State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

RESEARCH AND DEVELOPMENT
REPORT NO. 6A

AN INTERIM REPORT ON THE USE OF WATER REDUCING ADMIXTURES IN CONTINUOUSLY REINFORCED PORTLAND CEMENT CONCRETE PAVEMENT ON THE SOUTHWEST EXPRESSWAY (IHR-36)

Conducted by the Illinois Division of Highways
In Cooperation with the
U. S. Department of Transportation, Federal Highway Administration,
As Part of the Work for an
Investigation of Continuously Reinforced
Portland Cement Concrete Pavement
(IHR-36)

June 1966

A REPORT ON THE USE OF WATER-REDUCING ADMIXTURES IN CONTINUOUSLY REINFORCED PORTLAND CEMENT CONCRETE PAVEMENT

I. INTRODUCTION

Recently, water-reducing admixtures have been introduced for use in portland cement concrete pavement construction in an effort to improve workability. These admixtures are intended to reduce the quantity of water required to produce concrete of a given consistency without significantly changing other properties.

Admixture materials are usually complex organic chemicals which are sold under different trade names. Their compositions are usually protected by patents. Most admixtures used for water reduction and retardation consist of calcium, ammonium, sodium lignosulfonates, calcium lignosulfonates, or compounds of gluconic acids or adipic acids. Each admixture produces varied and complex chemical reactions in relation to the chemical reaction of the cement. For example, when calcium lignosulfonate is added to the concrete mix it causes dispersion of the cement particles by imparting to them a like electro-static charge. The trapped water within the cement flocs is then released to become a part of the mixing water. Thus, the water added at the mixer is reduced to maintain the same slump.

Since little information regarding performance of concrete highway pavements constructed with water-reducing admixtures is available, the Illinois Division of Highways with concurrence of the U. S. Department of Commerce, Bureau of Public Roads, approved requests by two contractors to use water-reducing admixtures in the concrete for the continuously reinforced pavement on two construction projects on the

Southwest Expressway (FAI 55) in Cook County. Approval of the contractor's request was contingent on the following conditions:

(1) If the paving concrete is adversely affected in strength, the operations will revert to presently approved project requirements.

(2) The sequence of adding the material must meet the approval of the engineer.

(3) No retarding admixture will be allowed to be added to the water-reducing admixture.

(4) In addition to the regular test specimens, concrete will be furnished for beams and cylinders to be made each day for 14 and 28 day tests.

(5) The contractor shall determine the exact amount of water-reducing admixture to be added, as well as the amount of water and air-entraining admixture so as to produce concrete having the required slump and air content.

(6) The cement factor shall be lowered to the normal amount used for the 3/4" to 1-1/2" slump. Slumps up to 3" will be permitted with this lower cement factor providing there is no increase over the theoretical design amount of water set by the engineer.

(7) The trial use of the water-reducing agent will be incorporated in IHR-36 as part of the research being conducted on continuously reinforced concrete pavement. Reports will

be submitted covering design mixes, observation of workability of the concrete with the admixture, observations and comparisons of workability of concrete pavement on adjacent sections without the admixture, concrete strengths, durability of pavement under traffic, etc., so that the benefits, if any, of the admixture can be adequately analyzed.

(8) There shall be no added cost to this project for the use of the water-reducing agent or for any delays and other changes that may be required to maintain high qaulity construction and controls.

Two types of water-reducing admixtures were used in this work: Dewey and Almy Chemical Division's Water-Reducing Agent W.R.D.A. 79 and Master Builder's Pozzolith (Improved-80. According to A.S.T.M. Designation C 494-65-T, W.R.D.A. 79 is classified as a water-reducer retarder (Type D) while Pozzolith (Improved-8) is a water reducer only (Type A).

This report is an interim report describing the construction with the water-reducing admixtures and presenting the results of tests conducted on the plastic and hardened concrete. A final report evaluating the effects of the water-reducing admixtures on durability of the pavement under traffic will be prepared at the conclusion of this study.

II. OBJECTIVES

1. To determine the effect of water-reducing admixtures on workability and physical properties of portland cement for concrete pavements.
2. To determine the effect of water-reducing admixtures on the durability of continuously reinforced concrete pavement under traffic.

3. To evaluate and report the benefits, if any, of using water-reducing admixtures in concrete pavement construction.

III. DESCRIPTION OF CONSTRUCTION PROJECTS

The construction project containing the Pozzolith (Improved-8) is officially identified as:

Project I-55-7(37)274
FAI Route 55
Section 404-640
Cook County

This project includes 0.54 miles of six-lane (2 @ 36') divided pavement. The pavement is ten inches thick, continuously reinforced with deformed bars (0.6 per cent longitudinal steel) placed 3.5 inches below the pavement surfaces, and constructed over a 6-inch granular subbase.

The project containing the W.R.D.A. 70 is officially identified as:

Project I-55-7(102)286
FAI Route 55
Section 207-1616.4-CF
Cook County

It includes 0.98 miles of two at 36-foot wide continuously reinforced concrete pavement over a six-inch granular subbase. The pavement is 10 inches thick and the reinforcement consists of two layers of cold-drawn deformed steel wire fabric placed 3.5 inches and eight inches below the pavement surfaces.

