PRESTRESSED CONCRETE BRIDGE BEAMS WITH MICROSILICA ADMIXTURE

Final Report
Experimental Features
Projects No. 93-01 A&B

by

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16. Abstract

Microsilica fume admixture in concrete beams was used in two coastal bridges to reduce chloride permeability. Cylinders were cast from the beam mixture for strength and permeability tests.

The fabricator found no problems with making these beams, except for the reduction in slump. After the beams were cast and cured they were transported from Harrisburg to the Oregon coast.

The construction contractor reported no problems with the placement of the beams related to using microsilica. Although the results of the permeability test by AASHTO T277 were acceptable, they were higher than the silica fume supplier predicted. The producer obtained better results by using a steam cure method before testing the cylinders. The job was still considered a success and silica fume admixture is recommended for future concrete bridge construction.

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SILICA FUME ADMIXTURE, MICROSILICA, CHLORIDE PERMEABILITY	Available through the Oregon Department of Transportation Research Unit

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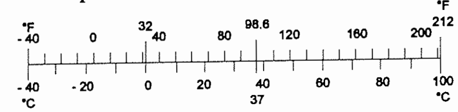
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		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	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters 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	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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DISCLAIMER

PRESTRESSED CONCRETE BRIDGE BEAMS WITH MICROSILICA ADMIXTURE

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1.0 INTRODUCTION

The cost associated with repairing and replacing traffic structures due to the corrosion of reinforcing steel is a major concern for transportation agencies nationwide. Chloride ions (cl-) are the primary cause of reinforcing steel corrosion. These chloride ions normally come from de-icing and anti-icing salts or naturally occurring air-borne salts. The chloride ions permeate the concrete until a critical concentration is reached at the level of the reinforcing steel. It is only then a matter of time until the expansive rust from the steel creates sufficient internal pressures in the concrete to cause cracking and spalling. The reinforcing steel also loses load carrying capacity due to the reduction in cross sectional area.

This report documents a project in which condensed silica fume (microsilica), added to concrete to reduce chloride permeability, was used in the production of precast prestressed steel reinforced bridge beams.

2.0 PROJECT DESCRIPTION

2.1 PROJECT LOCATION

The prestressed beams were produced by Morse Bros. Inc. at their Harrisburg, Oregon plant. After the beams were cured, they were transported to two bridge construction jobs on the Oregon coast. Fifty-five beams were transported 175 miles to Catching Slough near Coos Bay, Oregon. Another 27 beams were hauled 225 miles to Rocky Point near Port Orford, Oregon on US 101 (see Figures 2.1 - 2.3).

2.2 PROJECT CONSTRUCTION

Both jobs offered various construction challenges. In order to begin work at Rocky Point, crews had to construct a temporary bridge to keep US 101 open to vehicular traffic. Beam placement and concrete in-place pours were difficult because of the rocky ledges and narrow working space.

On the other hand, a temporary structure had to be built for pile drivers at Catching Slough in the center of the channel. This also enabled better placement of the large cranes used to place the prestressed beams. Another problem was the nesting time needed to hatch blue heron cranes located near the project. This delayed the project because the crew was unable to drive piles until the nesting period was complete. None of the construction problems experienced by the crews were caused by using microsilica in the prestressed beams (see Figures 2.5 - 2.8).

