A Field Investigation of Water-Reducing, Set-Retarding Admixtures in Concrete Pavement and Bridge Superstructures

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The test sections of reinforced portland cement concrete pavement and decks in this investigation were placed to evaluate and compare the properties of portland air-entraining cement concrete containing water-reducing, set-retarding admixtures with those of regular air-entraining portland cement concrete from the standpoint of their desirability for use on highway projects. The behavior of each admixture was studied with regard to the workability of the mix in placing and finishing including time involved, reduction in water-cement ratio, retardation of setting-time, and the effect of weather conditions on setting-time.

●THE investigation covers the use of the lignosulfonic acid type and the hydroxylated carboxylic acid type of water-reducing, set-retarding admixtures in highway concrete pavement and bridge superstructure wearing courses. The amount of each admixture used per sack of cement remained the same throughout the investigation. Data on actual placement of the pavement and bridge decks under typical Ohio field conditions only are presented.

The test pavement consists of six sections containing the admixtures and three control sections. These sections were placed intermittently throughout the project for a total distance of 1.6 mi of 9-in. reinforced concrete pavement, 24 ft wide.

The two bridge decks were divided into two sections each. A water-reducing, set-retarding admixture was added to the concrete mix of one section of each deck, the other section being designated as the control.

Previous to the placing of the experimental sections in the field, preliminary tests were made in the laboratory using admixtures, cements, and aggregates from sources to be used on the project. Each water-reducing, set-retarding admixture studied performed sufficiently well with respect to retardation of set, reduction in water-cement ratio, and increase in compressive strength to make it desirable to continue the study of the admixtures under actual field conditions.

It was desirable for test purposes to place the control and test sections under similar weather conditions, particularly with respect to ambient temperature. However, it was not always possible to realize this aim.

A progressive record covering each 50 lin ft of test pavement as a unit was maintained. This information included the customary field tests relative to consistency and density plus the elapsed time to various operations from the placing of the concrete on the subgrade to the spraying of the curing membrane on the finished pavement. The temperature of the concrete when spread is also included. The record of daily weather conditions covers air temperature, wind velocity and direction, amount of evaporation of water during the placing of the test sections, and condition of the sky. Similar observations, but in limited number, were recorded while placing the bridge sections.

A set of three 6- by 12-in. cylinders was made from the concrete of determined consistency and density for each 50 lin ft of pavement and tested in compression at 7, 28, and 90 days.

Rate-of-hardening tests were performed in a field laboratory according to the Tentative Method of Test for Rate of Hardening of Mortars Sieved from Concrete Mixtures by Proctor Penetration Resistance Needles (ASTM Designation: C-403-57T). The Proctor penetration resistance apparatus was based on plans furnished by the Bureau of Public Roads, Physical Research Branch, Washington, D.C. Needles with $^{1}/_{10}$- and $^{1}/_{30}$-sq in. bearing areas were used to perform the tests.

The cement factor for the structural concrete mix was 6.5 sacks per cu yd with 38.5 percent natural fine aggregate. The coarse limestone aggregate was used in the proportion of 50 percent No. 4 ($^{3}/_{8}$ - 1 in.) and 50 percent No. 3 ($^{3}/_{4}$ - 2 in.). The cement factors for the pavement sections were 6.5 sacks per cu yd and 5.75 sacks per cu yd with 33 percent natural fine aggregate and gravel coarse aggregate in the proportion of 45 percent No. 4 ($^{3}/_{8}$ - 1 in.) and 55 percent No. 3 ($^{3}/_{4}$ - 2 in.). The 5.75-sack mix was introduced to provide additional compressive strength data. Seventy and five-tenths pounds of No. 4 and No. 3 were added in these proportions to the coarse aggregate in the 5.75-sack mix to compensate for the difference in batch weights. The aggregate gradings remained reasonably constant throughout the project and no proportional change in the amounts of fine and coarse aggregate was necessary.

BRIDGE SUPERSTRUCTURES

Ready-mixed concrete was used for the structures. The air-entraining portland cement conformed to the requirements of ASTM Designation C-175 Type IA.

