LATEX-MODIFIED FIBER-REINFORCED CONCRETE BRIDGE DECK OVERLAY

Construction/Interim Report

Experimental Features
Project No. OR 90-01
Hayden Bridge in Lane County, Oregon

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ABSTRACT

Latex-modified concrete (LMC) is portland cement concrete (PCC) with an admixture of latex. LMC is considered to be nearly impermeable to chlorides and is extensively used to construct bridge deck overlays. Unfortunately, some of these overlays have developed premature cracking and debonding. In an effort to deter these problems, steel fibers have been added to LMC to create LMFRC.

Construction problems included insufficient quality control, quick-setting, poor workability of the mix, extra time taken to add materials on site, tearing of the latex mat during finishing and tining difficulties caused by snagging the fibers. Clumping of fibers is a problem reported in other studies. All in-situ strength test results were below the typical strength range of LMC samples. Preparation of the deck for resurfacing should cost the same for LMC and LMFRC but materials and labor are generally higher for LMFRC.

Two years after construction, the overlay had good bonding and no visible cracks. As compared to LMC overlays, LMFRC overlays are generally more difficult to construct and required more time, labor, and money.

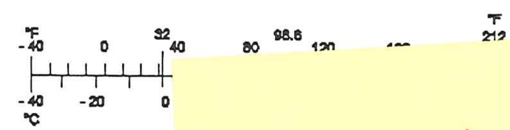
SI* (MODERN METRIC) CONVERSION FACTORS

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	kiiometers 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)

ORIGINAL

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Latex Modified Fiber Reinforced Concrete Bridge Deck Overlay

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1.0 INTRODUCTION

1.1 BACKGROUND

Latex-modified concrete (LMC) is portland cement concrete (PCC) with an admixture of latex. The LMC mix design has more cement, less water, less entrained air, and a higher slump than conventional PCC. The result is a concrete with increased durability, ductility, strength, and toughness[8]. The latex decreases the permeability of the concrete, making LMC an effective chloride barrier. LMC has been used to overlay bridge decks for over 30 years. It has largely replaced the use of conventional PCC for that purpose in Oregon.

Unfortunately, some LMC bridge deck overlays have shown cracking and delamination, resulting in increased maintenance. The cracks allow chloride-laden water to intrude into the deck and contact the rebar, initiating corrosion. Ensuing corrosion of the rebar results in cracking the surrounding concrete and causes overall deterioration of the deck.

In an attempt to increase the tensile strength of LMC and impede cracking, steel fibers have been added to the LMC mix. The result is latex-modified, fiber-reinforced concrete (LMFRC).

1.2 OBJECTIVES, SCOPE, AND FUNDING

The objective of this study is to evaluate LMFRC for suitability as a bridge deck overlay.

The construction portion of this report evaluates the placing, finishing, and curing of a LMFRC thin-bonded structural overlay. Also included are the post-construction documentation of construction costs, shrinkage cracking, bond strength, friction tests, and delamination.

This report also documents the first two years' performance of the LMFRC overlay. Cracking, delamination, tire-to-pavement friction, and maintenance needs are included.

A final report on this project will be published after the fourth year inspection. That report will address the overlay's maintenance needs and costs, skid resistance, and resistance to cracking, delamination, and rutting.

This project is jointly funded by the Federal Highway Administration (FHWA) and the Oregon Department of Transportation (ODOT).

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2.0 BRIDGE LOCATION, HISTORY AND PRECONSTRUCTION CONDITION

2.1 LOCATION

Hayden Bridge is located in Lane County, about five miles (8 km) east of Eugene, Oregon. It spans east-west over the McKenzie River. The bridge is on Marcola Road (FAS A464) and begins at milepoint 1.67 and ends at milepoint 2.12. Figures 2.1 (a) and (b) show the location of the bridge.

2.2 HISTORY AND PRECONSTRUCTION CONDITION

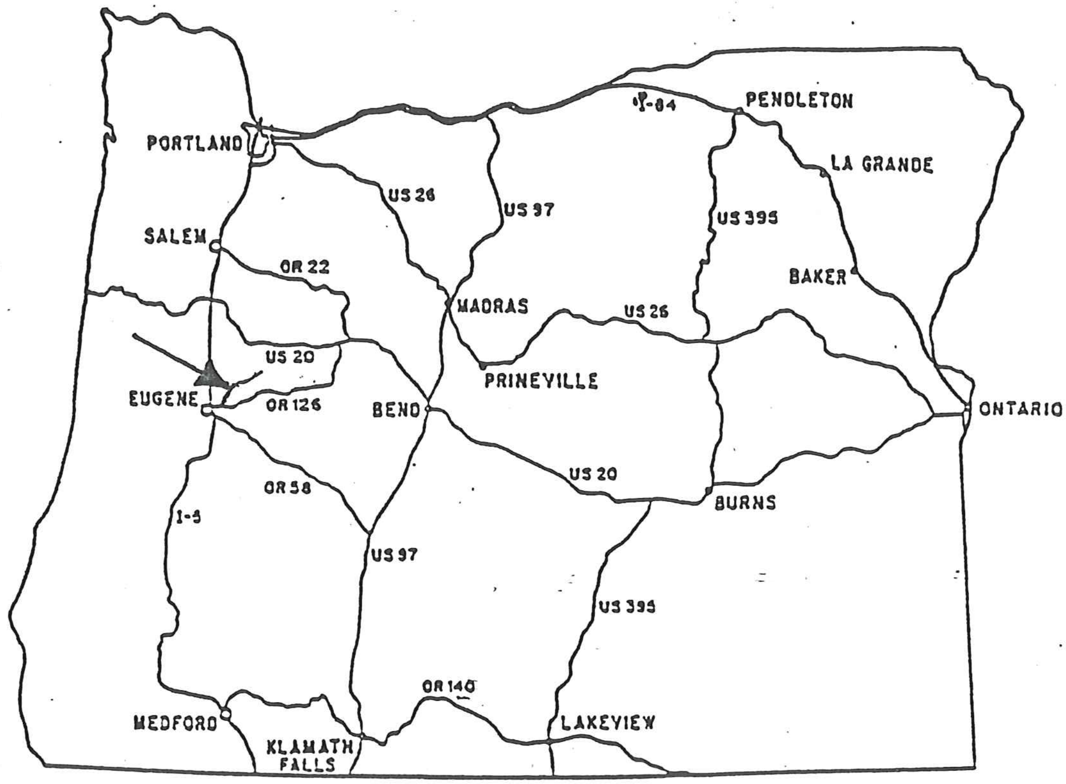
Hayden Bridge was designed by OBEC Consulting Engineers. The construction of this steel girder bridge was completed in 1969. It is 265'-4" (80.87 m) long and was originally 35'-9" (10.90 m) wide. The west abutment of the bridge is founded on dense sand and gravel over bedrock, and the other footings are keyed into one foot (0.3 m) of solid rock. The piers of the bridge were designed to support three lanes, but only two lanes were constructed in 1969.

An inspector reported "transverse cracking in deck with some map cracking starting to develop" in February of 1974.[5] Subsequent inspections report an increase in both cracking and wear over time. The cracking was apparent on the deck but was not visible from the underside.

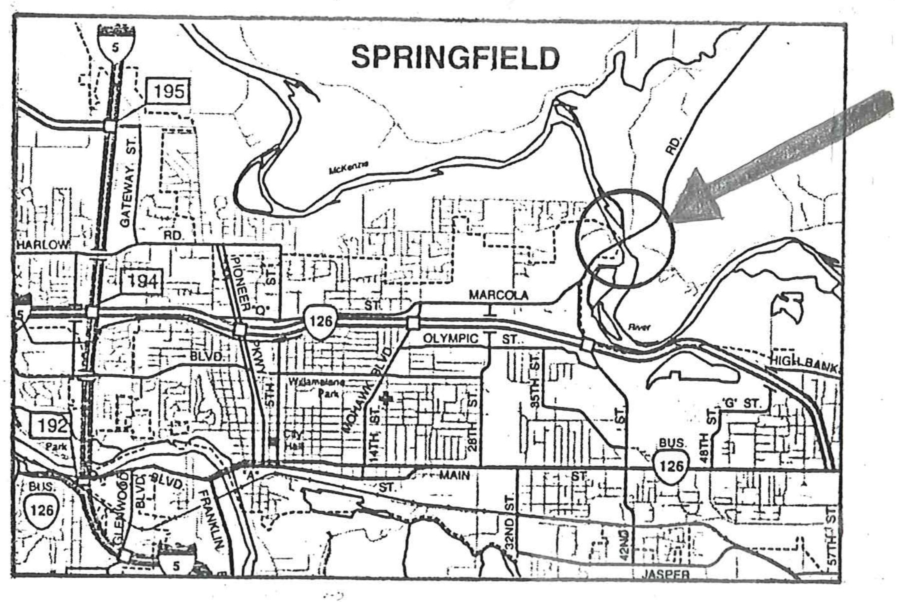
In 1988, Lane County retained OBEC to perform a condition survey of the bridge and to prepare designs to widen the deck. The new portion of the deck was to extend out from the north side of the bridge, supported by the existing piers.

Concrete coring of the existing deck revealed large, full-depth cracks. Crack surfaces in the cores were dirty but the rebar appeared clean, without rust, and in good condition. Further investigation found no evidence of structural failure; therefore, it was concluded that the cracking may have been due to shrinkage.

