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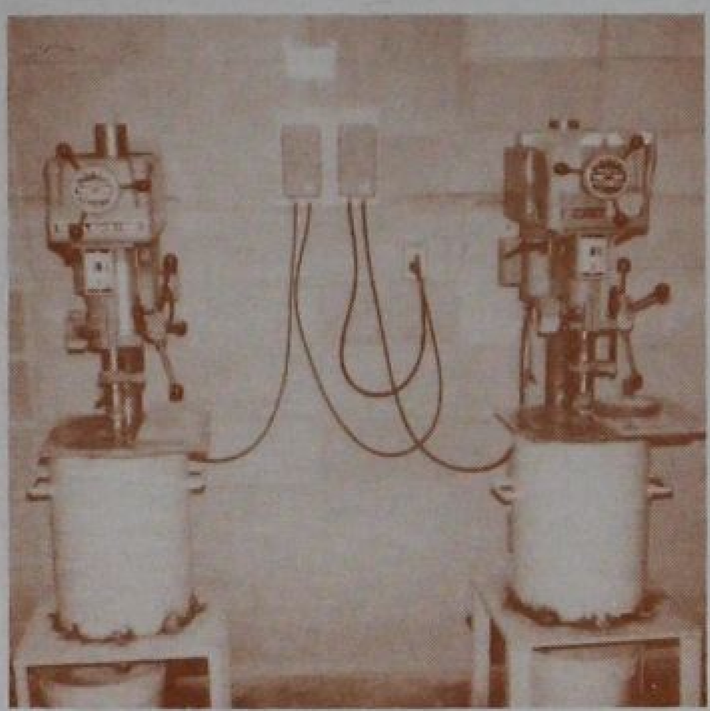

STRUCTURES
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MISCELLANEOUS PAPER SL-86-12

ABRASION-EROSION EVALUATION OF CONCRETE MIXTURES FOR REPAIR OF LOW-FLOW CHANNEL, LOS ANGELES RIVER

by

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The work described in this report involved abrasion-erosion testing of several concrete mixtures containing silica fume to evaluate the relative potential of the several mixtures to resist such attack. The mixtures were candidates for use in repair work to be conducted by the US Army Engineer District, Los Angeles. Concrete was placed in the field between 21 and 23 September 1983.

Conclusions included (1) the mixtures tested could provide excellent resistance to abrasion-erosion damage; (2) no more than 15 percent fume should be used; (3) mixtures were difficult to place and required special attention but were worth the extra effort; and (4) concretes containing silica fume appear to offer the best resistance to abrasion-erosion damage.

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PREFACE

The investigation described in this report was conducted for the U. S. Army Engineer District, Los Angeles, by the Concrete Technology Division (CTD) of the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES). Authorization for this investigation was given by DA Form 2544, CIV-83-48, dated 4 February 1983, and DA Form 2544, CIV-83-121, dated 11 August 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. Dr. Holland, Mr. Don Walley, and Mr. Frank W. Dorsey prepared the concrete mixtures and specimens. Mr. Dale Glass, Mr. Frank W. Dorsey, and Mr. Glenn Odom conducted the abrasion-erosion tests. Mr. Jack Rolston and Mr. Richard Gutschow served as the points of contact at the Los Angeles District. Mr. Rolston, in particular, provided many thoughtful insights during this investigation and the trial placements. This report was written by Dr. Holland. Mr. Odom helped to prepare the final version of the report.

The funds for publication of this report were provided by the Concrete Technology Information Analysis Center (CTIAC); it is CTIAC Report No. 78.

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 Technical Director.

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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
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
fluid ounces per cubic yard	38.6738	millilitres per cubic metre
fluid ounces per pound (mass)	65.1896	millilitres per kilogram
gallons per cubic yard	4.951132	litres per cubic metre
inches	25.4	millimetres
miles	1.609347	kilometres
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

* To obtain Celsius (C) 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 REPAIR OF LOW-FLOW CHANNEL, LOS ANGELES RIVER

PART I: INTRODUCTION

Purpose

1. The purpose of this investigation was to evaluate several concrete mixtures on the basis of resistance to abrasion-erosion damage. The data developed were to be used to assist the Los Angeles District (SPL) in selecting the concrete mixtures to be used during the planned repair project. Of particular interest in the investigation was an evaluation of concrete mixtures containing silica fume as a mineral admixture.

Scope

2. This investigation consisted of examinations of the various materials provided by the District staff, proportioning of concrete mixtures, preparation of specimens from the various concretes, and testing specimens for abrasion-erosion and compressive strength. Additionally, on-site assistance was provided during two field placements in Los Angeles. Finally, this report includes abrasion-erosion data generated from testing of specimens made during the actual field placements.

Background

3. Los Angeles District is responsible for operation and maintenance of approximately 12 mi* of the Los Angeles River channel structure. The concrete in the invert of the structure, particularly in the low-flow section, has experienced damage that appears to be the result of abrasion-erosion, scour, and possibly, chemical attack. The degree of damage ranges from minor to significant concrete loss. In some areas, the concrete loss is to a depth sufficient to expose reinforcing steel. The concrete in the low-flow section is

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

approximately 40 yr old. It was placed under various contracts and very few details concerning the concrete appear to be available.

4. During FY 1983, the staff of Los Angeles District planned to replace concrete in the low-flow section for a length of approximately 1/2 mi. This project was intended to serve as a test placement for rehabilitation work planned for the remainder of the channel beginning in FY 1984.

5. In February 1983, Mr. Jack Rolston, SPL, initiated discussions with representatives of the Concrete Technology Division (CTD) of the Waterways Experiment Station (WES) concerning abrasion-erosion-resistant concrete. These discussions led to the research program described in this report. Based on the results of related ongoing work for Pittsburgh District, CTD recommended that concretes containing silica fume be included in the test program. This recommendation was accepted.

6. The test program was developed jointly by representatives of CTD and SPL. Concretes included in the program were a conventional concrete (to be used as a control), two concretes containing silica fume, and one concrete containing silica fume and fly ash. (This last mixture was included in the test program at the specific request of SPL.) Two additional concrete mixtures containing higher cement contents were also included in the test program for comparison purposes--these mixtures were not being considered for field placements.

PART II: TEST METHOD, MATERIALS, AND CONCRETE MIXTURES

Test Method

7. Abrasion-erosion testing was conducted in accordance with CRD-C 63-80,* "Test Method for Abrasion-Erosion Resistance of Concrete (Underwater Method)." This test procedure involves subjecting the concrete specimens to abrasion-erosion caused by the wear of steel grinding balls on the concrete surface. The steel grinding balls are propelled by water in the test chamber. The water is in turn propelled by a submerged mixer paddle. Test specimens are periodically removed from the apparatus to determine the amount of abrasion-erosion damage. The damage is quantified and reported as a percentage of original mass lost.

8. The development of the test procedure and data from a large number of tests of various concrete mixtures were described by Liu (1980).

Materials

9. The aggregates, cement, and fly ash used in this test program were supplied by Los Angeles District. All other materials were WES laboratory stock. All of the materials used are described in the following paragraphs.

Aggregates

10. The coarse aggregate, Structures Laboratory (SL) serial No. LA-3 G-1, was supplied from the Consolidated Rock Products Company plant in the San Gabriel River. The coarse aggregate was divided into three fractions as follows: 1-1/2-, 1-, and 3/8-in. nominal maximum size. The gradings of the aggregates as produced in Southern California are intended to meet the requirements of the Los Angeles "Green Book," which is the Standard Specification for Public Works Construction (Southern California Chapter, American Public Works Association, 1982). Grading data, absorptions, and specific gravities for the coarse aggregates are presented in Table 1. As can be seen in the table, the coarse aggregates do not all comply with the grading requirements of the Green

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

Book. These coarse aggregates approximate the grading of ASTM C 33* (CRD-C 133), "Standard Specification for Concrete Aggregates," for the following nominal maximum sizes:

1-1/2 in.	ASTM C 33 size No. 4
1 in.	ASTM C 33 size No. 56
3/8 in.	ASTM C 33 size No. 8

11. The fine aggregate, SL serial No. LA-3 S-1, was from the same source as the coarse aggregate. Test data for this aggregate are presented in Table 2. As can be seen in the table, this aggregate does meet the grading requirements of the Green Book, but does not meet the grading requirements of ASTM C 33 (CRD-C 133). Because of a strong organic odor when the fine aggregate was received, it was tested in accordance with ASTM C 40 (CRD-C 121), "Standard Test Method for Organic Impurities in Fine Aggregates for Concrete." This test showed no organic impurities.

12. The coarse and fine aggregates were given a limited petrographic examination at WES. This examination showed all three coarse aggregate sizes and the fine aggregate to be similar in visual appearance. Scratch testing showed that the coarse aggregate ranged from easily scratched to could not be scratched with a steel needle. Approximately 16 percent of the 1-1/2-in. fraction were found to be easily broken when lightly struck with a hammer. No reactive particles were found. Overall, this aggregate was judged to be of poorer physical quality for use in an abrasive environment than the normal chert gravel found in Mississippi. The report of the petrographic examination is presented in Appendix A.

13. Review of TM 6-370, Test Data--Concrete Aggregates in the Continental United States (US Army Engineer Waterways Experiment Station 1953), showed that this aggregate source (Lat: 34^{o} N, Long: 117^{o} W, Index No. 1) was last reviewed for coarse aggregate in 1948 and for fine aggregate in 1954. The material properties of the aggregates have not changed significantly since the previous tests except for the percentage of weathered and unsound material in the coarse aggregate. As noted in para 12, the examination of the coarse aggregate at WES showed approximately 16 percent of the 1-1/2-in. fraction to be highly weathered while the earlier report (1948) showed only 8 percent to be "weathered and potentially unsound material." The WES examination did not

* All ASTM test methods are published in the Annual Book of ASTM Standards (American Society for Testing and Materials 1983).

provide an estimate of weathered particles in the fine aggregate. The 1948 report indicated approximately 7 percent of the fine aggregate to be "soft weathered granite."

Cement

14. The cement used, SL serial No. LA-3 C-1, was manufactured by the California Portland Cement Company, Colton, California. The cement meets the requirements of ASTM C 150 (CRD-C 201), "Standard Specification for Portland Cement," for a Type I (low-alkali) and a Type II (low-alkali) cement. The physical and chemical test results for the cement are presented in Table 3.

Mineral admixtures

15. The fly ash used, SL serial No. AD-727, was produced by Pozzolanic International, Rock Springs, Wyoming (this is the Jim Bridger Power Plant). This fly ash meets the requirements of 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 Concretes," for a Class F fly ash. Test data for this material are presented in Table 4.

16. The silica fume used, SL serial No. AD-536(5), was from the Reynolds Metals Company, Richmond, Virginia (the actual production location was Sheffield, Alabama). Test data for this material are presented in Table 5.

Chemical admixtures

17. The high-range water-reducing admixture (HRWRA) used was Grace D-19, from laboratory stock. The D-19 used was in a powder form. It is marketed in a liquid form with a solids content of approximately 42 percent. This product is a modified naphthalene sulfonate. It meets the requirements of ASTM C 494 (CRD-C 87), "Standard Specification for Chemical Admixtures for Concretes," as a Type A or Type F admixture. It is manufactured by W. R. Grace and Co., Cambridge, Massachusetts.

18. The water-reducing, retarding admixture used was Sika Plastiment from laboratory stock. This product is a hydroxylated carboxylic acid. It meets the requirements of ASTM C 494 (CRD-C 87) as a Type D admixture. It is manufactured by Sika Chemical Company, Lyndhurst, New Jersey.

Combined aggregate gradings

19. Given a situation in which the coarse aggregate was divided into three size fractions, there was an obvious requirement to develop a suitable combination. The aggregate producer, who is also a ready-mixed concrete supplier, provided a recommended combination to produce concrete with a high resistance to abrasion-erosion. The recommended relative proportions of the aggregates were as follows:

		Overall
1-1/2 in. 40%	63.5%	25.4 %
1 in. 50%		31.75%
3/8 in. 10%		6.35%
Fine Aggregate	36.5%	36.5 %
	100.0%	100.0 %

A combined grading using these recommended values is presented in Table 6. As can be seen in this table, the combined grading does meet the requirements of the Los Angeles Green Book. However, a test batch of concrete, made using these relative proportions, was extremely harsh and unfinishable. Additional mixtures were prepared maintaining the same relative proportions of the coarse aggregates but increasing the percentage of fine aggregate. These mixtures showed improvement, but were still not acceptable.

20. Given the difficulties experienced with the proportions recommended by the aggregate supplier, the combined grading of the coarse aggregates was compared to the optimum grading recommended by CRD-C 3-58, "Method of Selecting Proportions for Concrete Mixtures," (now superseded). This comparison is shown in Table 7. The relative proportions of the coarse aggregates as recommended by the aggregate supplier do not compare well with the optimum grading of CRD-C 3-58.

21. Based upon the initial trial batches of concrete, a decision was made to abandon the proportions recommended by the aggregate supplier. A trial and error approach was used to develop a combination of coarse aggregates that would more closely match the recommendations of CRD-C 3-58. The appropriate relative proportion of fine aggregate was established through additional trial batches. The proportions selected were:

		Overall
1-1/2 in. 33%		19.14%
1 in. 40%	58%	23.20%
3/8 in. 27%		15.66%
Fine Aggregate	42%	42.00%
	100%	100.00%

22. A combined grading using these relative proportions for the coarse aggregate is shown in Table 8. A combined grading of coarse and fine aggregates is shown in Table 9. The data in Table 8 show that the relative proportions developed at WES are a close match to the values recommended by CRD-C 3-58. The data in Table 9 show that the overall aggregate proportions as developed at WES are slightly outside the recommendations of the Los Angeles Green Book. However, since these mixtures performed well, these variations were deemed acceptable. The same relative proportions of aggregates were used in all of the concrete mixtures tested.

Mixture proportions

23. Six concrete mixtures were proportioned for this investigation. These mixtures were developed jointly by staff of CTD and SPL. A brief description of these six mixtures, along with the table in which detailed mixture proportions may be found, follows:

- a. Mixture LA1 (Table 10): Control mixture, high quality conventional concrete.
- b. Mixture LA2 (Table 11): Control mixture with the addition of 30 percent silica fume.
- c. Mixture LA3 (Table 12): Control mixture with the addition of 15 percent silica fume.
- d. Mixture LA4 (Table 13): Control mixture with the addition of 15 percent silica fume and 15 percent fly ash.
- e. Mixture LA5 (Table 14): Control mixture with the addition of 15 percent cement.
- f. Mixture LA6 (Table 15): Control mixture with the addition of 30 percent cement.

24. For the three mixtures that contained silica fume, the water to cement plus silica fume (and plus fly ash) ratio was held constant at 0.24. For those mixtures not containing silica fume, the water to cement ratio was held constant at 0.38. The slump for all mixtures was controlled by the amount of HRWRA added. The tables describing the mixture proportions show a nominal

HRWRA content of 1 or 2 percent (by weight of the cement, silica fume, and fly ash) for the nonsilica-fume and silica-fume mixtures, respectively. The actual amount of HRWRA added and the resulting slumps are shown in Table 16.

