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STRUCTURES AND MATERIALS RESEARCH
DEPARTMENT OF CIVIL ENGINEERING

STUDY OF CONCRETE PROPERTIES FOR PRESTRESSED CONCRETE REACTOR VESSELS

FINAL REPORT - PART I

by

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REPORT TO
GENERAL ATOMIC COMPANY
SAN DIEGO, CALIFORNIA

MARCH 1975

STRUCTURAL MATERIALS LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY CALIFORNIA

Report
to
General Atomic Company
San Diego, California

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SUMMARY AND CONCLUSIONS

The objective of this investigation is to develop concrete mixes having the strength and physical properties required by the design and construction specifications for prestressed concrete reactor vessels (PCRV's), and to confirm the properties of concrete under long-term loads at elevated temperatures used in the design of the PCRV's. This investigation is being conducted in the Structural Materials Laboratory of the Department of Civil Engineering, University of California (UC) at Berkeley for the General Atomic Company (GA), San Diego, California.

Specifically, this study is being conducted to acquire information on properties of concrete which is to be used in the construction of four PCRV's, two 1160 MW(e) units to be built for the Philadelphia Electric Company at its Fulton Generating Station, and two 770 MW(e) units for the Delmarva Power & Light Company at its Summit Power Station.

The test program was divided into three phases, as outlined in the UC research proposal UCB-Eng-3109 "A Study of Concrete Properties for a Prestressed Concrete Reactor Vessel", dated October 12, 1971, and given in more detail by GA in their Specification 900670 Issue B, dated September 5, 1974. In Phase I of the test program the concrete-making materials were evaluated, in Phase II concrete mixes were developed, and in Phase III, still in progress, the long-term behavior of the concretes using materials and mix proportions selected in Phases I and II is being investigated.

Results obtained in Phase I and Phase II of the test program are presented in this Part I of the Final Report, with a summary and conclusions given below. The results of Phase III will be given in Part II of the Final Report to be issued approximately a year from now.

Phase I - Material Selection and Evaluation

The selection of materials for evaluation of their concrete-making characteristics was made by GA. This included one brand of portland cement (Medusa Type II), one fine aggregate (Mason-Dixon sand), three coarse aggregates (York, Berks and Hempt), and three admixtures (Plastocrete-D, Daratard 40 and Pozzolith 300R).

The Medusa Type II low-alkali cement was supplied by the Medusa Portland Cement Company, York, Pa. Two shipments of this cement, received five months apart from one another and designated by UC as shipments "A" and "B", were used in this investigation. As the test program progressed, it was found that the strength development characteristics of shipment "A" cement were inadequate. Trial mixes containing up to 8 sacks per cubic yard (scy) of this shipment "A" cement did not produce concretes having a 60-day compressive strength of 7700 psi as required by GA. The shipment "B" cement proved to be superior in this respect, producing a 60-day compressive strength of well over 8000 psi with mixes containing 7.5 scy. Results of the standard mortar cube tests (ASTM C 109) confirmed that the rate of strength development of the two shipments of cement differed. This observed difference emphasizes that variations in the properties of cement may occur during the construction of the PCRV. The Medusa Type II cement would be satisfactory, provided the manufacturer can supply a cement producing compressive strengths similar to shipment "B" and have only minor variations in its characteristics from shipment to shipment as indicated by strength tests made prior to its use in the construction of the PCRV.

The fine aggregate selected by GA came from the Belvedere quarry of Mason-Dixon Sand & Gravel, Perryville, Md., a Division of York Building Products, York, Pa. It is a good quality natural sand suitable for use in PCRV concrete mixes. There were no significant variations in its properties among the four shipments of sand supplied to UC for this test program. This sand has a fineness modulus of 2.87, specific gravity of 2.63 and absorption of 0.8 percent.

Three crushed stone coarse aggregates, selected by GA were evaluated in concretes for their influence on compressive strength, elastic properties, drying shrinkage and thermal expansion. These materials, all from Pennsylvania deposits, included aggregate from the Oley quarry of Berks Products Corp., Reading, Pa., the York quarry of York Stone and Supply Co., York, Pa., and the Steelton quarry of Hempt Brothers, Inc., Camp Hill, Pa. Of these, the Berks and York coarse aggregates were selected by GA for further evaluation of their concrete making characteristics and in the development of two selected concrete mixes. These concretes were evaluated for compressive strength, splitting tensile strength and elastic properties. Both of these aggregates, which have a specific gravity of about 2.75 and absorption of 0.5 percent, performed well with respect to compressive and splitting tensile strength, drying shrinkage and thermal expansion, and are suitable for use in PCRV concretes.

The three brands of Type D (ASTM C494) water-reducing and retarding admixtures selected by GA for evaluation of their effect on properties of concrete included Plastocrete-D, Sika Chemical Corp., Lyndhurst, N.J., Daratard 40, W. R. Grace & Co., Cambridge, Mass., and Pozzolith 300R, Master Builders, Cleveland, Ohio. Of these, Daratard 40 and Pozzolith 300R were selected by GA for further evaluation and were used in the concrete mixes of Phase III specimens. Both of the admixtures performed satisfactorily and are suitable for use in the PCRV concrete. In the test program it was found that these admixtures perform better with respect to strength development when their addition to the concrete is delayed about 20 seconds after start of mixing. Should a different admixture addition procedure be used in the PCRV construction, tests should be made to evaluate the effect of that procedure on the properties of the concrete.

Phase II - Concrete Mix Development

The purpose of the Phase II program was to develop concrete mixes which would have a good workability, a slump of 4 1/2 ± 1/4 inches, and a 60-day compressive strength of the laboratory prepared moist-cured specimens of around 7700 psi. From all the mixes developed and evaluated, two 1 1/2 in. MSA mixes, (one Berks and one York) were chosen for study of their long-term behavior in Phase III of the test program. Some of the properties of these two mixes, designated in this report as Berks G-19 and York G-26, are given in the following tabulation:

PROPERTIES OF SELECTED CONCRETE MIXES

Property	Berks G-19		York G-26	
Cement Content, scy	7.5		8.0	
Admixture, fl.oz./100 lbs cement	Daratard 40 8.0		Pozzolith 300R 3.5	
Water-Cement Ratio, by wt.	0.38		0.38	
Slump, in.	4 1/2		4 1/2	
Air Content, %	4.5		2.2	
Temperature, °F	50		50	
Unit Weight, pcf	149.6		151.6	
Sand Content, % by wt.	40.0		41.0	
Compressive Strength, psi (moist-cured specimens)	Medusa Cement Shipment*			
Age, days	"A"+"B"	"B"	"A"+"B"	"B"
28	6560	7310	6660	7520
60	7400	8190	7620	8530
90	7960	....	8030	....
365	8850	....	9130	....

*"A"+"B" is a 1:1 blend of shipments "A" and "B"

Both these mixes are considered to be suitable for use in the construction of the PCRV's, having adequate strength, excellent workability, good cohesiveness and low bleeding characteristics. As shown in the above tabulation the 7.5 scy concrete mix (G-19) with shipment "B" Medusa Type II cement is more than adequate to produce the required 60-day cylinder compressive strength of 7700 psi (8190 psi), while the mix made with the blend of shipments "A" and "B" of the cement does not quite reach this level (7400 psi). By increasing the cement content to 8 scy (mix G-26) the 60-day cylinder strength was almost 7700 psi when using the 1:1 blend of shipments "A" and "B" (7620 psi) and substantially higher when using shipment "B" (8530 psi). Therefore, to attain the required strength level with the minimum cement content it would be desirable to use a Type II cement with the strength gaining characteristics of shipment "B". The use of a lower cement content is beneficial with respect to reducing the temperature rise of the concrete due to cement hydration.

The two selected concrete mixes Berks G-19 and York G-26 using the 1:1 blend of Medusa cement shipments "A" and "B", were used to cast the Phase III specimens which are now under test to establish the behavior of these concretes under long-term loads and elevated temperatures. Results obtained to date indicate that these concretes are suitable for use in the construction of the PCRV. The Phase III data will be given in Part II of the Final Report.

CONTENTS

CONTENTS, Continued

CONTENTS, Continued

CONTENTS, Continued

TABLES:

CONTENTS, Continued

GENERAL ATOMIC COMPANY

FINAL REPORT - PART I

on

PCRV Test Program - Phase I and Phase II
Evaluation of Materials and Concrete Mix Development

March 1975

1. INTRODUCTION

Presented in this Final Report-Part I are the results of Phases I and II of a three-phase investigation on the properties and long-term behavior of concretes being carried out at the University of California at Berkeley (UC) for the General Atomic Company (GA) under PO 418058, following the test program given in GA Spec. 900670, Issue B, dated September 5, 1974.

2. OBJECTIVE

The objective of this investigation entitled "A Study of Concrete Properties for Prestressed Concrete Reactor Vessels" is to develop concrete mixes having the strength and physical properties required by the design and construction specifications for prestressed concrete reactor vessels (PCRV's). Also to be confirmed in this study is the behavior of the concretes under exposure to long-term loads and elevated temperatures assumed in the design of a PCRV. Specifically this study is being conducted to determine the concrete properties for the following PCRV's:

Fulton Generating Station
Units 1 and 2
Philadelphia Electric Company
- Two 1160 MW(e) PCRV's -

Summit Power Station
Units 1 and 2
Delmarva Power & Light Company
- Two 770 MW(e) PCRV's -

3. TEST PROGRAM AND RESULTS REPORTED

3.1 Test Program

The test program of the investigation is divided into the following three phases:

Phase I - Materials' Selection and Evaluation
Phase II - Concrete Mix Development
Phase III - Concrete Long-Term Behavior

A detailed description of the test program is given in Appendix A. The following is a description of each of the three phases of this investigation.

3.1.1 Phase I.--This Phase I of the test program was concerned with the selection and evaluation of the concrete-making materials, including cement, aggregates and admixtures. The test program included the determination of the various properties of these materials and an evaluation of properties of fresh and hardened concretes made with three coarse aggregates from different sources and three admixtures. Tests made on the fresh concretes included slump, air content, unit weight, bleeding and time of setting. The properties determined on the hardened concretes included compressive strength up to age 60 days, elastic properties, coefficient of thermal expansion and drying shrinkage characteristics.

3.1.2 Phase II.--Phase II of the test program was concerned with the development of test data needed to establish concrete mixes that would have the required strength and physical properties for a PCRV. Since the design strength of PCRV concrete is 6,500 psi at 60 days, GA required that the laboratory mix attain a cylinder strength around 7,700 psi at this age.

In this phase, two coarse aggregates and two of the admixtures selected in Phase I were evaluated in mixes of varying cement contents. Based on the results obtained, a selected mix for each of the two aggregates containing a given admixture was established. Properties of fresh and hardened concrete were determined for all mixes. The properties of hardened concrete were evaluated on both sealed and moist-cured specimens and included compressive strength, tensile strength and elastic properties up to age 2 years.

3.1.3 Phase III.--The main objective of Phase III of the test program, still in progress, is to establish the behavior of the concretes under exposure to long-term loads and elevated temperatures. Creep characteristics are being determined on sealed concrete specimens made from the two selected mixes developed in Phase II.

The creep test conditions, used in selected combinations, include: three temperatures (73, 110 and 160°F), three load levels (30, 45 and 60 percent of ultimate strength at 73°F) and three ages of loading (28, 90 and 270 days). Also included in Phase III is an evaluation of the influence of thermal cycling on strength and elastic properties, and the determination of thermal properties of the concretes.

3.2 Results Reported

This Part I of the Final Report covers the results obtained in Phase I and Phase II of the investigation. Results of Phase III will be reported in Final Report-Part II to be issued approximately a year from now. The specific tests and specimens cast for Phases I, II and III, are shown in Appendix A. The procedures followed in the tests of Phases I and II are given in Appendix B, including a description of material preparation, mixing, tests for properties of fresh concrete, casting procedures, preparation and storage conditions of sealed and moist-cured specimens, compressive strength tests, tests for modulus of elasticity and Poisson's ratio, splitting tensile strength tests, and tests for determining the drying shrinkage and coefficient of thermal expansion characteristics of the concretes.

4. PROPERTIES OF CONCRETE MATERIALS - PHASES I AND II

The following portland cements, fine aggregate, coarse aggregates and admixtures, identified by their brand name or source and the name of their producer, were used in one or more phases of this test program:

Cements: Medusa Type II, Low-alkali, Medusa Portland Cement Co., York, Pa.

Permanente Type II-V, Low-alkali, Kaiser Cement & Gypsum Corp., Permanente, Calif.

Fine Aggregate: Belvedere quarry of Mason-Dixon Sand & Gravel, Perryville, Md., a Division of York Building Products, York, Pa.

Coarse Aggregates: York quarry of York Stone & Supply Co., York, Pa.
Oley quarry of Berks Products Corp., Reading, Pa.
Steelton quarry of Hempt Brothers, Inc., Camp Hill, Pa.

Admixtures: Plastocrete-D, Sika Chemical Corp., Lyndhurst, N.J.
Daratard 40, W.R. Grace & Co., Cambridge, Mass.
Pozzolith 300R, Master Builders, Cleveland, Ohio

It was desired by GA to use the same type and brand of cement in this test program as will be used in the construction of the PCRV. The decision as to what brand cement to use was not finalized at the start of Phase I tests. To prevent a delay in the test program at UC, a Permanente Type II-V cement was used, with the approval of GA, in the first trial mixes related to the evaluation tests of coarse aggregates. Prior to the next series of trial mixes, Medusa Type II cement was selected by GA for use in construction of the PCRV and therefore this cement was used throughout the remainder of the test program.

The Mason-Dixon sand and the three coarse aggregates, York, Berks and Hempt, were selected by GA for evaluation at UC. In addition to these aggregates, two shipments of size No. 467 aggregate (1000 pounds each) were received from the Cedar Hill and the Elk Mills quarries of D.M. Stoltzfus & Sons, Inc., Talmage, Pennsylvania. After initial inspection of these aggregates and review of data provided by GA, it was decided by GA not to include these materials in the test program.

Numerous shipments of cement, aggregate and admixtures were received over a two-year period as the test program progressed and as additional tests requested by GA, or suggested by UC, were carried out. The dates of these shipments, amounts received, and the properties of the cements and aggregates used in this test program are given in the following sections.

4.1 Cements

The Permanente Type II-V cement used was taken from the UC concrete laboratory stock. The Medusa Type II cement was supplied by the producer and received in two shipments, approximately five months apart. The dates of shipment and weights of cement received are tabulated below:

	Shipment	Date Received	No.of Bags	Weight, lbs
Medusa Type II cement	"A"	9/31/72	50	4700
	"B"	2/8/73	80	7520

Each shipment of cement was blended and stored in sealed 55 gallon steel drums in accordance with procedures described in Appendix B. The chemical composition and physical properties of the cements are discussed below.

4.1.1 Permanente Type II-V.--The chemical composition and physical properties of the Permanente Type II-V cement, as reported by the Permanente Cement Company, are shown in Table 1. This cement was a low-alkali and low heat of hydration cement with an alkali content expressed as Na_2O of 0.39 percent and a heat of hydration of 58 cal/g at 7 days. Since this cement was used only in the initial evaluation tests of the coarse aggregates, there was no need for its composition to meet the GA specification requirements.

4.1.2 Medusa Type II.--The chemical composition and physical properties of shipment "A" and "B" Medusa Type II cement, as reported by the Medusa Portland Cement Company and the UC data are given in Table 1.

A comparison of the Medusa and UC chemical analyses of the cement and of the compressive strengths of mortar cubes are summarized in the following two tabulations:

CHEMICAL COMPOSITION OF MEDUSA TYPE II CEMENT, %

Cement Shipment:	UC Analysis "A"	UC Analysis "B"	Medusa Analysis "A"	Medusa Analysis "B"	GA Spec. R0069
C_3S	54.0	47.9	50.3	51.2	40-50
C_2S	19.7	27.1	22.8	22.7	...
C_3A	4.6	2.0	5.0	6.1	0-6
C_4AF	12.1	14.2	11.9	11.0	11-16

COMPRESSIVE STRENGTH OF MEDUSA TYPE II CEMENT MORTAR CUBES, PSI

Cement Shipment:	Tests Made at UC "A"	"A"+"B" (1:1)	"B"	Tests by Medusa "A"	"B"	GA Spec. R0069
3 days	...	...	...	2800	2570	1000 min.
7 days	2920	2890	2790	3530	3370	1600 min.
28 days	4140	4180	4370	5000	5230	4000 min.
60 days	4440	4660	5100	...	...	...

In the chemical analyses supplied by Medusa, Shipment "A" cement has a slightly higher C_3S content than the GA specified requirements, and Shipment "B" has a slightly higher C_3S and C_3A content. In the UC chemical analyses, Shipment "A" cement has a higher C_3S content while Shipment "B" satisfied the GA specified requirements. It should be noted that the UC analyses were performed on representative samples of the cement actually used in this investigation whereas the Medusa analyses were made on composite samples representing a production run of over 1000 tons of cement.

The effect of the higher C_3S content will be primarily reflected in a slight increase of the heat of hydration. All sets of compressive strength results satisfy GA Specification R0069.

4.2 Fine Aggregate

The Mason-Dixon natural sand was used in all of the concrete mixes of this test program. A total of four shipments of this sand were received at UC. The dates and amounts received are tabulated below:

	Shipment Received	Weight, lbs
Mason-Dixon Sand	3/25/72	2000
	11/16/72	6500
	3/2/73	8000
	10/4/73	6000

Each shipment of the sand was blended and stored in 55 gallon drums. Table 2 gives the gradation and physical properties for each shipment of sand along with the requirements of GA specification R0068 which is identical to the ASTM C 33 specification for fine aggregate. The sand shipments of

3/25/72, 11/16/72 and 3/2/73 meet the gradation requirements of the GA specification. The 10/4/73 shipment has 78 percent passing the No. 8 sieve which is less than the 80 to 100 percent specified. However, this 10/4/73 shipment of sand was only used in the 4:2:1 blend of shipments 10/4/73, 3/2/73 and 11/16/72, respectively, with the resulting gradation (shown in Table 2) satisfying the GA specification.

The fineness modulus of the sand (2.83 to 3.00) was within the GA specified range of 2.3 to 3.1. The specific gravity of the blended sand was 2.63 and its absorbtion 0.8 percent.

Based on the gradation and physical properties determined, the Mason-Dixon sand was found to be satisfactory for use as the fine aggregate in the concrete mixes of the test program.

4.3 Coarse Aggregates

The three coarse aggregates, York, Berks and Hempt, evaluated in the test program were 1 1/2 in. to No. 4 crushed stone aggregates. The initial shipments of these aggregates received were ASTM C 33 size No. 467 (1 1/2 in. to No. 4). To minimize segregation, subsequent shipments of aggregates were ASTM C 33 size No. 4 (1 1/2 to 3/4 in.) and size No. 67 (3/4 in. to No. 4). During batching, the proportions of the No. 4 and 67 sizes of coarse aggregate were kept the same as in the No. 467 size material received.

Each type of aggregate shipment received was blended, its moisture adjusted for uniformity, and then stored in 55-gallon drums as described in Appendix B.

4.3.1 Initial Evaluation of York, Berks and Hempt Aggregates.--The gradation and physical properties of the first shipments of York, Berks and Hempt size No. 467 coarse aggregate received on 3/27/72 for their evaluation are shown in Table 3. Also shown in this table are the requirements of GA specification R0068, which is identical to the requirements of ASTM C 33.

The Hempt aggregate failed to meet the specifications since 78 percent of the material passes the 3/4-in. sieve size (maximum of 70 percent permitted). The York and Berks aggregates satisfied the specified grading requirements.

The York aggregate appears to have a better particle shape as compared to the other two aggregates. The York aggregate contained 3 percent flat and elongated particles compared to 7 and 12 percent for Berks and Hempt, respectively.

4.3.2 York Aggregate.--The following additional shipments of York aggregate were received:

		Size	Shipment Received	Weight lbs
York aggregate	# 67	3/4" to No. 4	2/12/73	3900
	# 67	3/4" to No. 4	11/7/73	2400
	# 4	1 1/2" to 3/4"	5/11/73	4000
	#467*	1 1/2" to No. 4	2/12/73	3300

*The 2/12/73 shipment of #467 was supposed to be ASTM C 33 size No.4 and was separated at UC into two sizes, 1 1/2 and 3/4 in., and 3/4 in. to No.4.

A total of two combined gradations of 1 1/2-in. maximum size York aggregate were used. The shipments combined and proportions used are summarized below. The gradations and physical properties of the several shipments and combinations of York aggregate are given in Table 3.

Combined gradation "A":	# 67	2/12/73	55.3%	
	# 4	5/11/73	44.7%	
Combined gradation "B":	# 67	2/12/73 2/12/73 11/7/73	1200 lbs 1400*lbs 2400 lbs	55.3%
	# 4	2/12/73 5/11/73	1400*lbs 1700 lbs	44.7%

*Separated from Size No. 467, 2/12/73

4.3.3 Berks Aggregate.--The following additional shipments of Berks aggregate were received:

		Size	Shipment Received	Weight, lbs
Berks aggregate	# 67	3/4" to No. 4	2/14/73	4800
	# 67	3/4" to No. 4	9/20/73	1800
	# 67	3/4" to No. 4	10/23/73	1200
	# 4	1 1/2" to 3/4"	2/14/73	3800
	# 4	1 1/2" to 3/4"	9/20/73	1800

During batching, the 1 1/2 to 3/4-in. and 3/4 in. to No. 4 sizes were combined to meet ASTM C 33 specifications for size No. 467, 1 1/2 in. to No. 4. A total of two combined gradations of Berks aggregate were used. The shipments combined and proportions used are summarized below. The gradation and physical properties of the several shipments and combinations of Berks aggregate are given in Table 3.

Combined gradation "A":	# 67	2/14/73	48.3%	
	# 4	2/14/73	51.7%	
Combined gradation "B":	# 67	2/14/73	1400 lbs	48.3%
		9/20/73	1800 lbs	
		10/23/73	1200 lbs	
	# 4	2/14/73	1400 lbs	51.7%
		9/20/73	1800 lbs	

4.4 Admixtures

The three brands of Type D (ASTM C 494) water-reducing and retarding admixtures evaluated in the test program were Plastocrete-D, Daratard 40 and Pozzolith 300R. These admixtures were supplied directly to UC by the producers. The dates and quantities of admixtures received are given below:

	Brand Name	Lot Number*	Shipment Received	Volume Received
Admixtures	Plastocrete-D	...	8/14/72	1 qt.
	Daratard 40	PB08-675-1	8/21/71	1 qt.
		PB04-675-2	4/12/72	1 gal.
		CC05-A112-1	4/27/73	4 gal.
	Pozzolith 300R	...	8/25/72	1 gal.
		...	4/9/73	1 gal.

*Lot numbers not supplied to UC by producers for shipments of Plastocrete-D and Pozzolith 300R.

These admixtures were evaluated for their performance in concrete but no individual tests on the admixtures alone were performed at UC.

5. CONCRETE TRIAL MIXES - PHASE I.

5.1 Evaluation of Coarse Aggregates - Phase I(a)

The primary purpose of these trial mixes was to evaluate the three coarse aggregates (York, Berks and Hempt), and to select a primary and secondary aggregate for continued investigation in the research program.

5.1.1 Test Program.--The evaluation of the three 1 1/2-in. maximum size aggregates (MSA) included tests for obtaining their physical properties and determining their concrete-making characteristics by testing concretes containing these aggregates for a) compressive strength and elastic properties at age 7, 28 and 60 days, b) drying shrinkage characteristics, and c) coefficient of thermal expansion in the range of 73 to 160°F.

5.1.2 Materials.--The concrete materials used in this aggregate evaluation program included:

Cement:	Permanente Type II-V
Fine Aggregate:	Mason-Dixon sand, 3/25/72
Coarse Aggregates:	York, Berks or Hempt 1 1/2 in. to No. 4, 3/27/72
Admixture:	Daratard 40, 8/21/71, 6.4 fl. oz./100 lbs. of cement

5.1.3 Mix Designs.--Based on results obtained in preliminary trial mixes, the mix proportions selected for the concrete made with the three kinds of coarse aggregate are given in Table 4, along with the properties of fresh concretes.

The concrete mixes had a nominal slump of 3 3/4 ± 1/4 in., a cement content of 7.5 scy, a water-cement ratio of 0.39 to 0.40 by weight, and contained 42 percent sand by weight of total aggregate. To minimize segregation the 1 1/2 in. to No. 4 coarse aggregate was separated into two sizes (3/4 in. to No. 4 and 1 1/2 to 3/4 in.), and each size was batched separately in the same proportions as those of the aggregate supplied to UC by the producer. Concretes were mixed and tested at 73°F. In all subsequent mixes, the concrete materials were cooled to produce a 50 ± 3°F temperature of the freshly mixed concrete.

The workability of the concretes containing the York or Berks aggregate was somewhat better than that of the concrete containing the Hempt aggregate. This is principally due to the shape of the coarse aggregate. The Hempt aggregate contains 12 percent of flat and elongated particles compared to only 3 and 7 percent for the York and Berks aggregates, respectively.

5.1.4 Compressive Strength and Elastic Properties.--The properties of hardened concrete including compressive strength, modulus of elasticity and Poisson's ratio at ages of 7, 28 and 60 days are summarized in Table 5. All specimens used were 6 by 12-in. cylinders moist-cured up to age of test, with three specimens tested at each test condition.

Concrete containing the York aggregate exhibits a higher strength at all three ages in comparison to the concretes made with the Berks or Hempt aggregates. The lowest strengths were obtained for the concrete containing the Hempt aggregate. The compressive strength results are summarized in the following tabulation:

COMPRESSIVE STRENGTH OF TRIAL MIXES, PSI

Age, Days	Coarse Aggregate		
	York	Berks	Hempt
7	4780	4450	4320
28	6490	6220	5590
60	6890	6640	6560

The modulus of elasticity and the Poisson's ratio at age 60 days were about the same for all three concretes. The 60-day modulus of elasticity ranges from 5.6 to 5.9 x 10^6 psi and Poisson's ratio from 0.20 to 0.21.

5.1.5 Drying Shrinkage.--The values of drying shrinkage up to 448 days of drying for concretes containing the three aggregates under investigation (York, Berks and Hempt) are given in Table 6. The drying shrinkage tests were performed in accordance with ASTM C 157. The three 4 by 4 by 11-in. prisms cast from each concrete were water-cured for 28 days and thereafter subjected to drying in an atmosphere of 50 percent relative humidity and 73°F.

Referring to Table 6 it is seen that the shrinkage after 448 days of drying was 390 micro-strains for York, 510 micro-strains for Berks, and 440 micro-strains for Hempt aggregate concrete. It should be noted that although the Berks aggregate concrete exhibited higher shrinkage than the York aggregate concrete, its drying shrinkage characteristics would still be considered to be relatively low in comparison to the shrinkage characteristics of concretes made with some other types of aggregate.

5.1.6 Coefficient of Thermal Expansion.--All three concretes (York, Berks and Hempt) were tested for their coefficient of thermal expansion by subjecting them to three thermal cycles within the range 73 to 160°F. The heating portion of each cycle was performed in the following four thermal steps: 73-90, 90-110, 110-135 and 135-160°F. Similar four thermal steps were used for the cooling portion of each cycle. Each thermal step required 24 hours, thus 8 days were required to perform one complete thermal cycle.

Three 6 by 16-in. concrete cylinders, instrumented with a 10-in. gage-length SL-10 Carlson strain meter, were used for each concrete mix. These cylinders were sealed by means of a butyl rubber jacket and stored up to age 28 days at 73°F prior to subjecting them to thermal cycling.

Results of the coefficient of thermal expansion tests are given in Table 7. The overall average linear coefficient of thermal expansion for York was 5.9, for Berks 6.4, and for Hempt 6.0 x 10^{-6} per °F.

5.2 Evaluation of Admixtures - Phase I(b)

Three brands of Type D (ASTM C 494) water-reducing and retarding admixtures were evaluated for their performance in concrete mixes. Based on the results of these tests, two of the admixtures were selected for further evaluation in Phase II and used in Phase III of the test program.

5.2.1 Test Program.--The properties of fresh and hardened concretes containing the three water-reducing and retarding admixtures, and of a control mix with no admixture, were determined in accordance with the following standard ASTM test procedures:

A - Tests of Freshly Mixed Concrete

a) Water Requirement for a 4 ± 1/4" slump - ASTM C 143.

b) Air Content - ASTM C 231.

c) Bleeding - ASTM C 232.

d) Time of Setting - ASTM C 403.

B - Tests of Hardened Concrete

a) Compressive Strength at 7, 14, 28 and 60 days - ASTM C 39.

b) Length Change (drying shrinkage) - ASTM C 157.

5.2.2 Materials.--The concrete materials used in this admixture evaluation program included:

Cement:	Medusa Type II, 9/31/72, Shipment "A"
Fine Aggregate:	Mason-Dixon sand, 3/25/72
Coarse Aggregate:	York 1 1/2 in. to No. 4, 3/27/72
Admixtures:	Plastocrete-D, 8/14/72, 2.13 fl.oz./100 lbs of cement
	Daratard 40, 4/12/72, 6.4 fl.oz./100 lbs of cement
	Pozzolith 300R, 8/25/72, 3.5 fl.oz./100 lbs of cement

The dosage of these three Type D (ASTM C 494) admixtures employed was that recommended by the producers for use in this admixture evaluation test program.

5.2.3 Mix Design and Properties of Fresh Concrete.--All concrete mixes used in this admixture evaluation test program were proportioned to have a nominal cement content of 7.5 scy and a water-cement ratio to produce a 4 ± 1/4 in. slump. The sand content used was 42 percent of the total aggregate weight. To minimize segregation the York 1 1/2 in. to No. 4 coarse aggregate was separated into two sizes (3/4 in. to No. 4 and 1 1/2 to 3/4 in.), and each size was batched separately.

After batching, the concrete materials were cooled and ice water was used in the mix to produce a 50 ± 3°F temperature of the freshly mixed concrete. The mix proportions and properties of fresh concretes are summarized in Table 4. All concrete specimens were stored and tested at 73°F. Results obtained are discussed in more detail in the following sections.

a) Water Requirement.--As shown in Table 4 the water-cement ratio of concretes containing the admixtures (0.41 - 0.43) was about 0.02 lower than that of the control mix (0.44).

b) Air Content.--As shown in Table 4, the admixtures entrained about 1 to 2 percent of additional air as compared to the control mix, with Daratard 40 entraining the highest percentage. This is a normal characteristic for these types of admixtures.

c) Bleeding.--In determining the bleeding characteristics of the concretes, each test sample was initially consolidated by vibration and subjected to two subsequent periods of vibration, one after a period of 30 minutes and one after one hour. Three test specimens were cast and tested for each of the four test conditions (3 admixtures and 1 control). Bleeding water was drawn off the surface of the concrete at regular intervals until no further water appeared on the surface of the concrete. This cessation of bleeding occurred at about 3 1/2 hours after casting of the test samples. During the test the ambient temperature was maintained at 73 ± 3°F. The temperature of the concrete after casting of the samples was 52°F, and at the end of the test (3 1/2 hours) was 65°F.

The total amount of bleeding, expressed as a percentage of the net mixing water, is given in the following tabulation:

BLEEDING OF CONCRETE

Admixture	Bleeding, %
None (Control)	1.1
Plastocrete-D	1.1
Daratard 40	0.3
Pozzolith 300R	0.3

The amount of bleeding of concrete containing Plastocrete-D was of the same magnitude as that of the control mix and about four times that obtained for Daratard 40 or Pozzolith 300R. However, it should be noted that even the 1.1 percent of bleeding obtained with Plastocrete-D would be considered to be of acceptable magnitude. The reason for the relatively low bleeding characteristics of the concrete mixes used is their high cement content and low water-cement ratio.

d) Time of Setting.--Three test specimens were prepared and tested for each of the concrete mixes investigated. The mortar fraction (minus No. 4 sieve) of the concrete used for preparing each one of the test specimens was taken from a separate batch.