The longitudinal steel in each layer amounts to 0.6 per cent of the cross-sectional area of the pavement.

IV. CONCRETE MATERIALS AND MIX DESIGNS

The portland cement concrete was produced by mixing cement and water with two sizes of coarse aggregate, a natural sand, an air-entraining agent, and a water-reducing agent. The types and sources of materials used on each of the

two construction projects are given in Table 1. Information on gradation and specific gravity of each aggregate size and on voids in coarse aggregate are given in Table 2.

The chemical compositions of Pozzolith (Improved-8) and W.R.D.A. #79 are protected under patents. Pozzolith (Improve-8) is a water reducer while W.R.D.A. #79 is classified as a water-reducer-retarder although the amount of retardation is significantly less than that produced by water-reducer-retarders normally used in bridge deck construction.

The basic concrete mix designs for both construction projects were established in accordance with the Division's"Manual of Instructions for Proportioning Engineers" to produce a workable plastic concrete with air content between 4 and 7 per cent, a slump between 3/4 and 1-1/2 inches, a 14-day compressive strength of not less than 3,500 psi, and a minimum modulus of rupture (center-point loading) at 14 days of 650 psi. Slumps in excess of 1-1/2 inches and up to 3 inches are permitted if the contractor agrees to supply enough additional cement that the water/cement ratio will not be increased and not less than 0.02 barrel per cubic yard of concrete will be added for each 1/2-inch increase in slump.

Permission to use water-reducing agents in the concrete for these two projects was granted with the understanding that the contractor could use the water-reducing admixture to increase the slump without increasing the cement factor above the basic mix design. To maintain a constant cement factor, yield, and mortar factor, the amounts of sand for the two mixes containing the water-reducing admixtures were higher than those of corresponding mixes without the admixtures.

The batch proportions per cubic yard of concrete for each of the two projects are listed in Table 3. The weights of aggregates are based on a saturated surface dry condition.

TABLE 1.
TYPE AND SOURCE OF MATERIALS

Material	Supplier	
	Pozzolith Pavement	W.R.D.A. #79 Pavement
Cement	Type 1. Marquette Cement Co., Oglesby, Illinois	Type 1. Marquette Cement Co., Oglesby, Illinois
Water-Reducing Admixture	Pozzolith (Improved-8) Master Builders, Chicago	WRDA #79 - Dewey & Almy Chemical Division, W.R. Grace & Company, Chicago
Air-entraining Agent	Darex	Highway AEA - Dewey & Almy Chemical Division, W.R.Grace & Company, Chicago
Aggregate SA Stone 1/	Dolese & Shepard Co., Hodgkins, Illinois	Material Service Corp., Romeoville, Illinois
B Stone 2/	Dolese & Shepard Co., Hodgkins, Illinois	Material Service Corp., Romeoville, Illinois
Sand	Concrete Material Co., Chillicothe, Illinois	Material Service Corp., Lockport, Illinois
Mixed Concrete	Dolese & Shepard Co., Hodgkins, Illinois	Material Services of Chicago

1/ 1-1/2-inch maximum size

2/ 1-inch maximum size

TABLE 2.
AGGREGATE TEST RESULTS

Project		Mechanical Analysis Percent Passing Based on Dry Weight							Specific Gravity	Voids in C.A.(Ave.Used)
	Sieve Size	1-1/2"	1"	1/2"	No. 4	No.16	No.50	No.100		
Pozzolith	SA Stone	100	50	1	1	-	-	-	2.86	40%
(Improved-8)	B Stone	-	100	37.4	4.3	-	-	-	2.86	
	Sand	-	-	100	99.0	70.3	17.1	2.7	2.67	
WRDA #79	SA Stone	100	42	4	1.6	-	-	-	2.68	41%
	B. Stone	100	96	40	3.4	-	-	-	2.68	
	Sand	-	-	100	96.6	65.4	18.1	4.0	2.68	

TABLE 3

PROPORTIONS PER CUBIC YARD

	Project Using Pozzolith (Improved-8)		Project Using W.R.D.A. 79		
	With Pozzolith	Without Pozzolith	With W.R.D.A. 79	Without W.R.D.A. 79	
Cement, lbs.	541(5.75 bags)	588(6.25 bags)	541.4(5.76 bags)	541.4(5.76 bags)	563.8(6.00 bags)
Sand, lbs. s.s.d.	1198	1105	1183.4	1133.4	1090
SA Stone, lbs. s.s.d.	1020	1003	1017.9	1017.9	1017.9
B Stone, lbs. s.s.d.	998	999	999.8	999.8	999.8
Water, gals.	24	27.1	27.6	30.03	31.2
Air entraining agent, fl.oz.	6.0	16.5	3.97	9.75	9.75
Water Reducing Admixture, fl.oz.	65	0	40.4	0	0

V. MIXING OF CONCRETE

Pavement with Pozzolith: Practically all of the pavement on this section was completed before the water-reducing admixture was added. Only bridge approach slabs and pavement transitions at bridge approaches were constructed of concrete with Pozzolith (Improved-8). Central-mixed concrete was delivered to the project site in trucks from the Dolese and Shepard Company plant located on East Avenue and 63rd Street in Hodgkins, Illinois. The plant was used exclusively by the contractor for this paving project. Two concrete mixes (with and without Pozzolith) were used each paving day. The day began with a standard mix concrete and ended with a Pozzolith mix concrete. The slump and air content for both mixes were kept as constant as possible. The change from one mix to the other was usually made at a construction joint.