PART III: TEST DATA AND DISCUSSION

Test Data

25. The properties of the fresh and hardened concretes for all six mixtures are presented in Table 16. Data in this table are slump, admixture (HRWRA) dosage, compressive strength, and average abrasion-erosion loss.

26. Detailed abrasion-erosion test data and photographs of the specimens after testing are presented as follows:

Mixture	Detailed Abrasion-Erosion Test Data	Photograph
LA1	Table 17	Figures 1, 2, and 3
LA2	Table 18	Figure 4
LA3	Table 19	Figures 5, 6, and 7
LA4	Table 20	Figure 8
LA5	Table 21	Figure 9
LA6	Table 22	Figure 10

27. The abrasion-erosion test data are plotted in Figure 11.

Discussion

28. The compressive strengths of the concrete mixtures containing silica fume were somewhat lower than anticipated based upon laboratory experience with similar mixtures. The reduction in compressive strength was probably attributable to the high percentage of highly weathered and friable particles found in the coarse aggregate. Examination of fragments of concrete from compressive strength cylinders show that failure occurred through numerous such particles.

29. The abrasion-erosion data showed no surprises. The three concretes containing silica fume all performed quite similarly as did the three mixtures without silica fume. The influence of the poor quality aggregate particles was apparent in the post test appearance of all of the specimens. Note particularly the large piece of coarse aggregate eroded away from the surface of the specimen from Mixture LA3 (Figure 5).

30. A specimen from Mixture LA1 was selected as being representative of the appearance of the specimens from concretes without silica fume. This specimen was cut with a diamond saw to provide the sectional views shown in Figures 2 and 3. Similarly, a specimen from Mixture LA3 was selected as representative of the concretes that did contain silica fume. This specimen was also saw cut and is shown in Figures 6 and 7. As would be expected, the specimens showing less mass loss in the abrasion-erosion test had a much smoother surface appearance.

31. A linear regression analysis was performed to compare the compressive strength of a concrete mixture (at the abrasion-erosion test age) with the abrasion-erosion loss. This analysis showed a dramatic relationship between these two variables--the coefficient of linear correlation (r) was found to be -0.9939. The data points from the six mixtures and the best fit straight line are plotted in Figure 12.

32. There was very little difference in the performance (compressive strength and abrasion-erosion loss) of the concretes containing 15 and 30 percent silica fume (Mixtures LA2 and LA3). While it may be assumed that the use of silica fume in excess of 15 percent has no effect, it may be true that the aggregate used will not allow development of compressive strengths in excess of those seen for these mixtures. Similarly, the aggregate may control a minimum value for abrasion-erosion loss of around 2.5 to 3.0 percent. There are simply not enough data available to make a definitive statement regarding the optimum percentage of silica fume to use. For the purpose at hand, the mixture with 15 percent silica fume appears to be quite satisfactory.

33. The data on the slump and HRWRA dosage in Table 16 show that there is a very close relationship between these two variables. Minor changes in HRWRA dosage can lead to significant changes in slump. This fact implies that extremely tight control over water content and admixtures dosages is critical for concretes containing silica fume. All of the concretes were initially proportioned to give a flowing concrete with a minimum slump of 6 in. WES was not made aware of the actual geometry of the placements with the sloping side walls until after the initial concretes had been proportioned.

34. The mixture containing both silica fume and fly ash (LA4) appears to offer no advantage over the mixture containing only the same amount of silica fume alone (LA3). Mixture LA3 showed higher compressive strengths at all ages than Mixture LA4.

PART IV: FIELD PLACEMENTS

Project Specifications

35. Draft specifications for the FY 83 concrete replacement project were prepared by Mr. Jack Rolston, SPL. This draft was jointly reviewed by Mr. Rolston, Dr. Tony C. Liu, Headquarters, US Army Corps of Engineers, and the author of this report. The modified draft was submitted by Mr. Rolston to the SPL Specification Section where it was further modified. Because of time constraints, there was no opportunity to review the final version of the specifications prior to the project being advertised.

36. The project specifications called for three concrete mixtures to be used in the placements. These mixtures were:

- a. Mixture I: This mixture was the control mixture containing only portland cement and fly ash. This mixture was developed by South Pacific Division Laboratory; therefore, CTD did not have an opportunity to conduct any abrasion-erosion testing using this mixture.
- b. Mixture II: This mixture was the silica-fume concrete. It is Mixture LA3 of this report.
- c. Mixture III: This mixture was the silica-fume and fly ash concrete. It is Mixture LA4 of this report.

37. Batch weights for each of the three concrete mixtures were included in the project specifications. For the mixtures proportioned at WES, the batch weights developed in the laboratory were reproduced in the specifications. The specified batch weights are shown in Table 23.

How to specify silica fume

38. The question of how to specify silica fume received a great deal of attention. The project specifications provide a weight of silica fume and an approximate dosage range of HRWRA to be used. There was also the possibility that the silica fume and HRWRA could be supplied as a proprietary product. The specifications, as written, tended to favor the use of separate silica fume and a commercially available HRWRA. The idea of allowing a provision for the use of a proprietary silica-fume and HRWRA product was apparently deleted during the final editing of the specifications.

39. The silica fume itself was treated as a mineral admixture, and appropriate requirements were established for the fume. These requirements were silicon dioxide content, fineness, moisture content, and loss on ignition. In

regard to silicon dioxide 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.

40. 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:

a. Moisture content: Maximum of 3.0 percent.

b. Loss on Ignition: Maximum of 6.0 percent.

c. SiO_2 content: Minimum of 85 percent.

d. Fineness: Minimum of 10,000 m^2/kg at a porosity of 0.50.

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 Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete," while the last item was to be calculated in accordance with ASTM C 204 (CRD-C 218), "Standard Test Method for Fineness of Portland Cement by Air Permeability Apparatus."

41. 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.

Trial Placements

42. Two trial placements were conducted in an area of the low-flow channel immediately upstream of the repair area. Trip reports describing detailed observations of each of these placements are presented in Appendices B and C. Several of the more significant points from these trip reports are below:

a. The concrete in the area of trial showed evidence of abrasion-erosion of larger aggregate particles and scour of the paste surrounding the aggregate particles. In general, the concrete damage was not particularly severe for the length of time the channel has been in service. There were several isolated areas of severe damage that I observed outside of the trial placement area.

b. The District staff had made trial mixtures of concrete containing silica fume during a prebid laboratory demonstration.

However, the ready-mixed concrete supplier selected by the contractor awarded the project apparently did not make any trial batches of the specified concrete mixtures. This failure to preview the specified concrete resulted in many of the problems seen during the first trial placement.

c. The development of the final mixture proportioning data and the trial placement should have been handled as two separate and distinct steps. Attempting to conduct the first trial placement without first "fine tuning" the concrete mixtures resulted in a trial placement that satisfied none of the participants.

d. Significant problems came to light during the second trial placement concerning grading and moisture content of the coarse aggregates. Once the problems were identified, the District staff took appropriate steps to monitor grading and moisture contents on a routine basis for the actual placements.

e. Given the geometry of the low-flow section, the District staff is faced with a very difficult problem in developing a satisfactory concrete mixture. On one hand, the concrete must be fluid enough to be discharged from a ready-mix truck (a minimum slump of 2 to 3 in. is probably necessary). On the other hand, the concrete must be stiff enough to stay on the sloped portions of the low-flow section and be thoroughly consolidated. Obviously, these two requirements are working against one another. During the second trial placement, the most fluid concrete (Mixture IIR) was very easy to discharge from the ready-mix trucks. However, this concrete would not hold the slope when vibrated.

f. Plastic shrinkage cracking resulting from the rapid loss of moisture from the concretes after placing was a problem during both trial placements. The concrete supplier was apparently unable to comply with the specification requirements concerning maximum concrete temperature. With the very low water contents and the essentially total lack of bleeding of the concretes containing silica fume, control of concrete temperature is one important aspect of controlling plastic shrinkage cracking.

43. One abrasion-erosion test specimen was made from each of the three concrete mixtures placed during the second trial placement. Detailed data from these specimens are presented in Table 24. In summary, the results were:

	Mixture II	Mixture IIR	Mixture III
Compressive strength, 28 day, psi	10,560	8,320	9,560
Abrasion-erosion loss at 72 hr	2.9%	4.0%	2.8%

The abrasion-erosion losses of Mixture II (Mixture LA3) and Mixture III (Mixture LA4) are in good agreement with the performance of these concrete mixtures when tested in the laboratory.

Actual Placements

44. Actual placements were initiated on 21 September 1983 using Mixture III (LA4). Placements were conducted as follows:

21 September	171 cu yd
22 September	252 cu yd
23 September	360 cu yd

These placements represented nearly all of the planned placements for this mixture. Plans were made to place the remaining small volume of Mixture III (LA4) on 24 September and to begin placing Mixture II (LA3). However, bad weather prevented the scheduled placement. After the project site was washed out three times, the District staff elected to abandon the remainder of the project. The portion of the low-flow channel from which the concrete had been removed was backfilled with stone and grouted.

45. The author of this report has no firsthand knowledge of the circumstances surrounding the actual placements. Description and comments concerning those placements will be reported by staff of Los Angeles District.

46. Six abrasion-erosion specimens were made during the field placements of specification Mixture III (LA4). Detailed test data for these specimens are in Table 25. Photographs were not made of these specimens--the visual appearance was similar to that of specimens of Mixture LA4. The data may be summarized as follows:

Specimens	28-day Compressive Strength, psi	Abrasion-Erosion Loss, percent, at 72 hr
28-37	9,740	3.2
38-47	8,940	4.6
58-67	10,790	3.8
68-77	10,770	3.2
88-97	10,210	3.9
98-107	10,740	2.6
Overall Average	10,200	3.6

47. Specimen 38-47 showed significant honeycombing and was apparently poorly consolidated in the mold. This poor consolidation probably contributed to the high degree of abrasion loss measured. The overall average loss

(3.6 percent) was slightly higher than the loss (3.0 percent) for Mixture LA4 measured in the laboratory. Part of this difference is probably attributable to the testing of the field specimens at 28 days while the Mixture LA4 specimens were tested at 90 days.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

48. The addition of silica fume and appropriate dosages of HRWRA produced concretes with excellent abrasion-erosion resistance, particularly when the poor quality of the locally available aggregate is considered. The District staff had requested that WES develop the most abrasion-erosion-resistant concrete possible. Mixtures LA2, LA3, and LA4 all seem to meet this requirement.

49. There appears to be no advantage to using more than 15 percent silica fume with the current source of aggregates. Similarly, there appears to be no advantage to using silica fume and the Class F fly ash.

50. The concretes containing silica fume were difficult to place at the slumps being used and do require special attention. However, this extra attention to the details of concrete manufacturing and placing is the price that must be paid for the increased abrasion-erosion resistance of these mixtures.

51. It is impossible to state with certainty the exact cause of the damage seen in the concrete in the low-flow channel. Given that the concrete is affected to an unknown degree by abrasion-erosion, scour of paste, and chemical attack, the best replacement material to use to counteract all of these sources of damage is a dense, well consolidated concrete with sound aggregate and a high compressive strength.

52. Concretes containing silica fume appear to offer the best resistance to abrasion-erosion. However, given the high dosages of HRWRA required with these concretes, it may not be possible to develop a silica fume concrete that can be readily mixed and placed at a 0- to 2-in. slump, which appears to be necessary to insure proper consolidation.

53. Regardless of what concrete is selected for use in future years, the District staff will be faced with the multifaceted problem of obtaining the correct degree of flowability to allow discharge from a ready-mix truck while maintaining the concrete in place on the slopes during consolidation.

54. Based upon the relationship that was seen between the compressive strength of the concrete and the abrasion-erosion resistance, the District staff should be able to select a desired level of performance and specify a concrete to provide that level of performance. Abrasion-erosion resistance can be specified indirectly by specifying compressive strength.

55. The failure of the contractor to prepare trial batches using the project materials was a serious error that led to many of the problems seen during the trial placements. Too much attention was diverted away from the placement procedures to the problems with the concrete mixtures.

56. The failure to provide time for a final review of the project specifications and the incorporation of laboratory mixture proportions directly into the specifications contributed to the problems that were experienced with the concrete.

Recommendations

57. Regardless of what type of concrete is placed during future repairs, there must be a continued effort to work on the basics of good practice for concrete manufacturing and placement, i.e., control of aggregate gradings, moisture contents, and temperature, and use of recognized techniques for hot weathering concreting.

58. If at all possible, a better source of aggregate should be identified for future work. Unless a significantly better aggregate is found, the 1-1/2-in. maximum size aggregate should be deleted from future use.

59. Consideration should be given to concrete manufacturing and transporting methods other than ready mix for the concrete in the sloped portions of the low-flow channel. Perhaps an on-site paving mixer capable of handling concretes with a zero or very low slump could be used.

60. Consideration should be given to alternative repair approaches. It does not appear necessary to remove all of the existing concrete--an overlay may be a better approach.

61. The District staff must decide exactly how much abrasion-erosion resistance is desired. If the decision is to use the most abrasion-erosion-resistant concrete possible (which, in all likelihood will include silica fume), then the difficulties of placing such a mixture must be anticipated and accepted. Alternatives that allow use of a silica-fume concrete with a more typical slump range (6 to 9 in.) should be investigated.

62. Given the difficulties seen in the placements to date, the District staff should consider the use of a performance specification. Use of such a specification would remove much of the responsibility for control of the types of problems that were seen from the District. Since there is such a clear

relationship between compressive strength and abrasion-erosion resistance, such a performance specification should be easier to prepare and enforce.

REFERENCES

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

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Southern California Chapter, American Public Works Association and Southern California District, Associated General Contractors of California. 1982. Standard Specifications for Public Works Construction, Building News, Inc., Los Angeles, Calif.

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

_________. 1953. "Test Data, Concrete Aggregates in the Continental United States" (with periodic supplements), Technical Memorandum No. 6-370, Vicksburg, Miss.