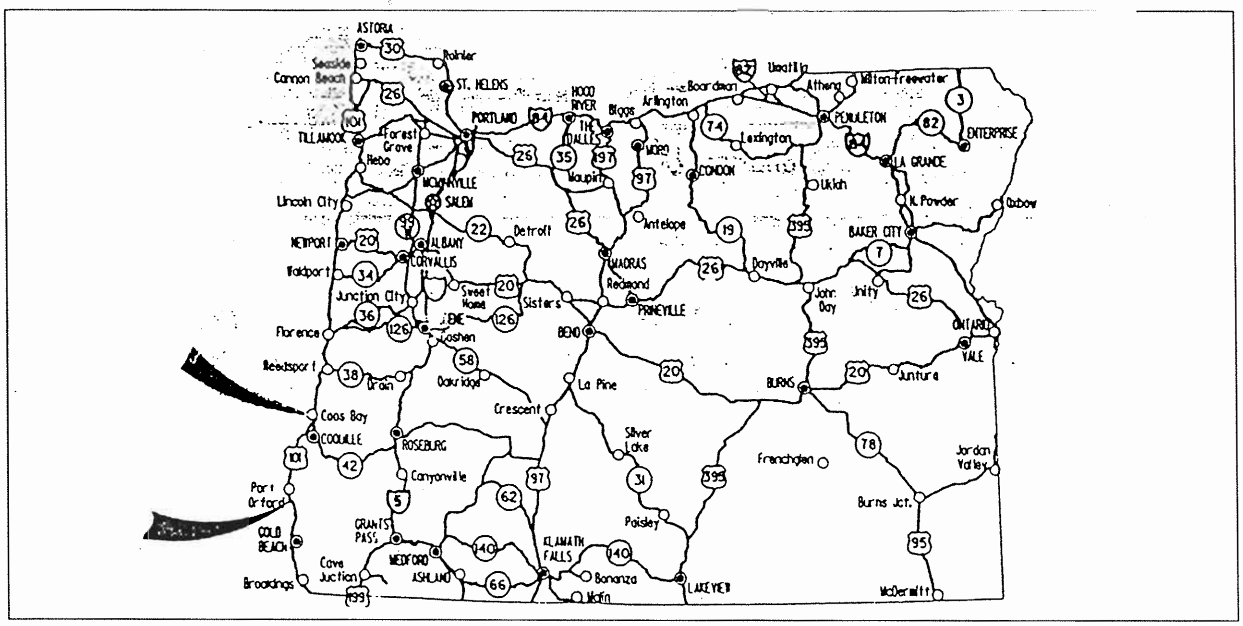

Figure 2.1 Vicinity Map

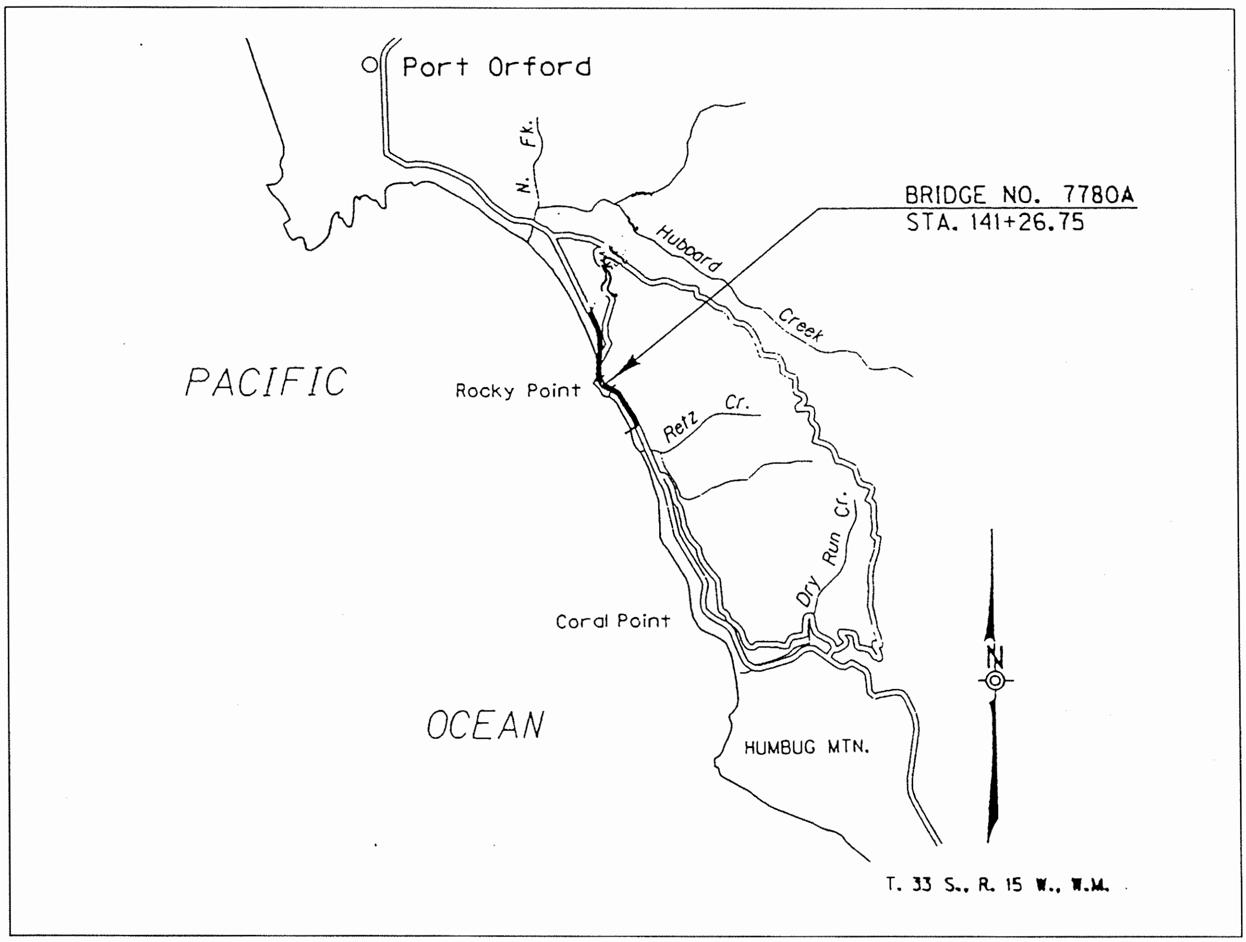

Figure 2.2 Rocky Point Viaduct near Port Orford

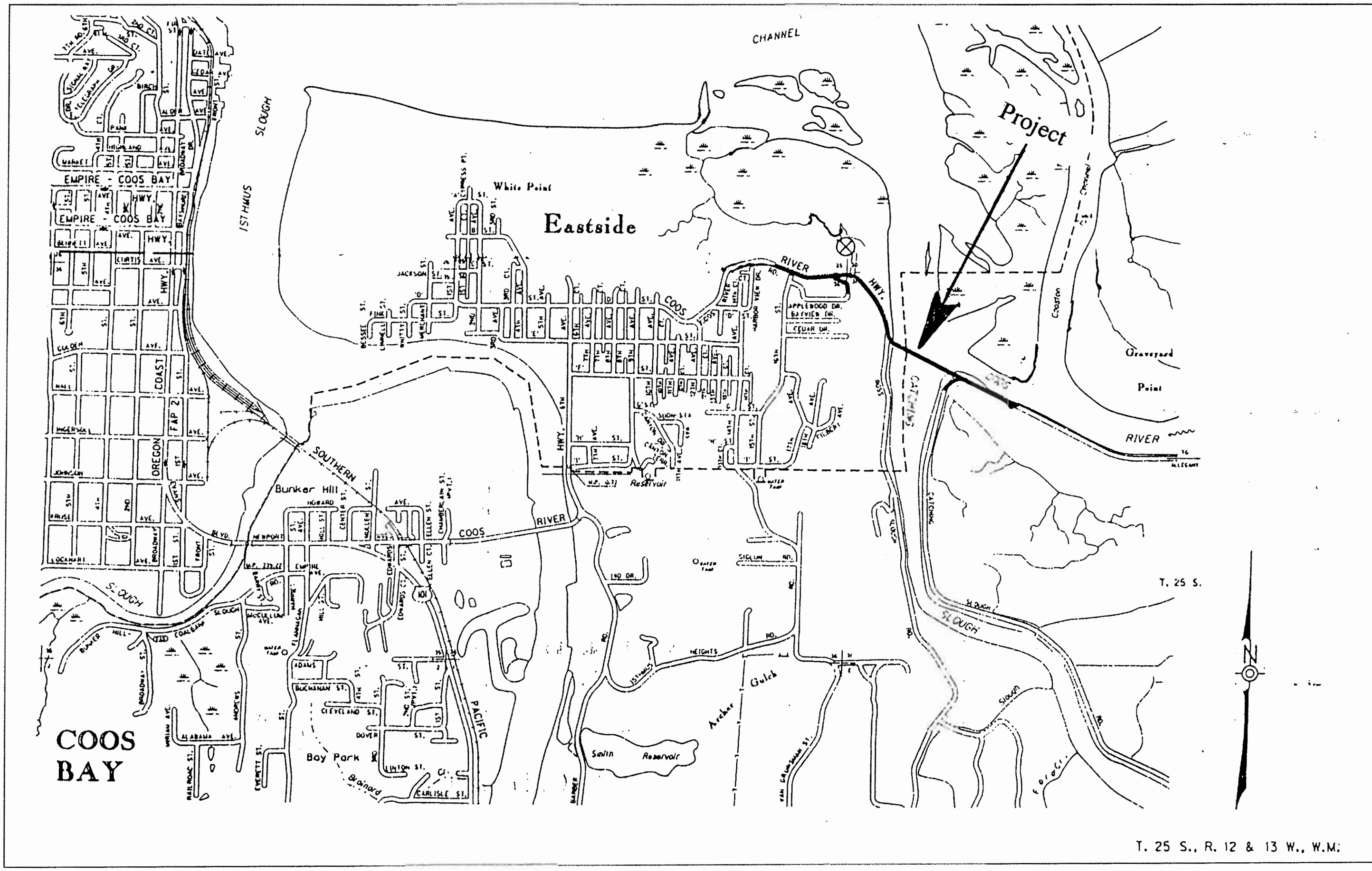

Figure 2.3 Catching Slough near Coos Bay, Oregon.

Figure 2.5 Prestressed Beams temporarily set on cross members at Catching Slough.

Figure 2.6 Temporary structure built in Catching Slough channel for large cranes used in the bridge construction.

Figure 2.7 Temporary Structure at Rocky Point Viaduct

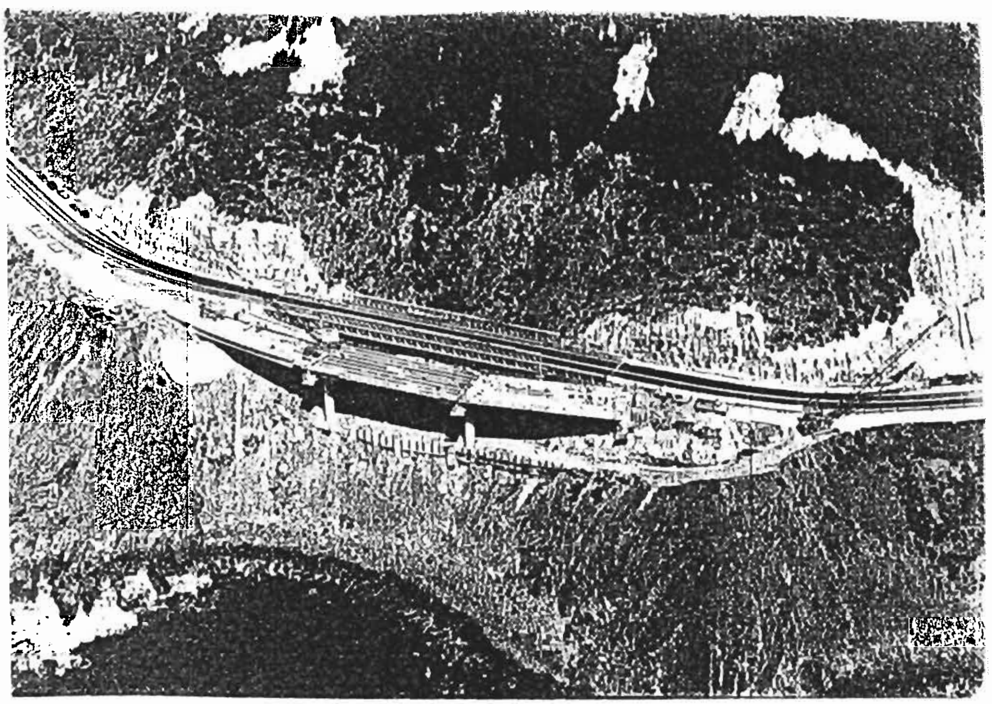

Figure 2.8 Aerial view of Rocky Point Viaduct under construction. Note the narrow working space.

