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

RESEARCH AND DEVELOPMENT - REPORT NO. 16A

USE OF A WATER - REDUCING ADMIXTURE IN CRPCC PAVEMENT ON INTERSTATE ROUTE 57 (IHR-36)

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

September 1967

USE OF A WATER - REDUCING ADMIXTURE IN CRPCC PAVEMENT ON INTERSTATE ROUTE 57 (IHR-36)

Water-reducing admixtures are used in portland cement concrete mixtures for the purpose of improving workability without significantly changing other properties. Admixture materials are usually complex organic chemicals which are sold under different trade names and usually protected by patents. Most admixtures used for water reduction and retardation consist of calcium, ammonimum, sodium lignosulfonates, calcium lignosulfonates, or compounds of gluconic acids. They produce varied and complex 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.

For a number of years water-reducing admixtures have been used in concrete for building construction. Only recently, however, have water-reducing agents been proposed for use in concrete for highway pavement construction.

Since little information regarding the effects of water-reducing admixtures on workability and durability of concrete used in highway pavements is available, the Illinois Division of Highways with concurrence of the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, has permitted their use on an experimental basis. In 1964, the trial use of two water reducing admixtures (Dewey and Almy Chemical Division's WRDA No. 79 and Master Builder's Pozzolith Improved-8) was allowed during the paving of a continuously reinforced pavement on two construction sections of the Southwest Expressway, (FAI Route 55) in Cook County. A report on this project

entitled "An Interim Report on the Use of Water Reducing Admixtures in Continuously Reinforced Portland Cement Concrete Pavement on the Southwest Expressway" was prepared to describe the construction and present the results of tests on the plastic and hardened concrete. Another water reducing admixture, Dewey and Almy Chemical Division's WRDA, was approved for experimental use on a portion of Interstate Route 57 south of Mattoon in Coles County. Approval of the contractors' requests was contingent on the following conditions:

" (1) If the concrete strength is affected the operations will revert to the presently approved project requirement without cost to the project.

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

" (3) No retarding admixture will be added to the water-reducing admixture. The water-reducing admixture shall not produce more than one-hour delay in the initial set of the concrete as determined by the standard laboratory tests set up by the Bureau of Materials. The water-reducing admixture shall be approved by the Engineer.

" (4) In addition to the regular test specimens, concrete will be furnished for two additional beams or cylinders each day for 28-day tests.

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

and air content. The amount of water used shall not be greater than the amount required to the standard design.

" (6) At least one-fourth of the pavement concrete placed on the project shall be of the standard design without a water-reducing admixture.

" (7) The standard design mixture shall be that required for the material used, to produce the specification slump of 3/4-inch to 1-1/2 inches. If slumps up to 3 inches are required, additional cement as required by the specifications shall be added. When the water-reducing admixture is used, the cement factor shall not be less than the standard design for 3/4-inch to 1-1/2 inch slump concrete. If required for proper consolidation, slumps up to 3 inches will be allowed when the water-reducing admixture is used without increasing the cement factor.

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

" (9) 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 shall be submitted covering the mixture design, workability, resulting test data, and general

statements on the use of the material. A follow-up program shall also be developed to observe and compare the durability of the pavement under traffic so that the benefits, if any, of the admixture can be adequately analyzed."

This report is an interim report on the use of WRDA in the concrete of the pavement on FAI Route 57. It describes the experimental construction and discusses the results of the observations and tests completed to date as they may relate to the effects of the water-reducing admixture on the workability, durability, and physical characteristics of the concrete.

OBJECTIVES

The objectives of this study are:

(1) To determine the effect of water-reducing admixtures on workability and physical properties of portland cement concrete for pavements.

(2) To determine the effect of water-reducing admixtures on the durability of concrete in continuously reinforced pavement under traffic.

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

LAYOUT OF RESEARCH PAVEMENTS

The portion of Interstate Route 57 which included the trial use of WRDA water-reducing agent is officially indentified as:

FAI Route 57
Project I-57-4(49)181
Section 15-21
and
Project I-57-4(45)184
Section 15-22

These projects included the construction of 9.3 miles of four-lane divided highway. Each roadway consists of a two-lane 24-foot wide pavement constructed over a 4-inch thick gravel subbase. The pavement is 8 inches thick, continuously reinforced with deformed wire fabric (0.6 per cent longitudinal steel) placed 2.5 inches below the pavement surface. Paved shoulders are included on each side of the pavement. The portion of the construction selected for testing is 3.1 miles long and located between Stations 340+00 and 505+34 on Section 15-21.

CONCRETE MATERIALS AND MIX DESIGNS

The types and sources of materials used in the concrete mixture are shown on Table 1. Information on gradation, specific gravity, and voids in the coarse aggregate for a typical aggregate sample is shown in Table 2.

The chemical composition of WRDA water reducing admixture, a compound of calcium lignosulfonate and a catalyst, is protected by patent.

The design of the basic concrete mix for the project was established in accordance with the Division's"Manual of Instructions for Proportioning Engineers" to produce a workable plastic concrete with an air content between 4 and 7 per cent, a slump between 3/4 and 1-1/2 inches, a minimum 14-day compressive strength of 3,500 psi, and a minimum modulus of rupture (center-point loading) of 650 psi at 14 days. 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 of cement per cubic yard of concrete will be added for each 1/2-inch increase in slump.

The contractor for these projects was granted permission to use WRDA water-reducing admixture to increase the slump of the mix without changing the cement factor of the mix.

TABLE 1.