Table 1

Coarse Aggregate Data

A. 1-1/2-in. Nominal Maximum Size Aggregate

Sieve Size	Cumulative Percentages Passing: As Tested at WES	Los Angeles Green Book	ASTM C 33 Size No. 4
2 in.	100	100	100
1-1/2 in.	100	90-100	90-100
1 in.	19	5-40	20-55
3/4 in.	3	0-15	0-15
1/2 in.	1	--	--
3/8 in.	1	0-5	0-5
No. 4	1	--	--

Specific Gravity: 2.67
Absorption: 0.93%

B. 1-in. Nominal Maximum Size Aggregate

Sieve Size	Cumulative Percentages Passing: As Tested at WES	Los Angeles Green Book	ASTM C 33 Size No. 56
1-1/2 in.	100	100	100
1 in.	96	90-100	90-100
3/4 in.	58	55-85	40-85
1/2 in.	17	--	10-40
3/8 in.	6	8-20	0-15
No. 4	3	0-5	0-5
No. 8	3	--	--

Specific Gravity: 2.66
Absorption: 1.27%

C. 3/8-in. Nominal Maximum Size Aggregate

Sieve Size	Cumulative Percentages Passing: As Tested at WES	Los Angeles Green Book	ASTM C 33 Size No. 8
3/4 in.	100	100	100
1/2 in.	100	--	100
3/8 in.	96	85-100	85-100
No. 4	9	0-30	10-30
No. 8	4	0-10	0-10
No. 16	3	--	0-5

Specific Gravity: 2.64
Absorption: 1.17%

Table 2

Fine Aggregate Data

A. Grading

Sieve Size	Cumulative Percentages Passing: As Tested at WES	Los Angeles Green Book	ASTM C 33
No. 4	97	95-100	95-100
No. 8	78	75-90	80-100
No. 16	63	55-75	50-85
No. 30	43	30-50	25-60
No. 50	19	10-25	10-30
No. 100	5	2-10	2-10

B. Other

Specific Gravity: 2.65
Absorption: 1.07%
Material Finer than No. 200 Sieve (CRD-C 105): 1.57%
Fineness Modulus: 2.93

Table 3. Cement Test Data

TO:
Structures Laboratory
Research Group
ATTN: Terry Holland

REPORT OF TESTS OF PORTLAND CEMENT

LA-3- C-1

FROM: CORPS OF ENGINEERS, U.S. ARMY
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P O Box 631
Vicksburg, MS 39180

TEST REPORT NO. WES-84-83	BIN NO.	CWT REPRESENTED:		DATE: 23 March 83	
SPECIFICATION: ASTM C150, Type I & II, LA		DATE SAMPLED: 3 March 83			
COMPANY: California Cement	LOCATION Colton, CA		BRAND:		

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1						
SiO_2, %	21.8						
Al_2O_3, %	4.5						
Fe_2O_3, %	3.1						
MgO, %	2.7						
SO_3, %	2.4						
LOSS ON IGNITION, %	2.0						
ALKALIES-TOTAL AS Na_2O, %	0.50						
Na_2O, %	0.25						
K_2O, %	0.44						
INSOLUBLE RESIDUE, %	0.17						
CaO, %	62.4						
C_3S, %	46						
C_3A, %	7						
C_2S, %	28						
$C_3A + C_3S$, %	53						
C_4AF, %	9						
$C_4AF + 2 C_3A$, %	23						
HEAT OF HYDRATION, 7D, CAL/G							
HEAT OF HYDRATION, 28D, CAL/G							
SURFACE AREA, SQ CM/G (A.P.)	3690						
AIR CONTENT, %	8						
COMP. STRENGTH, 3 D, PSI	1750						
COMP. STRENGTH, 7 D, PSI	3380						
COMP. STRENGTH, D, PSI							
FALSE SET-PEN, FIN. %	71						
SAMPLE NO.	1						
AUTOCLAVE EXP., %	0.02						
INITIAL SET, HR/MIN	3:10						
FINAL SET, HR/MIN	5:20						
SAMPLE NO.							
AUTOCLAVE EXP., %							
INITIAL SET, HR/MIN							
FINAL SET, HR/MIN							

REMARKS: Job No. 441-S836.13SC41

CC: Henry Thornton

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

Table 4

Pozzolan Test Data

LABORATORY:		
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN AD-727	REPORT NO.: WES-94F-83 SHEET 1 OF 1 DATE: 23 March 83

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic International, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT ☐ COMPLY ☐ DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT:

CONTRACT NO.:

DISTRICT(S):

SAMPLED BY: Terry Holland — DATE SAMPLED:

CAR NO.: — BIN NO.:

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 16 March 83 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
85.5	2.4	0.4	*	*		0.07	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.3	20	-	1040	103	2.34	
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N

(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Riverside, Oro Grande, CA

LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day Test Results Job #441-S836.13SC41

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

Table 5

Silica Fume Test Data

LABORATORY: Structures Laboratory, Waterways Exp Station, ATTN: Cem & Pozz Unit, P. O. Box 631, Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN AD 536(5)	REPORT NO.: WES-43S-83 SHEET 1 OF 2 DATE: 23 February 1983 28 March 1983

CLASS F N | KIND OF POZZOLAN: Silica Fume

SOURCE: Reynolds Metals, Sheffield, Ala | BRAND:

TEST RESULTS OF THIS SAMPLE LOT ☐ COMPLY ☒ DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

Fineness (AP) m^2/kg: 2584, e=0.727

" " " ": 3806, e=0.700

" " " ": 4783, e=0.678

Extrapolated m^2/kg:12780, e=0.500, Correlation Coefficent: -1

Date Sampled: 10 Feb 83

FIELD SAMPLE NO.:	LAB SAMPLE NO.:
DATE RECEIVED: 11 Feb 83	LAB JOB NO.:
TESTED BY: Cem & Pozz Unit	CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
				* 109		-0.14	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1			1	-	2140	* 120	2.25	-
Heat of Hydration								
Portland Cement, RC 883(4)						:	W/C:0.27	W/C:0.40
					7 days:		56	75 cal/gm
					28 days:		62	83 "
RC883(4), 85g + AD536(5), 15g + Hi range WRA, 4g :								
					7 days:		50	53 "
					28 days:		48	61 "
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N

(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED United, Artesia, MS

LABORATORY LIME USED Chemstone

REMARKS: *Fails water requirement.

R. E. Reinhold

R. E. REINHOLD

Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

Table 6

Aggregate Supplier's Recommended Combined Grading

Sieve Size	1-1/2 in. (25.4%)	1 in. (31.75%)	3/8 in. (6.35%)	Fine Aggregate (36.5%)	Combined	Los Angeles Green Book "A"
2 in.	100	100	100	100	100	100
1-1/2 in.	100	100	100	100	100	95-100
1 in.	19	96	100	100	78	64-80
3/4 in.	3	58	100	100	62	55-71
3/8 in.	1	6	96	100	45	37-53
No. 4	1	3	9	97	37	32-42
No. 8		3	4	78	30	25-35
No. 16			3	63	23	18-28
No. 30				43	16	10-18
No. 50				19	7	3-9
No. 100				5	2	0-3
No. 200				2	1	0-2

Table 7

Aggregate Supplier's Recommended Combined Grading

(Coarse Aggregate Only)

Sieve Size	1-1/2 in. (40%)	1 in. (50%)	3/8 in. (10%)	Combined	CRD-C 3-58
1-1/2 in.	100	100	100	100	100
1 in.	19	96	100	65.6	71.6
3/4 in.	3	58	100	40.2	54.7
1/2 in.	1	17	100	18.9	34.6
3/8 in.	1	6	96	13.0	22.6
No. 4	1	3	9	2.8	--

Table 8

Combined Grading as Developed at WES

(Coarse Aggregate Only)

Sieve Size	1-1/2 in. (33%)	1 in. (40%)	3/8 in. (27%)	Combined	CRD-C 3-58
1-1/2 in.	100	100	100	100	100
1 in.	19	96	100	71.7	71.6
3/4 in.	3	58	100	51.2	54.7
1/2 in.	1	17	100	34.1	34.6
3/8 in.	1	6	96	28.7	22.6
No. 4	1	3	9	4.0	--

Table 9

Combined Grading as Developed at WES

Sieve Size	1-1/2 in. (19.14%)	1 in. (23.20%)	3/8 in. (15.66%)	Fine Aggregate (42.00%)	Combined	Los Angeles Green Book "A"
2 in.	100	100	100	100	100	100
1-1/2 in.	100	100	100	100	100	95-100
1 in.	19	96	100	100	84	64-80
3/4 in.	3	58	100	100	72	55-71
3/8 in.	1	6	96	100	59	37-53
No. 4	1	3	9	97	43	32-42
No. 8		3	4	78	34	25-35
No. 16			3	63	27	18-28
No. 30				43	18	10-18
No. 50				19	8	3-9
No. 100				5	2	0-3
No. 200				2	1	0-2

Table 10. Proportions, Mixture LA1

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

PROJECT NAME: Los Angeles Abrasion Study	SYMBOL:	SERIAL NO.:	DATE: March 1983
CONCRETE REQUIRED FOR:			MIXTURE NO.: LA1

MATERIALS

PORTLAND CEMENT, SS-C-192, TYPE: I/II (Low Alkali); BRAND AND MILL: California Portland	POZZOLON OR OTHER CEMENT: TYPE: None; SOURCE:	AIR-ENT. ADMIXTURE: TYPE: None; AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Natural	TYPE: Natural; SIZE: 1-1/2 - No. 4
SOURCE: Consolidated Rock Products Los Angeles	SOURCE: Consolidated Rock Products Los Angeles

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	LA-3 C-1			3.15	
*					
*					
FINE AGGREGATE	LA-3 S-1	No. 4 - 200		2.65	1.1
COARSE AGGREGATE (A)	LA-3 G-1	1-1/2 - 3/4 in.	33	2.67	0.9
COARSE AGGREGATE (B)	LA-3 G-1	1 - 3/8 in.	40	2.66	1.3
COARSE AGGREGATE (C)	LA-3 G-1	3/8 in. - No. 8	27	2.64	1.2
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	600.0	3.051						
*									
*									
FINE AGGREGATE		1391.6	8.411						
COARSE AGGREGATE (A)		638.9	3.833						
COARSE AGGREGATE (B)		771.6	4.646						
COARSE AGGREGATE (C)		516.9	3.136						
COARSE AGGREGATE (D)									
WATER		228.0	3.652						
AIR (Entrapped)			0.270						
TOTAL		4147.0	27.000						

W/C (WT): 0.38	S/A, % VOLUME: 42
SLUMP (IN.)[4]:	THEO. UNIT WT (LB/CU FT): 155.1
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD):
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.

Admixtures

WRA: Sika Plastiment, 4 fl oz/94 lb cement

HRWR: Grace D-19 (Dry), 1% of weight of cement = 6.0 lb

WES FORM NO. 553
REV MAR 1972

Table 11. Proportions, Mixture LA2

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

PROJECT NAME: Los Angeles Abrasion Study	SYMBOL: SERIAL NO.:	DATE: March 1983
CONCRETE REQUIRED FOR:		MIXTURE NO.: LA2

MATERIALS

PORTLAND CEMENT SS-C-192. TYPE: I/II (Low Alkali) BRAND AND MILL: California Portland	POZZOLON OR OTHER CEMENT: TYPE: Silica Fume SOURCE: Reynolds Metals Co. Sheffield, AL	AIR-ENT. ADMIXTURE: TYPE: None AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Natural SOURCE: Consolidated Rock Products Los Angeles	TYPE: Natural SIZE: 1-1/2 - No. 4 SOURCE: Consolidated Rock Products Los Angeles

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	LA-3 C-1			3.15	
Silica Fume	AD-536(5)			2.22	
*					
FINE AGGREGATE	LA-3 S-1	No. 4 - 200		2.65	1.1
COARSE AGGREGATE (A)	LA-3 G-1	1-1/2 - 3/4 in.	33	2.67	0.9
COARSE AGGREGATE (B)	LA-3 G-1	1 - 3/8 in.	40	2.66	1.3
COARSE AGGREGATE (C)	LA-3 G-1	3/8 in. - No. 8	27	2.64	1.2
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	600.0	3.051						
Silica Fume		180.0	1.299						
*									
FINE AGGREGATE		1346.7	8.140						
COARSE AGGREGATE (A)		618.4	3.710						
COARSE AGGREGATE (B)		746.7	4.497						
COARSE AGGREGATE (C)		500.2	3.035						
COARSE AGGREGATE (D)									
WATER		187.2	2.999						
AIR (Entrapped)			0.270						
TOTAL		4179.2	27.000						

W/(C + SF): 0.24	S/A, % VOLUME: 42
SLUMP (IN.)[4]:	THEO. UNIT WT (LB/CU FT): 156.3
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD):
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.

Admixtures

WRA: Sika Plastiment, 4 fl oz/94 lb cement plus silica fume = 33.2 fl oz
HRWR: Grace D-19 (Dry), 2 lb/100 lb cement plus silica fume = 15.6 lb

WES FORM NO. 553 REV MAR 1972

Table 12. Proportions, Mixture LA3

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

PROJECT NAME: Los Angeles Abrasion Study	SYMBOL:	SERIAL NO.:	DATE: April 1983
CONCRETE REQUIRED FOR:			MIXTURE NO.: LA3

MATERIALS

PORTLAND CEMENT, SS-C-192, TYPE: I/II (Low Alkali) BRAND AND MILL: California Portland	POZZOLON OR OTHER CEMENT: TYPE: Silica Fume SOURCE: Reynolds Metals Co. Sheffield, AL	AIR-ENT. ADMIXTURE: TYPE: None AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Natural	TYPE: Natural SIZE: 1-1/2 - No. 4
SOURCE: Consolidated Rock Products Los Angeles	SOURCE: Consolidated Rock Products Los Angeles

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	LA-3 C-1			3.15	
·Silica Fume	AD-536(5)			2.22	
·					
FINE AGGREGATE	LA-3 S-1	No. 4 - 200		2.65	1.1
COARSE AGGREGATE (A)	LA-3 G-1	1-1/2 - 3/4 in.	33	2.67	0.9
COARSE AGGREGATE (B)	LA-3 G-1	1 - 3/8 in.	40	2.66	1.3
COARSE AGGREGATE (C)	LA-3 G-1	3/8 in. - No. 8	27	2.64	1.2
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:			BEAMS SIZE:		
				NO.	AGE	PSI	NO.	AGE	PSI
PORTLAND CEMENT	1.00	600.0	3.051						
·Silica Fume		90.0	0.649						
·									
FINE AGGREGATE		1415.9	8.558						
COARSE AGGREGATE (A)		650.1	3.900						
COARSE AGGREGATE (B)		785.1	4.727						
COARSE AGGREGATE (C)		525.9	3.191						
COARSE AGGREGATE (D)									
WATER		165.6	2.653						
AIR (Entrapped)			0.270						
TOTAL		4232.6	27.000						

W/(C + SF): 0.24	S/A, % VOLUME: 42
SLUMP (IN.)[4]:	THEO. UNIT WT (LB/CU FT): 158.3
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD):
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.

