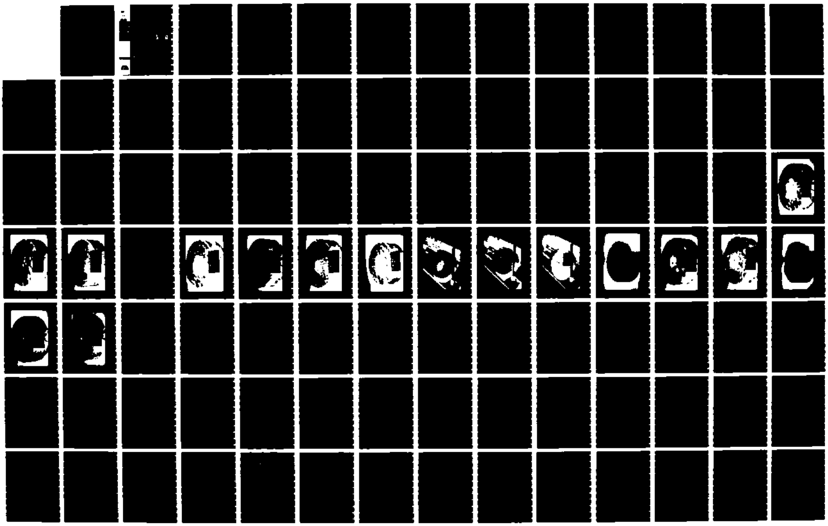
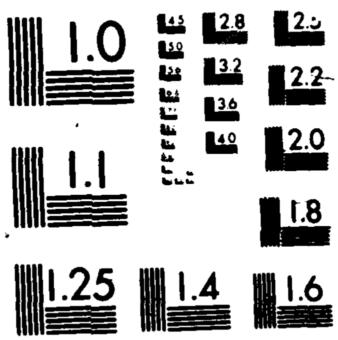
AD-A172 804 ABRASION-EROSION EVALUATION OF CONCRETE MIXTURES FOR STILLING BASIN REPAI..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS STRUC.. T C HOLLAND 1/2

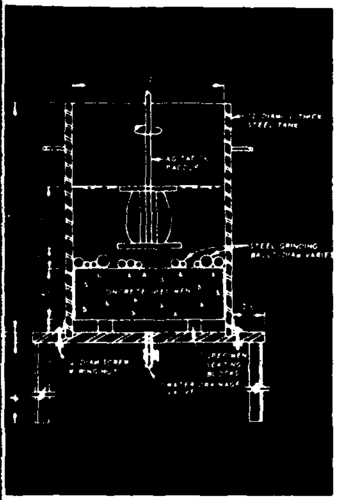
UNCLASSIFIED SEP 86 WES/MP/SL-86-14 F/G 11/2 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.8
3.2
3.6
4.0
4.5
5.0

US Army Corps of Engineers

AD-A172 804



STRUCTURES LABORATORY

(2)

MISCELLANEOUS PAPER SL-86-14

ABRASION-EROSION EVALUATION OF CONCRETE MIXTURES FOR STILLING BASIN REPAIRS, KINZUA DAM, PENNSYLVANIA

by

Terence C. Holland

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

September 1986

Final Report

Approved For Public Release, Distribution Unlimited

Prepared for US Army Engineer District, Pittsburgh
Pittsburgh, Pennsylvania 15222-4186

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

AD-A172 864

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp Date Jun 30, 1986

1a REPORT SECURITY CLASSIFICATION: Unclassified

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY:

2b DECLASSIFICATION/DOWNGRADING SCHEDULE:

3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S): Miscellaneous Paper SL-86-14

5 MONITORING ORGANIZATION REPORT NUMBER(S):

6a NAME OF PERFORMING ORGANIZATION: USAEWES Structures Laboratory

6b OFFICE SYMBOL (If applicable): WESSD

7a NAME OF MONITORING ORGANIZATION:

6c ADDRESS (City, State, and ZIP Code): PO Box 631, Vicksburg, MS 39180-0631

7b ADDRESS (City, State, and ZIP Code):

8a NAME OF FUNDING/SPONSORING ORGANIZATION: US Army Engineer District, Pittsburgh

8b OFFICE SYMBOL (If applicable):

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c ADDRESS (City, State, and ZIP Code): Pittsburgh, PA 15222

10 SOURCE OF FUNDING NUMBERS: See reverse

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification): Abrasion-Erosion Evaluation of Concrete Mixtures for Stilling Basin Repairs, Kinzua Dam, Pennsylvania

12 PERSONAL AUTHOR(S): Holland, Terence C.

13a TYPE OF REPORT: Final report

13b TIME COVERED: FROM ______ TO ______

14 DATE OF REPORT (Year, Month, Day): September 1986

15 PAGE COUNT: 106

16 SUPPLEMENTARY NOTATION: Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. This report is Concrete Technology Information Analysis Center (CTIAC) Report No. 73.

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number):
Concrete dams
Kinzua Dam (Pa.)
Stilling basins

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This report covers the execution and results of studies supplementing those given in report No. 1. The present work included development of additional concrete mixtures containing silica fume and high-range water-reducing admixtures (HRWRA). Abrasion-erosion testing was done on specimens from some mixtures. Trial placements of two such mixtures were made and reviewed. Finally, assistance was provided to the US Army Engineer District, Pittsburgh in preparation and review of specifications for this project.

It was concluded that the overall objective of providing concrete with a high degree of resistance to abrasion-erosion damage had been met. While these initial specifications were generally satisfactory, future ones will require some modification based on what has now been learned. Several questions regarding the use of silica fume were raised.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a NAME OF RESPONSIBLE INDIVIDUAL:

22b TELEPHONE (Include Area Code):

22c OFFICE SYMBOL:

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

10. SOURCE OF FUNDING NUMBERS (Continued).

DA Form 2544, ORPED-82-48, dated 21 April 1982, and Change 1 to DA Form 2544, dated 17 February 1983.

PREFACE

The investigation described in this report was conducted for the US Army Engineer District, Pittsburgh, by the Concrete Technology Division (CTD) of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES). Authorization for this investigation was given by DA Form 2544, ORPED-82-48, dated 21 April 1982. Additional work was authorized by Change 1 to the original DA Form 2544, dated 17 February 1983.

The investigation was performed under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. John M. Scanlon, Jr., Chief, CTD, and under the direct supervision of Dr. Terence C. Holland, who served as principal investigator. Mr. Steven A. Ragan prepared the concrete mixtures; Messrs. Dale Glass, Frank W. Dorsey, and Glenn Odom conducted the abrasion-erosion tests. Photographs of the specimens were taken by Mr. Chris Reinhold. Messrs. John Gribar and Anton Krysa served as the points of contact at the Pittsburgh District. Mr. Krysa prepared much of the data concerning the trial placements at Neville Island that are included in this report. This report was prepared by Dr. Holland.

The funds for publication of this report were provided by the Concrete Technology Information Analysis Center (CTIAC); it is CTIAC Report No. 73.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT	3
PART I: INTRODUCTION	4
Previous Work	4
Purpose	4
Scope of Work	4
PART II: DESCRIPTION OF WORK PERFORMED AND DISCUSSION OF TEST RESULTS	6
Task 1: Concrete Mixture Development	6
Task 2: Trial Placements	9
Task 3: Specification Preparation	14
PART III: CONCLUSIONS, UNANSWERED QUESTIONS, AND RECOMMENDATIONS	22
Conclusions	22
Unanswered Questions	22
Recommendations	23
REFERENCES	25
TABLES 1-15	
FIGURES 1-18	
APPENDIX A: PITTSBURGH DISTRICT MEMO DESCRIBING NEVILLE ISLAND TRIAL PLACEMENTS	A1
APPENDIX B: WES MEMO DESCRIBING NEVILLE ISLAND TRIAL PLACEMENTS	B1
APPENDIX C: NORCEM MIXTURE DATA	C1
APPENDIX D: ELBORG MIXTURE DATA	D1
APPENDIX E: NEVILLE ISLAND TEST DATA	E1
APPENDIX F: MATHER'S MEMO ON CURING OF SILICA-FUME CONCRETE	F1
APPENDIX G: EXCERPT FROM ACI STANDARD 308-81	G1
APPENDIX H: MANUFACTURER'S DATA SHEET FOR CONFILM	H1

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet per second	0.3048	metres per second
fluid ounces per cubic yard	38.6738	millilitres per cubic metre
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre
pounds (mass) per square foot per hour	4.882428	kilograms per square metre per hour

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9)(F - 32) + 273.15$.

ABRASION-EROSION EVALUATION OF CONCRETE MIXTURES FOR STILLING BASIN REPAIRS, KINZUA DAM, PENNSYLVANIA

Report 2

PART I: INTRODUCTION

Previous Work

1. Abrasion-erosion testing of concrete mixtures for possible use during the stilling basin repair at Kinzua Dam was initiated for Pittsburgh District in April 1982. Work accomplished through October 1982 was reported to the District with a letter dated 10 November 1982. This report has been printed (Holland 1983) and is hereinafter referred to as Report 1. The initial work covered in Report 1 included characterization of the materials provided by the District and the abrasion-erosion testing of nine sets of specimens.

Purpose

2. The overall purpose of the study has been to assist the District in selecting the most abrasion-erosion resistant concrete possible, within the limits of available materials and technology. The work accomplished for the first report resulted in a recommendation that very high strength concretes (achieved through the use of silica fume and high-range water-reducing admixtures (HRWRA)) be considered for the repairs. The purposes of the second phase of the project have been to define the mixture proportions and characteristics of these very high strength concretes more precisely and to assist the District in preparing for the use of these materials.

Scope of Work

3. The work covered by this report consisted of the following tasks:

- _a_. Task 1. Development of additional concrete mixtures containing silica fume and HRWRA. Abrasion-erosion testing was conducted on selected mixtures.

b. Task 2. Observation and review of the trial placements of two concretes containing proprietary silica fume additives. Specimens made during the trial placements or obtained by coring were tested for abrasion-erosion resistance.

c. Task 3. Assistance during preparation and review of specifications for silica fume concrete used during the repairs at Kinzua.

PART II: DESCRIPTION OF WORK PERFORMED AND DISCUSSION OF TEST RESULTS

4. Work performed in each of the three tasks listed in the Scope of Work (paragraph 3) is described in this part of the report. Test results are presented and discussed as appropriate.

Task 1. Concrete Mixture Development

5. The concrete mixtures containing silica fume that were described in Report 1 were not intended to represent typical mixtures for possible use in the Kinzua project. Instead, these mixtures were developed to demonstrate the potential benefit of using higher strength concretes. With the District's decision to pursue the use of very high strength concretes containing silica fume, the first work undertaken was to develop usable mixtures for additional testing.

6. Several problems and questions were identified during the initial laboratory work that had to be resolved before field use of silica fume in concrete could be considered practical. The laboratory work was aimed at answering these questions while developing usable mixture proportions. The overriding objective during these tests was to insure that procedures and mixtures developed in the laboratory would be usable in the field without effort beyond that normally required for a conventional placement. The questions investigated included the following (note that these problems are closely interrelated):

- a. Handling silica fume. Two techniques for batching and introducing silica fume into the mixer were examined. These techniques were dry batching and slurry batching of the silica fume.
- b. Correct batching and mixing sequence. The appropriate sequence for introducing the concrete components into the mixer and the appropriate mixing techniques were determined.
- c. Gumminess or stickiness of the mixture. The initial testing of concretes containing silica fume indicated that the mixtures often tended to be very sticky. As a result of this characteristic, it was difficult to dump the concrete from a mixer. Much of the mortar stayed on the blades and inside of the drum.
- d. Correct sand to aggregate ratio. The initial testing had also shown that the sand to aggregate ratio of the concrete would have to be adjusted to compensate for the use of the silica fume.

e. Adequate workability. The concrete had to have an adequate workability to allow for ease of placement in the field and to help remove the temptation to add additional water at the placement site. A slump range of 3 to 4 in.* was used as a target.

f. Adequate strength. Obviously, the intention behind using the silica fume was to increase significantly the compressive strength of the concrete. If such increases were not achieved, there would be no reason to use the material.

7. During December 1982 and January 1983, a variety of mixtures was proportioned, mixed, and when appropriate, tested. The findings of the testing program were as follows:

a. Handling silica fume. Initially, concrete mixtures were made using the silica fume as a slurry. The slurry was prepared by mixing the fume with a portion of the mixing water. Blending of the slurry was done by hand or by using an electric mixer. The slurry was added to the concrete mixer after all of the other ingredients had been added and mixed. While the slurry technique generally worked well, it was felt that the technique would not be appropriate for field use without a significant investment in equipment for preparing and handling the slurry. Therefore, dry batching of the silica fume was adopted.

b. Batching and mixing. Using the dry silica fume directly, various alternatives of batching sequence and mixing time were tried. Problems encountered included inadequate wetting of the silica fume and the subsequent inadequate mixing of the concrete as well as the stickiness and gumminess referred to earlier (paragraph 7c). The solution was found to be to batch all dry ingredients into the mixer (aggregates first and then cement and silica fume) and to mix the dry ingredients thoroughly. Then, the mixing water, including any liquid admixtures, was added. Usually, mixing times were increased to help insure that the concretes were adequately mixed. Mixing times of 150 to 200 percent of standard were used.

c. Gumminess and workability. It was found that the silica fume concretes were extremely sensitive to the amounts of water and HRWRA used in the mixtures. Small changes in water or HRWRA content made large changes in the properties of the fresh concretes.** The gumminess was eliminated by raising water contents slightly while simultaneously reducing the HRWRA content. Slumps were maintained in the target range of 3 to 4 in. It should be noted that a silica fume concrete with a 2- or 3-in. slump appeared to be much more workable than a conventional concrete with the same slump.

d. Sand to aggregate ratio. Concrete mixtures containing silica fume that were proportioned using conventional sand to aggregate

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

** It appeared to the investigators involved that the concretes containing silica fume were more sensitive to these small variations than conventional concrete.

ratios (appropriate for the maximum aggregate size and cementitious material content) tended to be harsh and difficult to finish. This was somewhat surprising, given the very high cementitious materials contents. Mixtures that would have been oversanded (by approximately 5 to 10 percent) for conventional concrete appeared to be correctly sanded for silica fume concrete.

e. Compressive strength. Adequate compressive strengths were achieved for nearly all of the concretes prepared. Since many of the mixtures were made only to evaluate mixing times or fume handling techniques, test samples for all ages were not prepared for all mixtures. For those mixtures tested, typical 7-day compressive strengths were 8500 to 9000 psi while 14-day compressive strengths usually exceeded 10,000 psi.

8. Once the various problems had been resolved to the satisfaction of the investigators, larger batches were prepared using the Kinzua aggregates described in Report 1. Testing included compressive strengths at 7, 28, and 90 days as well as abrasion-erosion testing at 28 days.

9. The first mixture tested used the Kinzua G1 aggregate and 30 percent silica fume (by weight of a total cementitious material content of 846 lb/yd^3). The mixture proportions for this concrete are shown in Table 1. The concrete had a slump of 3-1/4 in. and a 28-day compressive strength of 13,850 psi. (Table 2 contains additional test data.) The average abrasion-erosion loss at 72 hr was 2.2 percent (Table 3) when tested in accordance with CRD-C 63, "Test Method for Abrasion-Erosion Resistance of Concrete (Underwater Method)."* Posttest photographs of the specimens are in Figure 1.

10. The second mixture tested was identical to that described above except that the Kinzua G3 rather than the G1 aggregate was used. The concrete was prepared in conjunction with a visit to WES by several representatives from Elborg Technology Company. While at WES, the Elborg representatives also made concrete using the Kinzua G3 aggregate and their proprietary silica fume and admixture combination. The basic characteristics of the concretes were as follows:

	WES	Elborg
Slump, in.	3	Flowing
28-day compressive strength, psi	13,800	14,650
Abrasion-erosion loss, %	2.3	1.4

* All CRD-C test methods are published in the Handbook for Concrete and Cement (US Army Engineer Waterways Experiment Station (WES) 1949).

11. Detailed data from these tests are presented as follows:

	WES	Elborg
Mixture proportions	Table 4	Table 5
Abrasion-erosion	Table 6	Table 7
Characteristics of fresh and hardened concrete	Table 8	Table 8
Posttest photos of specimens	Figure 2	Figure 3

Discussion of test results

12. Following is a summary of test results. Abrasion-erosion data for the mixtures listed below are plotted in Figure 4. (Note that some mixtures from Report 1 have been included for comparison.)

Mixture	Compressive Strength, 28 day, psi	Abrasion-Erosion Loss, 72 hr, %
G1 aggregate	5,710	6.9
G3 aggregate	5,670	6.1
G1 with 30 percent silica fume	13,850	2.2
G3 with 30 percent silica fume (WES mixture)	13,800	2.3
G3 with silica fume (Elborg mixture)	14,650	1.4

13. The very high strength concretes showed a significant decrease in abrasion-erosion loss. Any of the three mixtures containing silica fume would certainly be acceptable for field use.

14. The question of the optimum amount of silica fume to be used was raised in conjunction with these tests. This problem is discussed in detail in paragraph 63 of this report.

Task 2. Trial Placements

15. Pittsburgh District contracted for trial placements using concretes containing silica fume. The two suppliers of proprietary silica fume products, who had been working with WES during the initial trials of silica fume concrete, each had the opportunity to demonstrate their products. These suppliers were:

Elborg Techology Company
Park West Office Center
Building 1
Pittsburgh, Pennsylvania 15275

Norcem, Inc.
5200 Second Avenue
Long Island City, New York 11101

16. WES involvement during the trial placements included preplacement advising to the District, observation of the actual placements, and preparation and testing of abrasion-erosion specimens. Also, abrasion-erosion testing of samples obtained by coring was accomplished.

Observation of placements

17. The trial placements were under the supervision of Mr. Anton Krysa and Mr. John Gribar of Pittsburgh District. Extensive photographic and television tape documentation was made during the placements. A brief report prepared by Mr. Krysa describing the trial placements is presented in Appendix A.

18. WES observations of the two placements were included in a trip report furnished to the District.* A copy is presented in Appendix B. Additional data concerning the placements are presented as follows:

a. Norcem concrete mixture data - Appendix C.

b. Elborg concrete mixture data - Appendix D.

c. Overall summary of test data - Appendix E.

19. As is discussed in the last portion of the trip report (Appendix B), after the trial placements had been completed, there were several areas identified concerning the use of silica fume concrete in the actual Kinzua placement where a decision had to be made before the specifications could be prepared. (Perhaps one of the most beneficial results of the trial placements was the identification of these areas.) These areas were (note that these are listed in the same order as they are discussed in the trip report):

a. Control of plastic shrinkage cracking.

b. Overall quality control involved.

c. Cement content.

d. Concrete slump.

e. How to specify silica fume concrete.

f. Size of individual placements.

g. Finish required.

---

* WESSC Memorandum for Record, subject: Silica Fume Concrete Placements, Pittsburgh District - Kinzua Stilling Basin Repair Project, dated 1 April 1983.

h. How to handle areas of deep abrasion wear.

i. Control of aggregate moisture.

j. How to batch silica fume.

k. Vibration required for a high-slump silica fume concrete.

l. How to insure adequate mixing.

m. Maximum size of coarse aggregate.

20. The problems associated with each of these items are discussed in the appendix. How each point was resolved and treated in the specifications is described beginning at paragraph 31 of this report.

Testing of samples

21. Four abrasion-erosion samples were taken from each of the two trial placements. The specimens were moist cured at Neville Island for 7 days and then shipped in a moist condition to WES. Upon receipt at WES, the specimens were placed into a curing tank until they reached an age of 28 days. At that time, they were tested for abrasion-erosion resistance. The data from these tests may be found as follows:

Specimen	Abrasion-Erosion Data	Posttest Photographs
Norcem Mix 1	Table 9	Figure 5
Norcem Mix 3	Table 10	Figure 6
Elborg Mix 1	Table 11	Figure 7
Elborg Mix 3	Table 12	Figure 8

22. An additional three samples were obtained by coring by the District for abrasion-erosion testing. These samples were taken from areas of interest in the trial placements. The two Norcem cores were taken over plastic shrinkage cracks. The Elborg core was taken from an area with a very rough surface finish.

23. The cores received at WES had an outside diameter of approximately 11-1/2 in. The cores were taken full depth through the silica fume concrete resulting in a core length of approximately 15 to 16 in. All three of the cores had portions of the original concrete attached to the bottoms showing that the silica fume concrete had bonded very well.

24. Abrasion-erosion specimens were prepared from the cores by cutting a 4-in.-thick slice off of the surface end of the core. Pretest photographs of the three specimens are in Figures 9, 10, and 11. The plastic shrinkage

cracking of the two Norcem specimens was very shallow and extended less than 1/2 in. into the concrete surface. The Elborg sample had a rough surface that resulted from the relatively stiff mix used in the second Elborg placement. A visual examination of the sides of the specimens showed them to be well and uniformly consolidated for the full 4-in. thickness.

25. After sawing, the specimens were placed into a curing tank for 72 hr to saturate the concrete surfaces. After the soaking period, the specimens were tested for abrasion-erosion resistance. Data for these tests may be found as follows:

Specimen	Abrasion-Erosion Data	Posttest Photographs
Core, Norcem Mix 2 (ORP No. 2-1)	Table 13	Figure 12
Core, Norcem Mix 2 (ORP No. 2-2)	Table 13	Figure 13
Core, Elborg Mix 2 (ORP No. 5)	Table 13	Figure 14

Since these cores were slightly smaller in diameter than the standard, laboratory-cast abrasion-erosion specimens, there was a possibility that during the testing the specimens could be placed off center in the test apparatus. If this situation occurred, some of the smallest size fraction of the grinding balls could have fallen between the specimen and the tank walls reducing the mass of the materials causing the abrasion-erosion. However, it is doubtful that such a change would be significant.

26. At the conclusion of the abrasion testing, the specimens obtained from the cores were inverted and tested on the opposite face. Abrasion-erosion data from those tests are presented in Table 14 while posttest photographs are in Figures 15, 16, and 17.

27. A summary of all data obtained from the specimens made during or cored from the test placements is below. The abrasion-erosion data are plotted in Figure 18.

Mixture	Compressive Strength, 28 day, psi (Lab Cylinders)	Abrasion-Erosion Loss, 72 hr, %
Norcem Mix 1	13,630	4.6
Norcem Mix 3	14,850	3.8

Mixture	Compressive Strength, 28 day, psi (Lab Cylinders)	Abrasion-Erosion Loss, 72 hr, %
Elborg Mix 1	15,770	4.6
Elborg Mix 3	14,690	3.0
Norcem Mix 2 Core OPR No. 2-1	14,590	4.1
Norcem Mix 2 Core ORP No. 2-1 Cracked face down	14,590	5.4
Norcem Mix 2 Core ORP No. 2-2	14,590	3.5
Norcem Mix 2 Core ORP No. 2-2 Cracked face down	14,590	4.3
Elborg Mix 2 Core ORP No. 5	12,880	3.6
Elborg Mix 2 Core ORP No. 5 Rough face down	12,880	2.5

28. Review of the data plotted in Figure 18 shows very little difference in the performance of the various concretes tested. Unfortunately, there are no data available representing the same aggregates used in conventional concretes. Comparison of the data in Figure 18 and the data for the control concretes shown in Figure 4 does give a general estimate of improvement in abrasion-erosion resistance. A general ranking of the mixtures would be as follows (from worst to best abrasion resistance).

a. Conventional concretes manufactured in the laboratory using the aggregates investigated for Report 1.

b. Silica fume concretes manufactured in the field using aggregates similar but not identical to those used in the laboratory, with the specimens prepared in the field or obtained by coring.

c. Silica fume concretes prepared in the laboratory using the aggregates investigated for Report 1.

29. In an effort to shed some light on the performance of these specimens, the data were tabulated as is shown in Table 15. There, the mixtures are arranged in the same order as they are plotted in Figure 18, except that the two cores from the second Norcem batch are averaged and entered as a single entry. There does not appear to be a strong correlation between abrasion-erosion

resistance and any of the other elements in the table. It must be noted that based on the small number of samples, it is very difficult to establish relationships among the variables involved.

30. Several other results from the tests are worthy of note:

a. The abrasion resistance and compressive strengths did not appear to improve significantly in the mixtures with higher cement contents.

b. There is less difference between the compressive strengths obtained from cylinders and from cores for the final two Elborg mixtures that were stiffer than for the other higher slump concretes. The stiffer mixtures received more vibration, which resulted in better consolidation of the cores.

c. None of the field samples performed as well as specimens prepared in the laboratory. This may be attributable to better consolidation and better curing conditions in the laboratory. Since no field and laboratory samples of the same concrete have been tested, it is impossible to state whether the difference seen here is significant.

d. The plastic shrinkage cracks in the two Norcem specimens tested did not have a significant effect on the abrasion resistance. The higher abrasion loss seen when these samples were inverted and tested suggests that the finishing process produced a very dense concrete near the surface, while the concrete below the surface was not as dense. This thought is in keeping with the low amount of vibration seen during the Norcem placements.

e. The rough surface of the one Elborg core tested did not cause a significant increase in abrasion loss. The lower loss seen when this specimen was inverted (2.5 versus 3.6 percent) may indicate that the Elborg concrete consolidated very well at the location of the core. However, with only one sample, it is very difficult to draw many conclusions.