Results of these rates of hardening tests are plotted in Figure 1 and the elapsed times required to reach initial and final set are given in the following tabulation:

TIME OF SETTING OF CONCRETE

	Time of Setting, hr.:min.	
Admixture	Initial (500 psi)	Final (4000 psi)
None (Control)	4:33	6:05
Plastocrete-D	5:48	7:17
Daratard 40	4:39	6:06
Pozzolith 300R	4:57	6:30

Admixture Plastocrete-D produced the greatest retardation of the concrete. Only a small amount of retardation was produced by the other two admixtures. However, it should be noted that the low initial temperature of the concrete (50 ± 3°F) would have a retarding effect on all of the concretes, including the control mix with no admixture, and therefore the time of setting limits given in the ASTM C 494 specification for this class of admixtures are not directly applicable to these test results. However under job conditions, especially during hot weather construction, it is desirable to use a Type D admixture to insure adequate retardation in order to eliminate cold joints in concrete. For this reason the use of a Type A water-reducing admixture in lieu of a Type D admixture would not be recommended.

5.2.4 Compressive Strength.--Compressive strength was determined at ages of 7, 14, 28 and 60 days on 6 by 12-in. cylinders moist-cured up to age of test. Individual results of the three cylinders tested at each test condition are given in Table 5 and the average values summarized in the following tabulation.

EFFECT OF ADMIXTURES ON COMPRESSIVE STRENGTH OF CONCRETE, PSI

Age, Days	None (Control)	Plastocrete D	Daratard 40	Pozzolith 300R
7	4030	4530	4590	4860
14	4750	5330	5160	5600
28	5340	5950	5720	6080
60	5960	6260	6250	6790

The largest increase in strength was produced by Pozzolith 300R. The increase in strength produced by the other two admixtures was of about the same magnitude.

5.2.5 Drying Shrinkage.--The drying shrinkage tests were performed in accordance with ASTM C 157, except that the initial temperature of the concrete during casting was 50 ± 3°F. Four 4 by 4 by 11-in. prisms were cast for each test condition, water-cured at 73 ± 3°F for 28 days and then subjected to drying in an atmosphere of 50 percent relative humidity and 73 ± 3°F.

Results of the drying shrinkage tests up to age 448 days are given in Table 6. The 448-day drying shrinkage values are given in the following tabulation:

EFFECT OF ADMIXTURES ON 448-DAY DRYING SHRINKAGE OF CONCRETE

Admixture	Drying Shrinkage, micro-strain
None (Control)	430
Plastocrete-D	440
Daratard 40	495
Pozzolith 300R	500

Although the shrinkage of the concretes containing the admixtures was somewhat greater than that of the control mix, the magnitudes of shrinkage observed would be considered to be small and certainly acceptable for a PCRV concrete.

5.3 Preliminary Evaluation of Cement Content

In reviewing the 60-day compressive strength results of the Phase I(b) trial mixes made for the evaluation of admixtures, it was noted that the desired compressive strength of 7700 psi at age 60 days was not being achieved. The highest strength at age 60 days was 6790 psi for the 7.5 scy mix containing Pozzolith 300R.

It was apparent that additional trial mixes were necessary before continuing with the specified test program and the compressive strength of the following additional mixes summarized below were determined:

Mixes (a) 8 scy concrete mixes containing Berks 1 1/2-in. MSA with either Daratard 40 or Pozzolith 300R, and evaluated against a control mix with no admixture.

Mixes (b) 8 scy concrete mixes containing Berks 3/4-in. MSA with either Daratard 40 or Pozzolith 300R, and evaluated against a control mix with no admixture.

Mixes (c) 8 scy mix with Daratard 40 and a 7.5, 8 and 8.5 scy concrete mix with Pozzolith 300R, containing Berks 1 1/2-in. MSA, and using a delayed addition of admixture to the mix.

The mix proportions, properties of fresh concrete and compressive strengths of these trial mixes are discussed in the following sections.

5.3.1 Trial Mixes (a).--Of the three concrete mixes evaluated, one was a control with no admixture (Mix G-1), one contained Daratard 40 (Mix G-2), and one Pozzolith 300R (Mix G-3). These mixes were proportioned to have a nominal cement content of 8 scy and a water-cement ratio to produce a slump of 4 1/2 ± 1/2 inches. Their sand content was 41 percent of the total aggregate weight. The concrete materials were cooled after batching and ice water was used in the mix to produce a 50 ± 3°F temperature of the freshly mixed concrete. The mix proportions and properties of the fresh concrete are shown in Table 8 and the materials used are described in the following tabulation:

Cement:	Medusa Type II, 9/31/72, Shipment "A"
Fine Aggregate:	Mason-Dixon sand, 11/16/72
Coarse Aggregate:	Berks 1 1/2 in. to No. 4, 3/27/72
Admixtures:	Pozzolith 300R, 8/25/72, 3.5 fl.oz/100 lbs of cement
	Daratard 40, 4/12/72, 8.0 fl.oz/100 lbs of cement

It should be noted that at the recommendation of the manufacturer the dosage of Daratard 40 was increased form 6.4 to 8.0 fl. oz. per 100 lbs of cement. This dosage of 8.0 ounces for Daratard 40 was then used throughout the remainder of the test program.

The compressive strength of trial mixes (a) were determined at ages 7, 14, 28 and 60 days on 6 by 12-in. concrete cylinders moist-cured at 73°F until age of test. The results obtained are given in Table 9 with the average 60-day strengths summarized below:

COMPRESSIVE STRENGTH - TRIAL MIXES (a), PSI

Age, Days	Control G-1	Daratard 40 G-2	Pozzolith 300R G-3
60	6210	6140	6620

None of these 60-day compressive strengths obtained were as high as expected. Although the strength of this 8 scy control mix concrete (6210 psi) was higher than that of the 7.5 scy control mix (5960 psi) obtained in Phase I(b), the strengths of the 8 scy mixes containing admixtures were on the average lower by 160 psi. It should be noted that York coarse aggregate was used in Phase I(b) and Berks in these trial mixes (a), but this does not explain the discrepancies obtained.

5.3.2 Trial Mixes (b).--To obtain some preliminary compressive strength data on 3/4-in. MSA concrete mixes and to further evaluate the behavior of the two admixtures, Daratard 40 and Pozzolith 300R, three additional mixes were tested; one mix containing Daratard 40, one Pozzolith 300R and one control mix with no admixture. All mixes contained Berks 3/4-in. MSA and were proportioned to have a nominal cement content of 8 scy and a water-cement ratio to produce a 4 ± 1/4-in. slump. Their sand content was 48 percent of the total aggregate weight. The concrete materials were cooled after batching and ice water was used in the mix to produce a 50 ± 3°F temperature of the freshly mixed concrete. The mix proportions and properties of the fresh concrete are shown in Table 8 and the materials used are described below:

Cement:	Medusa Type II, 9/31/72, Shipment "A"
Fine Aggregate:	Mason-Dixon sand, 11/16/72
Coarse Aggregate:	Berks 3/4 in. to No. 4, 3/27/72
Admixtures:	Pozzolith 300R, 8/25/72, 3.5 fl.oz/100 lbs of cement
	Daratard 40, 4/12/72, 8.0 fl.oz/100 lbs of cement

The compressive strength of trial mixes (b) were determined at ages 7, 14, 28 and 60 days on 6 by 12-in. concrete cylinders moist-cured at 73°F until age of test. The results obtained are shown in Table 9 with the average 60-day strengths summarized below:

COMPRESSIVE STRENGTH - TRIAL MIXES (b), PSI

Age, Days	Control G-4	Daratard 40 G-5	Pozzolith 300R G-6
60	6410	6100	7160

The compressive strengths at age 60 days were again lower than expected with a definite indication that Daratard 40 was not producing the desired results when used with Medusa Type II cement, Shipment "A". All of the casting and testing procedures were reviewed and discussions were held with representatives from the W. R. Grace Company, manufacturers of Daratard 40. It was speculated that an explanation for this behavior of the admixtures could be the presence of anhydrite in the cement as indicated by the test results obtained by the W. R. Grace Company and reproted in their April 9, 1973 report, a copy of which is attached as Appendix C. The problems encountered could possibly be overcome by a delayed addition of admixture to the mix. This was done with the last set of trial mixes (c).

5.3.3 Trial Mixes (c).--To evaluate the effect of cement content on compressive strength and to experiment with delayed addition of admixture to the mix, the following four mixes, all containing Berks 1 1/2-in. MSA were cast and tested:

Mix G-11	8 scy with Daratard 40
Mix G-12	7.5 scy with Pozzolith 300R
Mix G-7	8 scy with Pozzolith 300R
Mix G-13	8.5 scy with Pozzolith 300R

All mixes were proportioned to have a 4 3/4 ± 1/4-in. slump. The concrete materials were cooled after batching and ice water was used in the mix to produce a 50 ± 3°F temperature of the freshly mixed concrete. The mix proportions and properties of the fresh concrete are shown in Table 8 and the materials used are described below:

Cement:	Medusa Type II, 2/8/73, Shipment "B"
Fine Aggregate:	Mason-Dixon sand, 3/2/73
Coarse Aggregate:	Berks 1 1/2 in. to No. 4, Gradation "A"
Admixtures:	Pozzolith 300R, 8/25/72, 3.5 fl.oz/100 lbs of cement
	Daratard 40, 4/12/72, 8.0 fl.oz/100 lbs of cement

A delayed addition of admixture was used. This was accomplished by adding the admixture to the concrete mix 20 seconds after start of mixing.

The compressive strengths at age 7, 28 and 60 days, as determined on 6 by 12-in. concrete cylinders moist-cured at 73°F, are shown in Table 9. The average 60-day compressive strength of these concretes is given in the following tabulation:

COMPRESSIVE STRENGTH - TRIAL MIXES (c), PSI

	Daratard 40	Pozzolith 300R		
Age, Days	G-11 8 scy	G-12 7.5 scy	G-7 8 scy	G-13 8.5 scy
60	7400	7390	7900	7760

These results indicated that a 8 scy mix would yield the desired 60-day compressive strength of 7700 psi. With the change from Medusa Type II cement shipment "A" to shipment "B" and using the delayed addition of admixture, the 60-day compressive strength was considerably higher than previously obtained in prior trial mixes. A large portion of this improvement in strength is due to the better performance of shipment "B" cement with respect to 60-day strength as indicated by the results of the mortar cube strength tests made later in the program and discussed in the section on cements. However, as judged by the improved performance of Daratard 40 it appears that the delayed addition of this admixture is also beneficial with respect to strength development.

5.4 Evaluation of Sand Content

Five 8 scy concrete mixes containing Berks 1 1/2-in. MSA were cast to determine the effect of sand content on workability and compressive strength. Three of the mixes were cast using Pozzolith 300R containing a sand content of 36, 38 or 41 percent by weight of total aggregate, and two mixes were cast using Daratard 40 containing a sand content of 36 and 41 percent. The concrete materials used were:

Cement:	Medusa Type II, 2/8/73, Shipment "B"
Fine Aggregate:	Mason-Dixon sand, 3/2/73
Coarse Aggregate:	Berks 1 1/2 in. to No. 4, Gradation "A"
Admixtures:	Pozzolith 300R, 8/25/72, 3.5 fl.oz/100 lbs of cement
	Daratard 40, 4/12/72, 8.0 fl.oz/100 lbs of cement

Table 10 shows the properties of these 8 scy concrete mixes made with 1 1/2-in. MSA and containing 36, 38 and 41 percent sand by weight of total aggregate. The mixes containing 36 or 38 percent sand were not as workable as the mix with 41 percent sand which was judged to be of excellent workability. It was proposed that a sand content of 41 percent of total aggregate weight be used with the 8 scy 1 1/2 in. MSA mixes. The 8 scy mix made with 3/4-in. MSA (Table 8) was very workable with a 48 percent sand content. It was proposed that a 47 percent sand content be used with the 8 scy 3/4-in. MSA mixes.

5.5 Discussion of Phase I Trial Mix Data

Based on the results of the Phase I trial mix tests the concrete mixes proposed to be used in Phase II(a) and II(b) are given in the following tabulation.

PROPOSED MIXES FOR PHASE II(a) AND II(b)

Aggregate Size, in.	Nominal Cement Content, scy	Sand Content, % of Total Aggregate by Wt.
	7.5	42
1 1/2	8.0	41
	8.5	40
	7.5	48
3/4	8.0	47
	8.5	46

It was agreed that the water cement ratio of the 50 ± 3°F concretes be selected to produce a slump of 4 1/2 ± 1/4 in. taken within three minutes after the end of mixing. This value of slump was proposed to take into account the stiffening observed when using the admixtures in the mix. Figure 2 gives a summary of slump loss data observed for the 3/4-in. and 1 1/2-in. MSA mixes. The slump loss data shown in this figure indicates that the concretes containing the admixtures exhibited a fair amount of stiffening during the first 15 minutes after end of mixing. For example the 1 1/2-in. MSA mix containing Pozzolith 300R would stiffen in 15 minutes from an initial slump of 5 inches to a slump of 2 1/2 inches. However, after this initial stiffening there was no significant additional slump loss of these concretes in the next 10 to 20 minutes, the end of the slump loss test. This slump loss behavior is typical of water-reducing and retarding admixtures as reported by L.H. Tuthill et al, in the paper "Observations in Testing and Use of Water-Reducing Retarders", ASTM, STP No. 277, 1960, pp. 97-123. However, these water-reducing and retarding admixtures, although causing a slump loss, will retard the hardening of the concrete and thus are beneficial for use in the construction of the PCRV to prevent cold joints, especially during hot weather construction. Should this slump loss be observed during construction, it may be necessary to work with a concrete mix having a higher slump, perhaps up to 5 inches.

6. CONCRETE TRIAL MIXES - PHASE II(a) AND PHASE II(b)

6.1 Test Program

The test program for Phase II(a) and II(b), as given in GA Specification No. 900670, includes the following evaluation of properties of concretes for each of the two types of coarse aggregate used (Berks or York):

Phase II(a): Evaluation of properties of six concrete mixes, (three mixes for 1 1/2-in. and three mixes for 3/4-in. MSA) each having different mix proportions.

Phase II(b): Compressive strength of the six concrete mixes from Phase II(a) for both sealed and moist-cured specimens at ages of 7, 14, 28, 60 and 120 days. Six specimens to be tested at ages 28 and 60 days, and three at the other ages.

At the end of Phase I, two admixtures, Daratard 40 and Pozzolith 300R, were still under consideration for use in Phase II and III by GA. Because a definite decision between these two admixtures could not be made prior to the start of Phase II(a), it was suggested by UC to use Pozzolith 300R for the six proposed mixes of Phase II(a) and II(b) and to evaluate three additional 1 1/2-in. MSA mixes using Daratard 40, for each of the two aggregates, Berks and York. Thus, a total of eighteen mixes were evaluated in Phase II(a) and II(b), nine for each of the two aggregates, Berks and York.

Berks aggregate concretes were evaluated first using mixes having cement contents of 7.5, 8, and 8.5 scy. Moist-cured specimens were cast for all nine of the Berks aggregate mixes, G-15 to G-23, and sealed specimens for all but two of the mixes, G-19 and G-20, both containing Daratard 40.

Based on the initial compressive strength test results obtained for these Berks aggregate concretes, with the approval of GA, the following two modifications were made in the York aggregate concrete mixes G-24 to G-32: a) the cement content of the mixes was lowered to 7, 7.5 and 8 scy to decrease the 60 day compressive strengths and b) an additional set of 1 1/2-in. MSA sealed specimens was cast with Daratard 40 while eliminating one set of 1 1/2-in. MSA sealed specimens with Pozzolith 300R in order to further evaluate the trend observed for mix G-18 of higher compressive strength ratio of sealed to moist-cured specimens when using Daratard 40.

A summary of the aggregate, admixture and cement content used and specimens cast, is given in the tabulation below. Of the twenty-one 6 by 12-in. specimens cast for each sealed or moist-cured condition, three specimens were tested in compression at ages of 7 and 14 days, six at 28 and 60 days, and three at 120 days.

PHASE II(a) AND II(b) TEST PROGRAM

Aggregate	MSA, in.	Admixture	Mix Designation	Cement Content, scy	Specimens Cast	
					Sealed	Moist-Cured
Berks	1 1/2	Pozzolith 300R	G-15	7.5	21	21
			G-16	8	21	21
			G-17	8.5	21	21
	1 1/2	Daratard 40	G-19	7.5	-	21
			G-18	8	21	21
			G-20	8.5	-	21
	3/4	Pozzolith 300R	G-21	7.5	21	21
			G-22	8	21	21
			G-23	8.5	21	21
York	1 1/2	Pozzolith 300R	G-28	7	21	21
			G-24	7.5	-	21
			G-26	8	21	21
	1 1/2	Daratard 40	G-29	7	21	21
			G-25	7.5	-	21
			G-27	8	21	21
	3/4	Pozzolith 300R	G-30	7	21	21
			G-31	7.5	21	21
			G-32	8	21	21

In addition to these compressive strength tests, modulus of elasticity and Poisson's ratio was determined on three of the six specimens tested at ages of 28 and 60 days and on the three specimens tested at 120 days.

6.2 Materials

The materials used in this phase of the program included:

Cement: Medusa Type II, 2/8/73, Shipment "B"

Fine Aggregate:	Mason-Dixon sand, 3/2/73
Coarse Aggregate: (Gradation "A")	Berks 1 1/2 in. to No. 4 York 1 1/2 in. to No. 4
Admixtures:	Daratard 40, 4/12/72, 8.0 fl.oz./100 lbs of cement
	Pozzolith 300R, 8/25/72, 3.5 fl.oz./100 lbs of cement

6.3 Mix Proportions and Properties of Fresh Concrete

All mixes were proportioned to have a 4 1/2 ± 1/4-in. slump. The concrete materials were cooled after batching and ice water was used in the mix to produce a 50 ± 3 °F temperature of the freshly mixed concrete. The mix proportions and properties of fresh concretes for the Berks aggregate mixes (G-15 to G-23) are given in Table 11 and for the York aggregate mixes (G-24 to G-32) in Table 12.

A summary of the properties of the concrete mixes is given in the following tabulation:

PROPERTIES OF CONCRETE MIXES

Aggregate	MSA, in.	Admixture	Mix Designation	Cement Content, scy	W/C, Ratio by wt.	Sand Content, %	Air Content, %	Unit Weight, pcf
Berks	1 1/2	Pozzolith 300R	G-15	7.5	.393	42.0	2.8	150.4
			G-16	8	.370	41.0	2.6	151.7
			G-17	8.5	.367	40.0	2.6	151.6
	1 1/2	Daratard 40	G-19	7.5	.384	40.0	4.1	149.5
			G-18	8	.364	39.0	3.7	150.4
			G-20	8.5	.351	38.0	3.2	151.5
	3/4	Pozzolith 300R	G-21	7.5	.416	48.0	4.4	147.4
			G-22	8	.389	47.0	4.1	148.1
			G-23	8.5	.376	46.0	3.8	148.4
York	1 1/2	Pozzolith 300R	G-28	7	.414	43.0	3.3	149.5
			G-24	7.5	.399	42.0	3.2	150.0
			G-26	8	.376	41.0	3.1	150.5
	1 1/2	Daratard 40	G-29	7	.399	41.0	4.6	148.7
			G-25	7.5	.384	40.0	4.2	149.0
			G-27	8	.374	39.0	4.5	149.2
	3/4	Pozzolith 300R	G-30	7	.431	49.0	4.8	146.1
			G-31	7.5	.413	48.0	4.6	146.9
			G-32	8	.392	47.0	4.3	147.9

As shown in the above tabulation, Daratard 40 entrained a larger amount of air than Pozzolith 300R. The larger percentage of air is beneficial to the workability of the mix but will have a slightly adverse effect on strength. However, since the sand content of the Daratard 40 mixes was reduced by 2 percent of total aggregate weight, the required amount of mix water is also reduced, thus offsetting the small potential loss of strength due to higher air content.

6.4 Properties of Hardened Concrete

The properties of hardened concrete, including compressive strength, modulus of elasticity and Poisson's ratio were determined on 6 by 12-in. concrete cylinders which were either sealed or moist-cured up to the age of test. As shown earlier in this report, under Section 6.1 Test Program, moist-cured specimens were cast and tested for all of the 18 concrete mixes but sealed specimens for only 14 of these mixes.

6.4.1 Compressive Strength.--Compressive strength of the concrete was determined at ages of 7, 14, 28, 60 and 120 days, using three specimens at 7, 14 and 120 days and six specimens at 28 and 60 days.

Results of the compressive strength tests for the Berks aggregate concretes are given in Tables 13, 14 and 15. Table 13 gives results for the 1 1/2-in. MSA concretes containing Pozzolith 300R, Table 14 for 1 1/2-in. MSA concretes with Daratard 40, and Table 15 for concretes made with 3/4-in. MSA containing Pozzolith 300R.

Results of the compressive strength tests for the York aggregate concretes are given in Table 16, 17 and 18. Table 16 gives results for the 1 1/2-in. MSA concretes containing Pozzolith 300R, Table 17 for 1 1/2-in. MSA concretes with Daratard 40, and Table 18 for concretes made with 3/4-in. MSA containing Pozzolith 300R.

The purpose of this series of strength tests was to develop sufficient information for the selection of the concrete mixes which are to be used in Phase II(c), and Phase III of the test program. According to GA requirements, these selected concrete mixes are to attain a 60-day compressive strength of 7700 psi as determermiend on moist-cured specimens. A summary of the 60-day compressive strength results obtained is given in the following tabulation:

60-DAY COMPRESSIVE STRENGTHS

Aggregate	MSA, in.	Admixture	Mix Designation	Cement Content, scy	60-Day Compressive Strength, psi	
					Sealed	Moist-Cured
Berks	1 1/2	Pozzolith 300R	G-15	7.5	7030	7780
			G-16	8	7210	8210
			G-17	8.5	7520	8430
	1 1/2	Daratard 40	G-19	7.5	...	8190
			G-18	8	7700	8350
			G-20	8.5	...	8470
	3/4	Pozzolith 300R	G-21	7.5	7260	7980
			G-22	8	7570	8240
			G-23	8.5	7970	8510
York	1 1/2	Pozzolith 300R	G-28	7	6940	7840
			G-24	7.5	...	8010
			G-26	8	7530	8530
	1 1/2	Daratard 40	G-29	7	7390	7940
			G-25	7.5	...	7990
			G-27	8	7540	8120
	3/4	Pozzolith 300R	G-30	7	6750	7460
			G-31	7.5	7110	7720
			G-32	8	7460	8180

The above tabulated results show that for the moist-cured specimens, seventeen of the eighteen mixes tested yielded compressive strengths higher than the required 7700 psi. The single low value of 7460 psi was obtained for the York 3/4-in. MSA concrete (Mix G-30) containing Pozzolith 300R.

It appeared that in order to satisfy the 7700 psi 60-day strength requirement of a concrete made with either Berks or York aggregate and containing either Pozzolith 300R or Daratard 40, the selected mixes for Phase II(c), and Phase III of the test program should have a cement content of about 7.5 scy.

6.4.2 Elastic Properties.--Modulus of elasticity and Poisson's ratio were determined on three of the six specimens tested at ages 28 and 60 days and the three specimens tested at age 120 days, for both the sealed and moist-cured conditions. The values of these elastic properties of the concretes are shown along with the compressive strength data in Tables 13 to 15 for the Berks aggregate mixes and in Table 16 to 18 for the York aggregate mixes.

The values of the Poisson's ratio for all concretes tested were on the average between 0.20 to 0.23, with the 1 1/2-in. MSA concretes having a slightly higher value than the 3/4-in. MSA concretes.

The values of modulus of elasticity obtained for the 1 1/2-in. MSA moist-cured concretes are summarized in the following tabulation.

MODULUS OF ELASTICITY OF 1 1/2-in. MSA MOIST-CURED CONCRETES

Age, Days	Aggregate	Admixture	Modulus of Elasticity, psi x 10^6 Nominal Cement Content, scy			
			7	7.5	8	8.5
28	Berks	Pozzolith 300R	...	6.2	6.1	6.3
		Daratard 40	...	6.2	6.3	6.3
	York	Pozzolith 300R	5.8	5.9	6.0	...
		Daratard 40	5.7	6.0	6.0	...
60	Berks	Pozzolith 300R	...	6.3	6.3	6.4
		Daratard 40	...	6.3	6.5	6.6
	York	Pozzolith 300R	6.2	6.2	6.3	...
		Daratard 40	6.4	6.2	6.3	...
120	Berks	Pozzolith 300R	...	6.5	6.8	6.7
		Daratard 40	...	6.6	6.6	6.8
	York	Pozzolith 300R	6.3	6.5	6.4	...
		Daratard 40	6.3	6.3	6.5	...

These results show that the modulus of elasticity increased with increase in the cement content and with age. In general, the modulus of elasticity of the Berks aggregate concretes was slightly higher than that of the York aggregate concretes.

The modulus of elasticity of the 3/4-in. MSA moist-cured concretes are summarized in the following tabulation.

MODULUS OF ELASTICITY OF 3/4-in. MSA MOIST-CURED CONCRETES*

Age, Days	Aggregate	Modulus of Elasticity, psi x 10^6 — Nominal Cement Content, scy			
		7	7.5	8	8.5
28	Berks	...	5.6	5.7	5.7
	York	5.4	5.3	5.6	...
60	Berks	...	5.8	5.9	5.8
	York	5.6	5.8	5.9	...
120	Berks	...	6.1	6.2	6.0
	York	6.0	5.9	6.0	...

*All concretes contained Pozzolith 300R.

These results show that the modulus of elasticity of the 3/4-in. MSA concretes are on the average about 0.5 x 10^6 psi lower than those of the corresponding 1 1/2-in. MSA concretes.

An evaluation of the data obtained for the sealed concrete specimens shows that their modulus is lower by 0.1 to 0.2 x 10^6 psi than that of the corresponding moist-cured concrete. This is to be expected since the compressive strength of these sealed specimens is lower than that of moist-cured concretes.

6.5 Effect of Sealing on Compressive Strength

The compressive strength of sealed specimens is lower than that of the corresponding moist-cured specimens, with the difference being larger at later ages. These differences in strength were computed for each aggregate, admixture and MSA combination used, and are given in the six tabulations shown on the following pages. It will be noted from this tabulated data that at ages 7 and 14 days the average percentage differences ranged from 0 to 3 percent and from 2 to 7 percent, respectively. At the later ages of 28, 60 and 120 days the magnitudes of these differences were larger. These later age results are discussed in the following sections 6.5.1 and 6.5.2 for the Berks and York aggregate concretes, respectively.

6.5.1 Berks Aggregate Concretes.--The effect of sealing on compressive strength of the Berks concretes were evaluated for the following three groups of mixes: a) 1 1/2-in. MSA with Pozzolith 300R, b) 1 1/2-in. MSA with Daratard 40, and c) 3/4-in. MSA with Pozzolith 300R. Results are given below:

a) Berks 1 1/2-in. MSA Concretes with Pozzolith 300R.--Sealed specimens cast from mixes G-15 to G-17 containing 1 1/2-in. MSA using Pozzolith 300R have on the average a 28, 60 and 120-day compressive strength that is 10 to 12% lower than that of moist-cured specimens.

EFFECT OF SEALING - BERKS 1 1/2-in. MSA, POZZOLITH 300R

Age,	Compressive Strength, psi									
	7.5 scy (G-15)			8 scy (G-16)			8.5 scy (G-17)			Average
days	Sealed	Moist	M/S	Sealed	Moist	M/S	Sealed	Moist	M/S	M/S
7	4670	4910	105%	5070	5270	104%	5290	5350	101%	103%
14	5700	6140	108%	6000	6340	106%	6060	6560	108%	107%
28	6360	7100	112%	6640	7300	110%	6920	7380	107%	110%
60	7030	7780	111%	7210	8210	114%	7520	8430	112%	112%
120	7600	8440	111%	8040	8880	110%	8000	8980	112%	111%

b) Berks 1 1/2-in. MSA Concrete with Daratard 40.--The sealed specimens cast from mix G-18 containing 1 1/-in. MSA and Daratard 40 have on the average a 28, 60 and 120-day compressive strength that is 6 to 8% lower than that of the moist-cured specimens.

EFFECT OF SEALING - BERKS 1 1/2-in. MSA, DARATARD 40

Age,	Compressive Strength, psi		
	8 scy (G-18)		
days	Sealed	Moist	M/S
7	5110	5110	100%
14	6050	6160	102%
28	6850	7300	107%
60	7700	8350	108%
120	8400	8940	106%

c) Berks 3/4-in. MSA Concretes with Pozzolith 300R.--Sealed specimens cast from mixes G-21 to G-23, containing 3/4-in. MSA with Pozzolith 300R have on the average a 28, 60 and 120-day compressive strength that is 8 to 9% lower than that of moist-cured specimens.

EFFECT OF SEALING - BERKS 3/4-in. MSA, POZZOLITH 300R

Age,	Compressive Strength, psi									
	7.5 scy (G-21)			8 scy (G-22)			8.5 scy (G-23)			Average
days	Sealed	Moist	M/S	Sealed	Moist	M/S	Sealed	Moist	M/S	M/S
7	4640	4670	101%	5030	5220	104%	5320	5380	101%	102%
14	5560	6000	108%	5920	6390	108%	6310	6420	102%	106%
28	6400	7030	110%	6890	7290	106%	6950	7510	108%	108%
60	7260	7980	110%	7570	8240	109%	7970	8510	107%	109%
120	7760	8470	109%	8150	8790	108%	8390	9060	108%	108%

6.5.2 York Aggregate Concretes.--The effect of sealing on compressive strength of the York concretes were evaluated for the following three groups: a) York 1 1/2-in. MSA concretes with Pozzolith 300R, b) York 1 1/2-in. MSA concretes with Daratard 40,and c) York 3/4-in. MSA concretes with Pozzolith 300R.

a) York 1 1/2-in. MSA Concretes with Pozzolith 300R.--Sealed specimens cast from mixes G-26 and G-28, containing 1 1/2-in. MSA with Pozzolith 300R have on the average a 28, 60 and 120-day compressive strength that is 9 to 13% lower than that of moist-cured specimens.

EFFECT OF SEALING - YORK 1 1/2-in. MSA, POZZOLITH 300R

Age,	Compressive Strength, psi						
	7 scy (G-28)			8 scy (G-26)			Average
days	Sealed	Moist	M/S	Sealed	Moist	M/S	M/S
7	4590	4700	102%	5370	5330	99%	101%
14	5580	5890	106%	6090	6570	108%	107%
28	6400	7120	111%	7040	7520	107%	109%
60	6940	7840	113%	7530	8530	113%	113%
120	7570	8220	109%	8220	9150	111%	110%

b) York 1 1/2-in. MSA Concretes with Daratard 40.--Sealed specimens cast from mixes G-27 and G-29, containing 1 1/2-in. MSA with Daratard 40, have on the average a 28, 60 and 120-day compressive strength that is 7 to 8% lower than that of moist-cured specimens.

EFFECT OF SEALING - YORK 1 1/2-in. MSA, DARATARD 40

Age,	Compressive Strength, psi						
	7 scy (G-29)			8 scy (G-27)			Average
days	Sealed	Moist	M/S	Sealed	Moist	M/S	M/S
7	5000	5140	103%	5370	5460	102%	103%
14	6040	6240	103%	6250	6530	105%	104%
28	6760	7280	108%	7170	7540	105%	107%
60	7390	7940	107%	7540	8120	108%	108%
120	8010	8530	106%	8300	8950	108%	107%

c) York 3/4-in. MSA Concretes with Pozzolith 300R.--Sealed specimen cast from mixes G-30 to G-32, containing 3/4-in. MSA with Pozzolith 300R have on the average a 28, 60 and 120-day compressive strength that is 8 to 10% lower than that that of moist-cured specimens.