OBEC solicited recommendations for deck repair methods. Sika Corporation suggested using one of its sealants to inject into the cracks and cover the surface. The Adhesive Engineering Company (AEC) noted that dirt in the cracks would inhibit bonding of their own preferred sealant. In addition, the cracks would need to be covered with a very flexible wearing surface, and strength would be sacrificed in order to attain that flexibility. It was their opinion that cracks in the deck would be reflected through any new surface. In conclusion, AEC recommended that the existing deck be replaced.



(a)



(b)

Figure 2.1. Project Site a) General Location b) Specific Location

OBEC had previously used LMFRC to prevent reflective cracking. In fact, the first reported use of LMFRC in the United States was an OBEC project. That project was an overlay of the Morrison Bridge in Portland, Oregon in 1972.

OBEC recommended that LMFRC be used to construct a thin-bonded concrete structural overlay on the Hayden Bridge deck. An LMFRC overlay was chosen for the following reasons:

- It seemed more economical to prolong the life of the existing deck rather than replace it.

- The steel fibers in LMFRC were considered to provide a crack-arresting mechanism. They were expected to work together with the concrete to resist shrinkage cracking, minimize reflective cracking, and add flexural capacity to the overlay. LMFRC was considered to be a structural overlay, rather than only a good wearing surface.

- The latex additive in LMFRC makes it a relatively impermeable membrane against the intrusion of chlorides and water. Past experience has shown that LMC is less permeable than PCC for these intrusions. The latex was also expected to enhance workability and bonding.

- The fibers in the LMFRC were expected to provide impact resistance, absorbing the energy of truck traffic.

- LMFRC was considered to be resistant to abrasion.

Lane County officials decided to include an LMFRC overlay of the existing deck as a second phase to the construction project which widened the bridge. A new section of PCC deck was constructed on the north side of the bridge and now carries the westbound lane. The LMFRC overlay covers the south portion of the bridge deck which carries two eastbound lanes. The PCC lane is not a "control section" for this study, because it was not constructed under similar conditions to those of the LMFRC overlay; the LMFRC is an overlay on a cracked, existing deck whereas the PCC is not an overlay at all but a new deck.

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3.0 ENVIRONMENT AND TRAFFIC

Tables 3.1 and 3.2 summarize climate and traffic data, respectively. Winter maintenance includes snow plowing and sanding during freezing weather.

Table 3.1: Climate Data

Elevation of bridge deck above mean sea level	480 ft (146 m)
Average Daily Temperature of coldest month, January	41°F (5°C)
Mean Daily Temperature Swing in January	14°F (8°C)
Average Daily Temperature of Hottest Month, July	66°F (19°C)
Mean Daily Temperature Swing in July	30°F (17°C)
Average Annual Precipitation	40 in. (1.02 m)

Table 3.2: Traffic Data

Average Annual Daily Traffic (AADT)	6500 vehicles
Heavy Trucks	6.0% of AADT
18-Kip Equivalent Single Axle Loads (ESALS)	430/day

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4.0 CONSTRUCTION

4.1 SPECIFICATIONS

The LMFRC specifications used for this project are provided in the Appendix. OBEC was consulted in the preparation of the specifications because of their previous experience in the design of LMFRC bridge deck overlays. They stressed the importance of having detailed specifications because most contractors (at that time) were unfamiliar with LMFRC. The specifications used on this project appeared to be adequate if adhered to strictly.

4.2 DECK PREPARATION

The deck was prepared for resurfacing. Removal of the full deck thickness was not deemed necessary. Most of the deck was profiled with a CMI® 275 horsepower (205 kW), rubber-tired scarifier with a 6'8" (2.03 m) wide cutter. The depth of profiling was ¼ to ¾" (6 to 13 mm), with deeper grinding on the gutter line. A MacDonald® U5 scabbler and 25-lb (110 N) jackhammers equipped with bushing heads were used to profile the remaining area around the gutters and deck drains. Next, the deck was chain-dragged to check for delaminations caused by profiling. Minor spots of delamination and spalling were found and removed. The day before the pour, the deck was pressure-washed and then covered to be kept moist.

Some portions of the deck, including the last span overlayed, dried before they were poured.

4.3 MATERIALS

The contractor, Hamilton Construction, was not experienced with LMFRC, so OBEC prepared the mix design. The average cement factor was 7.44 sacks per cubic yard. The LMFRC mix design and suppliers of each ingredient used on this overlay project are shown in Table 4.1.

Steel fibers were available in two forms; bonded together in rows by a water soluble glue (similarly to staples) or loose. Dramix® ZC 50/.50 fibers, which are bonded, were used for this project. They are 50mm long, 0.50mm in diameter, and were manufactured by Bekaert Steel Wire Corporation.

Table 4.1: LMFRC Mix Design and Suppliers				
Ingredient	**lb per yd³ mix**	**kg per m³ mix**	**Supplier**	**Comments**
Cement	752	446	Ideal Company	Type I portland cement
Coarse Aggregate	1190	706	Morse Brothers, Inc.	½"-#4 sieve (12.7-4.75 mm), predominantly round with few fractured faces
Fine Aggregate	1455	863.2	Eugene Sand and Gravel	natural sand
Water	102	60.5	on site	
Latex Emulsion	235	139	Dow Chemical	47.2% Solids 52.8% Water
Steel Fibers	85	50	Bekaert Company	Dramix ZC® 50/.50 fibers
Entrained Air	4% assumed		natural	

4.4 MIXING, PLACING, FINISHING, AND CURING

In another ODOT study, the steel fibers in LMFRC showed a tendency to ball up[6]. This balling up made the mix difficult to pour and place. OBEC has had extensive experience adding fibers to a mix. They maintain that this problem can be alleviated if only small quantities of steel fibers are added gradually to the mix, rather than whole bags dumped in at one time. The gradual addition seems to allow the latex time to coat and lubricate the fibers before they contact other fibers, so that tangling is averted. OBEC specified that one of the following two methods of mixing must be used for this project:

1. A fiber feeder could add loose fibers to a self-contained mobile mixer. Either Dramix® ZL 50/.50 fibers or Zorex® 2" (50.8 mm) fibers could be used.

2. The bonded form of the fibers (Bekaert Dramix® ZP 50/.50 fibers) could be added to a revolving drum mix truck. With this method, the bonded fibers become coated with the mix while still in orderly rows and are less likely to tangle after the bonds break.

The contractor chose Method 2, using revolving drum type mix (Ready-Mix®) trucks rather than mobile mixers to reduce costs.

According to OBEC, latex suppliers prefer the use of self-contained mobile mixers for the following two reasons: First, they minimize the time lapse between mixing and placing of the mix, and secondly, they maintain better quality control. However, OBEC noted that "a considerable amount of care needs to be taken in calibrating the fiber feeder for the proper fiber volume. The Zorex 'straight' fibers are easier to calibrate than the Dramix 'hooked' fibers. Fibers are easier to add to standard ready mix trucks with better assurance of good distribution in the mix than using a self-contained mobile mixer with a fiber feeder attachment."

The LMFRC overlay was constructed on March 28, 1991 in the following favorable weather conditions:

	Beginning of Pour	End of Pour
Air Temperature	48° F (9°C)	52° F (11°C)
Wind Velocity	1 mph (0.45 m/s)	1 mph (0.45 m/s)
Relative Humidity	81%	69%

The cement and aggregate were dry-batched at Eugene Sand and Gravel's batch plant, a half hour before arriving at the job site. Latex was not added at the plant because it would have caused the concrete mix to set more quickly. Workers added latex, water, and steel fibers at the job site.

The specifications allowed for dry-batching at the plant but ODOT discourages it. ODOT does not approve of that practice because the moisture in the aggregate wets the cement while still at the plant. The aggregate used on this project was particularly damp (3 to 4% moisture). As a result, some cement hydration and matrix formation began long before the final water and latex were added to the mix. Some of the cement bonds which were created during the initial hydration were probably broken later during agitation with latex and water at the site. A fragmented cement matrix and, consequently, a weaker concrete may have resulted.

The latex was metered and pumped directly into the back of the trucks at the job site using a small hose. Workers manually fed bags of Dramix® ZC fibers into the mixers from an elevated platform. Latex emulsion was also spread out onto the prepared deck just ahead of the pour, to act as a bond coat between the deck and the LMFRC mix.

The first four truckloads of LMFRC required more time than anticipated to mix, pour, and place. The latex-metering gauge broke down when latex emulsion was being added to the first truckload of cement and aggregate. The cement in that load had hydrated considerably by the time the gauge repairs were completed, causing the load to be difficult to place. Adding fibers to the mix also required about ten (10) extra minutes. Learning to place an unfamiliar mix also prolonged the work. Delays caused the time interval "from plant to pour" of the first load to be over 70 minutes. OBEC prefers to keep that interval under 45 minutes. While workers were placing the first load, successive truckloads arrived on site but could not be poured. The fourth truckload was especially difficult to place, probably due to the delay. All mixes were visibly stiffened by the addition of fibers.