Task 3. Specification Preparation

31. The questions that resulted from the trial placements were identified earlier (paragraph 19). Pittsburgh District requested and received input on these questions from WES, OCE, and ORD. Mr. John Gribar of Pittsburgh District used the input to prepare a draft specification. This draft was jointly reviewed, in detail, by Dr. Tony Liu, OCE; Mr. Tom Hugenberg, ORD; and the author. Mr. Hugenberg presented the results of that review to Mr. Gribar, who prepared the final version of the specification.

32. The resolution of the problem areas is discussed in the following sections. The order of presentation has been revised for a more logical discussion. Where appropriate, several items have been combined into a single discussion.

How to specify silica fume concrete

33. The decision was made to specify the silica fume concrete in a modified performance specification giving the responsibility for proportioning the concrete to the contractor. However, the Corps imposed several restrictions on the contractor in addition to specifying a minimum compressive strength. The decision to use this type of specification evolved from a long series of discussions. Essentially, those involved felt that a better product would be obtained by allowing the contractor to work directly with the silica fume supplier while developing the mixture proportions. Since it was highly probable that the silica fume would be supplied by one of the two firms selling a proprietary additive package, we thought it would be better if the Corps did not retain responsibility for the mixture proportions.

34. The requirements and restrictions for the concrete are:

a. The specified compressive strength (f'_c) at 28 days is 12,500 psi. This value was selected as being satisfactory from an abrasion-erosion viewpoint and as being readily achievable by a contractor.

b. A maximum cement content of 700 lb/yd^3 was specified to prevent the use of higher amounts of cement as seen in the Norcem test placement. The extra cement appeared to offer no advantage in terms of strength and abrasion-resistance. There was also concern that higher cement contents could possibly lead to thermal problems.

c. A minimum cement content of 650 lb/yd^3 was also specified. The need for this item is questionable.

d. A minimum silica fume content of 15 percent by weight of cement was included. This value was felt to be a realistic lower limit for the amount of silica fume required to produce the specified strength. Specifying a minimum silica fume content was also done to insure that a concrete similar to those tested in the laboratory would be provided by the contractor.

e. A maximum water to cement plus silica fume ratio of 0.30 was specified. This was also done to insure that the field concrete would be similar to those produced and tested in the lab.

35. While the inclusion of these extra restrictions is somewhat unusual in a performance specification, this action was believed to be justified by

the unusual nature of the concrete desired for the placement. The limits imposed were all evaluated carefully to insure that none were contradictory.

<u>How to specify silica fume</u>

36. The question of how to specify the silica fume received a great deal of attention. The decision-making on this topic was complicated by the high probability that the silica fume would be supplied as part of a proprietary additive. We did not want the specifications to favor any proprietary product or to preclude a contractor from using a nonproprietary silica fume along with a separate, commercially available HRWRA. At the same time, we did not want to be in a position of not knowing what, in the way of admixture, was being put into the concrete.

37. The question was resolved by specifying the silica fume product in two parts. First, the silica fume itself was treated as a mineral admixture, and appropriate requirements were etablished for the fume. Second, all other ingredients, whether sold individually or as part of a similar fume product, were required to meet one of the categories of ASTM C 494,* (CRD-C 87) "Standard Specification for Chemical Admixtures for Concrete."

38. The specific requirements to be specified for the silica fume were silicon dioxide (SiO_2) content, fineness, moisture content, and loss on ignition. In regard to silicon content and fineness, a survey of silica fume producers was made. The data from the suppliers were used to insure that the specified material was actually available.

39. Based upon his experience with silica fume tested at WES and the data received from the survey of manufacturers, Mr. Ron Reinhold, Chief of the Cement and Pozzolan Group, recommended the following values:

<u>a</u>. Moisture content: Maximum of 3.0 percent.

<u>b</u>. Loss on Ignition: Maximum of 6.0 percent.

<u>c</u>. SiO_2 content: Minimum of 85 percent.

<u>d</u>. Fineness: Minimum of 10,000 m^2/kg at a porosity of [illegible].

The first three items were to be calculated in accordance with ASTM C 311 (CRD-C 256), "Standard Methods of Sampling and Testing Fly Ash or Natural [illegible] for Use as a Mineral Admixture in Portland Cement Concrete," while the last item was to be calculated in accordance with ASTM C 204 [illegible] Test Method for Fineness of Portland Cement by Air Per[illegible]

* All ASTM test methods are published in the Annual [illegible] (American Society for Testing and Materials 198[illegible]).

40. The values selected for moisture content and loss on ignition were taken from ASTM C 618 (CRD-C 255), "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement." Although silica fume is not covered by ASTM C 618, values were selected that applied to other mineral admixtures, basically because of a lack of evidence that any other values would be more appropriate.

41. The final specification required a fineness of 20,000 m^2/kg, based largely on the belief that the value of 10,000 m^2/kg was too low when compared to values that have appeared in the literature. (The appropriate fineness value to specify is discussed further under "Unanswered Questions" later in this report.

Maximum size aggregate

42. The initial interest in the use of an aggregate with a maximum size of 3/8 in. stemmed from recommendations received from the Norcem representative. Based upon observations of the trial placements, there appeared to be no advantage in using a smaller aggregate, and an aggregate gradation with 100 percent passing a 1-in. sieve and 90 to 100 percent passing a 3/4-in. sieve was specified. The data on compressive strength and abrasion-erosion resistance were not available when the specification was written. Review of the data at this time shows that there would have been no advantage in using the smaller aggregate.

How to batch silica fume

43. The selection of a specific batching method for the silica fume was left to the contractor. The specification requires that once a placement begins, there must be a continuous supply of concrete. The intent of the specification was to preclude, because of the length of time required and the potential for delays during placing, the use of drummed silica fume dumped directly into a ready-mix truck.

Maximum slump

44. A higher than normal (for Corps work) slump range of 7 to 10 in. was selected to produce a flowing concrete that would be easily finishable. This selection was based upon observations of the two trial placements where a higher slump concrete gave a very good finish. The exact range of 7 to 10 in. is admittedly somewhat arbitrary.

Finishing

45. The specifications require the final finish to be "as normally provided by a bull float." This requirement was generally met during the trial

placements using two passes of a vibrating screed for concretes with a slump in the range of 7 to 10 in. Based on observations of these placements, a second pass with the original screed was judged not practical; therefore, use of two screeds was specified for the actual projects. Although the specifications do allow bull floating immediately after screeding, it was believed that it would not be necessary to do so. It should be noted that finishing will be limited to that normally done immediately after placement. The concrete will be screeded twice and it may be bull floated, if necessary. There are no plans to do any finishing of the nature that is usually done after the concrete begins to set (i.e., final floating and trowelling).

Plastic shrinkage
cracking and curing

46. Review, internally within the Structures Laboratory at WES, of the trip report describing the trial placements (Appendix B) resulted in a second memo being prepared by Mr. Bryant Mather.* A copy of this memo is at Appendix F, and a copy of the portion of ACI 308-81, "Standard Practice for Curing Concrete" (American Concrete Institute Committee 308 1981), is referred to in Mather's memo is at Appendix G.

47. The item in the original trip report that caused the concern and the subsequent memo was the reference to the apparent high susceptibility of silica fume concretes to experience plastic shrinkage cracking. Both firms supplying the silica fume material recommended application of a curing compound immediately after screeding the concrete.

48. The objection raised by Mather involved the recommendation for applying a curing compound without waiting for the concrete to finish bleeding. When curing compound is applied too quickly to conventional concrete, two possible adverse situations may exist. First, consider a situation in which evaporation of bleed water is not occurring rapidly. Curing compound applied over bleed water will float on the water; as a result, the membrane that is formed may not be continuous, resulting in less than adequate curing. Second, consider a situation in which the bleed water is evaporating rapidly and the concrete is therefore susceptible to plastic shrinkage. The curing compound may be absorbed into the upper surface of the concrete creating an effective moisture barrier. As the concrete continues to bleed, water may be trapped

* Chief, Structures Laboratory, WES.

below the layer of paste containing the curing compound. The ACI document states that this situation may give rise to scaling.

49. Subsequent discussion with Mather brought out the fact that the silica fume concretes being proposed for use at Kinzua differ from conventional concretes in two important aspects in regard to bleeding. First, the silica fume provides a tremendous amount of surface area to adsorb water that could potentially become bleed water in other concretes. Second, the silica fume concretes contained very low amounts of water (water to cement plus silica fume ratios typically on the order of 0.30). These concretes, without the addition of HRWRA, show no measurable slump. Under these circumstances, the application of a curing compound immediately after finishing may not be an unacceptable practice.

50. The question of curing was addressed in the specifications by requiring the following sequence:

- a. The concrete will be screeded twice using two vibratory screeds.
- b. An evaporation retarder (Master Builders Confilm (Appendix H)) is to be applied.
- c. The concrete will be bull floated if necessary.
- d. Within 45 min of the application of the evaporation retarder, a membrane curing compound will be applied.
- e. The concrete will be kept continuously moist for 7 days.

51. Steps a, b, and c (if necessary) are required to be accomplished immediately after placement. Since bull floating will destroy any protective membrane developed by using the evaporation retarder, it appears that steps b and c should be reversed to protect the concrete between completion of floating and application of the curing compound. The District anticipates resolving the final details of the curing plan during the trial placements at the project site.

52. The specifications refer to Figure 2.1.4* of ACI 305, "Hot Weather Concreting" (American Concrete Institute Committee 305 1977). This figure relates air temperature, relative humidity, concrete temperature, wind velocity, and rate of evaporation. The specification requires the contractor to take precautions whenever the predicted evaporation rate equals or exceeds 0.2 $lb/ft^2/hr$. The point raised by Mather in his memo (Appendix F) concerning whether 0.2 $lb/ft^2/hr$ is the correct limit for silica fume concrete is certainly valid;

* The figure number is actually 2.1.5 in ACI 305R-77.

there is not sufficient data to argue one way or the other on this point. Inclusion of the reference to this figure in the specifications should cause the contractor to consider the potential for plastic shrinkage cracking and to approach preventing the problem in a logical manner.

Volume of placements

53. The decision to use a high slump concrete leads to a requirement to place nearly all of the concrete in a slab before finishing can begin. The specifications require the contractor to place each slab "without any interruption or delay."

54. The question of filling areas where wear is deeper than the base of the silica fume overlay was resolved by specifying the use of a fill concrete in those areas. This technique will reduce the volume of silica fume concrete required for the placements, which reduces the time required for each placement. This reduction in placement time will allow application of the evaporation retarder or curing compound earlier, which should be beneficial in preventing plastic shrinkage cracking.

Internal vibration of concrete

55. Based upon the compressive strengths and physical appearance of the cores taken from the trial placements, it is evident that vibration is certainly required, even for the high slump, flowing concrete that has been specified. The silica fume concrete apparently will require more effort to achieve satisfactory consolidation than conventional concrete, i.e., closer spacing of vibrator insertions and longer durations in the concrete for each insertion. The specifications do require internal vibration. The details of how to insure that adequate vibration has been achieved will have to be established during the field trial placements.

Quality control

56. The need for strict quality control/quality assurance when using silica fume concretes was pointed out in Report 1 and in the report covering the trial placements. The specifications cover the areas of particular concern, i.e., aggregate moisture control, adequate mixing, prohibition of adding additional mixing water, and testing for required compressive strength in adequate detail. As on any project, the adequacy of the quality control/quality assurance program will depend upon the dedication of the contractor and the government inspection staff.

Trial placements

57. The specifications require placement of two slabs of the same size as the slabs in the stilling basin. These slabs are to be placed outside the stilling basin shortly after the contractor moves to the site. The purpose for requiring the trial placements is to review all the contractor's equipment and procedures and to produce concrete specimens for testing.

Questions concerning specifications

58. Two questions concerning the silica fume concrete came up during the period after the specifications were issued to prospective bidders. These questions were:

a. Fineness. One silica fume supplier raised a question concerning measuring fineness in accordance with ASTM C 204. The supplier referred to a WES report (Buck and Burkes, 1981) that stated that C 204 could not be used to determine fineness of silica fume. Mr. Ron Reinhold advised that the general procedures of C 204 could be used except that the extrapolation technique described in the referenced report also has to be used. Mr. John Gribar discussed the problem with the supplier and a minor change to the specification was made. The change required that fineness of silica fume be tested using the procedures of ASTM C 204 rather than the more stringent requirement of testing in accordance with ASTM C 204.

b. Possible use of reactive fine aggregate. Mr. Tom Hugenberg, ORD, called WES with the information that several additional sources of fine aggregate were to be added to the specifications. These sources have varying amounts of chert particles in the aggregate. This fact raised the question of whether the silica fume would act as an effective pozzolan to reduce the potential for a harmful reaction. This question was discussed with Mr. Alan Buck, WES petrographer, who made the following points: (1) Silica fume was an effective pozzolan in his previous tests; (2) the potential of the aggregates to react is unknown; (3) the correct amount of silica fume to use is unknown. It appeared, under the circumstances, more conservative to specify a low alkali cement than to rely on silica fume. The requirement to use a low alkali cement was published in an amendment to the specification.

PART III: CONCLUSIONS, UNANSWERED QUESTIONS, AND RECOMMENDATIONS

Conclusions

59. The overall objective of providing concretes with a high degree of resistance to abrasion-erosion damage has been met. The silica fume concrete samples made in the laboratory, made in the field at the trial placements, or cored from the trial placements all performed well and all outperformed the conventional concretes described in Report 1. Based upon work accomplished to date, the use of silica fume concretes made with locally available aggregates appears to offer an economical approach to reducing the problem of abrasion-erosion damage at Corps hydraulic structures.

60. The trial placements conducted by Pittsburgh District at Neville Island were extremely beneficial. While all of the individuals involved learned a great deal about silica fume concrete, probably the most important result of these placements was the identification of questions and problem areas that had to be resolved before the project specifications were written.

61. The specifications that were produced for the silica fume concrete are generally very good. There are some areas needing fine tuning; however, that is to be expected when working with a new material.

Unanswered Questions

62. As of the time this report is being written, there are several unanswered questions concerning the use of silica fume concrete. These questions may be answered during the trial and actual placements at Kinzua or during additional laboratory studies. These questions are discussed in the following paragraphs.

Silica fume content

63. During the course of this test program, it became evident that there were two methods for expressing the amount of silica fume being used in a given volume of concrete. The initial work at WES was done by expressing the amount of silica fume as a percentage (by weight) of the total cementitious material (cement plus silica fume). This was essentially an arbitrary decision based upon WES experience with fly ash and other pozzolans. The second method of

expressing silica fume content, used by the two firms marketing proprietary silica fume products, is to express silica fume content as a percentage (by weight) of cement content.

64. Using the second method, the WES mixtures containing 30 percent silica fume would be expressed as containing 43 percent. Based on discussions with those involved with marketing silica fume concrete and on work being carried out at WES for silica fume use by the Los Angeles District, the use of 43 percent silica fume is apparently not necessary to achieve the higher compressive strengths. Additional laboratory work needs to be conducted to establish optimum silica fume contents.

Specifying silica fume

65. The correct value to specify for fineness of silica fume is largely an unknown. Fumes from different producers have been tested at WES using the ASTM C 204 air permeability procedure. The fineness values for these fumes have ranged from 6,600 to 27,000 m^2/kg. The survey of manufacturers (paragraph 38) developed values in the range of 15,000 to 22,000 m^2/kg, but the testing methods used are unknown. There are, at present, no data to relate properties of hardened concrete to the fineness of the silica fume used. Obviously, this is an area in which additional work is required.

66. A similar problem exists for the amount of silicon dioxide in the silica fume. There is an intuitive feeling that the more silicon dioxide the better; hence, the value of 85 percent was chosen. This was a very arbitrary decision and one that is certainly open to argument. This is also an area that requires additional work.

Recommendations

67. The caution expressed in Report 1 is worthy of repeating here. The quality of silica fume concrete in place in the stilling basin will be only as good as the Corps inspection and the overall quality control/quality assurance program. If this concrete is not tightly controlled, the abrasion resistance of the concrete will not be significantly better than that of conventional concrete.

68. There should be a thorough review of all aspects of this project once the work has been completed. All test data should be reviewed and evaluated. Additionally, field personnel should be interviewed to identify any

problems or weaknesses in the specifications. A final report should be prepared to insure that what is learned at Kinzua is made available to the rest of the Corps of Engineers.

REFERENCES

American Concrete Institute Committee 305. 1977. Hot Weather Concreting (ACI 305R-77), American Concrete Institute, Detroit, Mich.

American Concrete Institute Committee 308. 1981. Standard Practice for Curing Concrete (ACI 308-81), American Concrete Institute, Detroit, Mich.

American Society for Testing and Materials. 1983. Annual Book of ASTM Standards, Parts 13 and 14, ASTM, Philadelphia, Penn.

Holland, Terence C. 1983. Abrasion-Erosion Evaluation of Concrete Mixtures for Stilling Basin Repairs, Kinzua Dam, Pennsylvania. Miscellaneous Paper SL-83-16, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

US Army Engineer Waterways Experiment Station. 1949. Handbook for Concrete and Cement (with quarterly supplements), Vicksburg, Miss.

Buck, Alan D. and Burkes, J. P. 1981. Characterization and Reactivity of Silica Fume, Miscellaneous Paper SL-81-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1. Mixture Proportions, Kinzua G1 with 30 Percent Silica Fume

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS (CRD-C 3)

PROJECT NAME: Kinzua Stilling Basin Repairs	SYMBOL: SERIAL NO.:	DATE:
CONCRETE REQUIRED FOR:		MIXTURE NO.:

MATERIALS

PORTLAND CEMENT, SS-C-192, TYPE: I ADDITIONS: BRAND AND MILL: Marquette	POZZOLON OR OTHER CEMENT: Silica Fume TYPE: SOURCE: Reynolds Metals Co. Sheffield, AL	AIR-ENT. ADMIXTURE: TYPE: None AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Glacial Sand SOURCE: Buffalo Slag Co. Franklinville, NY	TYPE: Limestone SIZE: 1 in. SOURCE: Neidigh Bros. Quarry Boalsburg, PA

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	RC-888			3.15	
* Silica Fume	AD-536(4)			2.22	
*					
FINE AGGREGATE	PITT-8 S-1	No. 4 - 200		2.63	1.6
COARSE AGGREGATE (A)	PITT-8 G-1	No. 4 - 1 in.		2.71	0.4
COARSE AGGREGATE (B)					
COARSE AGGREGATE (C)					
COARSE AGGREGATE (D)					

MIXTURE DATA

MATERIALS	MIX BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)
PORTLAND CEMENT	1.00	592.2	3.013
* Silica Fume		253.8	1.832
*			
FINE AGGREGATE		1437.1	8.757
COARSE AGGREGATE (A)		1738.4	10.280
COARSE AGGREGATE (B)			
COARSE AGGREGATE (C)			
COARSE AGGREGATE (D)			
WATER		177.7	2.848
AIR 1%			0.270
TOTAL		4199.2	27.000

SPECIMEN DATA

CYLINDERS SIZE: NO.	AGE	PSI	BEAMS SIZE: NO.	AGE	PSI

W/(C + SF): 0.21	S/A, % VOLUME: 46
SLUMP (IN.)[4]: 3-1/4	THEO. UNIT WT (LB/CU FT): 157.1
BLEEDING (%)[2]	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]	THEO. CEMENT FACT (LB/CU YD): 846.0
AIR CONTENT (%)[4]	ACTUAL CEMENT FACT (LB/CU YD):

1 Calculated on the basis of:
2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9.
3 In the entire batch as mixed.
4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve.

* *For "other cement," pozzolan, second size of fine aggregate, as may be required.*

REMARKS: Condition of mix, workability, plasticity, bleeding, etc

HRWRA: 3 percent by weight (C + SF)
Dowell D-65 (dry)

WES FORM NO 553
REV MAR 1972

Table 2

Characteristics of Hardened Concrete, Gl Aggregate with 30 Percent Silica Fume

Property	Specimen 1	Specimen 2	Average
Compressive strength, psi			
7 day	10,520	10,500	10,510
28 day	13,930	13,760	13,850
90 day	16,130	15,420	15,780
Modulus, psi x 10^6	6.05	6.00	6.05
Poisson's ratio	0.23	0.25	0.24
Pulse velocity, ft/sec	16,950	16,950	16,950
Dynamic modulus, psi x 10^6	4.785	4.575	4.680
Unit weight of chunk sample: 155.7 lb/ft^3			

Table 3

Abrasion-Erosion Test Data

Concrete Mixture: Kinzua G1 Aggregate with 30 Percent Silica Fume

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	39.00	0.0	39.60	0.0	39.20	0.0	0.0
12	38.85	0.4	39.55	0.1	39.00	0.5	0.3
24	38.80	0.5	39.35	0.6	38.85	0.9	0.7
36	38.65	0.9	39.25	0.9	38.70	1.3	1.0
48	38.50	1.3	39.10	1.3	38.55	1.7	1.4
60	38.30	1.8	38.95	1.6	38.40	2.0	1.8
72	38.20	2.1	38.80	2.0	38.25	2.4	2.2

Notes:

Table 4. Mixture Proportions, Kinzua G3 with 30 Percent Silica Fume

REPORT OF SELECTION OF CONCRETE MIXTURE PROPORTIONS
(CRD-C 3)

PROJECT NAME: Kinzua Stilling Basin Repairs	SYMBOL: SERIAL NO.:	DATE:
CONCRETE REQUIRED FOR:		MIXTURE NO.:

MATERIALS

PORTLAND CEMENT, SS-C-192,	POZZOLON OR OTHER CEMENT:	AIR-ENT. ADMIXTURE
TYPE: I ADDITIONS:	TYPE: Silica Fume	TYPE: None
BRAND AND MILL: Marquette	SOURCE: Reynolds Metals Co. Sheffield, AL	AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Glacial Sand	TYPE: Grabbo SIZE: 1 in.
SOURCE: Buffalo Slag Co. Franklinville, NY	SOURCE: Luck Quarry Leesburg, VA

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	RC-888			3.15	
* Silica Fume	AD-536(4)			2.22	
*					
FINE AGGREGATE	PITT-8 S-1	No. 4 - 200		2.63	1.6
COARSE AGGREGATE (A)	PITT-8 G-3	No. 4 - 1 in.		2.99	0.5
COARSE AGGREGATE (B)					
COARSE AGGREGATE (C)					
COARSE AGGREGATE (D)					

MIXTURE DATA / **SPECIMEN DATA**

MATERIALS	MIX. BY WEIGHT	S. S. D. WEIGHTS ONE CU YD BATCH (LB)	SOLID VOL ONE CU YD (CU FT)	CYLINDERS SIZE: NO.	AGE	PSI	BEAMS SIZE: NO.	AGE	PSI
PORTLAND CEMENT	1.00	592.2	3.013						
* Silica Fume		253.8	1.832						
*									
FINE AGGREGATE		1437.1	8.757						
COARSE AGGREGATE (A)		1918.0	10.280						
COARSE AGGREGATE (B)									
COARSE AGGREGATE (C)									
COARSE AGGREGATE (D)									
WATER		177.7	2.848						
AIR 1%			0.270						
TOTAL		4378.8	27.000						

W/(C + SF): 0.21	S/A, % VOLUME: 46
SLUMP (IN.)[4]: 3	THEO. UNIT WT (LB/CU FT): 163.8
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD): 846.0
AIR CONTENT (%)[4]:	ACTUAL CEMENT FACT (LB/CU YD):

1 Calculated on the basis of:
2 Expressed as the percentage of mixing water separating from the concrete when tested by CRD-C 9.
3 In the entire batch as mixed.
4 In that portion of the concrete containing aggregate smaller than the 1-1/2-in. sieve.

* *For "other cement," pozzolan, second size of fine aggregate, as may be required.*

REMARKS: *Condition of mix, workability, plasticity, bleeding, etc.*

HRWRA: 3 percent by weight (C + SF)
Dowell D-65 (dry)

WES FORM NO. 553
REV MAR 1972

Table 5

Concrete Mixture Used by Elborg With G3 Aggregate

Powder (cement + silica fume + admixtures)	81.3 lb
Water	16.8 lb
Fine aggregate, SSD	81.7 lb
Coarse aggregate, SSD	122.6 lb

Water/powder = 0.21

Sand/aggregate = 0.40

Note: The ratio of the ingredients in the powder is proprietary information. The design volume for the above weights is unknown.