TYPE AND SOURCE OF CONCRETE MATERIALS

Material		Supplier
Cement	Type I & IA	- Lehigh Portland Cement Co., Iola, Kansas.
Water-Reducing Admixture	WRDA	- Dewey & Almy Chemical Division W. R. Grace & Company Chicago, Illinois
Air-Entraining Agent	DAREX	- Dewey & Almy Chemical Division W. R. Grace & Company
Aggregate		
La Stone 1/		- Lehigh Stone Company Kankakee, Illinois
B Stone 2/		Lehigh Stone Company Kankakee, Illinois
Sand		Mattoon Sand & Gravel Company Mattoon, Illinois

1/ 1-1/2 inch maximum size

2/ 1 inch maximum size

TABLE 2

AGGREGATE TEST RESULTS

	Per Cent Passing Sieve Based on Dry Weight									Specific Gravity	Voids in C.A.(Avg. Used) %
	2-1/2-in.	2-in.	1-1/2-in.	1-in.	1/2-in.	No. 4	No. 16	No. 50	No. 100		
LaStone	100	90	38	3	0.4	0.4	-	-	-	2.69	40
B Stone			100	97	35	0.3	-	-	-	2.69	
Sand						100	68	12	-	2.62	

The batch proportions per cubic yard of concrete are listed in Table 3. Aggregate weights are based on saturated surface dry conditions. The basic mix design established a cement factor of 1.42, or 5.68 bags of cement per cubic yard of concrete. This cement factor was used for the concrete mix containing the WRDA water-reducing admixture. The cement factor for the standard mix without WRDA was increased to 1.46, or 5.84 bags per cubic yard, to accommodate the increase in slump to 2-1/2 inches. To maintain a constant cement factor, yield, and mortar factor, the amount of sand was increased for the mix containing WRDA.

MIXING OF CONCRETE

Concrete from a central-mix plant erected on the job site by the contractor and used exclusively on these projects was delivered to the roadbed in agitator trucks. The plant was equipped with a water measuring device, automatic WRDA dispenser, air-entraining admixture dispenser, batching meters, and timing devices. The automatic WRDA and air-entraining admixture dispensers used are shown in Figure 1.

TESTING PROGRAM

The testing program designed to obtain information for answers to the objectives is concerned with the 3.1 miles of four-lane pavement constructed between Stations 340+00 and 505+34 on Section 15-21, and establishes a series of tests on the plastic and hardened concrete and specific observations and measurements on the experimental pavements during and after construction. Tests on plastic and hardened concrete were intended to provide information on the effects of WRDA on durability and physical characteristics of the concrete. The observations and measurements on the pavements were intended to provide some insight on the effects of WRDA on concrete workability and durability.

A total of 13 working days were required to construct the experimental pavements. A record was kept of the location and amount of pavement constructed each day with concrete containing water-reducing admixture and with concrete without the water-reducing admixture. The locations are shown in Figure 2.

TABLE 3.

BATCH QUANTITIES PER CUBIC YARD OF CONCRETE

	Mix With WRDA	Standard Mix Without WRDA
Cement, bags	5.68	5.84
Cement, pounds	534	549
Sand, pounds, s.s.d.	1128	1090
LaStone pounds, s.s.d.	1030	1023
B Stone, pound, s.s.d.	1030	1022
Water, gallons	29.0	32.0
Water Reducing Admixture, fl.oz.	34.1	-
Air Entrained Agent, fl.oz.	5.9	11.4