Admixtures

WRA: Sika Plastiment, 4 fl oz/94 lb cement plus silica fume = 29.4 fl oz

HRWR: Grace D-19 (Dry), 2 lb/100 lb cement plus silica fume = 13.8 lb

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Table 13. Proportions, Mixture LA4

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

PROJECT NAME: Los Angeles Abrasion Study	SYMBOL:	SERIAL NO.:	DATE: April 1983
CONCRETE REQUIRED FOR:			MIXTURE NO.: LA4

MATERIALS

PORTLAND CEMENT, SS-C-192,	POZZOLON OR OTHER CEMENT: *	AIR-ENT. ADMIXTURE:
TYPE: I/II (Low Alkali)	TYPE: Silica Fume	TYPE: None
BRAND AND MILL: California Portland	SOURCE: Reynolds Metals Co. Sheffield, AL	AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Natural	TYPE: Natural SIZE: 1-1/2 - No. 4
SOURCE: Consolidated Rock Products Los Angeles	SOURCE: Consolidated Rock Products Los Angeles

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	LA-3 C-1			3.15	
Silica Fume	AD-536(5)			2.22	
Fly Ash	AD-727			2.34	
FINE AGGREGATE	LA-3 S-1	No. 4 - 200		2.65	1.1
COARSE AGGREGATE (A)	LA-3 G-1	1-1/2 - 3/4 in.	33	2.67	0.9
COARSE AGGREGATE (B)	LA-3 G-1	1 - 3/8 in.	40	2.66	1.3
COARSE AGGREGATE (C)	LA-3 G-1	3/8 in. - No. 8	27	2.64	1.2
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	600.0	3.051						
Silica Fume		90.0	0.649						
Fly Ash		90.0	0.616						
FINE AGGREGATE		1349.0	8.154						
COARSE AGGREGATE (A)		619.4	3.716						
COARSE AGGREGATE (B)		748.0	4.504						
COARSE AGGREGATE (C)		501.1	3.040						
COARSE AGGREGATE (D)									
WATER		187.2	2.999						
AIR (Entrapped)			0.270						
TOTAL		4184.7	27.000						

W/(C + SF + FA): 0.24	S/A, % VOLUME: 42
SLUMP (IN.)[4]:	THEO. UNIT WT (LB/CU FT): 156.5
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD):
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.

* Fly Ash - Pozzolanic International, Rock Springs, NY

Admixtures

WRA: Sika Plastiment, 4 fl oz/94 lb cement plus silica fume plus fly ash = 33.2 fl oz

HRWR: Grace D-19 (Dry), 2 lb/100 lb cement plus silica fume plus fly ash = 15.6 lb

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Table 14. Proportions, Mixture LA5

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

PROJECT NAME: Los Angeles Abrasion Sutdy	SYMBOL: SERIAL NO.:	DATE: July 1983
CONCRETE REQUIRED FOR:		MIXTURE NO.: LA5

MATERIALS

PORTLAND CEMENT, SS-C-192, TYPE: I/II (Low Alkali) BRAND AND MILL: California Portland	POZZOLON OR OTHER CEMENT: TYPE: None SOURCE:	AIR-ENT. ADMIXTURE: TYPE: None AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Natural SOURCE: Consolidated Rock Products Los Angeles	TYPE: Natural SIZE: 1-1/2 - No. 4 SOURCE: Consolidated Rock Products Los Angeles

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP.*
PORTLAND CEMENT	LA-3 C-1			3.15	
*					
*					
FINE AGGREGATE	LA-3 S-1	No. 4 - 200		2.65	1.1
COARSE AGGREGATE (A)	LA-3 G-1	1-1/2 - 3/4 in.	33	2.67	0.9
COARSE AGGREGATE (B)	LA-3 G-1	1 - 3/8 in.	40	2.66	1.3
COARSE AGGREGATE (C)	LA-3 G-1	3/8 in. - No. 8	27	2.64	1.2
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	690.0	3.509
*			
*			
FINE AGGREGATE		1321.7	7.989
COARSE AGGREGATE (A)		606.9	3.641
COARSE AGGREGATE (B)		732.8	4.413
COARSE AGGREGATE (C)		490.9	2.979
COARSE AGGREGATE (D)			
WATER		262.2	4.200
AIR (Entrapped)			0.270
TOTAL		4104.5	27.000

SPECIMEN DATA

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

W/C (WT): 0.38	S/A, % VOLUME: 42
SLUMP (IN.)[4]:	THEO. UNIT WT (LB/CU FT): 153.6
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD):
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.

Admixtures

WRA: Sika Plastiment, 4 fl oz/94 lb cement = 29.4 fl oz
HRWR: Grace D-19 (Dry), 1 lb/100 lb cement = 6.9 lb

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Table 15. Proportions, Mixture LA6

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

PROJECT NAME: Los Angeles Abrasion Study	SYMBOL: SERIAL NO.:	DATE: July 1983
CONCRETE REQUIRED FOR:		MIXTURE NO.: LA6

MATERIALS

PORTLAND CEMENT, SS-C-192, TYPE: I/II (Low Alkali) BRAND AND MILL: California Portland	POZZOLON OR OTHER CEMENT: TYPE: None SOURCE:	AIR-ENT. ADMIXTURE: TYPE: None AMOUNT[1]:

FINE AGGREGATE	COARSE AGGREGATE
TYPE: Natural	TYPE: Natural SIZE: 1-1/2 - No. 4
SOURCE: Consolidated Rock Products Los Angeles	SOURCE: Consolidated Rock Products Los Angeles

MATERIALS	SAMPLE SERIAL NO.	SIZE RANGE	COARSE AGGR (%)	BULK SP GR (SSD)	ABSORP %
PORTLAND CEMENT	LA-3 C-1			3.15	
*					
*					
FINE AGGREGATE	LA-3 S-1	No. 4 - 200		2.65	1.1
COARSE AGGREGATE (A)	LA-3 G-1	1-1/2 - 3/4 in.	33	2.67	0.9
COARSE AGGREGATE (B)	LA-3 G-1	1 - 3/8 in.	40	2.66	1.3
COARSE AGGREGATE (C)	LA-3 G-1	3/8 in. - No. 8	27	2.64	1.2
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	780.0	3.966						
*									
*									
FINE AGGREGATE		1251.8	7.567						
COARSE AGGREGATE (A)		574.8	3.448						
COARSE AGGREGATE (B)		694.1	4.180						
COARSE AGGREGATE (C)		465.0	2.821						
COARSE AGGREGATE (D)									
WATER		296.4	4.748						
AIR (Entrapped)			0.270						
TOTAL		4062.1	27.000						

W/C (WT): 0.38	S/A, % VOLUME: 42
SLUMP (IN.)[4]:	THEO. UNIT WT (LB/CU FT): 152.0
BLEEDING (%)[2]:	ACTUAL UNIT WT (LB/CU FT):
AIR CONTENT (%)[3]:	THEO. CEMENT FACT (LB/CU YD):
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.

Admixtures

WRA: Sika Plastiment, 4 fl oz/94 lb cement = 33.2 fl oz

HRWR: Grace D-19 (Dry), 1 lb/100 lb cement = 7.8 lb

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Table 16

Characteristics of Fresh and Hardened Concrete

Mixture	Cement, lb/cu yd	Fly Ash, lb/cu yd	Silica Fume, lb/cu yd	HRWRA Dose, %*	Slump, in.			Compressive Strength, psi			Abrasion-Erosion Loss, %, at 72 hr
					T = 0 min	T = 30 min	T = 60 min	7 day	28 day	90 day	
LA1	600	0	0	1.0	9	7	3-3/4	6,110	7,470	8,060	6.4
LA2	600	0	180	1.0	4	NA	3-1/2	8,260	11,500	12,740	2.8
LA3	600	0	90	1.5	7	NA	4-1/2	7,800	10,950	11,580	2.7
LA4	600	90	90	2.0	10	NA	NA	6,810	9,470	10,630	3.0
LA5	690	0	0	0.5	7-3/4	3-1/2	2	5,780	6,890	7,240	6.9
LA6	780	0	0	0.0	7-1/2	5-1/4	3	6,020	6,830	7,940	7.0

* Percentage by weight of cement plus fly ash plus silica fume for dry HRWRA.

Table 17

Abrasion-Erosion Test Data

Concrete Mixture LA1 (Control)

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	37.70	0.0	38.25	0.0	38.50	0.0	0.0
12	37.20	1.3	37.80	1.2	38.15	0.9	1.1
24	36.85	2.3	37.45	2.1	37.80	1.8	2.1
36	36.35	3.6	37.05	3.1	37.40	2.9	3.2
48	35.80	5.0	36.50	4.6	37.05	3.8	4.5
60	35.20	6.6	36.05	5.8	36.75	4.5	5.6
72	35.00	7.2	35.70	6.7	36.45	5.3	6.4

Notes: Numerous soft aggregate particles visible on surface of all specimens.

Table 18

Abrasion-Erosion Test Data

Concrete Mixture LA2 (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	38.25	0.0	38.55	0.0	38.30	0.0	0.0
12	38.00	0.7	38.30	0.6	38.10	0.5	0.6
24	37.80	1.2	38.20	0.9	37.95	0.9	1.0
36	37.55	1.8	37.90	1.7	37.75	1.4	1.6
48	*	--	37.65	2.3	37.55	2.0	2.2
60	*	--	37.55	2.6	37.40	2.3	2.5
72	*	--	37.40	3.0	37.30	2.6	2.8

Notes: *Specimen A broken during handling; not tested for times indicated.

Table 19

Abrasion-Erosion Test Data

Concrete Mixture LA3 (15 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	39.45	0.0	38.60	0.0	37.65	0.0	0.0
12	39.30	0.4	38.50	0.3	37.50	0.4	0.4
24	39.15	0.8	38.40	0.5	37.40	0.7	0.7
36	39.10	0.9	38.30	0.8	37.30	0.9	0.9
48	38.80	1.6	38.15	1.2	37.20	1.2	1.3
60	38.55	2.3	37.85	1.9	36.90	2.0	2.1
72	38.35	2.8	37.60	2.6	36.65	2.7	2.7

Notes:

Table 20

Abrasion-Erosion Test Data

Concrete Mixture LA4 (15 Percent Silica Fume and 15 Percent Fly Ash)

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	37.20	0.0	39.10	0.0	38.90	0.0	0.0
12	37.00	0.5	38.90	0.5	38.80	0.3	0.4
24	36.85	0.9	38.80	0.8	38.60	0.8	0.8
36	36.55	1.7	38.55	1.4	38.45	1.2	1.4
48	36.30	2.4	38.35	1.9	38.30	1.5	1.9
60	36.10	3.0	38.15	2.4	38.15	1.9	2.4
72	35.90	3.5	37.95	2.9	37.90	2.6	3.0

Notes:

Table 21

Abrasion-Erosion Test Data

Concrete Mixture LA5 (15 Percent Additional Cement)

Elapsed Test Time, hr	Specimen A Wt, lb	A Percent Loss	Specimen B Wt, lb	B Percent Loss	Specimen C Wt, lb	C Percent Loss	Average Percent Loss
0	38.60	0.0	38.40	0.0	38.25	0.0	0.0
12	38.10	1.3	37.80	1.6	37.70	1.4	1.4
24	37.55	2.7	37.30	2.9	37.20	2.7	2.8
36	37.00	4.1	36.80	4.2	36.85	3.7	4.0
48	36.50	5.4	36.40	5.2	36.35	5.0	5.2
60	36.15	6.3	36.20	5.7	36.10	5.6	5.9
72	35.80	7.3	35.75	6.9	35.80	6.4	6.9

Notes:

Table 22

Abrasion-Erosion Test Data

Concrete Mixture LA6 (30 Percent Additional Cement)

Elapsed Test Time hr	Specimen A Wt, lb	A Percent Loss	Specimen B Wt, lb	B Percent Loss	Specimen C Wt, lb	C Percent Loss	Average Percent Loss
0	37.35	0.0	37.15	0.0	36.40	0.0	0.0
12	36.80	1.5	36.50	1.7	35.85	1.5	1.6
24	36.35	2.7	36.10	2.8	35.50	2.5	2.7
36	35.95	3.7	35.60	4.2	35.10	3.6	3.8
48	35.55	4.8	35.20	5.2	34.80	4.4	4.8
60	35.10	6.0	34.70	6.6	34.50	5.2	5.9
72	34.75	7.0	34.20	7.9	34.20	6.0	7.0

Notes:

Table 23

Concrete Mixture Proportions as Specified

	Mixture No. I, lb/cu yd	Mixture No. II, lb/cu yd	Mixture No. III, lb/cu yd
Cement	651	600	600
Pozzolan	117	0	90
Silica Fume	0	90	90
1-1/2-in. Aggregate	390	650	619
1-in. Aggregate	1057	785	748
3/8-in. Aggregate	459	526	501
Fine Aggregate	1115	1416	1349
Water-Reducing Agent	10-60*	10-60*	10-60*
High-Range Water-Reducing Admixture	0	10-60	10-60
Water	218	116	187

* Quantities for the water-reducing admixture were specified in fluid ounces. All other quantities shown are pounds.

Table 24

Abrasion-Erosion Test Data

Concrete Mixture: LA Test Placement No. 2

Elapsed Test Time	Specimen						Average Percent Loss
	A		B		C		
hr	Wt, lb	Percent Loss	Wt, lb	Percent Loss	Wt, lb	Percent Loss	
0	39.90	0.0	39.50	0.0	39.00	0.0	0.0
12	39.75	0.4	39.40	0.3	38.70	0.8	NA
24	39.60	0.8	39.25	0.6	38.50	1.3	NA
36	39.50	1.0	39.15	0.9	38.25	1.9	NA
48	39.15	1.9	38.75	1.9	37.90	2.8	NA
60	38.90	2.5	38.65	2.2	37.65	3.5	NA
72	38.75	2.9	38.40	2.8	37.45	4.0	NA

Notes: A = Mixture II; B = Mixture III; C = Mixture IIR.

Table 25

Abrasion-Erosion Test Data,

Specimens from Field Placements of

Specification Mixture III (Mixture LA4)

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
0	39.10	0.0	39.35	0.0	39.35	0.0
12	38.90	0.5	39.10	0.6	38.90	1.1
24	38.75	0.9	38.65	1.8	38.75	1.5
36	38.55	1.4	38.45	2.3	38.40	2.4
48	38.35	1.9	35.15	3.0	38.10	3.2
60	38.00	2.8	37.85	3.8	37.95	3.6
72	37.85	3.2	37.55	4.6	37.85	3.8

Notes: LA 28-37 is Specimen A; LA 38-47 is Specimen B; LA 58-67 is Specimen C.

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
0	39.20	0.0	40.75	0.0	39.05	0.0
12	38.85	0.9	40.45	0.7	38.90	0.4
24	38.80	1.0	40.05	1.7	38.60	1.2
36	38.50	1.8	39.90	2.1	38.55	1.3
48	38.20	2.6	39.65	2.7	38.50	1.4
60	38.05	2.9	39.50	3.1	38.35	1.8
72	37.95	3.2	39.15	3.9	38.05	2.6

Notes: LA 68-77 is Specimen A; LA 88-97 is Specimen B; LA 98-107 is Specimen C.

