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CHANNEL LINING WITH FIBER REINFORCED SHOTCRETE

Final Report

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16. Abstract

The Arizona Department of Transportation (ADOT) has used four brands of discrete synthetic fibers in a drainage outfall channel lining as part of construction project ACI-10-3(270). The use of the fibers was intended to test the constructibility and performance of four commercially available fibers. If the fibers had proven effective, a generic specification for synthetic fiber reinforced shotcrete would have been developed.

The drainage outfall channel is 500 ft long and has a 140 ft hydraulic perimeter. Each fiber was placed in a 50 ft long section of the 5 inch thick lining. The construction process was documented with video tape and still photography. Slump measurements were taken before and after addition of fibers. Compressive strength (ASTM C-42), flexural toughness (ASTM C-1018), and percent permeable voids (ASTM C-642) testing were conducted on samples cut from 2'x3' panels. Four panels were fabricated during the construction of each of the test sections. Shortly after construction, visible plastic and drying shrinkage cracks were painted. Each test section was subsequently photographed and the lineal feet of cracks was determined. Beam and core samples were extracted from the channel lining after two years of service and compared with panel samples taken at the time of construction and stored for two years.

Analysis of variance carried out at the 5% significance level indicates that the addition of fibers had no effect on compressive strength, flexural toughness, or percent permeable voids. The beam samples used in the flexural toughness testing did not indicate any flexural toughness beyond first crack. Crack surveys conducted shortly after construction and again after two years of service indicate that the lining is performing satisfactorily.

This project was conducted to test the constructibility and performance of synthetic fibers used at manufacturers recommended dosages (1.6 lbs/yd^3 for three of the fibers and 1.0 lbs/yd^3 for the other fiber). The test results indicate that at the levels of reinforcement used for this project the fibers provide no measurable advantage over plain shotcrete. Therefore no specification was developed as part of this project.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

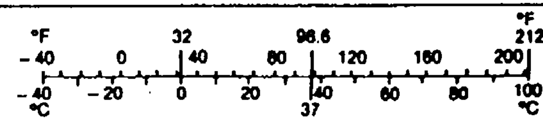
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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INTRODUCTION

This report documents the Arizona Department of Transportation's (ADOT) experience with synthetic fiber reinforcing at low dosages on one shotcrete channel lining project. This report begins by giving information on how the channel lining project became necessary and why fibers were specified. The report then gives some details about synthetic fiber reinforcing materials and mechanisms for action.

The construction process is documented in detail as is the material testing. Descriptions of construction of each test section are given in the order they occurred. Results from the material testing are given along with results of statistical testing. The results of this project represent a first step by ADOT in the investigation of potential applications and benefits for synthetic fiber reinforcing in concrete materials.

Background

Drainage facilities are an integral component of freeway systems and usually encompass a system of storm drains and subsequent outfalls into detention ponds, lakes, or rivers. This report documents the use of discrete synthetic fibers to provide secondary reinforcement for a shotcrete lined channel outfall. The particular outfall channel in this report serves the storm drains for the north-south running portion of the inner loop freeway. This outfall empties to the Salt River.

The above mentioned outfall was originally lined with gabions (Figure 1), but because the gabions allowed seepage into an adjacent sand and gravel pit, an impermeable lining became necessary. One of the most economical methods of providing an impermeable lining for channels is to use shotcrete. Shotcrete is a process whereby a grout-like material with maximum aggregate size of up to 1/2" is applied to the intended surface pneumatically.

FIGURE 1. GABION LINED CHANNEL

Problem Definition

The design consultant for the project recommended discrete synthetic fiber reinforcing at manufacturers recommended dosage, 1.6 lbs/yd^3. The special provisions for the project contained a specification that was restrictive in nature and which effectively limited the number of potential suppliers:

> "Reinforcing shall be a collated fibrillated, twisted bundle, polypropylene fibrous reinforcement and shall contain chemically and alkali inert, virgin polypropylene".

Because ADOT has no standard specification for the use of fiber reinforcing in shotcrete an Experimental Project (EP) was initiated to evaluate performance and possibly develop standard specifications. The experimental project was to compare a wide range of reinforcing fibers to determine which, if any, were suitable for future ADOT projects.

Synthetic Fiber Reinforcing

ASTM 1116-89 *Fiber-Reinforced Concrete and Shotcrete* states that there are three classifications of fiber reinforcing: 1) Type 1 - Steel, 2) Type 2 - Glass, and 3) Type 3 - Synthetic[1]. This experimental project was concerned with synthetic fiber reinforced shotcrete.

For a synthetic fiber reinforcing agent two properties are of special interest: 1) the material from which the fiber is manufactured, and 2) the configuration of the fiber. The material from which the fiber is manufactured must be resistant to the alkali environment of the shotcrete and also must be able to withstand the natural elements. For instance, when the shotcrete cracks the fiber will be exposed to ultraviolet radiation and moisture. The configuration is critical because most synthetic fibers are hydrophobic and the only bond between the cement paste and the fibers is mechanical. Therefore the configuration should, in some way, promote bonding. Configuration is also important as it relates to a phenomenon known in the fiber reinforcing industry as "balling", which will be discussed later.

ASTM C 1116-89 comments on the effectiveness of fiber reinforcing:

> "The performance of fiber-reinforced concrete or shotcrete depends strongly upon the susceptibility of the fibers to physical damage during the mixing process, their chemical compatibility with the normally alkaline environment within the cement paste, and their resistance to service conditions encountered within uncracked concrete or as a consequence of cracking, involving, for example, carbon dioxide, chlorides or sulfates in solution with water and oxygen or ultraviolet light in the atmosphere. The magnitude of improvements in the mechanical properties of the concrete or shotcrete imparted by fibers also reflects having a high modulus of elasticity and tensile strength being more effective on an equivalent volume basis then fibers of low modulus and strength."

There are several materials that fall under the heading of synthetic fiber: polypropylene, nylon, polyester, polyethylene, aramid, carbon, and acrylic[2]. Two of these materials were used for this project: polypropylene and polyester.

Manufacturers claim that the benefit of fiber as a reinforcing agent for concrete comes from the three dimensional nature of the reinforcing and its wide dispersion in the concrete matrix. However it has been pointed out that a portion of the fibers in any concrete mix will have an orientation that does not enhance the concrete[2].

Commercially available reinforcing fibers vary in their length, configuration, recommended dosage, and material makeup. The four proprietary reinforcing fibers used in this experimental project are listed in Table 1 along with their description and length. Figures two through five show the individual fibers as seen under a microscope and magnified 20 times.

TABLE 1. FIBER IDENTIFICATION

FIBER NAME	DESCRIPTION	LENGTH
Fibermesh	Collated Fibrillated Polypropylene Bundles	0.50"
Fiber-Lok	Monofilament Polypropylene	0.75"
Forta CR	Collated Fibrillated Polypropylene Twisted Bundles	1.50"
Nurlon	Monofilament Polyethylene Terpthalate (Polyester)	0.75"

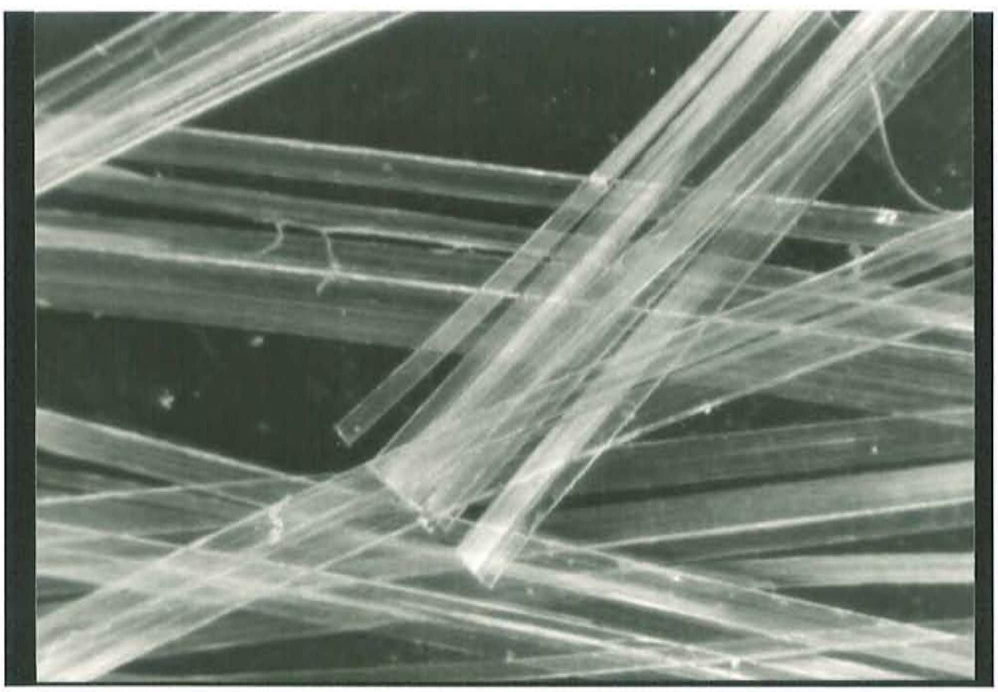


FIGURE 2. FIBERMESH MAGNIFIED 20 TIMES

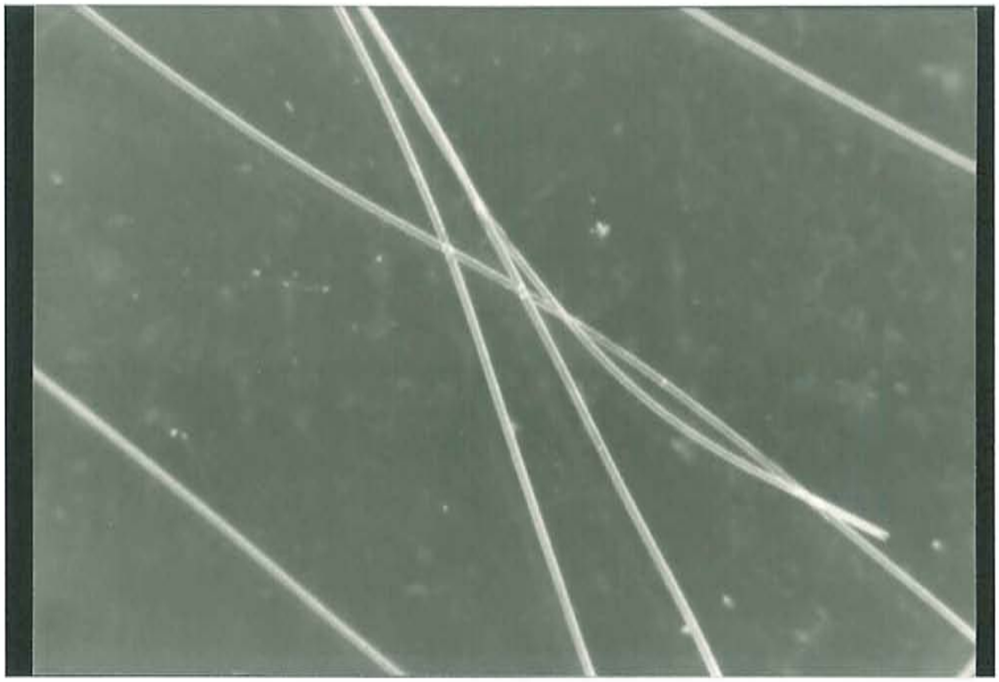


FIGURE 3. FIBER-LOK MAGNIFIED 20 TIMES

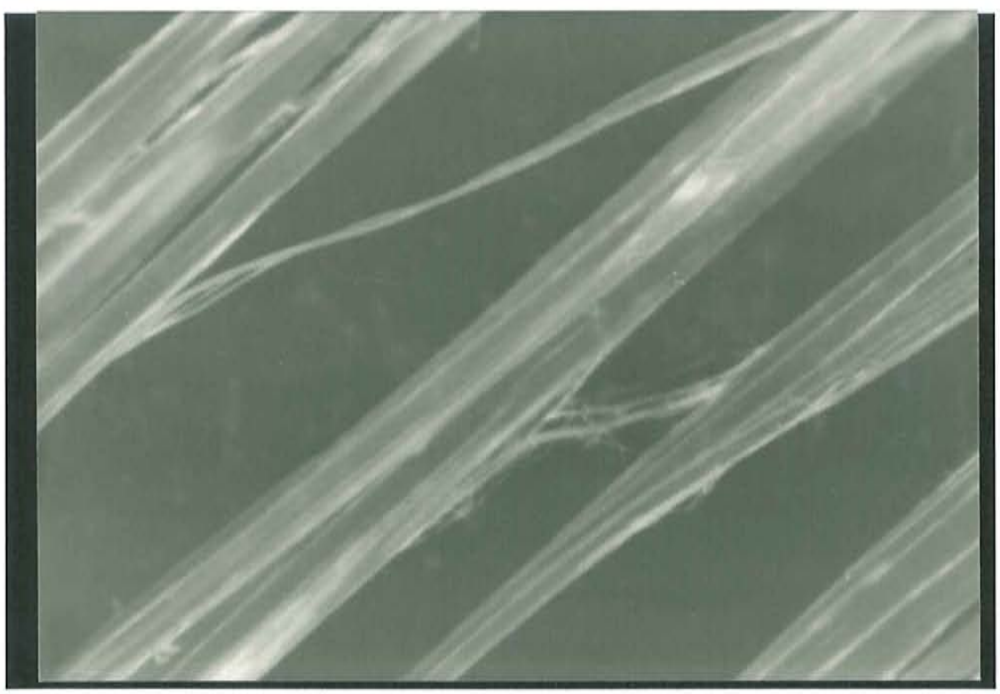


FIGURE 4. FORTA-CR MAGNIFIED 20 TIMES

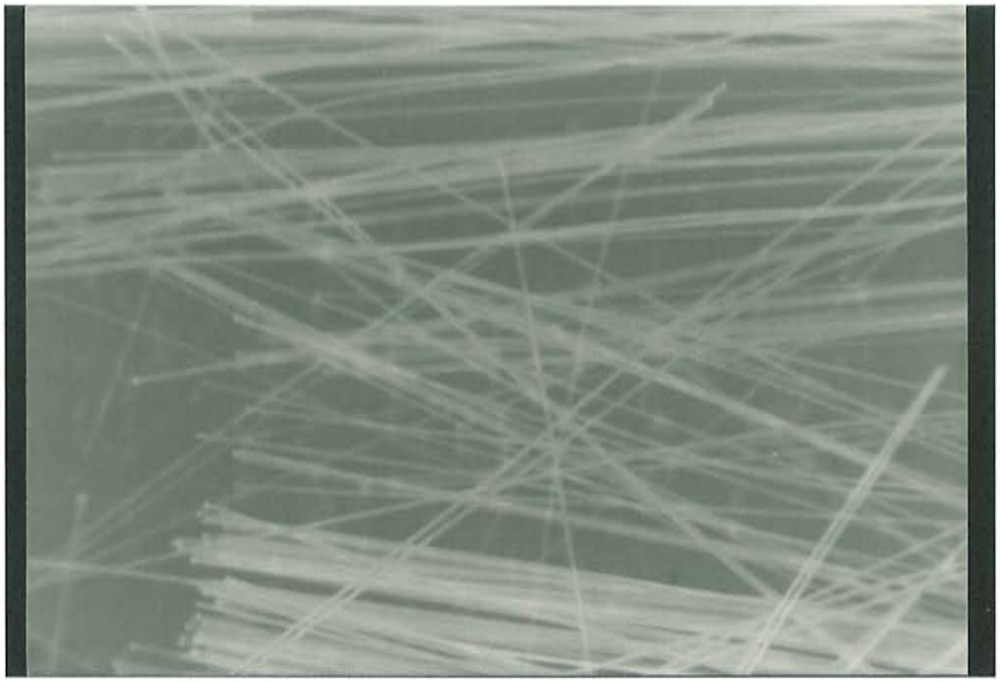


FIGURE 5. NURLON MAGNIFIED 20 TIMES

The two basic fiber configurations are monofilament and collated fibrillated. Monofilaments are round fibers and can be considered first generation[3]. The collated fibrillated fibers are single individual fibers which when rolled between the thumb and forefinger reveal an open netting pattern. Twisted bundles refer to the grouping of fibers by twisting them together. One of the constructibility problems with fiber reinforcing is called "balling". This is when the fibers clump together upon introduction into the mixer. Twisted bundles are reported to open up during the mixing process and alleviate the problem of balling.