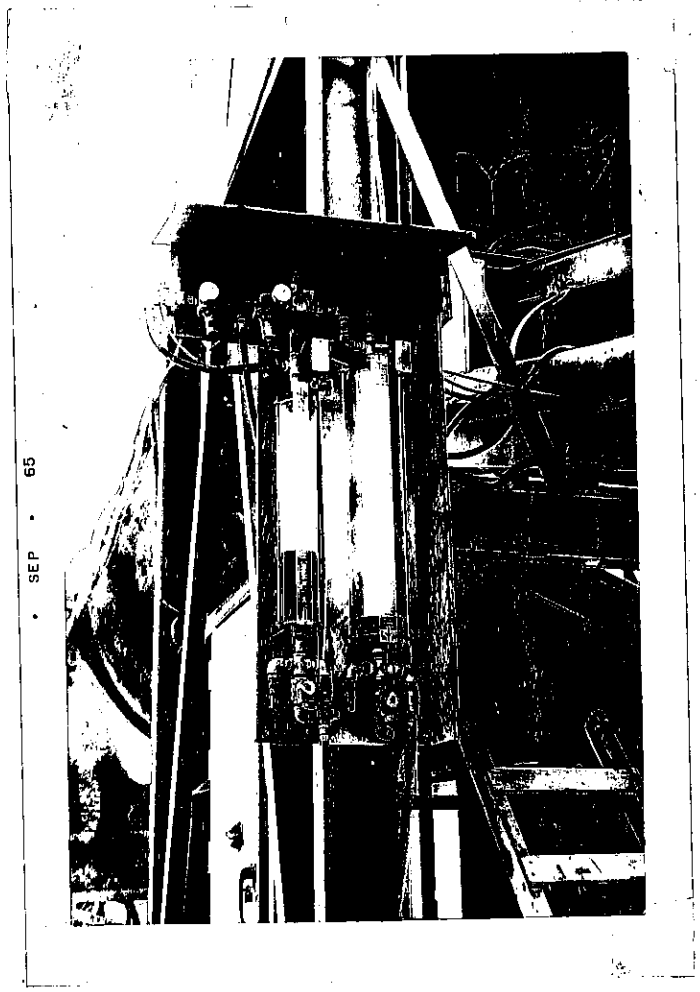
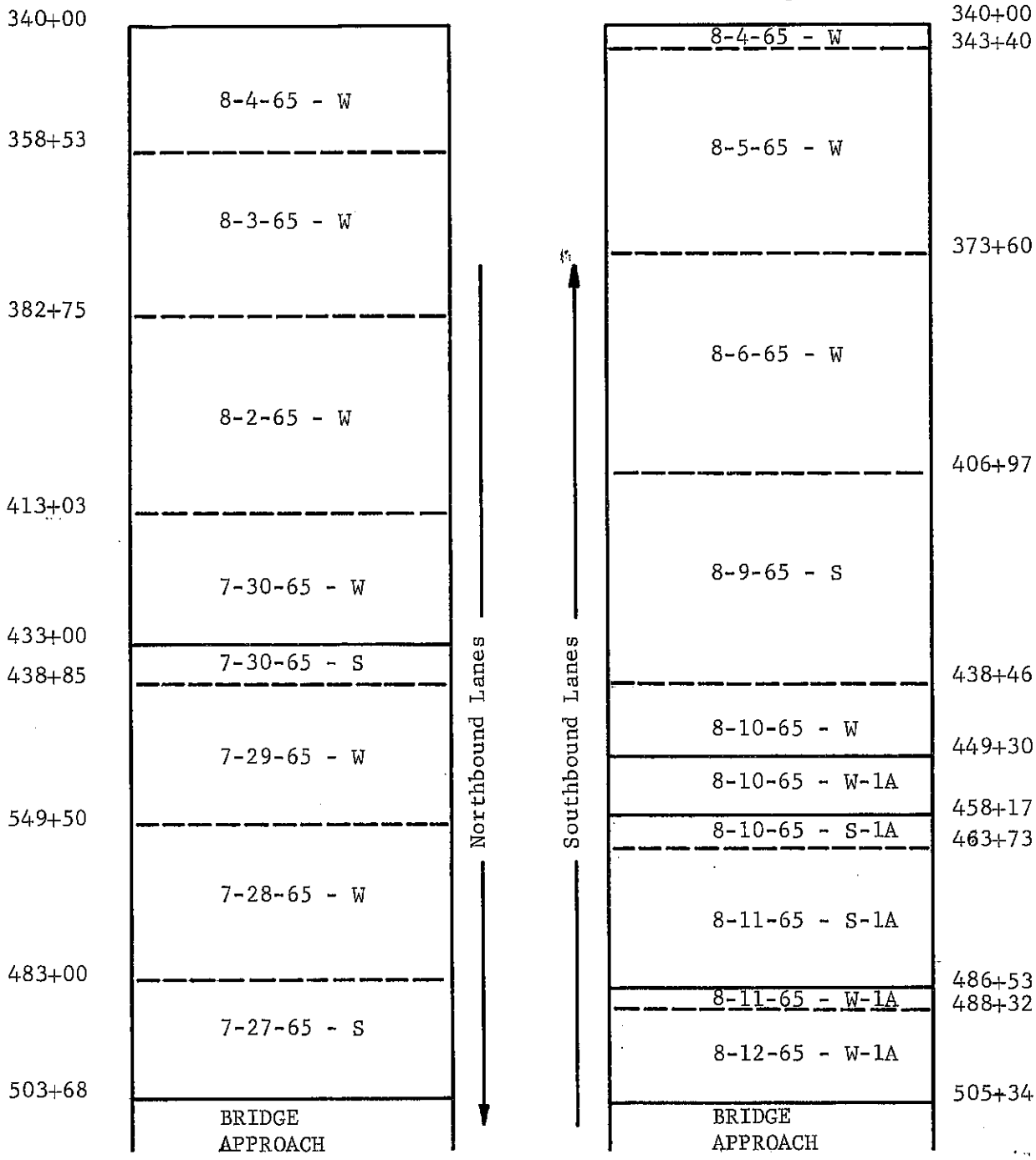


Figure 1. View of automatic water-reducing and air-entraining admixture dispensers.

The WRDA was added to the mixer a few seconds after all other materials were charged into the mixer. The WRDA was discharged by means of air pressure so that all the water-reducing admixture was in the mixer within about 15 seconds after all other materials were charged into the mixer. The concrete was mixed for about 70 seconds after the discharge of WRDA. The entire cycle was complete within approximately 90 seconds. The slump and air contents for standard and WRDA mixes were kept as constant as possible.

FAI Route 57
Section 15-21
Coles County
Project I-57-4(49)181

FIGURE 2.



= Construction Joint
= Change in Mix

S - Standard Mix
W - WRDA Mix
1A - Type 1A Cement

In addition to the normal routine testing for air content, slump, and 7-and 14-day flexural strengths made to assure uniform quality concrete meeting the specifications, two extra beams and cylinders were made each day for testing at 28 days. They were made from concrete taken from between the forms immediately after it was spread. Each time the specimens were made, air content and slump tests also were made.

On one day of paving, July 30, 1965, the contractor was required to pave one-half day with concrete with WRDA and one-half day with concrete without WRDA to permit a series of special tests to be run. All tests of the plastic concrete and all test specimens were made at the batch plant of concrete from a single batch for each of the mixes with and without WRDA. Nine cylinders and nine beams were molded for each of the two mixes for 90-day, 6-month, and 1-year strength tests. Modified cubes for testing in compression were made from pieces of the beams after being broken in flexure. Sonic beams and scaling slab specimens were molded for each mix. Penetration tests were run on mortar obtained by wet screening the concrete through a No. 4 Gilson Sieve. Air content, slump, and yield determinations were made on both mixes.