3.0 CONCRETE MIX DESIGN SELECTION

Morse Bros. produced seven trial batches, designed by Wiss, Janney, Elstner Associates, Inc. of Seattle, Washington, on February 18, 1992. These trial batches were used to determine the amount of microsilica and fly ash to be used in prestressed beams.

Each batch was tested for fresh concrete properties of slump, unit weight, temperature, and slump loss at 15 minutes. Cylinders were cast from each sample batch for testing compressive strength and chloride permeability. The mix proportions and the test results are summarized in Table 3.1. The best combination appeared to be batch #3. A complete batch weight table is included in Appendix A.

Table 3.1: Trial Batch Silica Fume and Fly Ash Percentages

BATCH NUMBER	SILICA FUME %	FLY ASH		PERMEABILITY CHARGE PASSED (COULOMBS) (AASHTO T277)	28-DAY COMPRESSIVE STRENGTH (psi)
		%	TYPE		
1 (2/18/92)	0	0	n/a	3321	8850
2 (2/18/92)	0	20	C	3006	8500
3 (2/18/92)	8	20	C	359	9550
4 (2/18/92)	5	20	C	776	9490
4a (2/18/92)	5	20	C	627	8830
5 (2/18/92)	5	30	C	460	8810
6 (2/18/92)	5	20	F	842	8640
7 (6/23/92)	5	30	C	800	8150
8 (6/23/92)	5	30	F	600	7890

Fly ash alone slightly reduced chloride permeability. This is demonstrated by the decreased permeability of sample batch #2 compared to batch #1. However, the addition of 8% microsilica in combination with fly ash, in batch #3 decreased the permeability by a factor of 10.

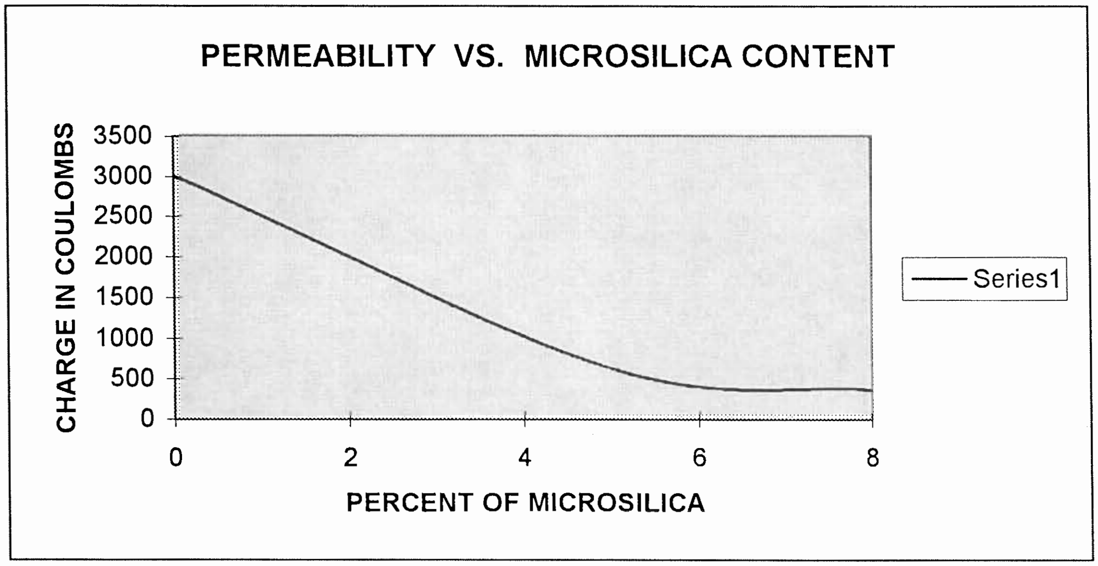

Figure 3.1 Microsilica Reduces Permeability

The amount of microsilica used in the final mix design was set at 5%. As shown in Figure 3.1, the slope of the curve starts decreasing at about 5%. This shows that the cost of adding more than 5% microsilica to the mixture may not be justified by the small increase in the reduced permeability of the mix.

Two more trial batches, one with type C fly ash and the other with type F fly ash, were mixed on June 23, 1992. The amount of fly ash in these batches was increased to thirty percent. The compressive strength requirements were met for both batches. Permeability was very low as defined by AASHTO T277. These test results are included in Table 3.1 as batch numbers 7 and 8.

3.1 PERMEABILITY TESTING

The curing method of the concrete cylinders produced differing permeabililty test results. Morse Bros. steam cured the test cylinders while ODOT used the standard moist cure. ODOT's cylinders tested higher in all cases. The lower values obtained by Morse Bros. were accepted by ODOT because the same cure method was used for the prestressed beams. In addition, most experts agreed that the steam curing method aged the concrete. Permeability is expected to decrease with the age of the sampled concrete. The predicted value would be lower (see Appendix A).

The AASHTO T277 test procedure does not specify the length of curing. Step 1 of the procedure instructs the user to: "obtain the core in a conventional manner (with a diamond core bit). Place core in plastic bag and return to laboratory" (AASHTO, 1990). The sample is then cut, washed and soaked in a lime solution for 17 to 19 hours before the current test is started. When the original experiment to establish the rapid testing procedure was conducted, test slabs were cured for 90 days. Three methods (moist, air and freezer) were used. Only a slight difference of about 3% was noted in the three cure methods (Whiting, 1981).

Table 3.2: Summary of Cure Tests of Test Mixes.

SAMPLE	DATE TESTED	AGE IN DAYS	CHARGE PASSED (COULOMBS)	CURE METHOD	SAMPLE SOURCE
TESTMIX1	3/18/92	28	3321	steam	cylinders
TESTMIX2	3/18/92	28	3006	steam	cylinders
TESTMIX3	3/18/92	28	359	steam	cylinders
TESTMIX4	3/18/92	28	776	steam	cylinders
TESTMIX4A	3/18/92	28	627	steam	cylinders
TESTMIX5	3/18/92	28	460	steam	cylinders
TESTMIX6	3/18/92	28	842	steam	cylinders
TESTMIX7	7/31/92	38	2488	moist	cylinders
TESTMIX8	7/31/92	38	2500	moist	cylinders
TESTMIX7	8/3/92	41	880	steam	cylinders
TESTMIX8	8/4/92	42	588	steam	cylinders
C104677	9/23/92	92	1655	moist	cylinders
C104678	9/23/92	92	1100	moist	cylinders
#1-B	3/30/94	43	1514	moist	beams
#1-C	3/30/94	47	1536	moist	beams
#1-D	3/30/94	49	1290	moist	beams
#3-B	3/29/94	64	1593	moist	beams
#3-C	3/29/94	62	1438	moist	beams
#3-D	3/29/94	56	1264	moist	beams

Note that cores cut from production beams in 1994 did not test as low as the test mixes (see Table 3.2). From this, it could be inferred that permeability did not decrease with age. However, the differences in laboratory testing methods could also explain this difference. In the original experiment establishing AASHTO T277, a variability of 31% was found which would include the value found on this project. For example a reading of 1000 coulombs passed could include values from 700 to 1300 and be in the 31% range.