Figure 1. Abrasion-erosion specimen at conclusion of testing, Mixture LA1

Figure 2. Sawn abrasion-erosion specimen at conclusion of testing, Mixture LA1 (full section view). This specimen is representative of Mixtures LA1, LA5, and LA6

Figure 3. Sawn abrasion-erosion specimen at conclusion of testing, Mixture LA1 (oblique view). This specimen is representative of Mixtures LA1, LA5, and LA6

Figure 4. Abrasion-erosion specimen at conclusion of testing, Mixture LA2

Figure 5. Abrasion-erosion specimen at conclusion of testing, Mixture LA3

Figure 6. Sawn abrasion-erosion specimen at conclusion of testing, Mixture LA3 (full section view). This specimen is representative of Mixtures LA2, LA3, and LA4

Figure 7. Sawn abrasion-erosion specimen at conclusion of testing, Mixture LA3 (oblique view). This specimen is representative of Mixtures LA2, LA3, and LA4

Figure 8. Abrasion-erosion specimen at conclusion of testing, Mixture LA4

Figure 9. Abrasion-erosion specimen at conclusion of testing, Mixture LA5

Figure 10. Abrasion-erosion specimen at conclusion of testing, Mixture LA6

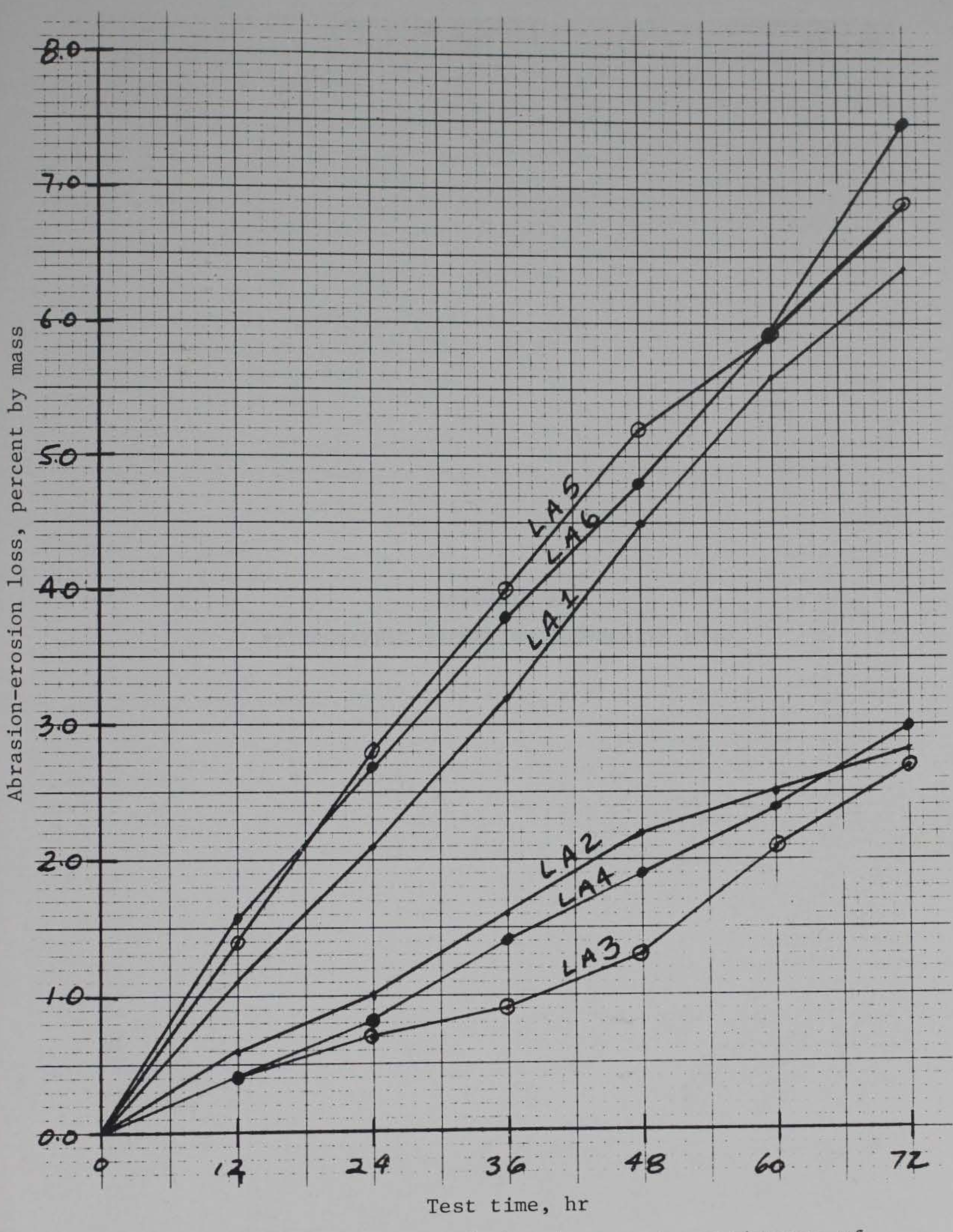

Figure 11. Comparison of abrasion-erosion resistance of concretes tested during this test program.

APPENDIX A

PETROGRAPHIC REPORT ON AGGREGATES USED

WESSC 20 June 1983

MEMORANDUM FOR T. C. HOLLAND, EVALUATION AND MONITORING GROUP (E&MG), CONCRETE TECHNOLOGY DIVISION (CTD)

FROM: J. C. AHLVIN, MATERIALS AND CONCRETE ANALYSIS GROUP, CTD

SUBJECT: Limited Petrographic Examination of Coarse and Fine Aggregate from Consolidated Rock Products Co., San Gabriel, California

1. Coarse aggregate in three size ranges and a sand sample from the same source were received for testing in early 1983. The samples were assigned the following serial numbers.

a. <u>LA-3 G-1</u>. This was coarse aggregate consisting of material in No. 8 to 3/8-in., 3/8- to 3/4-in., and No. 8 to 1-1/2-in. size ranges.

b. <u>LA-3 S-1</u>. Fine aggregate from the same source.

2. Each sample was inspected visually using a stereomicroscope. Some individual particles were tested with dilute hydrochloric acid; other selected particles were ground to pass a 45-µm (No. 325) sieve and examined by X-ray diffraction (XRD).

3. Particles from the largest size range were subjected to simple testing to determine their hardness and probable overall durability.

4. Selected particles were crushed and examined as immersion mounts using an index oil of 1.544.

5. The visual examination of all three size ranges of the coarse aggregate and of the sand showed them to be similar. Thus, the majority of the testing and examination was performed on the plus 1-1/2-in. size fraction.

6. The aggregate consisted primarily of igneous rock particles with some metamorphic rock particles and partially-metamorphosed (rock) particles. Individual particles were blocky, pyramidal, or tabular in shape with subangular to well rounded edges. Colors ranged from greenish black (5 GY 2/1)(1) to pinkish gray (5 YR 8/1)(1), and medium gray (N5)(1) to very light gray (N8).(1) Grain size ranged from very fine (<0.1 mm) to medium-grained (1 to 5 mm).(2)

---

(1) The Rock Color Chart Committee, E. N. Goddard, Chairman, "Rock Color Chart," 1975, The Geological Society of America, Boulder, Colorado.

(2) "Geologic Mapping Procedures - Open Excavations," Engineering Technical Letter ETL 1110-2-203, Department of the Army, Office, Chief of Engineers, 21 March 1975.

7. The majority of rock particles ranged in hardness from easily scratched with a steel needle to could not be scratched using a steel needle. This represented hardness ranging from moderately hard to very hard according to Geologic Mapping Procedures.(2) Some of the particles tended to disaggregate during handling and were easily broken when struck lightly with a hammer. These friable particles amounted to about 16 percent of the 1-1/2-in. fraction and tended to break along mica layers. They are considered to be highly weathered.(2) All of the rock particles examined were weathered.

8. No reactive aggregate particles were recognized by this limited examination. In addition, examination of two particles was made by X-ray diffraction (XRD) to determine the possible presence of reactive materials. None were found.(3) Further, no glassy material was seen when immersion mounts were examined.

9. The overall composition of the samples according to rock type was 45 percent igneous rocks consisting of porphyritic granite to gabbro particles and felsite.(4) Thirty-two percent was material transitional from igneous to metamorphic; and 23 percent consisted of metamorphic rock; these were gneiss and schist particles.(4)

10. The igneous rock particles appeared to be hard and resistant to abrasion. The finer-grained material should be more resistant than the coarser-grained material. Most of the igneous particles are coarse grained.

11. The gneiss and schist particles, because of grain orientation, contain inherent planes of weakness. These particles upon impact would tend to separate along these weaker zones. In instances where the particles are significantly weathered, friable particles would afford negligible abrasion resistance.

12. The rock in these samples is judged to be of a poorer physical quality for use in an abrasive environment than the normal chert gravel found in Mississippi.

Joyce C. Ahlvin

JOYCE C. AHLVIN
Materials and Concrete Analysis Group
Structures Laboratory

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(3) "Standard Practice for Concrete, Appendix B," Engineering Manual EM 1110-2-2000, Department of the Army, Office, Chief of Engineers, 30 September 1982.

(4) Shand, S. J., "Eruptive Rocks, Third Ed., John Wiley and Sons, Inc., New York, New York, 1947.

APPENDIX B

TRIP REPORT--FIRST TRIAL PLACEMENT

WESSC 26 September 1983

MEMORANDUM FOR RECORD

SUBJECT: Corrections to Trip Report

1. Reference: WESSC Memorandum for Record, subject: Trip Report - Observation of Trial Placements of Silica-Fume Concrete, Los Angeles District, 10-12 August 1983, dated 15 August 1983.

2. In light of information that I did not have when the referenced trip report was prepared, the following changes should be made:

a. Paragraph 3. This paragraph, as written, is not entirely correct. The amendment to the specification that is mentioned (Amendment No. 1, paragraph 8.1.1,(Incl 1)) did establish the correct weight of water to be used for the various concrete mixtures. The amendment also established a dosage rate of 10 to 60 fl oz/yd^3 for the water-reducing admixture (WRA). A dosage rate of 10 to 60 lb/yd^3 for the high-range water-reducing admixture (HRWRA) was also established. The specification, as amended, is well above the dosage rate of the WRA used in the laboratory and is slightly above the dosage rate of the WRA selected for use on the project. The specification, as amended, does cover the correct dosage rate for the HRWRA.

b. Paragraph 10e. Based upon the comments above concerning paragraph 3, this paragraph should be deleted in its entirety.

3. Copies of this MFR will be distributed to all recipients of the original Memorandum For Record.

TERENCE C. HOLLAND
Research Civil Engineer
Structures Laboratory

1 Incl
as

CF w/ incl:
Jack Rolston, SPL
Tony Liu, OCE
Tom Hugenberg, ORD

Reference: DACW09-83-B-0014-0001

Bid Opening Date: 12 May 1983

U. S. ARMY ENGINEER DISTRICT, LOS ANGELES
P.O. Box 2711
Los Angeles, California 90053

29 April 1983

AMENDMENT NO. 1

I. Specifications, Reference No. DACW09-83-B-0014, covering "Los Angeles River Improvement, Rehabilitation of Low Flow Channel and Curbs, Los Angeles County Drainage Area, Los Angeles County, California," are modified as follows:

1. INVITATION FOR BIDS.

1.1 Page I-3, Paragraph 14, Line 6. Delete "688-5485" and insert: 688-6263.

1.2 Page I-6, Paragraph 22, Line 3. After "...3 May", delete "193" and insert: 1983.

2. SPECIAL PROVISIONS.

2.1 Page SP-1.

2.1.1 Delete paragraphs 1 and 1.1 and insert:

1. COMMENCEMENT, PROSECUTION, AND COMPLETION OF WORK (1965 JAN).

1.1 General. The Contractor will be required to commence work under this contract within one calendar day after the date of receipt by him of notice to proceed, to presecute said work diligently, and to complete the entire work redy for use not later than 15 October 1983. The time stated for completion shall include final clean-up of the premises.

1.2 The foregoing completion date is based on the assumption that the successful bidder will receive the notice to proceed by 15 June 1983. The Government will extend the completion date by the number of calendar days after the above date that the Contractor receives the notice to proceed, except to the extent that the delay in issuance of the notice to proceed results from the failure of Contractor to execute the contract and give the required performance and payment bonds within the time specified in the bid.

1.3 If the work required under this contract is not completed prior to 1 November 1983, and failure to complete the work by this time is due to the Contractor's failure to meet the completion requirements above, the Contractor shall promptly restore the flood control channel to full flood capacity by sealing the channel. The Contractor will be required to remove temporary work and maintain the restored channel until 1 June 1984 without additional cost to the Government, and to complete remaining contract work after 1 June 1984.

2.1.2 Paragraph 3.1.

2.1.2.1 Delete the title for Contract Drawing No. 320/87 and insert: Project location.

2.1.2.2 In the title for Contract Drawing No. 320/88, after"....Conditions", delete "Plan and Excavation Limits".

2.1.2.3 In the Title for Contract Drawing No. 320/92, after "Type "A" and", delete "Type".

3. SECTION 1A, GENERAL REQUIREMENTS.

3.1 Page 1A-4, After paragraph 8.4.5, insert:
8.5.6 The Contractor shall not obstruct channel flows during the period 1 November through 31 May.

Am. 1

Incl 1

4. SECTION 1B, MEASUREMENT AND PAYMENT.

4.1 Page 1B-1.

4.1.1 Index. Delete "7. Silica Fume" and insert: 7. Payment for Silica Fume.

4.1.2 Paragraph 2, Line 3. After: removal of concrete," delete: asphalt curb.

5. SECTION 2A, DIVERSION AND CONTROL OF WATER.

5.1 Delete paragraph 1.4.

6. SECTION 2B, CLEARING SITE AND REMOVING OBSTRUCTIONS.

6.1 Page 2B-1. Delete paragraph 1.1.4.

7. SECTION 2G, SCOUR GAGES.

7.1 Paragraph 1. After "The scour gages", insert: (scour cones).

7.2 Paragraph 2.1, line 2. After "Mix Design", insert: No. 1.

8. SECTION 3A, CONCRETE.

8.1 Page 3A-1.

8.1.1 Paragraph 1, Table 3A-1. Delete the last two lines of the table and the footnote and insert:

Water Reducing Agent	10-60	10-60*	10-60*
High Range Water Reducing Admixture	0	10-60	10-60
Water	218	166	187

*Fluid ounces

8.1.2 Paragraph 1.1.

8.1.2.1 Line 13. Delete "Testing" and insert: Sampling and testing of concrete to be placed in the test sections

8.1.2.2 Line 15. Delete "INSTRUCTIONS TO BIDDERS" and insert: INVITATION FOR BIDS.

8.2 Page 3A-5, Paragraph 3.1.4.

8.2.1 Line 19. After "...these specifications", insert: and

8.2.2 Line 22. After "INVITATION FOR BIDS", insert: Paragraph 14.

8.3 Page 3A-6, Paragraph 5.1. Delete this paragraph and insert:

5.1 Water Reducing Admixtures.

5.1.1 Water Reducing Agents shall conform to ASTM C 494 Types A and D.

5.1.2 High Range Water Reducing Admixtures shall conform to ASTM C 494 Type F.

5.1.3 The total sum of all admixtures shall conform to ASTM C 494.

8.4 Page 3A-7, Paragraph 5.7. Delete this paragraph and insert:

5.7 Reinforcement. Yield strength of deformed bars shall be 60 ksi and shall conform to ASTM A 615.

8.5 Page 3A-8, Paragraph 6.2.4, line 1. After "...be capable", delete "for" and insert: of.

8.6 Page 3A-10, Paragraph 9. Delete the first sentence and insert: Continuity of reinforcement or other fixed metal items shall be as shown on the drawings.