Pavement with WRDA 79: Concrete for this project was mixed by means of dual-drum paver (Koehring 34-E) at the project site and was discharged on-to the subbase directly by means of a boom bucket. The mixer was equipped with a water measuring device, automatic WRDA dispenser, automatic air-entrained admixture dispenser, batching meters, and time devices. The slump and air contents for both mixes were kept as constant as possible.

The sequence of mixing established for this project required that all materials, including the mixing water, be in the mixer before the addition of the water-reducing admixture. This was accomplished by an automatic dispenser actuated by the skip of the mixer during the lowering cycle.

VI. TESTING PROGRAM AND RESULTS

The testing program followed on these two projects was similar to that followed on regular construction projects to assure uniform quality concrete meeting specification requirements. A record was kept of the locations where concrete with water-reducing admixture was placed. Additional concrete cylinders and beams were made for compressive and flexural strength tests at 14 and 28 days. Tests for air content, slump, and yield were made at regular intervals and each time additional concrete cylinders and beams were made. Mortar penetration tests were made during one day of paving to investigate the amount of retardation in initial set for the concrete containing WRDA 79.

As previously mentioned, only bridge approach slabs and pavement transitions at bridge approaches were constructed of concrete with Pozzolith (Improved-8) water-reducing admixture. The locations and dates of paving are depicted in Figure 1, showing separately the portions constructed of concrete with and without the water-reducing admixture.

Practically all of the pavement on Section 207-1616.4-CF was constructed of concrete with WRDA 79 water-reducing admixture. On four occasions, a limited number of batches of concrete without the admixture were produced as reference concrete for testing purposes and comparison. The cement content of the reference concrete was set at 5.76 and 6.00 bags per cubic yard. The locations within the completed pavement of the reference concrete are given in Table 4.

The results of tests on the plastic concrete are summarized in Tables 5 and 6 for Pozzolith (Improved-8) and WRDA 79, respectively. The tables include the cement content and quantities of water-reducing and air-entraining admixtures for each day's pour as well as the results of tests for slump, air content and yield.

Figure 1. Locations of Experimental Construction
FAI-55, Section 0404-640, Cook County