Table 6

Abrasion-Erosion Test Data

Concrete Mixture: Kinzua G3 Aggregate with 30 Percent Silica Fume

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	39.55	0.0	39.65	0.0		0.0	0.0
12	39.45	0.3	39.45	0.5			0.4
24	39.20	0.9	39.25	1.0			1.0
36	39.00	1.4	39.20	1.1			1.3
48	38.90	1.6	39.20	1.1			1.4
60	38.60	2.4	39.00	1.6			2.0
72	38.55	2.5	38.85	2.0			2.3

Notes:

Table 7

Abrasion-Erosion Test Data

Concrete Mixture: Kinzua G3 Aggregate with Elborg Cement and Silica Fume Product

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	39.75	0.0	39.10	0.0		0.0	0.0
12	39.65	0.3	38.95	0.4			0.4
24	39.55	0.5	38.85	0.6			0.6
36	39.45	0.8	38.80	0.8			0.8
48	39.40	0.9	38.75	0.9			0.9
60	39.30	1.1	38.70	1.0			1.1
72	39.20	1.4	38.60	1.3			1.4

Notes:

Table 8

Compressive Strengths of WES and Elborg Concretes

Made with Kinzua G3 Aggregate

Age, days	Compressive Strength, psi WES	Compressive Strength, psi Elborg
7	11,030	13,050
	11,250	10,560
	Avg: 11,140	Avg: 11,810
28	13,760	14,290
	13,850	14,330
		15,330
	Avg: 13,810	Avg: 14,650
90	16,870	Not tested
	15,770	
	Avg: 16,320	

Table 9

Abrasion-Erosion Test Data

Concrete Mixture: Norcem Mixture 1

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	38.00	0.0	38.20	0.0		0.0	0.0
12	37.75	0.7	37.90	0.8			0.8
24	37.55	1.2	37.65	1.4			1.3
36	37.30	1.8	37.45	2.0			1.9
48	36.90	2.9	37.00	3.1			3.0
60	36.70	3.4	36.65	4.1			3.8
72	36.40	4.2	36.30	5.0			4.6

Notes:

Table 10

Abrasion-Erosion Test Data

Concrete Mixture: Norcem Mixture 3

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	37.30	0.0	37.40	0.0		0.0	0.0
12	37.00	0.8	37.15	0.7			0.8
24	36.80	1.3	37.00	1.1			1.2
36	36.60	1.9	36.85	1.5			1.7
48	36.30	2.7	36.55	2.3			2.5
60	36.10	3.2	36.20	3.2			3.2
72	35.90	3.8	36.00	3.7			3.8

Notes:

Table 11

Abrasion-Erosion Test Data

Concrete Mixture: Elborg Mixture 1

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	39.40	0.0	38.90	0.0		0.0	0.0
12	39.05	0.9	38.85	0.1			0.5
24	38.80	1.5	38.50	1.0			1.3
36	38.50	2.3	38.20	1.8			2.1
48	38.20	3.0	37.75	3.0			3.0
60	37.90	3.8	37.50	3.6			3.7
72	37.55	4.7	37.20	4.4			4.6

Notes:

Table 12

Abrasion-Erosion Test Data

Concrete Mixture: Elborg Mixture 3

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss
0	39.00	0.0	39.60	0.0		0.0	0.0
12	38.75	0.6	39.40	0.5			0.6
24	38.70	0.8	39.35	0.6			0.7
36	38.50	1.3	39.20	1.0			1.2
48	38.30	1.8	39.00	1.5			1.7
60	38.00	2.6	38.70	2.3			2.5
72	37.80	3.1	38.50	2.8			3.0

Notes:

Table 13

Abrasion-Erosion Test Data

Concrete Mixture: Cores from Trial Placements, Upper Surfaces Tested

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss*
0	38.80	0.0	40.20	0.0	39.20	0.0	0.0
12	38.60	0.5	39.95	0.6	38.95	0.6	0.6
24	38.40	1.0	39.80	1.0	38.60	1.5	1.0
36	38.10	1.8	39.65	1.4	38.40	2.0	1.6
48	37.90	2.3	39.40	2.0	38.20	2.6	2.2
60	37.60	3.1	39.15	2.6	38.00	3.1	2.9
72	37.20	4.1	38.80	3.5	37.80	3.6	3.8

Notes: Specimen A = Core ORP No. 2-1.
Specimen B = Core ORP No. 2-2.
Specimen C = Core ORP No. 5.
* Average of Specimens A and B only.

Table 14

Abrasion-Erosion Test Data

Concrete Mixture: Cores from Trial Placements, Lower Surfaces Tested

Elapsed Test Time, hr	Specimen A Wt, lb	Specimen A Percent Loss	Specimen B Wt, lb	Specimen B Percent Loss	Specimen C Wt, lb	Specimen C Percent Loss	Average Percent Loss*
0	37.00	0.0	38.50	0.0	37.60	0.0	0.0
12	36.80	0.5	38.30	0.5	37.35	0.6	0.5
24	36.35	1.8	38.05	1.2	37.20	1.0	1.5
36	36.20	2.2	37.80	1.8	37.15	1.2	2.0
48	35.75	3.4	37.50	2.6	37.10	1.3	3.0
60	35.40	4.3	37.30	3.1	36.90	1.9	3.7
72	35.00	5.4	36.85	4.3	36.65	2.5	4.9

Notes: Specimen A = Core ORP No. 2-1.
Specimen B = Core ORP No. 2-2.
Specimen C = Core ORP No. 5.
* Average of Specimens A and B only.

Table 15

Summary of Test Data for Concretes Placed During the Trial Placements at Neville Island

Mixture	Abrasion-Erosion Loss, %	Comp Str, 28-Day Cyls,* psi	Comp Str, 28-Day Core,** psi	Comp Str, 90-Day Cyls,* psi	Compr Str, 90-Day Core,** psi	Slump, in.	Cement lb/yd^3	SF† lb/yd^3	SF†/CMT, %	W/(C + SF)
Norcem 1	4.6	13,630	7,740 (Bad Break)	15,720	14,000	8	600	111	16	0.35
Elborg 1	4.6	15,770	10,210	16,130	15,480	10	600	131	22	0.31
Norcem 3	3.8	14,850	10,830	17,520	13,700	7-3/4	1000	181	15	0.23
Norcem 2 (Cores)	3.8	14,590	11,340	16,800	13,200	10-1/4	800	139	15	0.29
Elborg 2 (Core)	3.6	12,880	12,700	16,660	13,070	7-1/4	650	116	18	0.28
Elborg 3	3.0	14,690	13,500	16,980	13,620	6-1/2	700	97	14	0.32

* Average of two 4- by 8-in. cylinders.

** One 4- by 8-in. specimen prepared from core.

† SF = silica fume.

Figure 1. Abrasion-erosion specimen at conclusion of testing, Mixture G1 (30 per cent silica fume)

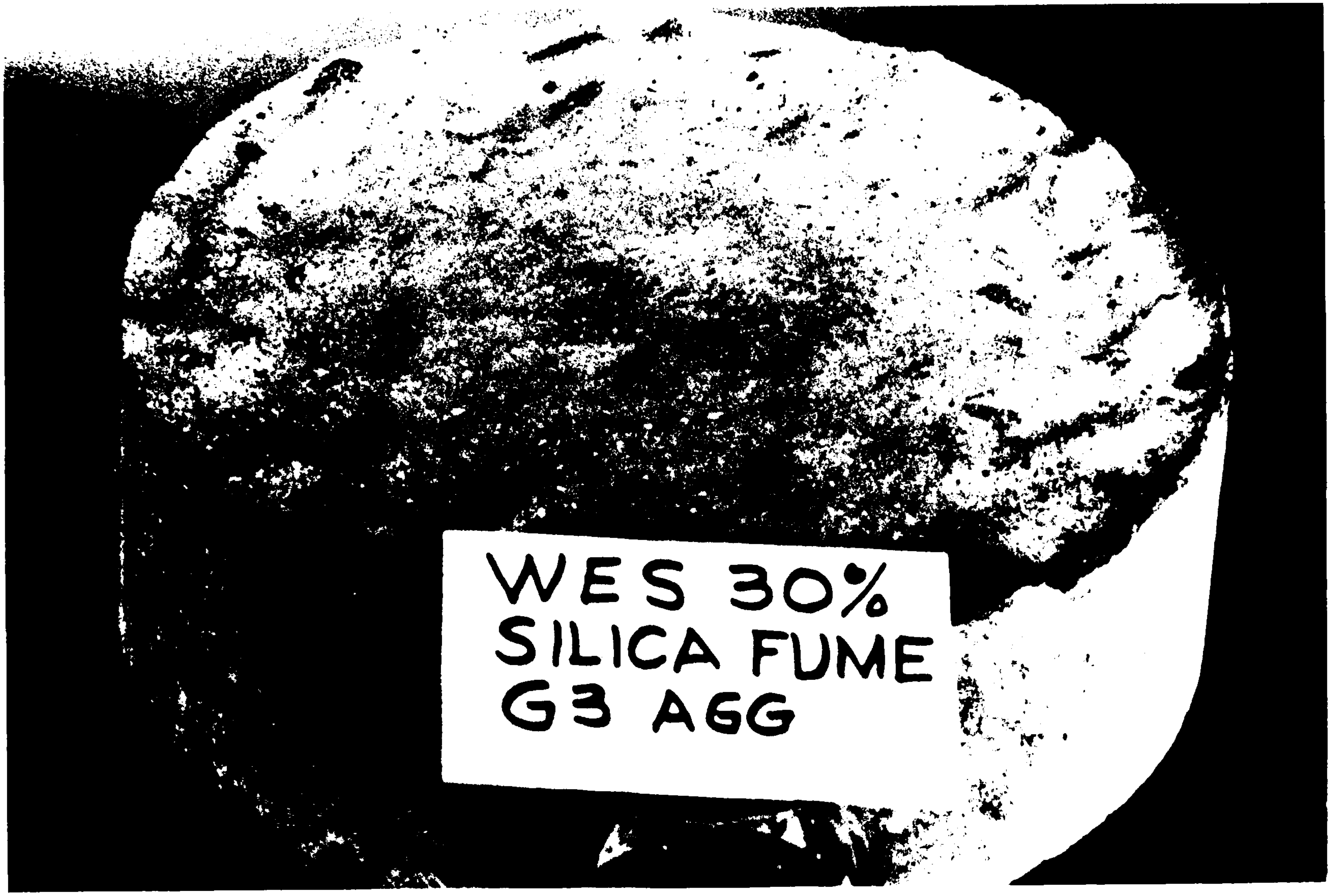


Figure 2. Abrasion-erosion specimen at conclusion of testing, Mixture G3 (30 per cent silica fume)

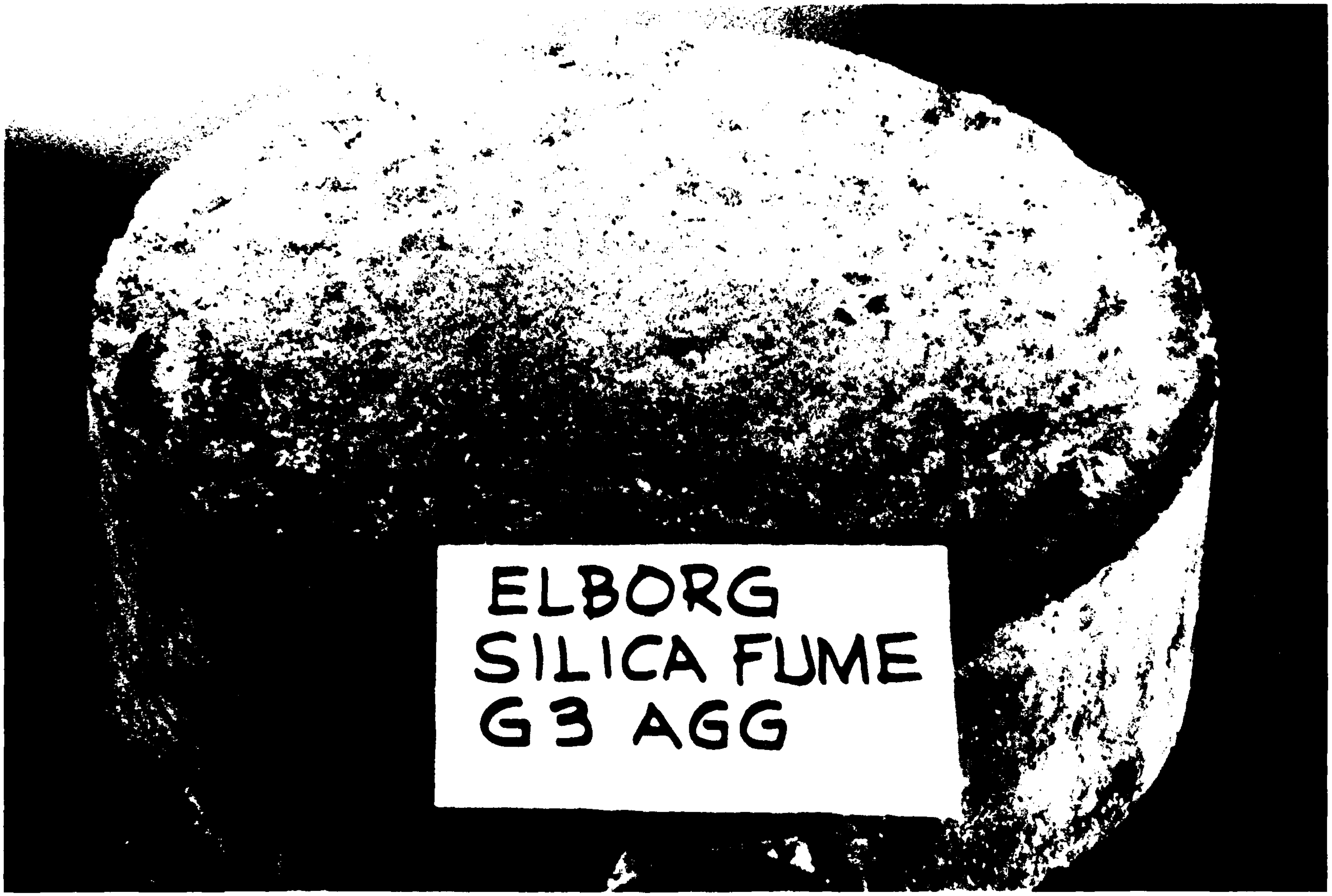


Figure 3. Abrasion-erosion specimen at conclusion of testing, Mixture G3 (Elborg product)

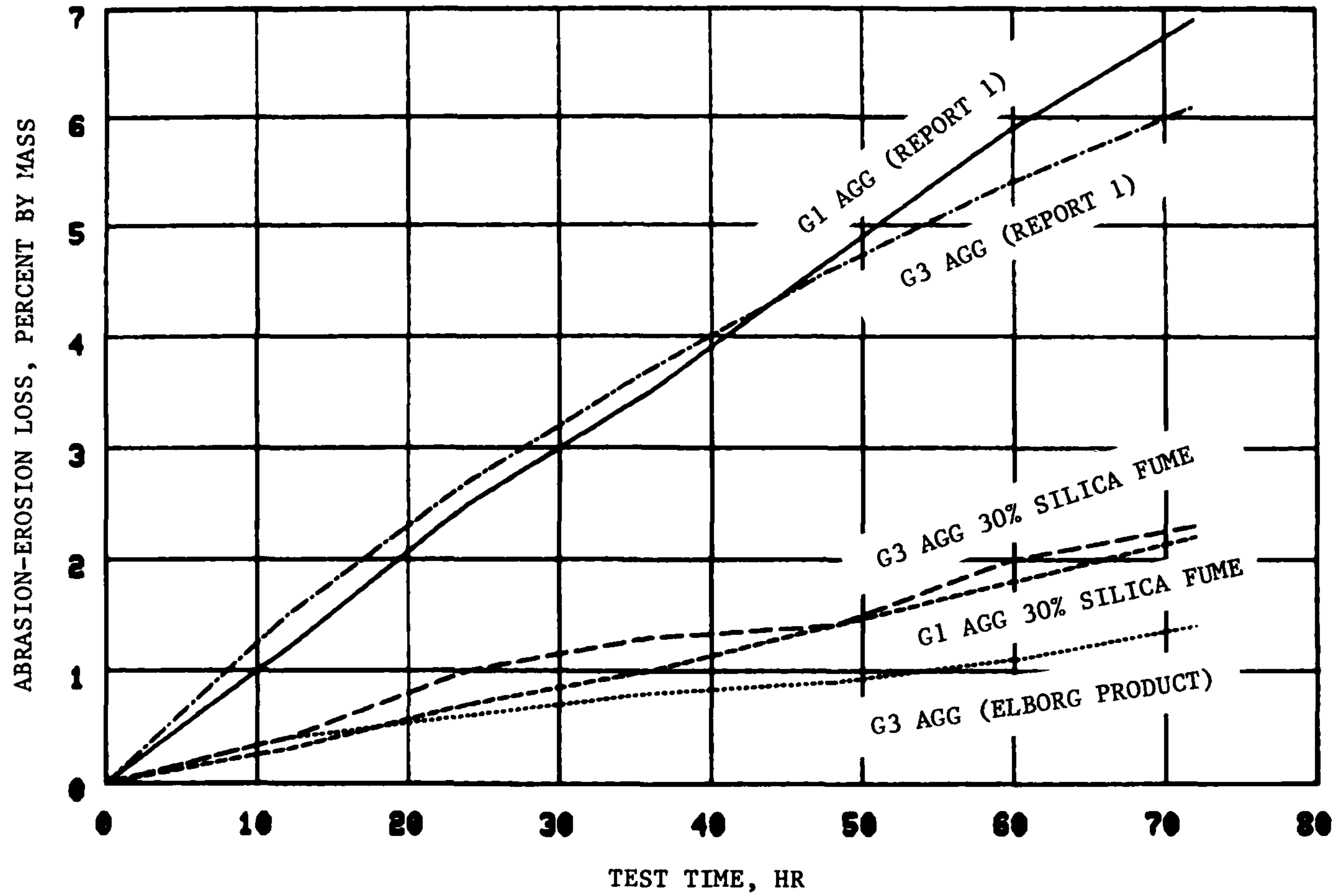


Figure 4. Abrasion-erosion performance of concrete mixtures prepared in the laboratory

Figure 5. Abrasion-erosion specimen at conclusion of testing, Mixture Norcem 1 from Neville Island trial placements

Figure 6. Abrasion-erosion specimen at conclusion of testing, Mixture Norcem 3 from Neville Island trial placements

Figure 7. Abrasion-erosion specimen at conclusion of testing, Mixture Elborg 1 from Neville Island trial placements

Figure 8. Abrasion-erosion specimen at conclusion of testing, Mixture Elborg 3 from Neville Island trial placements

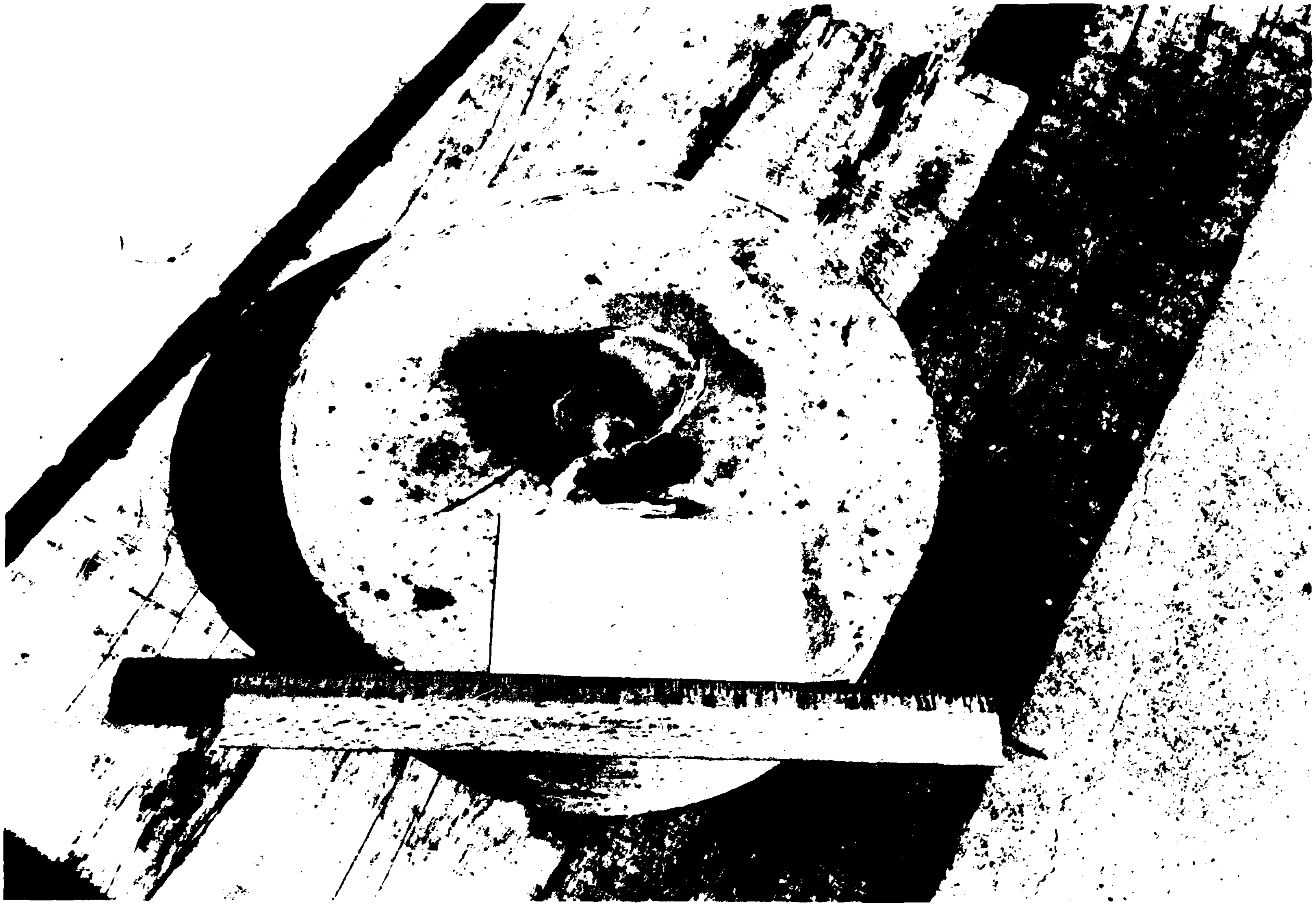


Figure 9. Abrasion-erosion specimen before testing, core ORP No. 2-1 from Neville Island trial placements

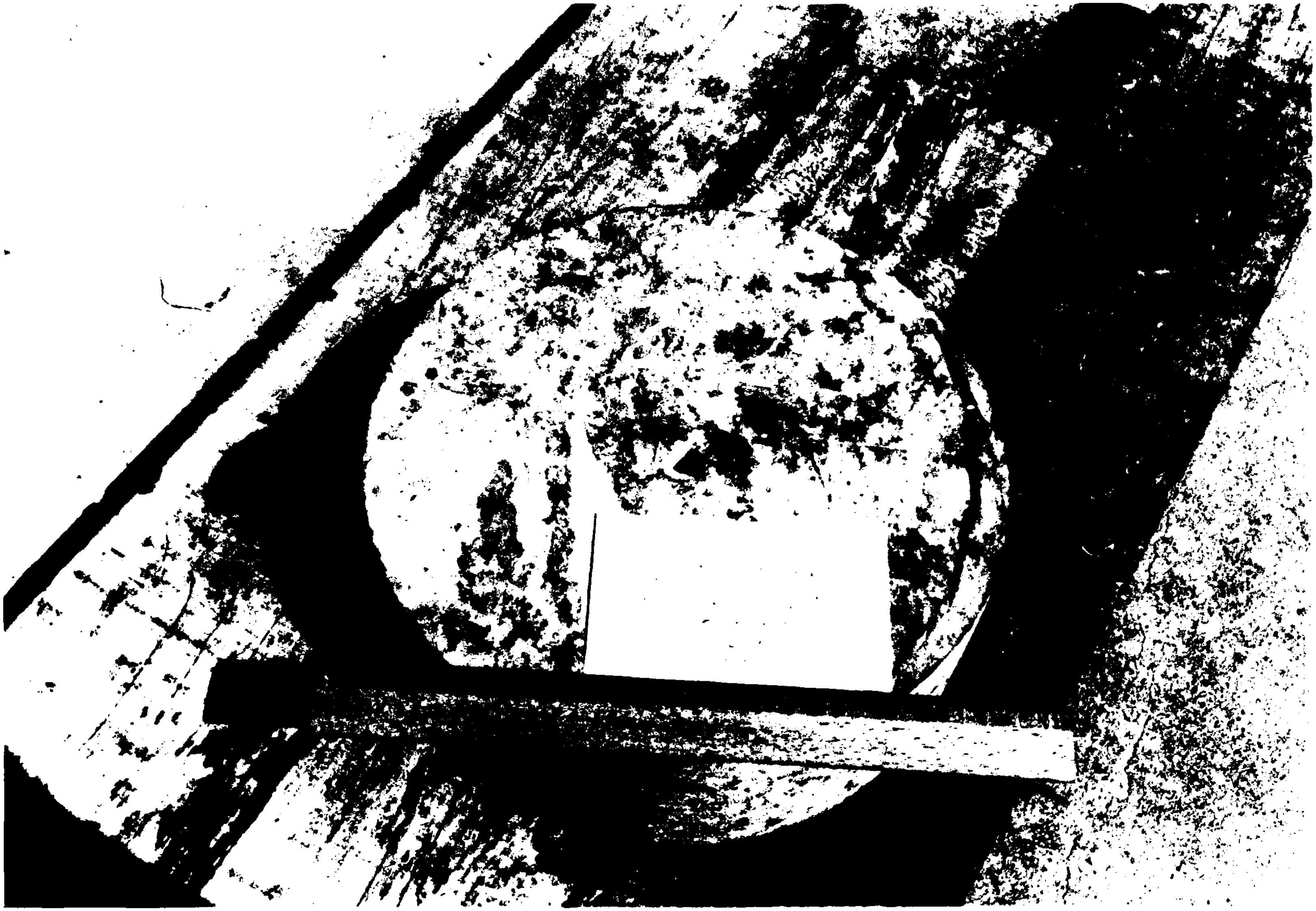


Figure 10. Abrasion-erosion specimen before testing, core ORP No. 2-2 from Neville Island trial placements