During paving, the operations of placing, strike-off and consolidation, floating, straightedging, and final finish with a burlap drag were closely observed in an effort to detect any differences in concrete workability that might exist between the mixes with and without the water-reducing admixture.

Testing of the completed pavement included measurements of the riding quality and crack surveys, each made separately for the portions of the pavement of concrete with and without the water-reducing admixture.

TESTING RESULTS AND DISCUSSIONS

The results of the tests on the plastic concrete are summarized in Table 4. Included in the table are data on cement and water contents, quantities of water-reducing and air-entraining admixtures, and the concrete yield for each

TABLE 4.

SUMMARY OF DAILY TEST RESULTS ON PLASTIC CONCRETE FOR TEST SPECIMENS

Date	Cement (bags per cy)	Water 2/ (gal.per cy)	WRDA (oz.per cy)	Hwy. AEA (oz. per cy)	Slump (in.)	Air Content (%)	Yield (cf)
7-27-65	5.84	27.1	-	11.5	4-1/4	6.2	27.0
7-28-65	5.68	23.2	34.1	6.6	2-1/4	6.1	27.0
7-29-65	5.68	23.8	40.8	6.6	2-3/4	6.4	27.0
7-30-65	5.84	26.3	-	11.7	2	5.7	-
7-30-65	5.68	23.5	34.1	5.7	1-3/4	5.8	27.2
8- 2-65	5.68	23.2	33.0	6.6	1-1/2	5.7	27.0
8- 3-65	5.68	23.5	28.4	5.4	2-1/4	7.0	26.8
8- 4-65	5.68	22.4	28.4	5.9	1-3/4	5.1	27.0
8- 5-65	5.68	22.4	34.1	6.8	2-1/2	6.3	26.9
8- 6-65	5.68	-	34.1	5.7	2-1/2	5.1	26.6
8- 9-65	5.84	23.5	-	11.0	3	6.6	26.9
8-10-65	5.68	-	28.5	8.0	2	6.6	-
8-11-65	5.84 1/	23.1	-	5.7	1-3/4	5.2	26.9
8-12-65	5.68 1/	19.9	28.4	0.0	1-3/4	5.4	26.9

1/ Type I-A Cement

2/ Amount of water added at mixes - does not include water in aggregates.

day of paving. As indicated by the results, the use of the water-reducing admixture effected a decrease in the amount of mixing water required to produce concrete of the same slump. The admixture also caused a reduction in the amount of air-entraining admixture required to produce concrete within the specified air-content range. The amount of air-entraining admixture per cubic yard ranged from 11.0 to 11.7 ounces in the standard mix; and from 5.4 to 6.8 ounces per cubic yard when WRDA was used in the mix.

The results of tests conducted on the hardened concrete are summarized for each day of paving in Table 5. Compressive strength data from testing cylinders are listed for ages of 28, 90, 180, and 360 days. Compressive strengths from modified cubes are listed for ages of 108, 201, and 374 days. Flexural strengths are shown for ages of 3, 7, 14, 28, 94, 194, and 365 days. The use of the WRDA water-reducing admixture in the concrete effected a substantial increase in compressive strength. The average increase over the compressive strength of the standard mix ranged from 747 psi at 28 days to 1580 psi at 360 days. Similar increases in compressive strength were obtained from tests of the modified cubes - 609 psi increase at 108 days and 1325 psi at 374 days. Flexural strengths obtained for the two mixes at various ages were nearly the same. The flexural strength of the mix with WRDA was 8 psi less at 7 days and 34 psi more at 365 days than that of the standard mix. The strengths indicates for both mixes show the concrete to be of very high quality. For example, the average flexural strength of the standard mix was 818 psi at 7 days and 900 psi at 14 days while the minimum requirement of the specifications is 650 psi at 14 days.

The results of penetration resistance tests made to determine time of set, shown in Table 6 and Figure 3, indicate that the WRDA water-reducing admixture had little affect on initial and final set of the concrete. Initial and final sets are considered to have occurred (ASTM: C403-65T) when the penetration resistance reaches 500 and 4000 psi respectively. As shown in Figure 3, initial set occurred in 4

TABLE 5

SUMMARY OF DAILY COMPRESSIVE AND FLEXURAL STRENGTH TESTS

Date Cast	Mix Designation	Cement Bags cu.yd.	Compressive Strength psi 28 day	90 day	180 day	360 day	Modified Cube Compressive Strength psi 108 day	201 day	374 day	Flexural Strength, psi Day 3	7	14	28	94	194	365
7-27-65	S	5.84	4390								802	867	939			
7-28-65	W	5.68	4990							536	797	873	984			
7-29-65	W	5.68	5220							556	771	1005	950			
7-30-65	S	5.84	3960	5363	6045	5770	5663	5231	5933	--	--	--	891	916	962	962
7-30-65	W	5.68	4740	6297	6870	7350	6274	5836	7258	550	868	981	1015	959	1019	996
8- 2-65	W	5.68	5840								849	925	1065			
8- 3-65	W	5.68	4950								795	862	954			
8- 4-65	W	5.68	5150								822	790	1002			
8- 5-65	W	5.68	5070								798	952	1035			
8- 6-65	W	5.68	4480								823	948	977			
8- 9-65	S	5.84	4630								778	890	943			
8-10-65	W	5.68	4940								832	914	966			
8-11-65	S	5.84	4140								873	942	1034			
8-12-65	W	5.68	4890								741	971	999			
Average	S		4280	5363	6045	5770	5665	5231	5933	--	818	900	952	916	962	962
	W		5027	6297	6870	7350	6274	5836	7258	547	810	922	995	959	1019	996

S - Standard
W - WRDA water-reducing agent

TABLE 6.