One of the problems with any concrete product is plastic and drying shrinkage cracking. As the cement hydrates a volume change takes place that causes these cracks. The accepted method of dealing with this problem is to use welded wire fabric (WWF) or small diameter reinforcing steel (#3 or #4 bars) to hold the cracks together. Shrinkage cracking is a function water content, aggregate, temperature, and curing [4].

Fibers are reported to reduce plastic shrinkage cracking by reducing bleeding and redistributing shrinkage stresses. Bleeding occurs when aggregate segregate to the bottom of the placed mix leaving water to rise and hence evaporate. Fibers are reported to act as a netting that prevents the aggregate from settling and thereby reduces bleeding and the subsequent plastic shrinkage cracks.

OBJECTIVES

The primary objectives of this experimental project were to evaluate the constructibility and performance of fiber reinforced shotcrete. From the experience with the construction process, a generic specification and a method for judging compliance could have been developed.

The development of a generic specification and method for judging compliance was contingent upon fibers producing measurable beneficial effects at a cost consummate with the benefits.

The evaluation of constructibility was straight forward. The question was whether or not any significant obstacles to construction existed and, if so, how could they be overcome. The performance question was more complex and was divided into two categories: 1) performance of samples in standard ASTM laboratory tests, and 2) subjective/analytical evaluation of the in-place shotcrete liner. The standard laboratory tests were compression (ASTM C-42), flexural toughness (ASTM C-1018), and percent permeable voids (ASTM C-642). The evaluation of the in-place shotcrete is subjective and analytical because crack determination is subjective and because projections of cracking were made to determine a value called apparent incipient cracking.

APPROACH

The Arizona Transportation Research Center (ATRC) prepared an experimental plan to evaluate the different fibers used as secondary temperature reinforcement. The experimental plan was implemented by a change order at a cost of $5,600.00. The salient portions of the special provisions and the change order are included in APPENDIX A.

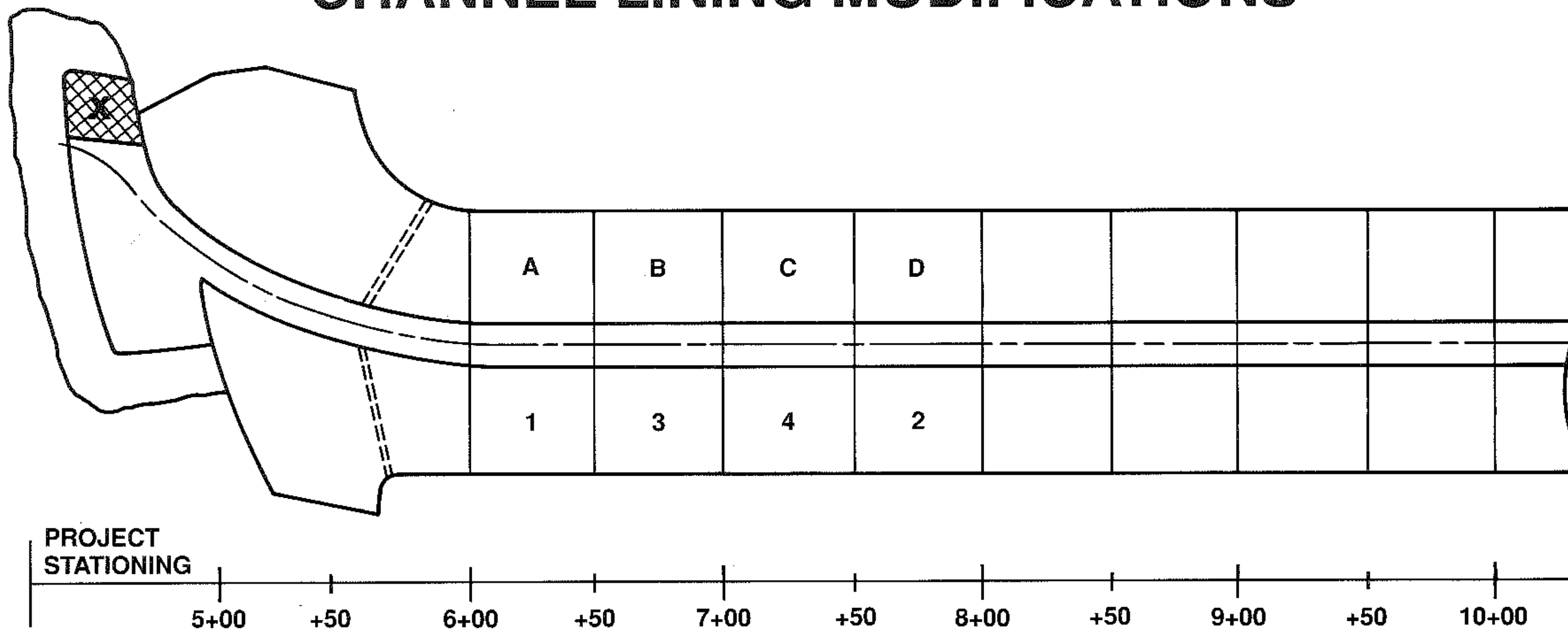
As is the normal procedure when beginning an experimental project a workplan was prepared that was acceptable by both ADOT management and the Federal Highway Administration (FHWA). The workplan is contained in APPENDIX B. The workplan outlines the laboratory testing program and the field evaluation program. The workplan was prepared after gathering comments from the various fiber manufactures and by reviewing available literature.

Experimental Plan

The experimental layout (Figure 6) shows a portion of the channel lining that has conventional secondary temperature reinforcement. This section was included to allow for a comparison between fiber reinforcing and conventional reinforcing. Unfortunately, the conventionally reinforced section was covered with mud shortly after construction when a heavy rainstorm occurred. Therefore no conclusions can be drawn about the difference in performance between fiber reinforcing and conventional secondary temperature reinforcing.

Ideally, an experiment to evaluate the effect of fiber reinforcing on shotcrete would systematically vary the fiber lengths, configurations, and chemical composition. This would allow a statistically valid conclusion to be reached about the effects of each of these factors on any of a number of responses (such as flexural toughness, compressive strength, percent permeable voids, and percent cracking). Due to limited resources this was not possible, and therefore only conclusions about the differences in responses between fiber brands is possible. However, if any one of the fibers had performed better than the others some extrapolations about fiber length, configuration, or chemical composition might have been possible.

EAST TUNNEL OUTFALL ACI-10-3(270)
CHANNEL LINING MODIFICATIONS



TYPE	SECTION	FIBER NAME	DOSAGE	FIBER LENGTH	DESCRIPTION
1	A	FIBERMESH	1.6 #/cy	1/2"	COLLATED FIBRILLATED POLYPROPYLENE BUNDLES
2	D	NURLON	1.0 #/cy	3/4"	MONOFILAMENT POLYETHYLENE TERPHTHALATE
3	B	FIBER-LOK	1.6 #/cy	3/4"	MONOFILAMENT POLYPROPYLENE
4	C	FORTA	1.6 #/cy	1 1/2"	COLLATED FIBRILLATED POLYPROPYLENE TWISTED BUNDLES
–	X	N/A	N/A	N/A	CONTROL SECTION APPROXIMATELY 25' X 25' #4 BARS @ 12"O.C. BOTH DIRECTIONS

FIGURE 6. EXPERIMENTAL LAYOUT

Material Test Plan

Material tests were performed to assess the difference between the properties of shotcrete containing each of four different fiber types and shotcrete without fibers. The material properties measured were; concrete slump before and after fiber addition, 28 day compressive strength of cylinders molded from the same truck mixer load before and after fiber addition, and the compressive strength, flexural toughness, and percent permeable voids of beam and core samples extracted from fiber reinforced shotcrete panels fabricated during construction.

A 4'x4' sheet of polyethylene was placed in the southeast corner of each test section. The purpose of the polyethylene was to provide a bond break between the first and second applications of shotcrete so that after two years beam and core samples could be extracted from the lining. The beam and core samples extracted from the lining were to be tested along with samples that were extracted from the 2'x3' shotcrete test panels fabricated at the time of construction and subsequently stored for two years. Both sets of samples were tested, at the same time, according to ASTM C-1018 and ASTM C-42.

During the construction of each test sections four truck mixers were chosen at random to provide shotcrete samples for testing. Testing included eight slump tests: each truck had a slump test before the addition of fibers and after addition of fibers (Figure 7). There were a total of sixteen molded cylinders made from each test section (Figure 8). Each truck had two cylinders molded without fiber and two cylinders molded with fibers. There were a total of four shotcrete panels fabricated during the construction of each test section (Figure 9). One panel was fabricated from each of four tucks randomly selected from the group of 15 or 16 truck mixers required to provide the approximately 110 cubic yards of shotcrete required for each test section.

FIGURE 7. SLUMP TEST

FIGURE 8. MOLDED CYLINDERS

FIGURE 9. SHOTCRETE TEST PANELS

PROJECT LOCATION AND DESCRIPTION

The construction project, ACI-10-3(270), which is the subject of this report is located in the middle southern portion of Arizona. Specifically it is located in central Phoenix between 19th and 20th streets just south of University drive. The outfall was constructed for draining storm water from the north south running portion of Interstate 10 that is sometimes called the inner loop freeway.

CONSTRUCTION

The construction activities related to ACI-10-3(270) consisted of modifying the outfall channel and included consolidating the dumped riprap, removing debris from the surface of the existing gabions and dumped riprap and applying shotcrete to the bottom and sides of the existing channel and additional project related work. The construction of this project was divided into two phases: 1) preparation of the channel for the 5" thick lining of fiber reinforced shotcrete, and 2) the application of the fiber reinforced shotcrete.

Phase 1

The application of shotcrete to cover the gabions contained no reinforcing fibers. Project specifications called for the first layer of shotcrete to penetrate the 18" gabion mattress to a depth of 8". Since ADOT is interested mainly in the performance of fiber reinforced shotcrete no detailed account of this phase of the construction is given except that the specification called for no curing agent to be used on this shotcrete. The curing agent was not permitted in order to promote a better bond between the first and second application. Sprinklers were used for seven days to give the first application a moist cure (Figure 10).

Upon completion of phase 1 the gabions of the channel slope were completely covered and only portions of the gabion stones wire baskets were visible (Figure 11). It was believed that the exposed wire would help bond the two applications of shotcrete.

Phase 2

Phase 2 began with the application of the 5" thick fiber reinforced shotcrete lining. The second application began at the north end of the project as did the first application. All sections of the lining contained Fibermesh fibers except the test sections which each contained one of the four fibers being tested. Calmat of Arizona supplied the shotcrete. The mix design for both the first and second application of shotcrete can be found in Appendix C. Calmat delivered the shotcrete to the project in 10 cubic yard truck mixers. The fibers for the test sections were added to the concrete when the trucks arrived on the job site. The fibers for all other sections were added to the shotcrete mix by Calmat at the batch plant. Each manufacturer of reinforcing fiber was contacted in advance to approve the on-site introduction of fibers. R.R. Hensler, Inc. construction company performed the work.

FIGURE 10. WET CURING OF FIRST APPLICATION OF SHOTCRETE

FIGURE 11. SURFACE OF FIRST APPLICATION OF SHOTCRETE

Construction Equipment

The type of shotcreting used in this project is termed "wet" in ACI 506R-85 *Guide to Shotcrete*. The term wet means the ingredients are already mixed when being introduced into the pump. There were two shotcrete pumps on the job, one for each side of the channel. Because only the west facing side of the channel was formally monitored the pumps were not interchanged and remained on their respective sides throughout shotcreting of the test sections. The shotcrete pump used for this project was a Mayco ST-30 and is shown in Figure 12. APPENDIX D contains manufacturer specifications for the Mayco ST-30.

FIGURE 12. SHOTCRETE PUMP

The diameter of the pump outlet and the hosing used on this job is of particular importance because plugging of the hosing is one of the construction concerns with shotcreting. The outlet from the pump is 5" which is connected directly to a 90° elbow that reduces to 3". Figure 13 shows the final reducer (3" to 2") that connects the 90° elbow to the hosing. The shotcrete nozzle is attached at the end of the hosing and has a diameter of 1" (Figure 14).

The addition of the fiber on-site was handled by erecting a small platform from which a worker could drop the fibers into the truck mixer drum (Figure 15). In some cases it was necessary for the truck mixer driver to assist by washing the fibers down into the drum with water (Figure 16). When the truck mixer arrived on-site the driver was instructed to reverse the direction of the drum in order to bring the mix to the top of the drum. Once the fibers were added the driver was instructed to rotate the drum at high speed, 18 revolutions per minute, for five minutes. All fibers appeared to be thoroughly mixed after this procedure was followed.

FIGURE 13. FITTINGS USED ON SHOTCRETE PUMP

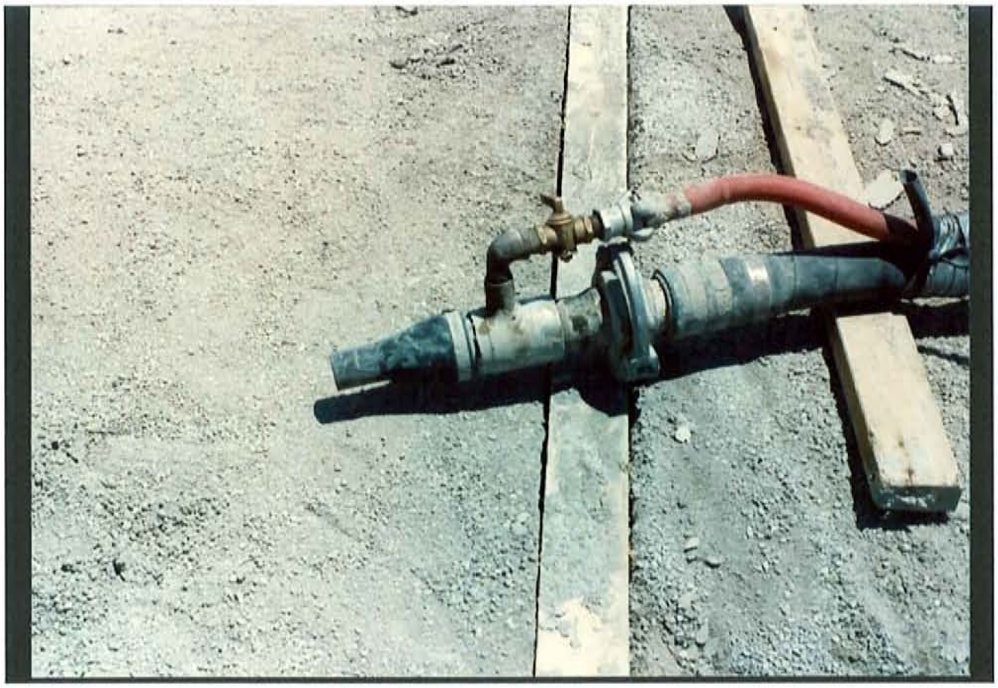


FIGURE 14. SHOTCRETE NOZZLE

FIGURE 15. ADDITION OF FIBERS TO SHOTCRETE TRUCK MIXER

FIGURE 16. WASHING OF FIBERS INTO SHOTCRETE TRUCK MIXER

Activities

In order to apply the shotcrete to the intended surface, benches were erected on the slope of the channel (Figure 17). The nozzle operator stood on the benches and one other worker helped to handle the hosing.

FIGURE 17. BENCHES USED TO APPLY SHOTCRETE

There was occasional plugging of the shotcrete hosing. This plugging occurred during both the fiber reinforced shotcreting and plain shotcreting operations. The plugging was alleviated by disassembling the fittings located between the flexible hosing and the shotcrete pump and clearing obstructions.