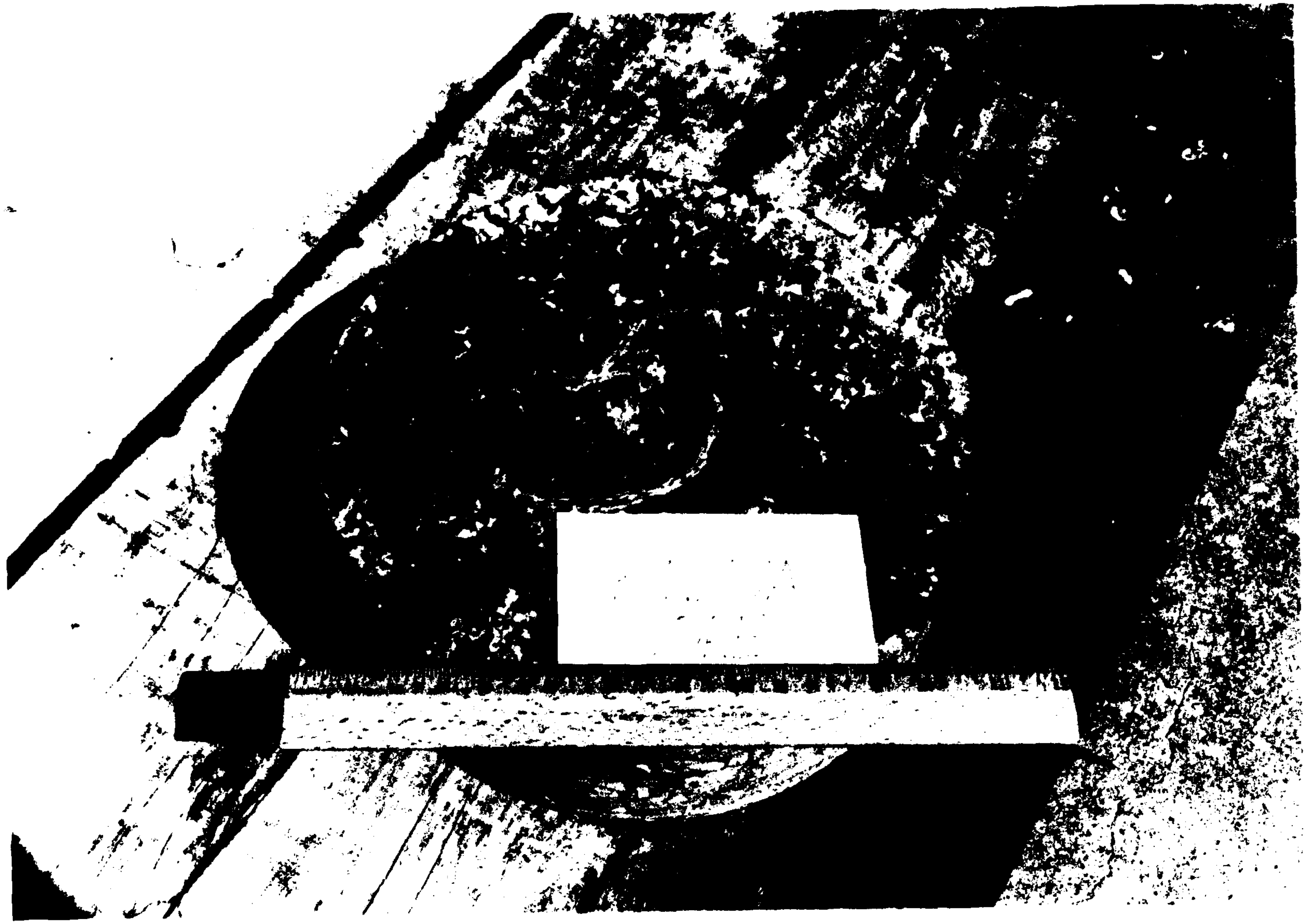


Figure 11. Abrasion-erosion specimen before testing, core ORP No. 5 from Neville Island trial placements

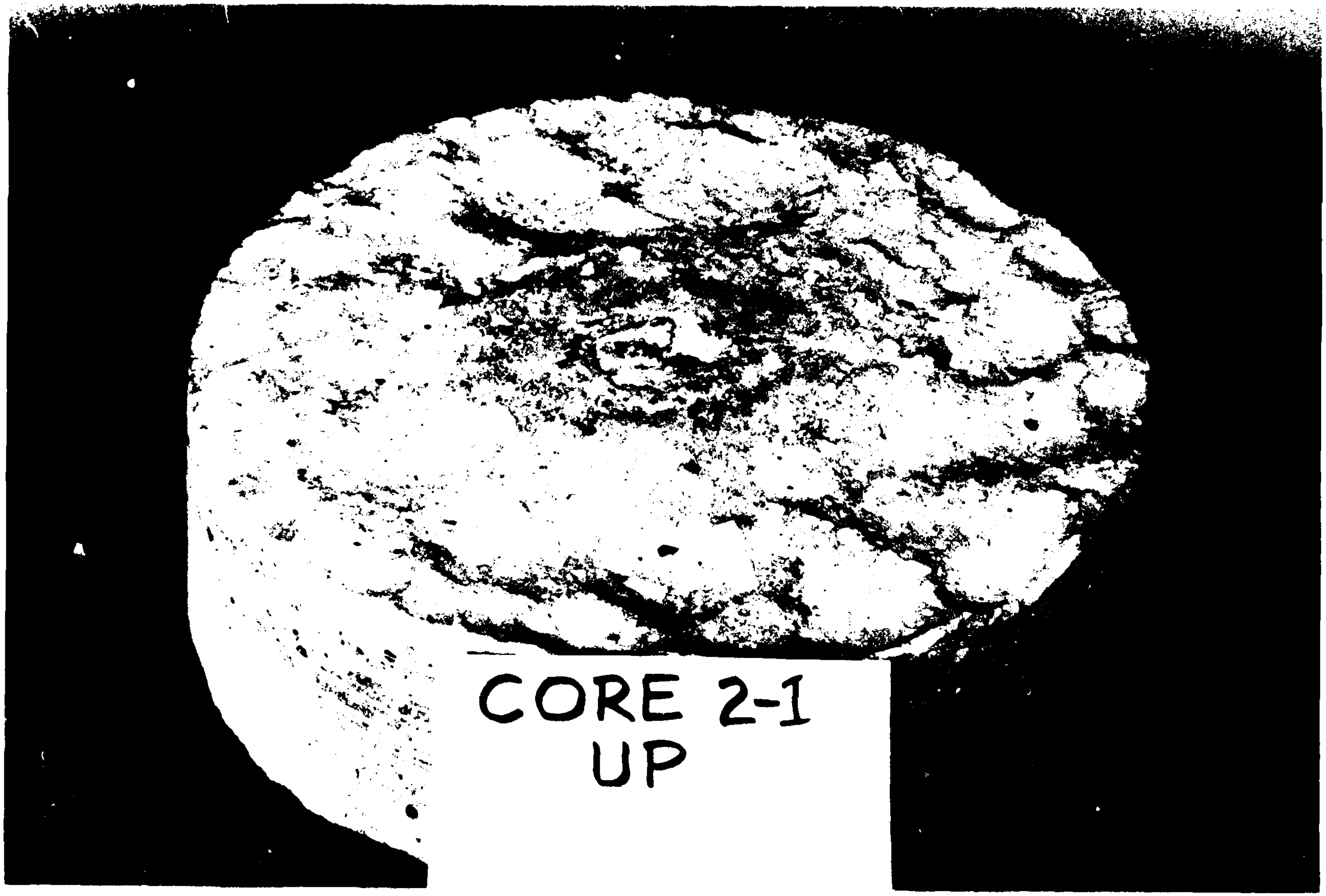


Figure 12. Abrasion-erosion specimen at conclusion of testing, core ORP No. 2-1 from Neville Island trial placements, upper surface tested

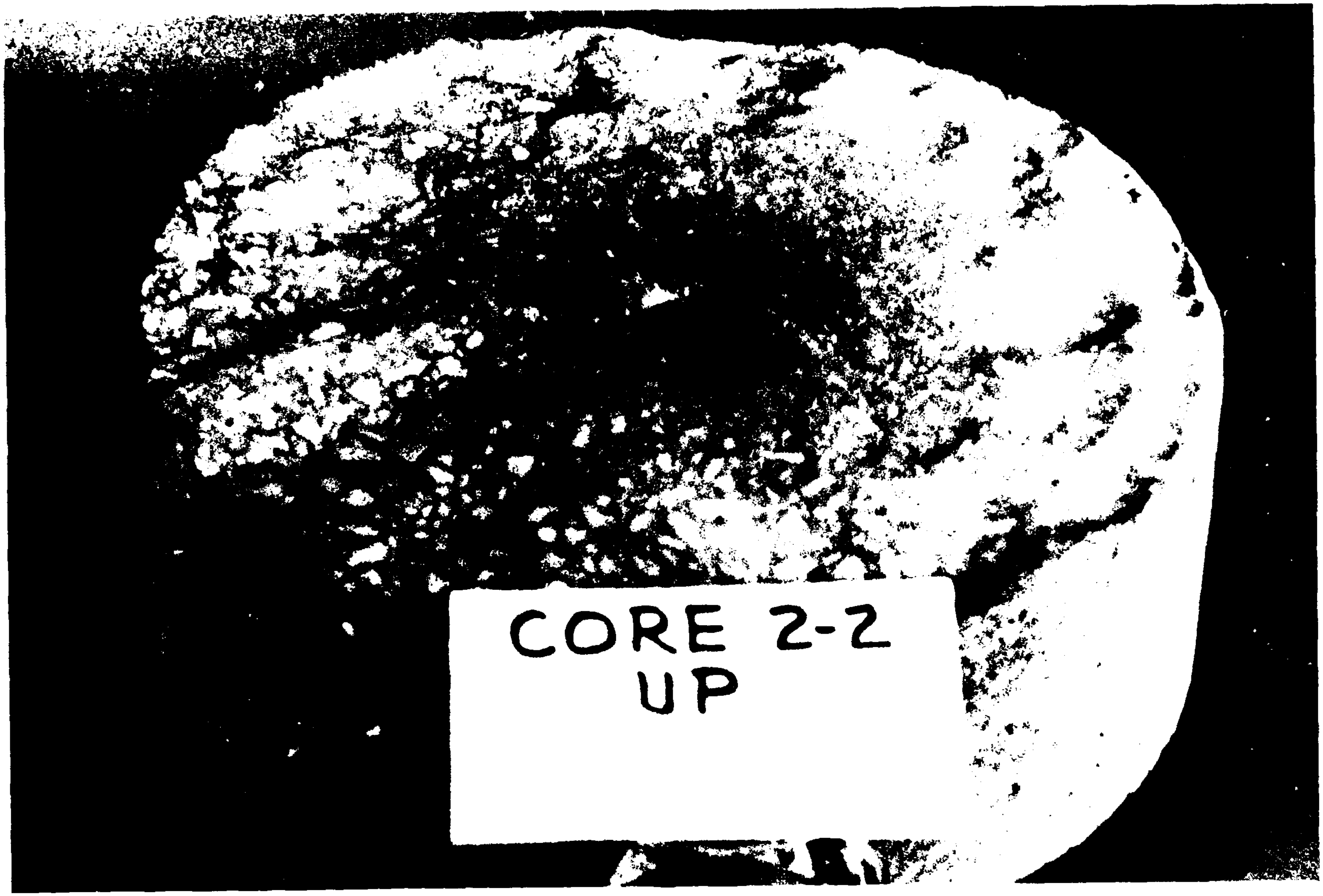


Figure 13. Abrasion-erosion specimen at conclusion of testing, core ORP No. 2-2 from Neville Island trial placements, upper surface tested

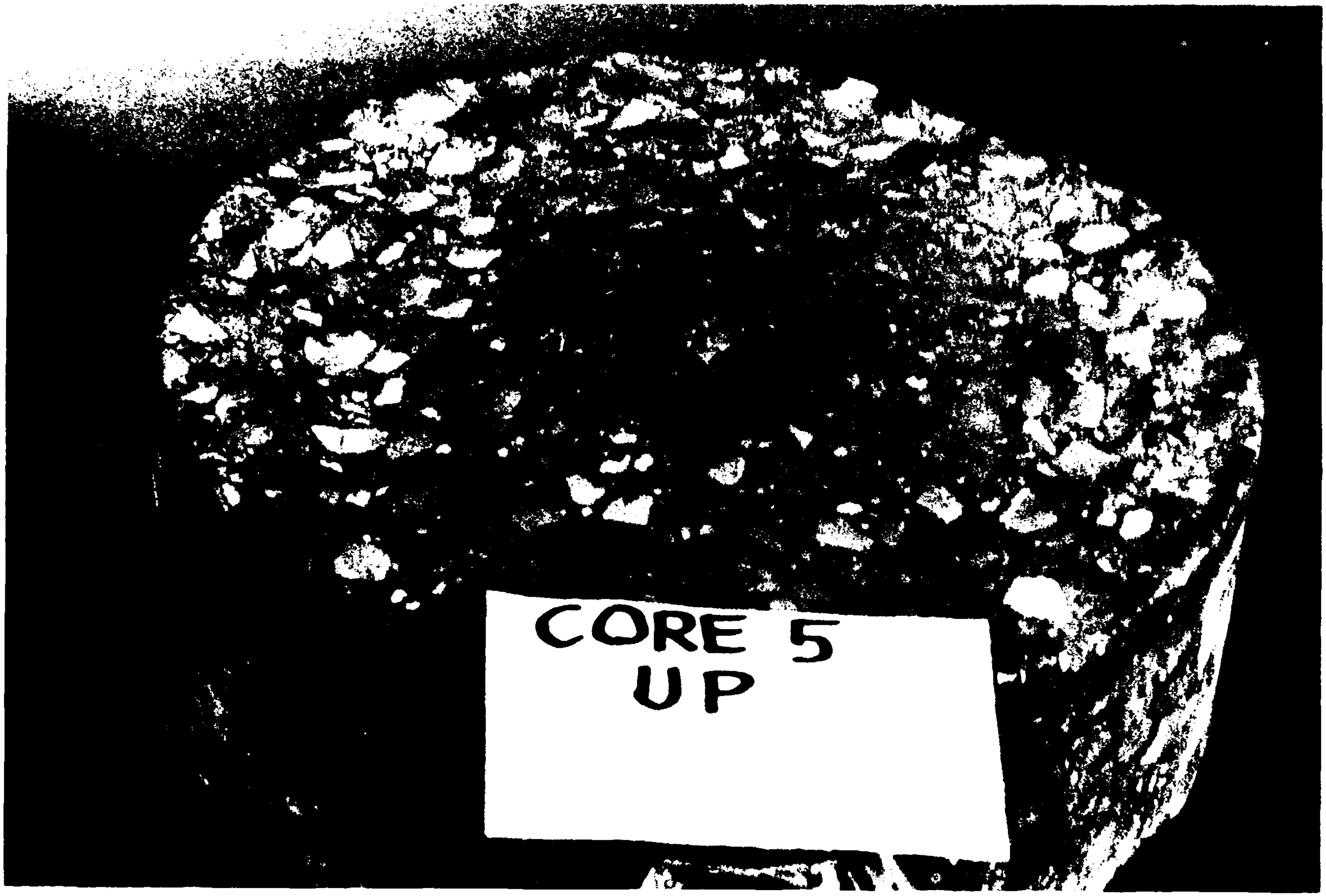


Figure 14. Abrasion-erosion specimen at conclusion of testing, core ORP No. 5 from Neville Island trial placements, upper surface tested

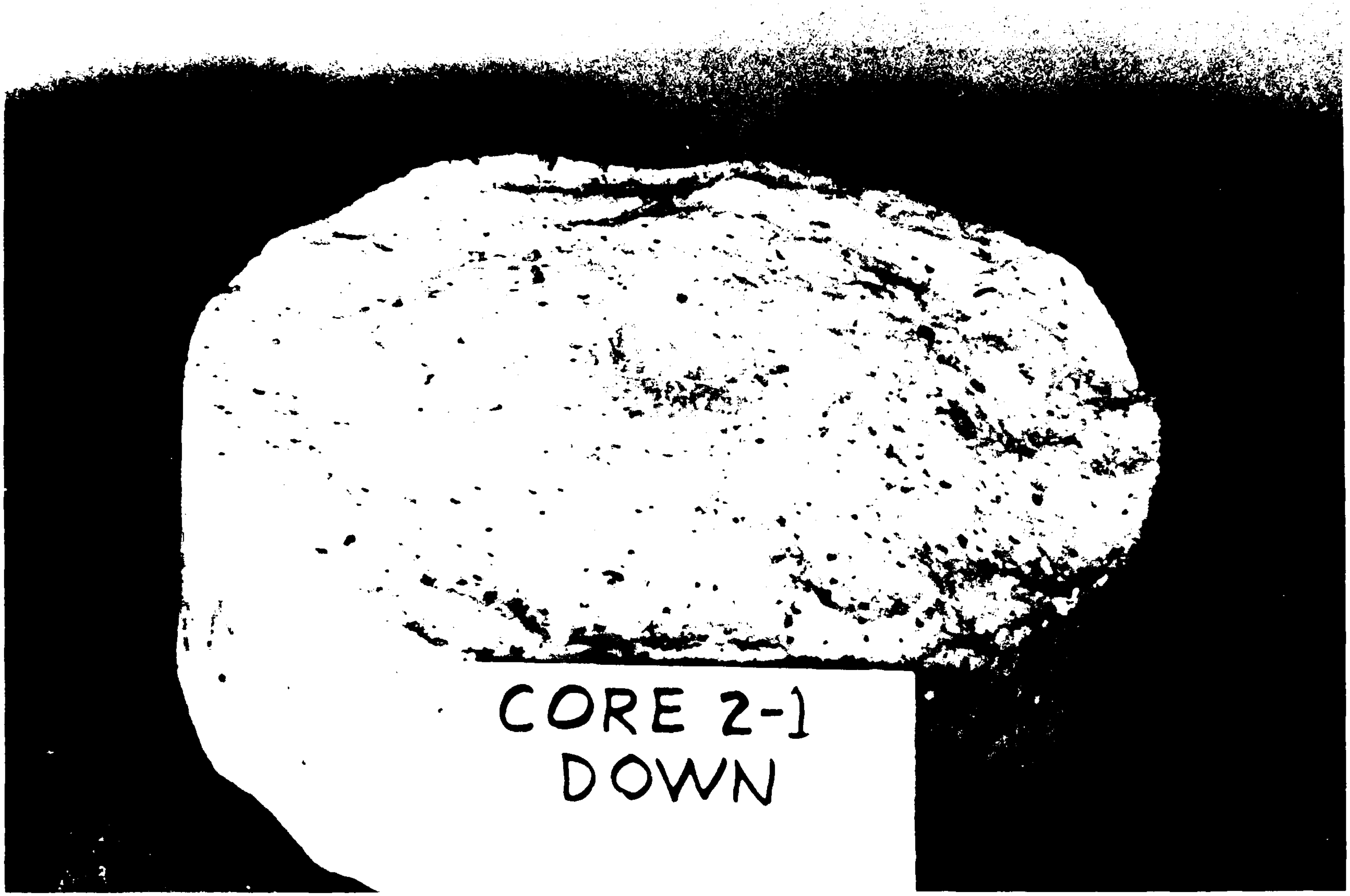


Figure 15. Abrasion-erosion specimen at conclusion of testing, core ORP No. 2-1 from Neville Island trial placements, lower surface tested

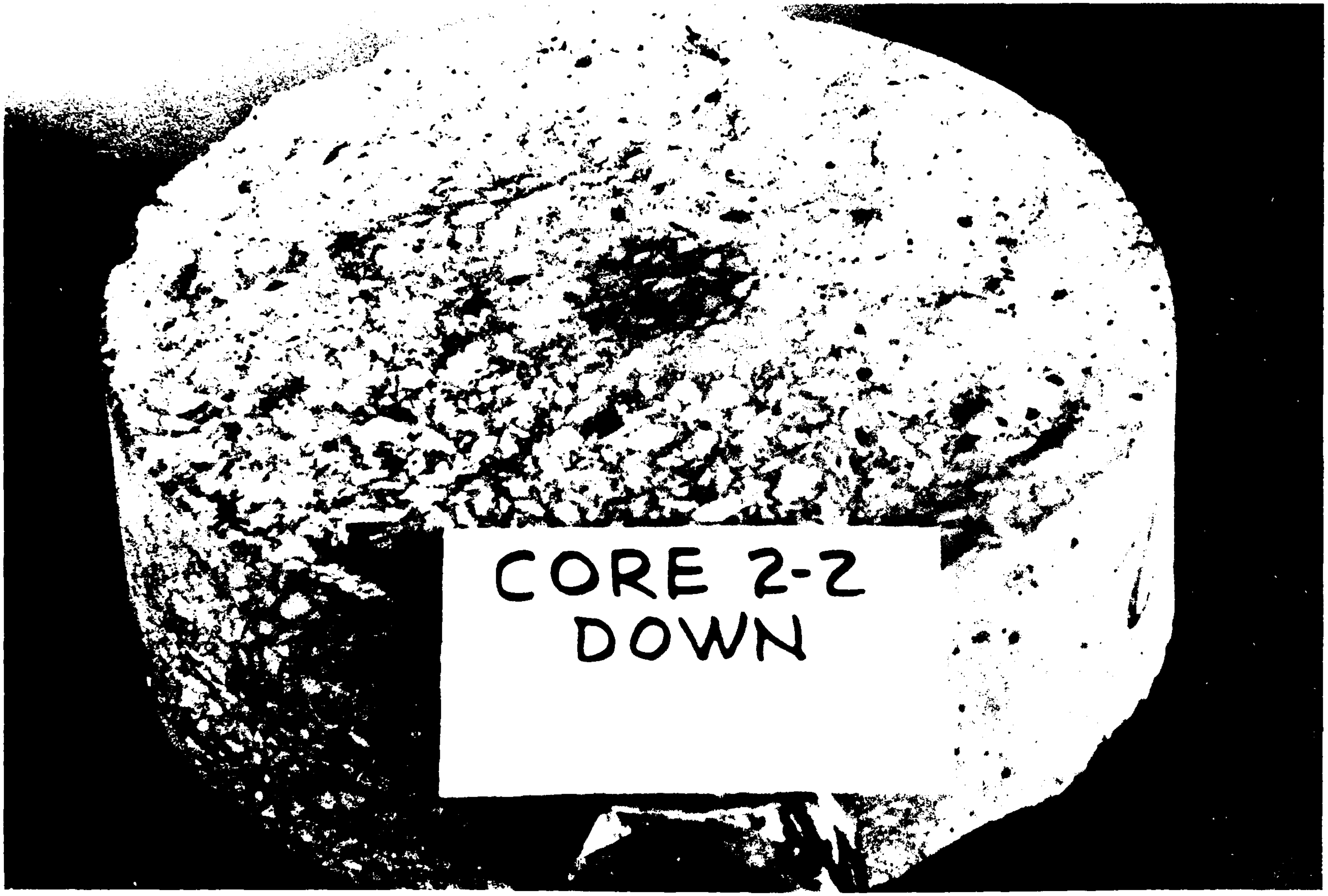


Figure 16. Abrasion-erosion specimen at conclusion of testing, core ORP No. 2-2 from Neville Island trial placements, lower surface tested