RESULTS OF CONCRETE PENETRATION RESISTANCE

Test No.	Cement Bags cu.yd.	WRDA oz/cu.yd.	Hwy. AEA oz/cu.yd.	Time	Time Hr.-Min.	Penetration Resistance * psi
1	5.84	0	11.7	8:35	0-0	0
				11:45	3-10	73
				12:00	3-25	115
				12:15	3-40	181
				12:30	3-55	337
				12:45	4-10	507
				1:00	4-25	693
				1:15	4-40	1033
	(Slump = 4-1/2 inches,			1:30	4-55	1707
	Air Content = 6.4%			1:45	5-10	1920
	Box No. 1,2, & 3)			2:00	5-25	2667
				2:15	5-40	3320
				2:30	5-55	3867
2	5.68	34.1	5.7	10:20	0	0
				1:50	3-30	97
				2:05	3-45	155
				2:20	4-0	235
				2:35	4-15	447
				2:50	4-30	683
	(Slump = 4-1/2 inches,			3:05	4-45	883
	Air Content = 6.7%			3:20	5-0	1647
	Box No. 4,5, &6)			3:35	5-15	1707
				3:50	5-30	3693

*Average of three tests. All tests were conducted on July 30, 1965.

TABLE 3.

CONCRETE PENETRATION RESISTANCE TEST RESULTS

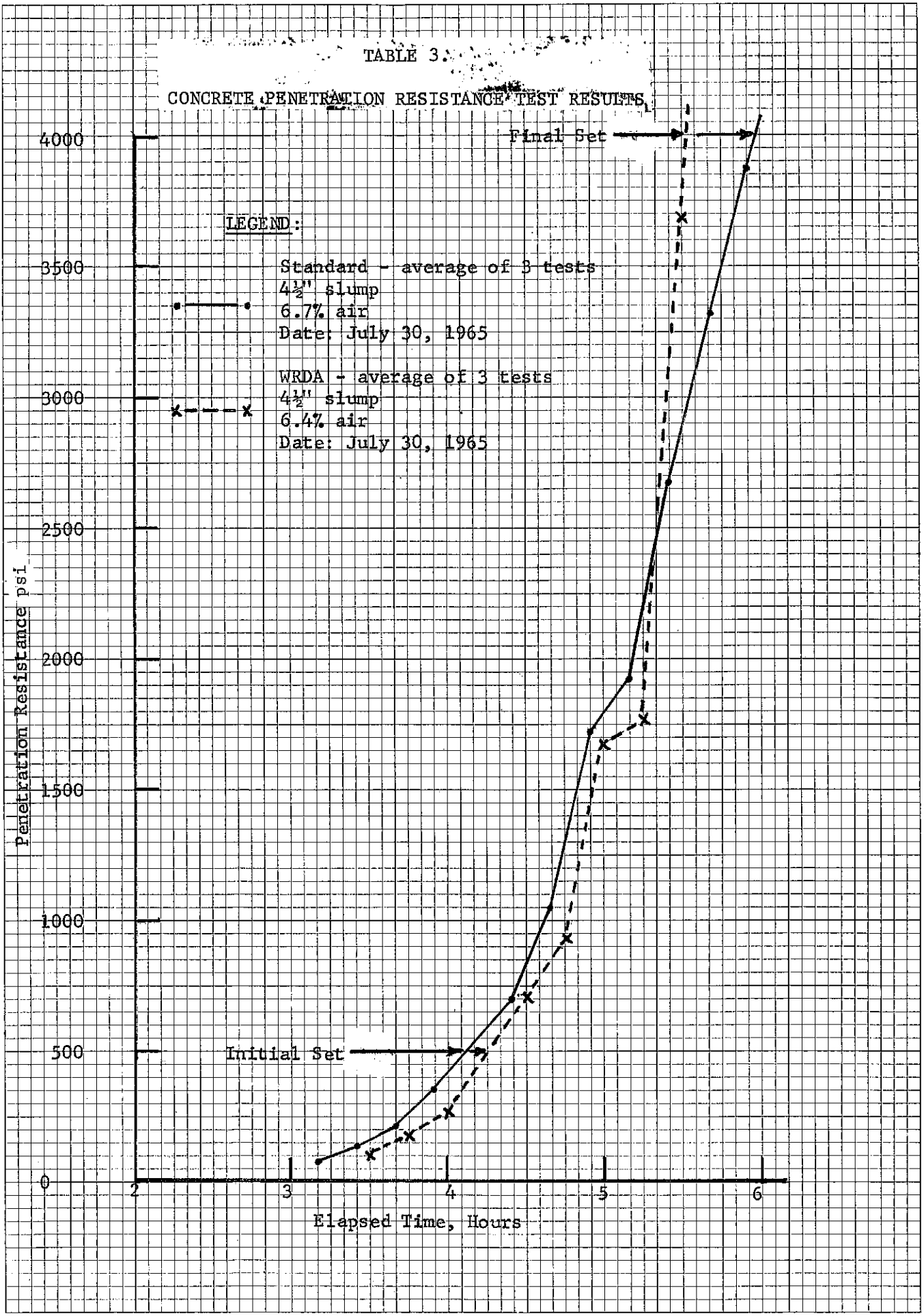
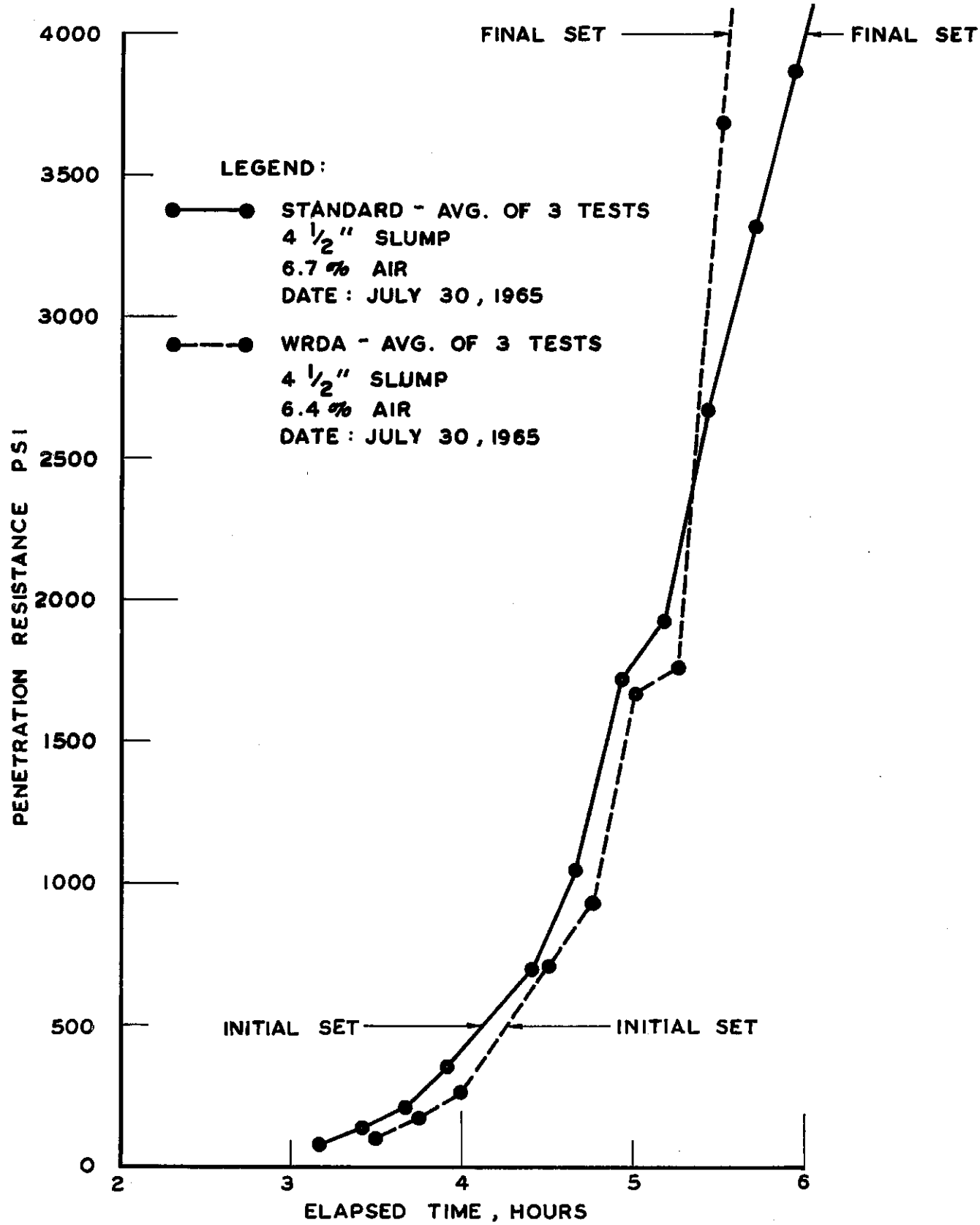


TABLE 3.

CONCRETE PENETRATION RESISTANCE TEST RESULTS



hours and 8 minutes for the standard mix and in 4 hours and 18 minutes for the mix containing WRDA. The final set for standard concrete occurred in 5 hours and 58 minutes as compared with 5 hours and 32 minutes for the concrete containing WRDA. The amount of retardation of the initial set for the mix with WRDA (10 minutes) is well within the maximum retardation of initial set stated in the conditions under which use of the water-reducing agent was permitted.

One objective of this study is to evaluate the effect of the water-reducing admixture on the workability of portland cement concrete. "Workability" is used to describe the ease or difficulty which will be encountered in placing and finishing concrete in a particular condition. It is difficult to evaluate and must be based on judgment and opinion since no procedure has been developed for quantitative measurement of this property. Close observations of various handling and finishing operations did not indicate that the WRDA water-reducing admixture improved the workability of the concrete over that of the standard mix which was designed for the same slump. Insofar as general appearance is concerned, no appreciable difference was noted between the two types of concrete either in the plastic or hardened states. Daily observations indicated workability of both mixes to be good and suggested that workability is affected much more by temperature, humidity, and wind velocity than by the addition of the water-reducing admixture. The only marked difference in finishing the two mixes was that the speed of the oscillating screeds of the finishing machine needed to be increased when WRDA was added to the concrete.