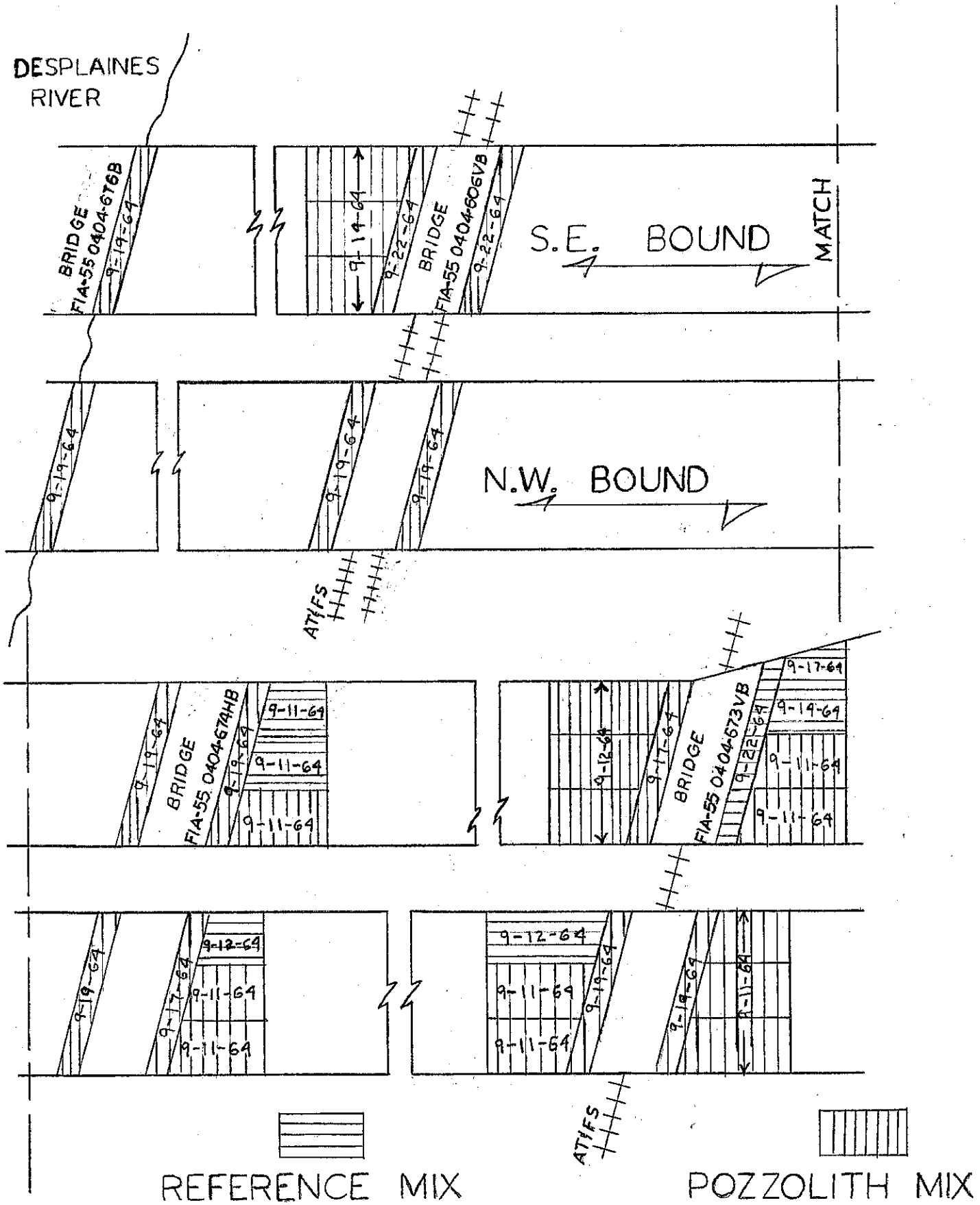


TABLE 4

LOCATIONS OF REFERENCE CONCRETE WITHOUT
WRDA 79 ADMIXTURE - SECTION 207-1616.4-CF

Date Placed	Cement Content Bags/ Cu.Yd.	Location	
		Sta. to Sta.	Pavement
7-30-64	6.00	191+61 - 191+81	So. 24' of EB lanes
7-30-64	5.76	191+81 - 192+11	So. 24' of EB lanes
7-31-64	6.00	218+99 - 221+99	No. 24' of WB lanes
8-5-64	5.76	Approach Slab 221+79	So. 24' of EB lanes

TABLE 5

DAILY SUMMARY OF TEST RESULTS ON
PLASTIC CONCRETE
-(POZZOLITH IMPROVED-8)-

Date	Cement Bags/Cu.Yd.	Pozzolith Oz.Cu.Yd.	Darex Oz./Cu.Yd.	Slump Inches	Air Content Per Cent	Yield Cu.Ft./Yd.
9-11-64	6.25	-	16.5	2.50	5.9	27.5
	5.75	65	6.0	2.50	6.1	27.3
9-12-64	6.25	-	15.5	3.25	5.0	-
	5.75	65	4.5	2.50	4.9	-
9-14-64	6.25	-	15.5	3.50	6.1	-
	5.76	65	4.5	3	5.7	-
9-17-64	6.25	-	15.5	3.25	6.5	27.8
	5.75	65	5.5	3.25	6.2	27.2
9-22-64	6.25	-	15.5	5*	5.8	-
	5.75	65	5.0	5*	5.0	-

* Concrete slump was purposely set high to determine effects on strength characteristics.

TABLE 6

DAILY SUMMARY OF TEST RESULTS ON
PLASTIC CONCRETE
-WRDA 79-

Date	Cement Bags/Cu.Yd.	WRDA 79, Oz./Cu.Yd.	Hwy. AEA Oz./Cu.Yd.	Slump Inches	Air Content Per Cent	Yield Cu.Ft./Yd.
7-28-65	5.76	40.5	4.0	3.25	5.0	26.7
7-29-65	6.00	-	9.8	3.00	6.0	26.8
	5.76	-	9.8	2.50	5.3	26.9
	5.76	40.5	3.3	3.25	5.6	27.1
7-30-65	5.76	40.5	3.3	2.50	5.7	26.9
7-31-65	6.00	-	9.8	2.50	5.2	26.7
	6.00	42	4.0	3.00	4.8	27.0
8-3-65	5.76	40.5	2.9	2.00	4.6	26.8
8-4-65	5.76	40.5	4.0	2.50	5.7	26.8
8-5-65	5.76	40.5	4.0	3.00	5.5	26.8
	5.76	-	8.7	2.00	6.0	27.1
	6.00	-	9.8	2.00	6.0	26.8
8-7-65	5.76	40.5	4.0	2.75	5.7	-
8-11-65	5.76	40.5	4.0	2.75	5.9	-
8-12-65	5.76	40.5	4.0	3.25	6.0	-
8-13-65	5.76	40.5	4.0	3.25	5.7	-
8-17-65	5.76	-	9.8	1.50	6.1	-
	5.76	40.5	4.0	2.75	5.8	-
8-19-65	5.76	-	9.8	3.00	5.5	-
	5.76	40.5	4.0	2.75	5.8	-
8-20-65	5.76	40.5	4.0	2.75	5.0	-
8-21-65	5.76	-	9.8	3.00	6.2	-
	5.76	40.5	4.0	2.75	5.8	-
8-24-65	5.76	40.5	4.0	2.75	5.5	-
8-25-65	5.76	-	9.8	2.25	5.0	-
	5.76	40.5	4.0	2.25	5.0	-