The ready-mixed concrete was batched from a non-automatic plant and delivered to the job site at an approximate rate of 50 cu yd per hr. Both types of admixtures were accurately measured and dispensed by automatic equipment furnished by the admixture producers. The liquid admixtures were added to the fine aggregate in the batch weigh bin. All coarse aggregate was maintained in the stock piles at a uniform moisture content not less than total absorption. It was occasionally necessary to add water to the batch at the job site to bring the concrete to the desired consistency. Accurate control of the mix is necessary if the desired results are to be obtained. Uniform slump canbe difficult to obtain with ready-mixed concrete, but the addition of the admixtures apparently did not magnify this problem. However, it is important that the concrete control inspector realize that the slump or workability of the mix cannot be determined by observation. The admixtures improved the workability of the concrete with reduced water-cement ratios. The bridge decks were machine-finished full width and cured with a double thickness of wet burlap which was continuously water sprayed for 7 days. The plastic concrete containing Admixture "B" "pulled" to some extent under the finishing machine. However, the "pulling" did not present a serious finishing problem. No change was made in the mix design. A similar occurrence was at times noted by the pavement finishers during the straightedging of the pavement. Similar field reaction was encountered when air-entrained concrete was first introduced into Ohio. At times, concrete containing water-reducing admixtures may present a slight surface "pulling" effect or "stickiness" when being finished. This was attributed to the lower water-cement ratio used with these admixtures which gave a richer-appearing mix containing a smaller volume of paste.

After removal of the forms, the underside of the concrete containing the admixture presented a clean, smooth surface in contrast to the control or regular concrete section which was pock-marked with small surface voids caused by air bubbles. This condition is common in superstructures today where there is little clearance ($1^{1}/_{4}$ in.) between the reinforcing and the falsework. The difference in under-surface condition between the two sections of the slab may be attributed to the greater plasticity of the mix containing the admixture.

It may also be assumed that the bond between the concrete and the bottom of the reinforcing bars would be greater, because the greater mobility of the concrete containing the admixture results, under vibration, in easier and more complete envelopment of the reinforcement.

PAVEMENT

Nine pavement test sections were placed between May 9 and June 9, 1960. One each of the two main classes of water-reducing, set-retarding admixtures was used in six of the sections in predetermined quantity as recommended by the manufacturer and as previously used in the laboratory. Three sections were designated as control sections for comparison with the water-reducing, set-retarding sections.

Considerably more use has been made of water-reducing, set-retarding admixtures in the field of structural concrete than in pavement, and consequently there is more familiarity with this aspect of their use. Most of the advantages of the use of admixtures in structures apply equally to pavement concrete. In addition, there are advantages peculiar to paving operations. Efficient operation combined with speed and timing are essential for economical paving operations. Any changes in the mix which upset the timing or delay operations eventually raise the cost of pavement. Of course, there may be times when the value of a modification more than justifies the cost. In this instance there was concern as to whether the addition of the admixtures would delay operating procedure at the batch plant, the paving operations, or the sawing of the transverse and longitudinal joints.

The lignosulfonic acid-type admixture is designated in this report as Admixture A. The hydroxylated carboxylic acid class of admixture is designated as Admixture B.

Another brand of air-entraining portland cement conforming to the requirements of ASTM Designation C-175 Type IA, was used in the pavement mix. The automatic batch plant was timed to weigh an aggregate batch every 7 sec. The accurate measuring and dispensing of the admixtures was accomplished in the allotted time by the automatic dispensing equipment furnished by the admixture manufacturers and installed at the batch plant. The admixtures were automatically added to the fine aggregate in the weigh bin. The fine and coarse aggregates were delivered daily to the batch plant by truck. Stock piles were kept small and an even moisture content was maintained throughout the paving operations.

The concrete was mixed for 1¼ min at the site in three dual-drum 34-E pavers at a speed of 16 rpm. A Heltzel Flex-plane was used in the screeding and finishing operation. Straightedging completed the finishing. After a suitable interval, the surface was burlap dragged, the pavement edged, and the slab sprayed with white waterproof curing membrane. The membrane was applied by means of an automatic mechanical sprayer. The retardation in setting time resulting from the addition of the admixture did not interfere with or delay these operations.