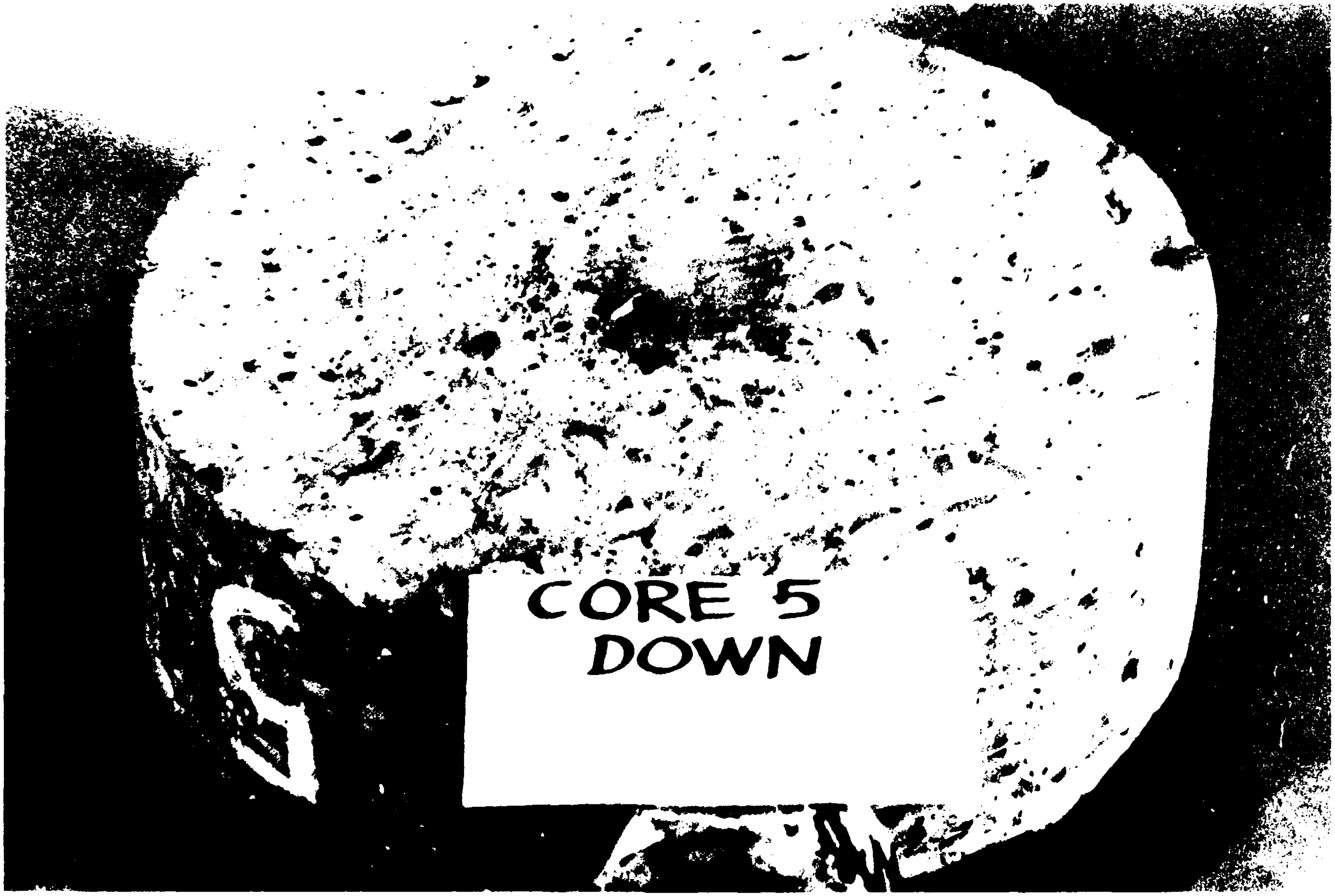


Figure 17. Abrasion-erosion specimen at conclusion of testing, core ORP No. 5 from Neville Island trial placements, lower surface tested

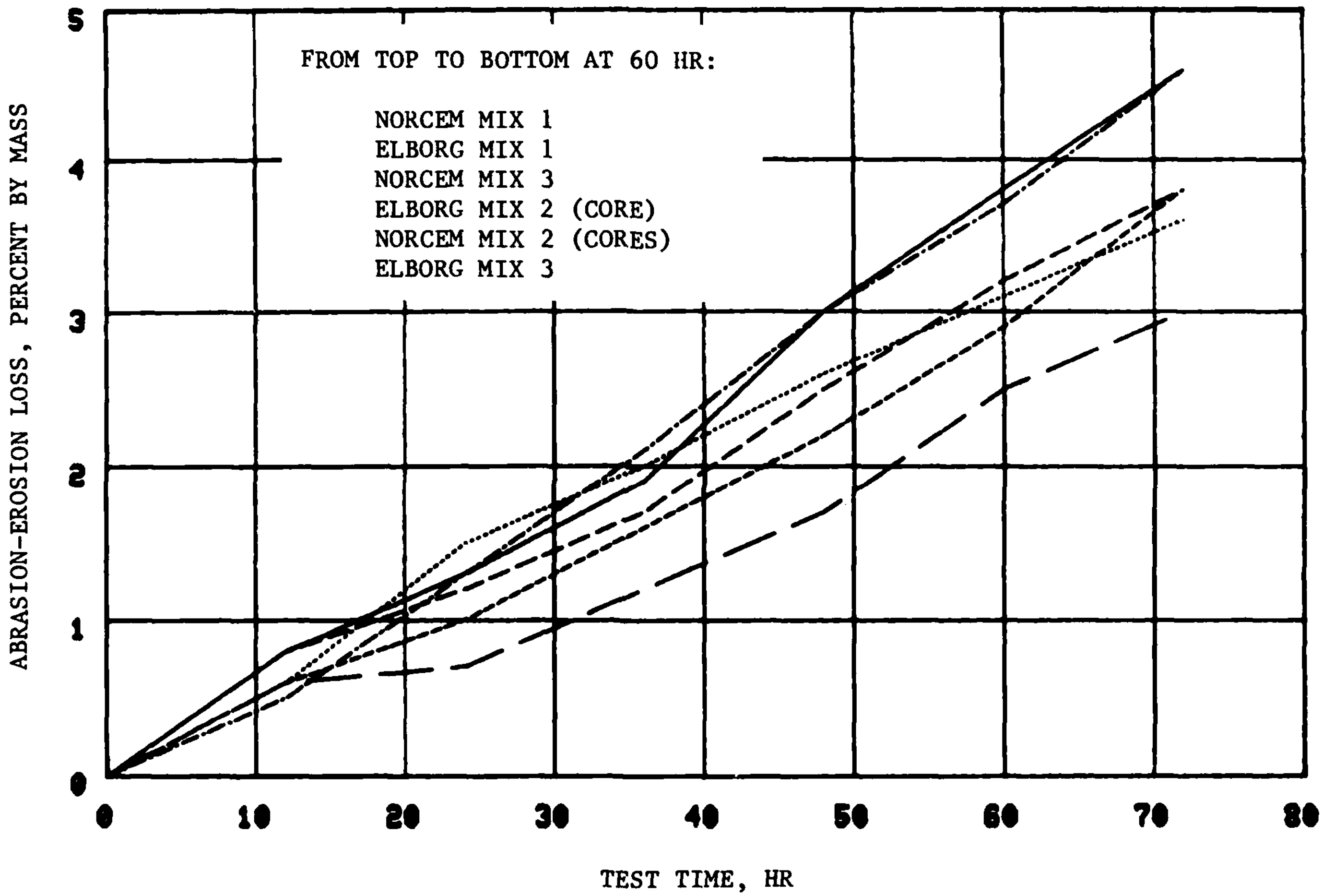


Figure 18. Abrasion-erosion performance of specimens and cores from the Neville Island trial placements

APPENDIX A

PITTSBURGH DISTRICT MEMO DESCRIBING NEVILLE ISLAND TRIAL PLACEMENTS

TRIAL PLACEMENT OF SILICA FUME CONCRETE
AT NEVILLE ISLAND
PITTSBURGH, PENNSYLVANIA

by
Anton H. Krysa

U.S. Army Engineer District, Pittsburgh
William S. Moorhead Federal Building
1000 Liberty Avenue
Pittsburgh, PA 15222

August 1983

STILLING BASIN EROSION

1. BACKGROUND

The Pittsburgh District's first involvement in stilling basin erosion occurred when recreational scuba divers reported large holes in the Kinzua Stilling Basin in September 1969. After a review of available materials and methods to repair the erosion damage, it was decided to use a steel fiber concrete which was known to have high impact resistance that could resist the pounding caused by waterborne gravel, rock and other debris. In 1973-74 the stilling basin was repaired with a one-foot overlayment using this material. Within a few years it was evident that the steel fiber concrete was not performing any better than the original concrete. Changes were made in the operating sequence of the lower sluice gates to minimize eddy currents that were bringing in large amounts of debris from downstream. After these changes, the rate of deterioration declined. Even so, nearly ten years after the repair, erosion damage had progressed to the degree when the first repair was made.

Several years after the repair (1977) and when it was evident that a test was needed to evaluate the relative resistance to concrete erosion due to the number of stilling basin erosion problems occurring across the country, WES developed a test method to evaluate the types of concrete and aggregate against abrasion-erosion damage. At this time the term abrasion-erosion was coined to describe the abrasion from waterborne debris such as hard rock like granite and the sequent erosion of the concrete enhanced by the abrasion and impact. The test consists of an electric drill turning an agitation paddle immersed in water housed by a cylindrical steel tank with 70 steel balls of various sizes that contains a 12-inch concrete specimen. The steel balls simulate the abrasive grinding action thought to occur in stilling basins. The water and steel balls are circulated in the container by the immersed agitation paddle for up to 72 hours. At 12-hour intervals the specimen is removed and weighed.

Conclusions reached from this investigation (see REF 1) indicated that steel fiber-reinforced concrete should not be used in new construction or for repair of stilling basins. It was found at that time that the conventional concrete with the lowest practical water to cement ratio and containing the hardest available aggregate should be used for new construction or repair where abrasion-erosion is to be expected. It was recommended that water to cement ratios less than 0.40 be used with compressive strengths in the 6000 to 9000 psi range.

Early in 1982, in preparation to again repair the stilling basin, the Pittsburgh District requested WES to recommend a concrete mix with suitable aggregates for use in the repair of Kinzua Dam Stilling Basin. There was also some interest in the evaluation of a polymer Portland Cement concrete that WES had some previous success in testing.

After the program was initiated, it was found that other work involving the MX missile program was investigating a silica fume concrete which exhibited high strengths. The District also had contact with a new company in the Pittsburgh area that used silica fume for high strength shotcreting. Since the emergence of silica fume as a new type of high strength concrete, it was decided to incorporate this type of concrete into the test and evaluation program. A letter report (REF 2) of the WES evaluation of this and other types of concretes was included within the Feature Design Memorandum for the Kinzua Dam Stilling Basin Rehabilitation.

The recommendations made by WES within this report were to use a conventional concrete with a better quality aggregate similar to that of chert, or use a silica fume with the best locally available limestone aggregate. The possibility of using silica fume with a high quality aggregate was explored but it was found that the degree of abrasion-erosion resistance was only slightly better than with silica fume and limestone and, therefore, the additional cost to obtain chert did not seem justifiable. The performance of polymer concretes from previous work done by Liu (REF 1) indicated that they would be good performers and results indicated that they did perform well but not quite as well as the silica fume concretes. Because the anticipated costs of the epoxy additive could add between $300 to $700 to the cost per cubic yard, polymer concrete was not seriously considered when the cost of silica fume concrete was projected to be much lower. From the results of the WES evaluation of abrasion-erosion resistant concretes, the District recommended in the FDM that repairs proceed using the new type of concrete with silica fume and plasticizers as additives. ORD concurred by response in the 1st Indorsement to proceed with the silica fume concrete. It was recommended that trial placements be made to establish criteria for the specifications and to work out any special requirements for placing, finishing and curing the concrete.

2. TRIAL PLACEMENTS

On 18 and 25 March trial batches of silica fume concrete using both slurry and dry powder forms were placed at the District's maintenance facility on Neville Island. The trial batches were witnessed by Huntington Construction personnel and representatives from ORD, OCE and WES. Both placements were preceded by trial batching at the ready-mix plant. Our workforce constructed the formwork and placed and finished the concrete under the direction of the silica fume supplier's representative. The following is a description of events and activities for the placement of the two types of silica fume concrete.

3. DRY POWDER FORM

Contact was made with Norcem, Inc., Long Island City, N.Y., a silica fume supplier, who has been actively placing silica fume concrete for approximately five years doing primarily small placements in chemical plants. Mr. Wolsiefer of their company expressed interest in participating in the trial. A supply contract for both types of silica fume was awarded to

Frank Bryan, Inc., Pittsburgh, PA to furnish 63 yards of silica fume concrete; 51 yards to be delivered to Neville Island and 12 to be batched at the plant. On 17 March, two, 3-yard trial batches of silica fume (dry powder) concrete were mixed at the ready-mix plant. The first mix contained 600 pounds of cement and 350 pounds of silica fume and the second, 800 and 450 pounds, respectively. Mr. Wolsiefer and Mr. Callahan from Norcem directed all aspects of the batching procedure. The aggregates consisted of 3/8-inch washed limestone meeting ASTM C33, No. 8 (Pennsylvania Grade 1B) and a fine aggregate meeting ASTM C33 or PennDOT Type A concrete sand (FM = 2.8). The limestone was a Loyalhanna limestone attained from Davison Sand and Gravel, Connellsville Quarry. The first step consisted of batching all ingredients into the truck, excluding the silica fume additive, and mixing as with normal concrete. This resulted in a very dry mix with a "base" slump of zero. Slump tests of the dry mix verified that there was zero slump. The silica fume including dry superplasticizers were added to the concrete truck hopper. These items were in dry powder form shipped in 50 pound dense paper drum containers. Trade name of the powder on the containers was "Corrocem". Mr. Wolsiefer directed the truck operator to rotate the drum forward and backward to mix the powder into the concrete. He also sprayed additional water around the mouth of the drum to wash down remaining powder into the interior of the drum. After he was satisfied that proper mixing had occurred, the concrete was placed in rectangular steel box forms at the batch plant as waste concrete. The concrete had transformed from a very dry mix to one with a slump of approximately nine inches. Slumps taken every 15 minutes for an hour after the silica fume was added to the concrete indicated that there was no noticeable slump loss. This test was to ascertain how much time the concrete remained at its high slump to determine maximum traveling time and idle time before the concrete should be placed. Supposedly, lab tests indicated that as much as three hours may be required before the effect of the superplasticizers wore off. Pittsburgh Testing Laboratory performed tests and measurements and attained the following tabulated results:

	Trial Batch No. 1	Trial Batch No. 2
Slump (initial)	9 3/4 inches	9 3/4 inches
Concrete Temperature	72° F	73° F
Air Temperature	53° F	53° F
Air Content	0.7%	0.7%
Unit Weight	154.4 pcf	153.7 pcf
Yield	25.39 cf	25.73 cf

The moisture content of the aggregates was measured to be 0.75% for the coarse and 4.3% for the fine. From the information obtained in the trial batches, it was noted that the yield of the concrete was below 27 cubic feet. Adjustments were made before the trial placements the following day.

On Friday, March 18, the trial placements began at the Pittsburgh District Neville Island maintenance facility (PEWARS). Two slabs, each approximately 20 by 30 in size were formed over an existing slab so that a minimum of one foot of concrete would be placed over the slab. Since the weather at first consisted of a light falling rain with temperatures in the low 50's, two skeleton frames with a tarp covering were placed over the slab. The existing slab was cleaned with a high pressure water hose and the loose concrete was removed. Shortly before the actual placement began in the forms, the existing concrete was lightly sprayed with water. No bonding agent or grout was used. The truck was batched with a conventional concrete using 600 pounds of cement per yard at 0945 hours and after a certain amount of mixing at the plant, arrived at the placement site around 1020 hours. Because a light rain was still falling, 20 barrels of the silica fume and plasticizer additive were added to the truck inside the warehouse. An unknown amount of water was added to the mix since it was let in from the truck's water tank. It was later estimated that 1500 pounds of water was added to the nine yard mix. As in the trial batches, Mr. Wolsiefer closely monitored the consistency of the concrete and the mixing of the additives. There appeared to be too much reliance on judgment to attain the proper mix with this batching method. At about 1110 hours, the first mix was begun to be placed in the form. Since there were to be three different mix proportions (600,800 and 1,000 pounds of cement per yard), it was intended to separate the mixes by means of a temporary bulkhead placed at the third points of the slab. This bulkhead was to be removed after the first mix had set up. After about one-half of the truck was emptied, concrete specimens were taken and slump measured. Pertinent measured data are tabulated in TABLE 1. The placement was completed around 1130 hours or a little over two hours after the concrete was first batched. The concrete was leveled to the top of the forms using a rented vibratory screed manufactured by Allen Engineering Corporation. The screed consisted of double screed blades constructed as part of a triangular truss. Vibration was transmitted to the screed blades by a 5 HP gasoline engine that rotated an off-center rotating shaft. Travel of the screed was produced by hand operating cable winches at each end of the screed. The first slab was screeded twice. The first time to primarily level the concrete and the second time to attain a better concrete finish. Two bull floats were also used and were covered with a teflon coating to prevent the concrete from sticking to the finishing surface. The concrete finish appearance did not improve using the bull floats. More often the bull float caused the surface to drag and tear and did not cause more fines to come to the surface to aid in the finishing operation. The slump of the first mix was approximately eight inches. The final finish was considered to be below average compared to that obtainable with conventional concrete; however, the finish did improve when the slump of the concrete was increased. A curing compound was applied after the screeding was completed. The curing compound consisted of a rubber chlorinated compound blended with epoxy and plasticizing resins. Application was with a hand operated garden-type sprayer. A two-foot wide aluminum scaffold spanning the 20-foot dimension of the slab was used to get access to the entire slab since the concrete surface could not be walked on.

The next mix consisted of 800 pounds of cement per yard. The truck arrived around 1230 hours and began discharging at 1315 hours. The same procedure was used for batching the silica fume that was used for the first mix; however, this time the addition of water was measured and amounted to 160 pounds. The placement was completed around 1330 hours and screeding was begun immediately after. The slump was measured to be 10-1/4 inches and the finish attained was the best of the three mixes tried. Before the mix was placed, the temporary bulkhead placed for the first mix was removed so that the following mix could be placed directly against the fresh concrete. However, even though about two hours had passed, the concrete had not set up sufficiently because once the bulkhead was removed, the concrete sloughed slightly, causing surface cracks parallel to the bulkhead to appear near where the bulkhead was located. Other than this problem, the concrete placement went smoothly and the final finish was judged to be equivalent to that obtainable with conventional concrete. The surface was bull floated but not to the same degree as for the first mix. Since there were some difficulties experienced after the first temporary bulkhead was removed, it was decided not to remove the bulkhead between the second and third mixes. Another bulkhead was positioned about a foot away so that both bulkheads could be removed once the concrete on each side of the bulkheads had set.

The final mix consisted of 1,000 pounds of cement per yard. The truck arrived at about 1415 hours and began discharging about 1440 hours. Twenty-nine barrels of silica fume with plasticizers were added with no additional water other than light spraying around the mouth of the drum. The slump was the lowest of the three mixes at 7-3/4 inches and the finish was the poorest of the three. Also, there appeared to be some balling in the concrete, probably related to the high cement content. By about 1500 hours, plastic shrinkage cracking had appeared on the surface of the first mix. The conditions for placing concrete were generally good in that it was a cool, cloudy day with a light rain falling; however, there was a stiff wind that later was found to average 12 mph. Three conditions could have contributed to the plastic cracking: the stiff wind, the curing compound may not have been as effective as other more well-known brands and the curing compound may have been applied too late. The amount of curing compound applied should have been more than enough. A five gallon container was used over the entire 20 by 30 foot area which amounts to a rate of 120 square feet per gallon. The recommended application by the manufacturer's literature was 200 to 600 square feet per gallon depending upon the porosity and finish of the concrete surface.

Upon conclusion of the placement of all three mixes, burlap was placed over the surface and wetted. After the weekend, the tarped skeleton frame was removed. The bulkheads left in place between the second and third mixes were removed after chipping out the waste concrete between them. Our maintenance workforce reported that this concrete was difficult to jackhammer out even after only two days.

Although stick type air vibrators were available for use, they were not used as extensively as for conventional concrete because the high slumps allowed the concrete to flow into position without much assistance. The amount of entrapped air in the concrete was considered to be on the high side, ranging from 1.3 to 2.6%. This high air was thought to have been caused in part by the lack of thorough vibration. Subsequent coring of the slabs also showed up a considerable amount of small air pockets. It was believed that additional vibration would have reduced the amount of entrapped air.

A testing program was established with the aid of WES and Pittsburgh Testing Laboratory to monitor the information pertinent for use at Kinzua Dam. Six, 4 x 8 concrete specimens were taken of each mix design, two each for 7, 28 and 90 day breaks. Also, the same number and size of cores were drilled through each mix the day before the corresponding breaks were to be made. In addition to the specimens and cores, a standard 6 x 6 beam for each mix was taken. Other tests taken were unit weight, yield, air content and slump. The 4 x 8 cylinders were required due to the high strength of the concrete. Most concrete compression testing machines cannot break standard 6 x 12 cylinders of such high strength concrete. Also most capping compounds are too weak and special capping material is required or the ends of the cylinders must be honed true to the vertical axis of the cylinder. Average compression strengths attained for the specimens and cores for 7, 28 and 90 day breaks are tabulated below.

Day Break	(psi) 600 lb Mix		(psi) 800 lb Mix		(psi) 1000 lb Mix	
	Specimen:	Core	Specimen:	Core	Specimen	Core
7	10630	6860	11560	9430	13180	11170
28	13630	7740	14590	11340	14850	10830
90	15720	14000	16800	13200	17520	13770

The beams attained strengths of 2026, 1495, and 1730 psi for the 600, 800, 1,000 pound mixes, respectively.

Terry Holland from the WES Concrete Structures Laboratory took 12-inch diameter samples for the first and third mix that were later sent to WES for abrasion-erosion testing.

This abrasion-erosion testing of the specimens indicated that the first mix (600 lb) had a 4.6% loss in 72 hours and the third mix (1,000 lb) had a 3.8% loss. Both specimens were begun to be tested when they attained an age of 28 days.

A few things were learned in handling, placing, and finishing the dry powder silica fume that required changes and adjustments in the procedures when the slurry silica fume was placed the following week. It was important that the finishing of the concrete be completed before crusting of the surface began. Also, the curing compound should be applied as soon after the final pass of the screed as possible. An overall evaluation of the placing and finishing process was that this type of concrete was more difficult to finish and required much more coordination of the work crew. Our workforce did not have a lot of experience finishing concrete but after trial placement, it was apparent that it did not make much difference.

4. SLURRY FORM.

On 23 March, two trial batches of six yards each were mixed at the ready-mix plant using a slurry containing 50% water with the rest being silica fume. The slurry was supplied by Elborg Techology Company, Pittsburgh, PA. Elborg brought a truck trailer to the batch plant in which they stored a special batching tank that circulated the slurry and could pump designated amounts of slurry through a flexible line into the mixing truck. The slurry was introduced after the all aggregates were batched in the truck followed with the batching of the cement. After the truck was batched, a liquid superplasticizer was dumped from a steel drum into the truck hopper. The truck next rotated the contents the normal number of revolutions. The first mix contained 700 pounds of cement and the next contained 600 pounds. An important observation made at this time was that the amount of moisture that the aggregate can contain is critical since the silica fume contains a fixed amount of water; i.e. the water in the slurry plus the water in the aggregate cannot exceed the total water for the mix. If there is too much water in the aggregates, then the required water to cement ratio will be exceeded and the strengths will be reduced. Since the water in the slurry is fixed, the only way the w/c ratio can be maintained is either by drying the aggregates or increasing the cement content. This problem occurred early in the morning when the mositure content of the aggregates was higher. Therefore, the reason the first mix used the higher cement content mix was because of the high moisture aggregate content. Later on in the day, the moisture contents were reduced allowing the lower cement mix to be batched. Mr. Sorensen and Mr. Larsen of Elborg provided the technical guidance for the trial batching. Elborg preferred to use 3/4-inch limestone rather than the 3/8 inch used by Norcem. The limestone used was actually an Axeman Dolomite from New Enterprise Stone and Lime Co., New Enterprise, PA. Pittsburgh Testing Laboratory performed the tests and measurements and attained the following tabulated results:

	Trial Batch No. 1	Trial Batch No. 2
Slump (initial)	10 inches	10.75 inches
Concrete Temperature	62° F	58° F
Air Temperature	30° F	34° F
Air Content	1.7%	1.8%
Unit Weight	158.0 pcf	156.6 pcf

The moisture content of the aggregates was measured to be 6% for the sand and 1.3% for the limestone. Since the moisture content of the aggregates was very important, several tests were performed to confirm it; however, it was very difficult to consistently attain the same result. Slumps were also taken at 15 minute intervals for an hour and did not indicate that there was any measurable slump loss. It was also noted that the air content was high.