EFFECT OF SEALING - YORK 3/4-in. MSA, POZZOLITH 300R

Age,	Compressive Strength, psi									
	7 scy (G-30)			7.5 scy (G-31)			8 scy (G-32)			Average
days	Sealed	Moist	M/S	Sealed	Moist	M/S	Sealed	Moist	M/S	M/S
7	4450	4520	102%	4770	4830	101%	5140	5340	104%	102%
14	5340	5760	108%	5740	6000	105%	6010	6550	109%	107%
28	6120	6790	111%	6460	6950	108%	6690	7460	112%	110%
60	6750	7460	111%	7110	7720	109%	7460	8180	110%	110%
120	7490	7990	107%	7460	8180	110%	8310	8930	107%	108%

6.5.3 Discussion of Influence of Admixtures.--In summary, sealed specimens containing either Berks or York 1 1/2-in. MSA and Pozzolith 300R have on the average a 28, 60 and 120-day compressive strength that is 8 to 13% lower than that of moist-cured specimens. However, concrete specimens with Daratard 40 have on the average a compressive strength that is only 6 to 8% lower than that for moist-cured specimens. It appears from these data that sealed specimens with Daratard 40 have a 3 to 5% advantage in strength over those containing Pozzolith 300R. Sealed specimens with 3/4-in. MSA, all using Pozzolith 300R, have on the average a compressive strength that is from 8 to 10% lower than that for moist-cured specimens, which is a slightly smaller difference than that observed from specimens with 1 1/2-in. MSA.

6.6 Effect of Admixtures on Compressive Strength

In making an evaluation of the effectiveness of Daratard 40 and Pozzolith 300R it should be noted that the mix proportions differed between mixes when Daratard 40 and Pozzolith 300R was used, and therefore any comparison made between admixtures are in effect comparisons for slightly different mixes designed to give similar results; i.e. the same workability, slump and compressive strength. The comparison is more a reflection on how the mixes compare as a whole, rather than the particular use of either admixture. The workability of the mixes was judged to be equal, the slumps obtained similar, but the air content of Daratard 40 mixes is slightly higher. The compressive strength results obtained for mixes with Daratard 40 and Pozzolith 300R are compared in the following two tabulations:

EFFECT OF ADMIXTURE ON BERKS 1 1/2-in. MSA MIXES

Age	Compressive Strength, psi								
	7.5 scy			8 scy			8.5 scy		
days	Pozz G-15	Dar G-19	Dar/Pozz	Pozz G-16	Dar G-18	Dar/Pozz	Pozz G-17	Dar G-20	Dar/Pozz
a) Moist-Cured									
7	4910	4930	100%	5270	5110	97%	5350	5330	100%
14	6140	6240	102%	6340	6160	97%	6560	6500	99%
28	7100	7310	103%	7300	7300	100%	7380	7620	103%
60	7780	8190	105%	8210	8350	102%	8430	8470	100%
120	8440	8540	101%	8880	8940	101%	8980	8970	100%
b) Sealed									
7	No sealed specimens for mixes G-15 and G-19			5070	5110	101%	No sealed specimens for mixes G-17 and G-20		
14				6000	6050	101%			
28				6640	6850	103%			
60				7210	7700	106%			
120				8040	8400	104%			

Note: Dar = Daratard 40, Pozz = Pozzolith 300R

EFFECT OF ADMIXTURE ON YORK 1 1/2-in. MSA MIXES

Compressive Strength, psi

Age, days	7 scy Pozz G-28	7 scy Dar G-29	7 scy Dar/Pozz	7.5 scy Pozz G-24	7.5 scy Dar G-25	7.5 scy Dar/Pozz	8 scy Pozz G-26	8 scy Dar G-27	8 scy Dar/Pozz
a) Moist-Cured									
7	4700	5140	109%	5040	4990	99%	5330	5460	102%
14	5890	6240	106%	6110	6130	100%	6570	6530	99%
28	7120	7280	102%	7210	7050	98%	7520	7540	100%
60	7840	7940	101%	8010	7990	100%	8530	8120	95%
120	8220	8530	104%	8490	8610	101%	9150	8950	98%
b) Sealed									
7	4590	5000	109%	No sealed specimens for mixes G-25 and 24			5370	5370	100%
14	5580	6040	108%				6090	6250	103%
28	6400	6760	106%				7040	7170	102%
60	6940	7390	106%				7530	7540	100%
120	7570	8010	106%				8220	8300	101%

Note: Dar = Daratard 40, Pozz = Pozzolith 300R

For the same nominal cement content, the mixes as designed appear to give similar compressive strengths when using Pozzolith 300R or Daratard 40. In averaging all strengths of moist-cured specimens, at all ages, a 1% higher compressive strength was obtained for mixes proportioned for use with Daratard 40. For sealed specimens, the overall average is 3 to 4% in favor of the Daratard 40 mixes.

6.7 Effect of Aggregate Type on Compressive Strength

In the following tabulations comparisons are made of compressive strengths of the 7.5 and 8 scy concrete mixes made with York and Berks coarse aggregates of different MSA and admixture combinations used in this test program.

EFFECT OF AGGREGATE ON COMPRESSIVE STRENGTH

a) 1 1/2-in. MSA-Pozzolith 300R

Age, days	Moist-Cured, 7.5 scy, Berks G-15	Moist-Cured, 7.5 scy, York G-24	Moist-Cured, 7.5 scy, York/Berks	Moist-Cured, 8 scy, Berks G-16	Moist-Cured, 8 scy, York G-26	Moist-Cured, 8 scy, York/Berks	Sealed, 8 scy, Berks G-16	Sealed, 8 scy, York G-26	Sealed, 8 scy, York/Berks
7	4910	5040	103%	5270	5330	101%	5070	5370	106%
14	6140	6110	99%	6340	6570	104%	6000	6090	102%
28	7100	7210	102%	7300	7520	103%	6640	7040	106%
60	7780	8010	103%	8210	8530	104%	7210	7530	104%
120	8440	8490	101%	8880	9150	103%	8040	8220	102%

Compressive Strength, psi

b) 1 1/2-in. MSA - Daratard 40

Age, days	Moist-Cured, 7.5 scy, Berks G-19	Moist-Cured, 7.5 scy, York G-25	Moist-Cured, 7.5 scy, York/Berks	Moist-Cured, 8 scy, Berks G-18	Moist-Cured, 8 scy, York G-27	Moist-Cured, 8 scy, York/Berks	Sealed, 8 scy, Berks G-18	Sealed, 8 scy, York G-27	Sealed, 8 scy, York/Berks
7	4930	4990	101%	5110	5460	107%	5110	5370	105%
14	6240	6130	98%	6160	6530	106%	6050	6250	103%
28	7310	7050	96%	7300	7540	103%	6850	7170	105%
60	8190	7990	98%	8350	8120	97%	7700	7540	98%
120	8540	8610	101%	8940	8950	100%	8400	8300	99%

Compressive Strength, psi

c) 3/4-in. MSA - Pozzolith 300R

Age, days	Moist-Cured, 7.5 scy, Berks G-21	Moist-Cured, 7.5 scy, York G-31	Moist-Cured, 7.5 scy, York/Berks	Moist-Cured, 8 scy, Berks G-22	Moist-Cured, 8 scy, York G-32	Moist-Cured, 8 scy, York/Berks	Sealed, 7.5 scy, Berks G-21	Sealed, 7.5 scy, York G-31	Sealed, 7.5 scy, York/Berks	Sealed, 8 scy, Berks G-22	Sealed, 8 scy, York G-32	Sealed, 8 scy, York/Berks
7	4670	4830	103%	5220	5340	102%	4640	4770	103%	5030	5140	102%
14	6000	6000	100%	6390	6550	103%	5560	5740	103%	5920	6010	102%
28	7030	6950	99%	7290	7460	102%	6400	6460	101%	6890	6690	97%
60	7980	7720	97%	8240	8180	99%	7260	7110	98%	7570	7460	99%
120	8470	8180	97%	8790	8930	102%	7760	7460	96%	8150	8310	102%

Compressive Strength, psi

The above data indicate that the differences in compressive strength obtained for Berks and York concretes are small enough that either Berks or York is a satisfactory aggregate that could produce concretes having the desired strength level specified for the construction of the PCRV's.

6.8 Effect of MSA on Compressive Strength

The compressive strengths obtained for concretes with either the 1 1/2-in. or 3/4-in. MSA Berks and York mixes are compared in the following tabulations:

EFFECT OF BERKS MSA ON COMPRESSIVE STRENGTH

Age, days	Compressive Strength, psi								
	7.5 scy			8 scy			8.5 scy		
	3/4 G-21	1 1/2 G-15	1 1/2 / 3/4	3/4 G-22	1 1/2 G-16	1 1/2 / 3/4	3/4 G-23	1 1/2 G-17	1 1/2 / 3/4
a) Moist-Cured									
7	4670	4910	105%	5220	5270	101%	5380	5350	99%
14	6000	6140	102%	6390	6340	99%	6420	6560	102%
28	7030	7100	101%	7290	7300	100%	7510	7380	98%
60	7980	7780	97%	8240	8210	100%	8510	8430	99%
120	8470	8440	100%	8790	8880	101%	9060	8980	99%
b) Sealed									
7	4640	4670	101%	5030	5070	101%	5320	5290	99%
14	5560	5700	103%	5920	6000	101%	6310	6060	96%
28	6400	6360	99%	6890	6640	96%	6950	6920	100%
60	7260	7030	97%	7570	7210	95%	7970	7520	94%
120	7760	7600	98%	8150	8040	99%	8390	8000	95%

EFFECT OF YORK MSA ON COMPRESSIVE STRENGTH

Age, days	7 scy 3/4 G-30	7 scy 1 1/2 G-28	7 scy 1 1/2 / 3/4	7.5 scy 3/4 G-31	7.5 scy 1 1/2 G-24	7.5 scy 1 1/2 / 3/4	8 scy 3/4 G-32	8 scy 1 1/2 G-26	8 scy 1 1/2 / 3/4
a) Moist-Cured									
7	4520	4700	104%	4830	5040	104%	5340	5330	100%
14	5760	5890	102%	6000	6110	102%	6550	6570	100%
28	6790	7120	105%	6950	7210	104%	7460	7520	101%
60	7460	7840	105%	7720	8010	104%	8180	8530	104%
120	7990	8220	103%	8180	8490	104%	8930	9150	102%
b) Sealed									
7	4450	4590	103%	No sealed specimens for mix G-24.			5140	5370	104%
14	5340	5580	104%				6010	6090	101%
28	6120	6400	105%				6690	7040	105%
60	6750	6940	103%				7460	7530	101%
120	7490	7570	101%				8310	8220	99%

Compressive Strength, psi

The above data show that the MSA has little effect on the strength of the Berks aggregate concretes. For the York aggregate mixes the concretes made with 1 1/2-in. MSA have a slightly higher compressive strength than those of the corresponding 3/4-in. MSA mixes. Based on these results it may be concluded that for the mix proportions used, about the same compressive strengths can be acheived when using either 3/4-in. or 1 1/2-in. MSA in concrete mixes of the same cement content.

7. SELECTED CONCRETE MIXES - PHASE II(c)

7.1 Test Program

The test program of Phase II(c) was to evaluate the fresh and hardened properties of two selected concrete mixes, a Berks and a York 1 1/2-in. MSA concrete. These two mixes were then to be used in the test program of Phase III. The properties of hardened concrete determined on both moist-cured and sealed specimens included a) compressive strength at ages of 7, 28, 60, 90, 120, 180, 270, 365 and 730 days, b) tensile strength at ages of 7, 28, 60, 90, 180, 270 and 730 days, and c) modulus of elasticity and Poisson's ratio of the compression specimens at ages of 28, 60, 90, 270 and 730 days.

Also evaluated in this Phase II(c) was the effect of slump (approx. 2-in. and 8-in.) on compressive strength of the Berks and York 1 1/2-in. MSA concretes. Specimens for this evaluation were cast on the same day as the strength specimens of the corresponding selected mixes (Berks or York). Six 6 by 12-in. specimens were cast for each slump, with three specimens each tested after 28 and 60 days of moist curing.

7.1.1 Selection of Mixes--Based on the results obtained from concrete trial mixes of Phase I, II(a) and II(b), a selected mix for each aggregate, Berks and York, was to be chosen by GA for evaluation in this Phase II(c) of the test program. The selected mix proportions chosen for the Berks 1 1/2-in. MSA concrete were those of mix G-19, a 7.5 scy concrete mix containing Daratard 40 which, as determined earlier in Phase II(b), had a 60-day compressive strength of 8190 psi for moist-cured specimens. The initially selected mix used for the York 1 1/2-in. MSA concrete had the proportions of mix G-25, a 7.5 scy concrete mix with Daratard 40 which, as determined in Phase II(b), had a 60-day compressive strength of 7990 psi. However, the 60-day compressive strength of the concrete specimens cast for Phase II(c) with these two mixes were lower (7400 psi for Berks G-19 and 7210 psi for York G-25) than those obtained in Phase II(b), due to use of a blend of the two shipments ("A" and "B") of Medusa Type II cement. After review of these test results with GA, it was agreed to use a higher cement content for the York aggregate concrete for the casting of the Phase III creep specimens. The mix selected had the proportions of mix G-26, an 8 scy concrete mix with Pozzolith 300R, and compressive strength specimens were cast and tested at ages 7, 28, 60, 90, 270, 365 and 730 days.

7.2 Materials

The following materials were used for the selected mixes:

Cement:	Medusa Type II, Blend of Shipment "A" and "B"
Fine Aggregate:	Mason-Dixon sand, Blend of 11/16/72, 3/2/73 and 10/4/73 shipments

Berks Selected Mix G-19

Coarse Aggregate:	Berks 1 1/2 in. to No. 4, Gradation "B"
Admixture:	Daratard 40, 4/27/73, 8.0 fl.oz./100 lbs. of cement

York Mix G-25

Coarse Aggregate: York 1 1/2 in. to No. 4, Gradation "B"

Admixture: Daratard 40, 4/27/73, 8.0 fl.oz./100 lbs. of cement

York Selected Mix G-26

Coarse Aggregate: York 1 1/2 in. to No. 4, Gradation "B"

Admixture: Pozzolith 300R, 4/9/73, 3.5 fl.oz./100 lbs. of cement

7.3 Mix Proportions and Properties of Fresh Concrete

The mix proportions and properties of fresh concrete of the three concrete mixes - Berks G-19, York G-25, and York G-26 - as obtained in Phase II(a), II(b) and the average values for Phase II(c) and III are given in Table 19. A comparison of the mix proportions and properties of the two mixes selected for use in the Phase III creep study, Berks G-19 and York G-26, is made in the following tabulation:

MIX PROPORTIONS AND PROPERTIES OF SELECTED MIXES

	Berks Mix G-19		York Mix G-26	
	Phase		Phase	
	II(a)	II(c)&III	II(a)	II(c)&III
1. Mix Proportions, lbs/cy				
Cement, Medusa Type II*	706	706	750	756
Water (Incl. Admixture)	271	269	282	290
Sand, Mason-Dixon	1224	1224	1243	1249
C.A., 3/4 in. to No. 4	887	887	989	993
C.A., 1 1/2 to 3/4 in.	949	952	800	804
Total	4037	4038	4064	4092
Admixture	Daratard 40 8.0 fl.oz./100 lbs		Pozzolith 300R 3.5 fl.oz./100 lbs	
2. Properties of Fresh Concrete				
Cement Content, scy	7.5	7.5	8.0	8.0
Water-Cement Ratio, by wt.	0.384	0.381	0.376	0.384
Slump, in.	4 3/4	4 1/2	4 5/8	4 1/2
Air Content, %	4.1	4.5	3.1	2.2
Temperature, °F	49	50	50	50
Unit Weight, pcf	149.5	149.6	150.5	151.6
Sand Content, % by wt	40	40	41	41

*Cement used in Phase II(a) was shipment "B" and that used in Phase II(c) and III was a 1:1 blend of shipment "A" and "B" Medusa Type II cement.

As can be seen in the above tabulation, there are no significant differences in the mix proportions developed in Phase II(a) in which shipment "B" Medusa cement was used, and the proportions and properties obtained for the mixes of Phase II(c) and III using the 1:1 blend of shipment "A" and "B" Medusa cement. The workability of all these concrete mixes was judged to be very good.

7.4 Properties of Hardened Concrete

The compressive strength, splitting tensile strength and elastic properties of Phase II(c) specimens were determined on 6 by 12-in. concrete cylinders which were sealed or moist-cured up to age of test. Three specimens were tested at 73°F at each age for each test condition described in section 7.1.

The values of compressive strength, modulus of elasticity, Poisson's ratio, splitting tensile strength and percentage of coarse aggregate fractured for both the moist-cured and sealed 6 by 12-in. concrete specimens are given in Table 20 for the Berks G-19 concrete and in Table 21 for the York G-25 concrete. Compressive strengths for York G-26 concrete are given in Table 22.

7.4.1 Compressive Strength.--The compressive strength results up to age 730 days of the Phase II(c) specimens are summarized in the following tabulation:

COMPRESSIVE STRENGTH OF PHASE II(c) CONCRETES, PSI

	Sealed			Moist-Cured		
	7.5 scy Daratard 40		8 scy Pozzolith 300R	7.5 scy Daratard 40		8 scy Pozzolith 300R
Age, days	Berks G-19*	York G-25	York G-26*	Berks G-19*	York G-25	York G-26*
7	5230	4730	...	5230	4730	5060
28	6590	6280	6280	6560	6570	6660
60	7180	6820	6780	7400	7210	7620
90	7510	7180	7200	7960	7630	8030
180	7790	7600	...	8200	8190	...
270	8220	7730	8200	8430	8430	8900
365	8400	8080	...	8850	8680	9130
730			...			

* Selected mixes for casting of Phase III creep specimens

Whereas all of the moist-cured specimens cast from the three mixes (G-19, G-25 and G-26) in Phase II(b) with shipment "B" Medusa cement exceeded the desired strength level of 7700 psi at age 60 days, none of the moist-cured specimens cast with the 1:1 blend of shipment "A" and "B" Medusa cement using the same three mixes, met this strength requirement. The effects of using either shipment "B" or the blend of shipments "A" and "B" on compressive strength is discussed in the following section.

7.4.2 Effect of Shipment "A" and "B" Medusa Cement on Strength--When comparing the relative compressive strengths of mortar cubes and of concrete specimens cast with shipment "B" cement with those cast with the 1:1 blend of shipment "A" and "B" cement, it appears that for the test ages available, the differences in strength can be explained primarily by the effect of using different shipments of cement. A summary of the mortar cube strengths and of the concrete strengths is given in the following tabulation:

COMPRESSIVE STRENGTHS OF MORTARS AND CONCRETES CAST WITH EITHER THE 1:1 BLEND OF SHIPMENT "A" AND "B" OR WITH ONLY THE SHIPMENT "B" OF MEDUSA CEMENT

Age, days	Cement Shipment	Compressive Strength, psi and (A+B)/B, %			
		Morter Cubes ASTM C 109	Berks G-19	York G-25	York G-26
7	A+B	2890	5230	4730	5060
	B	2790	4930	4990	5330
	$\frac{A+B}{B}$, %	104	106	95	95
28	A+B	4180	6560	6570	6660
	B	4370	7310	7050	7520
	$\frac{A+B}{B}$, %	96	90	93	89
60	A+B	4660	7400	7210	7620
	B	5100	8190	7990	8530
	$\frac{A+B}{B}$, %	91	90	90	89

The relative strength of mortar cubes cast from the two different cements is quite similar to the relative strength of concrete specimens containing corresponding cements. Also, it should be noted that the 28 and 60-day strengths of the shipment "B" cement mixes are higher than those of corresponding mixes made with the blend of shipment "A" and "B" cement. At the time when the decision was made by UC and GA to blend the two shipments of cement and to choose the selected mixes, the only data available on these cements were the results of the tests supplied by Medusa, shown in Table 1. These results indicated differences in the cements but not to the extent experienced in this research program with the two shipments of cements received. The differences in the strength gaining characteristics of shipments "A" and "B" can be explained by differences in their composition and fineness.

7.4.3 Modulus of Elasticity.--The modulus of elasticity for the Berks and the York aggregate concretes are consistent with the results obtained in Phase II(b). The values obtained for moist-cured specimens up to age of 730 days are summarized in the following tabulation.

MODULUS OF ELASTICITY, E x 10^6 PSI, OF PHASE II(c) MOIST-CURED CONCRETES

Age,	7.5 scy Daratard 40		8 scy Pozzolith 300R
days	Berks G-19	York G-25	Berks G-26
28	6.3	6.0	6.0
60	6.3	6.0	6.1
90	6.4	6.2	6.4
270	6.5	6.1	6.3
730			

It will be noted in Tables 20, 21 and 22 that sealed specimens had a modulus of elasticity which was up to 0.2 x 10^6 psi lower than the modulus of corresponding moist-cured specimens.

7.4.4 Splitting Tensile Strength.--The splitting tensile strength up to age 730 days for the Berks and York aggregate concretes are summarized in the tabulation on the next page along with the tensile strength expressed as a percentage of the compressive strength.

SPLITTING TENSILE STRENGTH OF PHASE II(c) CONCRETES, PSI

	Sealed 7.5 scy, Daratard 40				Moist-Cured 7.5 scy, Daratard 40			
	Berks G-19		York G-25		Berks G-19		York G-25	
Age, days	Tensile Strength psi	% of Compr. Str	Tensile Strength psi	% of Compr. Str	Tensile Strength psi	% of Compr. Str	Tensile Strength psi	% of Compr. Str
7	480	9	470	10	520	10	510	11
28	645	10	550	9	550	8	610	9
60	630	9	640	9	630	9	710	10
90	630	8	680	9	690	9	700	9
180	660	8	645	8	680	8	730	9
270	715	9	760	10	730	9	760	9
730								

The tensile strength for moist-cured and sealed concretes cast from both mixes averages to be about 9 percent of the compressive strength of companion specimens. The percentage of coarse aggregate fractured for both of the mixes was about 60 percent on the average.

7.5 Effect of Slump on Properties of Concrete

The main purpose of this phase of the test program was to determine the influence of change in the water content of a concrete mix, or here referred to as effect of slump, on mix proportions, compressive strength and elastic properties. Starting with the proportions of cement and aggregates used in mix G-19 and G-25, the water content was adjusted to produce concretes with a nominal slump of 2 or 8 ($\pm$1/2) inches. The corresponding Phase II(c) mixes having a nominal slump of 5 inches were cast on the same day and used as the control condition. The resulting mix proportions, properties of fresh concrete and the compressive strength and elastic properties obtained at 28 and 60 days are given in Table 23 for the Berks G-19 concrete and in Table 24 for the York G-25 concrete. The total amount of admixture Daratard 40 used in each mix was the same for both concretes and is based on 8.0 fl.oz./100 lbs of cement for the control 5-in. slump mixes.

7.5.1 Mix Proportions.--The effect of reducing the slump from 5 to 2 inches on mix proportions was to increase the relative cement and aggregate content of the 2-in. slump concrete by 2 to 4 percent above that of the 5-in. slump concrete, and to reduce the water content by 4 to 7 percent, by weight.

When the slump was increased from 5 to 8 inches, the relative effect on mix proportions was to decrease the cement and aggregate content by only 1 to 2 percent, and to increase the water content by 4 to 8 percent.

7.5.2 Properties of Fresh Concrete.--The properties of fresh concretes obtained for the mixes having nominal slumps of 2, 5 and 8 inches, are summarized in the following tabulation:

EFFECT OF SLUMP ON PROPERTIES OF FRESH CONCRETE

	Berks G-19			York G-25		
Nominal Slump, in.	2	5	8	2	5	8
Cement, scy	7.67	7.49	7.37	7.73	7.46	7.39
Water-Cement Ratio	0.356	0.381	0.418	0.344	0.383	0.404
Air Content, %	3.6	4.7	4.7	3.1	4.9	4.9
Unit Weight, pcf	152.2	149.1	147.7	152.0	147.8	147.0
Measured Slump, in.	2	4 5/8	8	1 3/4	5	7 1/2

7.5.3 Compressive Strength and Elastic Properties.--Compressive strength, modulus of elasticity and Poisson's ratio were determined at ages 28 and 60 days on moist-cured 6 by 12-in. specimens cast from the 2, 5 and 8-in. slump concretes. The average values of compressive strength and elastic properties for the three specimens tested at each age are given in the following tabulation:

EFFECT OF SLUMP OF CONCRETE ON COMPRESSIVE STRENGTH AND MODULUS OF ELASTICITY

	Berks G-19			York G-25		
a) Nominal Slump, in.	2	5	8	2	5	8
b) Compressive Strength, psi:						
28 days	7010	6590	6010	7110	6570	6130
60 days	7640	7400	6640	7820	7210	6990
c) Modulus of Elasticity, 10^6 psi:						
28 days	6.6	6.3	6.0	6.2	6.0	5.7
60 days	6.7	6.3	6.0	6.2	6.0	5.7
d) Poisson's Ratio:						
28 days	0.20	0.20	0.20	0.22	0.22	0.22
60 days	0.21	0.21	0.22	0.22	0.22	0.22

The compressive strengths of the 2-in. slump Berks and York concretes, compared to the corresponding 5-in. slump concretes, were higher by 6 and 8 percent at age 28 days, and by 2 and 8 percent, respectively, at 60 days.

For the 8-in. slump Berks and York concretes, the compressive strengths were lower by 8 and 7 percent at age 28 days and by 10 and 3 percent respectively at 60 days, in relation to the 5-in. slump concretes. The percentage variations in strength were in general similar but opposite to the percentage variations in water content.

The modulus of elasticity increased by 0.2 to 0.3 x 10^6 psi for the 2-in. slump concretes and decreased by 0.3 x 10^6 psi for the 8-in. slump concretes in comparison to the values obtained for the corresponding 5-in. slump concretes. The change in slump had no significant effect on the Poisson's ratio of the concretes.

7.6 Discussion of Phase II(c) Results

All three concrete mixes evaluated in Phase II(c), Berks G-19, York G-25 and York G-26, had excellent workability, good cohesiveness and low bleeding characteristics. The compressive strengths of these concretes using the 1:1 blend of Medusa shipment "A" and "B" cement were lower than when using shipment "B" alone, as discussed in section 7.4.2. However, it should be noted that the concretes continue to gain in compressive strength with age and will exceed the specified strength of 7700 psi shortly after age 60 days. For example, the moist-cured Berks G-19 specimens made using the 1:1 blend of shipment "A" and "B" cement had a compressive strength of 7400 psi at age 60 days, 7960 psi at 90 days, and 8850 psi at 365 days.

The compressive strength of sealed specimens is lower than that of corresponding moist-cured specimens as shown in the following tabulation:

EFFECT OF SEALING ON COMPRESSIVE STRENGTH-PHASE II(c), PSI

Age,	7.5 scy (Berks G-19) Daratard 40			7.5 scy (York G-25) Daratard 40			8 scy (York G-26) Pozzolith 300R		
Days	Sealed	Moist	M/S	Sealed	Moist	M/S	Sealed	Moist	M/S
7	5230	5230	100%	4730	4730	100%	....	5060	....
28	6590	6560	100%	6280	6570	105%	6280	6660	106%
60	7180	7400	103%	6820	7210	106%	6780	7620	112%
90	7510	7960	106%	7180	7630	106%	7200	8030	112%
180	7790	8200	105%	7600	8190	108%	....	....	....
270	8220	8430	103%	7730	8430	109%	8200	8900	109%
365	8400	8850	105%	8080	8680	107%	....	9130	....
730							....		....

On the average, the compressive strenght of the sealed specimens, between the ages of 28 and 365 days, to the strength of corresponding moist-cured specimens was 4 percent lower for Berks G-19, 7 percent lower for York G-25, and 12 percent lower for York G-26 specimens. While the moist-cured specimens of the 8 scy York G-26 mix has higher compressive strengths than the 7.5 scy Berks G-19 and York G-25 concretes, the sealed specimens of Berks G-19 containing Daratard 40 had higher compressive strengths than the York G-25 and York G-26 concretes containing Pozzolith 300R. These results of Phase II(c) are consistent with the results observed in Phase II(a) and II(b), given in Section 6.5.

The splitting tensile strength of sealed specimens was lower than that of the corresponding moist-cured specimens as shown in the following tabulation:

EFFECT OF SEALING ON SPLITTING TENSILE STRENGTH-PHASE II(c), PSI

Age, Days	7.5 scy (Berks G-19) Daratard 40			7.5 scy (York G-25) Daratard 40		
	Sealed	Moist	M/S	Sealed	Moist	M/S
7	480	520	108%	470	510	109%
28	...	...	...	550	610	111%
60	630	630	100%	640	710	111%
90	630	690	110%	680	700	103%
180	660	680	103%	645	730	113%
270	715	730	102%	760	760	100%
730						

On the average, the splitting tensile strength of the sealed specimens, between the ages of 60 and 270 days, to the strength of corresponding moist-cured specimens was 4 percent lower for Berks G-19, and 7 percent lower for York G-25 concrete. These results are similar to those obtained for compressive strengths. However, because of the limited data on splitting tensile strength and variations observed within the groups of specimens tested at a given age, these data can only be used as an indication of a possible trend. The sealed specimens in the splitting tensile strength test also had on the average 5 percent less coarse aggregate fractured than did the corresponding moist-cured specimens.

In reviewing the test results for Phase II(c), the 120 day compressive strength and 28 day splitting tensile strength results for Berks G-19 appear to be inconsistent, however they are reported in Table 20.

The selected mix proportions of Berks G-19 and York G-26 using the 1:1 blend of Medusa shipment "A" and "B" cement, were used to cast the Phase III(a) and III(b) specimens which are now under test to establish the behavior of these concretes under long-term loads and elevated temperatures. The mix proportion of Berks G-19 and York G-25, also using the 1:1 blend of shipment "A" and "B" cement, were used to cast the thermal cycling specimens of Phase III(c).

8. EVALUATION OF LABORATORY QUALITY CONTROL

An evaluation was made of the laboratory quality control using the results of the compressive strength tests of Phase II(b) as the criterion. The results of the compression tests do reflect the entire concrete making and testing operation, including materials preparation, batching, mixing, casting, curing, and testing. The variation in compressive strength of individual specimens, in each group of three or six companion specimens, was computed and expressed in percent of the average strength of this group of concrete specimens. The largest percent variation of an individual specimen in each group of companion specimens is given in Table 25. It will be noted from these data that the variation of individual cylinder strengths from the mean was generally much lower than 5 percent, with only 5 values being 5 and 3 being 6 percent, out of the 160 groups of specimens tested. The largest strength variations occurred in the groups of sealed specimens. The overall average percent variation for all of the 160 groups of specimens (sealed and moist-cured) was 2.4 percent, with the average of all sealed specimens being 2.5 percent and of moist-cured specimens 2.2 percent.

Although the number of specimens tested in each age group, three or six, is not sufficient for a valid statistical analysis, the standard deviation and coefficient of variation were computed for several specimen age groups of two mixes (G-15 and G-27) which had large percent variations in individual specimen strengths. The results obtained are given in the following tabulation.

STATISTICAL ANALYSIS OF SELECTED STRENGTH RESULTS

Mix Designation	Age, days	Curing Condition	Average Strength, psi	Largest Variation in Individual Strength, percent	Standard Deviation, psi	Coefficient of Variation, percent
G-15	28	Sealed	6360	5.0	207	3.3
	60	Sealed	7030	4.6	295	4.2
	60	Moist	7780	3.1	138	1.8
G-27	7	Sealed	5370	6.0	280	5.2
	28	Moist	7540	3.3	192	2.5
	60	Moist	8120	5.0	249	3.1

As is to be expected, the above data show that in all cases the largest percent variation in compressive strength of an individual specimen is higher than the coefficient of variation for the specimens in its age group. These low percentage variations reflect the attention that is being given to quality control in carrying out this test program.