The addition of fibers greatly reduced the slump in the mix, making it difficult to place. The original mix design specified 102 pounds of water per cubic yard of mix (60.5 kg/m^3) and had a water/cement (w/c) ratio of 0.31. Unfortunately, that mix had negligible slump. More water was added to bring up the slump to a typical 4½-5" (110-130 mm). The prepared mix actually had 113 pounds of water per cubic yard (67.0 kg/m^3), so that the w/c ratio was 0.35. Workers also sprayed water directly onto the poured mix to make it more workable, raising the actual w/c ratio even higher. The first load received the most liberal spraying. Ponded water was visible over many areas of the placed mix. Raising the w/c ratio lowered the ultimate strength of the mix and probably raised its permeability.

Workers had no significant problems with mixing and placing the material after placing the first four truckloads.

The average time from batching of aggregate and cement to discharge completion was 75-80 minutes.

The contractor used an old Bid-Well® finishing machine which was not equipped with a "vibrating screed or a vibrating pan" as required by the specifications. Without vibration, portions of the overlay were probably not adequately consolidated, so that voids may exist. Hand-held stinger vibrators were used along the edge of the pour only.

When the finishing machine moved at a normal rate of speed for an LMC pour (50-100 ft/hr or 4.2-8.5 mm/s), the LMFRC mat tore. To correct this problem, the rate of progression was lowered greatly during the first five loads. The machine covered the deck width in approximately twelve (12) seconds, advancing about three inches (8 cm) with each pass. This rate translates to a forward speed of 75 feet per hour (6.35 mm/s). Factors which possibly could have contributed to the tearing are the steel fibers in the mix, the dryness of the first batch due to delays, and the lack of vibration of the finishing machine.

Tining the surface of the overlay was difficult, because the tines snagged on the steel fibers and tore the mat. For this reason the surface was not deeply tined.

The LMFRC overlay was cured using a procedure typical for LMC overlays; promptly after finishing, the overlay was covered with wet burlap, which was then covered by a polyethylene film. Although the specifications required only 36 hours of this moist curing, the overlay was moist-cured for six (6) days. While the overlay was air-curing, traffic was detoured to the adjacent PCC deck.

4.5 TESTING

Figure 4.1 shows the strength test results of LMFRC cylinder samples, using the American Association of State Highway and Transportation Officials Test 22 (AASHTO T 22). Three (3) samples from a trial mix were cast and cured according to C192-90a of the American Society of Testing and Materials (ASTM). The LMFRC used in the overlay was required by the specifications to have a minimum 7-day strength of 3300 psi (22.8 MPa). The trial batch cylinder samples were required to surpass that minimum strength by 1000 psi (6.9 MPa). As Figure 4.1 shows, the trial batch strengths were acceptable.

On site, samples from Load 5 were cast according to AASHTO T 23 (ASTM C31-90). Load 5 appeared to be representative of loads 5-7, the driest batches. Load 5 had a final slump of 2½ inches (64 mm) and a w/c ratio of 0.29. Figure 4.1 shows that the 7-day strengths of Load 5 were all above the required 3300 psi (22.8 MPa).

From Load 5, ten samples were cured according to the contract specifications, and two samples were cured to AASHTO specifications. As can be seen from Figure 4.1, the AASHTO curing resulted in lower strengths but the difference between the strengths is not statistically significant.

Starting with Load 8, the mix appeared to be more workable. Load 9 appeared to be representative of loads 8-11, which seemed to have the most water. Load 9 had a final slump of 4 3/8 inches (111 mm) and a w/c ratio of 0.32. Four samples were cast from that load according to AASHTO T 23 (ASTM C31-90) and were cured according to the contract specifications. Figure 4.1 shows that Load Nine's 7-day strength, 3100 psi (21.4 MPa), did not meet the minimum specification. The strengths of loads other than numbers 5 through 11 probably fall within the envelope created by the extreme strength values of Loads 5 and 9.

For comparison, a typical range of 7-day strengths for LMC cylinder samples is 4100-5700 psi (28-39 MPa). These values result from 162 strength tests on 54 LMC mixes used for overlays by ODOT within the past two years. All LMFRC 7-day cylinder strengths were below the range of LMC typical values except the trial batch which was not used in the actual overlay.

OBEC cast four 6 X 6 X 20" beams from Load 5 to be tested in flexure according to AASHTO T 97. The beams were cured according to AASHTO T 141 and T 23. Figure 4.2 shows the resulting strengths, which OBEC considered low. ODOT does not ordinarily test LMC beams, so data for comparison is not readily available. The job specifications did not require that LMFRC beams be cast nor stipulate a minimum flexural strength.

Fig 4.1: Cylinder Strength Test Results

AASHTO T 22

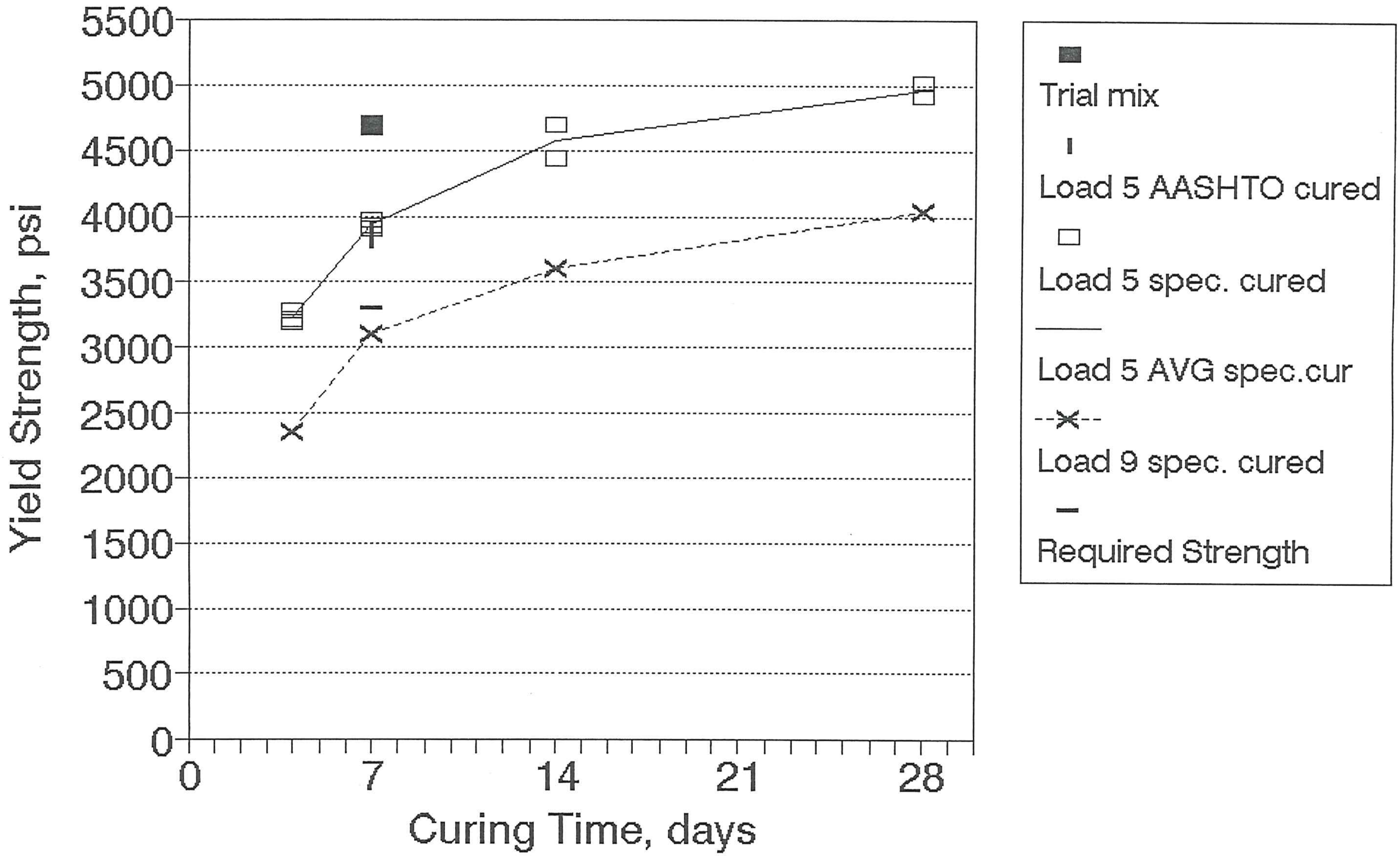
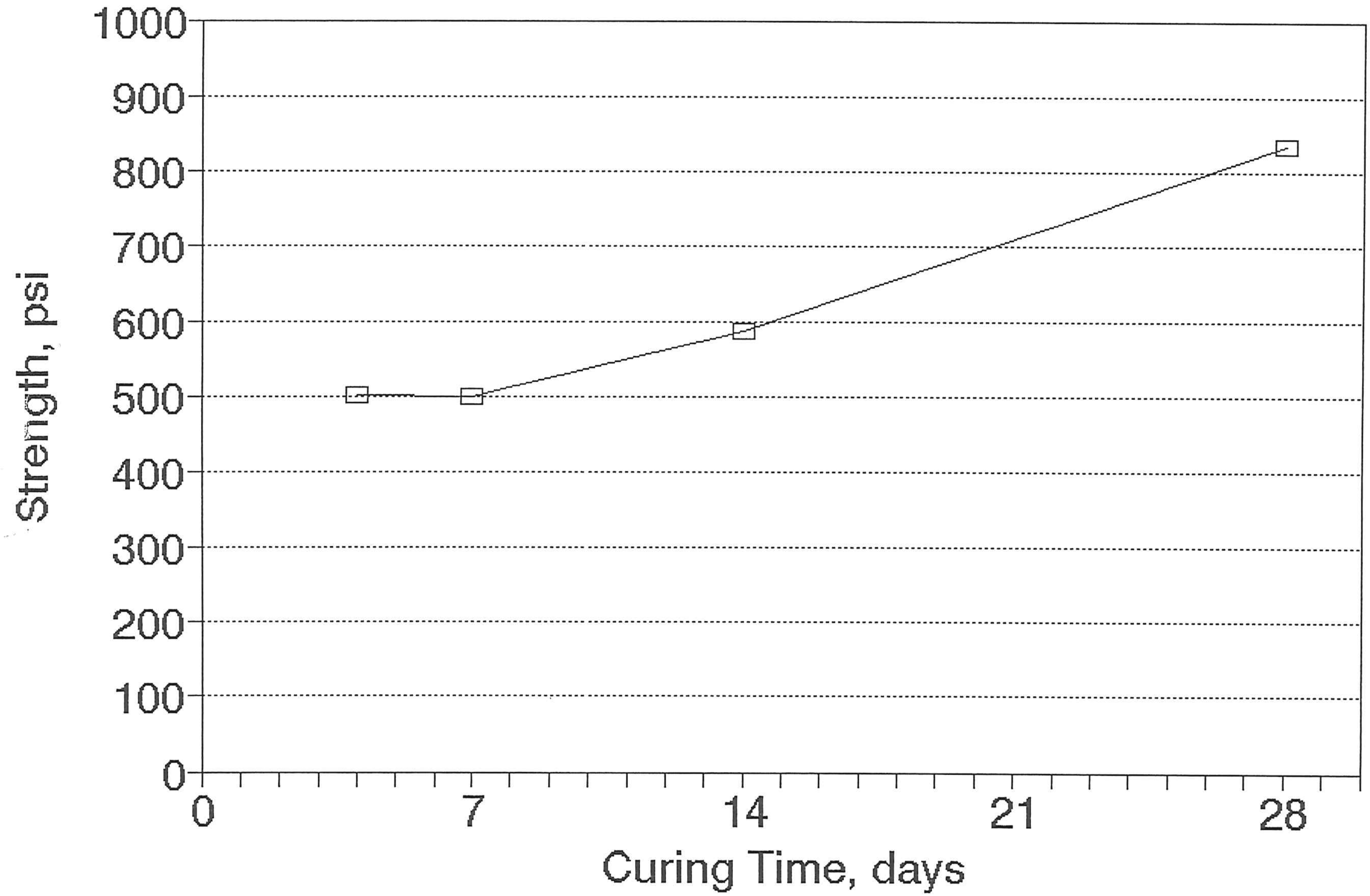