On 25 March, the trial placement of the silica fume concrete was begun at Neville Island. The weather was clear and cool with temperatures in the low 40's. Essentially the same preparations were made as for the trial placements for the previous week except that now instead of using temporary bulkheads to separate the mixes, permanent bulkheads were used. Also a grout was mixed using primarily cement and silica fume slurry to form a heavy bodied paste which was broomed into the existing concrete. Half of the 20 x 30 area was covered with this grout. It was later intended to evaluate the bond to the existing slabs with and without the grout, but the evaluation never was performed. When cores were drilled through the slab in the two different areas, there was no noted difference in breaking the core from the existing slab. Two bulkheads were set between each concrete mix and were separated by one foot to allow for their removal once the concrete had hardened. Because temperatures were anticipated to fall below or near freezing during the night, the skeleton frames used previously were now covered with heavy canvas along their sides. Before placement of the concrete began, the formwork and existing concrete floor were heated with a heater placed inside the enclosure, and shortly before the concrete truck arrived, the skeleton frame enclosure was removed. Unlike the previous placements where the silica fume was added at the placement site, the slurry fume with plasticizers was added to the concrete at the batch plant. Whether the silica fume was batched at the ready-mix plant or the placement site did not seem to make a significant difference other than that the plasticizers effective time would be reduced by the trucks travel time to the site, if the silica fume was added at the plant. The first mix was batched about 1020 hours and placement was completed about 1200 hours. The first mix contained 600 pounds of cement, the second 650, and the third, 700. Pertinent measured data is tabulated in TABLE 2 for the three mixes. When the first mix was discharged from the truck, large cement balls were present near the end of the truck load. All these balls were broken up or removed as they came down the chute before being placed into the slab formwork. The slump for the first mix was 10 inches and resulted with the best looking finish. The other mixes had slumps of 7-1/4 and 6-1/2 inches. In some areas of the surface, the aggregate was exposed with relatively little paste. It was felt at that time that the screed may have been too high in this area, and the surface did not achieve the necessary vibration. For the next two mixes the screed was lowered but the finish appearance did not appear to be any better. The lower slumps were requested by the District to observe the finishing characteristics of the lower slump concrete. In general, the finishing operation was made much more troublesome when the slump was reduced because it was more difficult to bring fines up to the surface. Because it was observed during the first trial placements that a higher than normal air content was present in the concrete, the concrete for the second trial was attempted to be vibrated more thoroughly. This extra effort did not seem to help appreciably since cores taken of the concrete still showed evidence of small air pockets. It seemed that the stick vibrators did not bring air bubbles to the surface as easily as for conventional concrete. Curing compound was sprayed on the slabs immediately after the slabs were finished. The curing compound was a wax based product made by Protex. Although wet burlap was ready to be placed, Elborg felt that it was not needed and no additional curing measures were taken other than using the curing compound. Unlike the first trial placements, the concrete did not develop plastic cracking. This could have been due to several factors: there was almost no wind, the curing compound was applied as the last pass of the screed was being made (earlier application) and the curing compound itself could have been a more reliable product. The final mix was placed and finishing completed about 1600 hours. The skeleton frames were placed back over top of the slabs and around 1900 hours two heaters were turned on to keep the slabs warm during expected over-night freezing temperatures.

Approximately the same amount of testing was performed for the second placement as for the first, expect that Elborg had PTL perform additional testing for their own benefit in areas not directly applicable to the Kinzua work. In addition to extra compressive and flexural strengths, this included testing for the Modulus of Elasticity, Poisson's Ratio, Shrinkage of Concrete, Scaling Resistance, Freeze and Thaw, and Time of Set. The average compressive strengths for the specimens and cores are tabulated below (See also Inclosure 1).

Day Break	(psi) 600 lb Mix		(psi) 800 lb Mix*		(psi) 1000 lb Mix *	
	Specimen:	Core	Specimen:	Core	Specimen:	Core
7	(10520) 10550	6400	(11030) 10930	10410	(11840) 11910	10120
28	(14960) 15770	10210	(13740) 12880	12720	(15110) 14690	13520
90	(16960) 16130	15480	(16500) 13070	13070	(16560) 16980	13620

Items within the parenthesis indicate an average of values that included specimens taken for Elborg. The beams attained strengths of 1745, 1690, and 1875 psi for the 600, 650, and 700 pound mixes, respectively. The abrasion-erosion testing of the specimens taken at the site indicated that the first mix (600 lb) had a 4.6% loss in 72 hours and 3.0% for the third mix (700 lb). Both specimens were begun to be tested when they attained an age of 28 days.

*Ed. Note: These numbers are incorrect - the 800 lb should read 650 lb and 1000 lb should read 700 lb - T. C. Holland.

5. CONCLUSIONS

From the testing program several things were learned. The most apparent is that the compressive strengths are not consistent with results expected for higher cement content mixes. For instance, Elborg's strength values for the 28-day breaks are higher for the first mix (600 lb) than for the second mix (650 lb). The core compressive strengths for Norcem's first mix was the highest of the three mixes. It is felt that some of these inconsistencies were due in part to the smaller diameter specimens (four inches verses the normal six inch). The most surprising result of the testing is that it seems that the silica fume concrete attains considerably more strength after 28 days. Both the dry powder and slurry form of the silica fume attained approximately another 2000 psi of strength between 28 and 90 days. It could mean that if abrasion-erosion tests were made at 90 days instead of 28 days, the results would show still lower losses. With a 28-day age, the silica fume concrete had losses two to three times lower than that tested for the steel fiber concrete removed from the stilling basin. If 90-day concrete were tested, it is conceivable that a more than three times lower loss could be attained. Based on early results of the testing program, the specifications were written so that a minimum compressive strength of 12,500 psi had to be attained. In those situations where there is less than 28 days left before the cofferdam is flooded, a seven day criteria was established whereby a value of 10,000 psi had to be attained. If any compressive strengths fall 500 psi below these values, then coring of the in-place slabs was required to be initiated to verify the lower strengths. The criteria for acceptance of the core strength results generally follows the requirements of ACI 318 where the concrete would be considered to be adequate if the compressive strength of the average of three consecutive core breaks is equal to at least 85 percent of 12,500 psi and if no single core is less than 75 percent.

6. RECOMMENDATIONS

The experience of placing the two trial placements aided in the preparation of the plans and specifications for the repair of the Kinzua stilling basin. The specifications require a test placement by the Contractor to iron out any problems and to acquaint himself and his workers with the idiosyncracies of the new type of concrete. From this additional placement there may develop supplemental recommendations. The recommendations made herein were essentially incorporated into the specifications and are directed toward two negative aspects of silica fume concrete. The first was the problem in attaining a satisfactory finished surface and the second is in preventing plastic cracking. The specifications required two screeds to be used, separated by three or four feet. The first screed was to level the concrete and the following screed was to do the actual finishing and to be comparable to that attainable by bull floating. Bull floating was not required since it was felt that it does not bring fines to the surface as does a vibrating screed. The solution to the finishing of concrete could also be resolved by using a better screed than that used for the initial trial placements. Apparently there are better screeds on the market that could impart much more vibration at the surface. To alleviate the possibility of plastic cracking, it was determined that a water barrier should be applied as soon as possible to retain the moisture within the concrete, especially at the surface since there essentially is no bleeding in silica fume concrete to replace the surface moisture lost to evaporation. Rather than using a curing compound immediately, a product by Master Builders, "Confilm", is required to be used immediately after the first screed. This seals in the moisture and allows the second screeding without detrimental effects to the surface. After approximately an hour, the Confilm evaporates since it's composed with an alcohol base and a regular curing compound must be applied. The advantage of using the Confilm product is due to its ability to be finished with the concrete after the evaporation barrier has been applied. Once curing compounds are applied, no additional finishing, such as hand troweling of small areas, can be performed.

7. JUSTIFICATION FOR USE

In summary, silica fume concrete was found to be the best available concrete to economically resist abrasion-erosion. Originally it was recommended that a conventional concrete be used with the lowest practical water to cement ratio and containing the hardest available aggregate. It was felt a concrete with a chert aggregate, a water to cement ratio of less than 0.40 and compressive strengths in the range of 6000 to 9000 psi would perform twice as well as steel fiber concrete and result with twice the life, i.e., 20 years. The silica fume concrete is required to have a water to powder (cement and silica fume) ratio of not more than 0.30 and attain 28-day compressive strengths greater than 12,000 psi. High concrete strengths do not necessarily guarantee a good abrasion-erosion resistant concrete but, for the most part, is a good barometer that can be verified by testing. The aggregate in a silica fume concrete, through testing, was found not to have as great an importance in abrasion-erosion resistance as for conventional concrete and, therefore, good limestone aggregate can be used without significant differences. This is probably due in part to the fact that the paste is considerably stronger. From previous discussions it can be reasonably expected that the life of the repair work using silica fume concrete will be 30 years under the same adverse conditions the original and steel fiber concrete was exposed to.

TABLE 1

NORCEM DATA DURING TRIAL PLACEMENT
DRY POWDER SILICA FUME

18 March 1983

Collected Data	Trial Batch No. 1 (600#/yd)	Trial Batch No. 2 (800#/yd)	Trial Batch No. 3 (1000#/yd)
Air Temperature	52°	54°	50°
Concrete Temperature	68°	73°	84°
Slump	8"	10-1/4"	7-3/4"
Unit Weight (lbs/cu. ft)	154.2	151.3	150.3
Entrapped Air	1.5%	1.3%	2.6%
Number of Yards	9	9	8
Sand (lbs)	13,930	12,080	8,560
Limestone (lbs)	15,510	15,470	13,810
Cement (lbs)	5,384	7,173	8,034
Silica Fume (lbs)	1,000	1,250	1,450
Water (lbs)	2,887 (Est)	1,814	1,746
Sand Moisture	4.3%	4.3%	4.3%
Limestone Moisture	0.68%	0.68%	0.68%
Calculated Data			
Water to Powder Ratio	0.35	0.26	0.23
Silica Fume to Powder Ratio	0.16	0.14	0.15
Fine Agg. to Total Agg. Ratio	0.47	0.44	0.38

TABLE 2

ELBORG DATA DURING TRIAL PLACEMENT
SLURRY SILICA FUME

25 March 1983

Collected Data	Trial Batch No. 1 (600#/yd)	Trial Batch No. 2 (650#/yd)	Trial Batch No. 3 (700#/yd)
Air Temperature	38°	42°	42°
Concrete Temperature	62°	62°	63°
Slump	10"	7-1/4"	6-1/2"
Unit Weight (lbs/cu. ft)	159.2	156.7	156.6
Entrapped Air	1.2%	2.5%	2.6%
Number of Yards	8.5	8.5	8.0
Sand (lbs)	12,650	12,660	11,960
Limestone (lbs)	15,040	15,080	14,160
Cement (lbs)	5,090	5,525	5,600
Silica Fume (lbs)	131**	116**	97**
Water (lbs)			
Sand Moisture	3.8%	3.8%	3.8%
Limestone Moisture	2.3%	2.3%	2.3%

Calculated Data			
Water* to Powder Ratio	0.33	0.29	0.27
Silica Fume to Powder Ratio	0.18	0.15	0.12
Fine Agg. to Total Agg. Ratio	0.46	0.46	0.46

* Includes High Range Water Reducer (Plasticizer)

**Ed. Note: These numbers are incorrect - the numbers shown should be multiplied by the batch size (8.5 $yd.^3$) to be compatible with the other numbers in the table.

131 (8.5) = 1114
116 (8.5) = 986
97 (8.5) = 825

\- T. C. Holland

REFERENCES

1. Technical Report C-78-4, Maintenance and Preservation of Concrete Structures, Report 3, Abrasion-Erosion Resistance of Concrete, T. C. Liu, July 1980, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

2. Letter Report, "Abrasion-Erosion Evaluation of Concrete Mixtures for Stilling Basin Repairs, Kinzua Dam, Pennsylvania", Terence C. Holland, Structures Laboratory, November 1982, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

3. Design Memorandum No. 16, Feature Design Memorandum, Stilling Basin Rehabilitation, Kinzua Dam, Allegheny River, Pennsylvania, November 1982, U.S. Army Engineer District, Pittsburgh, Pittsburgh, PA.

4. Specifications for Stilling Basin Rehabilitation, Kinzua Dam, Allegheny River, Pennsylvania, U.S. Army Corps of Engineers, Pittsburgh District.

5. Memorandum for Record (Trip Report), "Silica Fume Concrete Placements, Pittsburgh District - Kinzua Stilling Basin Repair Project", Terence C. Holland, Structures Laboratory, April 1983, WESSC.

6. Letter Report, "Abrasion-Erosion Evaluation of Concrete Mixtures for Stilling Basin Repairs, Kinzua Dam, Pennsylvania", Report 2, Terence C. Holland, Structures Laboratory, July 1982, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

7. "Silica Fume Concrete - Properties, Applications and Limitations", V. M. Malhotra and G. G. Carette, Concrete International, May 1983.

APPENDIX B

WES MEMO DESCRIBING *NEVILLE ISLAND*

TRIAL PLACEMENTS

WESSC 1 April 1983

MEMORANDUM FOR RECORD

SUBJECT: Silica Fume Concrete Placements, Pittsburgh District - Kinzua Stilling Basin Repair Project

1. On 17-18 March, Mr. Don Walley and I, and on 25 March, I observed placements of concretes containing silica fume as a mineral admixture. The purpose of the placements was to demonstrate placing and finishing of this type of concrete because Pittsburgh District is considering its use in the Kinzua project.

2. The placements were conducted using two proprietary silica fume products. The first placement used a product (Corrocem) from Norcem. The second placement used a product from Elborg. Concrete batching and mixing for both tests was done by Bryan Ready-Mix of Pittsburgh. Placement was done by Corps employees at the Neville Island service base. Technical representatives from the two firms were present to supervise the placing, finishing, and curing of their respective concretes.

3. Placement was done into a slab form approximately 20 by 30 ft in plan and 1 ft thick. This size is essentially the same size as the placements will be at Kinzua. To allow the two companies to demonstrate a variety of mixtures, each slab was divided into three segments. Removable partitions were used for the Norcem placement while permanent, leave-in-place partitions were used for the Elborg placement.

4. Norcem.

a. On 17 March, we observed trial batching of two concretes containing the Norcem product. These trials were intended to allow the Norcem technical representative to determine final mixture proportions. Since these were trial batches, I believe it would serve no purpose to comment on the concretes produced.

b. On 18 March, there were placements of three concretes containing the Norcem product. The basic characteristics of the three concretes were as follows:

	Mix 1	Mix 2	Mix 3
Cement, lb/yd^3	600.0	800.0	1000.0
Design water-powder ratio Norcem	0.35	0.26	0.23
Powder, % of cement wt	18.5	17.4	18.1
Unit wt, lb/ft^3	154.3	151.3	150.2
Concrete temp, ^{o}F	68	73	84
Air content, %	1.5	1.3	2.6
Slump, in.	6-3/4	10-1/4	7-3/4
Air temp, ^{o}F	52	54	50

c. The water to powder ratios (water to cement plus Norcem product) shown above were the design ratios. An undetermined amount of water was added to Mix 1 and a weighed amount of water was added to Mix 2. No water was apparently added to Mix 3.

d. Two abrasion-erosion test specimens were taken from Mix 1 and two from Mix 3. The specimens were manufactured and finished adjacent to the slab being placed. The specimens were cured using the curing compound being used for the slab segments. The specimens were left with the slab until Monday, 21 March, when they were demolded and placed into the Corps curing room. For identification purposes, the specimens from Mix 1 had a piece of light-colored hardened concrete placed into the bottom of the molds.

e. The Norcem method of manufacturing the concrete was to batch all regular ingredients at the ready-mix plant. The truck then traveled to Neville Island where the proprietary product was added dry from 50-lb drums. The powder contained silica fume, a high-range water-reducing admixture (apparently napthalene based), and whatever other proprietary ingredients are used in the product. The additional water (if any) was added after the powder and the concrete were mixed.

f. Norcem elected to use a 3/8-in. maximum size coarse aggregate for all three mixes. The aggregate was a crushed limestone.

g. In general, the three mixtures were very similar in appearance. All were "flowing concretes" that were essentially self-leveling. The high fluidity of the concrete is a new concept for the Corps and seemed to worry some of the Corps personnel present.

h. The concrete was finished after placement using a vibrating screed. A curing compound was sprayed onto the concrete surface after it was screeded. The Norcem technical representative made no comments to suggest that he was dissatisfied with the screeding and curing operations. (He did make such comments much later in the day.)

i. The fine aggregate contents of the mixtures were approximately 42 percent for Mix 1 and 36 percent for Mixes 2 and 3. All three of the mixes appeared to be undersanded to me.

j. The original placement plan was to place Mix 1 in the first third of the slab and then place Mix 2 in the center third. Before Mix 2 was placed, the divider was removed. Because of the high fluidity of the concretes, Mix 1 behind the divider slumped toward the center of the form. This slumping caused significant transverse cracking. Because of the cause of the cracking, I do not consider it significant in evaluating the performance of the product.

k. The third mix was very difficult to screed and finish. I believe the problem was the high cement content and the high slump, which gave the concrete a tendency to pump under the screed after it had passed over a section.

l. Attempts were made to bull float the concrete after screeding. These attempts were generally unsatisfactory. The problem may be partially attributed to the nature of the material and to the inexperience of the Corps placing crew. I do not consider this a significant drawback because, with a properly proportioned mixture, an adequate finish should be attained by screeding.

m. By late afternoon, longitudinal cracks had appeared in the first concrete placed. These cracks appeared to be plastic shrinkage cracks. When I questioned the Norcem technical representative, he attributed the longitudinal cracks to removal of the transverse form partitions and to the lack of placing wet burlap over the concrete. Both of these explanations appear to be doubtful to me.

n. It should be noted that weather conditions were generally good for placing concrete - it was a cool, cloudy, misty day. The relative humidity was very close to 100 percent. However, there was a noticeable wind present. No attempts were made to protect the concrete from the wind. The Norcem technical representative made no requests for such protection.

o. The following data were obtained from specimens tested at 7 days (compressive strengths in lb/in.^{2}; cylinders and cores were 4 by 8 in.):

Mix	Cylinders	Cores
1	10,750 10,510	6,860 (9,500 at 14 days)
2	11,660 11,460	9,430
3	13,330 13,020	11,170

The cylinders were capped with a "high-strength capping compound" supplied by Norcem. The cores were sawn. All testing was done by Pittsburgh Testing Laboratory (PTL). PTL reported that the cores contained more visible air voids than did the cylinders. The increased number of voids and the difference in end treatment may explain the differences in strengths.

p. Mr. Stu Long, ORP, had taken cores across the longitudinal cracks that were evident in the Norcem placement. He reported that the cracks were apparently very shallow and may have been only in the "skin" that forms on the surface of these types of concretes.

5. Elborg.

a. The Elborg trial mixes were made on 23 March. I did not observe these mixes.

b. On 25 March, Elborg placed its three concrete mixtures. The basic characteristics of the Elborg mixtures were as follows:

	Mix 1	Mix 2	Mix 3
Cement, lb/yd^3	600.0	650.0	700.0
Design water-powder ratio	0.315	0.285	0.265
Powder, % of cement wt	22.0	18.0	14.0
Unit wt, lb/ft^3	159.2	156.7	156.6
Concrete temp, ^oF	62	62	63
Air content, %	1.2	2.5	2.6
Slump, in.	10	7-1/2	6-1/2
Air temp, ^oF	38	42	42

c. No additional water was added to the Elborg batches. However, the actual water to powder ratios may have been somewhat higher than the design because of aggregate moisture that could not be compensated for.

d. Two abrasion-erosion test specimens were taken from Mix 1 and two from Mix 3. The specimens were manufactured and finished in the Corps material lab at the site. Because the weather was expected to be freezing the night of the placement, the specimens were left inside the heated building. They were cured using plastic sheets pressed into the surface of the specimen. The specimens were demolded on Monday, 28 March, and placed into the curing room. For identification purposes, the specimens from Mix 1 had a plastic cylinder mold cap placed into the bottom of the molds.

e. The Elborg method of manufacturing the concrete was to batch all ingredients at the ready-mix plant. The silica fume and a portion of the chemical admixtures were added as a slurry from a weigh batcher that Elborg provided. A portion of the admixtures was apparently added dry to the truck after the other ingredients were in.

f. Elborg elected to use a 3/4-in. maximum size coarse aggregate. It was also a crushed limestone.

g. The first Elborg mixture was very similar in appearance to the Norcem mixtures. It was a very fluid, flowing concrete. It was placed and screeded without much difficulty.

h. The second two Elborg mixes were extremely thixotropic and were more difficult to work with and finish. I believe this was due to the higher cement contents and lower water contents. Elborg had purposely reduced the slumps of these concretes at the Corps request.

i. The mixing water for the Elborg concretes was obtained from that in the slurry and the free moisture on the aggregates. Apparently, little or no additional water was added to the truck. As a result, a portion of the initial concrete from all three batches contained powder (apparently cement) that had been on the high-end mixer blades in the truck. I do not believe that this small amount of powder would be a serious problem. For mixes 2 and 3, there was a distinct tendency for aggregate particles to dry on the surface of the concrete during the placement. This could be a problem if a long period of time were to elapse between trucks.

j. The same finishing procedures were used for the Elborg concrete as for the Norcem concrete. Elborg had several engineers and technicians at the placement who took an active role in the operation. The concrete was cured using a Protex compound that was applied very quickly after screeding.

k. There was no attempt made to remove the form dividers from the placements for the Elborg concrete. Therefore, the problem of transverse cracking was eliminated.

l. The weather for the Elborg placement was bright and sunny, there was a light wind, and the humidity was much lower than for the Norcem placement. Because of predictions of overnight freezing, a tent was erected over the slab and a kerosene heater was used from about 1900 Friday until early Saturday. I would expect that the potential for plastic shrinkage cracking would have been more severe for the last two Elborg placements that were affected by the heating.

m. No shrinkage cracking was noted in the Elborg concrete when it was examined after the weekend.

n. The following data were obtained from specimens tested at 7 days (strengths in $lb/in.^2$, cylinders and cores were 4 by 8 in., flexural beams were 6 by 6 in.):

Mix	Cylinders	Cores	Beams
1	9,870	6,400	1,341
	11,230		1,720
2	10,470	10,410	1,339
	11,380		1,309
3	11,870	10,120	1,420
	11,940		

All cylinders and cores were sawn and ends polished by hand. All testing was done by PTL. PTL did not have an explanation for the variations in the results from Mix 1.

6. Observations and recommendations.

a. I thought both placements went well. The District learned a great deal and the persons responsible for planning and preparing specifications now have first hand knowledge of what silica fume concrete is and what problems to plan for in the actual placements.

b. I do not have a ready explanation for why the Norcem concrete cracked and the Elborg concrete did not. The cause may have been one or a combination of the following: (a) the curing compound used for the Norcem placements may not have been effective; (b) too much time may have elapsed between the screeding/finishing and the application of the curing compound; (c) the rate of evaporation may have been higher for the Norcem placements, in spite of the higher relative humidity. This last point could be verified by obtaining the actual weather data for the two placement dates and using Figure 2.1.5 from ACI 305R-77, "Hot Weather Concreting." This figure relates air temperature, relative humidity, concrete temperature, wind velocity, and rate of evaporation. Using approximate data, Anton Krysa and I estimated that the rate of evaporation was slightly lower for the Elborg placement. Both placements were done under conditions that were below a rate of evaporation of 0.2 $lb/ft^2/hr$.

c. I heard several comments from Corps field personnel to the effect that silica fume concrete is no good because you have to control the mixtures too carefully and that a contractor could not be expected to produce the concrete on a regular basis. Their comments imply, to me, that if a regular concrete were to be used, we would be very lax and allow the contractor to place just about anything. I would simply suggest that part of the reason for having to repair Kinzua for the second time is the relaxation of the controls of the concrete during the previous repairs.

d. A decision will have to be made as to how much cement to use per cubic yard. I agree with the Norcem representative that by adding additional cement, the strength of the concrete will go up. However, as was shown during these test placements, there are increasing difficulties in placing and finishing associated with increasing cement contents. There is also the question of heat generation and the increased potential for thermal cracking as cement contents are increased.

e. A decision must also be made on the slump to be used. However, this decision involves much more than just the slump - the entire concreting scheme must be determined. If a high slump, flowing concrete is used, the entire panel will have to be placed before any finishing can begin. Given the tendency of the silica fume concrete toward plastic shrinkage cracking, only a limited amount of time will be available for placing all of the concrete, screeding it, and initiating curing. This situation suggests that close cooperation and precise timing will be necessary on the part of the concrete supplier.

