of the results, which predicts successful joining even at 3 days.

6. CONCLUSIONS

The feasibility of placing a layer of extraordinarily set-retarded concrete between two horizontal concretes to be joined to improve their bond strength at the joint was examined by changing their mix proportions and consistency, joining time, and others. Setting time of the set-retarded concrete was delayed by 15 to 20 hrs in most parts of the study. The following conclusions seem reasonable. They are based on the materials used and the tests performed.

(1) It is possible to retard the setting time of concrete for about 30 hrs by means of the addition of setting retarders with a little reduction in the inherent strength at 28 days. There is a high possibility of extending the retardation further, probably for 3 days or more, depending on type of retarders, conditions at sites, and so forth.

(2) The joining of extraordinarily set-retarded concrete on ordinary fresh-concrete can be made as effectively as that between two ordinary fresh-concretes. However, sufficient consolidation needs to be provided at the boundary to ensure a better bonding, especially when the joining is delayed.

(3) Almost complete joining can be made between extraordinarily set-retarded concrete and new concrete if they are joined properly with enough compaction provided while the former concrete is still soft enough to be consolidated. The removal of laitance in the joining surface does not contribute to improve the joint strength in this case.

(4) In the case of retarding the setting time of concrete by 15 to 20 hrs considering the convenience of daily work, there is a time interval of about 10 hrs during which new concrete can be joined successfully, although earlier joining within the time interval tends to yield a little higher joint strength.

(5) The use of retarders of high water-reducing ability is preferable for the new joining method if the drying of the set-retarded concrete is effectively prevented. Air-entraining type retarders may be equally used for the same purpose unless they entrain too much air, for example, more than 10%, at the dosage required for the appropriate set-retardation of concrete. When some evaporation of water from the joining surface must be allowed as in usual construction sites, retarders which cause a relatively large amount of bleeding water in concrete may be also preferable in a sence that the bleeding water prevents the desiccation of the underlying concrete.

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Prof. N. Nishizawa of Chuo University, Tokyo, for his valuable suggestion on the topic. Acknowledgements are also extended to Messrs. P. A. Chen and J. E. Shiao, both of them are AIT Graduates, for their assistance in the experimental part of the study.

REFERENCES

1) U.S. Dept. of the Interior, Bureau of Reclamation: Concrete Manual, Eighth Edition, pp. 262~271, 1975.

2) Rippon C. S.: Construction joint clean-up method at Shasta Dam, ACI Journal, Vol. 15, No. 4, 1944.

3) Murdock, L. J. and G. F. Blackledge: Concrete Materials and Practice, London Edward Arnold Ltd. Fourth Edition, pp. 166~169, 1968.

4) ACI Committee 614: Recommended Practice for Measuring, Mixing, and Placing Concrete, ACI Manual of Concrete Practice, Part 1, 1970.

5) Kokubu, M.: Studies on the construction joints of concrete, Proc. of Japan Society of Civil Engineers, No. 8, pp. 1~24, Dec. 1950 (In Japanese).

6) Yamamoto Y.: Fundamental study on the use of setting retarders and water-reducing admixtures in concrete, Proc. of Japan Society of Civil Engineers, No. 265, pp. 91~106, Sept. 1977 (In Japanese).

7) Japanese Patent, Sho 48-38178: Improved Sliding Form Method Which Permits Intermittent Joining, 1973 (In Japanese).

8) Div. of Construction, Nagoya Branch, Takenaka Kohmuten: Sliding form method for day-work construction of crop soils, Kenchiku no Gijutsu Sekoh (Technology and Construction Practice for Building), pp. 27~42, May 1971 (In Japanese).

(*Received January 22, 1980*)