With the thought that any marked difference in workability might be expected to be reflected in the riding quality of the completed pavement, surface smoothness measurements were made with the Illinois BPR-type roadometer at the close of pavement construction. The results indicated no significant difference in riding quality. The Roughness Index (RI) value obtained for the portion of

the pavement constructed of concrete with WRDA was 88 inches per mile; that obtained for the portion without WRDA was 90 inches per mile. Corresponding Present Serviceability Index (PSI) values from AASHO Road Test equations are 3.7 in both instances.

Crack surveys of the pavement with and without WRDA were made following construction at selected locations in an effort to provide some information on the effect of WRDA on the shrinkage characteristics of the concrete. Surveys made on three separate occasions showed the following average crack spacings:

Date	Average Interval Between Transverse Cracks	
	With WRDA (ft)	Without WRDA (ft)
August 10, 1965	7.8	5.8
November 4, 1965	6.3	5.2
April 21, 1966	5.0	3.6

Transverse cracks that develop at an early age in continuously reinforced concrete pavement are generally a result of concrete shrinkage and temperature change. The average intervals found between transverse cracks for both the WRDA and standard mix sections are within the usual range for continuously reinforced pavement. The longer interval for the concrete with WRDA may indicate that this particular water-reducing admixture does not adversely affect concrete shrinkage.

Laboratory tests were made to obtain some information relative to the effect of the water-reducing admixture on the durability of the concrete. Resistance of concrete specimens to rapid freezing and thawing in water (ASTM:C290-63T), and salt scaling tests (Illinois Division of Highways), were made to determine relative durability under adverse environmental conditions. The salt scaling test is intended to determine the resistance of concrete to surface deterioration under

repeated cycles of freezing and thawing in the presence of brine. The results of freezing and thawing tests for standard concrete and WRDA concrete were very similar as may be seen in Figure 4. The results of the salt scaling tests were inconsistent. Initial tests indicated the standard mix to be slightly more resistant to scaling; further tests produced opposite results. The condition of manufactured specimens, the moisture content, and other characteristics of the test specimens may have materially influenced the tests. Although the tests were not conclusive, the results indicate that the WRDA admixture had no important effect on concrete durability.

The material costs for increasing the slump to 2-1/2 inches through the use of WRDA is more than twice that of using additional cement. Based on a material cost of 1 per cent per pound for cement and 1 cent per ounce for WRDA, material cost of WRDA is 34 cents per cubic yard of concrete as compared with 15 cents per cubic yard for the additional cement.

SUMMARY

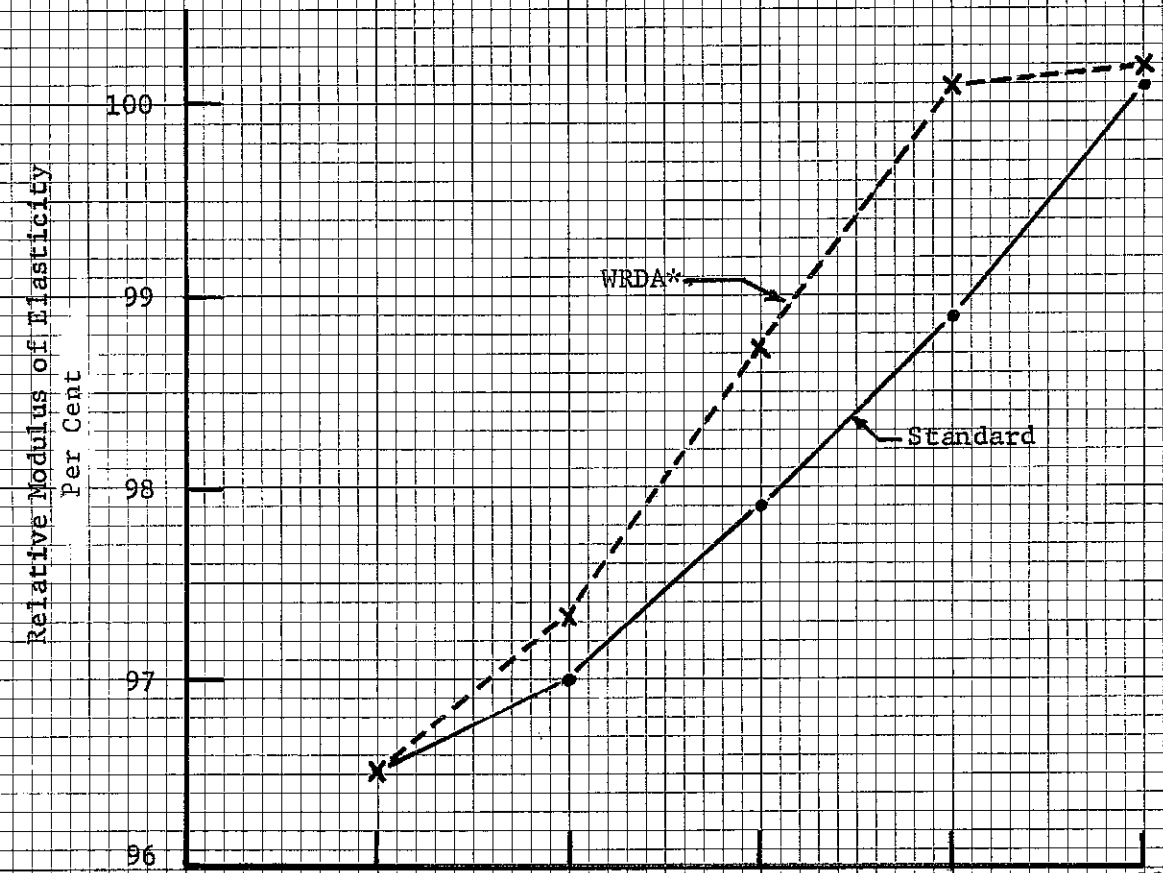
(1) The WRDA water-reducing admixture produced an increase in concrete slump without increasing the amount of mixing water.