3.2 FINAL CONCRETE MIX DESIGN

The fabricator (Morse Bros.) submitted a final trial batch to ODOT (Lab. No. 93-05372) for approval before casting the beams. Cylinders from the trial batch had been tested by an independent laboratory for compressive strength and permeability. Compressive strength was well above the 7000 psi design value at 10,600 psi. Permeability was found to be very low at 550 coulombs passed. The project specification was set at a minimum on 1000 coulombs passed as tested under AASHTO T277.

Table 3.3: Concrete Batch Design as Submitted by Morse Bros.

Item	Weight in lbs	Brand Name	Notes
Cement	549	Holnam Type III	
Fly Ash	147	Western Ash Type C	
Microsilica	37	Master Builders	dry
Aggregate (1/2-#4)	1905		SSD absorption 2.1%
Sand	1157		SSD absorption 3.2%
Mix Water	249		W/C Ratio = 0.34
Air Content	N/A		1.5%
Air Entraining Agent	N/A		none
Water Reducer		Master Builders 100xr	
Optional		Master Builders Polyheed	
High Range Water Reducer		Master Builders Rheobild 1000	*1997 Rheobild 2500

The fly ash and the microsilica were used as cement replacement. The percent of fly ash was then 147/696 x 100%=21.1% of the total cementitious material. The microsilica was then 37/696 x 100%=5.3% of the total cementitious material. Contract specifications allowed up to 30% cement replacement with fly ash.

4.0 PRESTRESSED BEAM PRODUCTION

The prestressed beams were cast at Morse Bros. plant near Harrisburg Oregon. One beam a day was produced for this project. Compressive strength tests were conducted at 17 and 19 hours to find if the beams met the minimum release compressive strengths specified on the girder plans. At this time the prestressed cables were released and the beams moved to curing section at Morse Bros. plant.

The producer reported only two minor problems with microsilica: high slump loss and air voids. Beams for this project not only contained microsilica to reduce permeability, but also contained cathodic protection cables. Working around the numerous cables slowed the consolidation of the concrete in the forms. The built in vibration system on the forms could not be used, so much of the vibration was done with hand held vibrators.

Contract specifications called for a smooth finish on beam surfaces visible to the public. The many small holes and some larger ones had to be hand patched. This increased the labor time for the beam production.

4.1 PRODUCTION TESTING

Quality control for the beam production was monitored by ODOT from November of 1993 until July of 1994. One beam (girder) per day was fabricated. Cylinders from each pour were cast and tested for compressive strength. The 17 and 19-hour cylinders were tested by Morse Bros. to ensure the required release strength. ODOT tested three cylinders for 28-day strength. Average compressive strengths, unit weight, slump, and water cement ratios are shown in Table 4.1 (See Appendix B for a complete daily listing).

Table 4.1: Average Concrete Property Values.

Month	Unit Weight lb/ft^3	Cement, lbs	Slump, in.	W/C	Compressive Strength, psi
Catching Slough					
Nov	148.8	707	6.2	0.34	8090
Dec	149.0	728	2.3	0.35	8070
Jan	149.8	735	2.6	0.33	9480
Feb	150.3	737	2.0	0.32	10,000
Ave	149.5	727	2.4	0.34	8910
Rocky Point					
Mar (1 beam)	148.9	733	3.0	0.34	9841
June	148.4	722	4.1	0.37	8665
July	147.9	720	5.5	0.38	7751
Ave.	148.4	725	4.2	0.36	8752

Note that higher water cement ratios were used on the Rocky Point beams than on those produced for Catching Slough. While the compressive strengths were slightly reduced, they still exceeded the design value of 7000 psi. The increased slump improved the workability of the concrete during consolidation.

4.2 CAMBER

Camber of the prestressed beams was measured at release and again after ninety days. ODOT bridge designers also calculate camber values by computer. A modulus of elasticity was assumed for this program based on ODOT's experience with prestressed beams. If the actual modulus differs from the assumed value, calculated camber will vary from the actual values. Both the measured and calculated values are summarized in Table 4.2.

Table 4.2 Average Camber Values.

PROJECT	CALC. REL. CAM.	ACT. REL. CAM.	COMP. STR. @ REL.	COMP. STR. @ 28 DAYS	CALC. 90-Day CAM.	ACT. 90-DAY CAM.	ERROR CALC-ACT		W/C
	in.	in.	lbs/in^3	lbs/in^3	in.	in.	in.		
							hi	lo	
Catching Slough	2.44	2.5	6082	7012	4.25	4.25	+3/8	-1/4	0.34
Rocky Point Viaduct	1.87	1.94	6242	8333	3.32	2.6	+1 1/4	+1/4	0.37

The actual release cambers for the beams at both bridges were slightly greater than the calculated values. The Catching Slough beams had an actual camber close to the calculated values at ninety days after release, while Rocky Point beam cambers were consistently lower than the calculated values. The main difference in the concrete used for these two bridges was the water cement ratio. Correction for the flatter camber is made in the field by building up the top of the beams (see Figure 4.1). This is done in order to have a uniform grade on which to place the deck forms

Some of the Catching Slough girders had a build up of 4 inches. A build up of this amount increases the dead load on the beams. Thus, the safety margin of the designed live load is reduced.

The change in camber caused by the weight of the deck did not match predicted values. Beams at Catching Slough had a mid-span deflection of about one half to two thirds of the predicted values. Beams at Rocky Point on the other hand, deflected more than the predicted values. Both conditions were corrected by adjustments to the deck grade. Bridge designers speculate that the problems were caused by assumptions made about the end conditions of the beams; i.e. fixed or free. In addition, the weight of the temporary supports for the deck forms and the weight of the reinforcing steel were not included in the deflection calculations. Appendix C includes the camber data.

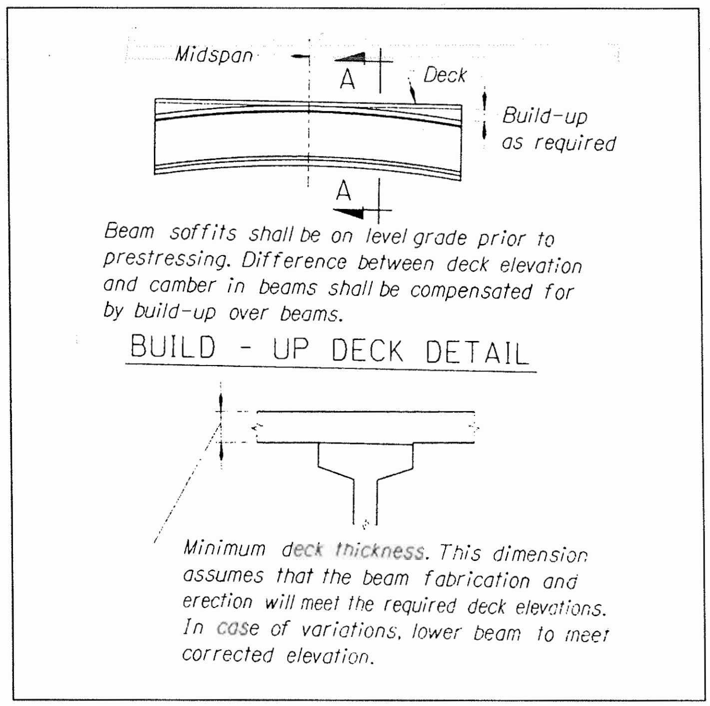

Figure 4.1 Deck Detail

5.0 COSTS

Addition of microsilica increased the production cost of the prestressed girders by about $230/per cubic yard. This increase, estimated by the producer, reflects higher material and labor costs.