The second option is to select a concrete with a low enough slump to allow placing and finishing from one end of a panel toward the opposite end. Thus, the majority of the first load of the concrete could be placed, screeded, and the curing compound applied, while waiting on the second load. This approach could lead to vertical cold joints between loads, depending upon how rapidly subsequent loads of concrete are produced and delivered.

f. A decision will also have to be reached on how to specify the concrete for the project - government furnished proportions or performance. If the government furnished proportions approach is selected, there will be difficulties in dealing with the proprietary ingredients in the Norcem and Elborg products, if either is selected by the contractor. If a performance spec is used, we will have to be very specific in determining the requirements for the concrete to meet.

g. The use of dividers to reduce the size of the placements to one truckload does not appear feasible. Based on experience at other structures, abrasion wear is more significant at joints. It does not appear to be a good idea to create additional joints solely for ease in placement.

h. For a properly sanded mixture, the surface produced by screeding should be adequate. We should not require floating.

i. The question of how to handle areas in which erosion damage is below the base of the planned wearing slab has also come up. The question boils down to whether a one-lift or two-lift placement should be used. The one-lift approach has the advantage of working in each area only once. The two-lift approach would require less concrete to complete a given panel since any deep areas would already be full. Given the problems of filling a panel quickly to lessen the chances of plastic shrinkage cracking, the two-lift approach seems preferred.

j. The project specifications should include reference to Figure 2.1.5 of ACI 305R-77. The contractor should be required to use the figure prior to all placements. If projected evaporation rates exceed recommended limits, the contractor should be required to take appropriate measures. The recommended limit for silica fume concrete may have to be reduced below the usual rate of evaporation of 0.2 $lb/ft^2/hr$.

k. The specifications should also include requirements for testing on a more frequent basis than is normally required. In particular, the moistures of the aggregates must be tightly controlled.

l. If the silica fume is added as a dry material, the contractor should be required to use a bin for the material rather than empty drums into the trucks. It may be possible to obtain the dry material in bulk rather than drums.

m. Even if a flowing concrete is used, the contractor must be required to vibrate the concrete. The differences in the strengths of the cores and the cylinders of the Norcem product show the need for this requirement.

n. The concretes made by both companies showed some problems with incomplete mixing. The contractor should be required to demonstrate that the material is being adequately mixed (i.e., mixer performance tests). The specifications should include limitations on the volume that may be mixed in a truck. It may be necessary to limit batch size to less than normal limits for these materials.

WESSC 1 April 1983

SUBJECT: Silica Fume Concrete Placements, Pittsburgh District - Kinzua Stilling Basin Repair Project

o. I see no particular advantage for using a smaller aggregate (3/8 in.). One of the original reasons for including silica fume in the concrete was to allow the use of aggregate available at or near the project site. Adequate strength and abrasion resistance should be obtainable using 3/4-in. MSA, which should be more readily available.

Terence C Holland

TERENCE C. HOLLAND
Research Civil Engineer
Structures Laboratory

CF:
John Gribar, ORP
Anton Krysa, ORP
Stu Long, ORP
Tom Hugenberg, ORD
Tony Liu, OCE
Don Walley, WES

APPENDIX C

NORCEM MIXTURE DATA

This appendix contains mixture proportioning data for the silica fume concrete containing the Norcem product. These data were prepared by Mr. Anton Krysa, Pittsburgh District. No mixture data were received from the Norcem representative.

CORPS OF ENGINEERS, U.S. ARMY OHIO RIVER DIVISION	COMPUTATION SHEET	PAGE OF PAGES DATE 21 MAR 83
INSTALLATION	SUBJECT KINZUA STILLING BASIN REPAIR	
COMPUTED BY AHC CHECKED BY	COMPUTATION SILICA FUME TEST PLACEMENT	NUMBER

NORCEM PRODUCT - DRY BATCHED

		17 MARCH 83		18 MARCH 83		
		TRIAL BATCH NO. 1	TRIAL BATCH NO. 2	(600) BATCH NO. 1	(800) BATCH NO. 2	(1000) BATCH NO. 3
AIR TEMP		53°	53°	52°	54°	60°
CONC TEMP		72°	73°	68	73	84
SLUMP	INCHES	9.75	9.75	8	10.25	7.75
UNIT WT	LBS/CF	154.40	154.37	154.23	151.34	150.25
ENTRAP AIR		0.7%	0.7%	1.5%(0.41)	1.3%(0.59)	2.6%(0.70)
SAND	LBS SG = 2.59	3980(8.21) 1327	3360(6.93) 1120	13930(7.58) 1548	12080(8.51) 1342	8560(6.62) 1070
LIMESTONE	LBS SG = 2.70	5120(10.13) 1707	5130(10.15) 1710	15510(10.23) 1723	15470(10.20) 1717	13810(10.25) 1726
CEMENT	LBS SG = 3.15	1799(3.05) 600	2392(4.06) 797	5334(3.04) 593	7173(4.05) 797	8034(5.11) 1004
SF	LBS SG = 2.22 (2.20)	350(0.84) 117	450(1.08) 150	1000(0.80) 111	1250(1.00) 139	1450(1.31) 181
WATER	LBS	510(2.72) 170	531(2.84) 177	1500 GAL 1387+? 167 (2.67)	1654+160 202 (3.23)	1746+0 218 (3.50)
SF/CMT+SF SF/CMT		0.16	0.16	0.16 (0.195)	0.14 (0.174)	0.15 (0.181)
SAND MOIST		4.33%(0.32)	4.33%(0.78)	4.3 %(1.07)	4.3 %(0.92)	4.5%(0.74)
COARSE MOIST		0.68%(0.11)	0.68%(0.11)	0.65 %(0.41)	0.65%(0.19)	0.65%(0.17)
W/C+SF		0.33 (0.34) NORCEM	0.25 (0.265) NORCEM	0.35 (.35 TERRY)	0.29 (0.26 TERRY)	0.23 (0.22 TERRY)
NO. OF YDS	CY	3	3	9 (9.33)	9 (9.42)	8 (8.42)
FA/FA+FC		0.44	0.40	0.47	0.44	0.38
YIELD	CF	26.06	26.03	27.99	28.25	28.42
TOTAL WATER	LBS	716	711	2204.5±	2439	2208

EVAP RATE

APPENDIX D

ELBORG MIXTURE DATA

This appendix contains mixture proportioning data for the silica fume concrete containing the Elborg product. Data prepared by Mr. Anton Krysa, Pittsburgh District, and by Elborg are included.

CORPS OF ENGINEERS, U.S. ARMY OHIO RIVER DIVISION	COMPUTATION SHEET	PAGE OF PAGES DATE 24 MAR 83
INSTALLATION	SUBJECT KINZUA STILLING BASIN REPAIR	
COMPUTED BY AHK CHECKED BY	COMPUTATION SILICA FUME TEST PLACEMENT	NUMBER

ELBORG PRODUCT - SLURRY BATCHED

		23 MARCH 83 TRIAL BATCH NO.1	TRIAL BATCH NO.2	25 MARCH 83 (600) BATCH NO. 1	(650) BATCH NO. 2	(700) BATCH NO. 3
AIR TEMP		30°	34°	38°	42°	42°
CONC TEMP		62°	58°	62°	62°	63°
SLUMP	INCHES	10	10.75	10	7.25	6.5
UNIT WT	LBS/CF	158.0	156.6	159.2	156.7	156.6
ENTRAP AIR		1.7%	1.8%	1.2% (0.32)	2.5% (0.65)	2.6% (0.70)
SAND	SG. = 2.59	9190 1532	9010 1502	12650 (9.21) 1433	12660 (9.22) 1489	11960 (9.24) 1415
LIMESTONE	SG = 2.83	10570 1762	10550 1758	15040 (10.02) 1769	15090 (10.05) 1774	14160 (10.04) 1770
CEMENT	SG = 3.15	4204 701	3600 600	5090 (3.05) 599	5525 (3.31) 650	5600 (3.52) 700
SF	SG = 2.22			131 (0.95)	116 (0.54)	97 (0.70)
SLURRY (50% SF)				264	232 234	194 200
WATER FROM SLURRY		0	0	131 (2.10)	116 (1.86)	97 (1.55)
WATER ADDED				0	0	60
SF/CMT+SF				0.18	0.15	0.12
SF/CMT				(0.22)	(0.18)	(0.14)
SAND MOIST		6%	4.3% ?	3.8%	3.8%	3.3%
PASTE VOL				0.29	0.29	.297
COARSE MOIST		1.3%	1.3%	2.3%	2.3%	2.3%
(ELBORG VALUES INCLS PLASTICIZER)				(.325)	(.292)	(.270)
W/C+SF				0.31	0.28	0.32
W/C				(.37)	(.345)	(.3[illegible])
NO. YDS		6.0	6.0	8.5	8.5	8.0
FA/FA+FC		0.47	0.46	0.46	0.46	0.46
YIELD				27.20	27.51	28.32
TOTAL WATER	PER YD			228 (3.65)	213 (3.41)	255 (4.09)
EVAP RATE						

Elborg Technology Company

Park West Office Center • Bldg. 1, Cliff Mine Road, Pittsburgh, PA 15275 ☐ Tel: 412/788-6490 Tlx: 812374, Elkem Chem Pgt

April 8, 1983 07-102

U.S. Army Corps of Engineers
Pittsburgh District
1934 Federal Building
Pittsburgh, PA 15222

Attention: Mr. Anton Krysa

Re: Mix Compositions of Microsilica Concrete for the Neville Island Test

Dear Mr. Krysa,

Enclosed please find the details of the concrete mix compositions used in the Neville Island test.

We all enjoyed working with you on this project and look forward to further associations.

Please do not hesitate to contact us regarding further information on the microsilica concrete as needed.

Sincerely,

Eigil V. Sorensen
Technical Manager

EVS:leb

Enclosure

CC: Terence C. Holland
USCE WES Vicksburg, Mississippi

ELBORG TECHNOLOGY COMPANY

CORPS OF ENGINEERS, NEVILLE ISLAND TEST
CONCRETE MIX COMPOSITIONS

Mix Designation	A		B		C	
	Batched, (~ lbs/cu.yd.)	Corrected acc. to measured unit wt. (lbs./cu.yd.)	Batched, (≈ lbs./cu.yd.)	Corrected acc. to measured unit wt. (lbs./cu.yd.)	Batched, (~ lbs./cu.yd.)	Corrected acc. to measured unit wt. (lbs./cu.yd.)
Cement	599	621	650	659	703	717
Microsilica slurry[1]	264	274	234	237	196	200
Water	94	98	94	96	102	104
Dravo Sand (SSD)[2]	1435	1489	1435	1455	1440	1468
Dolomite CA (SSD)[2]	1730	1795	1734	1759	1730	1764
HRWRA (liq.)[3]	23	24	25	25	30	30
W/C + MS[4]	0.325		0.292		0.270	
MS-Solid, % of Cem	22		18		14	
Measured unit wt. (lbs/cu.ft.)	159.2		156.7		156.6	
Air content, %	1.2		2.5		2.6	
Slump, in.	10		7½		6½	

[1] The slurry contains 50% solid microsilica by weight.

[2] Aggregate data used:

	Specific Gravity	Free Moisture Content %	Absorption %	Total Moisture Content %
Dravo Sand	2.58	3.8	1.4	5.2
Dolomite C.A.	2.83	2.3	0.4	2.7

[3] The High Range Water Reducing Admixture used is a naphthalene-based product containing 41% solids.

[4] The water to cement + solid microsilica ratio includes water from slurry and HRWRA.

APPENDIX E
NEVILLE ISLAND TEST DATA

This appendix contains the data sheets for the specimens prepared during the trial placements of the Norcem and Elborg silica fume concretes. All specimens were prepared and tested by Pittsburgh Testing Laboratory under contract to Pittsburgh District. Note that the Norcem product is referred to as "Corrocem Silica Fume Concrete" in these reports.

Form 407 Rev.-PG

PITTSBURGH TESTING LABORATORY

ESTABLISHED 1881

850 POPLAR STREET, PITTSBURGH, PA. 15220

PLEASE REPLY TO:
P. O. BOX 1646
PITTSBURGH, PA. 15230

AREA CODE 412 TELEPHONE 922-4000

LABORATORY No. 836559

CLIENT'S No. DACW59-83-M-0632

ORDER No. PG-21987

REPORT

June 20, 1983

REPORT OF CONCRETE
FOR
U. S. ARMY ENGINEER DISTRICT
PITTSBURGH CORPS OF ENGINEERS
1000 LIBERTY AVENUE
PITTSBURGH, PENNSYLVANIA 15222

Test Samples : Cast 3-18-83
Technician : V. J. Buechel
Specimens : (1)-4" x 8" Compressive Strength
(2)-6" x 6" x 22" Flexural Strength
(3)-4" Diameter Cores-Drilled by the Client

Cylinder and Beam Results- See Attached Pages

CORE RESULTS CORROCEM SILICA FUME CONCRETE

Core Number	Age	Diameter (In.)	Capped Height (In.)	Total Load	P.S.I.
1-1	7 Day	3.88	7.99	81,500	6860
2-1	7 Day	3.89	7.93	111,500	9430
3-1	7 Day	3.90	8.00	133,500	11170
P-1 (1-2)	28 Day	3.90	7.70	(a) 92,500	7740
P-2 (2-2)	28 Day	3.90	7.63	135,500	11340
P-3 (3-2)	28 Day	3.91	7.70	(b) 130,000	10830
1-5	90 Day	3.88	8.01	165,500	14000
2-5	90 Day	3.91	8.00	158,500	13200
3-4	90 Day	3.87	8.04	162,000	13770

(a)-Horizontal Break - Possible joint or layer of material.
(b)-Fracture thru several larger consolidation voids.

Respectfully submitted,

PITTSBURGH TESTING LABORATORY

R. E. Gardner

R. E. Gardner, Manager,
Cement and Concrete Department

CAS/mb
3-U. S. Army Engineer District
Pittsburgh Corps of Engineers

LAB. NO. 0427

PITTSBURGH TESTING LABORATORY

REPORT OF CONCRETE COMPRESSION TEST RESULTS

Form-9001 Rev 1
Order No.: PG-21987
Date Reported: June 20,1983

Client: U.S.Army Engineer District, Pgh. Corps of Engineers Client P.O. No. DACW59-83-M-0632

Project: Ultra High Strength Concrete at Pittsburgh Engineers Warehouse, Neville Island,PA

Location of Placement: South Section of Slab

Contractor: Corps of Engineers Concrete Supplier: Frank Bryan

Mix Identification: 600 # Cement

Strength Requirement: NA. - - - psi @ NA.- - - days

Test Specimens - Made by: [X] PTL [ ] Other:

- Delivered by: [X] PTL [ ] Other:

Number of Specimens Submitted: 6 Date Moulded: March 18, 1983
1 6" x 6" x 22" Beam

FIELD DATA

Slump: 8 in. Entrapped Air: 1.5% Conc. Temp: 68 °F Unit Wt.: 154.23 lbs./cu.ft.

Quantity Represented: 9 cu.yds. Batch Ticket No.: 007875

Weather Conditions: Cloudy Ambient Temperature: 52 °F

Above Determined by: [ ] PTL Inspection (Field Report Dated:) [ ] Others:

Test Procedure: ASTM-C-39-____(Yr) Test Machine No.: Caliper No.:

4" x 8" Cylinders

Specimens Marked	Days Age	Lab.No.	Date Recv'd.	Date Test	DIAMETERS (in) A	DIAMETERS (in) B	AREA (in^2) ☐ A ☐ N (1)	Total Lbs.	P.S.I	Fracture Type(2)	Test Tech.
A	7	0427	3-19-83	3-25-83	3.99	4.01	12.56	125,000	10750	F	CAS
TEST B	7	0427	3-19-83	3-25-83	4.00	4.00	12.56	132,000	10510	D	CAS
ZONE C	28	0427	3-19-83	4-15-83	4.00	4.00	12.56	173,500	13810	F	CAS
D	28	0427	3-19-83	4-15-83	4.00	4.00	12.56	169,000	13450	D	CAS
E	90	0427	3-19-83	6-16-83	4.00	4.00	12.56	195,500	15560	F	CAS
F	90	0427	3-19-83	6-16-83	4.00	4.00	12.56	199,500	15880	F	CAS
BEAM G	28	0427	3-19-83	4-15-83				24150	2026	---	CAS

(1) A=actual N=nominal (28.27 sq.inches) (2) If other than typical cone, indicate type below.

A B C D E Specify: F - Not enough left to identify

Record Specimen Length in REMARKS if outside the range of 1.8D to 2.2D.

Remarks: Specimens capped with supplier's material by supplier.
All specimens returned to the Client after test.

Acceptability: [ ] Conforms [ ] Does Not Conform [X] Not Applicable

Reported by: Pittsburgh Testing Laboratory Pittsburgh Office

[signature], Manager

LAB. NO. 0428

PITTSBURGH TESTING LABORATORY

REPORT OF CONCRETE COMPRESSION TEST RESULTS

Form-9001 Rev 1
Order No.: PG-21987
Date Reported: June 20,1983

Client: U. S. Army Engineer District, Pgh. Corps of Engineers   Client P.O. No. DACW59-83-M-0632

Project: Ultra High Strength Concrete at Pgh. Engineers Warehouse, Neville Island, Pa.

Location of Placement: Center Section of Slab

Contractor: Corps of Engineers   Concrete Supplier: Frank Bryan

Mix Identification: 800# Cement

Strength Requirement: NA. psi @ NA. days

Test Specimens - Made by: [x] PTL [ ] Other:

- Delivered by: [x] PTL [ ] Other:

Number of Specimens Submitted: 6   Date Moulded: March 18, 1983
1 6" x 6" x 22" Beam

FIELD DATA

Slump: 10¼ in.   Entrapped Air: 1.3 %   Conc. Temp: 73 °F   Unit Wt.: 151.34 lbs./cu.ft.

Quantity Represented: 9 cu.yds.   Batch Ticket No.: 007876-007877

Weather Conditions: Cloudy and Windy   Ambient Temperature: 50 °F

Above Determined by: [ ] PTL Inspection (Field Report Dated:) [ ] Others:
4" x 8" Cylinders

Test Procedure: ASTM-C-39-____(Yr)   Test Machine No.:   Caliper No.:

Specimens Marked		Days Age	Lab.No.	Date Recv'd.	Date Test	DIAMETERS (In) A	DIAMETERS (In) B	AREA (In^2) ☐ A ☐ N (1)	Total Lbs.	P.S.I.	Fracture Type(2)	Test Tech.
TEST	A	7	0428	3-19-83	3-25-83	4.00	4.00	12.56	146,500	11660	D	CAS
#TWO	B	7	0428	3-19-83	3-25-83	4.00	4.00	12.56	144,000	11460	D	CAS
	C	28	0428	3-19-83	4-15-83	4.00	4.00	12.56	186,000	14810	F	CAS
	D	28	0428	3-19-83	4-15-83	4.00	4.00	12.56	180,500	14370	F	CAS
	E	90	0428	3-19-83	6-16-83	4.00	4.00	12.56	212,500	16920	F	CAS
	F	90	0428	3-19-83	6-16-83	4.00	4.00	12.56	209,500	16680	F	CAS
BEAM	G	28	0428	3-19-83	4-15-83				19,150	1495	---	CAS

(1) A=actual N=nominal (28.27 sq.inches) (2) If other than typical cone, indicate type below.

A B C D E Specify: F-Not enough left to identify

Record Specimen Length in REMARKS if outside the range of 1.8D to 2.2D.

Remarks: Specimens capped with supplier's material by supplier
All Specimens returned to the Client after test

Acceptability: [ ] Conforms [ ] Does Not Conform [x] Not Applicable

Reported by: Pittsburgh Testing Laboratory Pittsburgh Office

______, Manager

LAB. NO. 0429

PITTSBURGH TESTING LABORATORY

REPORT OF CONCRETE COMPRESSION TEST RESULTS

Form-9001 Rev 1
Order No.: PG-21987
Date Reported: June 20,1983

Client: U.S.Army Engineer District, Pgh.,Corps of Engineers Client P.O. No. DACW59-83-M-0632

Project: Ultra High Strength Concrete at Pittsburgh Engineers Warehouse

Location of Placement: North Section of Slab

Contractor: Corps of Engineers Concrete Supplier: Frank Bryan

Mix Identification: 1000# Cement

Strength Requirement: NA psi @ NA days

Test Specimens - Made by: [x] PTL [ ] Other:

- Delivered by: [x] PTL [ ] Other:

Number of Specimens Submitted: 6 Date Moulded:
1 6" x 6" x 22" Beam

FIELD DATA

Slump: 7-3/4 in. Air: 2.6 % Conc Temp: 84 °F Unit Wt.: 150.25 lbs./cu.ft.

Quantity Represented: 8 cu.yds. Batch Ticket No.: 007878-007879

Weather Conditions: Light Rain Ambient Temperature: 50 °F

Above Determined by: [ ] PTL Inspection (Field Report Dated:) [ ] Others:
4" x 8" Cylinders

Test Procedure: ASTM-C-39-___(Yr) Test Machine No.: Caliper No.:

Specimens Marked	Days Age	Lab.No.	Date Recv'd.	Date Test	DIAMETERS (in) A	DIAMETERS (in) B	AREA (in^2) ☐ A ☐ N (1)	Total Lbs.	P.S.I.	Fracture Type(2)	Test Tech.
A	7	0429	3-19-83	3-25-83	3.99	4.00	12.56	167,500	13330	D	CAS
TEST B	7	0429	3-19-83	3-25-83	3.99	4.00	12.56	163,500	13020	D	CAS
THREE C	28	0429	3-19-83	4-15-83	4.00	4.00	12.56	192,500	15330	F	CAS
D	28	0429	3-19-83	4-15-83	4.00	4.00	12.56	180,500	14370	D	CAS
E	90	0429	3-19-83	6-16-83	4.00	4.00	12.56	220,500	17550	F	CAS
F	90	0429	3-19-83	6-16-83	4.00	4.00	12.56	219,500	17480	F	CAS
BEAM G	28	0429	3-19-83	4-15-83				20,700	1730		CAS

(1) A=actual N=nominal (28.27 sq.inches) (2) If other than typical cone, indicate type below.

A ☐ B ☐ C ☐ D ☐ E Specify: ☐ F-NOT ENOUGH LEFT TO IDENTIFY

Record Specimen Length in REMARKS if outside the range of 1.8D to 2.2D.

Remarks: Specimens capped with supplier's material by supplier
All specimens returned to the Client after test

Acceptability [ ] Conforms [ ] Does Not Conform [x] Not Applicable

Reported by: Pittsburgh Testing Laboratory Pittsburgh Office

______________, Manager

FORM 407 REV. PG

PITTSBURGH TESTING LABORATORY

ESTABLISHED 1881

850 POPLAR STREET, PITTSBURGH, PA. 15220

PLEASE REPLY TO:
P. O. BOX 1646
PITTSBURGH, PA. 15230

LABORATORY No. 836563

AREA CODE 412 TELEPHONE 922-4000

CLIENT'S No. DACW59-83-M-0632

ORDER No. PG-21987

REPORT

June 28, 1983

REPORT OF CONCRETE
FOR
U.S. ARMY ENGINEER DISTRICT
PITTSBURGH CORPS OF ENGINEERS
1000 LIBERTY AVENUE
PITTSBURGH, PENNSYLVANIA 15222

Test Samples	:	Cast 3-25-83
Technician	:	V. J. Buechel
Specimens	:	(1)-4" x 8" Compressive Strength
		(2)-6" x 6" x 22" Flexural Strength
		(3)-4" Diameter Cores-Drilled by the Client

Cylinder and Beam Results - SEE ATTACHED REPORT

CORE RESULTS (ELBORG SILICA FUME CONCRETE

Core Number	Age	Diameter (In.)	~~Capped~~ SAWED Height (In.)	Total Load	P.S.I.
4-1	7 Day	3.90	7.70	76,500	6400
5-1	7 Day	3.88	7.96	123,000	10410
6-1	7 Day	3.90	7.97	121,000	10120
1-4 *	14 ~~7~~ Day	3.90	7.76	113,500	9500
4-2	28 Day	3.90	7.82	122,000	10210
5-2	28 Day	3.90	7.84	152,000	12720
6-2	28 Day	3.90	7.83	162,000	13560
			CAPPED HEIGHT (IN.)		
4-3	90 Day	3.88	7.96	183,000	15480
5-3	90 Day	3.88	7.96	154,500	13070
6-3	90 Day	3.88	7.96	161,000	13620

* CORROCEM SILICA FUME

Respectfully submitted,

PITTSBURGH TESTING LABORATORY

R. E. Gardner

R. E. Gardner, Manager,
Cement and Concrete Department

CAS/mb
3-U.S.Army Engineer District
Pittsburgh Corps of Engineers

LAB. NO. 0650

Form-9001 Rev 1
Order No.: PG-21987
Date Reported: 6-28-83

PITTSBURGH TESTING LABORATORY
REPORT OF CONCRETE COMPRESSION TEST RESULTS

Client: Corps of Engineers Client P.O. No. DACW59-83-M-0632

Project: Ultra High Strength Concrete

Location of Placement: South Section of Slab

Contractor: Corps of Engineers Concrete Supplier: Frank Bryan

Mix Identification: 1-A

Strength Requirement: --- psi @ --- days

Test Specimens - Made by: [X] PTL [ ] Other:

- Delivered by: [X] PTL [ ] Other:

Number of Specimens Submitted: 6 Date Moulded: March 25, 1983

1 Beam (22" x 6" x 6")

FIELD DATA

Slump: 10 in. Entrapped Air: 1.2 % Conc. Temp: 62 °F Unit Wt.: 159.2 lbs./cu.ft.