(2) When the WRDA water-reducing admixture was added to the mix it was necessary to reduce the amount of air-entraining admixture substantially to maintain the same air content.

(3) Significantly higher compressive strengths at all ages tested through one year were obtained for the concrete containing the WRDA water-reducing admixture. No significant increase in flexural strength was obtained when WRDA was added to the concrete.

FIGURE 4.

RELATIVE MODULUS OF SONIC ELASTICITY
VS.
FREEZE-THAW CYCLES

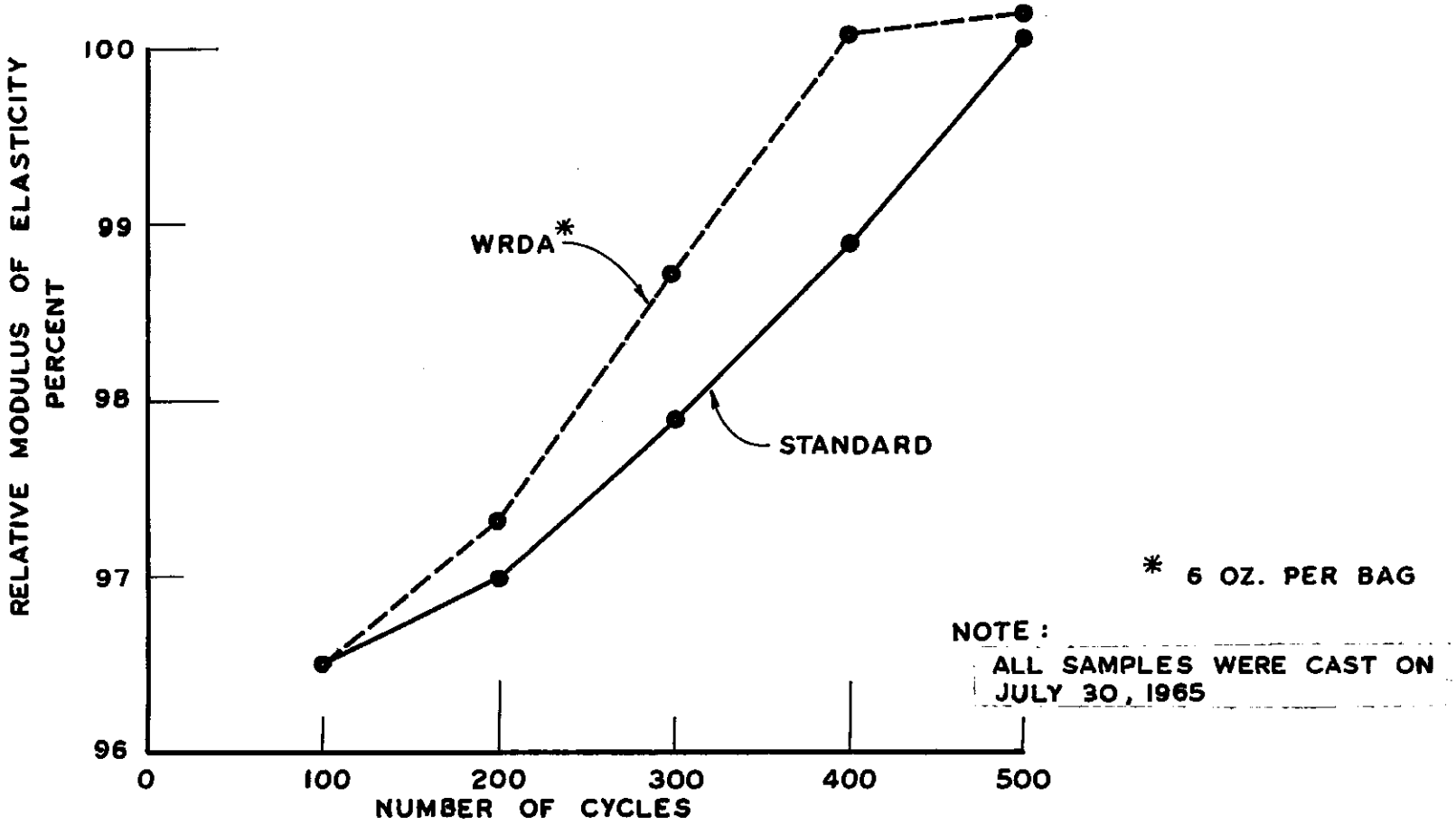


* 6 oz. per bag

NOTE: All samples were cast on July 30, 1965

FIGURE 4.

RELATIVE MODULUS OF SONIC RELASTICITY
VS.
FREEZE-THAW CYCLES



(4) No visible improvement in workability at the same slump could be observed when WRDA was added to the concrete.

(5) Freezing and thawing tests (ASTM: C290-63T) indicated satisfactory durability characteristics for both the concrete containing WRDA and the standard concrete.

(6) The use of WRDA in the concrete had little effect on its initial and final sets.

(7) Information obtained to date indicates that the water-reducing admixture did not adversely affect the shrinkage characteristics of the concrete.

(8) The additional material cost per cubic yard of concrete for increasing the slump to 2-1/2 inches is appreciably more when WRDA is used than when additional cement and water are used.