Both fly ash and microsilica were used in the production as cement replacement. Fly ash costs less than cement while microsilica costs much more. The 1997 cement material costs are shown in Table 5.1.

Table 5.1: Costs for Cementitious Materials: 1997 Prices.

ITEM	COST $/ton	COST $/lb	batch weight, lb	Cost, $/yd^3
Job Mix = 75 % cement, 20 % fly ash, 5 % microsilica				
Cement	92	.046	530	24.38
Fly Ash	35	.0175	140	2.45
Silica Fume	600	0.300	35	10.50
Total				37.33
Conventional mix = 80 % cement, 20 % fly ash				
Cement	92	.046	562	25.85
Fly Ash	35	.0175	140	2.45
Silica Fume	600	0	0	0
Total				28.30

In addition to the increase cost of cementitious material, a super plasticizer was also needed to prevent shrinkage cracking of the concrete during the cure period. This material was estimated to cost about $6.00/yd^3 of concrete. Other extra costs were incurred in the storing and handling of the silica fume. Also, this mix used 1/2 in. aggregates and sand in different amounts than conventional mixes.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Microsilica and fly ash added to the concrete reduced the permeability of the prestressed concrete beams. However, the actual reduction was not in the reported 400 - 800 Coulomb range initially measured, but was in the 1000 - 2000 Coulomb range (see Table 3.2). ODOT recommends the use of microsilica for future prestressed concrete beams. ODOT did not find any adverse side effects in the concrete properties when microsilica was added.

7.0 REFERENCES

American Association of State Highway and Transportation Officials (AASHTO), *Standard Specifications for Transportation Material and Methods of Sampling and Testing,* Fifteenth Edition Part II Tests 1990.

Whiting, D. *Rapid Determination of the Chloride Permeability of Concrete,* FHWA/RD-81-119, August 1981.

APPENDIX A

TRIAL BATCH MIXES

Table A.1: Batch Weights per yd³ (m³) (SSD), February 18, 1992

	1 (contr.)	2	3	4	4a	5	6
Cement, Type 3	705 (418)	565 (335)	510 (303)	530 (314)	530 (314)	460 (274)	530 (314)
Flyash	0	140 (83)	140 (83)	140 (83)	140 (83)	210 (131)	(F)140 (83)
Silica Fume	0	0	55 (31)	35 (21)	35 (21)	35 (21)	35 (21)
½ in. (13mm) CA	637 (378)	1920 (1139)	1910 (1133)	1910 (1133)	670 ¾ (397)	1900 (127)	1910 (1133)
¾ in. (19mm) CA	1187 (704)	0	0	0	1240 (736)	0	0
Sand	1238 (734)	1160 (688)	1150 (682)	1150 (682)	1150 (682)	1150 (682)	1150 (682)
Water	254 (151)	254 (151)	254 (151)	254 (151)	254 (151)	254 (151)	254 (151)

Table A.2: Test Results, February 19, 1992

	Control ¾ in. (19mm)	20% Ash, No SF	8% SF, 20% Ash	5% SF, 20% Ash	¾ in. (19mm) agg., 5% SF, 20% Ash	5% SF, 30% Ash	5% SF, 20% Class F
17 Hrs. Release	7321 (50.5)	6508 (44.9)	8736 (60.2)	8099 (55.8)	6685 (46.1)	7816 (53.9)	7746 (53.4)
	7003 (48.3)	6596 (45.5)	9125 (62.9)	8170 (56.3)	8064 (55.6)	6720 (46.3)	7392 (51.0)
19 Hrs. Release	7834 (54.0)	6861 (47.3)	9266 (63.9)	7958 (54.9)	7887 (54.4)	8524 (58.8)	7675 (52.9)
	7569 (52.2)	6826 (47.1)	9107 (62.8)	8807 (60.7)	8418 (58.0)	7392 (51.0)	8205 (56.6)
Average 17-Hr. & 19-Hr. Release	7431 (51.2)	6698 (46.1)	9058 (62.5)	8258 (56.9)	7764 (53.5)	7613 (52.5)	7755 (53.5)
28-Day (curing tank)	9567 (66.0)	9249 (63.8)	9885 (68.2)	10275 (70.8)	8789 (61.6)	9382 (64.7)	10266 (70.8)
28-Day (ODOT)	8850 (61.0)	8500 (58.6)	9550 (65.8)	9490 (65.4)	8830 (60.8)	8810 (60.7)	8640 (59.5)
RATIOS							
28-Day (Curing Tank Over the Average of Release)	1.29	1.38	1.09	1.24	1.13	1.23	1.32
28-Day (ODOT) Over the Average of Release	1.19	1.27	1.05	1.15	1.14	1.16	1.11
Chloride Permeability Test (AASHTO T-277)	3321	3006	359	776	627	460	842

Note: A combination of Master Builders' type A water reducer, 100 XR, and Type F high range water reducer, Rheobuild 1000 will be used in all mixes.

MORSE BROS. TEST PROGRAM

MIX DESCRIPTION OUTLINE

1. Control mix = MB P/S mix, C = 705 lbs./yd^3 (418 kg/m^3), W/C = 0.35-0.36, ¾ in. (19mm) agg. w/40% sand, no air, Rheo.

2. 20% Class C fly ash, no silica fume, C = 565 lbs./yd^3 (335 kg/m^3), F.A. = 140 lbs./yd^3 (83 kg/m^3), W/C = 0.36, 1/2 in. (13mm) agg.

3. 20% Class C fly ash, 8% silica fume, C = 510 lbs./yd^3 (303 kg/m^3), F.A. = 140 lbs./yd^3 (83 kg/m^3), S.F. = 55 lbs./y^3 (33 kg/m^3), W/C = 0.36, 1/2 in. (13mm) agg.

4. 20% Class C fly ash, 5% silica fume, C = 530 lbs./yd^3 (314 kg/m^3), F.A. = 140 lbs./yd^3 (83 kg/m^3), S.F. = 35 lbs./yd^3 (21 kg/m^3), S/C = 0.36, 1/2 in. (13mm) agg.

4a. 20% Class C fly ash, 5% silica fume, C = 530 lbs./yd^3 (314 kg/m^3), F.A. = 140 lbs./yd^3 (83 kg/m^3), S.F. = 35 lbs./yd^3 (21 kg/m^3), W/C = 0.36, 1/2 in. (13mm) agg. and ¾ in. (19mm) agg.

5. 30% Class C fly ash, 5% silica fume, C = 460 lbs./yd^3 (274 kg/m^3), F.A. = 210 lbs./yd^3 (131 kg/m^3), S.F. = 35 lbs./yd^3 (21 kg/m^3), W/C = 0.36, 1/2 in. (13mm) agg.

6. 20% Class F fly ash, 5% silica fume, C = 530 lbs./yd^3 (314 kg/m^3), F.A. = 140 lbs./yd^3 (83 kg/m^3), S.F. = 35 lbs./yd^3 (21 kg/m^3), W/C = 0.36, 1/2 in. (13mm) agg.

PROCEDURE

1. Make 1 or 2 – ½ m^3 batches for trial to fix admixture dosages w/fly ash (and silica fume).

2. Make 6 – 1 m^3 batches as per above.

3. Measure all fresh concrete properties, slump, unit weight, temperature, slump loss @ 15 min.

4. Make cylinders. (6in. (152mm) and/or 4 in. (102mm)) for test (compressive and rapid chloride permeability), FE @ 18-hour, 7-day, 28-day, and 56-day, Cl @ 28-day.