Quantity Represented: 8½ cu.yds. Batch Ticket No.: ---

Weather Conditions: Clear Ambient Temperature: 38 °F

Above Determined by: [X] PTL Inspection (Field Report Dated:) [ ] Others:

Test Procedure: ASTM-C-39-___(Yr) Test Machine No.: Caliper No.:

4" x 8" Cylinders

Specimens Marked	Days Age	Lab.No.	Date Recv'd.	Date Test	DIAMETERS (in) A	DIAMETERS (in) B	AREA (in²) ☐ A ☐ N (1)	Total Lbs.	P.S.I.	Fracture Type(2)	Test Tech.
1-A	7	0650	3-26-83	4-1-83	4.00	4.00	12.56	124,000	9870	B	JPS
1-A	7	0650	3-26-83	4-1-83	4.00	4.01	12.56	141,000	11230	D	JPS
1-A	28	0650	3-26-83	4-22-83	4.00	4.00	12.56	204,000	16240	F	CAS
1-A	28	0650	3-26-83	4-22-83	4.00	4.00	12.56	192,000	15290	F	CAS
1-A	90	0650	3-26-83	6-23-83	4.00	4.00	12.56	209,000	16640	F	CAS
1-A	90	0650	3-26-83	6-23-83	4.00	4.00	12.56	196,000	15610	F	CAS
BEAM	28	0650	3-26-83	4-22-83				21,400	1745		CAS

(1) A=actual N=nominal (28.27 sq.inches) (2) If other than typical cone, indicate type below.

A B C D E Specify: F-Not enough left to Identify

Record Specimen Length in REMARKS if outside the range of 1.8D to 2.2D.

Remarks: All specimens cut and polished
All specimens returned to the Client after test

Acceptability: [ ] Conforms [ ] Does Not Conform [X] Not Applicable

Reported by: Pittsburgh Testing Laboratory Pittsburgh Office

, Manager

LAB. NO. 0651

PITTSBURGH TESTING LABORATORY

REPORT OF CONCRETE COMPRESSION TEST RESULTS

Form-9001 Rev 1
Order No.: PG-21987
Date Reported: 6-28-83

Client: Corps of Engineers Client P.O. No. DACW59-83-M-0632

Project: Ultra High Strength Concrete

Location of Placement: Center Section of Slab

Contractor: Corps of Engineers Concrete Supplier: Frank Bryan

Mix Identification: 2-B

Strength Requirement: --- psi @ --- days

Test Specimens - Made by: [X] PTL [ ] Other:

- Delivered by: [X] PTL [ ] Other:

Number of Specimens Submitted: 6 Date Moulded: March 25,1983
1 Beam (22" x 6" x 6")

FIELD DATA

Slump: 7½ in. Air: 2.5 % Conc. Temp: 62 °F Unit Wt.: 156.7 lbs./cu.ft.

Quantity Represented: 8½ cu.yds. Batch Ticket No.: ---

Weather Conditions: Clear Ambient Temperature: 42 °F

Above Determined by: [X] PTL Inspection (Field Report Dated:) [ ] Others:

Test Procedure: ASTM-C-39-____(Yr) Test Machine No.: Caliper No.:

4" x 8" Cylinders

Specimens Marked	Days Age	Lab. No.	Date Recv'd.	Date Test	DIAMETERS (in) A	DIAMETERS (in) B	AREA (in²) ☐ A ☐ N (1)	Total Lbs.	P.S.I.	Fracture Type (2)	Test Tech.
2-B	7	0651	3-26-83	4-1-83	4.00	4.00	12.56	131,500	10470	D	JPS
2-B	7	0651	3-26-83	4-1-83	4.00	4.01	12.56	143,000	11380	D	JPS
2-B	28	0651	3-26-83	4-22-83	4.00	4.00	12.56	162,000	12900	F	CAS
2-B	28	0651	3-26-83	4-22-83	4.00	4.00	12.56	161,500	12860	F	CAS
2-B	90	0651	3-26-83	6-23-83	4.00	4.00	12.56	207,500	16520	F	CAS
2-B	90	0651	3-26-83	6-23-83	4.00	4.00	12.56	211,000	16800	F	CAS
BEAM	28	0651	3-26-83	4-22-83				20,560	1690		CAS

(1) A=actual N=nominal (28.27 sq.inches) (2) If other than typical cone, indicate type below.

A B C D E Specify: F-Not enough left to identify

Record Specimen Length in REMARKS if outside the range of 1.8D to 2.2D.

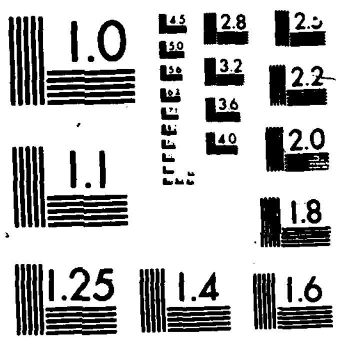
Remarks: All specimens cut and polished
All specimens returned to the Client after test

Acceptability: [ ] Conforms [ ] Does Not Conform [X] Not Applicable

Reported by: Pittsburgh Testing Laboratory Pittsburgh Office

, Manager

AD-A172 804   ABRASION-EROSION EVALUATION OF CONCRETE MIXTURES FOR   2/2
STILLING BASIN REPAI..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS STRUC..   T C HOLLAND
UNCLASSIFIED   SEP 86 WES/MP/SL-86-14   F/G 11/2   NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

LAB. NO. 0652

PITTSBURGH TESTING LABORATORY

REPORT OF CONCRETE COMPRESSION TEST RESULTS

Form-9001 Rev 1
Order No.: PG-21987
Date Reported: 6-28-83

Client: Corps of Engineers Client P.O. No. DACW59-83-M-0632

Project: Ultra High Strength Concrete

Location of Placement: North Section of Slab

Contractor: Corps of Engineers Concrete Supplier: Frank Bryan

Mix Identification: 3-C

Strength Requirement: --- psi @ --- days

Test Specimens - Made by: [X] PTL [ ] Other:

- Delivered by: [X] PTL [ ] Other:

Number of Specimens Submitted: 6 Date Moulded: March 25, 1983
1 Beam (6" x 6" x 22")

FIELD DATA

Slump: 6½ in. Air: 2.6 % Conc. Temp: 63 °F Unit Wt.: 156.6 lbs./cu.ft.

Quantity Represented: 8½ cu.yds. Batch Ticket No.: ---

Weather Conditions: Clear Ambient Temperature: 42 °F

Above Determined by: [x] PTL Inspection (Field Report Dated:) [ ] Others:

Test Procedure: ASTM-C-39-____(Yr) Test Machine No.: Caliper No.:

4" x 8" Cylinders

Specimens Marked	Days Age	Lab.No.	Date Recv'd.	Date Test	DIAMETERS (in) A	DIAMETERS (in) B	AREA (in²) ☐ A ☐ N (1)	Total Lbs.	P.S.I.	Fracture Type(2)	Test Tech.
3-C	7	0652	3-26-83	4-1-83	3.96	3.98	12.38	147,000	11870	D	JPS
3-C	7	0652	3-26-83	4-1-83	4.00	4.00	12.56	150,000	11940	D	JPS
3-C	28	0652	3-26-83	4-22-83	4.00	4.00	12.56	184,000	14650	F	CAS
3-C	28	0652	3-26-83	4-22-83	4.00	4.00	12.50	185,000	14730	F	CAS
3-C	90	0652	3-26-83	6-23-83	4.00	4.00	12.56	217,500	17320	F	CAS
3-C	90	0652	3-26-83	6-23-83	4.00	4.00	12.56	209,000	16640	F	CAS
BEAM	28	0652	3-26-83	4-22-83				23,120	1875		CAS

(1) A=actual N=nominal (28.27 sq.inches) (2) If other than typical cone, indicate type below.

A B C D E Specify: F-Not enough left to identify

Record Specimen Length in REMARKS if outside the range of 1.8D to 2.2D.

Remarks: All specimens cut and polished
All specimens returned to the Client after test

Acceptability: [ ] Conforms [ ] Does Not Conform [X] Not Applicable

Reported by: Pittsburgh Testing Laboratory Pittsburgh Office

R. E. G[illegible], Manager

APPENDIX F

MATHER'S MEMO ON CURING OF

SILICA FUME CONCRETE

WESSV 19 April 1983

MEMORANDUM FOR: TERRY HOLLAND

SUBJECT: Silica Fume Concrete

1. On 19 April there came across my desk a copy of your Memorandum for Record dated 1 April on experiences at Kinzua. On the routing slip, Jack Scanlon had written "The plastic shrinkage cracking should not be referred to as 'cracking.'" Since it is cracking, I fail to understand why he believes it should not be referred to as cracking. He then recommends that a product such as "Confilm" be sprayed on the silica fume concrete immediately after finishing.

2. My recommendation to the people in the concrete schools is that the concrete should be fogged or sprayed with an evaporation retardant film immediately after finishing whenever the possibility exists that the evaporation rate may exceed the bleeding rate with the result that the finished surface may lose its surface water sheen before setting has occurred and bleeding has stopped.

3. Mr. Scanlon remarks that plastic shrinkage cracking is a major problem with silica fume concrete. My own view is plastic shrinkage cracking is no greater a problem with silica fume concrete than any other concrete of comparable bleeding characteristics or, specifically, if silica fume concrete presents more of a problem it is not because of the silica fume but it is because of the low bleeding rate. Mr. Scanlon then observes that the major problem in plastic shrinkage cracking is the wind and observes that without wind plastic shrinkage cracking seldom occurs but it can.

4. I believe that it would be well to refer to Steve Gebler's paper, beginning on page 19 in Concrete International for April 1983, which addresses precisely this question. He quotes the nomograph relating air temperature, concrete temperature, relative humidity, and wind velocity, and remarks correctly that when the wind velocity is less than 2 mph it is difficult to exceed the 0.2 $lb/ft^2/hr$ evaporation rate that is generally taken to be the breakpoint between mandatory precautions against plastic shrinkage cracking and the absence of such need. However, Gebler also points out that plastic shrinkage cracking can occur for evaporation rates as low as 0.1 $lb/ft^2/hr$ which rate can occur with a wind velocity of 0 provided the concrete temperature is a little over 100 deg F.

5. The most troublesome aspect of this memorandum to me was the reference in para 4h and again in 5j to the application of a curing compound to the concrete surface almost immediately after it was finished. The harmfulness of this practice is spelled out in some detail in para 2.3.3 of the ACI Standard 308-81. Curing compound should never be applied until the concrete has set and the possibility of bleeding has stopped. Between the time of finishing and the time of setting, the surface must be kept moist one way or another.

WESSV 19 April 1983
SUBJECT: Silica Fume Concrete

6. In para 6b you suggest that you do not have a ready explanation about how one concrete cracked and the other concrete did not. You note that both were done under conditions that were estimated to be at an evaporation rate of less than 0.2 $lb/ft^2/hr$. If this is actually the case, it may be that the critical number for one or both of these concretes is smaller than 0.2 and it may be 0.1 or so as suggested to be possible by Gebler. My own opinion is that the difference may be a difference in bleeding by the two concretes. If one concrete has a little greater bleeding capacity, then it should tolerate an evaporation rate that perhaps the other one will not.

7. You suggest in subpara 6j that the project specifications include reference to Fig. 2.1.5 of ACI 305.R-77. I would suggest that in the event that this figure is referred to, it would be better to refer to the revised and corrected version that appears as Fig. 1 in the ACI Standard 308-81. However, I do not believe that it is desirable to refer to the figure at all in the specifications. I think rather what the specification should say is "The concrete, after being placed, shall be kept moist and its surface shall appear moist continuously until the time of setting, at which point the surface water sheen shall be allowed to evaporate and the surface shall then be immediately coated with white pigmented membrane-forming curing compound meeting CRD-C 300-77. The maintenance of free moisture at the surface of the concrete at all times can be insured by the use of a combination of fog nozzles, wind breaks, sunshades, and evaporation retarding films. The choice of methods is up to the contractor. If plastic shrinkage cracks occur, it is unequivocal indication that this provision of the specification has been violated."

Bryant Mather

BRYANT MATHER
Engineer
Chief, Structures Laboratory

CF:
John Scanlon
Don Walley
Al Buck
Tony Liu

APPENDIX G

EXCERPT FROM ACI STANDARD 308-81

Proposed ACI Standard
Standard Practice for Curing Concrete*

Reported by ACI Committee 308

Curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early stages so that desired properties may develop.

Basic principles of curing are stated; commonly accepted methods, procedures, and materials are described. Requirements are given for curing pavements and other slabs on ground; for structures and buildings; and for mass concrete. For each of these categories, methods, materials, time, and temperature of curing are stated. Curing requirements for precast products, shotcrete, preplaced-aggregate concrete, refractory concrete, plaster, and other applications are given.

Keywords: bridges (structures); buildings; cement-base paints; cold-weather construction; concrete construction; concrete pavements; concretes; **curing; curing compounds;** curing films and sheets; hot-weather construction; insulating concrete; insulation; mass concrete; **moist curing;** plaster; precast concrete; refractory concretes; reinforced concrete; sealers; shells (structural forms); shotcrete; slab-on-ground construction; slipform construction; **standards; steam curing;** stucco.

Contents

Chapter 1 — Introduction and Referenced Standards, page 46

1.1 — Scope
1.2 — Need for Curing
  1.2.1 — Satisfactory moisture content
  1.2.2 — Favorable temperature
1.3 — Referenced standards
  1.3.1 — ASTM Standards
  1.3.2 — ACI Standards and Reports
  1.3.3 — AASHTO Materials Standards

Chapter 2 — Curing Methods and Materials, page 48

2.1 — Scope
2.2 — Water curing
  2.2.1 — Ponding or immersion
  2.2.2 — Fog spraying or sprinkling
  2.2.3 — Burlap, cotton mats, and rugs
  2.2.4 — Earth curing
  2.2.5 — Sand and sawdust
  2.2.6 — Straw or hay
  2.2.7 — Termination
2.3 — Sealing materials
  2.3.1 — Plastic film
  2.3.2 — Reinforced paper
  2.3.3 — Liquid membrane-forming curing compounds
2.4 — Cold weather protection and curing
2.5 — Hot-weather curing
2.6 — High-pressure steam curing
2.7 — Low-pressure (or atmospheric-pressure) steam curing
2.8 — Evaluation of curing procedures
2.9 — Criteria for effectiveness of curing
  2.9.1 — General
  2.9.2 — Strength basis
  2.9.3 — Maturity-factor basis
2.10 — Minimum curing requirements

Chapter 3 — Curing for Different Constructions, page 52

3.1 — Pavements and other slabs on the ground
  3.1.1 — General
  3.1.2 — Curing procedures
  3.1.3 — Duration of curing
3.2 — Structures and buildings
  3.2.1 — Scope
  3.2.2 — Curing procedures
  3.2.3 — Duration of curing and protection
3.3 — Mass concrete
  3.3.1 — Scope
  3.3.2 — Temperature control
  3.3.3 — Methods and duration of curing
3.4 — Other construction
  3.4.1 — Precast units
  3.4.2 — Vertical slipform construction
  3.4.3 — Shotcrete
  3.4.4 — Refractory concrete
  3.4.5 — Cement paint, stucco, and plaster
  3.4.6 — Shell structures
  3.4.7 — Insulating concrete
  3.4.8 — Concrete with colored or metallic surfaces

*This proposed standard is intended to replace ACI Standard "Recommended Practice for Curing Concrete (ACI 308-71)." Discussion closes Feb. 1, 1981.

2.3.3 — Liquid membrane-forming curing compounds — Liquid membrane-forming compounds for curing concrete should comply with the requirements of ASTM C 309 (1.3.1.9), when tested at the rate of coverage to be used on the job. Such compounds consist essentially of waxes, natural and synthetic resins, and solvents of high volatility at atmospheric temperatures. Adequate ventilation should be provided and other safety precautions should be taken. The formulation must be such as to form a moisture-retentive film shortly after being applied and must not be injurious to portland-cement paste. White or gray pigments are often incorporated to provide heat reflectance, and to make the compound visible on the structure for inspection purposes. Curing compounds should not be used on surfaces that are to receive additional concrete, paint, or tile that requires a positive bond, unless it has been demonstrated that the membrane can be satisfactorily removed before the subsequent application is made, or that the membrane can serve satisfactorily as a base for the later application.

The compound should be applied at a uniform rate. The usual values for coverage range from 150 to 200 sq ft per gal. (0.20 to 0.25 litre/m^2). Tests to determine compliance with the requirements of ASTM C 309 are made at the coverage to be used in the field, or if not stipulated, at 200 ft^2/gal. (0.20 litre/m^2). When feasible, two applications at right angles to each other are suggested for complete coverage. On very deeply textured surfaces, such as used on some pavements to improve surface friction properties, there may need to be two separate applications each at 200 ft^2/gal. (0.20 litre/m^2) with the first being allowed to become tacky before the second is applied. Curing compound can be applied by hand or power sprayer, usually at about 75 to 100 psi (0.5 to 0.7 MPa) pressure. If the job size warrants, mechanical application is preferred because of speed and uniformity of distribution. For very small areas such as patches, the compound can be applied with a wide, soft-bristled brush or paint roller.

For maximum beneficial effect, liquid membrane-forming compounds must be applied after finishing and as soon as the free water on the surface has disappeared and no water sheen is visible, but not so late that the liquid curing compound will be absorbed into the concrete. If the ambient evaporation rate exceeds 0.2 lb/ft^2/hr (1.0 kg/m^2/hr) (See Fig. 1) the concrete may still be bleeding even though the surface water sheen has disappeared and steps must be taken to avoid excessive evaporation. If membrane-forming compound is applied to a dry-appearing surface, one or the other of two undesirable conditions may follow: (a) evaporation will be effectively stopped but bleeding may continue, resulting in a layer of water forming below the layer of cement paste to which the membrane is attached; such a condition promotes scaling; (b) evaporation will be temporarily stopped but bleeding may continue resulting in map cracking of the membrane film, requiring reapplication of the curing compound. In some highway work, the applicable specifications may allow water-soluble linseed-oil base membrane-forming compounds to be applied before the water sheen has gone. When forms are removed, the exposed concrete surface should be wet with water immediately and kept moist until the curing compound is applied. Just prior to application, the concrete should be allowed to reach a uniformly damp appearance with no free water on the surface and then application of the compound should be begun at once. Pigmented compounds must be stirred to assure even distribution of the pigment during application, unless the formulation contains a thixotropic agent to prevent settlement.

APPENDIX H

MANUFACTURER'S DATA SHEET FOR CONFILM

MASTER BUILDERS

CONFILM*

Construction Products Information

Evaporation retardant and finishing aid

DESCRIPTION:

CONFILM evaporation retardant and finishing aid helps produce high-quality, concrete flatwork. It retards water evaporat... n, regulates the surface condition of the slab and permits better adherence to finishing schedules.

Because CONFILM retards evaporation, it is especially effective in combating rapid-drying conditions (high concrete and/or ambient temperatures, low humidity, high winds, direct sunlight, work in heated interiors during cold weather, etc.).

RECOMMENDED FOR:

- Use with plain concrete.
- Use with any Master Builders cementitious product and finishing operation, except DPS Masterplate* safety floor hardener.

FEATURES/BENEFITS:

- Reduces surface moisture evaporation about 80% in wind and about 40% in sunlight. It has no effect on the cement hydration process. Concrete strength (early and ultimate), abrasion resistance and durability are not altered, except for the improvement in overall quality resulting from control of rapid evaporation.
- Gives concrete a better finish with less work. It eliminates or reduces crusting, stickiness and underlying sponginess which often results in unevenness and poor surface texture. The surface closes better under the trowel.
- Reduces and, in many instances, eliminates plastic-shrinkage cracking and wind crusting of flatwork surfaces. Also supplements the recommended practices for hot weather concreting.[1] Under some conditions CONFILM alone will provide the necessary safeguard against the ill effects of evaporation.
- Allows lower slump and lower unit water content in concrete used for flatwork, since CONFILM virtually eliminates the need to add extra mixing water to compensate for rapid evaporation during finishing.
- Encourages the use of air-entrained concrete—required for durability and workability—in situations where air entrainment might be avoided for fear that it would increase concrete's susceptibility to crusting and stickiness under drying conditions.
- Increases the amount of surface handled per finisher—even under rapid-drying conditions—because the surface remains plastic and finishable for a longer time. Thus, work can proceed whereas, without CONFILM, it might be postponed to avoid finishing problems.
- Timing of the various finishing operations is less critical, thus reducing overall cost.

[1] ACI Committee 302, "Guide for Concrete Floor and Slab Construction"; ACI Committee 305, "Recommended Practice for Hot Weather Concreting"; ACI Committee 308, "Standard Practice for Curing Concrete"; and ACI Committee 345, "Standard Practice for Concrete Highway Bridge Deck Construction" advise the use of a monomolecular film as a helpful measure to prevent rapid drying of fresh concrete.

A detailed technical discussion about the action of monomolecular films, typified by CONFILM, is contained in the *Journal of the American Concrete Institute*, Volume 62, pp. 977-985.

*Reg. U.S. Pat. & Tm. Off.

APPLICATION:

Apply with an ordinary, garden-type, tank sprayer or with the equipment used for application of a spray-on, membrane-type curing compound.

CONFILM evaporation retardant and finishing aid contains a fluorescent color tint which disappears completely upon drying. When sprayed onto the surface immediately *after screeding*, CONFILM forms a monomolecular film. This film is easily distinguished from untreated surfaces by its green-yellow color in the presence of surface moisture and ultraviolet rays (sunlight or artificial lighting).

The residue remaining on the surface of hardened concrete does not impair bonding or alter the color appearance. The protective shield of CONFILM usually lasts as long as the concrete remains *plastic, despite succeeding floating* and troweling operations.

YIELD/COVERAGE:

One U.S. gallon (3.8 litre) of CONFILM mixed with nine U.S. gallons (34.1 litre) of water yields 10 U.S. gallons (37.9 litre) of sprayable solution. This amount should cover 2,000 to 4,000 ft^2 (186 to 372 m^2) of fresh concrete.

If more than one application of CONFILM is made, as under adverse drying conditions, the quantity required will be increased accordingly.

PRECAUTIONS:

- CONFILM evaporation retardant and finishing aid is **not** a curing agent. Concrete treated with this product **must still be cured.**
- Master Builders is not responsible for compatibility or results when CONFILM evaporation retardant and finishing aid is used with other manufacturers' products.
- CONFILM reduces evaporation only while concrete is in its plastic state. *It is not a substitute for* early curing of hardened concrete, nor does it alter the effectiveness of membrane-type, curing compounds.
- Any residue remaining from spillage or spraying of CONFILM concentrate on the surface of **hardened** concrete should **not** be allowed to dry. Wipe it up immediately, then rinse the surface with water.

  If the CONFILM residue is allowed to dry on hardened concrete, a red-brown stain may appear. To remove the stain, place a cloth *saturated in a household-type*, chlorinated bleach onto the stain, then cover it with plastic to retard evaporation. After approximately one hour, the stain should disappear completely. Rinse the area with water.

PACKAGING:

CONFILM evaporation retardant and finishing aid is supplied in 1, 5 and 55 U.S. gallon (3.8, 18.9 and 208 litre) pails.

For additional information on CONFILM evaporation retardant and finishing aid, contact your local Master Builders representative.

MASTER BUILDERS
IMPROVING CONCRETE WORLDWIDE
CLEVELAND, OHIO 44122

Form CF-1n
Printed in U.S.A. 186

END

11-86

DTIC