9. SECTION 5A, MISCELLANEOUS METALWORK AND MATERIALS.

9.1 Page 5A-1. After Paragraph 1.2, insert:

1.3 American National Standard (ANSI)

ANSI B18.2.1	Square and Hex Bolts and Screws

II. This amendment shall be attached to and shall become a part of the specifications.

PAUL W. TAYLOR
Colonel, CE
Commanding

NOTICE: Bidders are required to acknowledge receipt of this amendment on the Bid Form, in the space provided, or by separate letter or telegram prior to opening of bids. Failure to acknowledge all amendments may cause rejection of the bid.

Necessity
Verified

WESSC 15 August 1983

MEMORANDUM FOR RECORD

SUBJECT: Trip Report - Observation of Trial Placements of Silica Fume Concrete, Los Angeles District, 10-12 August 1983

1. On 10 August 1983, I met with representatives of the Los Angeles District (SPL) to discuss the planned test placement. On 11 August, I viewed the placement site and met with representatives of the prime contractor and the concrete supplier. On 12 August, Don Walley and I observed and participated in the trial placement. Significant details of my (and Don's) observations are presented in this memo.

2. Background.

a. SPL is responsible for operation and maintenance of approximately 12 mi of the Los Angeles River structure. The structure has experienced abrasion damage, particularly in the portion of the invert called the low-flow section. During FY 83 a test project will replace approximately one-half mile of the concrete in the low-flow section. Concurrently, a design memorandum is being prepared covering repairs to the remaining 11.5 miles.

b. In February 1983, Jack Rolston (SPL) initiated discussions with representatives of the Concrete Technology Division (CTD), Waterways Experiment Station (WES), concerning abrasion-resistant concrete. These discussions led to a small research program ($14K) aimed at developing and testing several concrete mixtures using Los Angeles aggregates, cements, and fly ash. Because of related ongoing work for Pittsburgh District, CTD recommended to SPL that concretes containing silica fume be included in the test program. SPL agreed to this recommendation.

c. The test program developed included a conventional concrete (to be used as a control), two concretes containing silica fume, and one concrete containing silica fume and fly ash. (This last mixture was included in the test program at the specific request of SPL.) Two additional concrete mixtures containing higher cement contents were also included in the test program for comparison purposes - these mixtures were not being considered for field placements.

d. The mixtures selected for field placement (numbered as in the project specifications) were:

(1) Mixture 1 (control). The actual control mixture was developed by South Pacific Division (SPD) Lab rather than CTD. The CTD control mixture is included in the following discussion since no abrasion test data are available for the SPD Lab mixture.

(2) Mixture 2 (15 percent silica fume addition). This mixture was developed by CTD.

(3) Mixture 3 (15 percent silica fume and 15 percent fly ash addition). This mixture was developed by CTD.

e. Mixture proportions and compressive strength data for these concretes are presented in Table 1. The abrasion-erosion test data are also in Table 1 and are plotted in Figure 1. Based on examination of early compressive strength cylinder breaks and initial abrasion-erosion data from the control mixture, it became evident to me that the Los Angeles aggregate was not well suited for abrasion resistance because of the large percentage of weak, friable particles. This conclusion was also supported by the petrographic examination. My concerns over the aggregate were expressed to the District in a letter (14 April 1983) that strongly recommended that the use of alternate aggregate sources be explored.

f. The use of a very high strength concrete (achieved by addition of silica fume and a high-range water-reducing admixture (HRWR) gave satisfactory abrasion resistance as is shown in Figure 1. The use of both silica fume and fly ash showed no advantage over the silica fume alone.

g. Data on mixture performance, compressive strengths, and abrasion resistance were supplied to SPL (Jack Rolston) by telephone and letter as they became available. A letter that included the mixture proportions shown in Table 1 and the results of initial abrasion testing was furnished to SPL on 1 April 1983.

h. During all of my conversations with Jack, I stressed the amount of control and supervision that would be required to use the silica fume concrete successfully in a field placement.

3. Project specifications. The project specifications, as issued, included mixture proportions for all materials (as developed by SPD Lab and CTD) except water and chemical admixtures. A footnote stated that water and chemical admixture proportions would be established by the Contracting Officer. A subsequent amendment included the correct water weights and gave admixture dosage ranges of 10 to 60 fl oz per cu yd. The range of 10 to 60 fl oz does not correspond to the admixture dosage actually required. See 26 SEP Correct THH

4. Chemical admixture requirements. Mixture development work at WES was done using a water-reducing retarding admixture (Sika Plastiment) and a HRWR (Grace D-19). The D-19 used in the laboratory was a dry material. Dosage rates in the laboratory for D-19 were 1 to 2 percent by weight of cement plus silica fume or cement plus silica fume plus fly ash. Grace D-19 is typically used in the ready mix industry as a liquid with a solids content of 42 percent (by weight) and a unit weight of 9.5 lb per gal. Table 2 shows a conversion from the dry material to the liquid material. The amount of liquid admixture required is substantially higher than the range given in the project specifications. Note that the water in the liquid admixture (58 percent by weight) should be subtracted from the mixing water added to the concrete.

5. Observations. Following are my and Don's observations during our time in Los Angeles:

a. During my initial meeting with SPL personnel (Jack Rolston, Dale Haslem, and Rich Gutschow), I was given the impression that the District was interested in placing a very high strength concrete as had been designed.

b. On Thursday morning, I visited the placement site. The concrete in the project area had been broken using an impact device. Because there was some reinforcing steel in a part of the work area that the District was unaware of, some damage had been done to the underside of the concrete not being replaced. The reinforcing steel had apparently carried the impact loading into the concrete causing the damage. The damaged concrete will have to be removed and fill concrete placed under the slab.

c. The underside of the slab showed evidence of the accumulation of unknown chemicals, but there was no visual evidence of concrete deterioration. I recommended to Jack Rolston that a petrographic examination of concrete in contact with these chemicals be included in the next phase of the project.

d. On Thursday, we also met with Dean White of the concrete supplier. During that meeting, I was impressed that Dean had been extremely interested in the use of silica fume concrete and had done some limited experimenting on his own. Unfortunately, none of the experimenting had been with mixtures containing a very low water to cement plus silica fume ratio and a high dosage of HRWR. Dean adamantly insisted that our mixture proportions were incorrect, i.e., that the proportions would produce 29 rather than 27 ft^3 of concrete using the amount of water he calculated as being necessary to produce a usable concrete. Dean had not received the amendment to the specifications indicating the amount of water to be used or the admixture range selected by SPL. During our meeting, I explained that the proportions were correct and that we had been using the HRWR at approximately the 1 percent dosage. I did not perform the calculations necessary at that time to determine the mixture dosage for the liquid D-19, since Dean indicated that he understood the dosage rate we wanted. Jack Rolston furnished Dean the correct amount of water to be used.

e. The specifications required the contractor to place 60 lin ft of concrete with the same cross section as the actual project. The contractor was given two options for placing the test section: First, it could be done in the area from which the old concrete had been removed. This option would have required approximately 60 yd^3 of concrete and included the requirement that the test concrete be removed. Second, the test could be done as an overlay in a section of the low-flow area outside of the project limits. This option required the placement of approximately 30 yd^3 of concrete which did not have to be removed after the test. The contractor selected the second option.

f. Since the test section was to be an overlay, a length of the low-flow section had been carefully cleaned. This gave a better opportunity to examine the damage to the concrete. The concrete in the test section showed coarse aggregate (approximately 1-1/2-in. maximum size aggregate (MSA)) exposed throughout. The aggregate particles were polished indicating abrasion damage. There was also a loss of paste around the large aggregate particles, probably caused by scour by fine aggregate being carried by the river. Some portion of the damage is probably attributable to the chemicals in the water. A large hole (not through the concrete) was evident in the test area. This hole was just downstream from where an outlet of an underslab relief drain entered the low-flow area.

g. On Friday, Don and I arrived at the project site. The plan for the day was to place 9 yd^3 of Mixture 2, 9 yd^3 of Mixture 3, and 9 yd^3 of Mixtures 2 or 3 or a modification of one of the mixtures as indicated by the first two placements. Since no trial batches had been made, I recommended that a smaller batch be prepared to allow for any necessary adjustments. The contractor and Frank Qual (SPL Construction) agreed to this proposal. Don and I and the contractor's foreman went to the batch plant to observe the trial batching. When we arrived at the plant, we found that 9 yd^3 had been batched and was in the truck. The silica fume was being added by breaking 45-lb bags onto a conveyor. Once the silica fume was added, the concrete was mixed. A small amount of "concrete" was run into a wheelbarrow.

h. The material in the wheelbarrow was essentially aggregate particles coated with a cement and silica fume paste. The material was damp to the touch, but it exhibited no cohesiveness. The material appeared to me and Don as silica fume concrete that was underdosed with HRWR. Dean White was making statements that the concrete was too dry, that it was about to "go off" (?) in the truck, and that we were about to ruin a $12K drum. He wanted to add water immediately. Don and I suggested that a closer look at the HRWR dose was called for. With the help of the Grace technical representative, we did a series of calculations similar to those in Table 2. Based on these, we concluded that about 0.75 gal/yd^3 had been added when about 1.75 gal/yd^3 were required. Additional HRWR was added and the concrete was mixed. A sample taken after mixing was flowable, cohesive, and had a slump of 3-1/4 in. The contractor's representative worked the concrete with a wooden float and agreed that it was acceptable.

i. The truck being used had a flat tire that had to be changed before it could leave the plant. Because of the length of time required to batch, add the fume, change the tire, and travel to the site, the truck arrived at the placement site about 1-1/2 hr after the water and cement had been batched and about 30 to 45 min after the additional HRWR had been added. Additional HRWR was added and the truck began to unload. The concrete temperature had reached 97° F and the material had become too stiff to place. Rather than add additional HRWR (the concrete supplier was running out of it), the concrete was discarded by mutual agreement of all concerned.

j. A second 9-yd^3 load was batched and sent to the site. The truck arrived about 45 min after beginning to load. About 3-1/2 gal of HRWR were added at the site (this was all that was available). (A total of 13 gal had been added at the plant initially.) Thus, the total dose was below that desired. The initial concrete out of the truck looked very good. The contractor was attempting to move the concrete to the far side of the placement using the truck chutes. The chutes were simply not long enough; subsequently, the concrete finishers were trying to move the concrete by shovel. Approximately 20 min were required to place about the first cubic yard. At this time, by mutual agreement, we decided to add water to bring up the slump. The idea was to have an opportunity to observe the contractor's placement equipment and procedure.

k. The contractor had fabricated a very substantial vibrating screed with the correct profile for the section. It was equipped with two air-operated vibrators. The screed was to be moved longitudinally by means of cables attached to two vehicles (an air-tugger assembly is planned for the production placements). Almost immediately (before any concrete was screeded) an air line broke on the screed. While the air line was being repaired, the truck was unloaded (approximately 45 min total unloading time). By the time the screed was repaired, the concrete initially placed had begun to dry and would not respond well to being screeded. At some point in time, one of the two vibrators broke, resulting in very little vibration actually reaching the concrete. The finish of the concrete as placed in the test section was essentially unsatisfactory

l. It was very evident that two ready mix trucks will be required for all placements - the two simultaneously unloading on opposite sides of the placement. This procedure will eliminate the need to shovel large amounts of concrete. It will also allow screeding and finishing the concrete while it is workable.

m. The contractor acknowledged that additional vibrators are required on the screed. He will add the vibrators and make some other modifications as well.

n. During a postplacement discussion, Don and I recommended that the concrete be dry batched at the plant and that the water and HRWR be added at the site. This procedure would make it possible to have two trucks ready to unload simultaneously. Dean White rejected this proposal without giving any satisfactory explanation.

o. It appears that greater attention needs to be paid to the adjustment of batch weights for the moisture condition of all of the aggregates.

p. Samples of concrete were taken from the second truck by SPL personnel. Two abrasion specimens were cast that will be shipped to WES for testing. I am not certain whether the samples were taken before or after the water was added to the truck.

6. Hot weather concreting. Three facts concerning concrete placement in hot weather should be kept in mind while evaluating the results of this test placement. First, as ambient and concrete temperatures increase, additional water

is required to maintain a constant slump. Second, the slump loss of a HRWR will occur more rapidly at a higher temperature. Third, the ultimate compressive strength of concrete cured at higher temperatures is less than that for the same concrete cured at a lower temperature.

7. Lab versus field placements. Based upon the greater care taken in the laboratory and the more carefully controlled conditions, I would not expect the field placements to achieve the same compressive strengths seen in the laboratory. The higher curing temperature will further reduce strength as will any additional water that is added. The net result of these decreases in compressive strength will be a decrease in abrasion resistance. With good control at the batch plant and placement site, I would expect that the concrete in place in the structure will show an abrasion resistance between the extremes shown on Figure 1. The degree of control will determine how closely the field performance will follow the laboratory work.

8. Additional test placements. At the conclusion of the test placement, the contractor stated he would conduct additional test placements on Wednesday, 17 August. It was agreed initially to use two ready mix trucks and to continue to use Mixture 2. Dean White requested to place his own mixture containing an additional 50 gal of water per cubic yard from one truck. Frank Qual accepted this. (This change would raise the water to cement plus silica fume ratio to 0.31 from 0.24.) Dean also proposed that only one truck discharge at a time since he would have a problem taking samples. This was also agreed to. (This proposal is actually not workable; both trucks must discharge simultaneously or it will be impossible to screed the concrete.)