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TABLE 1 -- CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF CEMENTS

	Chemical Composition and Physical Properties	Permanente Type II-V	Medusa Type II Cement: Medusa Data "A" 9/31/72	Medusa Data "B" 2/8/73	UC Data "A" 9/31/72	UC Data "B" 2/8/73	UC Data "A+B" 1:1 Blend	GA Specification R0069
a.	Chemical Composition, %							
	C_3S	57.8	50.3	51.2	54.0	47.9	51.0*	40-50
	C_2S	23.5	22.8	22.7	19.7	27.1	23.4	...
	C_3A	4.5	5.0	6.1	4.6	2.0	3.3	0-6
	C_4AF	8.5	11.9	11.0	12.1	14.2	13.2	11-16
	Alkalies as Na_2O	0.39	0.60	0.55	0.65	0.45	0.55	0.60 max.
b.	Heat of Hydration, cal/gm							
	3-Day	...	...	...	66	...	...	...
	7-Day	58	...	...	72	67	69*	70 max.
	14-Day	...	...	...	77	...	...	...
	28-Day	71	...	...	82	76	79	...
c.	Blaine Fineness, sq. cm/gm	3050	3690	3700	3810	3620	3720*	3000-3600
d.	Compressive Strength, psi (ASTM C 109)							
	3-Day	1940	2800	2570	....	....	....	1000 min.
	7-Day	2900	3530	3370	2920	2790	2890	1600 min.
	28-Day	4250	5000	5230	4140	4370	4180	4000 min.
	60-Day	....	....	....	4440	5100	4660	....
e.	Air Content of Mortar, %	...	7.0	6.7	...	...	...	10 max.
f.	False Set, %	...	...	...	...	81	...	50% min. Penetration

* Numerical Average on Chemical Composition, Heat of Hydration and Blaine Fineness

TABLE 2 -- GRADATION AND PHYSICAL PROPERTIES OF MASON-DIXON SAND

Sieve Size	Percent Passing U.S. Standard Sieve				
	Shipment of Mason-Dixon Sand				Specification
	3/25/72	11/16/72 3/2/73	10/4/73	Blend*	GA R0068 and ASTM C 33
3/8"	100	100	100	100	100
No. 4	98	98	97	97	95-100
8	81	83	78	80	80-100
16	62	65	64	64	50-85
30	41	45	47	46	25-60
50	15	18	25	21	10-30
100	3	5	6	5	2-10
200	...	1.3	...	1.1	0-3
Fineness Modulus	3.00	2.86	2.83	2.87	2.3-3.1
Specific Gravity	2.61	2.63	2.63	2.63	
Absorption, %	0.7	0.8	0.8	0.8	

*4:2:1 Blend of Shipment 10/4/73, 3/2/73 and 11/16/72.

TABLE 3 -- PHYSICAL PROPERTIES AND GRADATION OF COARSE AGGREGATES

	Physical Properties			Percent Passing US Standard Sieve							
	Flat & Elong, %	Specific Gravity	Absorption %	2"	1 1/2"	1"	3/4"	1/2"	3/8"	No. 4	No. 8
I. No. 67 - 3/4 in. to No. 4											
A) York Shipments											
2/12/73	3	2.72	0.6	...	...	100	98	50	26	5	2
2/12/73, 2/12/73*, 11/7/73 (6:7:12)	...	2.72	0.6	...	...	100	98	40	18	3	...
B) Berks Shipments											
2/14/73	8	2.75	0.5	...	...	100	93	51	26	8	2
2/14/73, 9/20/73, 10/23/73 (7:9:6)	...	2.75	0.5	...	...	100	96	55	26	4	...
C) GA Specification R0068 and ASTM C 33	15 max.**	...	...	...	...	100	90-100	...	20-55	0-10	0-5
II. No. 4 - 1 1/2 to 3/4 in.											
A) York Shipments											
5/11/73	3	2.75	0.4	...	100	84	32	3	2	1	...
2/12/73*, 5/11/73 (14:17)	...	2.75	0.4	...	100	83	25	3	2	1	...
B) Berks Shipments											
2/14/73	4	2.77	0.4	100	99	57	9	2	1	1	...
2/14/73, 9/20/73 (7:9)	...	2.77	0.4	100	99	56	18	7	4	1	...
C) GA Specification R0068 and ASTM C 33	15 max.**	...	...	100	90-100	20-55	0-15	...	0-5	...	...
III. No. 467 - 1 1/2 in. to No. 4											
A) York Shipment 3/27/72	3	2.76	0.5	...	100	94	64	26	18	2	...
Berks Shipment 3/27/72	7	2.77	0.5	100	99	81	53	34	20	4	...
Hempt Shipment 3/27/72	12	2.73	0.4	...	100	99	78	33	13	2	...
B) York Combined Gradations											
Gradation "A" 55.3% #67 (2/12/73) 44.7% # 4 (5/11/73)				...	100	93	68	29	15	3	...
Gradation "B" 55.3% #67 (2/12/73, 2/12/73*, 11/7/73) 44.7% # 4 (2/12/73*, 5/11/73)				...	100	92	65	23	11	2	...
C) Berks Combined Gradations											
Gradation "A" 48.3% #67 (2/14/73) 51.7% # 4 (2/14/73)				100	99	78	50	25	13	4	...
Gradation "B" 48.3% #67 (2/14/73, 9/20/73, 10/23/73) 51.7% # 4 (2/14/73, 9/20/73)				100	99	77	56	30	15	2	...
D) ASTM Specification C 33 #467				100	95-100	...	35-70	...	10-3	0-5	...

* Seperated at UC from size No. 467   ** GA specification

TABLE 4--MIX PROPORTIONS AND PROPERTIES OF FRESH CONCRETE - PHASE I(a) AND I(b)

	Phase I(a)-Aggregate Evaluation			Phase I(b)-Admixture Evaluation			
	York	Berks	Hempt	None (Control)	Plastocrete D	Daratard 40	Pozzolith 300R
Date cast:	4/28/72	4/28/72	4/28/72	9/29/72	9/29/72	9/27/72	9/27/72
I. Mix Proportions, pcy							
Cement	707	706	700	703	707	710	719
Water and Admixture	279	283	281	308	289	303	301
F.A. - Mason-Dixon sand	1282	1279	1269	1282	1288	1253	1277
C.A. - 3/4 in. to No. 4	986	855	1230	986	991	964	982
C.A. - 1 1/2 to 3/4 in.	785	912	522	784	788	766	781
Total	4039	4035	4002	4063	4063	3996	4060
Admixture, fl.oz./100 lbs cement	Daratard 40, 6.4			None	2.13	6.4	3.5
II. Properties of Fresh Concrete							
Cement Content, scy	7.5	7.5	7.	7.5	7.5	7.6	7.6
Water-Cement Ratio, by wt.	0.39	0.40	0.40	0.44	0.41	0.43	0.42
Slump, in.	3 3/4	4	3 3/4	4	4	4	4 1/4
Air Content, %	3.9	4.2	4.2	2.7	3.5	4.7	4.2
Temperature, °F	73	73	73	50	50	51	50
Unit Weight, pcf	149.6	149.4	148.2	150.5	150.5	148.0	150.4
Sand Content, % by wt.	42	42	42	42	42	42	42
Bleeding, % of mix water	...	...	...	1.1	1.1	0.3	0.3
Time of Setting, hr:min							
Initial (500 psi)	...	...	...	4:33	5:48	4:39	4:57
Final (4000 psi)	...	...	...	6:05	7:17	6:06	6:30

Notes:

	Phase I(a)	Phase I(b)			
Admixture, Date Received	Daratard 40, 8/21/71	...	8/14/72	4/12/72	8/25/72
Time of Addition	With mix water	With mix water			
Cement	Permanente Type II-V	Medusa Type II, Shipment "A"(air freight)			
F.A.	Mason-Dixon, 3/25/72	Mason-Dixon, 3/25/72			
C.A. 1 1/2 in. to No. 4	York, Berks, Hempt, 3/27/72	York, 3/27/72			

TABLE 5 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE I(a) AND I(b)

Age, days	Spec. No.	Phase I(a)-Aggregate Evaluation - 7.5 scy									Phase I(b)-Admixture Evaluation - 7.5 scy			
		York			Berks			Hempt			None	Plast*	Dar*	Pozz*
		Comp psi	$Ex10^6$ psi	μ	Comp psi	$Ex10^6$ psi	μ	Comp psi	$Ex10^6$ psi	μ	Comp psi	Comp psi	Comp psi	Comp psi
	1	4750	4.8	0.20	4520	5.1	0.20	4300	4.9	0.21	4120	4570	4550	4840
7	2	4800	4.8	0.20	4420	5.1	0.20	4350	4.9	0.21	3960	4460	4730	4950
	3	4800	4.7	0.20	4390	5.0	0.20	4320	4.9	0.21	4020	4570	4500	4800
	Average	4780	4.8	0.20	4450	5.1	0.20	4320	4.9	0.21	4030	4530	4590	4860
	1										4730	5200	5210	5610
14	2	No specimens tested at age 14 days									4820	5470	5020	5680
	3										4710	5320	5250	5520
	Average										4750	5330	5160	5600
	1	6470	5.5	0.21	6150	5.7	0.22	5520	5.4	0.21	5340	5820	5810	6220
28	2	6660	5.4	0.21	6270	5.8	0.22	5470	5.4	0.22	5340	6180	5960	6030
	3	6350	5.7	0.17	6240	5.9	0.21	5790	5.7	0.22	5340	5840	5400	5990
	Average	6490	5.5	0.20	6220	5.8	0.22	5590	5.5	0.21	5340	5950	5720	6080
	1	6710	5.8	0.20	..**	...	...	6620	5.7	0.21	5990	6060	6440	6850
60	2	7240	5.8	0.20	6530	5.9	0.20	6590	5.7	0.21	5970	6310	6360	6750
	3	6730	5.8	0.21	6740	5.9	0.20	6470	5.4	0.21	5930	6400	5960	6770
	Average	6890	5.8	0.20	6640	5.9	0.20	6560	5.6	0.21	5960	6260	6250	6790

Notes: Mix proportions and properties of fresh concrete are given in Table 4.

	Phase I(a)	Phase I(b)
Admixture, Date Received	Daratard 40, 8/21/71	... 8/14/72 4/12/72 8/25/72
Time of Addition	With mix water	With mix water
Cement	Permanente Type II-V	Medusa Type II, Shipment "A" (air freight)
F.A.	Mason-Dixon, 3/25/72	Mason-Dixon, 3/25/72
C.A. 1 1/2 in. to No. 4	York, Berks, Hempt, 3/27/72	York, 3/27/72

Moist-cured 6 by 12-in. concrete cylinders

* Plast = Plastocrete - D Dar = Daratard 40, Pozz = Pozzolith 300R, ** Faulty Test

TABLE 6 -- DRYING SHRINKAGE OF CONCRETES - PHASE I(a) AND I(b)

Period of Storage at 50% R.H. and 73°F, days	Drying Shrinkage, micro-strain: Phase I(a)-Aggregate Evaluation			Phase I(b)-Admixture Evaluation			
	York	Berks	Hempt	None (Control)	Plastocrete D	Daratard 40	Pozzolith 300R
4	50	115	75	85	90	90	95
7	85	160	115	110	120	125	135
14	135	230	165	155	170	180	195
28	180	285	210	215	240	250	265
56	225	355	265	285	295	330	330
112	300	415	355	355	360	395	410
224	360	475	415	405	410	460	465
448	390	510	440	430	440	495	500

Notes: Mix proportions and properties of fresh concrete are given in Table 4.
Drying shrinkage tests performed in accordance to ASTM C 157, specimens demolded at age 1 day, water-cured at 73°F until age 28 days, and then subjected to drying in an atmosphere of 50 percent relative humidity and 73°F.

	Phase I(a)	Phase I(b)
Admixture, Date Received	Daratard 40, 8/21/71	... 8/14/72 4/12/72 8/25/72
Time of Addition	With mix water	With mix water
Cement	Permanente Type II-V	Medusa Type II, Shipment "A" (air freight)
F.A.	Mason-Dixon, 3/25/72	Mason-Dixon, 3/25/72
C.A. 1 1/2 in. to No. 4	York, Berks, Hempt, 3/27/72	York, 3/27/72

4 by 4 by 11-in. concrete prisms, Phase I(a) - average of three specimens
Phase I(b) - average of four specimens

TABLE 7 -- COEFFICIENT OF THERMAL EXPANSION OF CONCRETES - PHASE I(a)

Concrete Mix	Spec. No.	Coefficient of Thermal Expansion, per °Fx10^{-6}								
		73-90°F	90-110°F	110-135°F	135-160°F	160-135°F	135-110°F	110-90°F	90-73°F	Average
	1	6.6	6.4	5.7	5.4	5.7	5.9	6.1	5.9	
York	2	6.4	6.2	5.8	5.5	5.9	6.0	5.9	5.9	5.9
	3	6.5	6.0	5.6	5.4	5.7	5.9	5.9	5.7	
	Average	6.5	6.2	5.7	5.4	5.8	5.9	6.0	5.8	
	1	7.0	6.5	6.3	6.1	6.3	6.5	6.5	6.4	
Berks	2	6.7	6.5	6.1	5.9	6.1	6.4	6.4	6.2	6.4
	3	6.9	6.7	6.4	5.9	6.2	6.4	6.6	6.3	
	Average	6.9	6.6	6.3	6.0	6.2	6.4	6.5	6.3	
	1	6.5	6.2	5.5	5.2	5.6	5.9	6.0	5.8	
Hempt	2	6.5	6.2	5.9	5.5	5.7	6.1	6.2	6.0	6.0
	3	6.5	6.3	6.1	5.6	5.8	6.1	6.3	6.2	
	Average	6.5	6.2	5.8	5.4	5.7	6.0	6.2	6.0	

Notes: Mix proportions and properties of fresh concrete are given in Table 4.

Admixture, Date Received	Daratard 40, 8/21/71
Time of Addition	With mix water
Cement	Permanente Type II-V
F.A.	Mason-Dixon, 3/25/72
C.A. 1 1/2 in. to No. 4	York, Berks, Hempt, 3/27/72

Average of three sealed 6 by 16-in. concrete cylinders stored at 73°F for 28 days prior to thermal cycling.

TABLE 8 - MIX PROPORTIONS AND PROPERTIES OF FRESH CONCRETE - TRIAL MIXES (a), (b), (c)

	Trial Mixes (a)			Trial Mixes (b)			Trial Mixes (c)			
	G-1	G-2	G-3	G-4	G-5	G-6	G-11	G-12	G-7	G-13
Date cast:	2/14/73	2/14/73	2/14/73	3/7/73	3/7/73	3/7/73	4/9/73	4/9/73	4/9/73	4/9/73
I. <u>Mix Proportions</u>, pcy										
Cement	751	754	757	753	748	762	742	712	757	799
Water and Admixture	322	291	294	335	299	304	275	286	290	297
F.A. - Mason-Dixon sand	1232	1238	1243	1397	1389	1415	1221	1269	1248	1223
C.A. - 3/4 in. to No. 4	856	861	864	1519	1510	1538	846	882	867	849
C.A. - 1 1/2 to 3/4 in.	916	921	925	...	...	...	906	944	929	908
Total	4077	4065	4083	4004	3946	4019	3990	4093	4091	4076
Admixture, fl. oz./100 lbs cement	None (Control)	Dar* 8.0	Pozz* 3.5	None (Control)	Dar 8.0	Pozz 3.5	Dar 8.0	Pozz 3.5	Pozz 3.5	Pozz 3.5
II. <u>Properties of Fresh Concrete</u>										
Cement Content, scy	8.0	8.0	8.0	8.0	8.0	8.1	7.9	7.6	8.0	8.5
Water-Cement Ratio, by wt.	0.43	0.39	0.39	0.44	0.40	0.40	0.37	0.40	0.38	0.37
Slump, in.	4	4	5	4	4	4	5	4 3/4	4 3/4	4 5/8
Air Content, %	1.9	3.8	3.3	2.8	6.0	4.2	5.0	3.3	3.0	3.3
Temperature, °F	49	50	49	49	50	49	49	49	50	49
Unit Weight, pcf	151.0	150.6	151.2	148.3	146.1	148.9	147.8	151.6	151.5	151.0
Sand Content, % by wt.	41	41	41	48	48	48	41	41	41	41

Notes:	Trial Mixes (a)	Trial Mixes (b)	Trial Mixes (c)
Admixture, Date Received	... 4/12/72 8/25/72	... 4/12/72 8/25/72	4/12/72 8/25/72 8/25/72 8/25/72
Time of addition	With mix water	With mix water	Delayed addition
Cement, Medusa Type II	9/31/72, Shipment "A"	9/31/72, Shipment "A"	2/8/73, Shipment "B"
F.A.	Mason-Dixon, 11/16/72	Mason-Dixon, 11/16/72	Mason-Dixon, 3/2/73
C.A., Berks	1 1/2 in.to No.4, 3/27/72	3/4 in.to No.4, 3/27/72	1 1/2 in. to No. 4, Gradation "A"

*Dar = Daratard 40, Pozz = Pozzolith 300R

TABLE 9 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - TRIAL MIXES (a), (b), (c)

Age, days	Spec. No.	Trial Mixes (a)-8 scy G-1 Comp psi	G-2 Comp psi	G-3 Comp psi	Trial Mixes (b)-8 scy G-4 Comp psi	G-4 Ex10^6 psi	G-4 μ	G-5 Comp psi	G-5 Ex10^6 psi	G-5 μ	G-6 Comp psi	G-6 Ex10^6 psi	G-6 μ
	1	4370	4680	4720	4250	...	...	4360	...	...	4930	...	...
7	2	4450	4590	4460	4210	...	...	4470	...	...	5030	...	...
	3	4450	4550	4460	4230	...	...	4210	...	...	5020	...	...
	Average	4420	4610	4550	4230	...	...	4350	...	...	4990	...	...
	1	4960	5180	5230	4960	4.9	0.21	4930	4.8	0.20	6030	5.2	0.21
14	2	4840	5020	5390	5190	4.9	0.21	4960	4.8	0.21	5930	5.1	0.21
	3	4890	5040	5070	5230	5.0	0.21	5000	4.9	0.20	5820	5.2	0.21
	Average	4900	5080	5230	5120	4.9	0.21	4960	4.8	0.20	5920	5.2	0.21
	1	5570	5610	5900	5800	5.3	0.22	5500	...	...	6430	5.4	0.20
28	2	5530	5500	5840	6000	5.4	0.21	5660	...	...	6350	5.4	0.21
	3	5560	5690	5810	5880	5.3	0.21	5210	5.2	...	6460	5.4	0.21
	Average	5550	5600	5850	5890	5.3	0.21	5460	...	...	6410	5.4	0.21
	1	6280	6230	6590	6490	5.6	0.21	6160	...	...	7130	5.6	0.20
60	2	6110	5970	6590	6450	5.6	0.22	6170	...	...	7150	5.6	0.20
	3	6250	6210	6680	6290	5.5	0.20	5970	...	...	7210	5.6	0.21
	Average	6210	6140	6620	6410	5.6	0.21	6100	...	...	7160	5.6	0.20

Age, days	Spec. No.	Trial Mixes (c)-7.5, 8 or 8.5 scy G-11 (8 scy) Comp psi	G-11 Ex10^6 psi	G-11 μ	G-12 (7.5 scy) Comp psi	G-12 Ex10^6 psi	G-12 μ	G-7 (8 scy) Comp psi	G-7 Ex10^6 psi	G-7 μ	G-13 (8.5 scy) Comp psi	G-13 Ex10^6 psi	G-13 μ
	1	5160	...	...	4800	...	...	5310	...	...	5270	...	...
7	2	5070	...	...	4770	...	...	5360	...	...	5340	...	...
	3	....	...	...	....	...	...	....	...	...	....	...	...
	Average	5110	...	...	4780	...	...	5330	...	...	5300	...	...
14		No specimens tested at age 14 days											
	1	6820	6.2	0.21	6640	5.7	0.19	6970	6.1	0.24	7130	6.0	0.22
28	2	6620	6.0	0.21	6730	5.8	0.20	7020	6.1	0.22	7110	6.1	0.22
	3	....	...	...	....	...	...	....	...	...	....	...	...
	Average	6720	6.1	0.21	6680	5.8	0.20	6990	6.1	0.23	7120	6.1	0.22
	1	7610	6.2	0.22	7500	5.8	0.20	7890	6.5	0.22	7820	6.2	0.20
60	2	7200	6.4	0.22	7280	6.1	0.21	7910	6.4	0.22	7110	6.2	0.21
	3	....	...	...	....	...	...	....	...	...	....	...	...
	Average	7400	6.3	0.22	7390	6.0	0.21	7900	6.5	0.22	7760	6.2	0.21

Notes: Mix proportions and properties of fresh concrete are given in Table 8.

	- Trial Mixes (a) -	- Trial Mixes (b) -	- Trial Mixes (c) -
Admixture, Date Received	..., 4/12/72, 8/25/72	..., 4/12/72, 8/25/72	4/12/72, 8/25/72, 8/25/72, 8/25/72
Time of addition	With mix water	With mix water	Delayed addition
Cement, Medusa Type II	9/31/72, Shipment "A"	9/31/72, Shipment "A"	2/8/73, Shipment "B"
F.A.	Mason-Dixon, 11/16/72	Mason-Dixon, 11/16/72	Mason-Dixon, 3/2/73
C.A., Berks	1 1/2 in. to No. 4, 3/27/72	3/4 in. to No. 4, 3/27/72	1 1/2 in. to No. 4, Gradation "A"

Moist-cured 6 by 12-in. concrete cylinders

TABLE 10 -- EFFECT OF SAND CONTENT ON PROPERTIES OF CONCRETE

		Daratard 40 8.0 fl.oz./100 lbs.		Pozzolith 300R 3.5 fl.oz./100 lbs.		
		G-14	G-11	G-8	G-9	G-10
Date cast:		4/9/73	4/9/73	4/9/73	4/9/73	4/9/73
I. Properties of Fresh Concrete						
Sand Content, % by wt.		36	41	36	38	41
Cement Content, scy		8	8	8	8	8
Water-Cement Ratio, by wt.		0.41	0.37	0.38	0.42	0.38
Slump, in.		3	5	3	5 1/4	4 1/4
Air Content, %		3.9	5.0	2.3	2.2	3.1
Temperature, °F		51	49	53	49	48
II. Compressive Strength, psi						
Age, days	Spec. No.					
7	1	5090	5160	5250	5200	5480
	2	5200	5070	5270	5160	5450
	Average	5140	5110	5260	5180	5460
28	1	6610	6820	6930	6980	7090
	2	6580	6620	7250	7070	7530
	Average	6590	6720	7090	7020	7310
60	1	7370	7610	7530	7530	7800
	2	7520	7200	7870	7800	7950
	Average	7440	7400	7700	7660	7870

Notes:

Admixture, Date Received	4/12/72	8/25/72
Time of Addition	Delayed Addition	
Cement	Medusa Type II, 2/8/73, Shipment "B"	
F.A.	Mason-Dixon, 3/2/73	
C.A. 1 1/2 in. to No. 4	Berks, Gradation "A"	

Moist-cured 6 by 12-in. concrete cylinders

TABLE 11 -- MIX PROPORTIONS AND PROPERTIES OF FRESH CONCRETE - PHASE II(a)
BERKS AGGREGATE

	1 1/2 in. MSA Pozzolith 300R			1 1/2 in. MSA Daratard 40			3/4 in. MSA Pozzolith 300R		
	7.5 scy G-15	8 scy G-16	8.5 scy G-17	7.5 scy G-19	8 scy G-18	8.5 scy G-20	7.5 scy G-21	8 scy G-22	8.5 scy G-23
Date cast:	5/2/73	5/7/73	5/9/73	5/16/73	5/14/73	5/16/73	5/21/73	5/23/73	5/30/73
I. Mix Proportions, pcy									
Cement	707	758	803	706	756	807	702	751	796
Water and Admixture	278	281	295	271	275	283	292	292	300
F.A. - Mason-Dixon sand	1292	1253	1198	1224	1182	1140	1434	1390	1339
C.A. - 3/4 in. to No. 4	862	871	868	887	892	898	1553	1567	1571
C.A. - 1 1/2 to 3/4 in.	922	932	929	949	956	962	...	...	...
Total	4061	4095	4093	4037	4061	4090	3981	4000	4006
Admixture, fl.oz./100 lbs cement	3.5	3.5	3.5	8.0	8.0	8.0	3.5	3.5	3.5
II. Properties of Fresh Concrete									
Cement Content, scy	7.52	8.06	8.54	7.51	8.04	8.58	7.47	7.99	8.47
Water-Cement Ratio, by wt.	0.393	0.370	0.367	0.384	0.364	0.351	0.416	0.389	0.376
Slump, in.	4 3/4	4 1/4	4 1/2	4 3/4	4 1/2	4 3/8	4 1/2	4 1/2	4 1/2
Air Content, %	2.8	2.6	2.6	4.1	3.7	3.2	4.4	4.1	3.8
Temperature, °F	49	48	49	49	49	49	49	49	48
Unit Weight, pcf	150.4	151.7	151.6	149.5	150.4	151.5	147.4	148.1	148.4
Sand Content, % by wt.	42	41	40	40	39	38	48	47	46

Notes:

	1 1/2 in. MSA Pozzolith 300R	1 1/2 in. MSA Daratard 40	3/4 in. MSA Pozzolith 300R
Admixture, Date Received	8/25/72	4/12/73	8/25/72
Time of Addition	Delayed Addition	Delayed Addition	Delayed Addition
Cement, Medusa Type II	2/8/73, Shipment "B"	2/8/73, Shipment "B"	2/8/73, Shipment "B"
F.A., Mason-Dixon sand	3/2/73	3/2/73	3/2/73
C.A., Berks	Gradation "A"	Gradation "A"	3/4 in. to No. 4, 2/14/73

TABLE 12 -- MIX PROPORTIONS AND PROPERTIES OF FRESH CONCRETE - PHASE II(a)
YORK AGGREGATE

	1 1/2 in. MSA Pozzolith 300R			1 1/2 in. MSA Daratard 40			3/4 in. MSA Pozzolith 300R		
	7 scy	7.5 scy	8 scy	7 scy	7.5 scy	8 scy	7 scy	7.5 scy	8 scy
	G-28	G-24	G-26	G-29	G-25	G-27	G-30	G-31	G-32
Date cast:	7/2/73	6/25/73	6/26/73	7/2/73	6/25/73	6/26/73	7/9/73	7/9/73	7/10/73
I. Mix Proportions, pcy									
Cement	659	704	750	659	704	746	650	698	753
Water and Admixture	273	281	282	263	270	279	280	288	295
F.A. - Mason-Dixon sand	1335	1287	1243	1268	1220	1172	1477	1431	1384
C.A. - 3/4 in. to No. 4	979	982	989	1009	1012	1013	1537	1550	1560
C.A. - 1 1/2 to 3/4 in.	790	795	800	815	818	819	...	...	...
Total	4036	4049	4064	4014	4024	4029	3994	3967	3992
Admixture, fl.oz./100 lbs cement	3.5	3.5	3.5	8.0	8.0	8.0	3.5	3.5	3.5
II. Properties of Fresh Concrete									
Cement Content, scy	7.01	7.49	7.98	7.01	7.49	7.94	6.91	7.43	8.01
Water-Cement Ratio, by wt.	0.414	0.399	0.376	0.399	0.384	0.374	0.431	0.413	0.392
Slump, in.	4 1/2	4 3/4	4 5/8	4 3/8	4 3/4	4 1/2	4 1/2	4 5/8	4 1/2
Air Content, %	3.3	3.2	3.1	4.6	4.2	4.5	4.8	4.6	4.3
Temperature, °F	50	51	50	50	50	49	51	51	51
Unit Weight, pcf	149.5	150.0	150.5	148.7	149.0	149.2	146.1	146.9	147.9
Sand Content, % by wt.	43	42	41	41	40	39	49	48	47

Notes:

	1 1/2 in. MSA Pozzolith 300R	1 1/2 in. MSA Daratard 40	3/4 in. MSA Pozzolith 300R
Admixture, Date Received	8/25/72	4/12/72	8/25/72
Time of Addition	Delayed Addition	Delayed Addition	Delayed Addition
Cement, Medusa Type II	2/8/73, Shipment "B"	2/8/73, Shipment "B"	2/8/73, Shipment "B"
F.A., Mason-Dixon sand	3/2/73	3/2/73	3/2/73
C.A., York	Gradation "A"	Gradation "A"	3/4 in. to No. 4, 2/12/73

TABLE 13 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE II(b)
1 1/2 IN. BERKS MSA CONCRETE MIXES WITH POZZOLITH 300R

Age, days	Spec. No.	7.5 scy (G-15) Sealed Comp psi	Sealed $E\times10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E\times10^6$ psi	Moist-Cured μ	8 scy (G-16) Sealed Comp psi	Sealed $E\times10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E\times10^6$ psi	Moist-Cured μ	8.5 (G-17) Sealed Comp psi	Sealed $E\times10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E\times10^6$ psi	Moist-Cured μ
7	1	4760	...	...	4890	...	...	4930	...	...	5290	...	...	5360	...	...	5450	...	...
	2	4640	...	...	4930	...	...	5110	...	...	5250	...	...	5210	...	...	5180	...	...
	3	4600	...	...	4910	...	...	5160	...	...	5270	...	...	5290	...	...	5430	...	...
	Average	4670	...	...	4910	...	...	5070	...	...	5270	...	...	5290	...	...	5350	...	...
14	1	5660	...	...	6090	...	...	5860	...	...	6430	...	...	6140	...	...	6570	...	...
	2	5790	...	...	6140	...	...	5930	...	...	6140	...	...	5840	...	...	6550	...	...
	3	5640	...	...	6180	...	...	6200	...	...	6450	...	...	6210	...	...	6570	...	...
	Average	5700	...	...	6140	...	...	6000	...	...	6340	...	...	6060	...	...	6560	...	...
28	1	6230	6.0	0.23	7120	6.2	0.22	6550	5.8	0.19	7180	6.1	0.21	7090	6.1	0.23	7500	6.3	0.23
	2	6680	6.0	0.23	7160	6.1	0.23	6590	6.0	0.23	7120	6.0	0.21	6800	6.1	0.22	7430	6.1	0.22
	3	6390	6.1	0.23	7090	6.2	0.23	6770	5.9	0.20	7370	6.3	0.21	7160	6.0	0.21	7410	6.4	0.22
	4	6500	...	...	6960	...	...	6570	...	...	7520	...	...	6610	6.1	0.22	7360	...	...
	5	6250	...	...	7110	...	...	6550	...	...	7280	6.1	0.22	6750	...	...	7110	...	...
	6	6110	...	...	7180	...	...	6840	...	...	7360	...	...	7110	...	...	7500	...	...
	Average	6360	6.0	0.23	7100	6.2	0.23	6640	5.9	0.21	7300	6.1	0.21	6920	6.1	0.22	7380	6.3	0.22
60	1	6710	6.0	0.22	7800	6.4	0.22	7200	6.1	0.22	8230	6.4	0.22	7570	6.3	0.22	8540	6.5	0.22
	2	7320	6.1	0.22	7950	6.3	0.22	7320	6.3	0.22	8210	6.2	0.22	7460	6.4	0.23	8300	6.3	0.23
	3	6860	6.1	0.22	7750	6.3	0.22	7700	6.1	0.21	8160	6.2	0.21	7660	6.3	0.23	8360	6.4	0.23
	4	7020	...	...	7870	...	...	7000	...	...	8040	...	...	7660	...	...	8130	...	...
	5	7460	...	...	7790	...	...	6870	...	...	8050	...	...	7160	...	...	8480	...	...
	6	6840	...	...	7540	...	...	7200	...	...	8550	...	...	7620	...	...	8750	...	...
	Average	7030	6.1	0.22	7780	6.3	0.22	7210	6.2	0.22	8210	6.3	0.22	7520	6.3	0.23	8430	6.4	0.23
120	1	7630	6.3	0.22	8160	6.5	0.22	8050	6.4	0.22	8660	6.9	0.24	7820	6.6	0.21	8930	6.7	0.22
	2	7660	6.3	0.21	8630	6.6	0.22	8040	6.4	0.23	8860	6.7	0.23	7860	6.6	0.22	8980	6.7	0.22
	3	7500	6.3	0.22	8520	6.5	0.22	8020	6.5	0.22	9120	6.7	0.23	8320	6.4	0.23	9040	6.6	0.21
	Average	7600	6.3	0.22	8440	6.5	0.22	8040	6.4	0.22	8880	6.8	0.23	8000	6.5	0.22	8980	6.7	0.22

Notes: Mix proportions and properties of fresh concrete are given in Table 11.