Fig. 4.2: Beam Flexural Test Results

AASHTO T 94



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5.0 COSTS

The costs of preparing and resurfacing the bridge deck were as follows:

Class 1 Preparation
838 yd^2 @ \$10.00/yd^2 (700.7 m^2 @ \$11.96/m^2) . . . . \$ 8,380

Furnish LMFRC
40 yd^3 @ \$440/yd^3 (30.6 m^3 @ \$575.50/m^3) \$17,600

Construct LMFRC Resurfacing
838 yd^2 @ \$14/yd^2 (700.7 m^2 @ \$16.74/m^2) \$11,732

TOTAL \$37,712

Table 5.1 compares average LMC unit prices paid by ODOT in 1989, 1990, and 1991 to the LMFRC unit prices paid for the Hayden Bridge deck overlay. The table may be misleading in that it appears to be cheaper to use LMFRC than LMC, which is not true. A cost conclusion usually cannot be made based on a single project's bid prices. The cost of deck preparation should be the same for both LMFRC and LMC, but materials and labor are generally higher for LMFRC. Materials costs for LMFRC are generally raised about \$0.75 per cubic yard (\$0.98 per cubic meter) due to the price of the steel fibers. Labor costs are usually higher due to the extra work required to add materials on site.

Table 5.1, Average Unit Prices Paid by ODOT for Preparation and Resurfacing of Bridge Decks Using LMC and LMFRC

Contract Unit	LMC			LMFRC
	1989	1990	1991	Hayden Bridge Deck
Class 1 Preparation per yd^2 (per m^2)	\$ 10.91 (\$ 13.05)	\$ 26.17 (\$ 31.30)	\$ 28.94 (\$ 34.61)	\$ 10.00 (\$ 11.96)
Furnish LMC or LMFRC per yd^3 (per m^3)	\$345.41 (\$451.78)	\$519.50 (\$679.48)	\$463.01 (\$605.59)	\$440.00 (\$575.50)
Construct Resurfacing per yd^2 (per m^2)	\$ 8.26 (\$ 9.88)	\$ 23.71 (\$ 28.36)	\$ 21.01 (\$ 25.13)	\$ 14.00 (\$ 16.74)

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6.0 RESULTS

6.1 POST-CONSTRUCTION INSPECTION AND TESTING

In a post-construction inspection of the deck, OBEC found no cracks or delamination.

On July 5, 1991, the Pavements Unit of ODOT ran four friction tests on the outer lanes of the Hayden Bridge, two on the new PCC deck and two on the LMFRC overlay. The resulting friction numbers were adjusted to standard 40 mph (18 m/s) friction numbers (FN_{40}) using correlation equations. The test methods, calibration techniques, and equipment conformed to AASHTO T 242. There was no significant difference in friction numbers for the two surfaces. Both sections had adjusted friction numbers typical of newly constructed pavement in Oregon.

To test the bond between the LMFRC overlay and the existing deck, four samples were cored from the deck, each representing a different area of the overlay. The bond strength tests identified in the specifications resulted in strengths ranging from 151.6 to 186.7 psi (1.045 to 1.287 MPa). These strengths were above the specified minimum of 100 psi (689 kPa).

6.2 INTERIM INSPECTION

An inspection of the overlay two (2) years after construction revealed no visible cracks. The PCC deck beside the overlay had transverse shrinkage cracks that were 1½ to 10 feet (0.5 to 3 m) long.

Tining throughout the overlay was shallow. Some of the tining had worn off in an area about 3 feet (0.9 m) in diameter. That area was within the section of overlay poured first, when many construction problems occurred. Water was sprayed directly onto the surface of that section during construction. The water weakened the mix there and is probably the reason that the tining has worn down. Also, aggregate was visible in some areas of that section.

Steel fibers were visible throughout the surface of the overlay but they did not present a problem. They were shiny and not rusted.

We know of no maintenance having been done on the overlay, and it appeared that none was necessary.

6.3 PAST PROJECTS

OBEC has used LMFRC on past projects overlaying bridges in Oregon, Washington, and Idaho with inconsistent results.

OBEC reported good results overlaying the Morrison Bridge deck in Portland, Oregon with LMFRC. The crew reportedly overcame any mixing, placing and finishing problems during the first stage of the overlay. The w/c ratio was adjusted from 0.28 to 0.32 for better workability. Also, the contractor increased the size of his work force after the first pour to improve quality control. Fiber balling was not a problem.

In 1981, four bridges on the Sundial-Sandy River section of the I-84 Freeway were overlaid with LMFRC[6,7]. The Research Section of the Oregon State Highway Division studied that project as an Experimental Feature. They mixed various combinations of ingredients to produce four LMFRC trial batches in an effort to optimize workability and maximize the allowable work time of the LMFRC mix. The preferred mix had a cement factor of 8 sacks/cu. yd. (10.5 sacks/m^3, using 94 lb or 42.6 kg sacks of cement.) Researchers considered its workability after mixing to be good at 15 minutes, fair at 30 minutes, and poor at 45 minutes. The temperature during that testing was 68°F (20°C) and they expected workability to deteriorate at higher temperatures. When mixing was prolonged in a pan-type mixer, the steel fibers clumped up in a ball and could not be separated.

Many problems were encountered during construction. "The 'start-up' time of each pour was very slow," and fiber balling was a major problem. OBEC suggests that balling occurred on the project because the steel fibers were not kept dry before mixing. They believe that the bags of fibers may have been torn and that the fibers became wet before mixing. The moisture could have dissolved the fiber bonds, allowing loosened fibers to tangle and ball up in the mix. A lack of quality control on the I-84 project is evidenced by the inconsistent w/c ratios, ranging from 0.30 to 0.44, a cement factor consistently below the design value, and sample cylinder compressive strength test values varying between 2690 and 5590 psi (18.5 to 38.5 MPa). The deck surface was extremely uneven, possibly due to a faulty finishing machine and the fiber balling problem. Tining was difficult because the rake would dislodge and drag the steel fibers from the surface. Parts of an overlay were left uncovered for 90 minutes after placing and, consequently, developed large cracks.

Progressive cracking on the edges of the I-84 overlays was apparent during inspections over the first four years but bonding of the overlays was good. Large, transverse cracks that were in the underlying deck did not reflect through the overlays during that time. OBEC attributes excessive shrinkage cracking to the high wind velocities in the area.

OBEC reported good results overlaying the American bridge in Boise, Idaho with LMFRC. The contractor chose to use transit mixers for the project. According to OBEC, the contractor had excellent quality control and a consistent mix. An air vibratory screed provided a uniform finish to the overlay. Plastic shrinkage cracks appeared in the first stage of the overlay. OBEC attributes the cracks to a delay in proper curing procedure by the contractor. The contractor did not immediately cover the first pour with wet burlap and polyethylene film. Subsequently, when curing procedures kept up with finishing procedures, plastic shrinkage did not occur.