TABLE 6 (Continued)

Date	Cement Bags/Cu.Yd.	WRDA 79, Oz./Cu.Yd.	Hwy. AEA Oz./Cu.Yd.	Slump Inches	Air Content Per Cent	Yield Cu.Ft./Yd.
8-26-65	5.76	-	9.8	1.75	5.7	-
	5.76	40.5	4.0	3.00	5.2	-
8-27-65	5.76	-	9.8	3.00	5.7	-
	5.76	40.5	4.0	1.75	6.2	-
8-28-65	5.76	-	9.8	1.75	5.2	-
	5.76	40.5	4.0	2.00	5.6	-

The results of tests on the hardened concrete are given in Tables 7 and 8. Table 7 includes a daily summary of compressive and flexural strengths at ages of 7, 14, and 28 days for Pozzolith (Improved-8) additive. The compressive and flexural strengths for WRDA 79 additive are given in Table 8.

The results of the concrete penetration tests to determine the amount of retardation in the initial set for concrete containing WRDA 79 admixture are given in Table 9 and shown graphically in Figure 2. The tests were made on mortar obtained by wet screening through a No. 4 Gilson Sieve. A reading of 500 psi indicates initial set.

TABLE 7

DAILY SUMMARY OF COMPRESSIVE AND
FLEXURAL STRENGTH TESTS
- POZZOLITH (IMPROVED--8) -

Date Cast	Mix Designation [1]	Cement Bags/Cu.Yd.	Compressive Strength, PSI [2]			Flexural Strength, PSI [3]		
			7-Day	14-Day	28-Day	7-Day	14-Day	28-Day
9-11-64	S	6.25	3797	4883	5663	719	752	908
	P	5.75	5040	6173	6760	815	840	999
9-12-64	S	6.25	3787	4306	5106	714	765	833
	P	5.75	4680	5730	6393	819	928	984
9-14-64	S	6.25	3177	3897	4563 [4]	625	643	744
	P	5.75	4527	5380	6183 [4]	725	769	913
9-17-64	S	6.25	3040	3660	4320	556	620	761
	P	5.76	4520	5490	5977	615	784	859
9-22-64	S	6.25	3513	4237	4800	566	640	761
	P	5.76	4947	5983	6977	735	824	996
Average	S	6.25	3463	4197	4890	636	684	791
	P	5.76	4743	5753	6458	742	829	950

1/ S - Standard mix without Pozzolith (Improved-8).
P - Mix with Pozzolith (Improved-8) additive.

2/ Each value is the average of the results from three test cylinders.

3/ Each value is the average of two tests on a single test beam.

4/ 29-day compressive strength.

TABLE 8

DAILY SUMMARY OF COMPRESSIVE AND
FLEXURAL STRENGTH TESTS
- WRDA 79 -

Date Cast	Mix Designation [1]	Cement Bags/Cu.Yd.	Compressive Strength, PSI [2] 7-Day	14-Day	28-Day	Flexural Strength, PSI [3] 7-Day	14-Day	28-Day
7-28-65	W	5.76	5040	5323	5589	-	-	-
7-29-65	S	6.00	2954	3617	4607	586	693	1000+
	S	5.76	2688	3289	4023	608	829	-
	W	5.76	4280	5040	5527	863	900	-
7-30-65	W	5.76	4833	5454	6031	755	1000+	-
7-31-65	S	6.00	3077	3670	3962	624	811	-
	W	6.00	5288	5450	5818	888	929	-
8-3-65	W	5.76	5447	5757	6438	900	-	1000+
8-4-65	W	5.76	4651	5111	6040	912	861	1000+
8-5-65	W	5.76	5120	5889	6694	843	740	1000+
	S	5.76	-	-	-	730	675	929
	S	6.00	-	-	-	650	685	692
8-7-65	W	5.76	4537	5270	5829	808	943	1000+
8-11-65	W	5.76	4853	5624	-	875	1000+	975
8-12-65	W	5.76	5182	5788	-	893	1000+	1000+
8-13-65	W	5.76	4015	5271	-	826	1000+	1000+
8-17-65	S	5.76	3537	4076	4607	773	919	707
	W	5.76	3732	4466	5107	849	953	788
8-19-65	S	5.76	3236	3890	-	-	-	908
	W	5.76	6013	6809	-	-	-	1000+
8-20-65	W	5.76	4992	5691	6075	-	1000+	946
8-21-65	S	5.76	2874	3599	3953	-	755	-
	W	5.76	4899	6155	6597	-	1000+	1000+
8-24-65	W	5.76	4598	4846	5085	-	-	1000+
8-25-65	S	5.76	3790	4094	4536	-	836	865
	W	5.76	5350	5589	5960	-	890	1000+