Admixture, Date Recieved: Pozzolith 300R, 8/25/72
Time of Addition: Delayed Addition
Cement, Type II: Medusa, 2/8/73, Shipment "B"
6 by 12-in. concrete cylinders

F.A.: Mason-Dixon, 3/2/73
C.A.: Berks, 1 1/2 in. to No. 4, Gradation "A"

TABLE 14 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE II(b)
1 1/2 IN. BERKS MSA CONCRETE MIXES WITH DARATARD 40

Age, days	Spec. No.	7.5 scy (G-19) Sealed Comp psi	Ex10⁶ psi	μ	Moist-Cured Comp psi	Ex10⁶ psi	μ	8 scy (G-18) Sealed Comp psi	Ex10⁶ psi	μ	Moist-Cured Comp psi	Ex10⁶ psi	μ	8.5 scy (G-20) Sealed Comp psi	Ex10⁶ psi	μ	Moist-Cured Comp psi	Ex10⁶ psi	μ
7	1	....	...	...	4910	...	...	5230	...	...	5040	...	...	....	...	...	5230	...	...
	2	....	...	...	5020	...	...	5070	...	...	5070	...	...	....	...	...	5540	...	...
	3	....	...	...	4870	...	...	5040	...	...	5210	...	...	....	...	...	5230	...	...
	Average	....	...	...	4930	...	...	5110	...	...	5110	...	...	....	...	...	5330	...	...
14	1	....	...	...	6320	...	...	5960	...	...	6110	...	...	....	...	...	6340	...	...
	2	....	...	...	6200	...	...	6200	...	...	6250	...	...	....	...	...	6800	...	...
	3	....	...	...	6200	...	...	5980	...	...	6120	...	...	....	...	...	6370	...	...
	Average	...	...	...	6240	...	...	6050	...	...	6160	...	...	...	...	...	6500	...	...
28	1	....	...	...	7340	6.1	0.21	6930	6.2	0.22	7140	6.2	0.21	....	...	...	7550	6.3	0.22
	2	....	...	...	7270	6.2	0.21	6930	6.0	0.21	7230	6.4	0.22	....	...	...	7820	6.6	0.22
	3	....	...	...	7300	6.4	0.23	6870	6.4	0.23	7340	6.3	0.22	....	...	...	7610	6.1	0.22
	4	....	...	...	7320	6.1	0.22	6950	...	...	7360	...	...	....	...	...	7270*	...	...
	5	....	...	...	7160	...	...	6780	...	...	7320	...	...	....	...	...	7570	...	...
	6	....	...	...	7480	...	...	6640	6.5	0.23	7430	...	...	....	...	...	7570	...	...
	Average	....	...	...	7310	6.2	0.22	6850	6.3	0.22	7300	6.3	0.22	....	...	...	7620	6.3	0.22
60	1	....	...	...	8140	6.3	0.22	7860	6.4	0.21	8360	6.2	0.21	....	...	...	7960*	6.6	0.23
	2	....	...	...	8230	6.4	0.22	7640	6.4	0.22	8480	6.7	0.23	....	...	...	8710	6.7	0.21
	3	....	...	...	8340	6.3	0.22	7500	6.5	0.22	8120	6.5	0.23	....	...	...	8500	6.5	0.25
	4	....	...	...	7980	...	...	7840	...	...	8640	6.4	0.22	....	...	...	8200	...	...
	5	....	...	...	8180	...	...	7610	...	...	8340	...	...	....	...	...	8620	...	...
	6	....	...	...	8290	...	...	7730	...	...	8160	...	...	....	...	...	8300	...	...
	Average	....	...	...	8190	6.3	0.22	7700	6.4	0.22	8350	6.5	0.23	....	...	...	8470	6.6	0.23
120	1	....	...	...	8450	6.7	0.22	8320	6.6	0.22	8880	6.6	0.22	....	...	...	8960	6.6	0.22
	2	....	...	...	8540	6.6	0.22	8450	6.6	0.21	9050	6.7	0.23	....	...	...	8970	6.9	0.22
	3	....	...	...	8620	6.6	0.22	8430	6.2	0.21	8880	6.6	0.22	....	...	...	8980	6.9	0.22
	Average	....	...	...	8540	6.6	0.22	8400	6.5	0.21	8940	6.6	0.22	....	...	...	8970	6.8	0.22

* Value not averaged

Notes: Mix proportions and properties of fresh concrete are given in Table 11.

Admixture, Date Recieved: Daratard 40, 4/12/72
Time of Addition: Delayed Addition
Cement, Type II: Medusa, 2/8/73, Shipment "B"
6 by 12-in. concrete cylinders

F.A.: Mason-Dixon, 3/2/73
C.A.: Berks, 1 1/2 in. to No. 4, Gradation "A"

TABLE 15 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE II(b) 3/4 IN. BERKS MSA CONCRETE MIXES WITH POZZOLITH 300R

Age, days	Spec. No.	7.5 scy (G-21) Sealed Comp psi	Sealed $E \times 10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E \times 10^6$ psi	Moist-Cured μ	8 scy (G-22) Sealed Comp psi	Sealed $E \times 10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E \times 10^6$ psi	Moist-Cured μ	8.5 scy (G-23) Sealed Comp psi	Sealed $E \times 10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E \times 10^6$ psi	Moist-Cured μ
7	1	4870	...	...	4770	...	...	5070	...	...	5230	...	...	5300	...	...	5370	...	...
	2	4700	...	...	4680	...	...	5000	...	...	5300	...	...	5370	...	...	5390	...	...
	3	4360	...	...	4550	...	...	5020	...	...	5140	...	...	5280	...	...	5390	...	...
	Average	4640	...	...	4670	...	...	5030	...	...	5220	...	...	5320	...	...	5380	...	...
14	1	5590	...	...	5950	...	...	6070	...	...	6390	...	...	6370	...	...	6480	...	...
	2	5620	...	...	6030	...	...	5860	...	...	6410	...	...	6270	...	...	6410	...	...
	3	5460	...	...	6030	...	...	5840	...	...	6360	...	...	6290	...	...	6360	...	...
	Average	5560	...	...	6000	...	...	5920	...	...	6390	...	...	6310	...	...	6420	...	...
28	1	6450	5.5	0.20	7120	5.6	0.21	7090	5.6	0.21	7480	5.8	0.22	6900	5.7	0.21	7450	5.7	0.22
	2	6370	5.6	0.21	7050	5.6	0.21	6750	5.4	0.21	7320	5.6	0.22	6940	5.8	0.22	7520	5.8	0.21
	3	6320	5.4	0.21	6930	5.7	0.22	6820	5.6	0.20	7230	5.8	0.22	6960	5.4	0.20	7360	5.7	0.21
	4	6520	...	...	7020	...	...	7000	...	...	7140	...	...	7020	...	...	7700	...	...
	5	6360	...	...	7090	...	...	6800	...	...	7450	...	...	7050	...	...	7560	...	...
	6	6370	...	...	7000	...	...	6890	...	...	7140	...	...	6830	...	...	7480	...	...
	Average	6400	5.5	0.21	7030	5.6	0.21	6890	5.5	0.21	7290	5.7	0.22	6950	5.6	0.21	7510	5.7	0.21
60	1	7300	5.6	0.20	8090	5.7	0.20	7700	5.7	0.20	8430	5.8	0.20	8020	5.8	0.20	8540	5.7	0.20
	2	7440	5.6	0.21	8050	5.9	0.22	7500	5.5	0.20	8180	5.9	0.20	8000	5.8	0.21	8450	6.0	0.22
	3	7230	5.6	0.20	7930	5.7	0.21	7460	5.7	0.21	8160	6.0	0.21	7820	5.7	0.21	8370	5.7	0.21
	4	7270	...	...	7960	...	...	7820	...	...	8270	...	...	8180	...	...	8640	...	...
	5	7120	...	...	8020	...	...	7460	...	...	8090	...	...	7870	...	...	8570	5.8	0.20
	6	7210	...	...	7860	...	...	7480	...	...	8340	...	...	7930	...	...	8480	...	...
	Average	7260	5.6	0.20	7980	5.8	0.21	7570	5.6	0.20	8240	5.9	0.20	7970	5.8	0.21	8510	5.8	0.21
120	1	7710	5.8	0.21	8620	6.1	0.21	8280	6.0	0.22	8900	6.2	0.22	8680	6.1	0.22	9250	6.1	0.20
	2	7770	5.9	0.21	8430	6.0	0.21	8040	5.9	0.21	8630	6.1	0.22	8300	5.9	0.22	8910	6.0	0.22
	3	7790	5.8	0.21	8370	6.1	0.22	8130	5.9	0.21	8850	6.2	0.22	8200	6.0	0.22	9020	6.0	0.22
	Average	7760	5.8	0.21	8470	6.1	0.21	8150	5.9	0.21	8790	6.2	0.22	8390	6.0	0.22	9060	6.0	0.22

Notes: Mix proportions and properties of fresh concrete are given in Table 11.

Admixture, Date Received: Pozzolith 300R, 8/25/72
Time of Addition: Delayed Addition
Cement, Type II: Medusa, 2/8/73, Shipment "B"
6 by 12-in. concrete cylinders

F.A.: Mason-Dixon, 3/2/73
C.A.: Berks, 3/4 in. to No. 4, 2/14/73

TABLE 16 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE II(b)
1 1/2 IN. YORK MSA CONCRETE MIXES WITH POZZOLITH 300R

Age, days	Spec. No.	7 scy (G-28)						7.5 scy (G-24)						8 scy (G-26)					
		Sealed			Moist-Cured			Sealed			Moist-Cured			Sealed			Moist-Cured		
		Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ
7	1	4450	...	...	4640	...	...	....	...	...	4950	...	...	5340	...	...	5320	...	...
	2	4490	...	...	4590	...	...	....	...	...	5140	...	...	5450	...	...	5320	...	...
	3	4820	...	...	4880	...	...	....	...	...	5020	...	...	5320	...	...	5360	...	...
	Average	4590	...	...	4700	...	...	....	...	...	5040	...	...	5370	...	...	5330	...	...
14	1	5550	...	...	5840	...	...	....	...	...	5950	...	...	6120	...	...	6550	...	...
	2	5520	...	...	5800	...	...	....	...	...	6250	...	...	6050	...	...	6540	...	...
	3	5660	...	...	6040	...	...	....	...	...	6140	...	...	6090	...	...	6620	...	...
	Average	5580	...	...	5890	...	...	....	...	...	6110	...	...	6090	...	...	6570	...	...
28	1	6480	5.6	0.21	7070	5.8	0.22	....	...	...	7110	6.0	0.23	7140	5.8	0.21	7750	6.0	0.22
	2	6270	5.3	0.20	7090	5.9	0.21	....	...	...	7360	5.8	0.21	7120	5.8	0.21	7480	6.0	0.21
	3	6460	5.6	0.23	7090	5.6	0.20	....	...	...	7250	5.8	0.21	7090	5.8	0.22	7250	5.9	0.21
	4	6390	5.6	0.21	7140	...	...	....	...	...	7110	...	...	6960	...	...	7550	...	...
	5	6410	...	...	7090	...	...	....	...	...	7140	...	...	6930	...	...	7540	...	...
	6	6370	...	...	7230	5.9	0.21	....	...	...	7270	...	...	7020	...	...	7570	...	...
	Average	6400	5.5	0.21	7120	5.8	0.21	....	...	...	7210	5.9	0.22	7040	5.8	0.21	7520	6.0	0.21
60	1	6930	5.9	0.21	7800	6.2	0.22	....	...	...	8000	6.0	0.22	7270	6.0	0.23	8540	6.3	0.23
	2	6620	5.7	0.21	7810	6.2	0.22	....	...	...	8110	6.2	0.22	7610	5.9	0.22	8370	6.3	0.23
	3	7010	5.9	0.24	8030	6.3	0.23	....	...	...	7860	6.3	0.22	7660	6.1	0.23	8630	6.3	0.22
	4	7140	...	...	7610	...	...	....	...	...	7870	...	...	7800	...	...	8350	...	...
	5	6940	...	...	7930	...	...	....	...	...	8070	...	...	7360	...	...	8540	...	...
	6	7000	6.0	0.21	6520*	...	...	....	...	...	8180	...	...	7500	...	...	8730	...	...
	Average	6940	5.9	0.21	7840	6.2	0.22	....	...	...	8010	6.2	0.22	7530	6.0	0.23	8530	6.3	0.23
120	1	7570	6.0	0.21	8200	6.3	0.23	....	...	...	8360	6.6	0.23	8290	6.3	0.22	8960	6.3	0.22
	2	7520	6.0	0.21	8410	6.3	0.22	....	...	...	8680	6.4	0.24	8180	6.2	0.22	9180	6.5	0.23
	3	7610	6.0	0.21	8040	6.3	0.23	....	...	...	8430	6.4	0.23	8200	6.3	0.22	9300	6.4	0.22
	Average	7570	6.0	0.21	8220	6.3	0.23	....	...	...	8490	6.5	0.23	8220	6.3	0.22	9150	6.4	0.22

* Value not averaged

Notes: Mix proportions and properties of fresh concrete are given in Table 12.

Admixture, Date Received: Pozzolith 300R, 8/25/72
Time of Addition: Delayed Addition
Cement, Type II: Medusa, 2/8/73, Shipment "B"
6 by 12-in. concrete cylinders

F.A.: Mason-Dixon, 3/2/73
C.A.: York, 1 1/2 in. to No. 4, Gradation "A"

TABLE 17 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE II(b) 1 1/2 IN. YORK MSA CONCRETE MIXES WITH DARATARD 40

Age, days	Spec. No.	7 scy (G-29) Sealed Comp psi	Ex10⁶ psi	μ	Moist-Cured Comp psi	Ex10⁶ psi	μ	7.5 scy (G-25) Sealed Comp psi	Ex10⁶ psi	μ	Moist-Cured Comp psi	Ex10⁶ psi	μ	8 scy (G-27) Sealed Comp psi	Ex10⁶ psi	μ	Moist-Cured Comp psi	Ex10⁶ psi	μ
7	1	4860	...	...	5190	...	...	....	...	...	4890	...	...	5540	...	...	5710	...	...
	2	5070	...	...	5090	...	...	....	...	...	5070	...	...	5530	...	...	5460	...	...
	3	5070	...	...	5130	...	...	....	...	...	5000	...	...	5050	...	...	5210	...	...
	Average	5000	...	...	5140	...	...	....	...	...	4990	...	...	5370	...	...	5460	...	...
14	1	6000	...	...	6090	...	...	....	...	...	6110	...	...	6180	...	...	6570	...	...
	2	6110	...	...	6290	...	...	....	...	...	6140	...	...	6430	...	...	6650	...	...
	3	6020	...	...	6340	...	...	....	...	...	6140	...	...	6140	...	...	6360	...	...
	Average	6040	...	...	6240	...	...	....	...	...	6130	...	...	6250	...	...	6530	...	...
28	1	6640	5.7	0.21	7250	5.6	0.21	....	...	...	6860	6.0	0.21	7160	5.9	0.21	7790	6.1	0.22
	2	6980	5.6	0.20	7120	5.8	0.22	....	...	...	7140	6.1	0.22	7250	5.8	0.21	7390	6.0	0.21
	3	6620	5.6	0.21	7340	5.8	0.21	....	...	...	7040	6.0	0.21	7070	5.8	0.21	7460	5.8	0.21
	4	6650	...	...	7290	...	...	....	...	...	7120	...	...	7210	...	...	7710	...	...
	5	6910	...	...	7340	...	...	....	...	...	7210	...	...	7340	...	...	7610	...	...
	6	6790	...	...	7360	...	...	....	...	...	6910	...	...	6960	...	...	7300	...	...
	Average	6760	5.6	0.21	7280	5.7	0.21	....	...	...	7050	6.0	0.21	7170	5.8	0.21	7540	6.0	0.21
60	1	7300	6.1	0.22	8000	6.4	0.22	....	...	...	7610	6.3	0.22	7800	6.1	0.25	8090	6.3	0.22
	2	7520	6.1	0.21	7920	6.4	0.22	....	...	...	8040	6.3	0.21	7610	6.1	0.22	7710	6.3	0.22
	3	7180	6.0	0.23	8040	6.3	0.23	....	...	...	8160	6.1	0.20	7500	6.2	0.22	8020	6.3	0.22
	4	7550	...	...	7940	...	...	....	...	...	7950	...	...	7390	...	...	8230	...	...
	5	7530	...	...	7870	...	...	....	...	...	8290	...	...	7520	...	...	8430	...	...
	6	7270	...	...	7890	...	...	....	...	...	7890	...	...	7430	...	...	8270	...	...
	Average	7390	6.1	0.22	7940	6.4	0.22	....	...	...	7990	6.2	0.21	7540	6.1	0.23	8120	6.3	0.22
120	1	8050	6.1	0.22	8540	6.2	0.22	....	...	...	8540	6.4	0.23	8430	6.5	0.23	9070	6.6	0.23
	2	8020	6.1	0.22	8430	6.4	0.22	....	...	...	8770	6.4	0.23	8160	6.3	0.22	8890	6.4	0.24
	3	7960	6.0	0.23	8610	6.3	0.22	....	...	...	8540	6.2	0.23	8320	6.3	0.23	8880	6.5	0.22
	Average	8010	6.1	0.22	8530	6.3	0.22	....	...	...	8610	6.3	0.23	8300	6.4	0.23	8950	6.5	0.23

Notes: Mix proportions and properties of fresh concrete are given in Table 12.

Admixture, Date Received: Daratard 40, 4/12/72
Time of Addition: Delayed Addition
Cement, Type II: Medusa, 2/8/73, Shipment "B"
6 by 12-in. concrete cylinders

F.A.: Mason-Dixon, 3/2/73
C.A.: York, 1 1/2 in. to No. 4, Gradation "A"

TABLE 18 -- COMPRESSIVE STRENGTH, MODULUS OF ELASTICITY AND POISSON'S RATIO - PHASE II(b) 3/4 IN. YORK MSA CONCRETE MIXES WITH POZZOLITH 300R

Age, days	Spec. No.	7 scy (G-30)						7.5 scy (G-31)						8 scy (G-32)					
		Sealed			Moist-Cured			Sealed			Moist-Cured			Sealed			Moist-Cured		
		Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ
7	1	4340	...	...	4340	...	...	4800	...	...	5070	...	...	5270	...	...	5450	...	...
	2	4460	...	...	4520	...	...	4730	...	...	4710	...	...	5070	...	...	5370	...	...
	3	4550	...	...	4710	...	...	4770	...	...	4710	...	...	5090	...	...	5190	...	...
	Average	4450	...	...	4520	...	...	4770	...	...	4830	...	...	5140	...	...	5340	...	...
14	1	5250	...	...	5660	...	...	5890	...	...	6070	...	...	6070	...	...	6550	...	...
	2	5270	...	...	5660	...	...	5700	...	...	5950	...	...	6010	...	...	6660	...	...
	3	5500	...	...	5970	...	...	5640	...	...	5970	...	...	5960	...	...	6430	...	...
	Average	5340	...	...	5760	...	...	5740	...	...	6000	...	...	6010	...	...	6550	...	...
28	1	6090	5.1	0.20	6700	5.6	0.21	6460	5.2	0.20	7070	5.2	0.20	6680	5.5	0.20	7360	5.5	0.21
	2	6200	5.1	0.20	6680	5.3	0.20	6520	5.3	0.22	6750	5.3	0.21	6770	5.5	0.20	7570	5.5	0.20
	3	6270	5.2	0.20	6890	5.3	0.21	6540	5.3	0.20	6960	5.4	0.20	6620	5.4	0.21	7520	5.6	0.21
	4	6000	...	...	6710	5.3	0.21	6340	...	...	7090	...	...	6730	...	...	7540	5.6	0.21
	5	5960	...	...	6790	...	...	6380	5.3	0.20	6960	...	...	6660	...	...	7320	5.6	0.22
	6	6200	...	...	7000	...	...	6550	...	...	6870	...	...	6700	...	...	7450	...	...
	Average	6120	5.1	0.20	6790	5.4	0.21	6460	5.3	0.20	6950	5.3	0.20	6690	5.5	0.20	7460	5.6	0.21
60	1	6630	5.4	0.20	7500	5.6	0.21	7250	5.5	0.20	7770	5.8	0.21	7590	5.7	0.21	8060	5.9	0.21
	2	6790	5.5	0.19	7490	5.5	0.20	7050	5.4	0.20	7570	5.7	0.21	7570	5.7	0.21	8130	6.0	0.21
	3	6860	5.6	0.20	7410	5.7	0.21	7220	5.6	0.20	7820	5.8	0.20	7460	5.7	0.20	8300	5.8	0.21
	4	6590	...	...	7420	...	...	7140	...	...	7820	...	...	7480	...	...	8070	...	...
	5	6790	...	...	7410	...	...	6880	...	...	7660	...	...	7560	...	...	8320	...	...
	6	6810	...	...	7530	...	...	7110	...	...	7660	...	...	7110	...	...	8210	...	...
	Average	6750	5.5	0.20	7460	5.6	0.21	7110	5.5	0.20	7720	5.8	0.21	7460	5.7	0.21	8180	5.9	0.21
120	1	7300	5.6	0.22	8020	6.0	0.22	7590	5.9	0.22	8290	6.0	0.21	8390	5.9	0.22	9040	6.0	0.21
	2	7610	5.8	0.21	7930	6.0	0.22	7300	6.0	0.23	8040	5.9	0.21	8320	6.0	0.22	9020	6.0	0.21
	3	7550	5.8	0.21	8020	6.0	0.23	7480	5.9	0.22	8230	5.9	0.22	8230	5.9	0.22	8730	6.0	0.21
	Average	7490	5.7	0.21	7990	6.0	0.22	7460	5.9	0.22	8180	5.9	0.21	8310	5.9	0.22	8930	6.0	0.21

Notes: Mix proportions and properties of fresh concrete are given in Table 12.

Admixture, Date Received: Pozzolith 300R, 8/25/72
Time of Addition: Delayed Addition
Cement, Type II: Medusa, 2/8/73, Shipment "B"
6 by 12-in. concrete cylinders

F.A.: Mason-Dixon, 3/2/73
C.A.: York, 3/4 in. to No. 4, 2/12/73

TABLE 19 -- MIX PROPORTIONS AND PROPERTIES OF FRESH CONCRETE - PHASE II(c)
BERKS G-19, YORK G-25, YORK G-26

	Berks G-19 (7.5 scy) Daratard 40				York G-25 (7.5 scy) Daratard 40			York G-26 (8 scy) Pozzolith 300R		
Phase :	II(a)	II(c) Comp.	II(c) Tens.	II(c),III Average	II(a)	II(c) Comp.	II(c) Tens.	II(a)	II(c)	II(c),III Average
Date cast:	5/16/73	11/29/73	11/29/73		6/25/73	12/20/73	12/20/73	6/26/73	2/21/74	
I. Mix Proportions, pcy										
Cement	706	704	710	706	704	701	704	750	757	756
Water and Admixture	271	268	270	269	270	269	268	282	286	290
F.A. - Mason-Dixon sand	1224	1221	1230	1224	1220	1207	1212	1243	1250	1249
C.A. - 3/4 in. to No. 4	887	885	891	887	1012	1001	1005	989	996	993
C.A. - 1 1/2 to 3/4 in.	949	949	956	952	818	812	813	800	805	804
Total	4037	4027	4057	4038	4024	3990	4002	4064	4094	4092
Admixture, fl.oz./100 lbs cement	8.0	8.0	8.0	8.0	8.0	8.0	8.0	3.5	3.5	3.5
II. Properties of Fresh Concrete										
Cement Concrete, scy	7.51	7.49	7.55	7.51	7.49	7.46	7.49	7.98	8.05	8.04
Water-Cement Ratio, by wt.	0.384	0.381	0.380	0.381	0.384	0.384	0.381	0.376	0.378	0.384
Slump, in.	4 3/4	4 5/8	4 3/8	4 1/2	4 3/4	5	4 3/4	4 5/8	4	4 1/2
Air Content, %	4.1	4.7	4.2	4.5	4.2	4.9	4.9	3.1	2.2	2.2
Temperature, °F	49	50	51	50	50	50	51	50	50	50
Unit Weight, pcf	149.5	149.2	150.3	149.6	149.0	147.7	148.2	150.5	151.6	151.6
Sand Content, % by wt.	40	40	40	40	40	40	40	41	41	41

Notes:

	Berks G-19	York G-25	York G-26
Admixture, Date Received	4/12/72 4/27/73	4/12/72 4/27/73	8/25/72 4/9/73
Time of Addition	Delayed Addition	Delayed Addition	Delayed Addition

Cement, Medusa Type II
F.A., Mason-Dixon sand
C.A., 1 1/2 in. to No. 4

Phase II(a): 9/31/72, Shipment "B" 3/2/73 Gradation "A"

Phase II(c)&III: Blend of Shipment "A" and "B" Blend of 11/16/72, 3/2/73, 10/4/73 Gradation "B"

TABLE 20 -- STRENGTH AND ELASTIC PROPERTIES - PHASE II(c)
BERKS G-19 (7.5 scy)

		Compressive Strength, Modulus of Elasticity, and Poisson's Ratio						Splitting Tensile Strength and Percent C.A. Fractured			
		Sealed			Moist-Cured			Sealed		Moist-Cured	
Age, days	Spec. No.	Comp psi	$Ex10^6$ psi	μ	Comp psi	$Ex10^6$ psi	μ	Tens psi	Frac %	Tens psi	Frac %
	1	5320	...	...	5020	...	...	510	60	530	60
7	2	5020	...	...	5450	...	...	510	65	510	60
	3	5340	...	...	5210	...	...	420	50	525	55
	Average	5230	...	...	5230	...	...	480	60	520	60
	1	6520	6.1	0.19	6660	6.3	0.19	640	70	525	60
28	2	6790	6.4	0.20	6630	6.5	0.20	670	60	610	55
	3	6450	6.2	0.19	6390	6.2	0.20	620	70	515	50
	Average	6590	6.2	0.19	6560	6.3	0.20	645	65	550	55
	1	7020	6.3	0.22	7380	6.3	0.22	700	60	625	60
60	2	7250	6.3	0.21	7500	6.4	0.21	570	60	630	60
	3	7270	6.4	0.22	7320	6.3	0.21	625	55	630	60
	Average	7180	6.3	0.22	7400	6.3	0.21	630	60	630	60
	1	7500	6.2	0.21	7820	6.4	0.22	680	50	700	65
90	2	7550	6.4	0.23	8070	6.4	0.23	635	60	715	65
	3	7480	6.3	0.21	8000	6.3	0.22	575	50	655	70
	Average	7510	6.3	0.22	7960	6.4	0.22	630	55	690	65
	1	7020	...	...	7610	...	...	...	..	...	..
120	2	7590	...	...	7960	...	...	...	..	...	..
	3	6860	...	...	8020	...	...	...	..	...	..
	Average	7160	...	...	7860	...	...	...	..	...	..
	1	7500	...	...	7980	...	...	625	75	705	60
180	2	8000	...	...	8390	...	...	630	50	685	60
	3	7860	...	...	8230	...	...	730	65	680	60
	Average	7790	...	...	8200	...	...	660	65	680	60
	1	7840	6.4	0.22	8180	6.4	0.21	660	55	770	75
270	2	8390	6.4	0.22	8620	6.6	0.21	755	70	710	70
	3	8430	6.5	0.23	8480	6.6	0.21	730	60	730	70
	Average	8220	6.4	0.22	8430	6.5	0.21	715	60	730	70
	1	8320	...	...	8750	...	...	...	..	...	..
365	2	8550	...	...	9000	...	...	...	..	...	..
	3	8320	...	...	8800	...	...	...	..	...	..
	Average	8400	...	...	8850	...	...	...	..	...	..
	1										
730	2										
	3										
	Average										

Notes: Mix proportions and properties of fresh concrete are given in Table 19.

Admixture, Date Received	Daratard 40, 4/27/73
Time of Addition	Delayed Addition
Cement, Medusa Type II	Blend of Shipment "A" and "B"
F.A., Mason Dixon	Blend of 11/16/72, 3/2/73, 10/4/73
C.A., Berks	1 1/2 in. to No. 4, Gradation "B"

6 by 12-in. concrete cylinders

TABLE 21-- STRENGTH AND ELASTIC PROPERTIES - PHASE II(c)
YORK G-25 (7.5 scy)

Age, days	Spec. No.	Sealed Comp psi	Sealed Ex10^6 psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured Ex10^6 psi	Moist-Cured μ	Sealed Tens psi	Sealed Frac %	Moist-Cured Tens psi	Moist-Cured Frac %
		Compressive Strength, Modulus of Elasticity, and Poisson's Ratio						Splitting Tensile Strength and Percent C.A. Fractured			
7	1	4830	...	...	4930	...	...	535	60	515	60
	2	4840	...	...	4700	...	...	340	65	525	60
	3	4520	...	...	4550	...	...	410	55	490	65
	Average	4730	...	...	4730	...	...	470	60	510	60
28	1	6540	5.9	0.22	6700	6.0	0.23	590	60	555	70
	2	6290	6.0	0.22	6610	6.0	0.22	495	55	665	70
	3	6020	5.8	0.22	6390	5.9	0.22	570	55	610	65
	Average	6280	5.9	0.22	6570	6.0	0.22	550	55	610	70
60	1	7110	6.1	0.23	7270	6.1	0.22	650	55	710	65
	2	6770	6.0	0.22	7320	6.0	0.21	585	60	710	70
	3	6570	6.0	0.22	7050	5.9	0.22	690	65	710	65
	Average	6820	6.0	0.22	7210	6.0	0.22	640	60	710	65
90	1	7370	6.2	0.21	7870	6.2	0.22	695	55	670	65
	2	7160	6.2	0.22	7550	6.1	0.23	685	65	705	65
	3	7020	6.1	0.22	7460	6.2	0.23	655	55	730	70
	Average	7180	6.2	0.22	7630	6.2	0.23	680	60	700	65
120	1	7660	...	...	7870	...	...	...	..	...	..
	2	7370	...	...	8110	...	...	...	..	...	..
	3	7000	...	...	7730	...	...	...	..	...	..
	Average	7340	...	...	7900	...	...	...	..	...	..
180	1	7870	...	...	8450	...	...	630	70	675	75
	2	7480	...	...	8160	...	...	675	60	805	75
	3	7460	...	...	7950	...	...	630	60	710	85
	Average	7600	...	...	8190	...	...	645	65	730	75
270	1	8070	6.0	0.22	8750	6.2	0.22	765	75	805	85
	2	7340	6.1	0.22	8370	6.2	0.22	760	75	675	80
	3	7770	5.9	0.22	8160	6.0	0.22	755	75	805	80
	Average	7730	6.0	0.22	8430	6.1	0.22	760	75	760	80
365	1	7710	...	...	8790	...	...	...	..	...	..
	2	8610	...	...	8390	...	...	...	..	...	..
	3	7930	...	...	8860	...	...	...	..	...	..
	Average	8080	...	...	8680	...	...	...	..	...	..
730	1										
	2										
	3										
	Average										

Notes: Mix proportions and properties of fresh concrete are given in Table 19.

Admixture, Date Received	Daratard 40, 4/27/73
Time of Addition	Delayed Addition
Cement, Medusa Type II	Blend of Shipment "A" and "B"
F.A., Mason-Dixon	Blend of 11/16/72, 3/2/73, 10/4/73
C.A., York	1 1/2 in. to No. 4, Gradation "B"

6 by 12-in. concrete cylinders

TABLE 22 -- STRENGTH AND ELASTIC PROPERTIES - PHASE II(c)
YORK G-26 (8 scy)

Age, days	Spec. No.	Sealed Comp psi	Sealed $E \times 10^6$ psi	Sealed μ	Moist-Cured Comp psi	Moist-Cured $E \times 10^6$ psi	Moist-Cured μ
		Compressive Strength, Modulus of Elasticity and Poisson's Ratio					
7	1	....	...	...	5050	...	...
	2	....	...	...	5050	...	...
	3	....	...	...	5090	...	...
	Average	....	...	...	5060	...	...
28	1	6290	5.9	0.22	6910	6.1	0.22
	2	6230	5.8	0.22	6520	6.0	0.23
	3	6320	5.9	0.22	6540	5.9	0.23
	Average	6280	5.9	0.22	6660	6.0	0.23
60	1	6980	5.9	0.22	7610	6.1	0.23
	2	6680	6.0	0.22	7640	6.0	0.21
	3	6680	5.9	0.21	7620	6.2	0.23
	Average	6780	5.9	0.22	7620	6.1	0.22
90	1	7180	6.1	0.24	7980	6.3	0.24
	2	7340	6.2	0.23	8050	6.5	0.23
	3	7070	6.3	0.23	8050	6.4	0.23
	Average	7200	6.2	0.23	8030	6.4	0.23
270	1	8210	6.1	0.22	9000	6.2	0.23
	2	8390	6.3	0.22	8710	6.3	0.23
	3	8000	6.1	0.21	8980	6.3	0.23
	Average	8200	6.2	0.22	8900	6.3	0.23
365	1	....	...	...	9180	...	...
	2	....	...	...	9000	...	...
	3	....	...	...	9210	...	...
	Average	....	...	...	9130	...	...
730	1	....	...	...			
	2	....	...	...			
	3	....	...	...			
	Average	....	...	...			