9. Conclusions.

a. Although by no means a success, the test placement was a valuable exercise. I would hate to think that all of the problems noted had occurred during an actual production placement.

b. There appears to have been a significant lack of communication involving the District Materials and Construction personnel, the contractor, and the ready mix contractor concerning the exact nature of the concrete desired.

c. The lack of any preliminary attempts to prepare the concrete mixtures involved, prior to the day of the test placement, appears to have been a serious oversight. The failure of the ready mix supplier to have adequate HRWR available is clear evidence that little, if any, preliminary work had been done.

d. Of the 18 yd^3 of concrete prepared, only a small portion was seen that could be considered to be the design mixture. The small amount of concrete tested at the batch plant from the first truck and the initial concrete from the second truck were the only concrete that resembled the concrete developed by CTD. There seemed to be a consensus that this concrete was acceptable.

e. In order for the screed to function properly and to minimize the amount of time required to unload a ready mix truck, two trucks, on opposite sides of the placement, will be necessary.

f. Don and I had the distinct impression that Dean White had decided prior to the test that the mixture as designed by CTD was not going to work and that he was going to do little, if anything, to make it work.

g. Given the time required to batch the trucks (particularly the silica fume), the time required to reach the placement site, the hot temperature, and the necessity to have two trucks discharge a usable mixture simultaneously, it appears that the concrete will have to be dry batched at the plant with the water and HRWR added at the jobsite immediately before placement.

h. We saw nothing to convince us that the very high strength concrete as specified cannot be made and placed successfully.

i. The problems caused by the reinforcing steel that was not shown on the project drawings serve to reiterate the necessity to be alert for unanticipated conditions during any rehabilitation work.

10. Recommendations.

a. The District needs to reach a consensus among the Engineering, Materials, and Construction sections as to what concrete is desired in this placement and in future work. If a very high strength silica fume concrete as originally specified is desired, additional work to resolve the problems identified so far will be required.

b. The role of the concrete supplier needs to be reviewed in terms of material supplier versus provider of technical opinion.

c. The concrete supplier's objections to dry batching the material and mixing on site need to be reviewed. Unless overriding problems are surfaced, we believe this approach is the best to use. This will be the most economical approach in terms of HRWR required since the excessive delay between mixing and placing would be eliminated.

d. The development of an acceptable concrete mixture and the test placements should be viewed as two separate steps in preparing for the production placements. It is a waste of time and effort to try any additional test placements until problems with the concrete mixture can be eliminated. We recommend that the District personnel, in the District laboratory, prepare small batches of the three mixtures to gain knowledge of what the material will look like. Once this step is accomplished, small batches (2 to 3 yd^3) should be prepared by the concrete supplier. Only after the supplier has demonstrated that he can deliver concrete to the site should test placements resume.

WESSC 15 August 1983

SUBJECT: Trip Report - Observation of Trial Placements of Silica Fume Concrete, Los Angeles District, 10-12 August 1983

~~e. The District must acknowledge that an error was made in the specifications concerning the HRWR dosage and that the Corps is willing to pay for any material required over the amount originally specified. This should remove the supplier's reluctance to use the required amount.~~ Deleted See 26 Sep Corrections TA

f. Based upon limited observation of the condition of the concrete in the low-flow section, it appears that complete removal is not required. An overlay with a minimum thickness of 6 in. would be much more economical for the work in future years. Only severely damaged concrete should be removed rather than overlayed.

Terence C. Holland

TERENCE C. HOLLAND, D. Eng.
Research Civil Engineer
Structures Laboratory

3 Incl
Table 1
Table 2
Figure 1

CF w/incl:
Jack Rolston, SPL
Tony Liu, OCE
Tom Hugenberg, ORD

Table 1

Data on Concrete Mixtures

	WES Control	Project Mixture 2	Project Mixture 3
Cement	600*	600*	600*
Silica Fume	0	90	90
Fly Ash	0	0	90
1-1/2-in. Aggregate	639	650	619
1-in. Aggregate	772	785	748
3/8-in. Aggregate	517	526	501
Fine Aggregate	1,392	1,416	1,349
Water	228	166	187
Water/Cement	0.38	0.28	0.31
Water/Cement + Fume + Fly Ash	0.38	0.24	0.24
Compressive Strength, $lb/in.^2$			
7 day	6,110	7,800	6,810
28 day	7,470	10,950	9,470
90 day	8,060	11,580	10,630
Age at Abrasion Test, days	28	28	90
Abrasion Loss, % Mass at 72 hr	6.4	2.7	3.0

* lb/yd^3, SSD.

Table 2

Chemical Admixture Requirements (High-Range Water-Reducing Admixture)

1. Work done at WES to date has shown that a suitable dosage rate for high-range water-reducing admixtures (HRWR) is approximately 1 to 2 percent by weight of cement plus silica fume or cement plus silica fume plus fly ash. The percentage calculated is the weight of solids required.

2. For Grace D-19 (liquid):

   42 percent solids by weight
   9.5 lb/gal
   Solids = 4.0 lb/gal

Cement + Silica Fume + Fly Ash	Project Mixture 2 690 lb/yd^3	Project Mixture 3 780 lb/yd^3
Admixture Required at the Following Dosage Rates (per yd^3)		
0.75 percent	5.18 lb solids 1.29 gal 165 fl oz	5.85 lb solids 1.46 gal 187 fl oz
1.00 percent	6.90 1.73 221	7.80 1.95 250
1.25 percent	8.63 2.16 276	9.75 2.44 312
1.50 percent	10.35 2.59 331	11.70 2.93 374
1.75 percent	12.08 3.02 386	13.65 3.41 437
2.00 percent	13.80 3.45 442	15.60 3.90 499

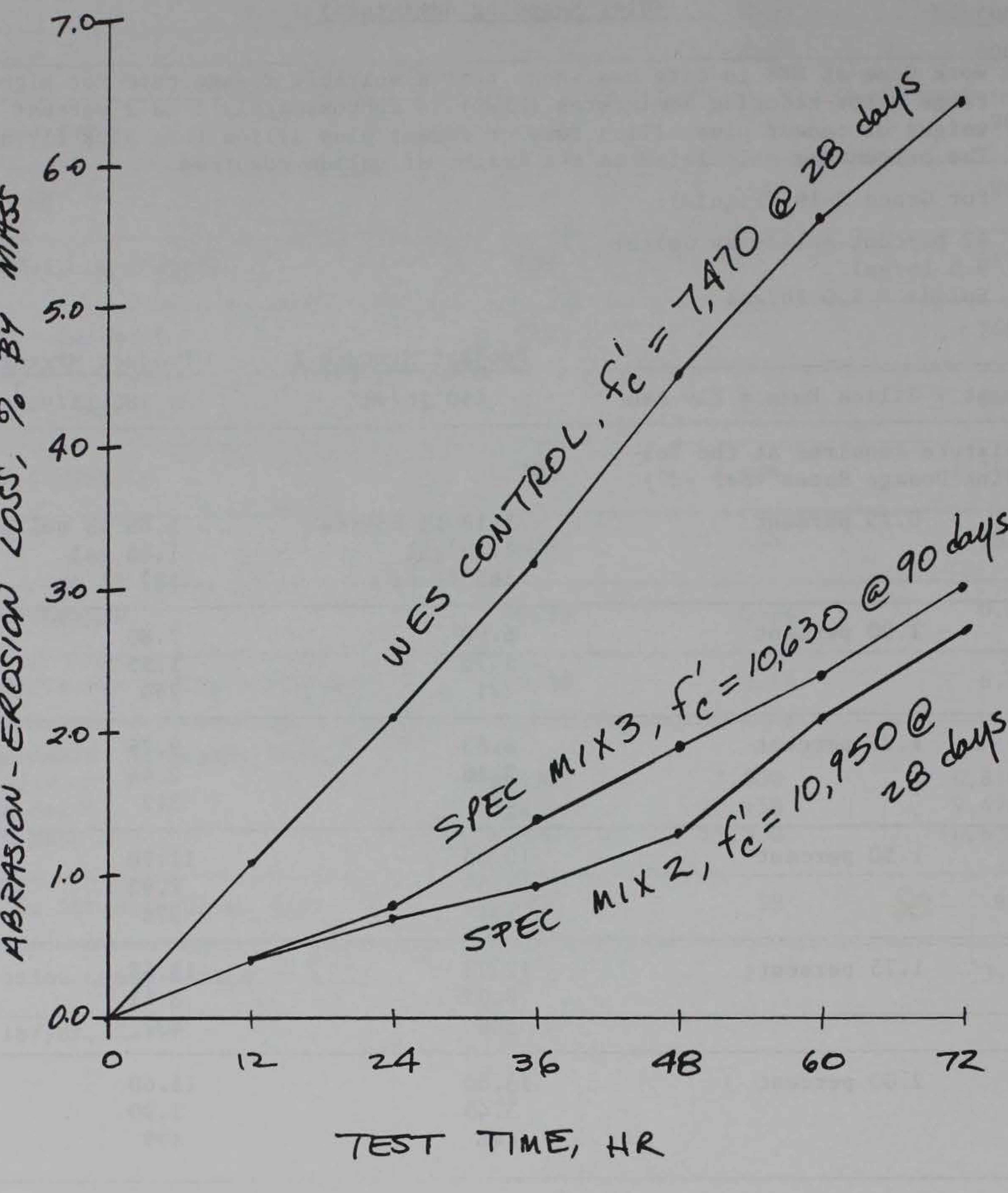

Figure 1. Abrasion-erosion performance of Los Angeles Mixtures

APPENDIX C

TRIP REPORT--SECOND TRIAL PLACEMENT

WESSC 18 October 1983

MEMORANDUM FOR RECORD

SUBJECT: Trip Report--Observation of Second Trial Placements of Silica Fume Concrete, Los Angeles District, 30 August - 1 September 1983.

1. References.

a. WESSC Memorandum for Record, subject: Trip Report - Observation of Trial Placements of Silica Fume Concrete, Los Angeles District, 10-12 August 1983, dated 15 August 1983.

b. WESSC Memorandum for Record, subject: Corrections to Trip Report, dated 26 September 1983.

2. Summary. On 30 August I met with representatives of the Los Angeles District to work on the concrete mixtures involved in this project. On 31 August the contractor conducted the second series of trial placements at the project site. On 1 September a meeting was held at Los Angeles District to review the status of the project.

3. Trial Mixtures.

a. On 30 August several trial batches of concrete were prepared at the District Laboratory in El Monte. Persons attending during this work were: Jack Rolston, SPL; Dale Haslem, SPL; Dick Gutschow, SPL; North Smith, SPDED; and R. L. Siesen, SPDED. Dean White, Conrock; Miron Kalbejian, Dyno Construction; and Frank Qual, SPL, were present for the last three batches.

b. All batches were made in a small rental mixer. The materials were from the Conrock Batch Plant and were presumed to be representative of those being used for the project. I had taken some of the dry high-range water-reducing admixture (HRWRA) with me to use. All batches were 1.5 cu ft. Compressive strength cylinders were made for all batches.

c. The following batches of concrete were made during the day:

- Batch 1, Mixture 2 (dry HRWRA). At a 1 percent dosage rate the slump was 4 in., and the concrete would flow. However, the material was extremely sticky.

- Batch 2, Mixture 2 (dry HRWRA). This batch was made after the aggregates were blended and new moisture tests were conducted. The dosage rate for the water-reducing admixture (WRA) (D79) was also increased to 7 fl oz/100 lb of cement plus silica fume. A dose of 2-1/2 percent of HRWRA was added and the mixture was still too dry. An additional 2-1/2 gal of water were added, resulting in a slump of 3-1/2 in. The concrete was still extremely sticky.

- Batch 3, Mixture 2 (liquid HRWRA). An additional 3 lb of water was added to this batch. The liquid HRWRA was added to give a dosage of 1-1/2 percent. The specific gravity of the HRWRA was taken as 1.22 based upon Conrock's testing. This concrete had a slump of 7 to 9 in. and was flowing.

- Batch 4, Mixture 3 (liquid HRWRA). An additional 2.6 lb of water was added to this batch. The HRWRA was used at the 1 percent dosage. The concrete had a slump of 7 to 8 in. and was flowing.

d. The original plan had been to have the Corps employees work on the concrete mixtures on one day, demonstrate the mixtures to the contractor on the second day, and conduct the trial placements on the third day. Because of scheduling problems, we were only able to prepare the first batch listed above before the contractor's representatives arrived at the laboratory.

e. During these trial mixes, none of the batches behaved as the same concretes had during the work at WES. The common problem seemed to be an increased water demand. A portion of the increased water demand was probably caused by the higher ambient temperature. There was also some initial confusion concerning the actual moisture contents on the aggregates; however, this was apparently resolved by blending and retesting. After the tests were completed, I was at a loss to explain the problem.

f. During the next day, two items came to light that helped to explain part of the problem. First, I consulted with the Grace technical representative to establish the proper dosage rate for the D-79 WRA. He stated that a dosage rate of 9 fl oz/100 lb of cement would be equivalent to a dosage of 4 fl oz/94 lb of cement of Sika Plastiment. Second, the gradings of aggregates used at the District laboratory were reviewed and found to differ significantly from those of the material shipped to WES for mixture proportioning work. The gradings are presented in Table 1. Apparently, the higher ambient temperature, the change in the admixture dosage (WRA), and the change in the aggregate gradings all contributed to the increased water demand.

4. Trial placements.

a. On 31 August the contractor conducted trial placements in the same area as used for the earlier trial (Reference 1 a). (The silica fume concrete placed during the first placement had washed away during heavy rains.) The trials consisted of two 6-cu-yd truck mixer loads for the following mixtures: Mixture 2, Mixture 3, and Mixture 2R (this was Mixture 2 as modified by Conrock).

b. Placements were conducted using two truck mixers to discharge ahead of the screed. One truck was on either side of the low flow section. The trucks were batched at the batch plant, the silica fume was added at the plant but using a separate conveyor (essentially breaking 45-lb bags on a conveyor), a portion of the HRWRA was added at the plant, and the concrete was mixed. The truck was then sent to the site. At the site, the slump was estimated by looking at the concrete in the drum and an additional dose of HRWRA was added. Once two trucks were at the site and redosed, the placement was started. There was always a delay of 15 to 30 minutes between the two trucks with the same mixture arriving at the site.

c. The mixture proportions used, based upon the batch weights, were the specified weights. The D-79 WRA was used at a rate of 7 fl oz/100 lb cement plus silica fume or 7 fl oz/100 lb cement plus silica fume plus fly ash. The dosage rate of the D-19 HRWRA varied from truck to truck. Since the addition of the HRWRA at the site was largely done by guessing at the slump in the trucks, the actual slumps of the resulting concretes varied greatly from truck to truck. Mixture 2 was heavily redosed, Mixture 3 received only a small additional amount of HRWRA, and Mixture 2R was not redosed at all. Amounts of HRWRA used are shown in Table 2.

d. There was no provision being made for moisture on the coarse aggregate during the batching process. Based on the belief that the coarse aggregates were dryer than SSD, additional water was added at the site as follows:

Mixture 2: 15 gal/6 cu yd.

Mixture 3: 10 gal/6 cu yd.

Mixture 2R: None.