APPENDIX B

CONCRETE PROPERTIES

CATCHING SLOUGH (CONTRACT C11265)

		UNIT WT		CEMENT		SLUMP		Water/ Cement	28-Day Compressive Strength	
DATE	C sheet #	lbs//ft³	kg/m³	lbs	kg	inches	cm		psi	kg/cm²
11/4/93	101496	147.7	2365.9	171	325	2.25	5.72	0.36	9293	653.4
11/8/93	101497	148.4	2377.1	535	243	3.5	8.89	0.36	7537	529.9
11/11/93	101498	149	2386.8	732	332	2.75	6.99	0.34	8150	573
11/15/93	101499	148.4	2377.1	737	334	2	5.08	0.33	8007	562.9
11/17/93	101500	149.6	2396.4	734	333	4.25	10.8	0.34	7607	534.8
11/19/93	101503	149.6	2396.4	732	332	1.5	3.81	0.33	8063	566.9
11/23/93	101504	149.9	2396.4	728	330	2.5	6.35	0.32	7987	561.5
11/29/93	101505	147.8	2367.5	723	328	2	5.08	0.35	8350	587.1
11/30/93	101506	149.2	2390	724	328	2.5	6.35	0.35	7847	551.7
mean		148.8	2383.6	707	321	2.58	6.55	0.34	8093	569
st.dev.		0.81	13	65	29	0.84	2.13	0.01	516.6	36.3

		UNIT WT		CEMENT		SLUMP		Water/ Cement	28- Day Compressive Strength	
DATE	C sheet #	lbs/ft³	kg/m³	lbs	kg	inches	cm		psi	kg/cm²
12/1/93	101507	149.9	2396.4	730	331	2.25	5.72	0.35	8027	564.4
12/3/93	101508	148.8	2383.6	728	330	2	5.08	0.34	8400	590.6
12/6/93	101509	148.8	2383.6	727	330	2	5.08	0.35	8103	570
12/7/93	101510	149.6	2396.4	731	332	2.25	6.35	0.34	7720	542.8
12/8/93	101511	148.8	2383.6	727	330	21	5.08	0.34	7843	551.4
12/9/93	101512	147.7	2365.9	725	329	2.75	6.99	0.35	8377	589
12/10/93	101513	149.3	2391.6	731	332	3	7.62	0.35	8447	593.9
12/13/93	101514	149.3	2391.6	727	330	3	7.62	0.35	8063	566.9
12/14/93	101515	149	2386.8	726	329	2	5.08	0.34	8200	576.5
12/15/93	101516	149.2	2390	729	331	2	5.08	0.35	7950	558.9
12/16/93	101517	149.3	2391.6	728	330	3	7.62	0.34	8043	565.5
12/17/93	101518	149	2386.8	731	332	2	5.08	0.35	7890	554.7
12/20/93	101519	150.1	2404.4	739	335	1.75	4.45	0.34	8230	578.6
12/21/93	101521	149.3	2391.6	726	329	3.5	8.89	0.35	7593	533.8
12/22/93	101522	147.7	2365.9	723	328	2	5.08	0.34	7917	556.6
12/23/93	101523	148.1	2372.3	720	327	1.5	3.81	0.35	7900	555.4
12/27/93	101524	148.3	2375.5	724	328	1.5	3.81	0.34	8130	571.6
12/28/93	101525	149.7	2398	731	332	2.51	6.38	0.35	8223	578.1
12/29/93	101526	149.1	2388.4	731	332	1.5	3.81	0.35	8187	575.6
12/30/93	101527	150.1	2404.4	732	332	2.5	6.35	0.35	8070	567.4
mean		149.	2288.4	728	3303	2.26	5.74	0.35	8066	567.1
stdev.		0.70	11.2	4.04	1.83	0.56	1.42	0.01	221.5	15.6

		UNIT WT		CEMENT		SLUMP		Water/ Cement	28-Day Compressive Strength	
DATE	C sheet #	lbs//ft^3	kg/m^3	lbs	kg	inches	cm		psi	kg/cm^2
1/3/94	101528	149.1	2388.4	724	328	1.5	3.81	0.34	8603	604.9
1/4/94	101529	148.7	2382.1	730	331	1.751	4.45	0.35	9123	641.4
1/5/94	101530	148.9	2385.2	730	331	1.5	3.81	0.35	8110	570.2
1/6/94	101531	149.3	2391.6	736	321	2.5	6.35	0.34	8167	574.2
1/7/94	101532	148.7	2382.1	725	329	4.5	11.43	0.35	9840	691.9
1/10/94	101533	149.9	2406.2	731	332	3	7.62	0.35	10610	746.6
1/11/94	101534	148.9	2385.2	729	331	3.5	8.89	0.35	9983	701.9
1/12/94	101535	148.1	2372.3	720	327	3	7.62	0.34	9725	683.7
1/13/94	101536	149.2	2390.1	736	334	2	5.08	0.32	10433	733.5
1/14/94	101537	150.2	2406.0	739	335	1.5	3.81	0.32	10610	746.0
1/17/94	101539	151.9	2433.2	743	337	2.5	6.35	0.33	9923	607.7
1/18/94	101541	149.9	2401.2	738	335	3	7.62	0.32	9363	658.3
1/19/94	101543	150	2402.8	740	336	2	5.08	0.32	9043	635.8
1/20/94	101545	151.5	2426.8	740	336	2	5.08	0.32	9447	664.2
1/21/94	101548	150.3	2423.6	740	336	3.75	9.53	0.32	9230	648.9
1/24/94	101549	150.9	2417.2	743	337	3.5	8.89	0.31	9197	646.6
1/25/94	101551	151.7	2430	753	342	2.5	6.35	0.31	9267	651.5
1/27/94	101553	149.7	2398.0	733	332	2.5	6.35	0.32	9873	694.1
mean		149.8	2399.6	735	333	2.6	6.60	0.33	9475	666.2
stdev.		1.10	17.62	8.1		0.86	2.18	0.015	733.5	51.57

		UNIT WT		CEMENT		SLUMP		Water/ Cement	28-Day Compressive Strength	
DATE	C sheet #	lbs/ ft^3	kg/m^3	lbs	kg	inches	cm		psi	kg/cm^2
2/1/94	101557	150.2	2406.0	735	333	1	2.54	0.32	10563	742.7
2/2/94	101559	150.2	2406.0	733	332	1.25	3.18	0.32	9717	683.2
2/3/94	101560	151.6	2428.4	740	336	4.25	10.80	0.33	10143	713.1
2/7/94	101565	150.3	2407.6	739	335	2	5.08	0.33	9843	692.0
2/9/94	101567	150.1	2404.4	735	333	1.5	3.81	0.33	10610	746.1
2/11/94	101568	150.3	2423.6	738	335	2	5.08	0.32	9617	676.1
2/15/94	101569	149.9	2401.2	736	334	2	5.08	0.32	9873	694.1
2/17/94	101570	149.7	2398.0	740	336	2	5.08	0.32	9610	675.7
mean		150.3	2423.6	737	331	2	5.08	0.32	9997	702.9
stdev.		0.57	9.13	2.62	1.19	0.99	2.52	0.01	104.6	28.24

ROCKY POINT VIADUCT (CONTRACT C11381)

		UNIT WT		CEMENT		SLUMP		Water/ Cement	28 Day Compressive Strength	
DATE	C sheet #	lbs/ ft³	kg/m³	lbs	kg	inches	cm		psi	kg/cm²
3/29/94	101575	148.9	2385	733	332	3	7.62	0.34	9830	191.1