Notes: Mix proportions and properties of fresh concrete are given in Table 19.

Admixture, Date Recieved	Pozzolith 300R, 4/9/73
Time of Addition	Delayed Addition
Cement, Medusa Type II	Blend of Shipment "A" and "B"
F.A., Mason-Dixon	Blend of 11/16/72, 3/2/73, and 10/4/73
C.A., York	1 1/2 in. to No. 4, Gradation "B"
6 by 12-in. concrete cylinders	

TABLE 23 -- EFFECT OF SLUMP ON PROPERTIES OF CONCRETE
BERKS G-19

	Nominal Slump, inches 2	5	8
I. Mix Proportions, pcy			
Cement	722	704	693
Water and Admixture	257	268	290
F.A. - Mason-Dixon sand	1251	1221	1202
C.A. - 3/4 in. to No. 4	907	885	871
C.A. - 1 1/2 to 3/4 in.	972	949	933
Total	4109	4027	3989
II. Properties of Fresh Concrete			
Cement Content, scy	7.67	7.49	7.37
Water-Cement Ratio, by wt.	0.356	0.381	0.418
Slump, in.	2	4 5/8	8
Air Content, %	3.6	4.7	4.7
Temperature, °F	52	50	51
Unit Weight, pcf	152.2	149.1	147.7
Sand Content, % by wt.	40	40	40

III. Compressive Strength and Elastic Properties

Age, days	Spec. No.	Comp psi	Ex10[6] psi	μ	Comp psi	Ex10[6] psi	μ	Comp psi	Ex10[6] psi	μ
	1	7200	6.5	0.21	6660	6.3	0.19	5950	6.0	0.20
28	2	6730	6.6	0.19	6630	6.5	0.20	6070	5.9	0.20
	3	7090	6.6	0.20	6390	6.2	0.20	6000	6.1	0.19
	Average	7010	6.6	0.20	6590	6.3	0.20	6010	6.0	0.20
	1	7590	6.7	0.20	7380	6.3	0.22	6730	6.0	0.21
60	2	7570	6.8	0.22	7500	6.4	0.21	6590	6.0	0.21
	3	7770	6.7	0.22	7320	6.3	0.21	6590	6.0	0.24
	Average	7640	6.7	0.21	7400	6.3	0.21	6640	6.0	0.22

Notes: Slump was varied by adjusting water content of control 5-in. slump Berks G-19 mix. Mix proportions computed using measured unit weights.

Admixture, Date Received	Daratard 40, 4/27/73
Time of Addition	Delayed Addition
Cement, Medusa Type II	Blend of Shipment "A" and "B"
F.A., Mason-Dixon	Blend of 11/16/72, 3/2/73, 10/4/73
C.A., Berks	1 1/2 in. to No. 4, Gradation "B"

Moist-cured 6 by 12-in concrete cylinders

TABLE 24 -- EFFECT OF SLUMP ON PROPERTIES OF CONCRETE
YORK G-25

	Nominal Slump, inches		
	2	5	8
I. Mix Proportions, pcy			
Cement	727	701	695
Water and Admixture	250	269	281
F.A. - Mason-Dixon sand	1252	1207	1198
C.A. - 3/4 in. to No. 4	1038	1001	993
C.A. - 1 1/2 to 3/4 in.	839	812	803
Total	4106	3990	3970
II. Properties of Fresh Concrete			
Cement Content, scy	7.73	7.46	7.39
Water-Cement Ratio, by wt.	0.344	0.383	0.404
Slump, in.	1 3/4	5	7 1/2
Air Content, %	3.1	4.9	4.9
Temperature, °F	51	50	52
Unit Weight, pcf	152.0	147.8	147.0
Sand Content, % by wt.			

III. Compressive Strength and Elastic Properties

Age, days	Spec. No.	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ	Comp psi	$E \times 10^6$ psi	μ
	1	7180	6.2	0.22	6700	6.0	0.23	6160	5.7	0.22
28	2	7140	6.2	0.23	6610	6.0	0.22	6160	5.7	0.22
	3	7020	6.1	0.22	6390	5.9	0.22	6050	5.7	0.22
	Average	7110	6.2	0.22	6570	6.0	0.22	6130	5.7	0.22
	1	7800	6.2	0.21	7270	6.1	0.22	....	5.7*	0.22
60	2	7840	6.3	0.22	7320	6.0	0.21	6960	5.6	0.21
	3	....	6.2*	0.22	7050	5.9	0.22	7020	5.8	0.22
	Average	7820	6.2	0.22	7210	6.0	0.22	6990	5.7	0.22

Notes: Slump was varied by adjusting water content of control 5-in slump York G-25 mix. Mix proportions computed using measured unit weights.

Admixture, Date Received	Daratard 40, 4/27/73
Time of Addition	Delayed Addition
Cement, Medusa Type II	Blend of Shipment "A" and "B"
F.A., Mason-Dixon	Blend of 11/16/72, 3/2/73, 10/4/73
C.A., York	1 1/2 in. to No. 4, Gradation "B"

Moist-cured 6 by 12-in concrete cylinders

* Specimen tested at age 39 days

TABLE 25 -- LARGEST PERCENT VARIATION OF INDIVIDUAL CYLINDER STRENGTH FROM MEAN

Concrete Mix		Age of Concrete -- Curing Condition										Average for Mix		
		7 Days		14 Days		28 Days		60 Days		120 Days				
		Sealed	Moist	Sealed	Moist	Sealed	Moist	Sealed	Moist	Sealed	Moist	Sealed	Moist	Sealed & Moist
Berks 1 1/2 in. Pozzolith 300R														
G-15	7.5 scy	1.9	0.4	1.6	0.8	5.0	2.0	4.6	3.1	1.3	3.3	2.9	1.9	2.4
G-16	8 scy	2.8	0.4	3.3	3.2	3.0	3.0	6.8	4.1	0.3	2.7	3.2	2.7	3.0
G-17	8.5 scy	1.5	3.1	3.6	0.2	4.5	3.7	4.8	3.8	4.0	0.7	3.7	2.3	3.0
Berks 1 1/2 in. Daratard 40														
G-19	7.5 scy	...	1.8	...	1.3	...	2.3	...	2.6	...	1.1	...	1.8	1.8
G-18	8 scy	2.3	2.0	2.5	1.5	3.1	2.2	2.6	3.5	1.0	1.2	2.3	2.1	2.2
G-20	8.5 scy	...	3.9	...	4.6	...	3.8	...	5.0	...	0.1	...	3.5	3.5
Berks 3/4 in. Pozzolith 300R														
G-21	7.5 scy	6.0	2.6	1.8	0.8	1.9	1.4	2.5	1.5	0.6	1.8	2.6	1.6	2.1
G-22	8 scy	0.8	1.5	2.5	0.5	2.9	2.6	3.3	2.3	1.6	1.8	2.2	1.7	2.0
G-23	8.5 scy	0.9	0.2	1.0	0.9	1.7	2.5	2.6	1.6	3.5	2.1	1.9	1.5	1.7
York 1 1/2 in. Pozzolith 300R														
G-28	7 scy	5.0	3.8	1.4	2.5	2.0	1.5	4.6	2.9	0.7	2.3	2.7	2.6	2.7
G-24	7.5 scy	...	2.0	...	2.6	...	2.1	...	2.1	...	2.2	...	2.2	2.2
G-26	8 scy	1.5	0.6	0.7	0.8	1.6	3.6	3.6	2.3	0.9	2.1	1.7	1.9	1.8
York 1 1/2 in. Daratard 40														
G-29	7 scy	2.8	1.0	1.2	2.4	2.8	2.2	2.8	1.3	0.6	1.2	2.0	1.6	1.8
G-25	7.5 scy	...	2.0	...	0.3	...	2.7	...	4.8	...	1.9	...	2.3	2.3
G-27	8 scy	6.0	4.6	2.9	2.6	2.9	3.3	3.4	5.0	1.7	1.3	3.4	3.4	3.4
York 3/4 in. Pozzolith 300R														
G-30	7 scy	2.5	4.2	3.0	3.6	2.6	3.1	2.4	0.9	2.5	0.8	2.6	2.5	2.6
G-31	7.5 scy	0.8	5.0	2.6	1.2	1.9	2.9	3.2	1.9	2.1	1.7	2.1	2.5	2.3
G-32	8 scy	2.5	2.8	1.0	1.8	1.2	1.9	4.7	1.7	1.0	2.2	2.1	2.1	2.1
Average for Age		2.7	2.3	2.1	1.8	2.7	2.6	3.7	2.8	1.6	1.7	2.5	2.2	2.4

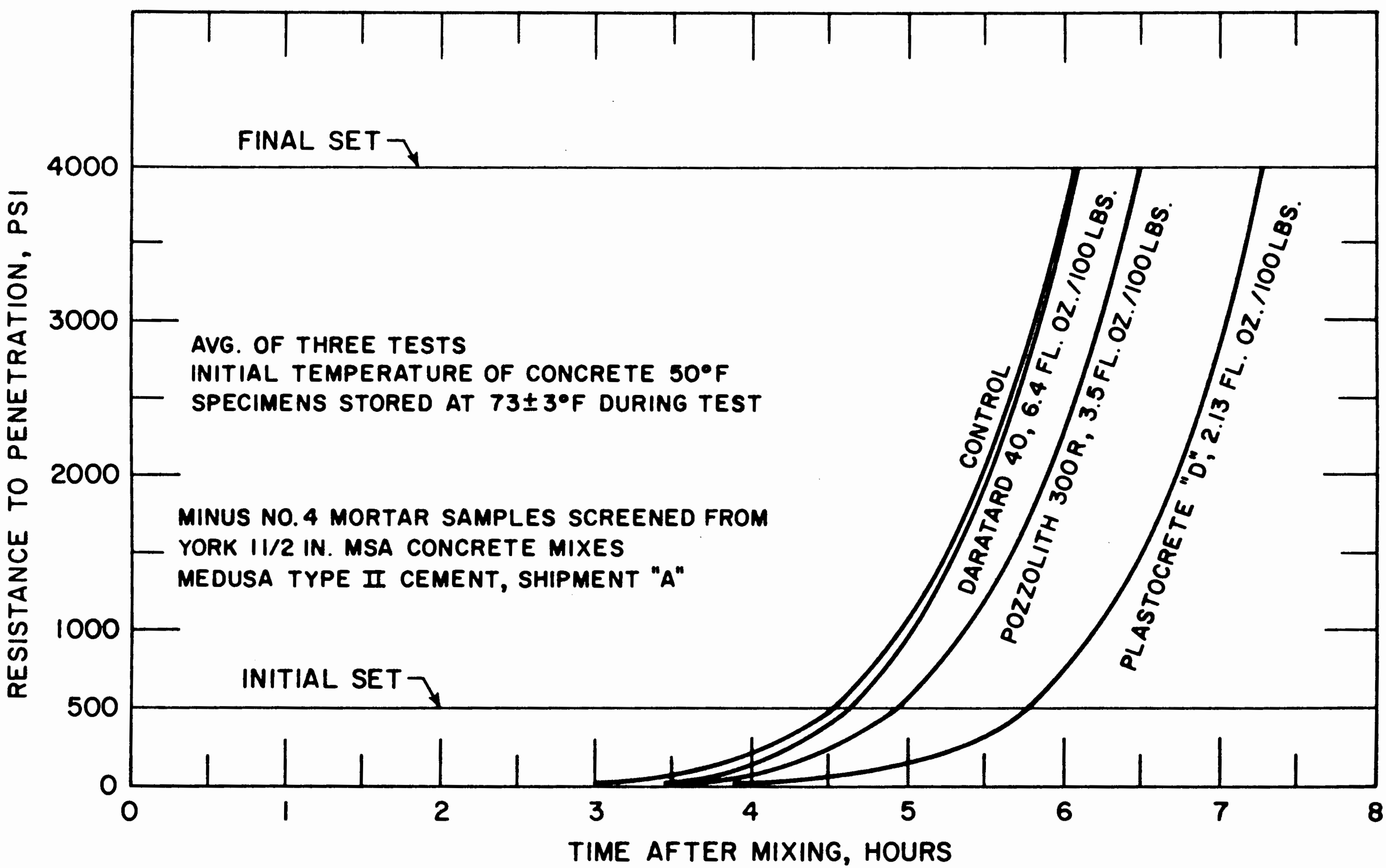

FIGURE 1-- TIME OF SETTING OF 7.5 SCY CONCRETES CONTAINING ADMIXTURES

FIG. 1

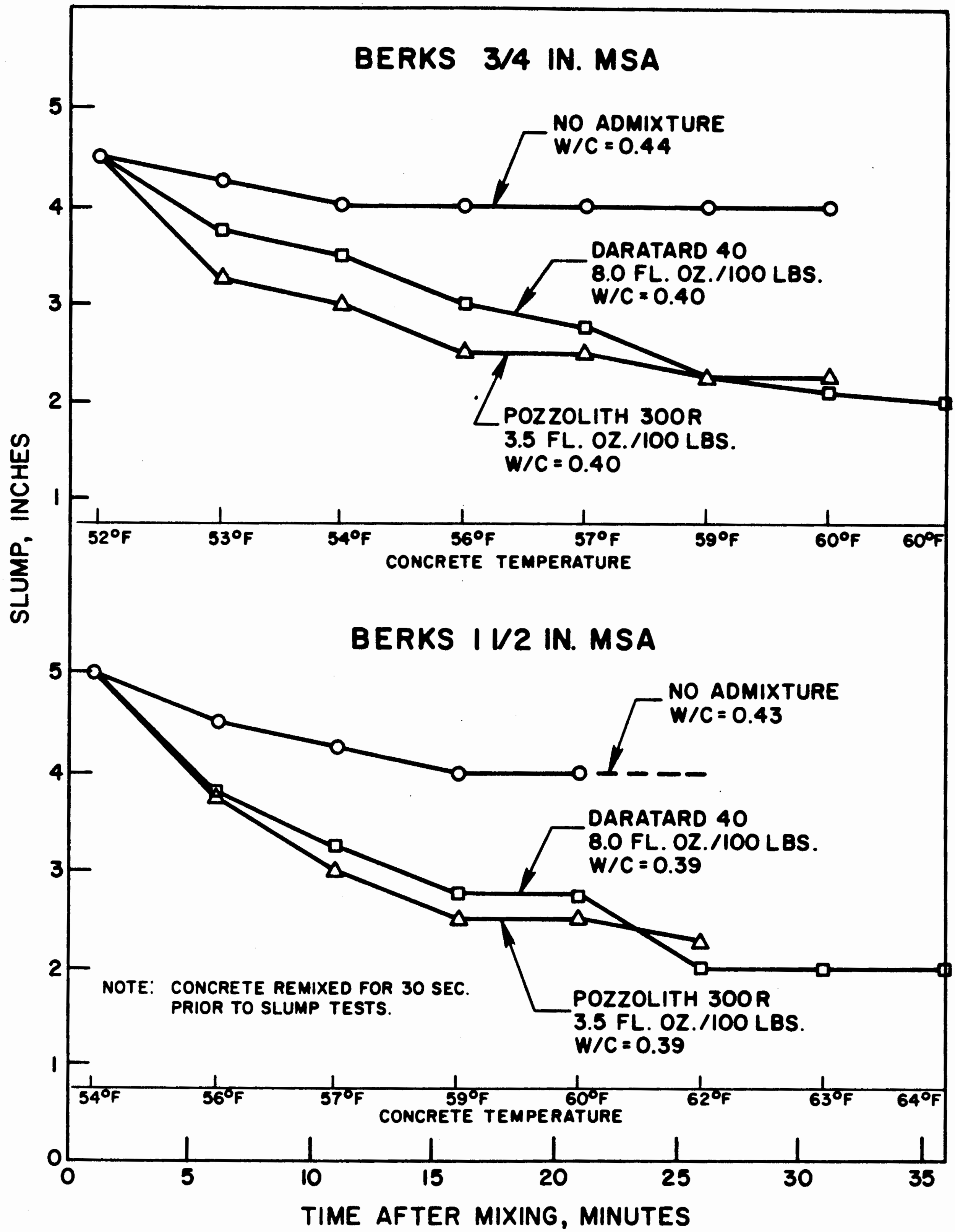

FIGURE 2-- SLUMP LOSS OF 8 SCY CONCRETES, MEDUSA TYPE II LOW ALKALI CEMENT

APPENDIX A -- TEST PROGRAM

APPENDIX A--TEST PROGRAM

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The test program consists of the following three phases:

I. Materials' Selection and Evaluation

II. Concrete Mix Development

III. Concrete Long-Term Behavior

A description of the three phases, the number of concrete specimens cast and the tests conducted are given below for each phase. The investigation satisfies the General Atomic (GA) test program specification 900670, Issue B, 9/5/74. A comparison is made of actual tests conducted at the University of California, Berkeley (UC), to the requirements of GA specification 900670. The total number of specimens cast for each phase of the research program is summarized on pages A20 and A21.

1. Phase I - Materials' Selection and Evaluation

This phase of the program was concerned with the evaluation of the concrete-making materials. The following four groups of tests, 1.1 to 1.4, were conducted.

1.1 Evaluation of Coarse Aggregates - Phase I(a).--Three coarse aggregates, York, Berks, and Hempt, were tested using 1 mix design. The following three tests were conducted:

1.1.1 Compression.--A total of 27 - 6x12-in. specimens were cast with 9 containing York, 9 containing Berks and 9 containing Hempt coarse aggregate. The specimens were moist-cured at 73°F and tested in compression at the ages indicated in the following tabulation. Modulus of elasticity and Poisson's ratio were determined on all of the compression specimens.

1.1.2 Drying Shrinkage.--A total of 9 - 4x4x11-in. concrete prisms were cast, three for each aggregate type (York, Berks and Hempt). Drying shrinkage (after moist-curing until age 28 days) for storage at 50% relative humidity at 73°F was reported for ages 4, 7, 14, 28, 56, 112, 224, and 448 days.

1.1.3 Coefficient of Thermal Expansion.--A total of 9 - 6x16-in. specimens were cast, each instrumented with a 10-in. gage length SL-10 Carlson meter. Three specimens were tested for each aggregate type (York, Berks and

Hempt). The specimens were sealed and subjected to three temperature cycles of 73-90-110-135-160-135-110-90-73°F beginning at age 28 days.

SPECIMENS FOR EVALUATION OF COARSE AGGREGATES - PHASE I(a)

Test	Number of Specimens Tested at Following Ages, Days			Total No. of Specimens
	7	28	60	
A) UC				
1.1.1 Compression				
a) York	3	3	3	9
b) Berks	3	3	3	9
c) Hempt	3	3	3	9
			Total 6x12-in. =	27
1.1.2 Drying Shrinkage				
a) York	3 - 4x4x11-in.			3
b) Berks	3 - 4x4x11-in.			3
c) Hempt	3 - 4x4x11-in.			3
			Total 4x4x11-in. =	9
1.1.3 Coefficient of Thermal Expansion				
a) York	3 - 6x16-in. instrumented			3
b) Berks	3 - 6x16-in. instrumented			3
c) Hempt	3 - 6x16-in. instrumented			3
			Total 6x16-in. =	9
B) 900670, Issue B, 9/5/74				
Compression			6x12-in. =	27
Drying Shrinkage			4x4x11-in. =	9
Coefficient of Thermal Expansion			6x16-in. =	9

1.2 Evaluation of Admixtures - Phase I(b).--Three admixtures, Pozzolith 300R, Daratard 40 and Plastocrete-D, were evaluated using 1 mix design with the following six (6) tests conducted: slump, bleeding, air content, time of setting, compressive strength and drying shrinkage. The following specimens were cast for the compression and drying shrinkage tests:

1.2.1 Compression.--A total of 48 - 6x12-in. specimens were cast, 12 containing each of the three admixtures, Pozzolith 300R, Daratard 40 and Plastocrete-D, and 12 as controls containing no admixture. The specimens were moist-cured at 73°F and tested in compression at the ages indicated in the following tabulation.

1.2.2 Drying Shrinkage.--A total of 16 - 4x4x11-in. concrete prisms were cast, four (4) for each of the three admixtures (Pozzolith 300R, Daratard 40 and Plastocrete-D and four (4) for the control containing no admixture. Drying shrinkage for storage at 50% relative humidity at 73°F was reported for ages 4, 7, 14, 28, 56, 112 and 448 days.

SPECIMENS FOR EVALUATION OF ADMIXTURES - PHASE I(b)

Test	Number of Specimens Tested at Following Ages, Days				Total No. of Specimens
	7	14	28	60	
A) UC					
1.2.1 Compression					
a) Control	3	3	3	3	12
b) Pozzolith 300R	3	3	3	3	12
c) Daratard 40	3	3	3	3	12
d) Plastocrete-D	3	3	3	3	12
			Total 6x12-in. =		48
1.2.2 Drying Shrinkage					
a) Control		4 - 4x4x11-in.			4
b) Pozzolith 300R		4 - 4x4x11-in.			4
c) Daratard 40		4 - 4x4x11-in.			4
d) Plastocrete-D		4 - 4x4x11-in.			4
			Total 4x4x11-in.=		16
B) 900670, Issue B, 9/5/74					
Compression				6x12-in. =	48
Drying Shrinkage				4x4x11-in. =	12

1.3 Preliminary Evaluation of Cement Content.--The following three groups of trial mixes, 1.3.1 to 1.3.3, were cast for evaluation of cement content versus compressive strength:

1.3.1 Trial Mixes (a).--Three 8.0 scy mixes made with 1 1/2-in. MSA were tested. One mix contained Pozzolith 300R, one contained Daratard 40 and one contained no admixture and was used as a control. A total of 36 - 6x12-in. specimens were cast. The specimens were moist-cured at 73°F and tested in compression at the ages indicated in the following tabulation.

1.3.2 Trial Mixes (b).--Three 8.0 scy mixes made with 3/4-in. MSA were tested. One mix contained Pozzolith 300R, one contained Daratard 40 and one contained no admixture and was used as a control. A total of 36 - 6x12-in. specimens were cast. The specimens were moist-cured at 73°F and tested in compression at the ages indicated in the following tabulation. Modulus of elasticity and Poisson's ratio were determined at ages 14, 28 and 60 days on the compression specimens.

1.3.3 Trial Mixes (c).--Four trial mixes were tested using 1 1/2-in. MSA. Three of the mixes contained Pozzolith 300R as the admixture and had a cement content of 7.5, 8.0 and 8.5 scy, respectively. The fourth mix contained Daratard 40 and had a cement content of 8.0 scy. A total of 24 - 6x12-in. specimens, 6 from each one of the four mixes, were cast and tested in compression at the ages indicated in the following tabulation. Modulus of elasticity and Poisson's ratio were determined on the 28 and 60-day compression specimens.

SPECIMENS FOR PRELIMINARY EVALUATION OF CEMENT CONTENT

Test		Number of Specimens Tested at Following Ages, Days				Total No. of Specimens
		7	14	28	60	
A) UC						
1.3.1	Trial Mixes (a) - Compression					
	a) Control	3	3	3	3	12
	b) Pozzolith 300R	3	3	3	3	12
	c) Daratard 40	3	3	3	3	12
					Total 6x12-in. =	36
1.3.2	Trial Mixes (b) - Compression					
	a) Control	3	3	3	3	12
	b) Pozzolith 300R	3	3	3	3	12
	c) Daratard 40	3	3	3	3	12
					Total 6x12-in. =	36
1.3.3	Trial Mixes (c) - Compression					
	a) 7.5 scy Pozzolith 300R	2	...	2	2	6
	b) 8.0 scy Pozzolith 300R	2	...	2	2	6
	c) 8.5 scy Pozzolith 300R	2	...	2	2	6
	d) 8.0 scy Daratard 40	2	...	2	2	6
					Total 6x12-in. =	24
B) 900670, Issue B, 9/5/74						NO TESTS

1.4 Evaluation of Sand Content.--Four mixes were tested to evaluate the effect of sand content on the properties of the fresh concrete and on compressive strength. Three of the mixes contained Pozzolith 300R and had a sand content of 36, 38 and 41 percent of total aggregate weight, respectively, and the fourth mix contained Daratard 40 and a sand content of 36%. A total of 24 - 6x12-in. specimens, 6 from each of the four mixes, were cast and moist-cured at 73°F. The specimens were tested in compression at the ages indicated in the following tabulation.

SPECIMENS FOR EVALUATION OF SAND CONTENT

Test	Number of Specimens Tested at Following Ages, Days			Total No. of Specimens
	7	28	60	
A) UC				
Compression				
a) 36% sand, Pozzolith 300R	2	2	2	6
b) 38% sand, Pozzolith 300R	2	2	2	6
c) 41% sand, Pozzolith 300R	2	2	2	6
d) 36% sand, Daratard 40	2	2	2	6
			Total 6x12-in. =	24
B) 900670, Issue B, 9/5/74				NO TESTS

2. Phase II - Concrete Mix Development

This phase of the program was concerned with the development of concrete mixes which will have the required strength and physical properties specified for the construction of the PCRV. The following two groups of tests, 2.1 to 2.2, were conducted in this phase.

2.1 Concrete Trial Mixes - Phase II(a) and II(b).--A total of 18 mixes, 9 containing York aggregate and 9 containing Berks aggregate were evaluated. The MSA, admixture and cement content used in each mix is tabulated on the following page along with the total number of 6x12-in. sealed or moist-cured specimens cast from each mix.

CONCRETE TRIAL MIXES - PHASE II(a) and II(b)

Aggregate	MSA, inches	Admixture	Mix Designation	Cement Content, scy	Specimen Cast	
					Sealed	Moist-Cured
	1 1/2	Pozzolith 300R	G-15	7.5	21	21
			G-16	8	21	21
			G-17	8.5	21	21
Berks	1 1/2	Daratard 40	G-19	7.5	-	21
			G-18	8	21	21
			G-20	8.5	-	21
	3/4	Pozzolith 300R	G-21	7.5	21	21
			G-22	8	21	21
			G-23	8.5	21	21
	1 1/2	Pozzolith 300R	G-28	7	21	21
			G-24	7.5	-	21
			G-26	8	21	21
York	1 1/2	Daratard 40	G-29	7	21	21
			G-25	7.5	-	21
			G-27	8	21	21
	3/4	Pozzolith 300R	G-30	7	21	21
			G-31	7.5	21	21
			G-32	8	21	21

A total of 672 - 6x12-in. specimens were cast, 336 for each aggregate group. Of the 336, 147 were sealed specimens and 189 were moist-cured specimens. The specimens were tested in compression at the ages indicated in the following tabulation; Berks on page A8 (2.1.1) and York on page A9 (2.1.2).

In addition to these compressive strength tests, modulus of elasticity and Poisson's ratio was determined on three of the six compression specimens tested at ages of 28 and 60 days and on the three compression specimens tested at 120 days.

SPECIMENS FOR CONCRETE TRIAL MIXES - PHASE II(a) AND II(b)

Test		Number of Specimens Tested at Following Ages, Days: 7	14	28	60	120	Total No. of Specimens
A) UC							
2.1.1 Berks Aggregate - Compression							
a) Sealed Specimens							
Pozzolith 300R 1 1/2-in. MSA	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
	8.5	3	3	6	6	3	21
Daratard 40 1 1/2-in. MSA	8	3	3	6	6	3	21
Pozzolith 300R 3/4-in. MSA	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
	8.5	3	3	6	6	3	21
Total Sealed Berks 6x12-in.							= 147
b) Moist-Cured Specimens							
Pozzolith 300R 1 1/2-in. MSA	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
	8.5	3	3	6	6	3	21
Daratard 40 1 1/2-in. MSA	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
	8.5	3	3	6	6	3	21
Pozzolith 300R 3/4-in. MSA	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
	8.5	3	3	6	6	3	21
Total Moist-Cured Berks 6x12-in.							= 189
Total Berks 6x12-in.							= 336

SPECIMENS FOR CONCRETE TRIAL MIXES - PHASE II(a) AND II(b)
(Continued)

Test		Number of Specimens Tested at Following Ages, Days 7	14	28	60	120	Total No. of Specimens
2.1.2 York Aggregate - Compression							
a) Sealed Specimens							
Pozzolith 300R 1 1/2-in. MSA	7	3	3	6	6	3	21
	8	3	3	6	6	3	21
Daratard 40 1 1/2-in. MSA	7	3	3	6	6	3	21
	8	3	3	6	6	3	21
Pozzolith 300R 3/4-in. MSA	7	3	3	6	6	3	21
	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
		Total Sealed York 6x12-in.					= 147
b) Moist-Cured Specimens							
Pozzolith 300R 1 1/2-in. MSA	7	3	3	6	6	3	21
	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
Daratard 40 1 1/2-in. MSA	7	3	3	6	6	3	21
	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
Pozzolith 300R 3/4-in. MSA	7	3	3	6	6	3	21
	7.5	3	3	6	6	3	21
	8	3	3	6	6	3	21
		Total Moist-Cured York 6x12-in.					= 189
		Total York 6x12-in.					= 336
		Total Berks and York 6x12-in.					= 672

SPECIMENS FOR CONCRETE TRIAL MIXES - PHASE II(a) AND II(b)
(Continued)

Test	Number of Specimens Tested at Following Ages, Days					Total No. of Specimens
	7	14	28	60	120	
B) 900670, Issue B, 9/5/74 - Phase II(a)						
Primary Aggregate - Compression						
Sealed Specimens - 3 Mixes for Each Aggregate Size (3x)						
1 1/2-in. MSA (3x)	3	3	6	6	3	63
3/4-in. MSA (3x)	3	3	6	6	3	63
Moist-Cured Specimens - 3 Mixes for Each Aggregate Size (3x)						
1 1/2-in. MSA (3x)	3	3	6	6	3	63
3/4-in. MSA (3x)	3	3	6	6	3	63
Total for Primary Aggregate 6x12-in.						= 256
Alternate Aggregate - Same as Primary Aggregate						
Total for Alternate Aggregate 6x12-in.						= 256
Total for Phase II(a) and II(b) 6x12-in.						= 504

2.2 Selected Concrete Mixes - Phase II(c).--The concrete mixes selected for evaluation in Phase II(a) and II(b), mix Berks G-19 and mix York G-25 were tested for compressive strength, tensile strength, modulus of elasticity and Poisson's ratio as determined from both sealed and moist-cured 6x12-in. specimens and the effect of slump on compressive strength was determined from 6x12-in. moist-cured specimens. When the compressive strength of mix G-19 and G-25 concretes was lower than expected, the selected mix for York aggregate concretes for use in Phase III was changed to mix York G-26, also developed in Phase II(a) and II(b).

All specimens were cured at 73°F until age of test. The specimens cast, curing conditions and tests for each concrete mix are discussed below. The ages of test are given in the following tabulation.

2.2.1 Mix Berks G-19.--A total number of 108 - 6x12-in. specimens were cast in Phase II(c) with mix Berks G-19. The number of specimens used for each test is given on page A12.

a) Compressive Strength and Elastic Properties.--A total of 54 - 6x12-in. specimens were cast for determination of compressive strength at ages 7, 28, 60, 90, 120, 180, 270, 365 and 730 days. Twenty-seven (27) were sealed and 27 were moist-cured. The modulus of elasticity was determined on the compression specimens at ages 28, 60, 90, 270 and 730 days.

b) Tensile Strength.--A total of 42 - 6x12-in. specimens were cast for determination of splitting tensile strength, at age 7, 28, 60, 90, 180, 270 and 730 days. Of these 21 were sealed and 21 were moist-cured. The percent of coarse aggregate fractured was determined for each specimen tested.

c) Effect of Slump on Compressive Strength.--On the same day of casting of the selected mix specimens, specimens were cast for the evaluation of the effect of change in slump on compressive strength (approx. 2-in. and 8-in. slump). Six 6x12-in. specimens were cast for each slump, with three specimens each tested in compression after 28 and 60 days of moist-curing.