Work for each of the test sections began at approximately 5:00 am and required a full eight hour day and approximately 110 cubic yards of shotcrete to complete. Some specific information will now be given on the construction of each test section.

Test Section D

Test section D, which contained Nurlon fibers, was the first test section constructed. Work for this test section took place on August 4, 1989. The maximum temperature that day was 105° F. Fifteen, 10-cubic yard capacity, truck mixers were required to construct this test section. Each truck mixer contained approximately 7 cubic yards. The 4th, 6th, 9th, and 13th trucks were selected for material sampling. The shotcrete pump pressures corresponding to the loads being tested were 1500 psi, 1200 psi, 1400 psi, and 1400 psi respectively. Three gallons of water were added to the 6th truck, after material samples had been obtained, to facilitate pumping.

Test Section C

Test section C, which contained Forta CR fibers, was the second test section constructed. Work for this test section took place on August 7, 1989. The maximum temperature that day was 106° F. The 4th, 7th, 10th, and 15th truck mixers were selected for material sampling. Fifteen truck mixers were required to provide shotcrete for this test section. Pump pressures were unacceptably high during pumping of many of the shotcrete loads and necessitated that construction personnel add water to facilitate pumping. Truck number 1 required 16 gallons of water, truck number 3 required 14 gallons of water, truck number 4 required 4 gallons of water, truck number 6 required 4 gallons of water, and truck number 7 required 10 gallons of water.

Test Section B

Test section B, which contained Fiber-Lok fibers, was the third test section constructed. Work for this test section took place on August 8, 1989. The maximum temperature for the day was 107° F. The 4th, 10th, 14th, and 15th truck mixers were selected for material sampling. The shotcrete pump operator commented that this material pumped very similar to the material in test section D. No additional water was required in this section.

Test Section A

Test section A, which contained Fibermesh fibers (as did the other portions of the channel lining that were not formally monitored) was the fourth test section constructed. Work for this test section took place on August 9, 1989. The maximum temperature for the day was 108° F. The 4th, 7th, 9th, and 14th trucks were chosen for material sampling. No additional water was required to facilitate pumping in this section. There was a pump breakdown during construction of this test section; but it was repaired by replacing a hydraulic seal.

Control Section

The control section was the last portion of shotcreting on the job and contained no reinforcing fibers. This section was completed August 14, 1989. As mentioned previously this section was submerged under water and mud and was therefore invalidated as a control section. There were also some pumping problems in this section, which indicate that the pumping equipment, mix design, or some factor other than the fibers contributed to the pumping problems experienced in the other sections.

Flooding

Four days after the contractor completed the shotcreting operation, rain fell in the area of the project. The precipitation at Phoenix Sky Harbor International Airport, which is extremely close to the project site, was recorded as 0.45" and 0.63" for August 15th and 16th respectively. The contractor was about ready to apply joint sealer to the construction joints on the project but the rain occurred before this could be accomplished. In addition to the rain falling directly on the project and getting moisture in the joints there was also a discharge of storm water in the channel from the rain falling on the inner loop freeway (Figure 18). The control section, was covered with approximately 6" of mud.

FIGURE 18. FLOOD FOUR DAYS AFTER SHOTCRETE COMPLETION

MATERIAL TEST RESULTS

Beam and core samples taken at the time of construction were tested according to three ASTM procedures. Slump tests were performed before and after the addition of fibers to give an indication of the effect of fibers on shotcrete workability.

Samples extracted from shotcrete panels, fabricated during construction of each test section, were stored indoors for two years. The samples were stored indoors for two years so they could be compared against beam and core samples extracted from the lining after two years. This should have given information about the environmental deterioration of fibers. Unfortunately, the samples taken from the liner were highly irregular and did not yield useful information. The results from these irregular beams are reported in the interest of completeness.

The test results from samples taken during construction are given first under the heading of Unaged Samples. Subsequent testing results, after two years, for samples stored and samples extracted from the channel lining are given under the heading of Aged Samples.

Unaged Samples

Specimens collected during the construction of ACI-10-3(270) were tested according to ASTM C-1018 for flexural strength and toughness, ASTM C-642 for percent permeable pore space, and ASTM C-42 for cylinder compressive strength. ADOT Material Testing Services performed the tests on the cylinders while Western Technologies Inc. performed all other tests. In addition to these laboratory tests, slump tests were performed in the field by ADOT personnel.

Tests of flexural strength and toughness of the fiber reinforced shotcrete were conducted for each of the four test sections A, B, C, and D, where fiber reinforced shotcrete was used. For each test section, a set of eight 21"x6"x5" beam samples, each containing eight specimens were used. For test section X where plain shotcrete was used four beam specimens were used for testing flexural strength and toughness. Pieces of the broken beams were used for determining the percent of permeable pore space. Table 2 summarizes the results of tests conducted on beams cut from the shotcrete test panels.

TABLE 2. SUMMARY OF CONCRETE BEAM TEST RESULTS

TEST SECTION	AVERAGE FLEXURAL STRENGTH (PSI)	AVERAGE FIRST CRACK TOUGHNESS (IN-LBS)	AVERAGE VOLUME OF PERMEABLE PORE SPACE
A (Fibermesh)	552.5	121.5	19.7
B (Fiber-Lok)	546.3	137.6	19.9
C (Forta)	591.3	160.9	20.2
D (Nurlon)	593.8	139.1	19.7
X (No Fiber)	587.5	119.3	19.1

To make comparisons between the five test sections, an analysis of variance (ANOVA) was carried out independently on three response variables: flexural strength, first crack toughness, and percent permeable pore space. The results of all three ANOVA showed that at the 5% significance level, that there were no differences between the test sections in terms of flexural strength, first crack toughness, or percent permeable pore space.

Similar statistical analysis and hypothesis testing were performed on the data sets gathered from molded cylinder and panel cylinder compressive strength test results. The results of testing on molded cylinder for compressive strength are summarized in Table 3.

TABLE 3. MOLDED CYLINDER COMPRESSIVE STRENGTH RESULTS

TEST SECTION	FIBERS	NUMBER OF CYLINDERS	MEAN COMPRESSIVE STRENGTH (PSI)	STANDARD DEVIATION
A	NO	8	5094	324.9
A	YES	8	4965	468.5
B	NO	8	4967	146.7
B	YES	8	4901	182.8
C	NO	8	4957	320.0
C	YES	8	4914	374.9
D	NO	8	4492	540.1
D	YES	8	4740	178.3
ALL	NO	32	4877	414.4
ALL	YES	32	4880	321.5

The results of hypothesis testing using paired t-tests on cylinder compressive strength data showed that, at 5% significance level, fibers had no effect.

Using ANOVA and DUNCAN's multiple comparison procedure, the average compressive strength of those cylinders, made out of the batches of plain shotcrete, which was used in the Nurlon test section (D), were significantly different from that of the plain shotcrete used in the other test sections. Interestingly enough, this difference between the test sections could not be observed when average compressive strengths obtained for cylinders-with-fibers were compared.

The results obtained from 28-day compressive strength test results is summarized in Table 5. All cylinders were cored from the 2'x3' shotcrete test panels and therefore all cylinders were fiber reinforced.

Similar analyses were carried out on panel compressive strength data set to make comparisons between the concrete properties of the five different test sections. Using DUNCAN's procedure, test sections B, C, and D differ significantly from test section A at the confidence level of 95%. However, these differences were not significant at the same confidence level when the more conservative SCHEFFE's procedure was used.

Another analysis was made between molded cylinder compressive strengths and panel cylinder compressive strengths to identify any differences. From the analysis, it was found that there exists a significant difference between the compressive strengths measured from the two types of test specimens. This difference was also observed separately in all test sections.

TABLE 4. 28-DAY PANEL COMPRESSIVE STRENGTH TEST RESULTS

TEST SECTION	NUMBER OF CYLINDERS	MEAN 28-DAY COMPRESSIVE STRENGTH (PSI)	STANDARD DEVIATION
A	8	4170.3	450.7
B	8	3431.5	673.4
C	8	3487.1	666.4
D	8	3474.1	282.1
X	4	3882.0	73.0

The next data set that was analyzed contained the measured slump values before and after the addition of fibers to the shotcrete. When the data was grouped so that all tests with fibers and all tests without fibers were compared the analysis revealed that there is a significant effect on slump due to the addition of fibers and/or additional mixing. But in two independent analysis for test section A and C, average slump values for the two cases, before-and-after fiber added, appeared to be the same. For test sections B and D, the two average slump values were different. A summary of the test results is given in Table 5.

TABLE 5. SLUMP TEST RESULTS

TEST SECTION	NUMBER OF READINGS	MEAN SLUMP BEFORE FIBERS	MEAN SLUMP AFTER FIBERS
A	4	2.81	2.44
B	4	3.44	2.75
C	4	2.75	2.00
D	4	3.19	2.63

Aged Samples

Two years after the construction of the channel, beam and core samples from each of the test sections were extracted. These samples along with the shotcrete test panel samples that had been stored were sent to ATL Testing Laboratories in Phoenix, Arizona for testing. Table 6 shows the results of the panel shotcrete beams that were stored indoors for two years. Table 7 shows the results of panel shotcrete cylinders that were stored indoors for two years.

TABLE 6. SUMMARY OF AGED CONCRETE BEAM TEST RESULTS

TEST SECTION	AVERAGE FLEXURAL STRENGTH (PSI)	STANDARD DEVIATION	AVERAGE FIRST CRACK TOUGHNESS (IN-LBS)	STANDARD DEVIATION
A (Fibermesh)	495.00	83.88	26.91	17.87
B (Fiber-Lok)	440.00	46.64	37.35	10.28
C (Forta)	521.43	113.31	43.89	21.31
D (Nurlon)	443.13	47.35	43.93	18.33

TABLE 7. AGED PANEL COMPRESSIVE STRENGTH TEST RESULTS

TEST SECTION	NUMBER OF CYLINDERS	MEAN COMPRESSIVE STRENGTH (PSI)	STANDARD DEVIATION
A	8	4293.75	514.39
B	8	4343.75	403.13
C	8	4575.00	509.20
D	8	4620.00	608.82

ANOVA carried out at the 5% significance level show that there is no difference in flexural strength, first crack toughness, or compressive strength for any of the different fibers.

The plan for extracting samples from the lining for testing included four 21"x6"x5" beams and four 2.75" diameter cores. As mentioned, during construction a 4'x4' polyethylene sheeting was placed in the upper northeast portion of each test section between the first application of shotcrete and the second application of shotcrete. This sheeting was to act as a bond breaker to allow the retrieval of samples.

Some shifting of the 4'x4' polyethylene sheeting had taken place during the construction of all test sections. Also, the surface of the first application of shotcrete was highly irregular. Because of these two problems a great deal of difficulty was encountered when trying to extract samples from the lining. Only one beam and two cores from each test section could be extracted.

Tables 8 and 9 give the results of testing conducted on the shotcrete beam and core samples extracted from the lining.

TABLE 8. EXTRACTED BEAMS TEST RESULTS

TEST SECTION	FLEXURAL STRENGTH (PSI)	AVERAGE FIRST CRACK TOUGHNESS (IN-LBS)
A (Fibermesh)	370	33.75
B (Fiber-Lok)	Beam could not be tested due to dramatic cavities	
C (Forta)	485	26.25
D (Nurlon)	420	60.75

TABLE 9. EXTRACTED CORES TEST RESULTS

TEST SECTION	COMPRESSIVE STRENGTH (PSI)
A (Fibermesh)	3330
B (Fiber-Lok)	4100
C (Forta)	3040
D (Nurlon)	4110

EVALUATION OF CRACKING IN TEST SECTIONS

Crack Mapping

All visible cracks in the test sections were marked with white paint. Full section photographs were taken in order to measure the linear feet of cracking (Figures 19, 20, 21, 22). These full section photographs were enlarged to 8x10 and a geometrically scaled grid system was superimposed onto the photograph. A map measure was used to measure linear feet of cracking in each cell of the grid system and was then converted to actual feet of cracking (Table 10). When cracks were extended, they tended to form block patterns on the order of 10'x10'. The linear feet of cracking associated with the extension of cracks in blocks is referred to as apparent incipient cracking in Table 10 and Figures 23, 24, 25, and 26.