DATE	C sheet #	lbs/ ft³	kg/m³	lbs	kg	inches	cm		psi	kg/cm²
6/7/94	101652	148.9	2385	726	329	2.25	5.72	0.36	10200	171.1
6/9/94	101653	149.1	2388	724	328	2.5	6.35	0.36	9367	686.8
6/14/94	101654	148.1	2372	723	328	5	12.7	0.37	8547	600.9
6/16/94	101657	148.5	2379	728	330	4.5	11.43	0.36	8417	591.8
6/20/94	101660	148.1	2372	719	326	5.75	14.61	0.36	8233	578.8
6/21/94	101661	147.5	2363	717	325	3.75	9.53	0.37	8523	599.2
6/23/94	101662	148.3	2376	720	327	5	12.7	0.37	8373	588.7
6/24/94	101663	147.3	2360	718	326	3.5	8.89	0.37	8193	576.0
6/27/94	101664	148.7	2382	726	329	5.75	14.61	0.36	8260	580.7
6/28/94	101665	148.7	2382	729	331	3.75	9.53	0.36	8603	604.9
6/30/94	101667	148.9	2385	725	329	3.5	8.89	0.38	8547	600.9
	mean	148.4	2377	723	328	4.1	10.41	0.37	8660	608.9
	stdev.	0.58	9.29	4.12	1.89	1.19	3.02	0.01	601.7	42.30

		UNIT WT		CEMENT		SLUMP		Water/ Cement	28-Day Compressive Strength	
DATE	C sheet #	lbs/ ft³	kg/m³	lbs	kg	inches	cm		psi	kg/cm²
7/5/94	101668	147.9	2369	716	325	5	12.7	0.38	7463	524.7
7/6/94	101670	149.1	2388	728	330	5.75	14.61	0.38	7357	517.2
7/8/94	101673	147.9	2369	712	323	5.5	13.97	0.38	7543	530.3
7/11/94	101674	146.9	2352	716	325	7	17.78	0.38	7820	549.8
7/13/94	101675	146.7	2382	727	330	4	10.16	0.36	8120	570.9
7/14/94	101676	148.7	2382	720	327	6.5	16.51	0.37	8027	564.4
7/15/94	101677	148.1	2372	719	326	4.5	11.43	0.37	7730	543.5
7/18/94	101678	149.1	2388	721	327	5	12.7	0.38	8043	565.5
7/20/94	101682	147.9	2369	717	325	6	15.24	0.38	7617	535.5
	mean	148	2371	720	327	5.47	13.89	0.38	7747	544.7
	stdev.	0.71	11.4	5.2	2.4	0.96	2.44	0.011	274.3	19.29

APPENDIX C

CATCHING SLOUGH BRIDGE CAMBER INFORMATION

Catching Slough Bridge
Camber Information

			Calculated Release Camber		Actual Release Camber		Strength @ Release		28-day Strength		Calculated 90-day camber		Actual 90-day camber	
Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
1A	2-17-94	101570	2 5/8	6.68	2 1/2	6.35	5800	407.78	9610	675.65	4 1/4	10.80	4	10.16
1B	2-15-94	101569	2 1/8	5.41	2 1/8	5.41	5168	363.65	9870	693.93	3 7/8	9.86	4 1/16	10.32
1C	2-11-94	101568	2 1/8	5.41	2 1/8	5.41	7083	947.98	9620	676.35	3 7/8	9.86	4	10.16
1D	2-9-94	101567	1 7/8	4.78	2	5.08	6773	476.19	10,610 +	745.96+	3 7/8	9.86	3 7/8	9.86
1E	2-7-94	101565	2 1/8	5.41	2 1/4	5.72	5438	382.33	9840	649.64	3 3/4	9.86	3 7/8	9.86

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
2A	11-4-93	101496	2 1/4	5.72	2 5/8	6.68	5296	372.35	9290	653.15	4	10.16	3 3/4	9.53
2B	11-8-93	101497	2 1/4	5.72	1 7/8	4.78	4970	349.43	7540	530.11	4	10.16	4	10.16
2C	11-11-93	101498	2 1/4	5.72	2 1/2	6.35	5146	361.80	8150	573.00	4	10.16	4 1/8	10.49
2D	11-23-93	101504	2 1/4	5.72	2 3/4	6.99	6065	426.41	7990	561.75	4	10.16	4	10.16
2E	2-2-94	101559	2 3/4	6.99	2 3/4	6.99	6004	422.12	9720	683.38	4 3/4	12.07	5	12.70

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
3A	11-19-93	101503	2 3/4	6.99	2 1/4	5.72	5850	411.30	8060	566.67	4 3/4	12.07	4 3/4	12.07
3B	1-25-94	101551	2 3/4	6.99	2 3/4	6.99	7170	504.10	9270	651.75	4 3/4	12.07	5	12.70
3C	1-27-94	101553	2 3/4	6.99	2 1/2	6.99	6508	475.56	10,180	715.73	4 3/4	12.07	4 3/4	12.07
3D	2-1-94	101557	2 3/4	6.99	3	7.62	7260	510.43	10,560	742.44	4 3/4	12.07	4 3/4	12.07
3E	2-3-94	101560	3	7.72	2 1/2	6.35	7684	540.24	10,140	712.91	4 3/4	12.07	4 1/2	11.43

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
4A	11-15-93	101499	2 1/2	6.35	2 3/4	6.99	5863	412.21	8010	563.16	4 3/8	11.13	3 7/8	9.86
4B	11-17-93	101500	2 1/2	6.35	2 5/8	6.68	6287	442.02	7610	535.04	4 3/8	11.13	4 1/4	10.80
4C	1-20-94	101545	2 1/2	6.35	2 5/8	6.68	5818	409.05	9450	664.40	4 3/8	11.13	4 1/2	11.43
4D	1-21-94	101548	2 3/4	6.99	2 5/8	6.68	7118	500.45	9230	648.93	4 3/8	11.13	4 1/2	11.43
4E	1-24-94	101549	2 3/4	6.99	2 7/8	7.32	5720	402.16	9200	646.82	4 3/4	12.07	4 3/8	11.13

			Calculated Release Camber		Actual Release Camber		Strength @ Release		28-day Strength		Calculated 90-day camber		Actual 90-day camber	
Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
5A	11-29-93	101505	2 3/8	6.05	2 9/16	4.60	6367	447.64	8350	587.06	4 1/8	10.49	4 1/8	10.80
5B	11-30-93	101506	2 3/8	6.05	2 1/2	6.35	5890	414.11	7850	551.91	4 1/8	10.49	3 7/8	9.86
5C	12-1-93	101507	2 3/8	6.05	2 3/8	6.05	5845	410.94	8030	564.57	4 1/8	10.49	4	10.16
5D	12-3-93	101508	2 3/8	6.05	2 3/4	6.99	7225	507.97	8400	590.58	4 1/8	10.49	3 3/4	9.53
5E	12-6-93	101509	2 3/8	6.05	2 1/2	6.35	5730	402.86	8100	569.49	4 1/8	10.49	3 3/4	9.53

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
6A	12-7-93	101510	2 3/8	6.05	2 5/8	6.68	5680	399.34	7720	507.62	4 1/8	10.49	4	10.16
6B	12-8-93	101511	2 3/8	6.05	2 1/2	6.35	5234	367.99	7840	551.21	4 1/8	10.49	3 7/8	9.86
6C	12-9-93	101512	2 3/8	6.05	2 3/8	6.05	5694	400.33	8380	589.17	4 1/8	10.49	4	10.16
6D	12-10-93	101513	2 3/8	6.05	2 5/16	5.87	7160	503.40	8450	594.09	4 1/8	10.49	4 1/4	10.80
6E	12-13-93	101514	2 3/8	6.05	2 1/2	6.35	5588	392.88	8060	566.67	4 1/8	10.49	4 1/8	10.49