6.4 DISCUSSION

In resurfacing a deck, at least a portion of the deck is replaced with overlay material. That overlay material must be at least as strong as the original deck material to restore the deck to design strength. Trial batches of LMFRC have achieved strengths above 3300 psi (22.8 MPa). Unfortunately, in the cases researched in this report, these strengths have not been consistently reproduced in the field.

A major contributor to the strength problem in the Hayden Bridge overlay and past projects is a lack of quality control. This inadequacy is partly the result of workers having to batch mixes in the field. In the field the conditions are not as easily controlled as at the plant.

Also to blame for the poor quality control is the following problem. LMFRC mix sets up quickly, at a rate comparable to LMC. Unfortunately, LMFRC is more difficult to place than LMC and, therefore, requires more time. In placing LMFRC mix before it sets, workers may be overburdened with too much to do in too little time. This challenge may cause quality to suffer.

Time-consuming elements include the extra duties of adding fibers and other ingredients on site. Overcoming workability problems is also time-consuming, and slow screed movement prolongs finishing time.

Poor workability motivates workers to add extra water to the mix, weakening it. For this reason, poor workability contributes to the lowered in place strengths of LMFRC.

6.5 CONCLUSIONS

LMFRC is difficult to construct due to the clumping of fibers, slow work pace, tining difficulties, and overall poor workability. To deal with these problems and the added workload associated with LMFRC, more workers may be needed in the construction crew. Although it was not evidenced by this project, LMFRC overlays are a costly overlay alternative, due to the extra labor and materials needed.

Regardless of the low strength of the in situ LMFRC and the construction problems, the Hayden Bridge overlay has not yet developed the visible cracks associated with many LMC overlays. It also appears to have good bonding. The impermeability of LMFRC should be measured and compared to that of LMC. A comparably impermeable overlay with no cracks and no delamination would be proper protection for the deck.

Construction of an LMFRC overlay on a new deck in Oregon is not likely to be cost-effective. The tensile strength of a new deck should be designed into the rebar and need not be added by the use of steel fibers.

In conclusion, it may be possible to construct a successful overlay by using LMFRC. Unfortunately, LMFRC construction generally will be more difficult and require more time, labor, and money than LMC construction.

6.6 RECOMMENDATIONS

Clumping problems experienced on the Sundial-Sandy River project suggest that LMFRC should not be over-mixed after the fibers have been added.

Spraying water on the freshly placed LMFRC overlay of this project resulted in patches of concrete which showed increased wear. When exposed to conditions which may cause premature drying during placement operations, the placed mix may be fogged; however, the mix should never be wetted by a spray of water.

Mobile mixers should be specified rather than transit mixers for two reasons. First, quality control is better with mobile mixers. Secondly, after LMFRC mix is batched at the plant, its set up time is too short to allow much travel time in a transit mixer. This problem shall not be remedied by "drybatching" the cement and aggregate at the plant in a transit mixer and then adding the remaining ingredients on site. Although the drybatch method was used on this project, it is prohibited by ODOT specifications.

In addition, OBEC has recommended the following construction practices when using LMFRC:

- Inform the contractor that the mixing and placement will take extra time so that he/she can budget time and money to do a careful, good job.

- Prepare only 2 to 3 cubic yards (1.5 to 2.3 cubic meters) of mix for the first batch for the following reasons. First, the broomer, who must apply latex just ahead of the pour, encounters more difficulty keeping ahead of the first batch if it is large. Secondly, the crew can gain experience working with the small, first batch before having more mix than they can deal with at one time. Finally, it is easier to alter the mix design if the first batch is small. Generally, after the first load, a good size load for production and placement is four (4) cubic yards (3 cubic meters).

- As required by ODOT specifications, the water used in the mix must be accurately measured. This precaution will prevent the mix from being too wet. Use a five gallon bucket rather the meter on the water truck to carefully monitor the addition of water to the mix.

- Use a finishing machine with oscillation of at least 6000 vibrations per minute (vpm), much higher than the 4000-4500 vpm range called for in typical standard specifications. OBEC has had its best results with an air-operated vibrator screed which attained a maximum vibration of 10,500 vpm.

- Cover the finished LMFRC immediately with burlap and a polyethylene film. Latex modified concrete is susceptible to cracking if left uncovered.

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7.0 REFERENCES

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KEY ORGANIZATIONS AND PERSONNEL

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APPENDIX
PARTIAL PROJECT SPECIFICATIONS

SECTION 509
PORTLAND CEMENT CONCRETE
RESURFACING OF BRIDGE DECKS

Delete Section 509 of the 1984 Standard Specifications and substitute the following:

SECTION 509
FIBER REINFORCED LATEX MODIFIED CONCRETE
RESURFACING OF BRIDGE DECKS AND PAVEMENT

509.00 Scope - This work shall consist of preparing and surfacing bridge decks with fiber reinforced latex modified concrete (FRLMC).

One of the two following systems of resurfacing the bridge deck shall be selected by the Contractor:

System 1: Latex-modified fibre reinforced concrete using standard ready-mix trucks with Dramix ZP 50/.50 fibers.

System 2: Latex-modified fibre reinforced concrete using a self-contained mobile mixer, fiber feeder and either Dramix ZL 50/.50 fibers or Zorex 2" fibers.

509.01 Abbreviations and Definitions:

ACI - American Concrete Institute
CCT - Concrete Control Technician
FRLMC - Fiber Reinforced Latex Modified Concrete
PCC - Portland Cement Concrete
QCT - Quality Control Technician
QPL - Qualified Products Listing

509.04 Preplacement Conferences - Supervisory personnel of the Contractor and any subcontractors who are to be involved in the FRLMC work, including aggregate production for FRLMC, shall meet with the Engineer for a preplacement conference at a time mutually agreed upon. At this conference, the Contractor shall present and discuss methods of accomplishing all phases of the FRLMC work.

A second preplacement conference shall be held at the jobsite one hour before the first placement begins to discuss placement procedures. It will be attended by the Engineer and the Contractor's entire placement crew.

Materials

509.11 General - Materials shall meet the requirements of the following Part 700 subsections of the Standard Specifications as well as modifications and/or additions given in this subsection and Section 701 of these special provisions:

Air-Entraining and Other Chemical Admixtures	701.03
Coarse Aggregate	703.02
Curing Materials	701.05
Epoxy Cement	701.06
Fine Aggregate	703.01
Fly Ash	701.07
Formulated Latex Admixture	701.09
Portland Cement	701.01
Poured Filler	705.03
Preformed Elastomeric Joint Seals	705.02
Preformed Expansion Joint Fillers	705.01
Proprietary Epoxy and Nonepoxy Bonding Agents	701.10
Steel Fibers	509.14
Water	701.02

701.01 - Portland Cement - The portland cement shall be Type I or II.

703.01 Fine Aggregates for Portland Cement Concrete - Delete 703.01(b) and substitute the following:

(b) General requirements - Fine aggregates shall consist of natural sand having hard, strong, durable particles. A 100 pound sample of fine aggregate shall be submitted to the Engineer at least 30 calendar days prior to intended use for qualification testing at the beginning of production unless the fine aggregate source has been qualified within the past 12 months.

Fine aggregate furnished during the progress of the work which show a variation greater than 0.20 from the fineness modulus of the fine aggregate used in the Contractor's mix design may be rejected or, at the option of the Engineer, may be accepted subject to such changes in concrete proportions as may be necessary by reason of such variation. The FINENESS MODULUS of the fine aggregate shall be determined according to OSHD TM 771.

In 703.01(c) change the limit for friable particles from 3 percent to 1.50 percent maximum.

In 703.01(f) add a No. 8 sieve between No. 4 and No. 16 for determination of the fineness modulus only.

In 703.01(g) change the sand equivalent for fine aggregate from not less than 68 to not less than 75.

703.02 Coarse Aggregates for Portland Cement Concrete - Delete 703.02(b) and substitute:

(b) General requirements - Coarse aggregates shall consist of uncrushed, clean gravel having hard, strong, durable particles free from adherent coatings.

A 100 pound sample of coarse aggregate shall be submitted to the Engineer at least 30 calendar days prior to intended use for qualification testing at the beginning of production unless the coarse aggregate source has been qualified within the past 12 months.

In 703.02(c) change the limit for friable particles from 2.00 percent to 1.00 percent maximum.

In 703.02(f-2) delete the table of "Grading Requirements" and substitute the following:

Sieve Size	Percent Passing (by weight) Min.	Max.
3/4"	100	
1/2"	85	100
3/8"	20	50
No. 4	0	10
No. 200	0	1.5

In 703.02(f-2) add the following to the last paragraph:

Elongated pieces in the coarse aggregate will be determined as described in OSHD Test Method 229N, with the proportional caliper device set at a ratio of 4:1, and shall not exceed 10 percent by weight of the material retained on the No. 4 sieve.

509.13 FRLMC Mix Design and Review - The Contractor shall be responsible for developing a FRLMC mix design and submitting it to the Engineer for review. If the Engineer determines that the design complies with specifications, the mix design will be accepted for use on the project.

(a) Proportioning of the mix - The mix proportions shall be determined by a CCT (See 509.15(a)). The mix shall be designed by the volumetric method and shall meet the limits of subsection 509.14.