Atmospheric conditions prevailing at the time of the placing of each test section varied. Ambient temperatures ranged from a low of 72 F (Dyer Rd. bridge deck) to a high of 98 F (Big Run bridge deck). Pavement sections were placed with temperatures ranging between 75 and 88 F. Wind velocities ranged from 2 - 15 mph. Amount of evaporation of water during the placing of the test sections ranged from a low of 0.05 in. to a high of 0.14 in. These variations in weather conditions caused slight differences in the rate of hardening of the concrete, but may be considered insignificant insofar as affecting the placing and finishing operations. Change in water-cement ratio, providing other conditions remained constant, was the most dominant factor causing a change in the rate of hardening of the concrete.

On superelevated curves, the cohesiveness of the plastic concrete containing the admixtures was advantageous to finishing operations. There was less slippage of the plastic concrete from the elevated side of the pavement, thus eliminating any extra manipulation of the concrete by the finishers. The sawing of the transverse joints and the longitudinal joint was not delayed by the addition of the admixtures to the concrete. The transverse joints were cut approximately 8 hr after placement of the concrete and the longitudinal joint about 24 hr later. This schedule applied both to test sections and regular pavement.

Most of the test pavement was placed on days when the ambient temperature ranged from the middle seventies to the low eighties with winds of low velocity. Under these conditions, there was no realization of the benefits accruing from the use of these types of admixtures during hot weather concreting. However, when placing the deck on the

Big Run bridge under conditions of high temperatures, low humidity and with a drying breeze, the placing and finishing of the concrete was materially facilitated by the increased workability of the set-retarded, low water-cement ratio concrete.

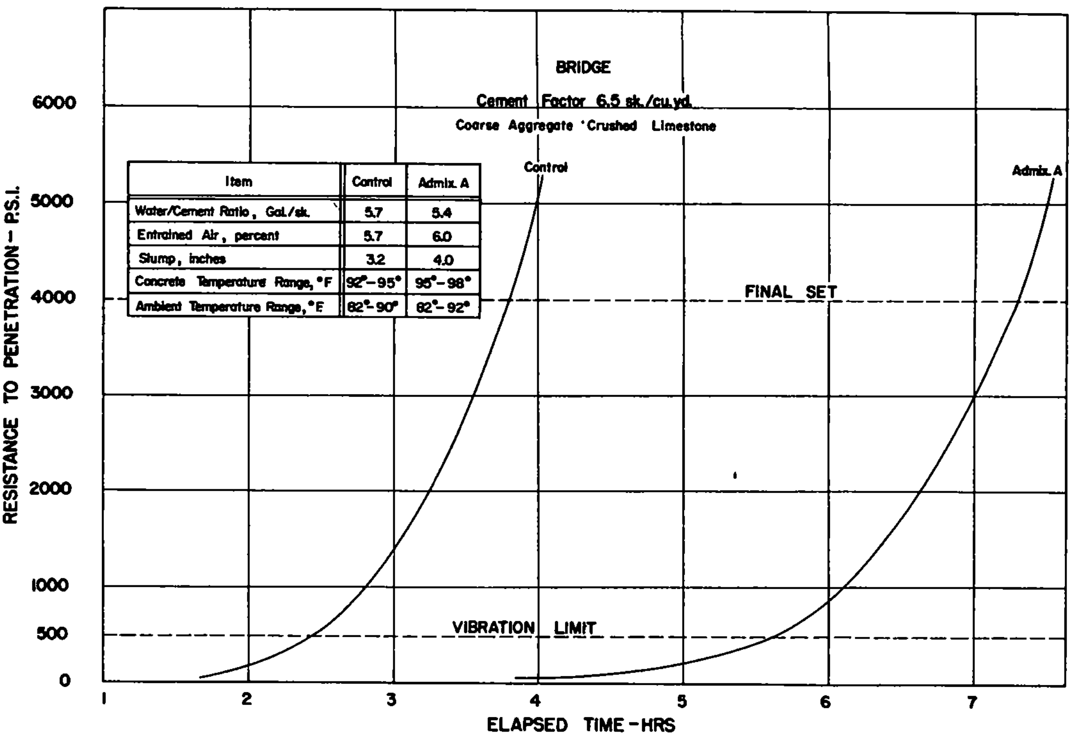
The elapsed time for placing and finishing operations for each 50-lin ft unit of pavement varied, but the differences were not caused by the inclusion of the admixtures in the concrete.