FIGURE 19. INITIAL CRACK EVALUATION: TEST SECTION A

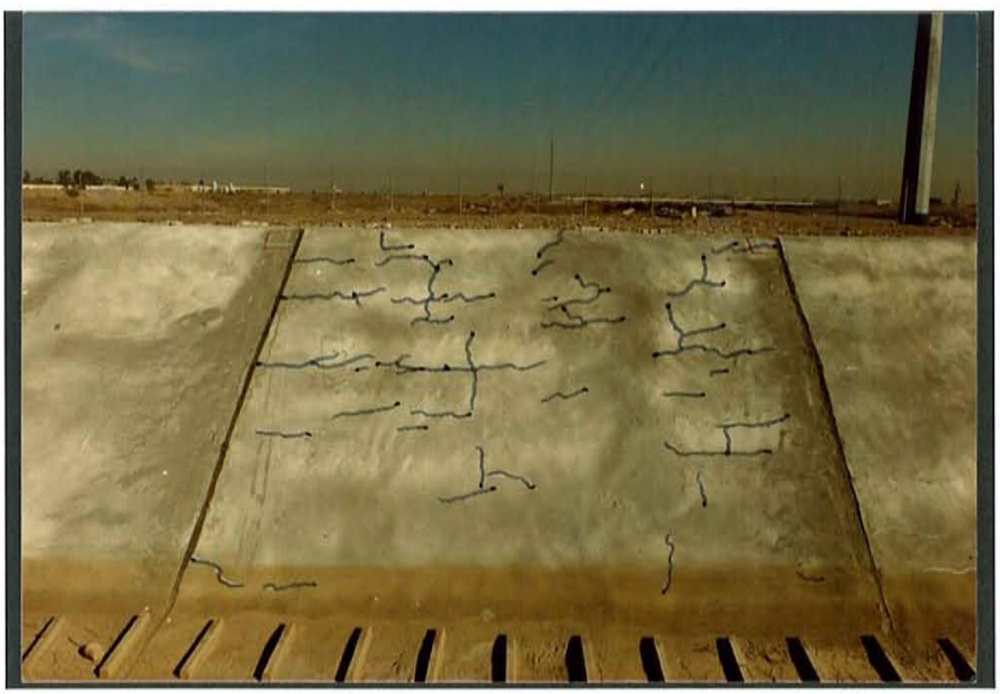


FIGURE 20. INITIAL CRACK EVALUATION: TEST SECTION B

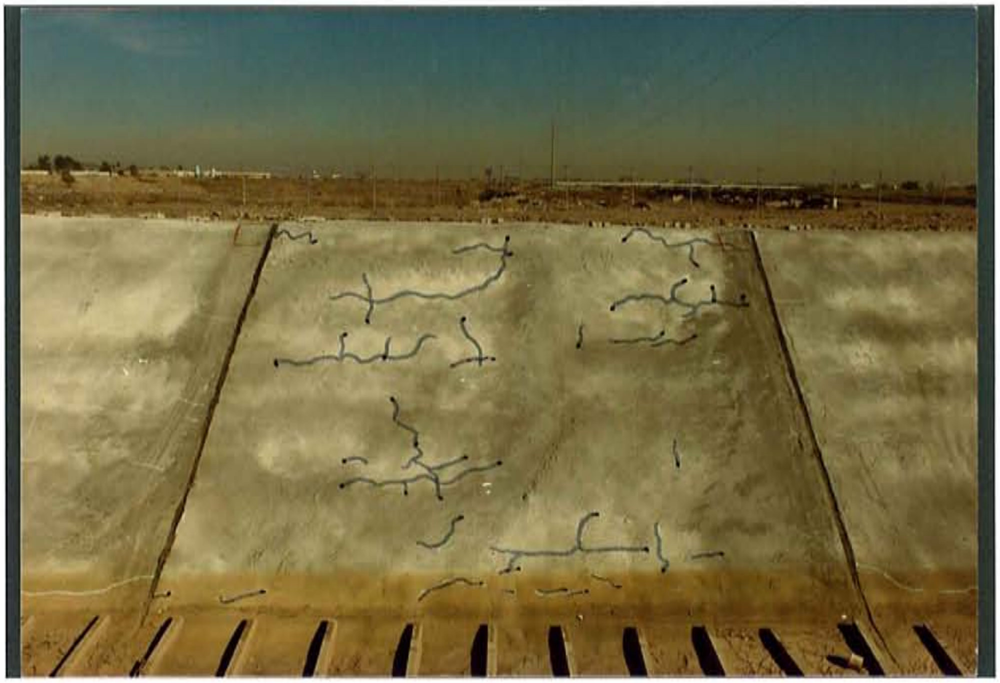


FIGURE 21. INITIAL CRACK EVALUATION: TEST SECTION C

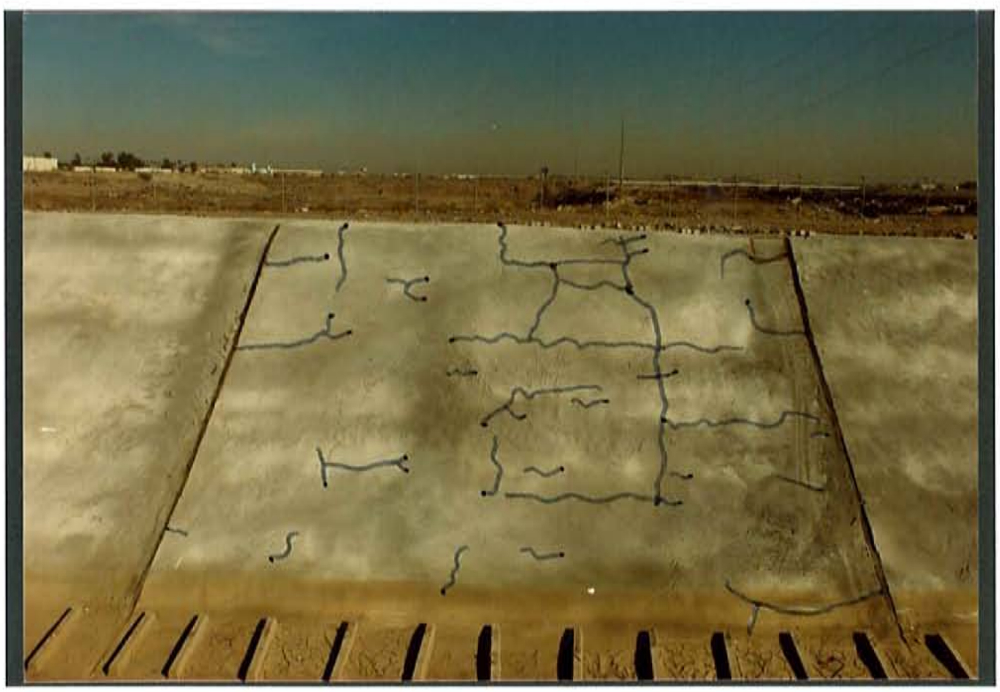


FIGURE 22. INITIAL CRACK EVALUATION: TEST SECTION D

FIGURE 23. APPARENT INCIPIENT CRACKING: TEST SECTION A

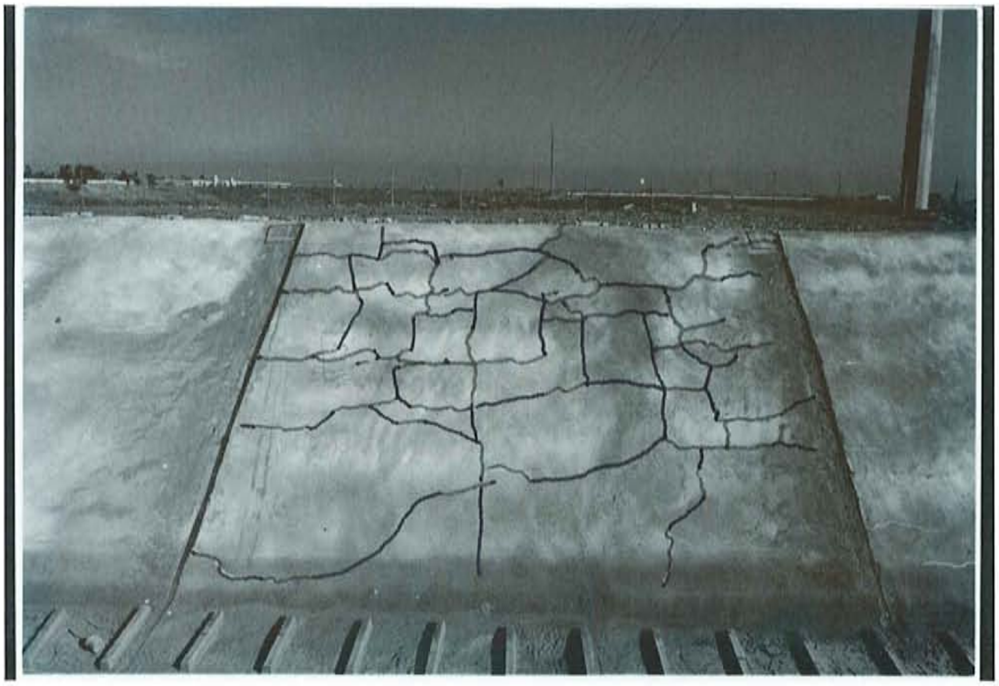


FIGURE 24. APPARENT INCIPIENT CRACKING: TEST SECTION B

FIGURE 25. APPARENT INCIPIENT CRACKING: TEST SECTION C

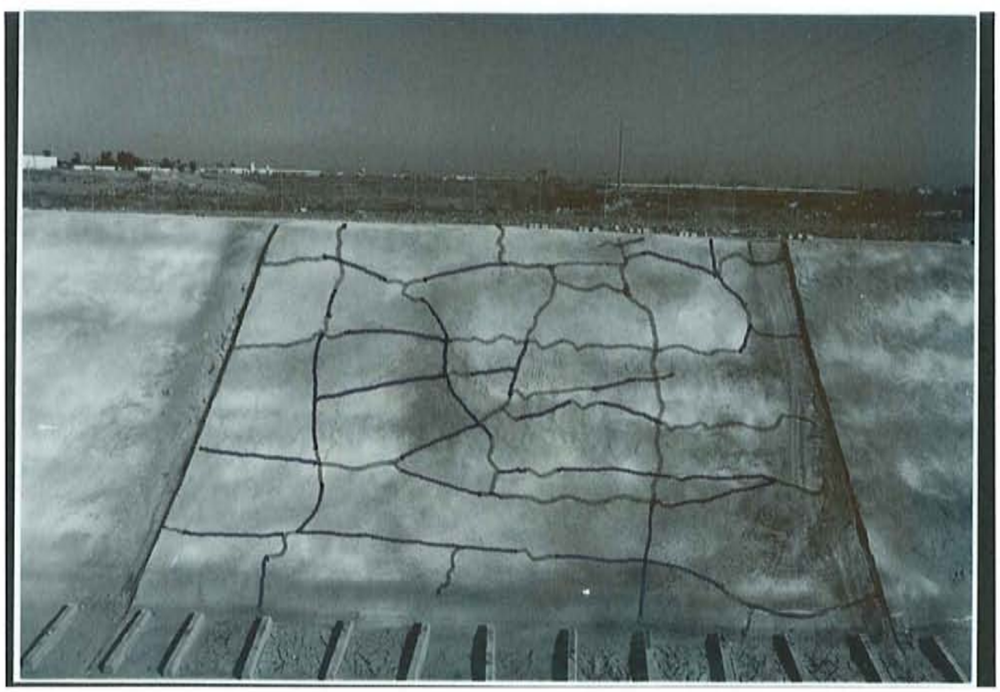


FIGURE 26. APPARENT INCIPIENT CRACKING: TEST SECTION D

TABLE 10. ACTUAL AND APPARENT INCIPIENT CRACKING

TEST SECTION	ACTUAL CRACKING (FT)	APPARENT INCIPIENT CRACKING (FT)
A	406.7	580.7
B	304.2	440.3
C	227.2	437.3
D	292.1	488.7

The apparent incipient cracking did not develop. This can be taken as an indication that the fibers had some ability to prevent crack propagation.

Crack Measurements

Six cracks from each test section were selected for measurement and monitoring. Two levels of severity were designated, with three cracks of each severity being selected for monitoring. The cracks were located with x-y coordinates having an origin in the south corner of each test section. Cracks were measured shortly after construction, approximately one year after construction. Table 11 shows the results.

TABLE 11. CRACK WIDTHS

TEST SECTION	X COORDINATE	Y COORDINATE	CRACK WIDTH (inches) 11/7/89	CRACK WIDTH (inches) 1/11/91	CHANGE
D	49.9	16.8	0.02	0.03	.01
	44.6	6.4	0.02	0.03	.01
	41.6	29.0	0.01	0.03	.02
	18.7	32.2	0.05	0.06	.01
	13.9	24.0	0.03	0.04	.01
	6.4	19.6	0.05	0.06	.01
C	38.6	9.8	0.01	0.02	.01
	34.4	32.4	0.06	0.06	---
	30.7	10.8	0.05	0.05	---
	27.7	16.2	0.01	0.02	.01
	10	15.9	0.02	0.03	.01
	5.4	8.9	0.01	0.01	---
B	43.1	19.5	0.04	0.04	---
	41.9	10.9	0.01	0.05	.04
	37.2	3.9	0.04	0.06	.02
	31.1	25.2	0.03	0.04	.01
	11.7	17.2	0.06	0.06	---
	8.8	26.9	0.02	0.03	.01
A	40.6	8.5	0.02	0.02	---
	35.1	14.6	0.03	0.03	---
	34.7	30.5	0.01	0.03	.02
	30.1	2.7	0.04	0.04	---
	19.2	8.7	0.02	0.02	---
	12.2	28.1	0.04	0.04	---

The table indicates that 14 of the 28 cracks, or 58 percent, have widened an average of 0.014 inches. In light of temperature changes that would have taken place and the difficulty in measuring cracks to the one-hundredth of an inch on a unfinished (not trawled) surface it is difficult to say that the fibers have not held the cracks together.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this project was to evaluate fiber reinforced shotcrete. The objective was carried out by evaluating a channel lining that incorporated fiber reinforcing and by carrying out a laboratory testing program. If the fibers had proven effective, both in terms of field performance and in terms of laboratory testing, a standard specification would have been developed. The fibers did not prove effective with respect to laboratory testing and therefore no standard specification is forthcoming.

It is usually difficult to draw a conclusion with respect to a product on the basis of one project. Some products may be more applicable in certain situations than others. From a statistical viewpoint one project is a sample size of one.

A control section was included in this project that would have yielded information with respect to the differences between conventional secondary reinforcement and synthetic fiber reinforcement. The loss of the control section due to flooding was indeed a significant hindrance to the evaluation. If a factorial experiment which varied the fiber lengths and dosages could have been implemented that would have provided data to make statistically valid inferences. The number of test sections required for this type of experiment was prohibitive.

The reader should keep in mind that reinforcing steel and synthetic fibers are different approaches to crack control. Reinforcing steel is intended to hold cracks together once they occur. Of course the effectiveness of the reinforcing steel (or wire mesh) is dependent upon the steel being placed and maintained at the correct depth during the construction process. Synthetic fiber reinforcing is intended to prevent bleeding and to redistribute stresses in the plastic shotcrete.

In the view of the authors the crack evaluations of the test sections indicated that one of the fibers (Forta-CR) had less cracking than the others. The authors believe that this is due to the length of those fibers.

The laboratory test plan did not indicate any effect on shotcrete from synthetic fibers. Slump tests, performed in the field, indicated that fibers do reduce slump. However there is not indication that fibers reduce pumpability or workability. The beams cut from shotcrete test panels did not indicate any toughness beyond first crack. The reader should bear in mind that the test developed specifically for fiber reinforcing (ASTM C1018) was developed for steel fiber. The authors believe that higher doses of synthetic fibers are necessary before any toughness beyond first crack will be observed.

The work done on this project does not show that fibers are beneficial at the dosages used. However, the authors recommend additional laboratory and field testing at varying fiber lengths and dosages. If the fibers should prove to have an effect at higher dosages then economics become the question.

REFERENCES

1. American Society for Testing Materials, "Standard Specifications for Fiber Reinforced Concrete and Shotcrete", ASTM C116-89, 1989.

2. Panarese, William C., "Fiber: Good for the Concrete Diet ?", Civil Engineering, May 1992.

3. Zellers, Robert C., "High Volume Applications of Collated Fibrillated Polypropylene Fiber" Fiber Reinforced Cements and Concretes: Recent Developments 1989.

4. Neville, A.M., Properties of Concrete, Longman Scientific and Technical, 1981.

APPENDIX A: SPECIAL PROVISIONS AND CHANGE ORDER

ARIZONA DEPARTMENT OF TRANSPORTATION

ADVERTISEMENT FOR BIDS

BID OPENING: FRIDAY, JUNE 9, 1989 AT 11:00 A.M.

PROJECT NO: ACI10-3(270)
TRACS NO: 10MA 149 H 0128 05C
TERMINI: PHOENIX-CASA GRANDE HIGHWAY
LOCATION: East Tunnel Outfall Modification

ROUTE NO.	DISTRICT	ITEM NO.
I-10	1	463

The location and description of the proposed work and the representative items and approximate quantities are as follows:

The proposed work is located in the City of Phoenix South of University Drive, between 19th and 20th Streets. Major cross streets are 16th Street and University Drive, approximately one mile south of Interstate 10 and the 16th Street Traffic Interchange. The work consists of modifying the outfall channel and includes consolidating the dumped riprap, removing debris from the surface of existing gabions and dumped riprap and applying shotcrete to the bottom and sides of the existing channel and additional project related work.

Pipe, Reinforced Concrete, 24"	L.Ft.	120
Headwall	Each	1
Concrete Curb, Precast (Roughness Control Device)	Each	224
Shotcrete (First Application)	Sq.Yd.	7,970
Shotcrete (Second Application)	Sq.Yd.	10,450
Force Account Work (Channel Surface Preparation)	L.Sum	1
Construction Survey and Layout	L.Sum	1

The number of working days specified for the completion of the work is 60.

The Arizona Department of Transportation hereby notifies all bidders that pursuant to this advertisement for bids, Disadvantaged Business Enterprises will be afforded full opportunity to submit bids in response to this solicitation and will not be discrimated against on the grounds of race, color, sex, or national origin in consideration for an award.

The minimum goals for participation by Disadvantaged Business Enterprises in the work, as a percentage of the total amount bid, shall be 0.

SPECIAL PROVISIONS
ARIZONA PROJECT ACI 10-3(270)
10 MA 149 H0128 05C

EAST TUNNEL OUTFALL MODIFICATION

PROPOSED WORK:

The proposed work is located in the City of Phoenix south of University Drive, between 19th and 20th Streets. Major cross streets are 16th Street and University Drive, approximately one mile south of Interstate 10 and the 16th Street Traffic Interchange. The work consists of modifying the outfall channel and includes consolidating the dumped riprap, removing debris from the surface of existing gabions and dumped rip rap and applying shotcrete to the bottom and sides of the existing channel and additional project related work.

PROJECT DESIGNATION:

All references on the project plans to Project I 10-3(270) shall be changed to read Project ACI 10-3(270).

ITEM 9120001A - SHOTCRETE (First Application):
ITEM 9120001B - SHOTCRETE (Second Application):

Description:

Shotcrete shall conform to the requirements of Section 912 for the wet mix process except as modified by these special provisions.

General:

Shotcrete shall be applied in two separate applications. The purpose of the first application is to fill the voids between the rocks in the gabions to a minimum depth of 9 inches and the voids in the riprap at the bottom and ends of the channel to a minimum depth of 18 inches. The second application shall have a minimum thickness of 5 inches.

Materials:

Materials shall conform to the requirements of Subsection 912-2 except for the following:

Reinforcement:

Reinforcing shall be a collated fibrillated, twisted bundle, polypropylene fibrous reinforcement and shall contain chemically and alkali inert, virgin polypropylene.