(b) Chemical admixtures - All chemical admixtures to be used must be on the Division's QPL. The quantity of each chemical admixture to be used in the FRLMC mix shall be determined by trial batches prior to its use in FRLMC produced for incorporation into the project. However, this quantity may have to be adjusted by actual field use to obtain the quantity indicated in 509.14. Each chemical admixture shall be added to the FRLMC mix according to the manufacturer's recommendations.

(c) Trial batch - The CCT shall make at least one trial batch with the proposed mix design to verify that the mix will produce FRLMC in compliance with these specifications. Preparation and testing of the trial batch and molding, curing and strength testing of the cylinders shall be done by the Contractor and will be witnessed by the Engineer.

(c-1) Plastic FRLMC - The Contractor shall test the slump, air content and unit weight and shall calculate the water-cement ratio for each trial batch. Slump, air content and water-cement ratio must be within the specification limits for the trial batch to be valid.

(c-2) Strength tests - At least five 6"x12" test cylinders shall be cast for each mix design and tested at 7 days. The cylinders shall be cast in single-use plastic molds. All strength specimens shall be cast and cured in accordance with AASHTO T 23 or T 126. The cylinders shall be tested in accordance with AASHTO T 22.

(c-3) Required strength - The average 7-day compressive strength of the trial batch cylinders must exceed the specified compressive strength by at least 1000 psi.

(d) Mix design review - Each mix design proposed by the Contractor for use shall be identified by a unique number and submitted to the Engineer for review. The Contractor shall not proceed with concrete placement using the mix design until the Engineer has determined that all materials and the mix design are in compliance with specifications. Review of concrete mixes, materials, and production procedures by the Engineer will not relieve the Contractor of responsibility to provide concrete conforming to the specifications. The Contractor shall submit all the following data and the samples requested in 509.15(b) to the Engineer at least 14 calendar days prior to intended use:

(d-1) Mix design proportions - Provide the weight per cubic yard and absolute volume of cement, latex emulsion, each size of aggregate, water and mineral admixtures. Indicate dosage rates of chemical admixtures.

(d-2) Materials identification - Identify type and brand of cement, latex emulsion and admixtures to be used. Identify the source of the aggregates by OSHD source number.

(d-3) Reports on plastic concrete - Report on slump, air content, unit weight, water-cement ratio and calculated cement content of trial batch(es).

(d-4) Compressive strength results - Report on 7-day compressive strength tests from the trial batch(es).

(d-5) Test reports on aggregate - See subsection 509.15(b).

(d-6) Test report on water - See 701.02.

(e) Changing mix proportions - Once a mix design has been reviewed and accepted by the Engineer no changes in proportions shall be made by the Contractor without written concurrence of the Engineer. If the Contractor proposes adjustments considered by the Engineer to be significant, the Contractor shall submit a new mix design proposal to the Engineer with verification of strength by trial batch.

(f) Contractor costs - All materials, equipment and work required for designing the mixes, testing materials, and making trial batches to verify the design for final use shall be furnished by the Contractor and the entire cost thereof shall be borne by the Contractor. Costs of State personnel monitoring or performing check tests will be borne by the Division.

509.14 FRLMC Mixture Tolerances and Limits - Steel fibers used in the FRLMC shall be one of the following:

1. Dramix ZL 50/.50 or ZP 50/.50 - manufactured by:

Bekaert Steel Wire Corporation Phone: (800) 241-4126
1395 Marietta Parkway
Building 500, Suite 100
Marietta, Georgia 30067

2. Zorex 2" - manufactured by:

Ribbon Technology Corp. Phone: (800) 848-0477
P. O. Box 30758
Gahanna, Ohio 43230

The FRLMC shall be a workable mixture uniform in composition and consistency with the following properties or limits:

Material or Property	Unit	Quantity	Specification or Test Method
Percent fine aggregate	percent of total aggregate by weight	50-60	509.21(b-1)
Cement content	lbs./cu.yd.	750	509.21(b-1)
Latex emulsion admixture	gal./cu.yd.	28	509.21(b-1)
Water/cement ratio (incl. free moisture in aggregate and non-solids in latex.)	lbs. water/ lbs. cement	0.35 max.	OSHD TM 729
Air content	percent of plastic mix	6.0 max.	AASHTO T 152 609.15(d)
FRLMC temperature	degrees F	50 min. 80 max.	ASTM C 1064
Slump	inches	7 max.	AASHTO T 119 509.15(d)
Yield	cu. yd.	± 2 percent	509.15(e) 509.21(b-1)
Compressive strength at 7 calendar days	psi	3,300 min.	OSHD TM 719 509.13 & 509.16(a)
Fibers (System 1)	lbs./cu.yd.	85 lbs. ZP 50/.50	
(System 2)	lbs./cu.yd	85 lbs. ZL 50/.50 or 100 lbs. Zorex 2"	

The fiber batch weight for System 1 may be adjusted to between 82 and 90 lbs. per cubic yard so that an even number of the prepackaged bags of fiber are required for the particular batch size chosen by the Contractor. The standard 66-pound bag weight may be used as an acceptable measure for the amount of fibers added provided that an accurate bag count per batch is made.

509.15 Process Control - The Contractor shall be responsible for quality control in accordance with 106.18(a) and (b) of the Supplemental Standard Specifications and shall perform process control sampling and testing according to 509.15(b) and 509.15(c):

(a) Certified technicians - The Contractor shall provide a certified CCT and a certified QCT, with authority to control the production of FRLMC. These certifications shall be from a Division accredited organization. A list of the accredited organizations may be obtained from the Engineer. If there are none, the Division will serve in this capacity. Certification will be required by the Engineer before the CCT and QCT are allowed to commence work on the project. The Contractor shall allow at least 14 calendar days for the Division certification process to be completed.

(a-1) Concrete control technician - The CCT shall develop and verify FRLMC mix designs. The CCT shall instruct the plant control personnel how to adjust the batch weights of the ingredients required to maintain the proper water-cement ratio, cement content, air content, and aggregate proportions to produce the specified FRLMC. When FRLMC is placed, the CCT shall be present at the plant, or at the job site if radio contact is maintained with the plant, to supervise control or adjustment of the mix.

(a-2) Quality control technician - The QCT shall perform tests on plastic FRLMC according to 509.15. The QCT shall be assigned at the location where FRLMC is being placed any time placement is in progress. The QCT shall be responsible for insuring all FRLMC complies with specifications, shall reject FRLMC not complying with specifications, and shall notify the CCT of such rejection and the cause for rejection.

(b) Aggregates - Each size of aggregate shall be stockpiled separately. The Contractor shall take samples and perform the following tests on each size aggregate:

(b-1) Required tests:

Test	Test Method	Aggregates	Minimum Frequency Schedule: Start of Production	One per 5 Shifts*	One per Shift*
Dry Rodded Unit Weight	AASHTO T-19	Coarse	X		
Bulk Specific Gravity and Absorption	AASHTO T-85 AASHTO T-84	Coarse Fine	X X		
Friable Particles	OSHD TM 221	All	X	X	
Wood Particles	OSHD TM 225	Coarse	X	X	
Elongated Pieces	OSHD TM 229N	Coarse	X	X	
Fineness Modulus**	OSHD TM 771	Fine	X		X
Sand Equivalent**	OSHD TM 101	Fine	X		X
Sieve Analysis** (with P200 from OSHD TM 205)	OSHD TM 204	All	X		X

*A shift means: a production shift or 500 cubic yards whichever results in the greatest sampling frequency.
**Perform at least 3 tests per project.

(b-2) Split samples - The Contractor shall provide split samples to the Engineer.

(b-3) Additional testing - The Engineer may perform any of the above testing under (b-1) and additional tests such as lightweight pieces, and qualifying tests for soundness, degradation, abrasion and organic impurities. The test results will be provided to the Contractor.

(b-4) Removal of failing material - The Contractor shall make appropriate operational adjustments and conduct a second test immediately whenever a test result, other than sieve analysis and sand equivalent, does not meet specifications. The Contractor shall remove all failing material from the stockpile if the second test result does not meet specifications.

(b-5) Preproduced aggregate - Compliance of aggregates produced and stockpiled before the award date of this contract will be determined by either:

a. Continuing production records meeting the requirements of 509.15(b-1) through (b-4), or

b. Sampling and testing the entire stockpile according to AASHTO T 2 on the following minimum frequency schedule:

- "Start of production," meaning one set of tests per stockpile.

- "One per 5 shifts," meaning one set of tests per 2,500 cubic yards.

- "One per shift," meaning one set of tests per 500 cubic yards, with a minimum of 3 sets of tests per project.

(c) Fine aggregate moisture - The Contractor shall maintain positive control of the amount of moisture in the fine aggregate by:

(c-1) Keeping the stockpiled fine aggregate free moisture content variation to a maximum of 1.0 percent but in no case more than 6.0 percent free moisture.

(c-2) Being able to report to the Engineer at any time the moisture content within ± 0.5 percent.

(d) Air content and slump - The Contractor shall conduct air content and slump tests modified as follows:

(d-1) The minimum sampling and testing frequency for each mixer during each placement shall be performed by the QCT as required for process control from the early part of the first load of each placement, whenever there is a visual change in the mix, and whenever a set of cylinders is obtained by the Engineer.

(d-2) The sample shall be taken to the test site in a container with the FRLMC not over 6 inches deep and allowed to remain undisturbed for 4 to 5 minutes from the time of discharge. The specified procedure for testing for air content and slump shall then be used.