TABLE 8 (Continued)

Date Cast	Mix Designation [1]	Cement Bags/Cu.Yd.	Compressive Strength, PSI [2]			Flexural Strength, PSI [3]		
			7-Day	14-Day	28-Day	7-Day	14-Day	28-Day
8-26-65	S	5.76	3943	4430	4908	-	661	767
	W	5.76	4757	5487	5491	-	803	911
8-27-65	S	5.76	3287	3748	4103	-	-	823
	W	5.76	4854	5642	6155	-	-	1000+
8-28-65	S	5.76	3219	3696	3908	-	710	865
	W	5.76	4217	4616	4996	-	-	1000+
Average	S	5.76	3322	3855	4291	704	769	838
	S	6.00	3015	3644	4285	620	730	846+
	W	5.76	4809	5465	5841	852	930+	976+
	W	6.00	5288	5450	5818	888	929	-

1/ W - mix with WRDA 79 additive.
S - mix without WRDA 79 additive.

2/ Each value is the average of the results from two test cylinders.

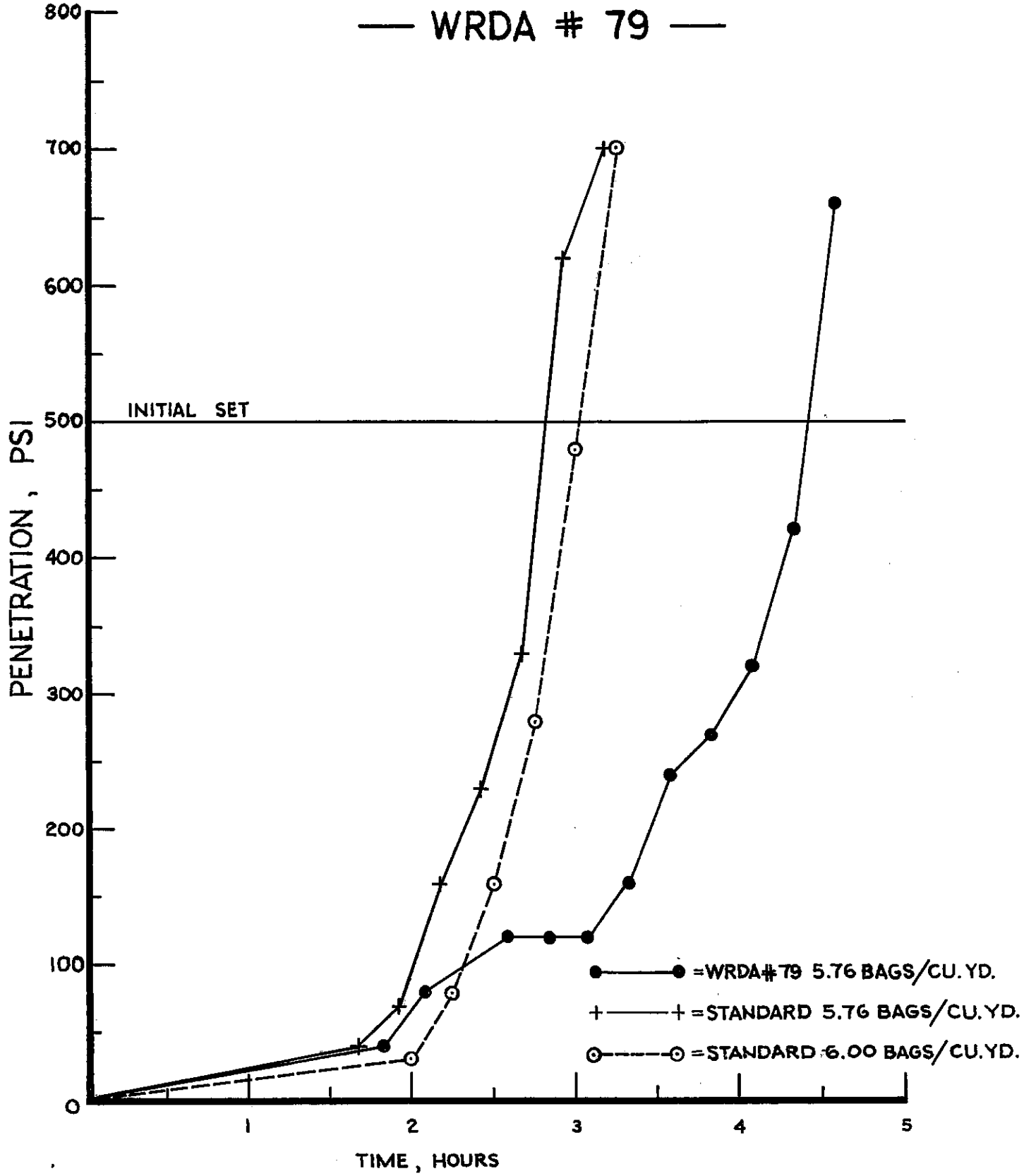
3/ Each value is the average of two tests on a single test beam.