The fibrous reinforcement shall have the following physical characteristics:

Characteristic	Requirement	Test Method
Specific gravity:	0.91	ASTM D-792
Tensile strength:	70 ksi minimum	ASTM D-1682
Modulus of elasticity:	0.70×10^6 psi	ASTM C-469

Fiber length: as recommended by the manufacturer.

Certificates of Compliance will be required in accordance with Subsection 106.05.

Surface Sealant:

Surface sealant shall be a waterproofing material of the penetrating type that contains no added chlorides or sodium compounds, is organic, non-toxic, resists chemical attack and conforms to the following:

	Physical Property	Result	Test Method
	Adhesion	175± 9 psi	ASTM C-452
	Tensile Strength	332± 16 psi @ 100% RH 118± 6 psi @ 50% RH	ASTM C-190
	Flexural Strength	472± 24 psi	ASTM C-580
*	Permeability	2.63 x 10\-10 ± 5% CM/Sec (1 coat)	CRD-48-73

* Tested at water heads of 461± ft. (200 psi) for surface waterproofing.

The contractor shall obtain from the manufacturer, for submittal to the Engineer, SEM photographic proof showing penetration into a substrate which has received application of the waterproofing material.

Certificates of Compliance will be required in accordance with Subsection 106.05.

Joint Sealant:

Joint sealant shall consist of styrene butadiene styrene black polyer cross-linked with bitumen. It shall have an elongation greater than 2000 percent and retain flexibility at temperatures down to -25 degrees C. The joint sealant shall be resistant against rodents, roots, salt solutions, diluted acids, and shall be stable against aggressive water.

The joint sealant shall conform to the following:

Physical Property	Result		Test Method
Viscosity @ 180° C.	2000 approximate		ASTM D2170
Viscosity @ 160° C.	3000 approximate		
Tensile strength and elongation (25° C, 50 cm/min elongation speed)			
Modulus 300% - Kp/Cm^2		0.8± .04	ASTM D2523
Modulus 500% - Kp/Cm^2		1.3± .07	
Puncture elongation - percent		2200± 110	ASTM D1708
Puncture resistance - Kp/Cm^2		10.5± 0.5	
Olinsis resistance 3 day, 50° C with B-80 used as impregnating fluid	mm	0.3± 0.015	ASTM D1370
Stain test, 18 hrs, 100° C		6-7	ASTM D1328

The contractor shall furnish the Engineer with three sample strips of cured joint sealant material 1"x6"x1/2" thick. Strips shall be able to be extended 400 percent by hand without fracturing. Follow extenstion, the material shall have the recovery and memory to return to the original configuration within 5 minutes.

Certificates of Compliance will be required in accordance with Subsection 106.05.

Construction Requirements:

Construction requirements shall conform to the requirements of Subsection 912-3 except for the following:

First Application:

The first application of shotcrete shall be premixed non-reinforced mortar and shall consist of not less than 6.0 sacks of portland cement per cubic yard, fine aggregate and water mixed to a desired consistency, generally to a slump that will provide the penetrations specified above for gabions and riprap.

The material may be mixed at a central mixing plant or at the project site. If mixing is done at the project site, the mixer shall be capable of thoroughly mixing the specified materials in sufficient quantity to maintain continuous placing of the mortar.

Second Application:

The second application of shotcrete shall not be placed until the entire first application of shotcrete has been completed.

The contractor shall determine the mix proportions and shall furnish concrete for pneumatic placement which contains a minimum of 7 sacks of portland cement per cubic yard of concrete and which attains a minimum 28-day compressive strength of 3,000 psi. Fine aggregate and coarse aggregate shall conform to the requirements of Subsection 912-2.02. The total mix shall contain, by weight, 15 to 20 percent coarse aggregate.

If ready-mixed concrete is used, it shall conform to the requirements of ASTM C 94.

Fibrous reinforcement shall be added to the mix for the second application at the time of batching in an amount of 1.6 + lbs. per cubic yard of concrete as directed by the Engineer and by a method recommended by the manufacturer to assure a uniform and complete dispersion of the fibers. The contractor shall provide the services of a qualified technical representative of the manufacturer to assist the contractor in proper batching and mixing of materials.

In no case shall the slump be greater than four inches for the second application. Slump will be measured prior to the introduction of the fiber into the concrete mix.

Fibrous reinforced concrete shall be placed in accordance with the requirements of Section 912 and as directed by the Engineer. Tined rakes will not be allowed as a means of moving the fibrous concrete. The ready mix discharge chute shall be raised approximately 12 inches above the pump grate or screen as directed by the Engineer at the time of discharging concrete.

Testing:

First Application:

The contractor shall first apply the shotcrete to the gabions and riprap at the south end of the channel as a test area at an exact location designated by the Engineer. The Engineer will then examine the test area to determine that the required penetration has been attained. If the required penetration has not been attained then the Engineer will direct the contractor to adjust the mix and repeat the test.

Second Application:

Tests to determine the physical quality of the shotcrete for the second application will be performed by the Engineer periodically during the work as required. Test panels and cores shall be prepared by the contractor.

Test panels at least 12 inches square and as thick as the structure being constructed shall be prepared by gunning shotcrete mix on a piece of plywood form. Cores shall be taken from the panels for compressive strength tests and for visual examination. Cores shall have a minimum diameter of three inches and a length to diameter ratio of at least one. Test panels shall be cured in the same manner as the production work.

Cores shall be obtained and tested in accordance with the requirements of AASHTO T 24. The cores will be tested for a minimum compressive strength of 3,000 psi at 28 days.

The cut surfaces of the test specimens will be carefully examined for soundness and uniformity of the material and shall be free from laminations and sand pockets.

Construction Joints:

Construction joints shall be in accordance with the details shown on the project plans and these special provisions.

A construction joint shall be placed at the end of each days operations or every 200 feet, whichever is less. The contractor may either construct transverse construction joints that are continuous and coincidental across the entire section of channel or he may construct longitudinal construction joints on each of the sloped sides of the channel a minimum of 3 feet vertically from the bottom of the channel. If the longitudinal joints are constructed, the location of transverse joints do not have to coincide; however, the longitudinal joints shall be continuous from beginning to end of the channel.

The contractor shall submit a written plan to the Engineer for approval showing the method he plans to use in determining the location of construction joints. Once the plan is approved, the contractor shall not deviate from the plan unless approval in writing is obtained from the Engineer.

The surface sealant and the joint sealant shall be prepared and applied at a time and in a manner recommended by the manufacturer and as approved by the Engineer. The contractor shall provide the services of a qualified technical representative of the manufacturer during the process of sealing joints.

The concrete (shotcrete) surface shall be clean, structurally sound and free of all contaminates including curing compounds, form release agents, dust, dirt and oil coatings just prior to applying the surface sealant and the joint sealant.

Curing:

The surface of the first shotcrete application shall be kept continuously moist immediately after placement by means of either a water spray or fog system for a minimum of seven days. The use of membrane forming curing compound or sheeting will not be allowed.

The surface of the second application of shotcrete shall be kept continuously moist for at least seven days, beginning immediately after placement by means of either a water spray or fog system capable of being applied continuously or by liquid membrane-forming compound or by polyethylene sheeting conforming to the requirements specified in ASTM C 171.

If polyethylene sheeting is used, it shall be white opaque and adjoining sheets shall overlap at least 12 inches and the laps secured to provide an airtight and windproof joint. If liquid membrane-forming compound is used it shall be Type I conforming to the requirements of ASTM C 309 and the application rate shall be 100 square feet per gallon.

Method of Measurement and Basis of Payment:

The method of measurement and the basis of payment will be in accordance with Subsections 912-4 and 912-5 except that the surface area for measurement will be the separate area of the first and second applications and the contract price shall include the cost of fibrous reinforcement and having a manufacturer's representative present during batching and applying the second application of shotcrete and during the sealing of construction joints.

ITEM 9240010 - FORCE ACCOUNT WORK (Channel Surface Preparation):

The work under this item consists of preparing the surface of the existing outfall channel and riverbed rip-rap for the application of shotcrete and includes, but is not limited to, removing mud and debris, resetting gabions, consolidating riprap and removing projecting portions of rock to obtain a reasonably uniform surface.

Payment for channel surface preparation will be made on a Force Account Basis in accordance with Subsection 109.04.

GEOTECHNICAL INVESTIGATION REPORT:

A copy of a geotechnical investigation report is available for prospective bidders to review at Contracts and Specifications Services, 1651 West Jackson Street, Room 121-F, Phoenix.

BIDDING SCHEDULE

PROJECT NO. ACI 10-3(270)
10 MA 149 H0128 05C

	ITEM NO.	ITEM DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	AMOUNT
1		SHOTCRETE OVER EXISTING OUTFALL CHANNEL				
2	2060001	FURNISH WATER SUPPLY	L.SUM	1		
3	2070001	DUST PALLIATIVE	M.GAL.	500	8.00	4,000.00
4	5011025	PIPE, REINFORCED CONCRETE, CLASS V, 24"	L.FT.	120		
5	6016088	HEADWALL (C14.30) (DOUBLE)	EACH	1		
6	9010001	MOBILIZATION	L.SUM	1		
7	9080114	CONCRETE CURB, PRECAST (Roughness Control Device)	EACH	224		
8	9120001A	SHOTCRETE (First Application)	SQ.YD.	7,970		
9	9120001B	SHOTCRETE (Second Application)	SQ.YD.	10,450		
10	9240010	FORCE ACCOUNT WORK (Channel Surface Preparation)	L.SUM	1	25,000.00	25,000.00
11	9250001	CONSTRUCTION SURVEY AND LAYOUT	L.SUM	1		
12	9250102	2-PERSON SURVEY CREW	HOUR	10	65.00	650.00
13	9250103	3-PERSON SURVEY CREW	HOUR	10	75.00	750.00
14	9250104	4-PERSON SURVEY CREW	HOUR	10	85.00	850.00
15			TOTAL			
16						
17						

ARIZONA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

SUPPLEMENTAL AGREEMENT

[X] Change Order
[ ] Force Account Work Request

Project No. ACI-10-3(270)/H012805C Fund Code 4147 No. 1

Name of Project East Tunnel Outfall Modification Contractor R.R. Hensler, Inc.

DESCRIPTION AND REASON

REQUEST: To create Item No. 9120002A, Shotcrete (Fiber Reinforced)(Special), as a basis of payment for constructing four different types of fibrous reinforced shotcrete in accordance with the attached plan and specifications (Attachments 1 & 2). Additionally, a 25'x25' section of steel reinforced shotcrete lining will be constructed in lieu of fibrous reinforced shotcrete in accordance with attached plan and specifications (Attachments 1 & 2). Material testing will be performed as outlined in Attachment 2.

REASON: This change was requested by the AZ. Trans. Research Center to assess the performance of multiple fiber types, develope a generic contract specification for synthetic fiber reinforcement and determine methods for determining contract compliance on future projects.

COST:

Item No.	Description	Quantity	Unit Price	Amount
9210002A	Shotcrete (Fiber Reinforced) (Special),	+1 L. Sum	$5,650.00	+$5,650.00

U.S. DEPARTMENT OF TRANSPORTATION RECEIVED DEC 22 '89 AZ DIV. PHOENIX

~~Extension of Contract Time [ ] will [ ] will not be considered as a result of this Supplemental Agreement.~~

TOTAL DIFFERENCE

PLUS	MINUS
$ 5,650.00	$

Date August 16, 1989 Date ______ Date 12/12/89 Date DEC 14 1989

Submitted M. Harrington RES. ENGR. Approved ______ CITY/COUNTY ENGR. Approved [signature] DISTRICT ENGR. Checked R. [signature] FIELD REPORTS SERVICES

For Valuable Consideration, it is mutually agreed that the matter detailed above shall be done and payment made as shown herein for a Supplemental Agreement Change Order, all in accordance with the terms of the contract. For work being performed as a Supplemental Agreement Force Account Request, final payment shall be made as stipulated in the Standard Specifications and its supplements upon completion of said work.

Date Aug 15, 1989 Date 12/21/89 Date DEC 26 1989

Approved for R.R. Hensler, Inc. CONTRACTOR Approved for State of Arizona Approved with/~~without~~ Federal Participation.

By [signature] By [signature] DEPUTY STATE ENGR. By [signature] DIVISION ADMINISTRATOR, FEDERAL HIGHWAY ADMINISTRATION

for

12-1801 R1/84

CHECKED R. [illegible] FIELD REPORTS SERVICES DATE 12-14-89

ARIZONA DEPARTMENT OF TRANSPORTATION

CHANGE ORDER OR FORCE ACCOUNT WORK REPORT

To accompany { Change Order / ~~Force Account Order~~ / ~~Fiscal Variance Report~~ } No. 1 Project No. ACI-10-3(270) FUND CODE 4147

Additional pertinent information not contained in the transmitted document.

RECEIVED

DEC 18 1989

H.N.T.B.

Doug Lattin, Arizona Transportation Research Section, requested this change order on July 15, 1989.

Dan Lance, Assistant District I Engineer, was contacted on July 31, 1989 and concurred.

Prior approval was granted at the project level on August 2, 1989.

Discussed With Federal Highway Administration. Date ______ F.H.W.A. AREA ENGR.
Explain Their Comments.

Phil Bleyl, Area Engineer, F.H.W.A., was contacted on July 31, 1989 and gave his tentative approval.

Submitted by Mike Harrington Title Res. Eng. Date 8/17/89

District Engineer's Comments:

RECEIVED DATE RECEIVED

AUG 21 1989 DEC 14 1989

DISTRICT 1 Field Reports Branch

DISTRICT ENGINEER

	SIGN IN PROPER COLUMN			DATE
	APPROVED	*DISAPPROVED	*REVISIONS	
F.A. FINANCE OFFICER	M Bloom			12-14-89
MATERIALS SECTION	[illegible]			12-15-89
ENGINEER OF ~~PLANS~~ H.N.T.B	[illegible]			12-18-89
STRUCTURES SECTION				
TRAFFIC CIVIL ENGINEER				
ENGINEER ROADSIDE DEVELOPMENT				
CHIEF RIGHT OF WAY AGENT				
RIGHT OF WAY APPRAISALS				
RIGHT OF WAY PLANS				
LEGAL				
ASST. DIR. ADMIN. SERV.				
UTILITIES ENGINEER				
FIELD REVIEW BRANCH	[illegible]			12-15-89

*Fully explain on separate sheet.

(Original copy only to be attached to Change Order, F.A.W.R., or Fiscal Variance Report. Use additional sheets if necessary.)

12-14-89 MW

10-0701 R11/83

ARIZONA DEPARTMENT OF TRANSPORT ION

OFFICE MEMO

August 2, 1989

TO: DAN POWELL
District Engineer

FROM: MICHAEL J. HARRINGTON
Resident Engineer

RE: ACI 10-3 (270)
East Tunnel Outfall Modification
Change Order No. 1 Authorization

This confirms that authorization was granted by the Resident Engineer for Change Order No. 1 to reimburse the Contractor for additional work to be performed on the East Tunnel Outfall Modification. The performance of multiple fiber types will be assessed so that a generic contract specification for synthetic fibers and a method for establishing compliance on future projects can be developed. Four 50' test sections will be constructed with four different types of fiber. In addition, a 20' x 20' section will be reinforced with reinforcing steel and the shotcrete in this control section will not contain any fibrous reinforcement.

The total cost of this change order will be $5,600.00.

Doug Lattin of Arizona Transportation Research Section requested this change order on July 15, 1989.

Dan Lance, Assistant District I Engineer was contacted on July 31, 1989 and concurred.

Phil Bleyl, Area Engineer for the FHWA was contact on July 31, 1989 and gave his tentative approval.

Michael J Harrington
MICHAEL J. HARRINGTON, RES. ENGR.

Approved: Dan Powell
DAN POWELL, DIST. ONE ENGR.