The moisture in the fine aggregate was being accounted for automatically at the batch plant. Review of the batch tickets indicated that the specified amount of water was being added, plus or minus the net contribution of the coarse aggregate.

d. The third mixture placed (Mixture 2R) was recommended by Conrock. It was essentially the specification Mixture 2 with a higher water content (water/cement plus silica of 0.30 vs 0.24). This mixture was very fluid and did not stay on the sloped portion of the invert well. Any attempts to consolidate the concrete caused it to flow down the slope.

e. Placing was accomplished using the same basic procedures used for the first trial. The major exception was the discharge of the two trucks on opposite sides of the channel. This procedure removed the long time delays seen during unloading for the first trial placement. Consolidation of the concrete was better than during the first trial placement, but it was still not adequate, particularly for Mixture 2R.

The finish achieved by the screed varied from very rough to acceptable. A considerable amount of hand work was done in an attempt to develop a smooth surface appearance. This hand work included the application of large amounts of water to the surface to ease the finishing.

f. Overall, Mixture 2 remained the most difficult to place and finish. Mixture 3 placed reasonably well. Mixture 2R was easier to place than Mixture 2, but I doubt that the strength and abrasion-resistance will be at an acceptable level.

5. Review Meeting. A meeting was held at the District Office on 1 September to discuss the placement and the status of the project to date. A list of attendees is in Table 3. The following items were discussed:

a. I expressed my opinion that, after looking at the damaged concrete, the damage in the channel was probably caused by a combination of scour and abrasion with a possible contribution from the pollutants in the water. The best solution for all of these problems would be to place a dense, high-strength concrete. The concrete mixtures being tested during this placement should be satisfactory for use in the project.

b. The printing in the specifications of the proportions developed at WES was discussed. I stated that the specific mixture proportions as developed at WES would probably never work using the project materials since a different WRA was being used, aggregates with a different grading were being used, a different source of silica fume was being used, and the concrete was being batched and placed at a different (higher) temperature. The step of having the contractor submit material to the Division lab for final mixture proportioning was omitted. This was obviously a serious omission.

c. I suggested that under the circumstances, a compromise on Mixture 2 would probably be in order to obtain a more placeable concrete. An appropriate compromise could be as shown:

WES TEST MIXTURE:	W/C + SF = 0.24
CONROCK (2R):	W/C + SF = 0.30
TRY:	W/C + SF = 0.27

d. The dosage for the HRWRA was also discussed. I pointed out that the 1-percent level is not a fixed number. My recommendation was to fix the W/C + SF value and then add HRWRA as necessary to produce a suitable slump. The dosage rate of the HRWRA will probably change during the day as the ambient temperature changes.

e. I made the following specific recommendations:

(1) Get better data on the grading of the aggregates to be used. Attempt to get historical data on the aggregate, as used at the batch plant, from Conrock.

(2) Get better data on the moisture contents of the fine and coarse aggregates at the barch plant. If Conrock is unwilling or unable to make adjustments for moisture content of the coarse agggregate, then the Corps may have to do so in order to get a satisfactory concrete.

(3) Increase the dosage rate of the D-79 to 9 fl oz/100 lb of cement plus fume. This increase should improve the water reduction and help to maintain the slump for a longer period of time.

(4) Consider the use of a sun screen and foggers to slow the surface drying of the concrete.

(5) Increase the effort being made to provide satisfactory consolidation.

(6) Slow down the longitudinal movement of the screed to improve the finish of the surface. (This item should be resolved when the contractor goes into the production placements.)

f. I left the meeting with the impression that the remaining problems had been identified and that the District personnel would be capable of taking the necessary follow-up action and making any required changes.

6. Addendum.

a. On 20 September 1983, Dale Haslem provided me with a revised set of gradings for the project aggregates (Table 4). As can be seen by comparing Tables 1 and 4, there were large differences in the gradings, particularly as measured from the aggregates used at the District Laboratory.

WESSC

18 October 1983

SUBJECT: Trip Report--Observation of Second Trial Placements of Silica Fume Concrete, Los Angeles District, 30 August - 1 September 1983

Using these revised gradings, Dale had calculated a minor change to the relative proportions of the coarse aggregates. He had determined the revised proportions by trial and error attempting to achieve a combined grading as close to that used in the WES lab work as possible. The revised proportions for Mixture 2 and combined gradings are shown in Table 5.

b. Using the revised gradings and to maintaining the same relative proportions of the aggregates shown in Table 5, I prepared revised versions of Mixtures 2 and 3 (Tables 6 and 7). Note that the entrapped air estimate was increased to 1.5 percent to reflect values measured in the field.

c. Placements of Mixture 3 were conducted in Los Angeles on 21, 22, and 23 September using the original specified proportions. No changes were made for the revised gradings.

d. The following compressive strengths were reported to me by Jack Rolston. These strengths are from cylinders made during the test placement.

	3-Day, psi	7-Day, psi
Mixture 2	7083 Corps 7976 Conrock 4-Day	7840 Corps 8878 Conrock
Mixture 3	6305 Corps 7145 Conrock 4-day	7680 Corps 8306 Conrock
Mixture 2R	5138 Corps 5824 Conrock 4-day	6600 Corps 6466 Conrock

e. Abrasion-erosion testing of specimens made during the trial placement was conducted at WES. One specimen was tested for each mixture. Testing for all concretes was done at 28 days. Results are in Table 8.

TERENCE C. HOLLAND, D. ENG.
Concrete Technology Division
Structures Laboratory

8 Incl
Tables 1 - 8

CF w/incl:
Jack Rolston, SPL
Frank Qual, SPL
Tony Liu, OCE
Tom Hugenberg, ORD

TABLE 1: Aggregate Gradings Used in Laboratory Batches

1. As used at Los Angeles District Lab:

Sieve	1-1/2 in.	1 in.	3/8 in.	FA
1-1/2 in.	98*	98		
1	71	39		
3/4	9	25	100	
3/8	4	20	95	
No. 4		17	14	100
8				75
16				59
30				37
50				15
100				4

2. As used at WES to proportion concrete:

Sieve	1-1/2 in.	1 in.	3/8 in.	FA
1-1/2 in.	100*	100		
1	19	96		
3/4	3	58	100	
3/8	1	6	96	100
No. 4	1	3	9	97
8				78
16				63
30				43
50				19
100				5

3. Combined gradings of coarse aggregates:**

Sieve	WES	LA Lab	CRD-C 3
1-1/2 in.	100*	98	100
1	72	67	72
3/4	51	40	55
1/8	29	35	23
No. 4	4	11	--

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* Cumulative percentages passing.

** Based on the following proportions of the coarse aggregates:

1-1/2 in.: 33 percent
1 in.: 40 percent
3/8 in.: 27 percent

TABLE 2: Dosages of HRWRA used in Trial Placements

Mixture	HRWRA Added at Plant (fl oz)	HRWRA Added at Site (fl oz)	Total
Mixture 2			
- Truck 1 (6 cu yd)	1260	900	2160
- Truck 2 (6 cu yd)	1260	900	2160
Mixture 3			
- Truck 1 (6 cu yd)	1640	200	1840
- Truck 2 (6 cu yd)	1640	200	1840
Mixture 2R			
- Truck 1 (4 cu yd)	840	None	840
- Truck 2 (4 cu yd)	840	None	840

TABLE 3: Attendees at Meeting of 1 September 1983 on the LA River Invert Rehab Project

John Lohman	Materials
R. A. Gutschow	SPL-GI
Dale Haslem	SPLED-GI
Terry Holland	WES
Cliff Ford	SPLED-DB
Jane Cho	SPLED-DB
John Karakawa	SPLED-DB
Frank Qual	Construction Div.
Jack Rolston	SPLED-G
North Smith	SPDED-G
R. L. Siesen	SPDED-G
Dave Weaver	SPLED-DM
Larry Lauro	SPLED-G

TABLE 4: Revised Gradings of Project Aggregates [From Dale Haslem [20 September 1983)]

Gradings of Aggregates at Batch Plant

Sieve	1-1/2 in.	1 in.	3/8 in.	FA
1-1/2 in.	99*	100	100	100
1	16	98	100	100
3/4	0.9	77	100	100
3/8	0.3	16	83	100
No. 4		6	3	97
8		5	0.3	80
16				66
30				44
50				19
100				5

*Cumulative percentages passing.

TABLE 5: Revised Mixture Proportions

1. Mixture 2 (Original).

Aggregate	lb/cu yd	Percent by Weight
1-1/2 in.	650	19.3
1 in.	785	23.2
3/8 in.	526	15.6
FA	1416	41.9
	3377	100.0

2. Mixture 2 (Revised).

Aggregate	lb/cu yd	Percent by Weight
1-1/2 in.	700	20.8
1 in.	785	23.2
3/8 in.	476	14.1
FA	1416	41.9

3. Combined Gradings (Coarse and Fine Aggregates).

Sieve	Mixture 2 (as Proportioned at WES)*	Mixture 2 (Revised)**
1-1/2 in.	100.0†	99.8
1	83.4	82.1
3/4	71.5	74.1
3/8	58.5	57.4
No. 4	42.9	42.5
8	34.4	34.7
16	26.9	27.7
30	18.0	18.4
50	8.0	8.0
100	2.1	2.1

*Using gradings of aggregates shipped to WES.

**Using gradings shown in Table 4.

†Cumulative percentages passing.

Table 6. Revised Mixture Proportions, Mixture 2

*********** CONCRETE MIXTURE PROPORTIONS

PROJECT: LOS ANGELES DISTRICT ABRASION
MIXTURE: LA3 15% SILICA FUME

*********** MATERIALS DATA

MATERIAL	IDENT	PCT AGG	BULK SP GR	ABS	TOT MOIST	NET MOIST
CMT MTL 1	PORT CEMENT LA-3 C-1	------	3.15	------	------	------
CMT MTL 2	SILICA FUME AD-536(4	------	2.22	------	------	------
CMT MTL 3	0	------	0.	------	------	------
FINE AGG 1	SAND LA-3 S-1	100.0	2.65	1.1	0.	-1.1
FINE AGG 2	0	0.	0.	0.	0.	0.
COARSE AGG 1	1.5 IN. LA-3 G-1	35.5	2.67	0.9	0.	-0.9
COARSE AGG 2	1 IN. LA-3 G-1	40.0	2.66	1.3	0.	-1.3
COARSE AGG 3	3/8 IN. LA-3 G-1	24.5	2.64	1.2	0.	-1.2
COARSE AGG 4	0	0.	0.	0.	0.	0.
WATER		------	1.00	------	------	------

ADMIXTURES:

PLASTIMENT	4.0	FL OZ PER 94.0 LB
GRACE D-19 (DRY)	2.0	LB PER 100.0 LB

*********** PROPORTIONS FOR BATCH OF 1 CU YD, SSD

MATERIAL	IDENT	VOLUME	WEIGHT
CMT MLT 1	PORT CEMENT LA-3 C-1	3.051	600.0
CMT MLT 2	SILICA FUME AD-536(4	0.649	90.0
CMT MLT 3	0	0.	0.
FINE AGG 1	SAND LA-3 S-1	8.502	1406.5
FINE AGG 2	0	0.	0.
COARSE AGG 1	1.5 IN. LA-3 G-1	4.168	694.7
COARSE AGG 2	1 IN. LA-3 G-1	4.696	779.9
COARSE AGG 3	3/8 IN. LA-3 G-1	2.876	474.1
COARSE AGG 4	0	0.	0.
WATER		2.653	165.6
AIR		0.405	------

ADMIXTURES:

PLASTIMENT	29.4	FL OZ
GRACE D-19 (DRY)	13.8	LB

WATER-CEMENTITIOUS MATERIAL RATIO, BY WEIGHT: 0.24
SAND PERCENTAGE OF AGGREGATE VOLUME: 42.0
DESIGN AIR CONTENT, PERCENT: 1.5

Table 7. Revised Mixture Proportions, Mixture 3

*********** CONCRETE MIXTURE PROPORTIONS

PROJECT: LOS ANGELES DISTRICT ABRASION
MIXTURE: LA4 15% FUME-15% ASH

*********** MATERIALS DATA

MATERIAL	IDENT	PCT AGG	BULK SP GR	ABS	TOT MOIST	NET MOIST
CMT MTL 1	PORT CEMENT LA-3 C-1	------	3.15	------	------	------
CMT MTL 2	SILICA FUME AD-536(4	------	2.22	------	------	------
CMT MTL 3	FLY ASH AD-727	------	2.34	------	------	------
FINE AGG 1	SAND LA-3 S-1	100.0	2.65	1.1	0.	-1.1
FINE AGG 2	0	0.	0.	0.	0.	0.
COARSE AGG 1	1.5 IN. LA-3 G-1	35.5	2.67	0.9	0.	-0.9
COARSE AGG 2	1 IN. LA-3 G-1	40.0	2.66	1.3	0.	-1.3
COARSE AGG 3	3/8 IN. LA-3 G-1	24.5	2.64	1.2	0.	-1.2
COARSE AGG 4	0	0.	0.	0.	0.	0.
WATER		------	1.00	------	------	------

ADMIXTURES:

PLASTIMENT 4.0 FL OZ PER 94.0 LB
GRACE D-19 (DRY) 2.0 LB PER 100.0 LB

*********** PROPORTIONS FOR BATCH OF 1 CU YD, SSD

MATERIAL	IDENT	VOLUME	WEIGHT
CMT MLT 1	PORT CEMENT LA-3 C-1	3.051	600.0
CMT MLT 2	SILICA FUME AD-536(4	0.649	90.0
CMT MLT 3	FLY ASH AD-727	0.616	90.0
FINE AGG 1	SAND LA-3 S-1	8.098	1339.7
FINE AGG 2	0	0.	0.
COARSE AGG 1	1.5 IN. LA-3 G-1	3.970	661.7
COARSE AGG 2	1 IN. LA-3 G-1	4.473	742.8
COARSE AGG 3	3/8 IN. LA-3 G-1	2.740	451.5
COARSE AGG 4	0	0.	0.
WATER		2.999	187.2
AIR		0.405	------

ADMIXTURES:

PLASTIMENT 33.2 FL OZ
GRACE D-19 (DRY) 15.6 LB

WATER-CEMENTITIOUS MATERIAL RATIO, BY WEIGHT: 0.24
SAND PERCENTAGE OF AGGREGATE VOLUME: 42.0
DESIGN AIR CONTENT, PERCENT: 1.5

Table 8 . Abrasion-erosion test data.

Concrete mixture: LA TEST PLACEMENT #2

elapsed test time hours	SPECIMEN A wt, lb	A percent loss	B wt, lb	B percent loss	C wt, lb	C percent loss	average percent loss
0	39.90	0.0	39.50	0.0	39.00	0.0	0.0
12	39.75	0.4	39.40	0.3	38.70	0.8	NA
24	39.60	0.8	39.25	0.6	38.50	1.3	NA
36	39.50	1.0	39.15	0.9	38.25	1.9	NA
48	39.15	1.9	38.75	1.9	37.90	2.8	NA
60	38.90	2.5	38.65	2.2	37.65	3.5	NA
72	38.75	2.9	38.40	2.8	37.45	4.0	NA

Notes:

A ≡ MIXTURE 2

B ≡ MIXTURE 3

C ≡ MIXTURE 2R