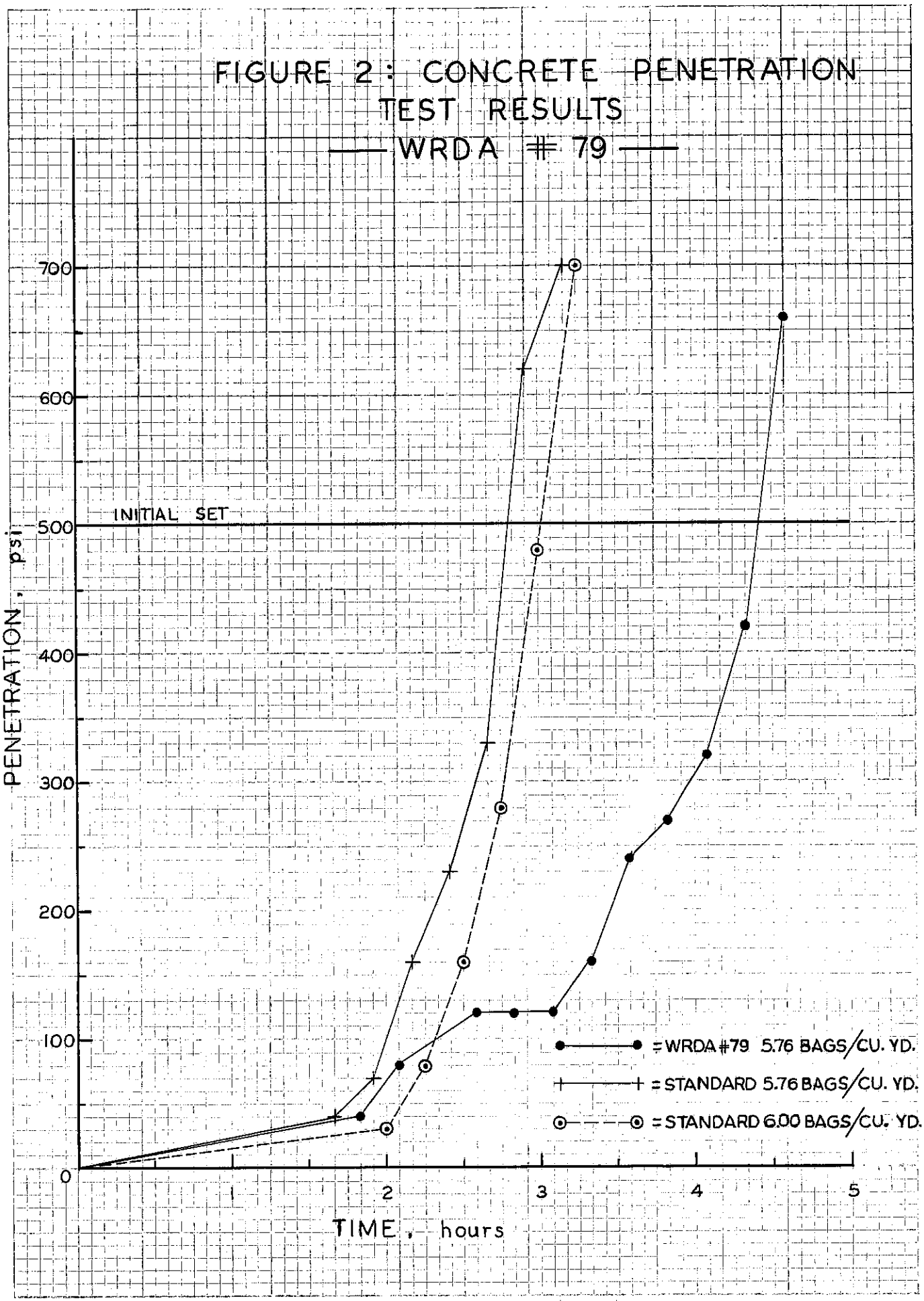
TABLE 9

RESULTS OF CONCRETE PENETROMETER TESTS
- WRDA 79 -

Test No.	Cement Bags/Cu.Yd.	WRDA 79, Oz./Cu.Yd.	Hwy. AEA, Oz./Cu.Yd.	Time	Temperature Air	Temperature Mortar	Penetration PSI	Time Hr.-Min.
1	5.76	40.5	4.0	8:40	78	80		0
				9:50	79	81		1-10
				10:00	79	81		1-20
				10:30	80	82	40	1-50
				10:45	80	83	80	2-05
				11:00	80	84	100	2-20
				11:15	80	84	120	2-35
				11:30	80	85	120	2-50
	(Slump = 3", Air Content = 5.5%)			11:45	80	85	120	3-05
				12:00	80	85	160	3-20
				12:15	80	87	240	3-35
				12:30	80	89	270	3-50
				12:45	80	89	320	4-05
				1:00	82	90	420	4-20
				1:15	82	90	660	4-35
2	5.76	0	8.7	9:50	79	80		0
				10:00	79	81		0-10
				10:30	80	82		0-40
				10:45	80	83		0-55
				11:00	80	84		1-10
				11:15	80	84		1-25
	(Slump = 2", Air Content = 6.0%)			11:30	80	85	40	1-40
				11:45	80	85	80	1-55
				12:00	80	85	160	2-10
				12:15	80	87	230	2-25
				12:30	80	89	330	2-40
				12:45	80	89	620	2-55
				1:00	82	90	700	3-10
3	6.00	0	9.8	10:45	80	83		0
				12:30	80	85		1-45
				12:45	80	85	30	2-00
	(Slump = 2-1/2", Air Content = 6.0%)			1:00	82	87	80	2-15
				1:15	82	88	160	2-30
				1:30	80	88	280	2-45
				1:45	80	88	480	3-00
				2:00	80	89	700	3-15