MJH:SAK:dm

xc: Chief Deputy State Engineer
Highway Operations
Field Reports Services
Larry Scofield (Az. Trans. Research Center)
FHWA
Project File (#610 CO #1)

DATE RECEIVED
AUG 21 1989
Field Reports Branch

8-9590 2/75
(FORMERLY 8-954)

ARIZO DEPARTMENT OF TRANSPORTA N
RES ENT ENGINEER'S COST ANALYS
AND ADDITIONAL JUSTIFICATION

[X] Change Order No. 1 Project No. ACI-10-3(270)
[ ] Force Account Work Request No. ______ Fund Code ______

Resident Engineer's independent cost or price analysis:

1) REDUCED READY MIX LOADS:

In order to have a good mix with the fiber added on site. Ready mix loads had to be reduced from 9 cys. to 7 cys.

The contractor has been ordering 9 cys. per truck for the first and second application of shotcrete. Therefore, additional trips will have to be made to secure the same production rate. On the average the contractor pumps 110 cys. per day. The net increase in trips will be:

$\frac{110}{9} - \frac{110}{7}$ 12 - 16 4 additional trips

No additional trucks will be involved. However, four extra batches are needed. Calmat quoted an extra $3.50 per cubic yard for the extra batches and the trips.

(447 + 10% mixer waste) x $3.50 = $1,722.00 ✓

2) FIBER PLACEMENT:

Two pumps will be utilized, and two laborers will be needed to place the fiber in the mixer trucks.

Labor	=	$11.00/Hr		
Surcharge	=	20% x $11.00	=	$ 2.20/Hr
Insurance	=	15% x $11.00	=	$ 1.65/Hr
Fringes	=			$ 2.77/Hr
TOTAL				$17.62

Four days will be needed to place the test sections.

48 Hours x $17.62/Hr x 2 Laborers = $1,691.52 ✓

3) FURNISH AND PLACE REBAR FOR 20'X20' TEST SECTION:

Steel: 400 Ft x 0.668 Lb/Ft x 0.20 $/Lb = $ 53.44

Iron Worker:

Labor	=	$15.0/Hr		
Surcharge	=	20% x $15.00	=	$ 3.00/Hr
Insurance	=	15% x $15.00	=	$ 2.25/Hr
Fringes			=	$ 2.77/Hr
TOTAL				$23.02

23.02 x 3 Hrs = $69.06

Furnish and place rebar = $69.06 + $53.44 = $122.50 ✓

4) OPERATION:

Addition of fiber on the project site, adjustment of slump and testing and reduced mixer loads will result in reduced pumping efficiency.

$$\text{Loss of efficiency} = \frac{\text{2 cy reduction in mixer loads}}{\text{9 cy of normal mixer loads}} = 22\%$$

22% x 8 hr/day = 1.76 hours/day ≈ 2 hours/day

This loss of efficiency will be made up by working two additional hours each day to finish each test section.

A) PUMPING CREW:

Foreman	= $16./hr x 1 Foreman	= $16./hr
Labor	= $11./hr x 6 Laborers	= $66./hr
Nozzelman	= $15./hr x 2 Nozzelmen	= $30./hr
Pump Operator	= $13./hr x 2 Operators	= $26./hr
Subtotal		$138.00
Surcharge	= 20% x $138./hr	= $27.60/hr
Insurance	= 15% x $138./hr	= $20.70/hr
Fringes	= 11 personnel x $2.77/hr	= $30.47/hr
Total Labor Cost		$216.77

B) EQUIPMENT:

Tow pickup	$9./hr
Concrete Pump (35 cy/hr)	$45./hr
Total Equipment Cost	$54./hr

Increased pumping cost = (54.00+216.77)/hr x 2 hr/day x 4 days

= $2,166.16 ✓

5) CONSTRUCTION JOINTS:

No extra joints will be needed, since each controlled section is equal to a day's production and will be done in the same day.

6) MATERIAL TESTING:

Sixteen test panels at least 3 feet by 2 feet and as thick as the structure being constructed shall be prepared. The shotcrete on the panels shall be sawcut and cored, so that 2 beams and 4 cores can be tested from each panel.

COST:

a) Panels:

1. Materials	$100.00	
2. Shotcrete	2 cy x $55./cy =	$110.00

1) Labor

Labor		=	$11./hr
Surcharge	20% x $11./hr	=	$1.65/hr
Insurance	15% x $11./hr	=	$2.25/hr
Fringes	$2.77/hr x 1 Labor	=	$2.77/hr
			$17.62

Three hours will be needed to construct the panels
$17.62/hr x 3 hrs = $52.86
Total cost of panels - $52.86 + $110. hr + $100. = $262.86

b)	Coring = 64 cores x $10./core	=	$640.00
c)	Sawing = 32 beams x 6 ft/beam x $2.00 ft	=	$384.00

Total cost of Material Testing $1,286.86 ✓

7) FIBER: *

The Department will supply the fiber for three of the test sections. Calmat will credit the contractor $6.00/cy for not adding the fibermesh to the concrete used in the three test sections. The fourth section will have fibermesh in it, except that it will be added on the jobsite.

(337 cy + 10% mixer waste) x $6.00 = $2,224.00

SUMMARY OF COSTS:

1)	Reduced ready mix loads	+ $1,722.00
2)	Fiber placement	+ $1,691.52
3)	Furnish and place rebar	+ $ 122.50
4)	Operation	+ $2,166.16
5)	Construction joints	+ $ 00.00
6)	Material testing	+ $1,286.86
		+ $6,989.04

Total cost - $6,989.04 x 15% overhead and profit = $8,037.40 ✓

*Fiber-lock, Nurlon and Forta fibers will be donated to the Department by the manufacturers.

SUMMARY OF CREDITS:

7) Fiber $2,224.00

Total cost for Change Order No. 1 $8,037.34 - $2,224.00 =

+$5,813.34

PS: The contractor's cost analysis did not include material testing, however, it included a cost for added joints. The Department negotiated with the contractor to deduct the cost of the construction joints and to deduct the cost of the fibermesh for three sections only instead of four. The manufacturer of fibermesh refused to donate the fiber for testing purposes. Therefore, the Department deducted $3,242.84 from the contractor's total cost for the extra joints and added $726.00 for the fibermesh in the forth section.

The contractor agreed to perform the work for $5,650.00.

$8,155.24 - $3,242.84 + $726.00 = $5,638.40

This price is within one percent of the Department's Cost Analysis, therefore, it is recommended to authorize the work requested in Change Order No. 1.

Michael J Herrington 8/17/89

Resident Engineer Date

12/12/89

Asst. DE

(Original copy to be attached to C.O. or F.A.W.R. for transmittal to Field Reports Branch only)

R. R. HENSLER, INC.
Mining • Contractors • Construction
1425 EAST UNIVERSITY DRIVE
PHOENIX, ARIZONA 85034
(602) 257-1656

H020

RECEIVED
JUL 2
JEFFERSON FIELD OFFICE
ORG. 4147

July 24, 1989

Arizona Department of Transportation
2015 E. Jefferson
Phoenix, AZ 85034

Atten: Mr. Mike Harrington
Resident Engineer

Subject: ADOT Project ACI-10-3(270)
(H012805L)
Change Order No. 1 - Fiber

Gentlemen:

We have made the following analysis of increased cost to preform the work as outlined in your request. It is our understanding the experimental fibers will be added by us on the jobsite. Added cost:

1. Increase in mixer cycle time
2. Reducing mixer loads from 11 cu yds to 7 cu yds to facilitate jobsite mixing
3. Labor and scaffolding to add fiber
4. Increased pumping costs
5. Cost of furnishing and placing reinforcing steel for 20 ft. by 20 ft. test section
6. Increase estimated construction joint by 180 lin. feet

Cost Analysis:

1. Increased cycle time
   a. Spot mixer at fiber loading platform and add fiber to load -- 10 minutes

      Mix in fiber -- 10 minutes

      Total increased time per 7 cy load -- 20 minutes

2. Reduced readymix loads from 11 cu yds to 7 cu yds - 64% reduction. This will require approximately 63 additional mixer trips.

Calmat has quoted an additional $3.25 per cubic yard to their original quote without fiber for readymix for Item 9120001B shotcrete (second application).

~~455.4~~ 447 cubic yard + 10% mixer loss and waste =
~~501~~ 492 cy x [illegible] + 15% overhead & profit = $ ~~1,872.49~~ 1838.85

Calmat fiber credit $6.00 per cubic yard

3. Labor - 2 men at $~~10.58~~ 11.00 + ~~28%~~ 20%+15% labor burden + 2.77 fringes = $~~15.93~~ 17.62 per hour. Estimated 6 - 8 hour days to add fibers, erect and dismantle scaffold for 2 men.

48 hours x 2 x ~~15.93~~ 17.62 =	$ ~~1,529.28~~	1691.52
Plus 15% =	~~229.39~~	253.73
Scaffold rent, delivery & pickup	~~100.00~~	0
Total	$ ~~1,858.67~~	$1945.25

4. Increased pumping costs:
Estimate loss of efficiency due to testing, spoting mixer, adjusting for charging fiber etc. 2 hours per day for four days equals 8 hours additional time.
Crew Cost:

1 ~~½~~ Foreman @ 16.00 per hour =	$ ~~8.00~~	16.00
2 - Nozzelmen @ $~~15.51~~ 15.00 per hour =	~~31.02~~	30.00
2 - Mixer men @ $~~14.37~~ 13.00/hr. per hour =	~~28.75~~	26.00
6 ~~4~~ - Laborers @ ~~10.58~~ 11.00 per hour =	~~42.32~~	66.00
	$ ~~110.09~~	138.00
$110.09 ~~x 1.28~~ +20% burden +15% Insurance burden =	~~140.92~~	186.30
Fringe ~~6~~ 11 labor x $2.77 =	~~18.01~~	30.47
~~Fringe 2 operators x $3.78 =~~	~~7.56~~	
	$ ~~166.49~~	216.77

$~~166.49~~ 216.77 + 15% overhead & profit =
Total labor cost per hour $ ~~191.46~~ 249.29

Equipment:

1 ~~½~~ Foreman Pickup @ 8.64	$ ~~4.32~~	8.64
1 Pump tow vehicle @ 8.64	8.64	
1 Concrete Pump, inc. hose, nozzles etc.	36.50	
1 Air compressor 160 cfm	7.75	

Hourly Equipment Cost $ ~~57.21~~ 61.53

Total pump crew cost per hour	$	~~248.67~~ 310.82
x ~~2~~ pump crews =	$	~~497.34~~ 310.82
x 8 hours = 4 days x 2 hrs./day extra		
Increased pumping cost		$ ~~3,978.72~~ $2486.56

5. Furnish and place rebar on 12" C.C.E.W. in 20' x 20' test section
400 ft x 0.668 lb/ft x $0.20/lb.

~~536~~ ft rebar F.O.B. jobsite @ $120.00 + ~~15%~~	$	~~138.00~~ 53.44
Estimated chairs & tie wire 20.25		~~11.00~~
~~8~~ hour iron worker $~~16.00 x 1.28~~ 15.00 + 20% + 5.10 + ~~15%~~ +15% x ~~8~~ 3 hrs.		~~59.52~~ 76.05
15% O/H =		19.42
		$ ~~208.52~~ $148.91

6. Provide Test Panels & Core ~~Increase construction joint 180 l.f.~~

1 laborer ~~10.58 x 1.28~~ 11.00 + 20% + 2.77 + 15%	$	~~18.76~~ $20.26
times ~~8~~ 3 hours =	$	~~150.08~~ 60.78
Materials (lumber, etc)		115.00
~~Joint seal subcontract $ 15.62 per l.f. x 180 l.f. + 10% overhead & profit =~~ Shotcrete 2 C.Y. x $55.00/c.y. +15%		~~3,092.76~~ 126.50
Coring 64 Cores x $10.00/core +15%		736.00
Saw cutting 32 beams x 6 ft/beam x $2.00/ft. +15%		441.60
~~Total added joint cost~~		$ ~~3,242.84~~ $1,479.88

Summary of additional cost for change order # 1

1.	Additional readymix cost	$	~~1,872.49~~ $1,838.85
2.	Additional cost to add fiber		~~1,858.67~~ $1845.25
3.	Fiber credit from Calmat at $6.00 per cubic yard times 501 cubic yards		(3,006.00) $(2,224.06)
4.	Increased pumping cost		~~3,978.72~~ $2,486.56
5.	Rebar cost		~~208.52~~ $148.91
6.	~~Construction joint cost~~ Material Testing (Provide Test Panels) (Cores)		~~3,242.84~~ $1,479.88
	Total added cost for C.O. # 1	$	~~8,155.24~~ $5,675.45

Any cost incurred by delays during the testing that are not the fault of the contractor will be payed for as provided under Section 109.04 Extra and Force Account.

We are concerned with both 90 minute time limit and the temperature requirements for the readymix operation with the fiber being added in the field.

Contractor Agreed to
Cost of $5,650.00.
M/H.

It has been agreed that the slump tests prior to adding the fiber to the mix during the research period will furnish ADOT their required data.

We request a two day time extention for Change Order # 1.

Sincerely,

R. R. Hensler, Inc.

J. A. Mason
Manager of Construction

APPENDIX B: WORKPLAN

ARIZONA DEPARTMENT OF TRANSPORTATION

HIGHWAYS DIVISION

206 South Seventeenth Avenue Phoenix, Arizona 85007

ROSE MOFFORD
Governor

CHARLES L. MILLER
Director

THOMAS A. BRYANT, II
State Engineer

ARIZONA TRANSPORTATION RESEARCH CENTER

August 23, 1989

Ed Wueste
Division Administrator
Federal Highway Administration
234 N. Central Ave., Suite 330
Phoenix, Arizona 85004

Attn: Nate Banks

Dear Sir:

The ATRC is currently documenting the construction of experimental project AZ-8902, *Channel Lining With Synthetic Fiber Reinforced Shotcrete*. ATRC participation was solicited by the FHWA in early 1989 at which time the project had already been designed by a consultant using only one fiber type. In July the ATRC initiated a change order on this project so that three other fiber types would be included and a comparison could be made.

Enclosed for your use is a copy of the experimental project workplan which has been followed thus far along with an initial FHWA form 1461 for each proprietary product (A-D). The construction report will follow within 120 days. Questions regarding project specifics should be addressed to Doug Lattin of my staff.

Sincerely,

F. R. McCullagh

Frank R. McCullagh
Assistant State Engineer
Research Section

DJL

Enc. AZ-8902 Detailed Workplan
Form 1461 for AZ-8902(A-D)

ARIZONA TRANSPORTATION RESEARCH CENTER

EXPERIMENTAL PROJECTS PROGRAM
AZ-8902 DETAILED WORKPLAN

CHANNEL LINING WITH SYNTHETIC FIBER REINFORCED SHOTCRETE

I. PROBLEM STATEMENT

Drainage facilities are essential components of a highway system. The current and forthcoming quantity of new highway construction in Arizona motivated ADOT to publish a report in February of 1989 titled *Channel Lining Design Guidelines*. The conclusions of this report focus on the use of welded wire fabric (WWF) or other secondary steel reinforcement in concrete channel linings. Reinforcement of this nature is not expected to prevent cracking in a concrete channel lining but is expected to hold cracks together once they are formed.

Shotcrete is concrete that is placed by projection onto a surface at high velocity. Channel lining is one activity in which shotcrete reinforced exclusively with discontinuous discrete synthetic fibers may have application. In such a situation the fiber would be used to reduce formation of early plastic shrinkage cracks. Inclusion of fibers in the concrete mix can also result in a material with increased toughness, lower permeability, higher flexural and compressive strength, and greater abrasion and fatigue resistance. The degree and manner in which these material properties are affected depends upon the type, length, strength, configuration, and quantity of the fiber incorporated into the concrete mix.

In order to gain future consideration, synthetic fiber reinforced shotcrete linings must be capable of controlling all cracking equal to or better than channel linings with conventional secondary steel reinforcement. Any claimed material property improvements must be confirmed and not negated by excessive material and labor costs. Furthermore, the fiber reinforced shotcrete must not present any fiber related construction problems.