Roadsite operations were timed for one hundred and sixty-nine 50-lin ft units of which 60 were control sections. For the control sections, average elapsed time in minutes from the deposition of the concrete on the subgrade until the completion of the operations designated were: spreading—4, finishing—8, burlap drag—20. For the admixture concrete: spreading—4, finishing—10, burlap drag—24. In comparing these averages, consideration must be given to the fact that the control sections were closer to the batch plant and were placed on days when the weather conditions were what the paving contractors call "perfect finishing weather."

A reduction in water-cement ratio was maintained through the use of the admixtures, while the slump remained approximately the same as that of the regular concrete with a higher water-cement ratio. The average ratio for the control sections was 4.8 gal per sack in comparison with 4.5 gal per sack for the concrete containing the admixtures—a 6.25 percent reduction.

The average rate of hardening of the structural concrete is shown by the curves in Figures 1 and 2 which show similar relationship between the control and the retarded concrete. The approximate difference in time of retardation on the different days may be attributed mainly to the difference in ambient temperature.

The average compressive strength of the structural concrete (6.5 sacks per cu yd) is shown in Figure 3. Admixture A shows an increase in strength of 720 psi over the control concrete. Admixture B shows an increase of 990 psi over its control concrete. The compressive strength of the concrete containing Admixture B was lower than that



Item	Control	Admix. A
Water/Cement Ratio, Gal./sk.	5.7	5.4
Entrained Air, percent	5.7	6.0
Slump, inches	3.2	4.0
Concrete Temperature Range, °F	92°–95°	95°–98°
Ambient Temperature Range, °F	82°–90°	82°–92°

Figure 1. Average rate of hardening of concrete compiled from penetration test data determined in the field.

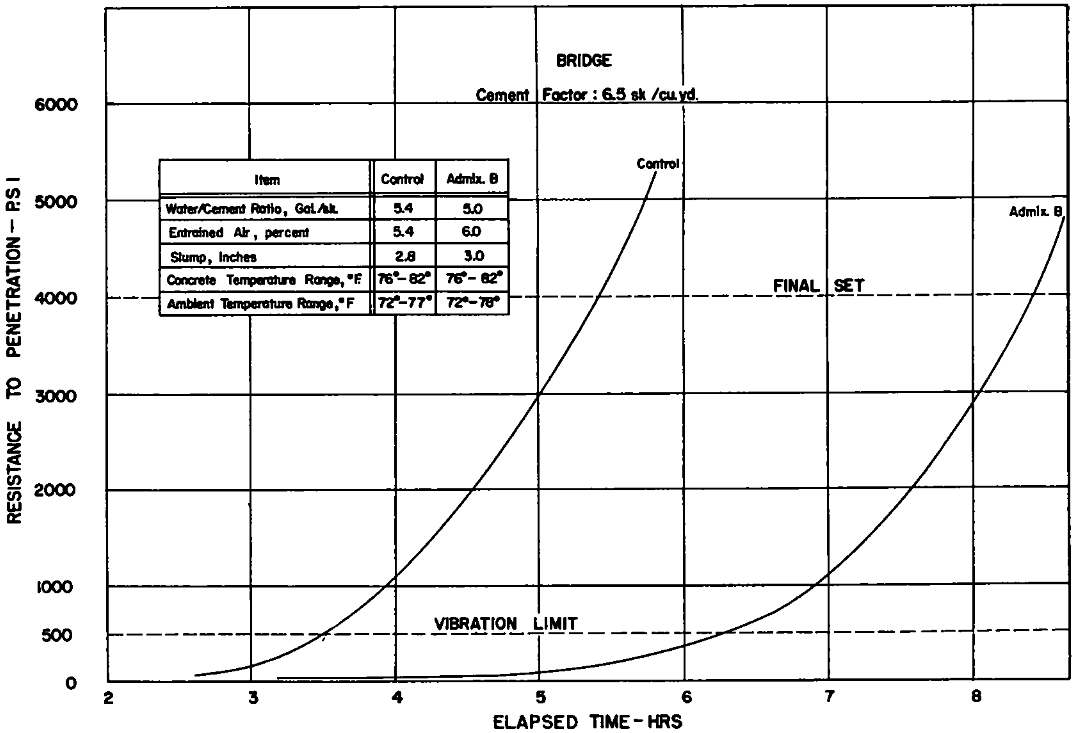


Figure 2. Average rate of hardening of concrete compiled from penetration test data determined in the field.