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
7A	12-14-93	101515	2 3/8	6.05	2 1/2	6.35	5447	382.96	8200	576.52	4 1/8	10.49	3 7/8	9.86
7B	12-15-93	101516	2 3/8	6.05	2 5/8	6.68	5624	395.41	7950	588.94	4 1/8	10.49	4 1/8	10.49
7C	12-16-93	101517	2 3/8	6.05	2 3/4	6.99	5721	402.16	8040	565.27	4 1/8	10.49	4	10.16
7D	12-17-93	101518	2 3/8	6.05	2 1/2	6.35	7507	527.79	7700	541.36	4 1/8	10.49	4 1/8	10.49
7E	12-20-93	101519	2 3/8	6.05	2 1/2	6.35	6269	440.75	8230	578.63	4 1/8	10.49	4 1/8	10.49

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
8A	12-21-93	101521	2 3/8	6.05	2 1/2	6.35	5535	389.15	7590	389.15	4 1/8	10.49	4	10.16
8B	12-22-93	101522	2 3/8	6.05	2 3/8	6.05	5641	396.60	7920	556.83	4 1/8	10.49	4 1/8	10.49
8C	12-23-93	101523	2 3/8	6.05	2 1/2	6.35	6092	482.31	7900	555.43	4 1/8	10.49	4 1/8	10.49
8D	12-27-93	101524	2 3/8	6.05	2 3/8	6.05	5358	376.71	8130	571.60	4 1/8	10.49	4 1/8	10.49
8E	12-28-93	101525	2 3/8	6.05	2 1/8	5.41	6128	430.84	8220	577.92	4 1/8	10.49	4 1/8	10.49

			Calculated Release Camber		Actual Release Camber		Strength @ Release		28-day Strength (psi)		Calculated 90-day camber		Actual 90-day camber	
Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
9A	12-29-93	101526	2 3/8	6.05	2 3/8	6.05	5902	414.95	8190	575.81	4 1/8	10.49	4 1/8	10.49
9B	12-30-93	101527	2 3/8	6.05	2 1/2	6.35	6233	438.22	8070	567.38	4 1/8	10.49	4	10.16
9C	1-3-94	101528	2 3/8	6.05	2 3/8	6.05	5854	411.58	8600	604.64	4 1/8	10.49	4 1/4	10.80
9D	1-4-94	101529	2 3/8	6.05	2 1/2	6.35	6685	470.00	9120	641.20	4 1/8	10.49	4	10.16
9E	1-5-94	101530	2 3/8	6.05	2 1/4	5.72	5510	387.40	8110	570.19	4 1/8	10.49	4 1/8	1049

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
10A	1-6-94	101531	2 3/8	6.05	2 3/8	6.05	5871	412.77	8170	574.41	4 1/8	10.49	4 3/8	11.13
10B	1-7-94	101532	2 3/8	6.05	2 1/2	6.35	6215	436.96	9840	691.82	4 1/8	10.49	4	10.16
10C	1-10-94	101533	2 3/8	6.05	2 1/2	6.35	5517	387.88	10,610+	745.96+	4 1/8	10.49	4	10.16
10D	1-11-94	101534	2 3/8	6.05	2 3/8	6.05	5615	394.77	9980	701.66	4 1/8	10.49	4 1/8	10.49
10E	1-12-94	101535	2 3/8	6.05	2 1/4	6.05	5712	401.60	9730	684.09	4 1/8	10.49	4 1/4	10.80

Unit #	Date	C-sheet #	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
11A	1-13-94	101536	2 5/8	6.68	2 5/8	6.69	5809	408.41	10,430	733.02	4 5/8	11.76	4 1/2	12.07
11B	1-14-94	101537	2 5/8	6.68	2 1/4	5.72	7763	545.79	10,610+	745.96+	4 5/8	11.76	4 5/8	11.76
11C	1-17-94	101539	2 5/8	6.68	2 5/8	6.68	6455	453.83	9920	697.45	4 5/8	11.76	4 1/2	11.43
11D	1-18-94	101541	2 5/8	6.68	2 1/4	5.72	5898	414.67	9360	658.07	4 5/8	11.76	4 3/4	12.07
11E	1-19-94	101543	2 5/8	6.68	2 3/16	5.56	5685	399.70	9040	635.58	4 5/8	11.76	4 1/2	11.43

Rocky Point Viaduct
Prestressed Girder Camber Information

			Calculate Release Camber		Actual Release Camber		Release Strength		28-day Strength		Calculate 90-day Camber		Actual Camber 12/15/94	
Unit #	Date	C-sheet	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
A1	7/15/94	101677	2 1/2	6.35	2 1/2	6.35	7304	513.52	7730	543.47	4 3/8	11.13	3 5/8	9.09
A2	6/30/94	101667	2 1/8	5.41	2 1/4	5.72	6742	474.01	8550	601.12	3 5/8	9.09	2 7/8	7.32
A3	6/20/94	101660	1 7/8	4.78	1 3/4	4.45	6012	422.89	8230	578.63	3 1/4	8.26	2 3/4	6.99
A4	6/14/94	101654	1 5/8	4.14	1 3/4	4.45	6105	429.22	8550	601.12	2 7/8	7.32	2 1/4	5.72
A5	6/9/94	101653	1 3/8	3.51	1 1/4	3.18	7030	494.26	9370	658.78	2 3/8	6.05	2 1/8	5.41
A6	6/7/94	101652	1 1/8	2.87	1 1/4	3.18	6729	473.10	10,200	717.31	2	5.08	1 3/4	4.45
A7	3/29/94	101575	1	2.54	1	2.54	5260	369.82	9830	691.12	1 7/8	4.78	1 3/8	3.51

Unit #	Date	C-sheet	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
B1	7/14/94	101676	2 3/8	6.05	2 1/2	6.35	6066	426.48	8030	564.57	4 1/4	10.80	3 1/4	8.26
B2	7/11/94	101674	2 1/8	5.41	2 1/4	5.72	5783	406.59	7820	549.98	3 3/4	9.53	2 5/8	6.68
B3	7/6/94	101670	1 7/8	4.78	2	5.08	6400	499.97	7360	517.46	3 3/8	8.59	2 5/8	6.68
B4	6/28/94	101665	1 7/8	4.78	2	5.08	5685	399.70	8600	604.64	3 3/8	8.59	2 1/2	6.35
B5	6/24/94	101663	1 7/8	4.78	2	5.08	5792	407.22	8190	575.81	3 3/8	8.59	2 3/8	6.05
B6	6/21/94	101661	1 3/4	4.45	1 3/4	4.45	5871	412.77	8520	599.02	3	7.62	2 3/8	6.05
B7	6/16/94	101657	1 3/4	4.45	1 3/4	4.45	6145	432.04	8420	591.99	3	7.62	2 3/8	6.05

Unit #	Date	C-sheet	inches	cm	inches	cm	psi	kg/sq.cm	psi	kg/sq.cm	inches	cm	inches	cm
C1	7/20/94	101682	2 3/8	6.05	2 1/2	6.35	5890	414.11	7620	535.74	4 1/8	10.49	3 5/8	9.09
C2	7/18/94	101678	2 1/4	5.72	2 3/8	6.05	5757	404.76	8040	565.27	3 7/8	9.86	3 1/8	7.95
C3	7/13/94	101675	2 1/8	5.41	2 1/8	5.41	5880	413.41	8120	570.89	3 3/4	9.53	2 7/8	7.32
C4	7/8/94	101673	2	5.08	2	5.08	7286	512.26	7540	530.11	3 1/2	8.89	2 1/4	5.72
C5	7/5/94	101668	2	5.08	2	5.08	6172	433.94	7460	524.49	3 1/2	8.89	2 3/4	6.99
C6	6/27/94	101664	1 7/8	4.78	1 7/8	4.78	6640	466.84	8260	580.74	3 3/8	8.59	2 1/2	6.35
C7	6/23/94	101662	1 5/8	4.14	1 5/8	4.14	6479	544.52	8370	588.47	3	7.62	2 1/2	6.35