II. OBJECTIVES

The primary objective of this project is to develop a *generic specification for synthetic fibers* used in shotcrete and to establish a *testing program for verifying compliance* with this specification. Preliminary material and construction specifications will be tested on ADOT project ACI-10-3(270). This project involves modifying the East Papago Tunnel Outfall channel by applying a 5" thick fiber reinforced shotcrete lining. The channel is approximately 500' long with a 130' cross section perimeter. Four 50' test sections will be constructed using four different fiber brands. The fibers used will be FIBERMESH, FIBER-LOK, FORTA, and NURLON as shown on the attached Figure 1. An additional small control section will be included using a conventional steel reinforced lining.

The variation between measured material properties of shotcrete using different fiber types and configurations will be analyzed and compared with the control shotcrete. Material properties to be measured are the slump of a given concrete mix before and after the addition of fibers, the 28 day compressive strength of the same mix with and without fibers, and the compressive strength, flexural toughness, and percent permeable voids of beam and core samples extracted from shotcrete panels.

Assessment of construction differences between different fibers is another main objective. Reporting will focus on the ability to place the different types of fiber on the channel without fiber related construction problems such as improper mixing, fiber balling, or plugging of the shotcrete pump.

Early field evaluations will be performed to determine if fiber reinforced shotcrete does in fact minimize early plastic shrinkage cracking. The different fiber materials and fiber geometries are included in this project to determine if these variables affect the ability of a fiber to mitigate this type of cracking. Furthermore, in the event that cracking does occur due to early plastic shrinkage or any other cracking mechanism, the fibers will be expected to inhibit further crack propagation. The relative ability of different fibers to achieve this goal will be substantiated by flexural toughness tests and by detailed field monitoring over time.

Verification of different fiber material inertness in an alkali environment is research that may be performed in the context of this channel lining project. If any fiber used on this project does deteriorate this will be manifested by substandard performance. In addition, petrographic or other laboratory analyses may be performed on field samples to determine the degree to which the fiber has deteriorated over time.

III. IMPLEMENTATION

Specifications developed and refined during this project can be used on future ADOT projects where channel lining or similar activities are required. Based on the findings of this research effort, the applicability of the different fiber types and configurations will be identified in terms of design objectives and distributed to designers.

IV. WORKPLAN

1. Review literature on the use and control of fiber reinforced concrete, conventional shotcrete, and fiber reinforced shotcrete. Compile an appropriate collection of articles and a bibliography for placement in the ATRC library.

2. Select appropriate fibers to be included in this project so that the primary fiber materials and fiber geometries can be compared.

3. Establish appropriate laboratory test procedures to evaluate the quality of the shotcrete and the effects of the fiber.

4. Establish field quality control procedures to be employed on this project so that the fiber addition and the concrete mixing, testing, and shotcreting is performed in a uniform and consistent manner.

5. Prepare additions and modifications to the construction documents as required for project ACI-10-3(270). Both a change order to the special provisions and a diagram, Figure 1, identifying test sections are necessary on this project.

6. Monitor and document all relevant phases of test section construction. Primary emphasis will be placed on identification of critical construction activities that may affect the ability to deliver the shotcrete to the channel surface in an acceptable manner. Mixing times, pumping pressures, production rates, and equipment types will also be recorded.

7. Insure that all material testing requirements are satisfied at the proper time, in the proper location, and in the proper manner. All sample labels will be cross referenced to AZ-8902 sample ID format. ID format is SECTION-TRUCK-SAMPLE. SECTION is the test section designation A, B, C, D, or X as defined on Figure 1. TRUCK is the truck sequence 1, 2, 3, or 4. SAMPLE is the sample type and sequence defined below.

All samples in parts (a) and (b) are to be obtained in accordance with AASHTO T141 with the exception that the samples are from the beginning portion of the loads by necessity. All sampling methods are to be consistent.

(a) SLUMP: The following test shall be run and recorded by ADOT personnel in the field on the material delivered by at least 4 randomly selected concrete trucks per test section:

S0 Slump test before fiber is added to the concrete.

S1 Slump test after fiber is added to the concrete and mixed per fiber manufacturer representative's recommendation.

One additional slump test shall be performed on the control section material:

S* Control section slump test.

A cumulative total of 32 slump tests will be conducted on the test section material and one on the control section material. No additional testing or saving of the material used in these tests is required.

(b) COMPRESSIVE STRENGTH: The following samples shall be fabricated and labelled by ADOT personnel in the field using the material delivered by the same 4 concrete trucks selected in (a) above:

C01,C02 Two concrete cylinder test specimens fabricated in accordance with the requirements of AASHTO T23 shall be taken prior to the addition of fibers to the concrete.

C11,C12 Two concrete cylinder test specimens fabricated in accordance with the requirements of AASHTO T23 shall be taken after fiber is added to the concrete and mixed per fiber manufacturer representative's recommendation.

One additional concrete cylinder set will be fabricated and labelled by ADOT personnel using the material from the control section:

C*1,C*2 Two concrete cylinders test specimens fabricated in accordance with the requirements of AASHTO T23.

A cumulative total of 64 cylinders fabricated from test section material and 2 cylinders fabricated from the control section shall be tested for compressive strength in accordance with the requirements of AASHTO T22 at 28 days.

(c) PANEL FABRICATION: The following specimens shall be fabricated by the contractor under supervision of ADOT personnel in the field using the material delivered by the same 4 concrete trucks selected in (a) above:

P1 One 2'x3' panel will be shot with shotcrete to a depth of approximately 5". The panel will be sawed as indicated in Figure 2 and will be cured in the same manner as the channel for 28 days.

Additional panels will be fabricated from the material delivered by the only truck delivering to the control section:

P*1,P*2 Two 2'x3' panels will be shot with shotcrete to a depth of approximately 5". The panel will be sawed as indicated in Figure 2 and will be cured in the same manner as the channel for 28 days.

A cumulative total of 16 panels will be fabricated from the test section material and 2 panels fabricated from the control section.

(d) PANEL TESTING: The following beam and core specimens shall be obtained from each panel fabricated in step (c) above no more than 7 days prior to testing:

- FLEXURAL TOUGHNESS: Beams will be tested for flexural toughness in accordance with the requirements of ASTM C-1018.

T1 Two beams of dimensions 21"x6"x5" for testing at 28 days.

T2 Two beams of dimensions 21"x6"x5" for testing at 2 years.

A cumulative total of 32 flexural toughness tests will be performed on test section material and 4 more on control section material at 28 days.

A cumulative total of 32 flexural toughness tests will be performed on test section material and 4 more on control section material at 2 years.

- COMPRESSIVE STRENGTH: Cores will be tested for compressive strength in accordance with the requirements of AASHTO T22.

C1 Two cores with diameter 2.5" and height 5" for testing at 28 days.

C2 Two cores with diameter 2.5" and height 5" for testing at 2 years.

A cumulative total of 32 compressive strength tests will be performed on test section material and 4 more on control section material at 28 days.

A cumulative total of 32 compressive strength tests will be performed on test section material and 4 more on control section material at 2 years.

- PERMEABILITY: Scrap material remaining after testing beams and cores above will be tested in accordance with ASTM C642 for percent of permeable voids.

8. Compliation and analysis of all short term test data will be included in the construction report. An analysis of variance will be performed on all test results to verify the validity of the sampling program. Inclusion of long term test data will not be possible until the final report.

9. Field evaluations will be scheduled for 1 month, 1 year, and 2 years from the time of construction. Field evaluations will consist of documenting the number of cracks, type of cracks, crack widths, crack lengths, and vertical displacement across cracks. Crack maps will be prepared for each section at each evaluation. All measurements will be analysed over time to determine the degree to which crack growth is inhibited.

10. Field samples will be obtained from a predetermined location after 2 years. Field beams and cores obtained at this time will be tested in exactly the same manner and at the same time as the remaining panel samples which were obtained during construction. A petrographic or similar analysis may be performed on the field samples at this time.

V. REPORTING

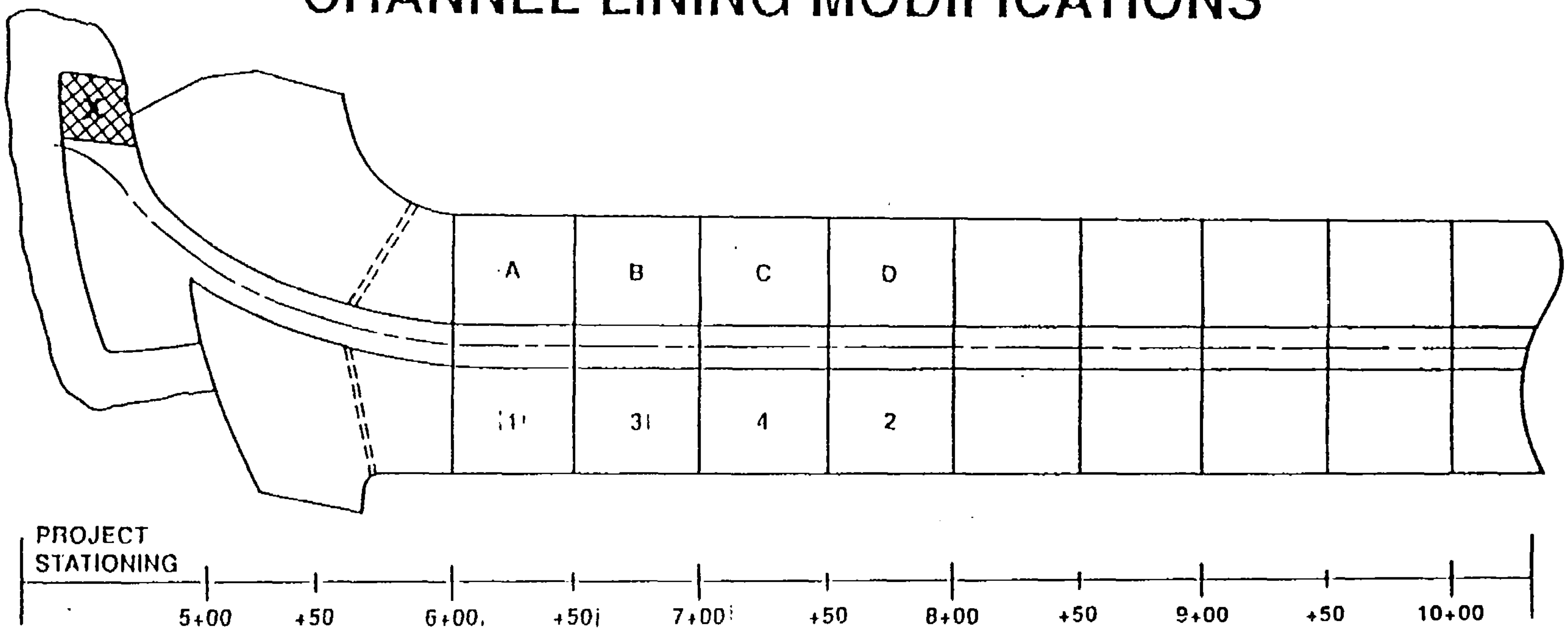
A construction report will be prepared in accordance with ATRC procedures for reporting on experimental projects and submitted to the FHWA within 120 days after completion of the last construction activity.

A technical summary, 1-2 pages in length, will also be prepared which summarizes the findings and conclusions of the construction report.

An implementation report will be prepared within 120 days after submission of the construction report.

A final report will be prepared in accordance with ATRC procedures for reporting on experimental projects and submitted to the FHWA within 120 days of the last field evaluation. The report will detail all activities included in this experimental project and discuss the findings and conclusions.

EAST TUNNEL OUTFALL ACI-10-3(270)
CHANNEL LINING MODIFICATIONS

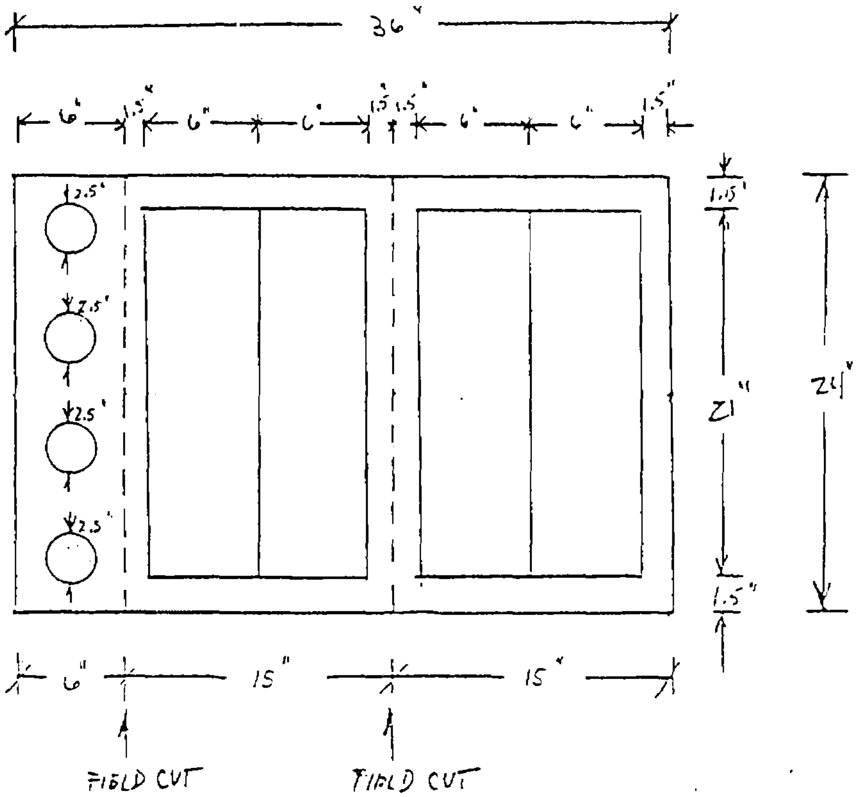


TYPE	SECTION	FIBER NAME	DOSAGE	FIBER LENGTH	DESCRIPTION
1	A	FIBERMESH	1.6 #/cy	1/2"	COLLATED FIBRILLATED POLYPROPYLENE BUNDLES
2	D	NURLON	1.0 #/cy	3/4"	MONOFILAMENT POLYETHYLENE TERPHTHALATE
3	B	FIBER-LOK	1.6 #/cy	3/4"	MONOFILAMENT POLYPROPYLENE
4	C	FORTA	1.6 #/cy	1 1/2"	COLLATED FIBRILLATED POLYPROPYLENE TWISTED BUNDLES
–	X	N/A	N/A	N/A	CONTROL SECTION APPROXIMATELY 25' X 25' #4 BARS @ 12" O.C. BOTH DIRECTIONS

FIGURE 1

REV. 7/14/89

TEST PANEL SPECIFICATIONS



- ~~FIVE~~ FOUR PANELS WILL BE SHOT IN EVERY TEST SECTION.
- EACH PANEL COMES FROM DIFFERENT TRUCK.
- EACH PANEL WILL HAVE A DEPTH OF 5" THROUGHOUT ITS ENTIRE AREA.
- CONTRACTOR WILL PERFORM FIELD CUTS AS SPECIFIED IN DRAWING.
- CONTRACTOR WILL PLACE RESULTING 3 SECTIONS ON CANAL LIP & CURE SAME AS CHANNEL LINING.

FIGURE 2

APPENDIX C: SHOTCRETE MIX DESIGN

FIRST APPLICATION S' CRETE

Calmat of Arizona

06-Jul-89

PRODUCT CODE 3860

Mix Specifications

6.0 SACK SAND/CEMENT/FLY ASH/WATER
ADOT PROJECT: PHOENIX-CASA GRANDE HWY(EAST TUNNEL OUTFALL(ACIR-10-3(270))
CONTRACTOR: RR HENSLER
PLANT: 32: 1801 E. UNIVERSITY DRIVE, PHOENIX, AZ.