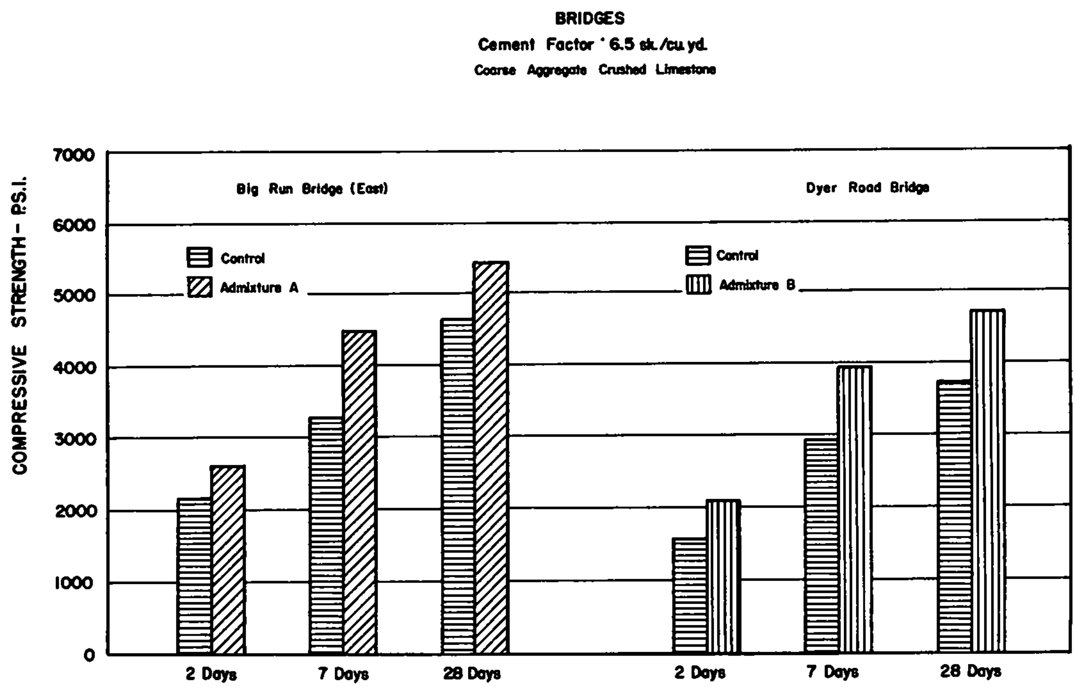


Figure 3. Average compressive strength—PSI.

of the concrete containing Admixture A, and a similar situation existed with the control concretes.

Pavement concrete placed on the same day as the Admixture B concrete and its control also developed lower-than-average strength.

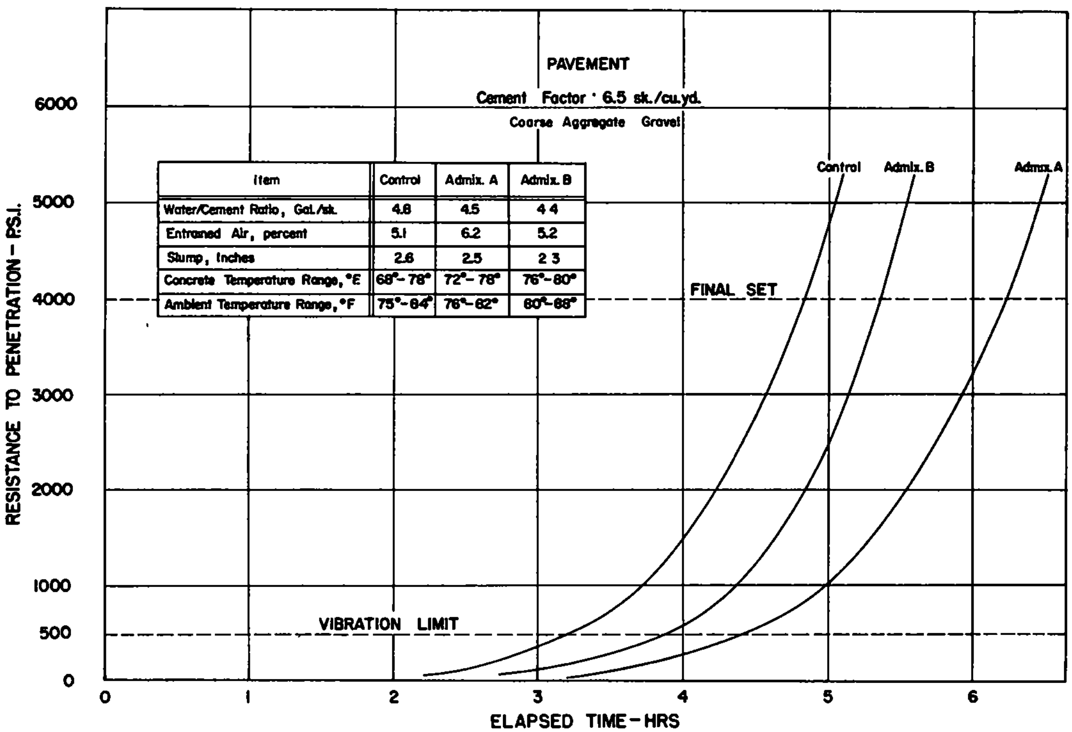
Figures 4 and 5 show average rate-of-hardening curves for the 6.5 sacks per cu yd and 5.75 sacks per cu yd pavement mix, respectively. In Figure 4 the average retardation is less for Admixture B than for Admixture A. No explanation is offered.