2.2.2 Mix York G-25.--A total number of 108 - 6x12-in. specimens were cast in Phase II(c) with mix York G-25. The number of specimens used for each test is given on page A12.

a) Compressive Strength and Elastic Properties.--Same as 2.2.1a.

b) Tensile Strength.--Same as 2.2.1b.

c) Effect of Slump on Compressive Strength.--Same as 2.2.1c.

2.2.3 Mix York G-26.--A total number of 33 - 6x12-in. specimens were cast in Phase II(c) with mix York G-26. The number of specimens used for each test is given on page A13.

a) Compressive Strength and Elastic Properties.--A total of 33 - 6x12-in. specimens were cast for determination of compressive strength. Of these, 12 were sealed and tested at ages 28, 60, 90 and 270 days and 21 were moist-cured and tested at ages 7, 28, 60, 90, 270, 365 and 730 days.

b) Tensile Strength.--No tests were requested by GA.

c) Effect of Slump on Compressive Strength.--No tests were requested by GA.

SPECIMENS FOR SELECTED CONCRETE MIXES - PHASE II(c)

Test	Number of Specimens to be Tested at the Following Ages, Days									Total No. of Specimens
	7	28	60	90	120	180	270	365	730	
A) UC										
2.2.1 Mix Berks G-19										
a) Compression										
Sealed	3	3	3	3	3	3	3	3	3	27
Moist-Cured	3	3	3	3	3	3	3	3	3	27
b) Tension										
Sealed	3	3	3	3	...	3	3	...	3	21
Moist-Cured	3	3	3	3	...	3	3	...	3	21
c) Slump										
Moist-Cured										
Low, 2 in.	...	3	3	...	...	...	...	...	...	6
High, 8 in.	...	3	3	...	...	...	...	...	...	6
Total for Mix Berks G-19 6x12-in.										= 108
2.2.2 Mix York G-25										
a) Compression										
Sealed	3	3	3	3	3	3	3	3	3	27
Moist-Cured	3	3	3	3	3	3	3	3	3	27
b) Tension										
Sealed	3	3	3	3	...	3	3	...	3	21
Moist-Cured	3	3	3	3	...	3	3	...	3	21
c) Slump										
Moist-Cured										
Low, 2 in.	...	3	3	...	...	...	...	...	...	6
High, 8 in.	...	3	3	...	...	...	...	...	...	6
Total for Mix York G-25 6x12-in.										= 108

SPECIMENS FOR SELECTED CONCRETE MIXES - PHASE II(c)

(Continued)

Test	Number of Specimens to be Tested at the Following Ages, Days									Total No. of Specimens
	7	28	60	90	120	180	270	365	730	
2.2.3 Mix York G-26										
a) Compression										
Sealed	...	3	3	3	...	...	3	...	...	12
Moist-cured	3	3	3	3	...	...	3	3	3	21
	Total for Mix G-26 6x12-in.									= 33
	Total for Phase II(c) 6x12-in.									= 249

Test	Number of Specimens to be Tested at the Following Ages, Days						Total No. of Specimens
	7	14	28	60	120	180	
B) 900670, Issue B, 9/5/74							
Primary Aggregate							
Compression							
Sealed	3	3	3	3	3	3	18
Moist-cured	3	3	3	3	3	3	18
Tension							
Sealed	3	3	3	3	3	3	18
Moist-cured	3	3	3	3	3	3	18
Slump							NO TEST
	Total for Primary Aggregate 6x12-in.						= 72
Alternate Aggregate - Same as Primary Aggregate							
	Total for Alternate Aggregate 6 x 12-in.						= 72
	Total for Test Phase II(c) 6x12-in.						= 144

3. Phase III - Concrete Long-Term Behavior

In this phase, currently in progress, the behavior of the selected mix Berks G-19 and York G-26 concretes under exposure to long-term loads and elevated temperatures is investigated. Also the thermal properties of mix Berks G-19 and York G-26 concretes and effect of thermal cycling on strength and mechanical properties of the mix Berks G-19 and York G-25 concretes is determined.

3.1 Creep under 30% f'_c at 73°, 110° and 160° - Phase III(a).--A total of 54 - 6x16-in. creep specimens are tested for determination of creep characteristics at a 30 percent f'_c load level determined at the age of loading at 73°F. Twenty-seven (27) specimens are cast from mix Berks G-19 and 27 from mix York G-26. Of the 27 specimens for each aggregate type, 9 specimens each are tested at 73, 110 and 160°F. Of the 9 specimens at each temperature, 3 specimens each are loaded at ages of 28, 90 and 270 days.

A total of 42 - 6x16-in. creep control specimens are tested for autogenous volume change or drying shrinkage, with 21 specimens tested for each aggregate type. Only three (3) creep control specimens are required at 73°F, while at 110°F and 160°F there are nine (9) creep control specimens, three for each loading age. Of the three creep control specimens at a given age of loading, two will be sealed and one will be unsealed at time of loading.

In addition, each of the specimen groups at each temperature will have 12 - 6x12-in. sealed compressive strength control specimens. Three of these specimens will be tested at age 7 days as a control on the concrete mix used, and three specimens each tested subsequently at the age of loading for the creep specimens at 28, 90 and 270 days, to determine the percentage of load applied on the creep specimens, which is to have a nominal value of 30 percent of f'_c. A summary of the specimens cast and the test conditions are summarized in the following tabulation for the concretes of mixes Berks G-19 (3.1.1) and York G-26 (3.1.2).

SPECIMENS FOR 30% f'_c CREEP TESTS - PHASE III(a)

Test	Number of Specimens Tested at Following Ages, Days: 7	28	90	270	Total No. of Specimens
A) UC					
3.1.1 Mix Berks G-19					
a) Tests at 73°F					
Creep	-	3	3	3	9
Creep Control	-	3	-	-	3
Compression	3	3	3	3	12*
b) Tests at 110°F					
Creep	-	3	3	3	9
Creep Control	-	3	3	3	9
Compression	3	3	3	3	12*
c) Tests at 160°F					
Creep	-	3	3	3	9
Creep Control	-	3	3	3	9
Compression	3	3	3	3	12*
Total for Mix Berks G-19			6x16-in.		= 48
			6x12-in.		= 36*
3.1.2 Mix York G-26					
a) Tests at 73°F					
Creep	-	3	3	3	9
Creep Control	-	3	-	-	3
Compression	3	3	3	3	12*
b) Tests at 110°F					
Creep	-	3	3	3	9
Creep Control	-	3	3	3	9
Compression	3	3	3	3	12*
c) Tests at 160°F					
Creep	-	3	3	3	9
Creep Control	-	3	3	3	9
Compression	3	3	3	3	12*
Total for Mix York G-26			6x16-in.		= 48
			6x12-in.		= 36*
Total for Phase III(a)			6x-16-in.		= 96
			6x12-in.		= 72*

SPECIMENS FOR 30% f'_c CREEP TESTS - PHASE III(a)
(Continued)

Test	Number of Specimens Tested at Following Ages, Days					Total No. of Specimens
	7	28	90	270		
B) 900670, Issue B, 9/5/74						
Creep - Same as A)					6x16-in.	= 54
Creep Control - Same as A)					6x16-in.	= 42
Compression						NO TEST
Total for Phase III(a)					6x16-in.	= 96

3.2 Creep Under 45% and 60% f'_c at 73° and 160°F - Phase III(b).-- A total of 24 - 6x16-in. creep specimens are tested for the determination of creep characteristics at a 45 or 60 percent f'_c load level determined at the age of loading at 73°F. For each aggregate type 12 - 6x16-in. creep specimens will be cast, six for each stress level with three tested at 73°F and three at 160°F. All creep specimens will be loaded at age 90 days. There are no creep control specimens cast with these specimens since the controls cast for the 30% load level specimens, 3.1, at 73° and 160°F also serve as controls for the higher stress level creep specimens. Nine (9) 6x12-in. compressive strength controls will be cast for each aggregate type. Three of these will be tested at age 7 days as a control on the concrete mix used, and three specimens each will be tested at 90 days at 73°F and at 160°F. A summary of the specimen cast and test condition is given below for the concretes of mixes Berks G-19 (3.2.1) and York G-26 (3.2.2).

SPECIMENS FOR 45% AND 60% f'_c CREEP TESTS - PHASE III(b)

	Number of Specimens Tested at Following Temperatures		Total No. of Specimens
	73°F	160°F	
A) UC			
3.2.1 Mix Berks G-19			
Creep at 45% f'_c	3	3	6
60% f'_c	3	3	6
Compression at			
7 days	3	...	3*
90 days	3	3	6*
Total for Mix Berks G-19		6x16-in. 6x12-in.	= 12 = 9*

SPECIMENS FOR 45% AND 60% f'_c CREEP TESTS - PHASE III(b)
(Continued)

Test	Number of Specimens Tested at Following Temperatures		Total No. of Specimens
	73°F	160°F	
3.2.2 <u>Mix York G-26</u>			
Creep at 45% fc'	3	3	6
Creep at 60% fc'	3	3	6
Compression at			
7 days	3	...	3*
90 days	3	3	6*
	Total for Mix York G-26	6x16-in. 6x12-in.	= 12 = 9*
	Total for Phase III(b)	6x16-in. 6x12-in.	= 24 = 18*
B) 900670, Issue B, 9/5/74			
Creep - Same as A)		6x16-in.	= 24
Compression			NO TEST
	Total for Phase III(b)	6x16-in.	= 24

3.3 Thermal Cycling - Phase III(c).--A total of 96 - 6x12-in. and 6 instrumented 6x16-in. specimens are tested for the effect of thermal cycling on compressive and splitting tensile strength and for the determination of residual strain. For each aggregate a total of 48 - 6x12-in. specimens and 3 instrumented 6x16-in. specimens will be cast using the selected concrete mixes (Berks and York). Of these specimens 30 - 6x12-in. and the 3 instrumented 6x16-in. specimens will be cycled beginning at age 90 days for up to 5 temperature cycles of 73-160-73°F. All specimens will remain sealed during curing and cycling. At the end of every cycle three specimens will be tested in compression and three in splitting tension. The three instrumented 6x16-in. specimens will be used to monitor residual strains during the thermal cycling. Eighteen (18) of the 6x12-in. specimens will be used as controls at 73°F, with three being tested in compression and three in splitting tension at the start of cycling, after the second cycle and at the end of cycling. Modulus of elasticity and Poisson's ratio will be determined on all compression specimens. A summary of the specimens to be cast and at which cycle they are to be tested is given in the following tabulation for the concretes of mixes Berks G-19 (3.3.1) and York G-25 (3.3.2).

SPECIMENS FOR THERMAL CYCLING TESTS - PHASE III(c)

	Number of Specimens to be Tested at the End of the Following Cycle No.						Total No. of Specimens
	0	1	2	3	4	5	
A) UC							
3.3.1 Mix Berks G-19							
Cycled 73-160-73°F							
Compression	...	3	3	3	3	3	15
Tension	...	3	3	3	3	3	15
Instrumented	Three - 6x16-in., monitored for residual strains						3*
Controls at 73°F							
Compression	3	...	3	...	...	3	9
Tension	3	...	3	...	...	3	9
	Total for Mix Berks G-19					6x12-in. 6x16-in.	= 48 = 3*
3.3.2 Mix York G-25							
Cycled 73-160-73°F							
Compression	...	3	3	3	3	3	15
Tension	...	3	3	3	3	3	15
Instrumented	Three - 6x16-in., monitored for residual Strains						3*
Controls at 73°F							
Compression	3	...	3	...	...	3	9
Tension	3	...	3	...	...	3	9
	Total for Mix York G-25					6x12-in. 6x16-in.	= 48 = 3*
	Total for Test Phase III(c)					6x12-in. 6x16-in.	= 96 = 6*

SPECIMENS FOR THERMAL CYCLING TESTS - PHASE III(c)
(Continued)

Test	Number of Specimens to be Tested at the End of the Following Cycle No.						Total No. of Specimens
	0	1	2	3	4	5	
B) 900670, Issue B, 9/5/74							
Primary Aggregate							
Cycled 73-160-73°F - Same as A)							
Compression				Total			6x12-in. = 15
Tension							6x12-in. = 15
Instrumented							6x16-in. = 3
Controls at 73°F							NO TEST
Total for Primary Aggregate							6x12-in. = 30 6x16-in. = 3
Alternate Aggregate							
Cycled 73-160-73°F - Same as A)							
Compression				Total			6x12-in. = 15
Tension							6x12-in. = 15
Instrumented							6x16-in. = 3
Controls at 73°F							NO TEST
Total for Alternate Aggregate							6x12-in. = 30 6x16-in. = 3
Total for Phase III(c)							6x12-in. = 60 6x16-in. = 6

3.4 Thermal Properties.--Adiabatic temperature rise is determined for Berks G-19 concrete only. In addition to the adiabatic temperature rise, there are 12 - 6x12-in. sealed compression controls. Six 6x12-in. specimens are cured adiabatically with the 27x30-in. specimen for two weeks and subsequently at 110°F until age of test. Six 6x12-in. specimens are cured at 73°F. Three specimens from each group are tested at ages 28 and 60 days.

For the Berks G-19 and York G-26 concretes specific heat and diffusivity is determined.

4. Summary of Test Program

The following is a summary of the test program as performed at the University of California (UC) and as specified by General Atomic (GA) in its Specification 900670, Issue B, 9/5/74. The size and number of specimens used in the three phases of test program are given in the following tabulation:

SIZE AND NUMBER OF SPECIMENS USED IN THE TEST PROGRAM

Test Program		Used in UC Tests	GA Spec. 900670, Issue B, 9/5/74
1. Phase I - Materials' Selection and Evaluation			
1.1 Evaluation of Coarse Aggregate Phase I(a)			
1.1.1 Compression	6x12-in.	27	27
1.1.2 Drying Shrinkage	4x4x11-in.	9	9
1.1.3 Coeff. of Thermal Exp.	6x16-in.	9	9
1.2 Evaluation of Admixture Phase I(b)			
1.2.1 Compression	6x12-in.	48	48
1.2.2 Drying Shrinkage	4x4x11-in.	16	12
1.3 Preliminary Evaluation of Cement Content			
1.3.1 Trial Mixes (a)	6x12-in.	36	...
1.3.2 Trial Mixes (b)	6x12-in.	36	...
1.3.3 Trial Mixes (c)	6x12-in.	24	...
1.4 Evaluation of Sand Content	6x12-in.	24	...
Total Phase I		229	105
2. Phase II - Concrete Mix Development			
2.1 Compression Phase II(b)	6x12-in.	672	504(252)*
2.2 Selected Mix	6x12-in.	249	144 (72)
3. Phase III - Concrete Long-Term Behavior			
3.1 Creep at 30% f'_c - Phase III(a)			
Creep and Creep Controls	6x16-in.	96	96 (48)
Compression	6x12-in.	72	...
3.2 Creep at 45 and 60% f'_c - Phase III(b)			
Creep	6x16-in.	24	24 (12)
Compression	6x12-in.	18	...

Continued next page

* See footnote on next page

SIZE AND NUMBER OF SPECIMENS USED IN THE TEST PROGRAM
(Continued)

		Used in UC Tests	GA Spec. 900670 Issue B, 9/5/74
3.3 Thermal Cycling			
Cycled 73-160-73°F			
Instrumented	6x16-in.	6	6 (3)*
Compression	6x12-in.	30	30 (15)
Tension	6x12-in.	30	30 (15)
Controls at 73°F	6x12-in.	36	...
3.4 Thermal Properties			
Adiabatic	27x30-in.	1	...
Compression	6x12-in.	24	...
Specific Heat	8x16-in.	2	...
Diffusivity	8 1/2 x17-in.	2	...
	Total Phase II and III	1262	834 (417)
	Total Phase I	229	105 (105)
	Total for Test Program	1491	939 (522)

* The value in ( ) represents the number of specimens for one aggragate as specified for Phase II and III in GA Specification 900670 Issue B. In the test program, two aggregates were evaluated.

APPENDIX B--SUMMARY OF TEST PROCEDURES

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The test procedures used in Phase I and Phase II of the test program are summarized in this Appendix. Included is a description of material preparation and testing, mixing, tests for properties of fresh concrete, casting procedures, preparation and storage conditions of sealed and moist-cured specimens, and testing of concretes for compressive strength, modulus of elasticity and Poisson's ratio, splitting tensile strength, drying shrinkage and linear coefficient of thermal expansion.

1. Material Preparation

1.1 Aggregates.--To assure a uniform gradation and moisture content of the aggregates used in the concretes of this test program, each shipment of aggregate type was blended and brought to a moisture content close to a saturated surface dry (SSD) condition. The aggregate was then stored in labelled and numbered sealed 55-gallon steel drums. Each drum was labelled with the aggregate name, size, date of receipt, date of blending and research project name and identification number.

Prior to batching the aggregate from any particular drum, the aggregate within that drum was reblended to assure a uniformity of moisture content. After reblending, the moisture content of the aggregate was determined (ASTM C 566 - Total Moisture Content of Aggregate by Drying). The coarse and fine aggregates were then batched for each mix from these reblended aggregate drums. As the material inside the drums diminished to a point that there was not enough material for the batching of a complete mix, the remaining materials in the drums were set aside and used later in the preparation of additional drums of aggregates. This blending procedure gave a good aggregate moisture control for the several batches required for any given mix.

Blending of different shipments of each aggregate type was accomplished by consolidating the material from the different shipments into one stockpile and then blending the entire stockpile to assure uniform gradation and moisture content. The aggregate was then again stored in sealed 55-gallon steel drums.

1.2 Cement.--The cement was blended as soon as it was received in the laboratory. Blending of the cement was accomplished by placing one scoopful at a time from each bag received into each one of the 55-gallon capacity steel storage drums. The drums were then sealed with a sheet of plastic and the steel lid and stored in a 73°F controlled room until ready for use. Cement was batched from one drum at a time until it was emptied.

When two shipments of cement were used in a given mix, equal weights of shipment "A" and "B" were batched at the time of batching to yield the total weight of cement required for each mix. This assured that all batches had the same proportions of cement from each shipment.

2. Material Testing

Material testing at UC was limited to checking the properties and gradation of the aggregate needed for development of a good mix design and to check the properties and chemical analysis of the Medusa Type II cement shipments "A" and "B" when it became apparent that the two shipments of cement had different strength gain characteristics. All procedures followed were in accordance with standard test methods as listed below.

2.1 Aggregates.--The specific test methods used in testing of aggregates are:

ASTM C 33	Specification for Concrete Aggregates
ASTM C 117	Materials Finer than No. 200 Sieve in Mineral Aggregates by Washing
ASTM C 127	Specific Gravity and Absorption of Coarse Aggregate
ASTM C 128	Specific Gravity and Absorption of Fine Aggregate
ASTM C 136	Sieve or Screen Analysis of Fine and Coarse Aggregates
ASTM C 566	Total Moisture Content of Aggregate by Drying
CRD C 119	Corps of Engineers Method of Test for Flat and Elongated Particles in Coarse Aggregate

2.2 Cement.--The chemical analysis and heat of hydration of the cement and the compressive strength of mortar cubes were performed in accordance with the following test methods:

ASTM C 114	Chemical Analysis of Hydraulic Cement
ASTM C 186	Heat of Hydration of Hydraulic Cement
ASTM C 109	Compressive Strength of Hydraulic Cement Mortars

3. Mixing and Properties of Fresh Concrete

3.1 Number of Batches Used.--A 2 cu. ft. capacity "Lancaster" pan-type mixer was used for all castings in Phase I and II with the exception of York mix G-26 in Phase II(c) for which a 5 cu. ft. capacity "Cumflow" pan-type mixer was used. A summary of the number and size of batches mixed for each test phase, shown in Appendix A, is given in the following tabulation:

BATCHES USED FOR CASTING PHASE I AND II SPECIMENS

Specimen Group	No. of Batches	Size of Batches, cf
Phase I(a) Evaluation of Aggregates		
York	3	1.3
Berks	3	1.3
Hempt	3	1.3
Phase I(b) Evaluation of Admixtures		
Control	2	1.8
Plastocrete-D	2	1.8
Daratard 40	2	1.8
Pozzolith 300R	2	1.8
Preliminary Evaluation of Cement Content		
Trial Mixes (a)		
G-1 Control	2	1.3
G-2 Daratard 40	2	1.3
G-3 Pozzolith 300R	2	1.3
Trial Mixes (b)		
G-4 Control	2	1.6
G-5 Daratard 40	2	1.6
G-6 Pozzolith 300R	2	1.6
Trial Mixes (c)		
G-7 7.5 scy, Pozzolith 300R	1	1.5
G-12 8 scy, Pozzolith 300R	1	1.5
G-13 8.5 scy, Pozzolith 300R	1	1.5
G-11 8 scy, Daratard 40	1	1.5
Evaluation of Sand Content		
G-14 36%, Daratard 40	1	1.5
G-8 36%, Pozzolith 300R	1	1.5
G-9 38%, Pozzolith 300R	1	1.5
G-10 41%, Pozzolith 300R	1	1.5

BATCHES USED FOR CASTING PHASE I AND II SPECIMENS, Continued

Specimen Group				No. of Batches	Size of Batches, cf
Phase II(a) - Evaluation of Cement Content					
Berks Aggregate Concrete					
G-15	7.5	scy		6	1.5
G-16	8	scy	1 1/2-in. MSA, Pozzolith 300R	6	1.5
G-17	8.5	scy		6	1.5
G-19	7.5	scy		3	1.5
G-18	8	scy	1 1/2-in. MSA, Daratard 40	6	1.5
G-20	8.5	scy		3	1.5
G-21	7.5	scy		6	1.5
G-22	8	scy	3/4-in. MSA, Pozzolith 300R	6	1.5
G-23	8.5	scy		6	1.5
York Aggregate Concretes					
G-28	7	scy		6	1.5
G-24	7.5	scy	1 1/2-in. MSA, Pozzolith 300R	3	1.5
G-26	8	scy		6	1.5
G-29	7	scy		6	1.5
G-25	8.5	scy	1 1/2-in. MSA, Daratard 40	3	1.5
G-27	8	scy		6	1.5
G-30	7	scy		6	1.5
G-31	7.5	scy	3/4-in. MSA, Pozzolith 300R	6	1.5
G-32	8	scy		6	1.5
Phase II(c) - Selected Mixes					
Berks Aggregate Mix G-19					
Compression				6	1.9
Tension				6	1.45
Loss of Slump				2	1.3
York Aggregate Mix G-25					
Compression				6	1.9
Tension				6	1.45
Loss of Slump				2	1.3
York Aggregate Mix G-26					
Compression				2	3.5*

* 5 cu. ft. capacity mixer.

3.2 Cooling Batches.--Cement and aggregate batches were cooled by storing them at 40°F for 24 hours prior to mixing, and ice water was used in the mix to produce a concrete temperature of 50 $\pm$ 3°F at the end of mixing.

3.3 Mixing Procedure.--A pan-type mixer having a capacity of 2 cu. ft. was used for the mixing of all individual batches, except two. For those two batches, York mix G-26, a 5 cu. ft. capacity mixer was used. The mixing room temperature was maintained at 73°F. The following is a step by step procedure used in mixing each of the concrete batches.

1) Prime mixer with a throw away batch to coat the mixing pan and blades with mortar and thus prevent loss of mortar from batches used for casting of specimens.

2) Add coarse aggregate to mixer.

3) Add approximately one-half of the mix water and let the aggregate soak for two minutes.

4) Start mixer, add sand and blend with coarse aggregate for one minute. When the 5 cu. ft. capacity mixer was used, the sand was added to the mixer at the same time as the coarse aggregate.

5) Add remaining mix water and cement simultaneously over a twenty-second time period. Begin timing mix after all cement and water is added.

6) After twenty seconds of mixing add admixtures (referred to as delayed addition of admixture).

7) Stop mixer after 3 minutes of mixing.

8) Let concrete rest for 3 minutes, with the mixer being covered by a plastic sheet to prevent loss of moisture.

9) Re-start mixer and mix for 2 additional minutes. During this final mixing period slight adjustments in water can be made if needed to obtain the desired 4 1/2 $\pm$ 1/4-in. slump.

To insure a more efficient distribution of the admixtures in the concrete mix, they were diluted with a small amount of mixing water prior to being added to the mix. Before delayed addition of admixture became part of the mix procedure, the admixture was added at the same time as the second addition of mix water.

3.4 Properties of Fresh Concrete.--Immediately after mixing of each batch the temperature of the concrete was measured and a slump test performed. The slump test was completed within 2 1/2 minutes after end of mixing when using the 2-cu. ft. capacity mixer and within 3 1/2 minutes after end of mixing when using the 5-cu. ft. capacity mixer. The performance of the slump test itself was always completed within a 2 1/2-minute period. However, when using the 5 cu. ft. capacity mixer an additional minute was required to allow for emptying the mixer and blending the concrete prior to making the slump test.

The unit weight and/or air content of the concrete was determined on all batches as described in the following two sections.

3.4.1 Six-Batch Casting.--When 6 batches of concrete were used to cast a group of specimens of a given mix, the unit weight was determined (using a 0.5 cu. ft. container) for the 1st, 3rd, and 5th batch of concrete mixed. Air content and unit weight (using the 0.2 cu. ft. air meter container) were determined for the 2nd, 4th and 6th batch of concrete mixed.

3.4.2 Three, Two or One-Batch Casting.--When three, two or one batch(es) of concrete were used to cast a group of specimens, the unit weight and air content tests were performed on each one of the batches. The concrete used in the slump and unit weight tests was reblended by hand with the remaining concrete in the mixer and used in casting of the specimens.

The procedures used in determining the properties of fresh concrete were in accordance with the following applicable ASTM methods of tests:

ASTM C 143 Slump of Portland Cement Concrete
ASTM C 138 Unit Weight of Concrete
ASTM C 231 Air Content of Freshly Mixed Concrete by the Pressure Method

4. Casting of Specimens

4.1 6 by 12-in. Specimens.--The basic casting procedure used in preparation of the 6 by 12-in. concrete specimens was in accordance with ASTM C 192 method of test. The specimens were cast in three layers of equal volume of concrete, each being compacted by rodding. The individual layers were composed of concrete from one or two batches as described in Section 4.4 of this Appendix.

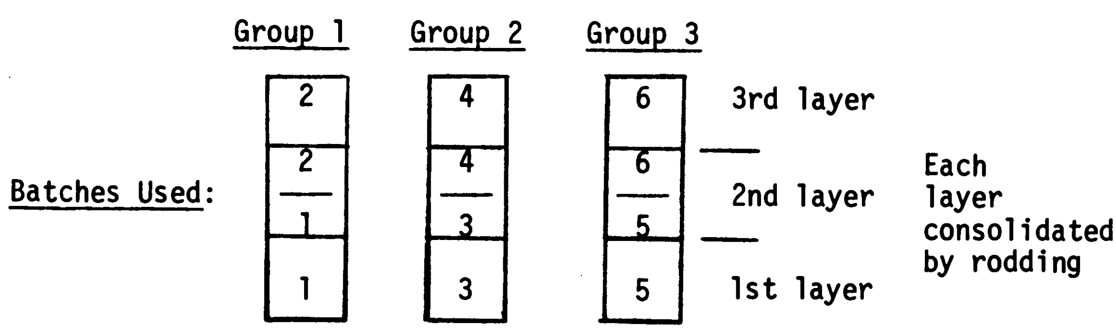
4.2 6 by 16-in. Specimens.--The 6 by 16-in. instrumented concrete specimens were cast in accordance with University of California (UC) method of test for "Setting Up, Casting, Sealing and Storage of 6 by 16-in. Internally Instrumented Concrete Specimens," copy enclosed with this Appendix B. These specimens were used in Phase I(a) in the determination of the coefficient of thermal expansion. The distribution of concrete from batches used to cast specimens for each mix is described in Section 4.4 of this Appendix.

4.3 4 by 4 by 11-in. Specimens.--The basic casting procedures used in preparation of the 4 by 4 by 11-in. concrete drying shrinkage specimens was in accordance with ASTM C 157 "Length Change of Hardened Cement Mortar and Concrete." The two individual layers were composed of concrete from two batches as described in Section 4.4 of this Appendix.

4.4. Distribution of Concrete from Batches

4.4.1 Six-Batch Mixes.--The specimens cast from a six-batch mix were divided into three equal groups with two batches of concrete used to cast each one of the three groups. The specimen group batch composition is illustrated below.

SPECIMEN BATCH COMPOSITION FOR SIX-BATCH MIX



Each 6 by 12-in. specimen within the group was cast in three equal layers of concrete. The number 1 batch was mixed first and used, as shown in the diagram, to cast the first layer and one-half the second layer. The first layer was consolidated by rodding prior to the placement of the subsequent half-layer. The specimens were covered with a plastic sheet to prevent the loss of moisture while the number 2 batch was mixed. The placement of the second layer of concrete was then completed with the number 2 batch and this second layer consolidated by rodding. The third layer was cast using the remainder of the number 2 batch. Average time between mixes was approximately 15 to 20 minutes. The same casting procedure was used with the other two sets of batches, 3 to 6. Using this casting procedure a group of three specimens represents all six batches. The three or six specimens to be tested at each age were chosen to represent the concrete of all batches mixed.

4.4.2 Three-Batch Mixes.--For mixes with three batches, the specimens were divided into three equal groups with each batch used to cast one of these groups, following ASTM C 192 test method. The selection of specimens for testing was the same as for the six-batch mixes.

4.4.3 Two-Batch Mixes.--For mixes with two batches all specimens were cast at the same time, with half the volume of the specimens cast using the first batch and the remaining volume cast using the second batch, similar to the Group 1 of the six-batch mixes (Sec. 4.4.1).

4.4.4 One-Batch Mix.--All specimens were cast at the same time from the single batch following ASTM C 192 test method.

5. Sealing or Moist-Curing of Specimens

5.1 Sealed Specimens.--The sealing of the concrete specimens was accomplished after 20 hours and within 48 hours after casting. The procedures used are described below.

5.1.1 6 by 12-in. Specimens.--Prior to casting, the bottom and side seam of the standard sheet metal molds (ASTM C 470) are soldered and painted with a light-colored anti-rust paint. This assures moisture tightness of the mold and enables easy inspection of the seams. After casting, the top lids are placed on the molds and each specimen covered with a plastic bag to minimize water evaporation.

After 20 hours and within 48 hours after casting top lids are removed, and the top edge of the mold cleaned with steel wool. A bead of silicone rubber sealant/adhesive is placed around the outside top perimeter of the mold and the top lid pressed down over the sheet metal mold, distributing the silicone rubber between the lid and mold. Another bead of silicone rubber is then placed around the joining surface of the lid and mold. The specimens are then placed inside a plastic bag and stored at 73°F.

To check the effectiveness of the sealing method used, a soldered mold was filled two-thirds full of water and the top sealed on in the manner described above. The water vapor developed inside this water-filled test mold imposes a more critical condition for sealing than if the mold was filled with concrete. After 1 1/2 years of storage the weight of the mold plus water has remained constant indicating no loss of moisture.

During storage, the sealed specimens are periodically inspected by checking the painted soldered joints for discoloration or signs of water vapor inside the plastic bags. A final inspection is given prior to stripping of the molds before testing and the surface moisture condition of the specimens is visually inspected after demolding. To date, no signs of leakage have been detected for any of the sealed specimens.

5.1.2 6 by 16-in. Specimens.--The 6 by 16-in. specimens were sealed using steel end plates and butyl rubber jackets in accordance with UC method of test, "Setting Up, Casting, Sealing and Storage of 6 by 16-in. Internally Instrumented Concrete Specimens," copy enclosed with this Appendix B.

5.2 Moist-Cured Specimens.--The moist-cured 6 by 12-in. specimens are cast in standard sheet metal molds conforming to ASTM specification C 470. After casting of the specimens the top lids are placed on the molds to assure a circular diameter of the concrete cylinder and to prevent evaporation of water. After 20 hours and within 30 hours after casting, the molds are stripped and the specimens then stored in the fog room maintained at 100 percent relative humidity and 73°F. Daily inspection is made of the specimens and of the fog room to assure that the specimen surfaces are moist and that the fog room is properly operating. Because of the high cement content of the concrete, the amount of water used for the early-age hydration of the cement is more than the amount of water that the surfaces of the specimens can absorb from the moist air of the fog room. For this reason the specimens are wetted down periodically with a hose during the first three days in the fog room to insure that the surfaces are kept moist during this early age of curing. The specimens in the fog room are stored three deep on shelves, with ample space between each specimen to allow adequate moisture to reach its surface. In addition the specimens are periodically relocated on the shelves according to a regualr schedule in order to provide the same moisture exposure conditions to all of the specimens.