(d-3) Tested material shall not be incorporated into the FRLMC overlay.

(e) Yield test - The Contractor shall have the QCT perform yield tests for process control.

(e-1) Frequency - On each mixer used prior to each placement, and when requested by the Engineer.

(e-2) Procedure - According to the AASHTO Test Method T 121 except the same measuring bowl and strike off procedure used in AASHTO T 152 may be used.

(e-3) Material disposal - Material used in the yield test shall not be incorporated into the FRLMC unless it can be placed in a manner satisfactory to the Engineer. If rejected, it shall be wasted in a manner satisfactory to the Engineer.

509.16 Acceptance Sampling and Testing - Acceptance sampling and testing will be performed according to the following:

(a) Compressive strength - One set of three cylinders will be cast by the Engineer from each 50 cubic yards of FRLMC placed on the project. A minimum of one set will be cast per production shift. Each set of cylinders will be cast in conformance with AASHTO T 141 and T 23, as modified herein, except that cylinders will be cast in 6-inch diameter by 12-inch single-use plastic molds and tested by the Engineer for compressive strength at 7 days. The cylinders will be moist cured in the molds at the site for the first 24 hours, then stripped and air cured by the Engineer for 6 days. The average strength of the three cylinders will constitute the test result. Material represented by a test result of less than 3,300 psi shall be removed and replaced at the Contractor's expense, unless the Engineer determines the material can be left in place at a reduced price.

(b) Surface tolerance - The finished work, when tested with a 12-foot straightedge, shall not vary from the testing edge by more than 0.01-foot at any point. The Contractor shall furnish the straightedge and operate it under the direction of the Engineer. If the FRLMC does not conform to the prescribed limits of deviation, the operations shall be stopped until revised methods, changes in equipment, or correction of procedures are proposed, and are approved by the Engineer for trial. The revised operation shall also be stopped if it does not produce a surface complying with specified requirements.

The Contractor shall correct all nonspecification surface tolerance with a diamond grinder at the Contractor's expense, including required traffic control.

(c) Bond - The Contractor shall cut cores, conduct bond tests on all cores, and the Engineer will analyze the tests as required by this subsection. The Contractor shall then restore the area voided by the cores by bush hammering all faces, air blowing, wetting, and then filling with FRLMC. Cost of cutting the cores, making the bond tests, and restoring the deck or pavement shall be borne by the Contractor except as modified in 509.16(c-2). All areas which are damaged, fail to develop bond or are delaminated shall be removed and replaced at the expense of the Contractor.

(c-1) Bond Test - The Contractor will be required to make two satisfactory bond tests per pour in the presence of and at locations designated by the Engineer within 28 days of placement. The tests shall consist of coring through the FRLMC overlay and about 1-inch into the existing concrete, attaching a device to the top of the core, and exerting a tensile load to the core sufficient to cause failure. Bond strength of the test core less than 100 psi will be considered unsatisfactory. All cores shall be pulled to failure.

(c-2) Delamination survey - The FRLMC resurfacing will be surveyed by the Engineer for delaminations, bond failure or other damage by use of a chain drag and coring or other suitable devices. The cost of any core with a bond strength of less than 100 psi will be borne by the Contractor. The cost of any coring, except those required in 509.16(b-1) and 509.33, with a bond strength of 100 psi or greater will be paid by the Division as Extra Work.

Equipment

509.21 Equipment - The Contractor shall furnish and operate equipment meeting the following requirements for the work specified. Equipment shall not be used until approved by the Engineer. Any equipment leaking oil or any other contaminant, shall be immediately removed from the jobsite until repaired. Each mixer used shall be equipped with diapers, or the prepared deck or pavement may be covered, to protect it from contaminant spills during placement.

(a) Surface preparation equipment:

(a-1) Sawing equipment - The Contractor shall provide power driven concrete saws for sawing joints and as required for surface texture. The saws and related equipment shall be of proven adequacy and design to perform efficiently and shall be subject to immediate replacement if the specified results are not obtained.

(a-2) Scarifying equipment shall be power-operated mechanical scarifiers or scabblers, diamond grinders or water blast machines capable of uniformly removing the existing surface to depths required.

a. Scarifiers and scabblers shall weigh less than 20 tons.

b. Diamond grinders shall be a power driven self-propelled unit with the cutting head made up of diamond cutting blades.

c. Water blasting equipment shall be capable of removing at least ten cubic feet of concrete per hour. All water used shall be potable.

(a-3) Power-driven hand tools for removal of unsound concrete will be permitted with the following restrictions:

a. Class 2 preparation equipment - Chipping hammers equal to or less than a nominal 15-pound class shall be used.

b. Class 3 preparation equipment - Jackhammers equal to or less than a nominal 30-pound class shall be used.

(a-4) Hand tools such as hammers and chisels shall be used to remove final particles of unsound concrete or to achieve the required depth.

(a-5) Air compressor shall be equipped with functioning oil traps and deliver oil-free air.

(a-6) Water spraying system shall be readily available to all parts of the deck being resurfaced and shall discharge potable water. Placement shall not start until potable water is available.

b. Mixing, placing and finishing equipment - Placing and finishing equipment shall include hand tools for placement of FRLMC and for work down to approximately the correct level for striking off with the screed. Manual type screeds or metal plates with approved vibrators attached shall be used to consolidate and finish the smaller areas. Spud vibrators will be required when depths exceed 2-1/2 inches, along edges, and adjacent to joint bulkheads. Supplemental vibration shall be provided along the meet lines where adjacent pours come together and along curb lines. Hand finishing with a wood float may be required along the edge of the pour.

(b-1) System 1 - An existing ready mix concrete plant or portable batch plant shall be used. The mixture shall be transported from the batch plant to the site in standard ready-mix trucks. Both the plant and trucks shall meet all requirements of ASTM C94.

If the batch plant is not located within an approximate 15 minute haul of the construction site, only the design batch quantity per cubic yard of fine aggregate, coarse aggregate and cement shall be added at the plant. The required latex emulsion, fibers and water shall then be added to the ready-mix truck at the site and shall be discharged within 45 minutes after the start of batch of those materials. The allowed time from batching to discharge of the entire mix shall not exceed 1-1/2 hours. Each load batched shall carry with it a "time batching started" card. The mix shall then be screeded and consolidated within 5 to 10 minutes after being discharged.

(b-2) System 2 - Proportioning, mixing and placing equipment shall be self-contained, mobile, continuous mixing, and shall conform to the following:

The mixer shall be self-propelled and shall carry sufficient unmixed dry bulk cement, sand, coarse aggregate, latex modifier, and water to produce on the site at least 6 cubic yards of FRLMC.

The fiber feeder shall have a variable control range capable of feeding the steel fibers into the mobile mixer with controlled accuracy. Approved fiber feeder is the shotcrete plus wire fiber feeder manufactured by Master Builders Shotcrete Division, 23700 Chagrin Boulevard, Cleveland, Ohio 44122, phone (800) 553-3414.

The mixer shall provide positive measurement of cement being introduced into the mix. A recording meter visible at all times and equipped with a ticket print out shall indicate this quantity.

The mixer shall provide positive control of the flow of water and latex emulsion into the mixing chamber. Water flow shall be indicated by flow meter and shall be readily adjustable to provide for minor variations in aggregate moisture.

Flow meters for water and latex emulsion shall be accurate to within $\pm$ 2 percent.

Each mixer shall be calibrated to automatically proportion and blend all components of indicated composition on a continuous or intermittent basis, as required by the finishing operation, and shall discharge mixed material full-width directly in front of the finishing machine. Sufficient mixing capacity of mixers shall be provided to permit placement without interruption.

Calibration to accurately proportion the specified mix shall be performed according to the manufacturer's specifications by a commercial material testing laboratory. The testing laboratory must certify the yield to be true within a tolerance of $\pm$ 1 percent. New calibrations shall be performed by the testing laboratory as follows:

1. Prior to the first placement.
2. Whenever the source of material changes.
3. Following material or equipment failures.
4. Whenever the actual yield determined according to 509.15(e) varies from the calibration yield by more than ± 2 percent.
5. Before reuse, whenever the mixer leaves the project for repair or other use.
6. When requested by the Engineer.

(b-3) FRLMC finishing machine - The FRLMC finishing machine shall be:

- Self-propelled with positive control in both forward and reverse direction.

- Capable of raising screed, pan and rolls to clear the screeded surface and capable of positive, vertical control to the specified grade.

- Equipped with augers.

- Equipped with an oscillating, vibrating screed or a vibrating pan, followed by (a) finish roller(s). All screeds, pans and rolls shall travel laterally at a rate between 60 and 65 feet per minute.

- Capable of vibration frequency between 4000 and 4500 vpm.

- Used on all new surfaces except those noted in 509.21(b).

The finishing machine shall travel upon continuous supporting rails which are supported at 2-foot centers. The rails shall be sufficiently rigid that there is no visible deflection under the weight of the machine. Anchorage for supporting rails shall provide horizontal and vertical stability. Hold-down devices shot into new FRLMC will not be permitted. Screed and bulkhead rails shall not be treated with parting compound to facilitate their removal.

When placing FRLMC in a lane abutting a previously completed lane, the side of the finishing machine adjacent to the completed lane shall be equipped to travel on the completed lane. The finishing machine shall be capable of finishing to the edge of previously placed FRLMC.