Pavement compressive strength averages by cement factor and admixtures are shown in Figures 6 and 7. Tests at 90 days show an average increase in compressive strength of 22 and 26 percent, respectively, for Admixtures A and B concretes over the 6.5 sacks per cu yd pavement mix without admixture. The admixture concrete with 5.75 sacks per cu yd shows an increase of 16 and 18 percent, respectively, at 90 days over the control for concretes containing Admixtures A and B.

OBSERVATIONS

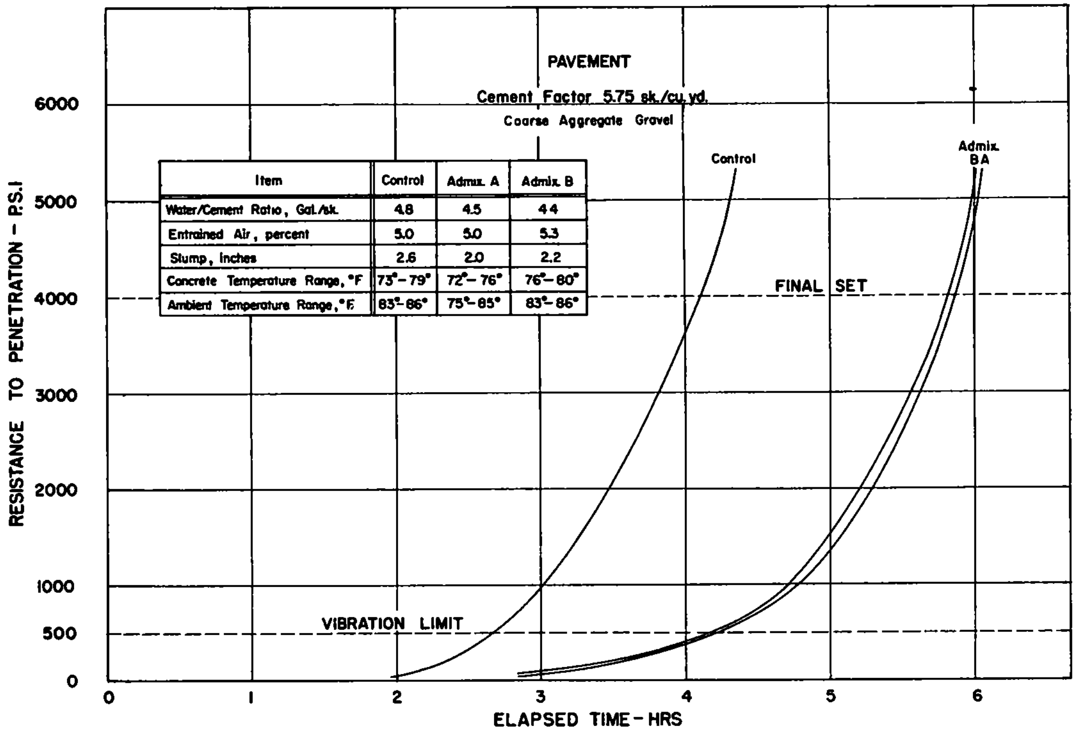
In conclusion, the following observations were made:

1. Both admixtures were apparently compatible with the cements, fine aggregates, and both the gravel and limestone coarse aggregates used on the project.
2. Many factors may influence the setting time of retarded concrete in the field, the most important of which is the amount of mixing water. In a lesser degree, the ambient temperature, wind velocity, humidity, intensity of the sunshine, and the temperature of the mix were observed to be determinants. Control by experienced inspectors is necessary to obtain desired results.
3. Admixture B apparently did not entrain air; that Admixture A entrained a slight amount is inferred from the fact that slightly less air-entraining agent was added to the mix in conjunction with Admixture A to obtain the same air content. It was not practical



Item	Control	Admix. A	Admix. B
Water/Cement Ratio, Gal./sk.	4.8	4.5	4 4
Entrained Air, percent	5.1	6.2	5.2
Slump, Inches	2.6	2.5	2 3
Concrete Temperature Range, °F	68°-78°	72°-78°	76°-80°
Ambient Temperature Range, °F	75°-84°	76°-82°	80°-88°

Figure 4. Average rate of hardening of concrete compiled from penetration test data determined in the field.



Item	Control	Admix. A	Admix. B
Water/Cement Ratio, Gal./sk.	4.8	4.5	4.4
Entrained Air, percent	5.0	5.0	5.3
Stump, Inches	2.6	2.0	2.2
Concrete Temperature Range, °F	73°-79°	72°-76°	76°-80°
Ambient Temperature Range, °F	83°-86°	75°-85°	83°-86°

Figure 5. Average rate of hardening of concrete compiled from penetration test data determined in the field.

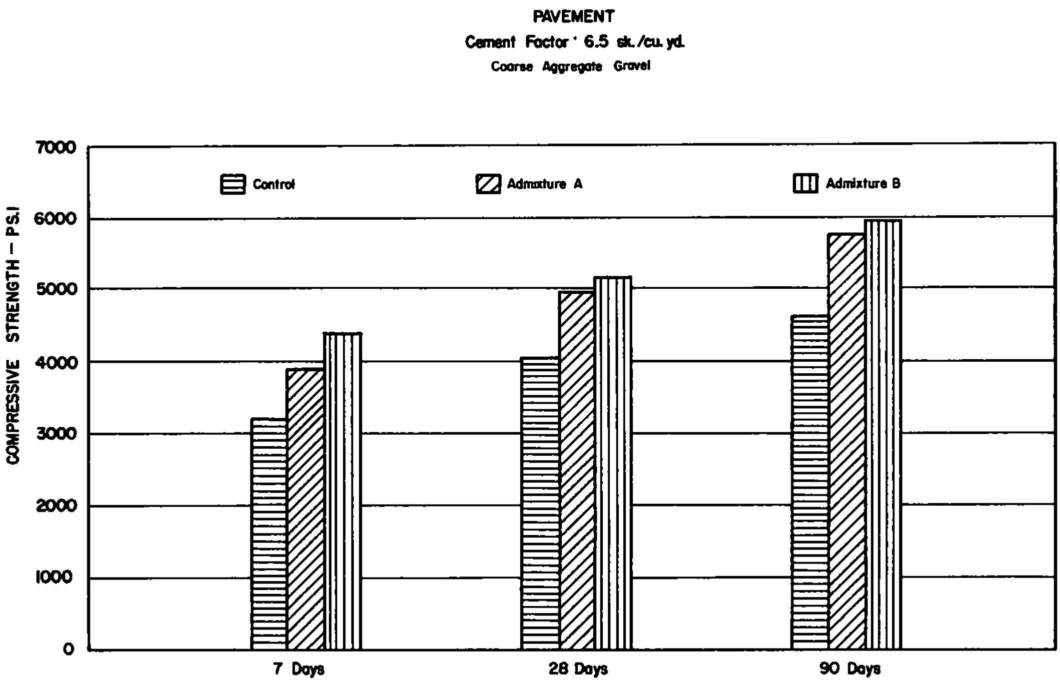


Figure 6. Average compressive strength—PSI.