FIGURE 2 : CONCRETE PENETRATION TEST RESULTS
— WRDA # 79 —





VII. DISCUSSION

The use of the water-reducing admixtures in the portland cement concrete mixes effectively increased the slump without increasing the amount of mixing water. The use of the water reducing admixtures also caused a reduction in the amount of air-entraining agent necessary to produce concrete within the specified air content range. The amount of Darex per cubic yard of concrete was reduced from 15.5-16.5 ounces to 4.5-6.0 ounces when Pozzolith (Improved-8) was used in the mix. The amount of Highway AEA per cubic yard of concrete was reduced from 8.7-9.8 ounces to 3.3-4.0 ounces when WRDA 79 was used.

The use of both water-reducing admixtures in lieu of additional cement and water to increase slump effected an increase in compressive and flexural strength of the concrete. The increase in compressive strength was more pronounced than the increase in flexural strength, although both were significantly increased. Referring to Table 7, it can be seen that with the addition of Pozzolith (Improved-8) the average compressive strength was increased by 1,280, 1,556 and 1,568 psi at the age of 7, 14, and 28 days, respectively. The corresponding increases in flexural strength (mid-point loading) were 106, 145, and 159 psi at the ages of 7, 14, and 28 days. Similar increases in compressive and flexural strengths were obtained when WRDA 79 was added to the mix in lieu of additional cement and water to increase the slump, as indicated by the average values given in Table 8.

The higher strengths at early ages can have certain advantages during construction, especially in situations when it is advantageous to open a completed section of pavement as soon as possible after completion or when constructing multiple-lane pavements in partial widths.

The results of the penetration tests made in connection with the trial use of WRDA 79 water-reducing admixture indicated that the admixture retarded initial set. Initial set is considered to have occurred when the penetration reaches 500 psi. As shown in Figure 2, initial set of the standard concrete occurred in 2 hrs 48 min for the 5.76-bag mix and in 3 hrs 02 min for the 6.00-bag mix; 4 hrs 25 min were required for initial set when WRDA 79 was used.

The most important reason for the use of water-reducing admixtures in concrete mixtures is to improve workability without an increase in water content. The term "workability", as applied to concrete mixtures, indicates the ease with which the mass of plastic material may be deposited in its final resting place in the forms without segreation or honeycomb to produce a uniform, homogeneous mass.[1/] It is difficult to evaluate and must be based on judgment and opinion since no quantitative measure of this property is available.

The use of the standard mixtures on the two projects covered by this report was not sufficient to permit a reliable comparison of the workability of the concrete with and without the water-reducing admixtures. However, both the contractors and engineers indicated that, based on their general experiences, the water-reducing admixtures improved workability over the basic mix design (3/4-to 1-1/2-inch slump).

1/ Mills, Abelbert P., Hayward, Harrison W., Redes, Lloyd F., Material of Construction, John Wiley & Sons, 1955 P. 387.

It appears reasonable to expect that the increase in slump gained by the use of a water-reducing admixture generally would improve the workability of a concrete mix designed for a 3/4-to 1-1/2-inch slump, especially on hot, dry, windy days. The question needing to be answered is whether or not there is an improvement in workability when a water-reducing admixture is used to increase the slump as compared to redesigning the mix for the higher slump.

Later approval of requests to use water-reducing admixtures in portland cement concrete for pavement construction are being granted on the condition that at least one-fourth of the pavement be constructed of concrete without a water-reducing admixture in an attempt to answer this question.

In summary, the results of this study to date have indicated the following:

1. The slump of the concrete was increased by the water-reducing admixtures without increasing the amount of mixing water.

2. The addition of the water-reducing admixtures necessitated a reduction in the amount of air-entraining agent to produce concrete of the same air content.

3. Significantly higher compressive and flexural strengths at 7, 14, and 28 days were obtained when the water-reducing admixtures were used. The increase in compressive strength was more pronounced than was the increase in flexural strength.

4. The project did not provide an opportunity to compare workability of concrete with the addition of the water-reducing admixtures to that of concrete designed for the same slump.

5. Increases in concrete slump while maintaining the same water/cement ratio can be achieved at less material costs with the addition of water and small amounts of cement than with the addition of water reducing admixtures.