6. Testing of Specimens

The following is a brief description of the test methods used in determining compressive strength, modulus of elasticity and Poisson's ratio, splitting tensile strength, drying shrinkage and linear coefficient of thermal expansion. All of the compression specimens of Phases I and II of the investigation were capped with sulfur prior to testing.

6.1 Compressive Strength.--The compressive strength tests on all of the 6 by 12-in. concrete specimens were performed on a 400-kip Baldwin hydraulic testing machine in accordance with the standard method of test ASTM C 39 "Compressive Strength of Cylindrical Concrete Specimens." The rate of loading used was 60,000 pounds per minute or approximately 35 psi per second. No adjustment in controls was made immediately before failure when specimen is yielding rapidly.

6.1.1 Capping.--A schedule for the capping of the cylinders was established to assure that the sulfur capping compound used has adequate strength at the time of the compression test. Specimens to be tested at age of 7 and 14 days were capped a minimum of two hours prior to the time of test. Specimens to be tested at age of 28 and 60 days were capped two days prior to testing, and all the later age specimens three days prior to testing.

After capping of the moist-cured specimens, they were placed back in the fog room where they remained until time of test. Just prior to the compression test the specimens were removed from the fog room and wrapped with moisture proof plastic film to prevent the loss of moisture during testing. The sealed specimens were demolded, immediately wrapped in the plastic film and capped, sealing the ends of the moisture-proof plastic film. In addition the specimens were placed in two plastic bags to insure that no moisture is lost prior to testing. These sealed specimens were then stored at 73°F until time of test.

6.2 Modulus of Elasticity and Poisson's Ratio. --A compressometer equipped with four linear variable differential transformers (LVDT's) is used to determine the modulus of elasticity and Poisson's ratio.

The longitudinal deformation of the specimen is measured by two LVDT's mounted vertically parallel to the axis of the specimen diametrically opposite each other. The effective gage length for each LVDT is eight inches. The compressometer is centered at midheight of the specimen and rigidly attached to it.

The lateral deformation of the specimen is measured by two LVDT's mounted horizontally on a ring located at midheight of the compressometer and suspended by four springs from the top ring of the compressometer. The springs were designed with a sufficient stiffness to minimize the weight of this ring with the lateral LVDT's and to insure that the ring remains at midheight of the compressometer after the spacer bars are removed. The ring itself is also attached to the specimen by spring loaded set screws. The horizontal LVDT's are mounted perpendicular to the axis of the specimen, diametrically opposite each other and rotated 90° from the LVDT's used to measure longitudinal deformation. The effective gage length of each of these two LVDT's on a six-inch diameter specimen is three inches. Prior to testing, the moisture-proof plastic film used to wrap the specimen is removed from the immediate area of the contact tip of the LVDT's and the tip is allowed to make direct contact with the surface of the concrete specimen.

Prior to each day's testing, the longitudinal and lateral LVDT's are calibrated in pairs, using a "super-micrometer" having a least reading of "10 μ" (.000010 inches), by setting off known displacements. An XYY' recorder is calibrated simultaneously to record directly the average strain from the known LVDT displacements. During the compression test the load applied to the specimen is taken directly off the testing machine by means of an electric pressure transducer and recorded as stress on the XYY' recorder. The stress calibration of the XYY' recorder is performed by applying a specific load on the testing machine and adjusting the load scale of the XYY' recorder to record the corresponding stress for a 5.97 inch diameter (28.0 sq. in. area) specimen. During the compression test a continuous recording of stress versus longitudinal strain, and lateral strain versus longitudinal strain is obtained. From these curves the modulus of elasticity and Poisson's ratio can be directly computed.

In Phase II(c), an additional calibration step was added to the procedure. After the calibraitons for strain and stress are performed, and prior to testing of the concrete specimens, the calibration is checked by placing the compressometer on a calibrated steel cylinder which is then loaded. The strain and stress levels, at given load levels, are compared with known calibration values.

To obtain the modulus of elasticity and Poisson's ratio for a given specimen, the specimen is loaded to 40% of its estimated ultimate strength three consecutive times. The last two recordings are averaged to obtain the modulus of elasticity and Poisson's ratio for the specimen. The loading is done at 60,000 lbs/min or approximately 35 psi/sec. The lateral LVDT's are then disconnected from the compressometer and a time ramp generator is connected to the XYY' recorder in place of the input from the lateral LVDT's. The time ramp generator is calibrated to record time. The specimen is then loaded to obtain its ultimate compressive strength. During this test to failure a stress vs. longitudinal strain curve and time vs. longitudinal strain curve are obtained. The time vs. longitudinal strain curve in conjunction with the stress vs. longitudinal strain curve is used as a check on the loading rate.

A typical XYY' record is shown in reduced size in Figure B1 (actual size being 10 by 15 in.). ASTM C 469 "Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," was used as the reference standard.

6.3 Splitting Tensile Strength.--The splitting tensile strength tests on all of the 6 by 12-in. concrete specimens were performed on a 120 or 400-kip Baldwin hydraulic testing machine in accordance with the standard method of test ASTM C 496 "Splitting Tensile Strength of Cylindrical Concrete Specimens." The rate of loading used was 16,000 lbs per minute or approximately 140 psi per second. Specimens were tested in a special self-aligning splitting tensile strength testing rig which has alignment marks that are coordinated with the alignment marks on the testing machine platform, assuring proper alignment of the testing rig, and thus of the test specimen, in the testing machine.

Splitting tensile strength specimens were stripped from their molds at the same time as compressive strength specimens. Moist-cured specimens were sealed with moisture -proof plastic film immediately after removal of the specimens from the fog room. Sealed specimens were wrapped with the plastic film immediately upon stripping and placed in two plastic bags. The plastic film was removed from both the moist-cured and sealed specimen just prior to the testing of an individual specimen.

The percentage of coarse aggregate fractured during the splitting tensile strength test was determined by counting the number of fractured and not fractured pieces of aggregate on a representative section of concrete, equal to at least a half of the fractured surface of the 6 by 12-in. cylinder.

6.4 Drying Shrinkage.--The drying shrinkage tests on concretes were performed in accordance with ASTM C 157, except that the initial temperature of the concrete during casting was 50 ± 3°F. The 4 by 4 by 11-in. specimens were demolded at age 1 day, water-cured at 73 ± 3°F up to age 28 days, and then subjected to drying in an atmosphere of 50 percent relative humidity and 73 ± 3°F. Three specimens per condition were used in the aggregate evaluation phase of the program, and four specimens per condition for the admixture evaluation tests.

Measurements of drying shrinkage were made using a dial-gage comparator having a least reading of 0.0001 in. and conforming to ASTM C 490. Results reported are the average values for each group of specimens tested.

6.5 Linear Coefficient of Thermal Expansion.--In Phase I(a), a total of nine sealed 6 by 16-in. instrumented specimens were subjected to thermal cycling between 73 to 160 to 73°F. They included three specimens for each of the three coarse aggregate mixes, York, Berks and Hempt, which were cast in accordance with UC method of test for "Setting Up, Casting, Sealing and Storage of 6 by 16-in. Internally Instrumented Concrete Specimens," given as Enclosure 1 of this Appendix. The SL-10 Carlson strain meters used in the specimens were calibrated by the manufacturer. A copy of the manufacturer's description of this meter is given as Enclosure 2. The temperature for these Phase I(a) thermal cycling specimens was increased in the following four steps; from 73 to 90, 90 to 110, 110 to 135°F, and from 135 to 160°F.

The thermal steps between 73 and 135°F were accomplished in a variable temperature room, and the 135 to 160°F step in a 160°F chamber. To accomplish the last step, the specimens were wrapped in fiberglass insulation and transferred directly to the 160°F chamber. Each temperature level was maintained for 24 hours. The cooling phase of the thermal cycle, 160 to 73°F, progressed in the reverse order with a 24-hour hold period at 135, 110, 90 and 73°F. To complete the cycle from 73 to 160 to 73°F took eight days. The specimens were subjected to a total of three thermal cycles.

Strain gage readings, using a Carlson test set, were taken at 73, 90, 110, 135, 160, 135, 110, and 73°F during each cycle just prior to increasing or decreasing the temperature to the next level.

Reduction of data was made using the strain meter constants supplied by the manufacturer. A set of sample calculations for computing the linear coefficient of thermal expansion for one meter and one change in temperature is given below.

STRAIN METER DATA REDUCTION - YORK SPECIMEN NO. 1

Strain Meter Constants - Meter No. L1

Meter Resistance at 0.0°F	(R_o)	= 47.66 ohms
Temp. Calibration Constant	(C_t)	= 10.33°F/ohm change in Resistance
Strain Calibration Constant	(C_s)	= 3.14 microstrain/0.01% ratio change
Meter Coeff. of Thermal Expansion	(α_m)	= 7.5 microstrain/°F

Strain Meter Readings - Thermal Cycle No. 1

Cycle Temperature °F	Ratio	Resistance R, ohms	Specimen Temperature $T=(R-R_o)xC_t$, °F
73 ± 3	100.826	54.77	73.45
90 ± 3	100.777	56.47	91.01
Change (Δ)	- 0.049	+ 1.80	+ 17.56

Measured Strain = Δ Ratio x C_s x 100 = (-0.049x3.14x100) = - 15 microstrain

Meter Expansion = α_m x ΔT = (7.5x17.6) = 132 microstrain

Concrete Expansion = Measured Strain + Meter Expansion = 117 microstrain

Linear Coefficient of Thermal expansion 73 to 90°F

= Concrete Expansion/ΔT = 117/17.6 = 6.6 microstrain/°F

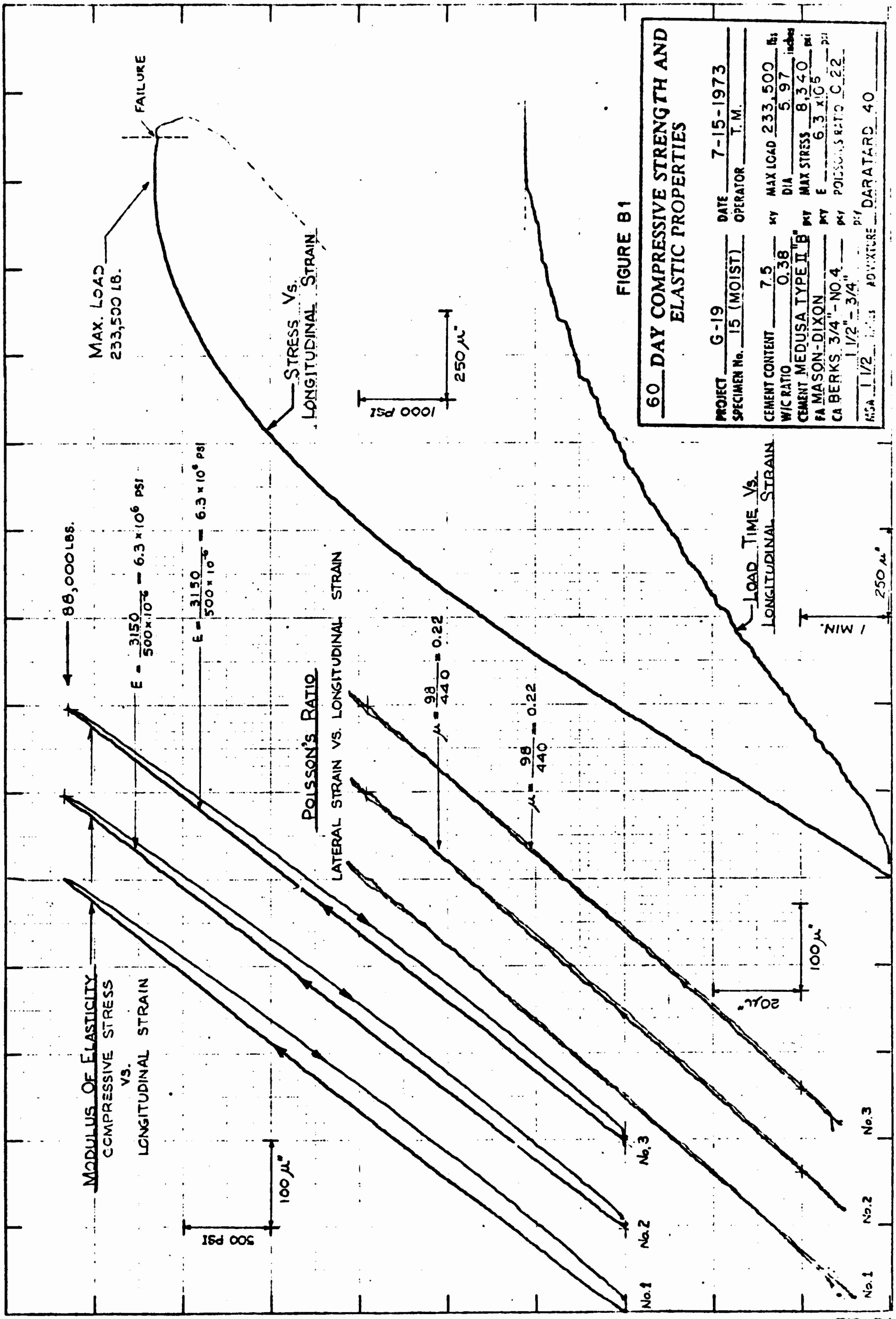

60 DAY COMPRESSIVE STRENGTH AND ELASTIC PROPERTIES
PROJECT G-19
DATE 7-15-1973
SPECIMEN No. 15 (MOIST)
OPERATOR T.M.
CEMENT CONTENT 7.5
MAX LOAD 233,500 lbs
W/C RATIO 0.38
DIA 5.97 inches
CEMENT MEDUSA TYPE II "B"
MAX STRESS 8,340 psi
FA MASON-DIXON
E 6.3 x 10^6 psi
CA BERKS 3/4" - NO.4
POISSON'S RATIO 0.22
1 1/2" - 3/4"
MSA 1 1/2
ADMIXTURE DARATARD 40
FIGURE B1
FAILURE
MAX. LOAD 233,500 LB.
STRESS VS. LONGITUDINAL STRAIN
1000 PSI
250 μ"
LOAD TIME VS. LONGITUDINAL STRAIN
1 MIN.
250 μ"
88,000 LBS.
E = 3150 / 500 x 10^-6 = 6.3 x 10^6 PSI
E = 3150 / 500 x 10^-6 = 6.3 x 10^6 PSI
POISSON'S RATIO
LATERAL STRAIN VS. LONGITUDINAL STRAIN
μ = 98 / 440 = 0.22
μ = 98 / 440 = 0.22
20 μ"
100 μ"
MODULUS OF ELASTICITY
COMPRESSIVE STRESS VS. LONGITUDINAL STRAIN
100 μ"
500 PSI
No.1
No.2
No.3
No.1
No.2
No.3

FIG. B1

Method of Test for

SETTING-UP, CASTING, SEALING AND STORAGE OF 6 BY 16-IN. INTERNALLY INSTRUMENTED CONCRETE SPECIMENS

1. SCOPE

This method covers procedures for setting up molds for 6 by 16-in. internally instrumented concrete specimens, casting of these specimens, sealing the specimens and storage of specimens until time of test.

2. APPARATUS (FOR EACH SPECIMEN)

2.1 Molds--Cast iron 6 by 18-in. cylindrical molds. Note: These molds were manufactured by casting the mold in two halves, their edges milled parallel, and then with the two halves bolted together, their inside diameter machined to 6 $\pm$ .001 inches.

2.2 End Plates--Two (2) 6-in. dia. steel end plates, one 2-in. thick and the other 1 1/2-in. thick. The 2-in. thick end plate has a hole and slot for instrument lead wire. The 1 1/2-in. end plate is solid. Both end plates have eye hooks or concrete nails to prevent end plates from being sheared off specimen.

2.3 Strain Gage--A Carlson or a Microdot strain gage for embedment in concrete.

2.4 Alignment Rig--Strain gage alignment and tensioning rig with soft wire for securing and aligning instrument in cast iron mold and to maintain its alignment during casting.

2.5 Sealing Jacket--Butyl rubber sheet, 1/16-in. thick, cut to size 18 by 23 in., with one of its 18-in. sides beveled by sanding. The side is beveled to prevent bulging of rubber at 4-in. lap splice.

2.6 Leveling Plate--Leveling plate especially manufactured for leveling the top steel plate on creep specimens.

3. PROCEDURE

3.1 Setting Up Molds--Setting up of the 6 by 18-in. molds and installation of the strain gage includes the following:

3.1.1 Inspect molds for cleanliness and oil lightly.

3.1.2 Check strain gage to be installed for defects and make certain the strain gage can be read.

3.1.3 Inspect rubber gasket on mold base plate for defects and cleanliness. Thread lead wire through hole in the 2-in. end plate and fit "O-ring" washer and nut.

3.1.4 Use soft wire to position strain gage axially in mold. Loop wire around bottom flange once and secure to eye bolts in 2-in. end plate. Strain gage should be positioned so that distance between bottom of strain gage's lower flange and top surface of 2-in. bottom end plate is according to size of strain gage used as follows:

4-in. strain gage: $6 \pm 1/4$ in.	8-in. strain gage: $4 \pm 1/4$ in.
6-in. strain gage: $5 \pm 1/4$ in.	10-in. strain gage: $3 \pm 1/4$ in.

3.1.5 Tighten nut with "O-ring" to assure seal of lead wire opening. Grease edge of the 2-in. end plate and position it in the one side of the 6 by 18-in. mold.

3.1.6 Loop soft wire around top flange of strain gage and through strain gage alignment and tensioning rig resting on top edge of mold. Align strain gage and tension top wire as little as possible to maintain strain gage in vertical position.

3.1.7 Check position of strain gage from bottom end plate again. Take reading on strain gage. Make sure strain gage is positioned correctly and can be read. Check strain gage identification number and show this number on lead wire tag. Grease edges of mold and tighten mold halves together.

3.1.8 Place instrumented mold in storage area and cover to prevent dirt from entering mold.

3.2 Casting Instrumented Specimens--The instrumented specimens are cast as follows:

3.2.1 Place instrumented molds on cart and cast molds on cart if feasible to prevent having to lift molds after casting. Inspect molds for cleanliness.

3.2.2 Check strain gages to make certain they can be read.

3.2.3 Specimens are to be cast vertically according to ASTM C 192 "Making and Curing Concrete Test Specimens in the Laboratory," modified to include the following:

(a) Cast the concrete in layers, consolidating each layer by rodding 25 times. Extreme caution must be taken to prevent damage to instrument during rodding. A smaller diameter rod may be used to consolidate the concrete in the immediate proximity of the strain gage.

(b) The layer of concrete from 1 in. below to 1 in. above the strain gage should be cast from the same batch if possible, and in as short a time span as feasible. Maintain alignment of instrument during casting. Concrete above and below the strain gage level is cast using standard practice.

(c) Place concrete with a scoop gently into mold. Care must be taken to prevent dropping concrete directly on the strain gage. Alternate placing of concrete from one side of the strain gage alignment rig to the other, keeping concrete evenly distributed in the mold.

3.2.4 After completion of casting, cover specimens with plastic film and move on cart to place of storage. Remove cover, cut wires, remove alignment rig and cover specimen again with plastic film secured to mold with rubber bands.

3.3 Sealing of Specimens--Specimens are sealed against moisture loss as follows:

3.3.1 Before placing top end plate, allow approximately 5 hours time after casting so that no more bleeding water rises to the surface. Then form a conical-shaped layer of mortar on top of each cylinder. This mortar is obtained from the original mix, or prepared separately at time of casting, to allow time for bleeding to cease prior to its use. Work the 1 1/2-in. top plate back and forth into position on each specimen until the mortar appears to be spread uniformly between the plate and the specimen. Use the leveling plate to assure top plate is normal to the axis of the specimen. Move specimens to 73^{o}F room.

3.3.2 Strip cast iron molds from specimens not earlier than 24 hours but no later than 48 hours after casting. Just prior to stripping molds off specimen prepare the sealing jacket by applying rubber cement to the 1/16-in. thick butyl rubber sheet at surfaces of the lap splice joint, and on 2-in. wide strips along each edge of 23-in. side. Then within 3 minutes after removing cast iron mold the following operations shall be performed:

(a) Clean end plates.

(b) Coat edges of end plates and adjacent 1-in. strip of concrete specimen, as well as 2-in. vertical strip on specimen for attaching of rubber sheet.

(c) Wrap the 1/16-in. thick butyl rubber sheet around the concrete (beveled edge outward) bonding the top and bottom edge of the rubber to the steel end plates.

(d) Inspect bonding of the 4-in. lap splice. Tighten the 6-in. dia. hose clamps over the butyl rubber and steel end plates to assure specimen will be thoroughly sealed.

3.4 Storage of Specimens--After sealing, specimens are to be stored in 73°F room until time of test. They are to be stored vertically with lead wire coming out at the top of specimen (opposite to position of casting).

3.5 Labeling of Specimens--Prior to sealing the specimen will be identified by instrument number and concrete mix from which it was cast. After sealing each specimen is to have the following information tagged to it.

(a) Meter No.:______, Ratio range:______.

(b) Concrete: Mix No.:______, Batch No.:______,

Date cast:__________.

(c) Temperature (to be loaded at):_____°F, Loading level____%.

(d) Age of loading:______days, Date to be loaded:_______.

(e) Pre-heating to begin:_______.

3.6 Carlson Strain Gage Readings--Carlson strain gage readings prior to casting can be taken with either the Carlson or the SESM test set. The initial reading on the strain gage after casting of the specimen must be taken with both test sets. Subsequent readings will be taken with the SESM test set, except that periodically readings with both test sets must be taken as a double check on strain gage readings.

3.6.1 The following is a summary of required strain gage readings:

(a) Check of strain gage prior to use.

(b) Check of strain gage after setting up mold.

(c) Check of strain gage prior to casting specimen.

(d) Check of strain gage after casting.

(e) Initial readings 24 hours after casting.

(f) Subsequent readings at intervals depending on type test being prepared.

CARLSON ELASTIC WIRE STRAIN METER*

July 1, 1972

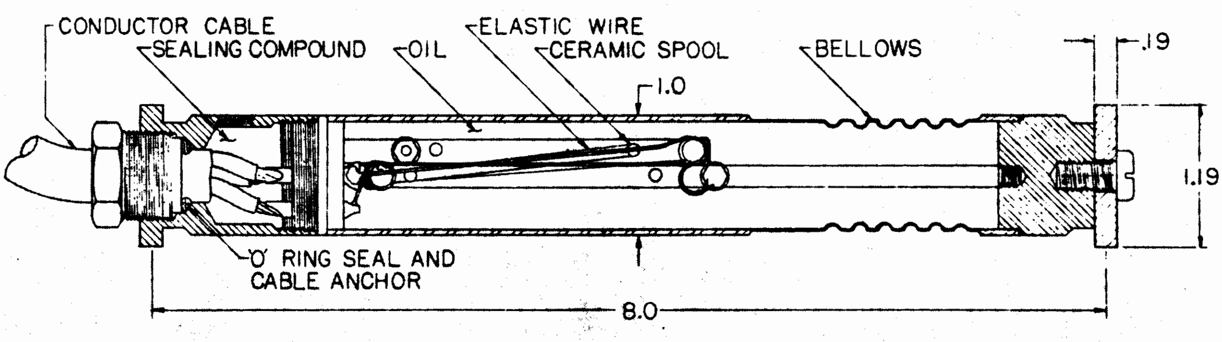
The standard strain meter can be embedded in concrete or it can be attached to a surface with saddle mounts. It measures change in length (strain) and temperature with the help of a simple Wheatstone-bridge type testing set (James Biddle Model 72-4010). The meter contains two coils of highly elastic steel wire, one of which increases in length and electrical resistance when a strain occurs, while the other decreases. The ratio of the two resistances is independent of temperature (except for thermal expansion) and therefore the change in resistance ratio is a measure of strain. The total resistance on the other hand is independepandent of strain since one coil increases the same amount as the other decreases due to a change in length of the meter. Thus, the total resistance is a measure of temperature. The improved strain meter is a better thermometer than the earlier ones, which had one coil within the other and therefore of different lengths.

The strain meter is furnished in three different lengths, from 8 inches to 20 inches, but all with the identical sensing element. The end away from the cable has a tapped hole (1/4-28 UNF) to permit attachment to a spider for mass concrete embedment, or for adding an extender to increase the length and sensitivity. The body is covered with cotton sleeving to break the bond with the concrete.

The conductor cable most commonly used is neoprene rubber-covered, portable cord with either three or four conductors. The four-conductor cable permits the testing set to make automatic subtraction of cable resistance for the determination of temperature only. If the user does not specify cable length, the meter is supplied with 30 inches of 16/3 SO cord. However, it is often preferred to attach the cable at the job site in the full length to be needed. In this case, the user must specify the diameter of the cable to be used so that the sealing chamber can be made to order and supplied separately with the meters. Instructions for attaching the cables and sealing chambers are supplied to the user. It is recommended that no greater than 600 ft. of 16 AWG cable be used. Larger wire should be used with longer lengths.

The strain meter frame is all steel, thus reducing the temperature correction (for thermal expansion of the frame) from the former value of 7.5 micro-strain per degree. The improved strain meter is more nearly compensating for thermal expansion than before, because the 6.7 value is more nearly the same as the thermal expansion of concrete. This is advantageous in that not much of the range of the meter is lost because of temperature change.

*See page entitled "Improved Sensing Element for Carlson Instruments"



SPECIFICATIONS - A SERIES

Former Model Number	S1-8	SL-10	...	SA-20
Current **Model Number**	**A8**	**A10**	**A105****	**A20**
Range (micro-strain)*	2600	2100	2100	1050
Least reading (micro-strain)	3.9	3.1	3.1	1.6
Least reading, temperature (°F)	0.1	0.1	0.1	0.1
Gauge length (inches)	8	10	10	20
Weight (lbs)	.8	1.3	1.3	3.5

*Normally set at factory for 2/3 of range in compression Within limits, other settings may be specified.

**Saddle mount. Mounting diameter is 1-1/16 inches.

CARLSON INSTRUMENTS

DR. ROY W. CARLSON

1203 DELL AVENUE - CAMPBELL, CALIF. 95008

IMPROVED SENSING ELEMENT FOR CARLSON INSTRUMENTS

Carlson strain meters, stress meters and pore pressure cells all use an elastic-wire electrical resistance device as the sensing element. The device is both a strain meter and a thermometer. It consists of two coils of fine steel wire, wound on ceramic spools. One of the coils increases in length and resistance with strain while the other decreases. The change in resistance is due mainly to stress and not to change in dimensions; when the length of a coil is increased by 1 per cent the electrical resistance is increased 3.6 per cent. The ratio of electrical resistance of the two coils is directly proportional to change in gauge length, while the total resistance of the two coils is directly related to temperature. Electrical resistances and ratios can be measured accurately with a Wheatstone bridge type testing set to 0.01 ohm and 0.01 per cent, respectively.

The improvement of the sensing element has come about through a simplification largely by eliminating internal screws. A new design of ceramic spool permits it to be mounted without screws, and similarly, the flat-spring guides are now attached without screws. These innovations permit the sensing element to be slender enought to be suitable for miniature strain meters and yet fully satisfactory for larger instruments. Thus, the new sensing element can be used with only minor modification for all Carlson meters except thermometers and joint and foundation meters.

The improved sensing element is a more precise thermometer than before. In the past it has been necessary to mount one coil of elastic wire within the other to insure that they would be of equal temperature, and thus one coil had to be shorter than the other. In the new and more slender sensing element, the coils are mounted close enough to each other that they can be of equal length and yet of substantially equal temperature. There is no longer any effect of strain on the determination of temperature.

The sensing element for the miniature strain meters is necessarily shorter than for other meters. Its electrical resistance is only about 55 ohms at room temperature. For stress and pore cells, resistance of the two internal coils is 70 ohms. For standard strain meters the resistance is 90 ohms.

All of the Carlson Instruments using this type of sensing element are sold as 5% instruments, that is, the accuracy of any measurement is within ±5% of full range. The linearity is within ±2% of full range of a line joining the end points. The average meter will be much better than specified, however, to tighten the specifications would increase the cost considerably.

CARLSON [redacted]
DR. ROY W. CARLSON
1203 DELL AVENUE - CAMPBELL, CALIF. 95008

APPENDIX C -- W. R. GRACE & CO. REPORT

April 9, 1973

CONSTRUCTION PRODUCTS DIVISION

W. R. GRACE & CO., 62 WHITTEMORE AVENUE, CAMBRIDGE, MASSACHUSETTS 02140, U.S.A.

April 9, 1973

Dr. Milos Polivka
Professor of Civil Engineering
College of Engineering
University of California
Berkeley, California 94720

Dear Milos:

We have measured the sulfate ion content of the cement/water aqueous phase using the two cement samples that you sent Byron Adams. Our procedure entails mixing 100 grams of cement with 75 grams of water at time zero. After an arbitrarily chosen time of vigorous agitation, the mixture is then rapidly vacuum filtered and an aliquot portion of the clear aqueous filtrate is analyzed for its sulfate ion content.

We chose mixing times of 1 and 10 minutes for your two samples. When an admixture was used, it was predissolved in the 75 grams of mix water in an amount equivalent to its recommended addition rate for use in concrete (i.e., Daratard 40 @ 7 oz./sk.). The results are summarized in Table I.

TABLE I

		Sulfate Ion Content of Aqueous Phase, g./liter	
Cement	Mixing Time	No Admixture	Daratard 40
C975	1 min.	4.0	3.0
	10 min.	2.8	3.2
C981	1 min.	4.0	3.5
	10 min.	2.4	3.8

The two cements, in the absence of the admixture, seem to be essentially the same, from the standpoint of their contributing soluble sulfate ion to the aqueous phase. The drop in sulfate content from the 1 minute to the 10 minute period indicates one of two things -- either the cement is undergoing a mild false set or the amount of gypsum in the cement, which is readily soluble in the aqueous phase, is rapidly diminishing and the aqueous phase is becoming dependent on the anhydrite in the cement, which is slowly soluble, to provide sulfate ion. The sulfate ion contents measured when Daratard 40 was used seem to point to the latter phenomenon.

For all practical purposes, both cements behaved the same when Daratard 40 was used. In the case of cement C975, the one minute reading in the presence of Daratard 40 is 3.0 g./liter, 1.0 gm/liter less than the value measured in the absence of the admixture. This indicates that the admixture is in some way reducing the normal solution rate of the sulfate in the cement. We have found in our earlier research work that if anhydrite is present in the cement, it becomes immediately coated with the admixture (whether it be a lignosulfonate, glucose polymer or hydroxycarboxylic acid salt based admixture) and its slow solution rate is further reduced. I think that this explains the 1.0 gm/liter difference at the 1 minute mixing period.

If the admixtur reduces the rate of solution of the sulfate ion into the aqueous phase to a point that there isn't sufficient sulfate to satisfy the needs of the C_3A, then the C_3A will begin to combine with the admixture. I think that this explains the higher sulfate ion content found at the 10 minute mark when Daratard 40 was used. This process in conjunction with the sorption by the anhydrite ties up a certain amount of the admixture and its effective concentration is reduced. By effective, I mean dispersing, water reducing and set retarding properties.

I think that we all agree that neither the Pozzolith nor the Daratard is producing the kind of results in your concrete work that we know they should, and can. It's my feeling that their normal performance is being inhibited by the sorption and C_3A reaction, just discussed. We talked about the possible use of delayed addition on the phone. I think that this could be one way out of the problem. By delaying the addition of the admixture (by 15 to 30 seconds) to the concrete, the anhydrite has a chance to start dissolving in the

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mix water. Once this process starts, the anhydrite's tendency to sorb the admixture is nullified and the normal processes can occur in the concrete.

Best regards,

Vance H. Dodson, Ph.D.
Technical Service Manager

VHD:cjd

cc: A. B. Adams
S. D. Burks