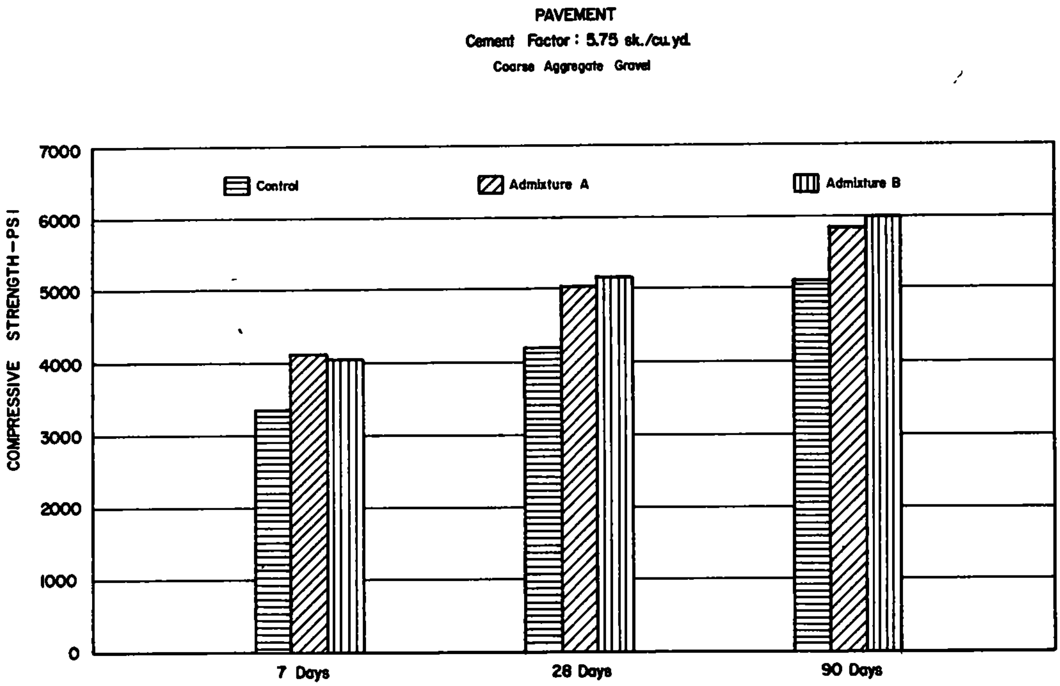


Figure 7. Average compressive strength—PSI.

to determine with precision the amount of air entrained by Admixture A, although it is estimated to be less than 1 percent.

4. An increase in compressive strength over the control mixes was obtained through the use of both admixtures with both cement factors at all ages. Tests were made at 2, 7 and 28 days on the structural concrete and at 7, 28 and 90 days for the pavement concrete.

5. Through controlled retardation of setting time, a bridge deck may be placed and finished in a continuous pour while the entire mass of concrete is still plastic. Cracks caused by the continually increasing deflection of the forms or girders due to the changing dead weight as the placing of the concrete progresses may thus be eliminated.

6. The paving concrete mixed at the roadsite was more easily controlled than the ready-mixed concrete.

7. After retardation has reached the "vibration limit," normal setting of the concrete may be expected.

8. The use of water-reducing, set-retarding admixtures did not delay, nor did it necessitate any change in normal paving operations.

9. This study indicates that economies may result from the use of water-reducing, set-retarding admixtures for one or more of the following reasons:

(a) Because with concrete containing these admixtures, bridge deck placing and finishing operations may be delayed beyond the time required to complete the same operations with ordinary concrete, fewer workmen may be required, and due to regulations governing labor compensation, a saving in wages may be effected.

(b) Not infrequently, ordinary concrete with low water-cement ratios "hangs up" in the concrete bucket on structural pours, with consequent loss of time in the placing of the concrete. No such difficulty was encountered with the admixture concretes.

(c) Because the concrete containing the admixtures gave greater strength than the ordinary concrete, it may be possible to obtain a specified strength with less cement where a minimum cement factor is not required.

10. Exactness in the dispensing of the admixture at the batch plant is vital to obtaining the benefits to be derived from their use. An increase may cause a "wet" batch and may excessively retard the set, whereas a decrease may lower the slump and require the addition of water to the mix, with resultant loss of strength through increase in water-cement ratio.

11. Until more data are accumulated as to what can be expected from the use of water-reducing, set-retarding admixtures, it is advisable to conduct a laboratory study prior to field use, employing the same aggregates and cement to be used in the field. Where such data already exist, the laboratory study can of course be omitted.

HRB: OR-467