Slump range: 0.00 To 4.50
Unit Weight: 142.93

Fineness Modulus: 2.75
Percent fine aggregate: 100.00%

Weight
Weight per cubic yard: 3859.00
Water/Cement: 0.798
Water/(C+P): 0.660

Volume
Total volume: 27.06
Water/Cement: 9.001 (gls/sk)
Water/(C+P): 7.449 (gls/sk)

Material	Quantity	Weight	Specific Gravity	Absorption	Volume
Cement ASTM C150 TYPE I/II LA(ARIZONA PORTLAND CEMENT,RILLITO,AZ.)	0.000	480.0	3.150	0.00	2.442
Flyash ASTM C-618 TYPE F (NAVAJO) PAGE, AZ.	0.000	100.0	2.300	0.00	0.697
Water CITY/WELL (POTABLE)	0.000	383.0	1.000	0.00	6.138
Fine Aggregate ASTM C33 (MANUFACTURED)(SALT RIVER)AASHTO M6-81	0.000	2896.0	2.650	0.00	17.513
Entrapped Air 0-3% ASTM C-260 @ 2 OZ/PCY (MASTERBUILDERS MBVR-STD)	0.010	0.0	0.000	0.00	0.270
Admixture ASTM C-494 TYPE A @ 2.5 Oz/CWT(MASTERBUILDERS 220N)	0.000	0.0	0.000	0.00	0.000

Calmat of Arizona

15-Jun-89 PRODUCT CODE 1873

Mix Specifications

7.0 SK 20% 3/8" 3000PSI AT 28 DAYS
ADOT PROJECT: PHOENIX-CASA GRANDE HWY(EAST TUNNEL OUTFALL(ACIR-10-3(270))
CONTRACTOR: RR HENSLER
PLANT 32: 1801 E. UNIVERSITY DRIVE, PHOENIX,AZ.

Slump range: 1.00 To 3.00
Unit Weight: 146.59

Fineness Modulus: 2.75
Percent fine aggregate: 79.66%

Weight
Weight per cubic yard: 3958.00
Water/Cement: 0.532
Water/(C+P): 0.532

Volume
Total volume: 27.07
Water/Cement: 6.000 (gls/sk)
Water/(C+P): 6.000 (gls/sk)

Material	Quantity	Weight	Specific Gravity	Absorption	Volume
Cement	0.000	658.0	3.150	0.00	3.348
ASTM C-150 TYPE I/II LA(ARIZ PORTLAND CEMENT,RILLITO,AZ.)					
Water	0.000	350.0	1.000	0.00	5.609
CITY/WELL (POTABLE)					
Fine Aggregate	0.000	2350.0	2.650	0.00	14.211
ASTM C33 (MANUFACTURED)(SALT RIVER-AASHTO M6-81)					
Coarse Aggregate	0.000	600.0	2.650	0.00	3.628
ASTM C33 SIZE #8 (3/8")(SALT RIVER-AASHTO M43-82)					
Entrapped Air	0.010	0.0	0.000	0.00	0.270
0-3% ASTM C-260 @ 2+- 2 OZ/PCY (MBVR STD)					
Admixture	0.000	0.0	0.000	0.00	0.000
ASTM C-494 TYPE A @ 2.5 OZ/CWT (16.5 OZ/PCY)(MB: 220N)					

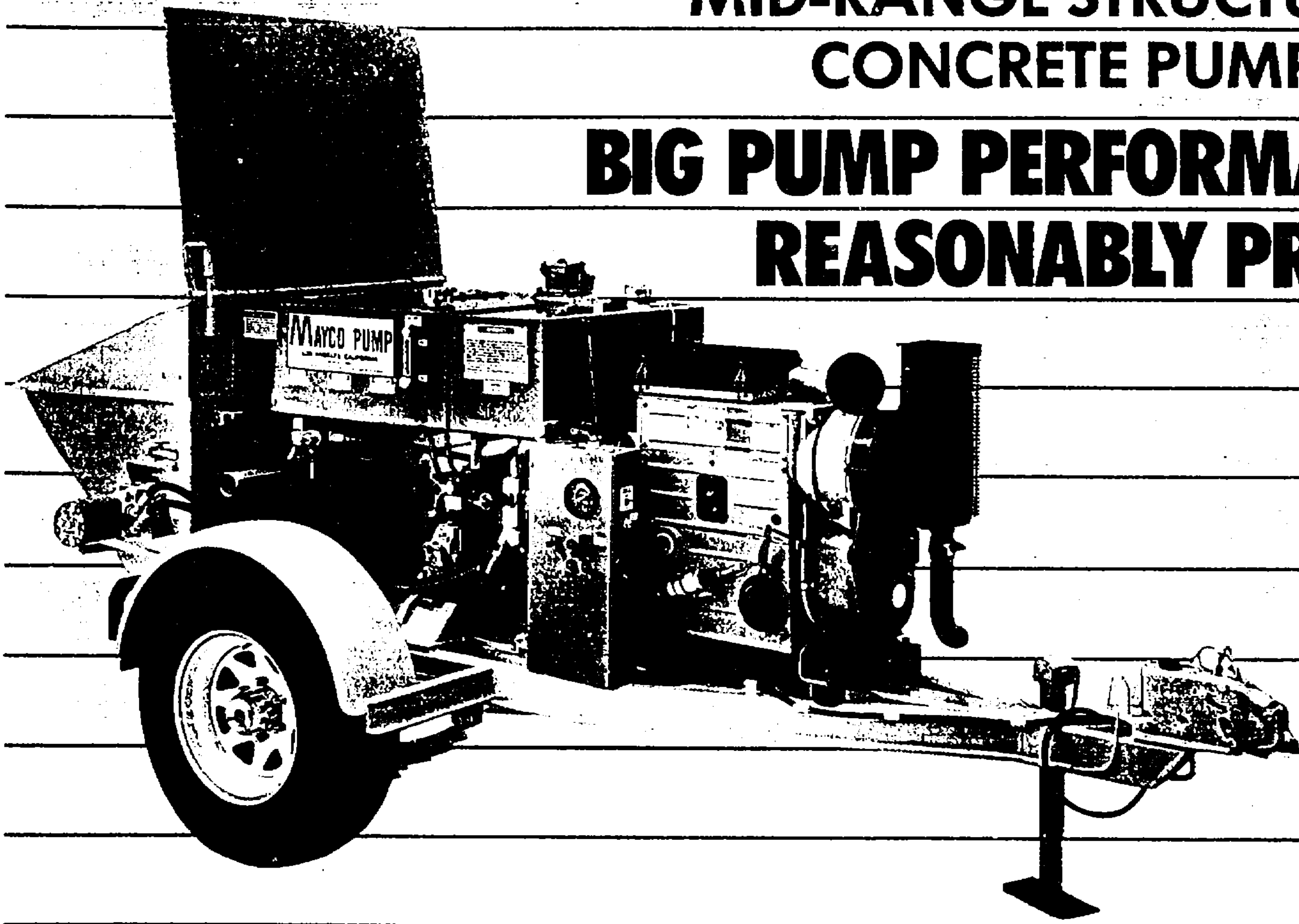
APPENDIX D: SHOTCRETE PUMP TECHNICAL SPECIFICATIONS

MAYCO PUMP CORP.

ST-30

MID-RANGE STRUCTURAL CONCRETE PUMP

BIG PUMP PERFORMANCE REASONABLY PRICED



BALANCED HYDRAULICS™

- Volume output from 0 to 30 cubic yards per hour (23 m/hr)
- Designed to handle the larger ¾″ and 1″ aggregate (25 mm)
- Concrete piston face pressure of 750 psi (52 bar)
- "Cushioned" hydraulic cylinders means a smoother pumping stroke
- Shotcrete, masonry block fill, slabs, footings, lightweight mixes
- Reverse pumping...pistons are reversed, not the concrete valve
- Full flow, cast steel Shuttle-Tube
- Reversible, hardened wear components for longer life and less maintenance

SPECIFICATIONS

PERFORMANCE

Volume Output	30 yds/hr (23 m/hr)*
Maximum Aggregate Size	1½ inch (35 mm)*
Minimum Concrete Slump	0 inch (0 mm)*
Vertical Pumping Height	200 ft (60 m)*
Horizontal Pumping Distance	1000 ft (300 m)*
Maximum Concrete Pressure	750 psi (52 bar)*

*These figures will vary due to concrete mix design, line size, job-site conditions and engine options.

ENGINEERING

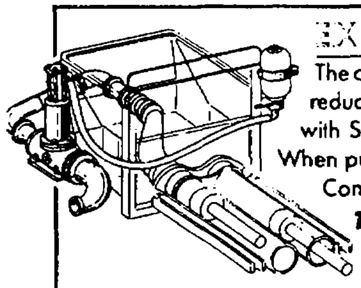
Engine — diesel	57 or 36 hp (42 or 26 kW)
— gas	65 hp (48 kW)
Concrete Cylinders	6 x 24 inch (150 x 610 mm)
Hydraulic Cylinders	3 x 24 inch (76 x 610 mm)
Hyd. Oil Capacity	70 gallons (265 liters)
Hyd. Oil Cooler	standard on all models
Pump Outlet Diameter	5 inch raised end (125 mm)
Hopper Height	43 inch (1090 mm)
Hopper Capacity	10 cu ft (283 liters)
Brakes	hydraulic surge type

DIMENSIONS

L x W x H	140 x 67 x 54 inch
	356 x 170 x 137 cm
Weight	3500 lbs (1588 kg)

OPTIONS

Hopper remixer, engine cover (hood), Auto-Comp,™ rear hydraulic out-riggers, hopper vibrator, Hatz, Deutz or Wisconsin engines, Silent Pack engines, electric motor, high pressure water pump, wireless remote control, electric brakes, skid or truck mount.



EXCLUSIVE MAYCO AUTO-COMP

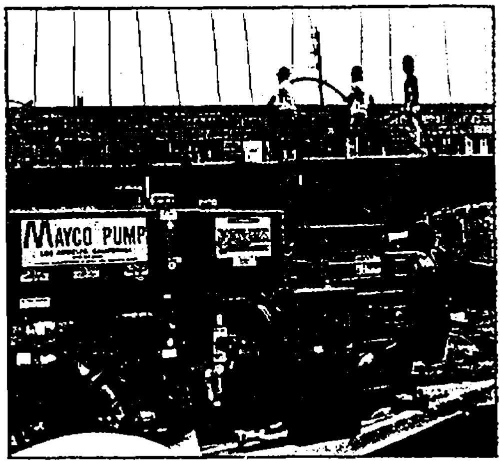
The optional Auto-Comp™ eliminates destructive line surge and reduces hose wear. Now you can place ½" minus aggregate with SMOOTH, even, continuous flow at the end of the hose. When pumping large aggregate mixes, simply bypass the Auto-Comp™ and attach the larger 3" and 4" hoses.

The Shotcrete Advantage

A Mayco ST-30 swing tube pump with AUTO-COMP™

*Specifications subject to change without notice.

VERSATILITY



We carry a complete line of superior pumping accessories and delivery systems for all makes of pumps.

MAYCO PUMP CORP.
4640 Sperry St., Los Angeles, CA 90039
(818) 507-3900 TELEX 292479
FAX (818) 244-4799

"MAKE IT A MAYCO"

Your Dealer:

ST-30 AND LST STRUCTURAL CONCRETE PUMP

HOW IT WORKS

The Mayco series of structural concrete pumps are hydraulically operated, trailer mounted pumps designed to pump concrete mixes through steel pipes and flexible discharge hoses (placing line). The engine powers an hydraulic pump which delivers oil, under pressure to operate the system.

The concrete valve on this series a shuttle-tube or swing tube, which provides a 4-way action in feeding concrete into the concrete cylinders and in discharging the concrete into the placing line.

Concrete is poured into the hopper and as the shuttle-tube is aligned with one concrete cylinder (B), the other concrete cylinder (A) is on the intake stroke, drawing concrete into the concrete cylinder (see figure 1). A piston cup or mud cup is attached to the "ram" in the hydraulic cylinder and serves as the agent to both draw concrete into the concrete cylinder and to expel concrete through the shuttle-tube into the placing line.

As the intake stroke is completed and cylinder A is fully charged with material, cylinder B will have completed its discharge stroke at the same time. Simultaneous with cylinder A now in the discharge stroke and cylinder B now on the intake stroke (see figure 1A), the shuttle-tube will swing over to cylinder A and align itself and concrete will continue to flow through the shuttle-tube into the placing line. This process is continuously repeated, at the desired volume level, until the job is completed.

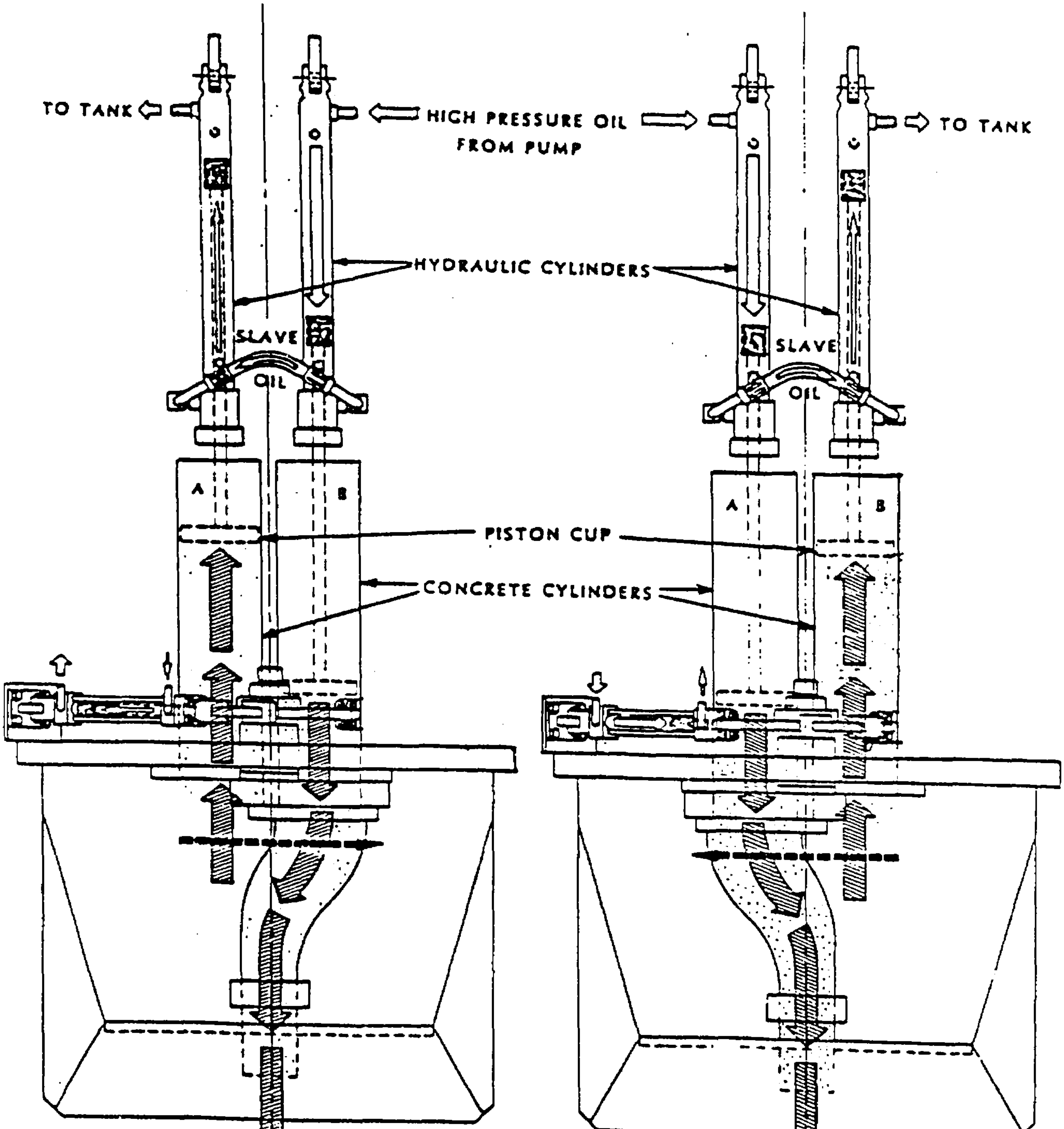


FIGURE 1
CYLINDER A — INTAKE STROKE
CYLINDER B — DISCHARGE STROKE

FIGURE 1A
CYLINDER A — DISCHARGE STROKE
CYLINDER B — INTAKE STROKE