(b-4) Straightedge - The straightedge shall be 12 feet long.

(b-5) Recording thermometer - The thermometer used shall be a 24-hour recording thermometer accurate to ± 1°F.

(b-6) Coring equipment - The equipment used to cut the cores required in 509.16 shall produce a core at least three inches in diameter.

(b-7) Bond testing equipment - The equipment used to perform the bond test required in 509.16(c) shall be compatible with the core tested, exert a tensile load to the core sufficient to cause failure above 100 psi, and shall be equipped with a measuring device capable of reading tensile force exerted within 1 percent accuracy.

Construction

509.31 Preparation - During scarifying, chipping, sawing, sandblasting, sweeping, water blasting and flushing operations, deck drains and catch basins shall be blocked to prevent material from entering them. No ridging greater than 1/4-inch will be allowed. Machine scarifying shall not be performed within one foot of any joint. Material within one foot of any joint shall be removed so that the joint is not damaged, in a manner acceptable to the Engineer.

Surface concrete shall be removed by approved hand methods in areas, such as those near barriers and drains, that cannot be reached by scarifying machines.

All materials requiring removal from the deck shall become the property of the Contractor and be disposed of in a manner satisfactory to the Engineer.

Any damage to abutting concrete surfaces, joints, and other surfaces shall be repaired by the Contractor at Contractor expense.

(a) Initial preparation - Class 1 preparation shall be finished far enough in advance of resurfacing so that any further preparation deemed necessary by the Engineer can be satisfactorily completed. Bridge deck preparation shall be classified as follows:

(1) Class 1 preparation shall consist of:

- Removing any existing asphalt concrete wearing surface.
- Removing concrete from the entire surface area with approved surface preparation equipment to a nominal

depth of 3/4-inch and a maximum depth of 1-inch at any point below the existing PCC surface.

- Protecting visible steel and steel in those areas where the plans show the existence of steel within one inch of the surface.

(2) Class 2 preparation - Areas where Class 2 preparation is to be performed will be designated by the Engineer and performed on an Extra Work basis. Concrete removal shall be done by waterblasting or chipping. Class 2 preparation shall consist of:

a. Removing all unsound concrete from the lower limit of Class 1 preparation down to a maximum depth equal to half the total thickness of the existing deck or pavement.

b. Removing a minimum of 3/4 inch of concrete around reinforcing bars that:

   - Lack bond between existing concrete and reinforcing steel, or

   - Are exposed one-half the bar diameter or more for a distance greater than 12 inches along the bar.

c. Sandblast reinforcing bars pitted with rust to remove all rust.

(3) Class 3 preparation - Areas where Class 3 preparation is to be performed will be designated by the Engineer and performed on an Extra Work basis.

Just prior to placing new concrete in Class 3 preparation areas, the areas shall be cleaned and treated with a epoxy or nonepoxy bonding agent from the Division's QPL in accordance with the manufacturer's recommendations. Class 3 concrete placement shall be completed at least 5 days before the placement of FRLMC.

Class 3 preparation shall consist of:

- Removing the full thickness of deck or pavement remaining below the lower limit of Class 1 or Class 2 preparation.

- Sandblast reinforcing bars pitted with rust to remove all rust.

- Replace the concrete removed with Class 4000-3/4 PCC up to the lower limit of Class 1 or Class 2 preparation as directed.

(b) Final preparation - Any surface to be contacted by the FRLMC including vertical contact areas, shall in sequence be:

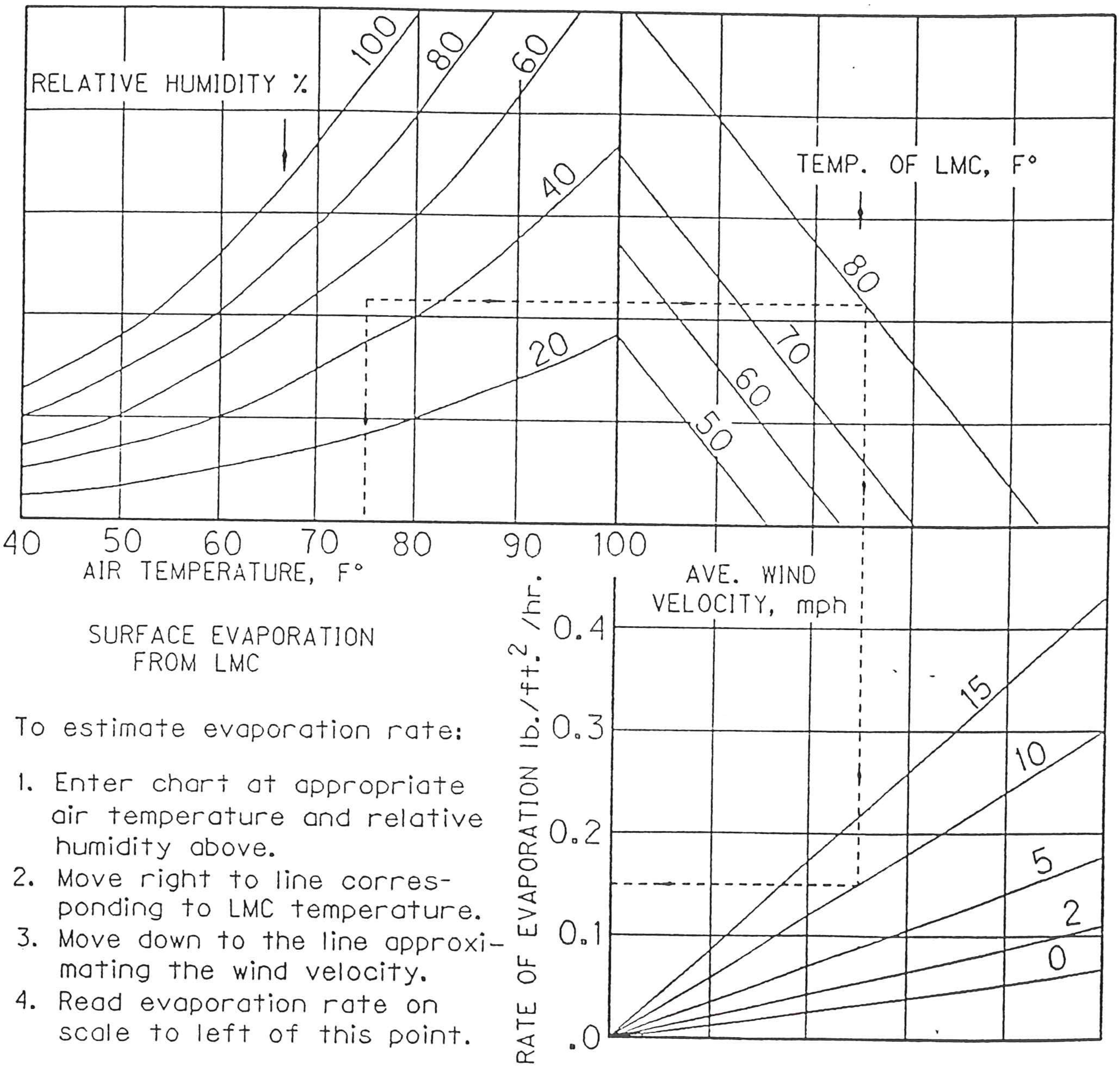
- Sandblasted within 24 hours of the FRLMC placement.
- Cleaned with water or compressed air and saturated with water for a minimum of one hour just prior to placing FRLMC.
- Resandblasted, cleaned and saturated as above if FRLMC pour is delayed and in the judgment of the Engineer is necessary.
- Blown out with compressed air, just ahead of FRLMC placement, in areas where there is standing water in depressions.

509.32 Placing:

(a) Placement Conditions - FRLMC shall be placed on prepared surfaces only when all of the following conditions exist:

(a-1) The combination of air temperature, relative humidity, temperature of latex modified concrete and wind velocity produces an evaporation rate of less than 0.15 pounds per square foot of surface per hour as determined from the following table:

TABLE 509-1 SURFACE EVAPORATION FROM LMC



SURFACE EVAPORATION FROM LMC

To estimate evaporation rate:

1. Enter chart at appropriate air temperature and relative humidity above.
2. Move right to line corresponding to LMC temperature.
3. Move down to the line approximating the wind velocity.
4. Read evaporation rate on scale to left of this point.

(a-2) All the following individual conditions are met:

- The surfaces temperature is 45°F or greater and less than 80°F. It will be measured by the Engineer in three 1/4-inch diameter by 1/2-inch deep holes predrilled in the deck by the Contractor for each placement.

- The air temperature is at least 45°F at the start of FRLMC placement and is forecast to remain above 45°F for 8 consecutive hours after the pour is completed.

- Wind at the site measures less than 15 MPH at the start of FRLMC placement and is forecast to remain under 15 MPH for duration of placement.

- It is not raining.

- During the hours of darkness, work areas shall be illuminated at the Contractor's expense.

(b) Thickness - FRLMC shall be placed with variable thickness as shown on the plans or as directed by the Engineer.

(c) Construction limitations - FRLMC shall be placed against a firmly fixed bulkhead. Control of sagging or running of freshly placed FRLMC in areas of steep gradient may be by one or more of the following methods:

- Modifying direction or method of placement.
- Modifying slump.

Unless permitted by the plans, traffic will not be allowed in the lane adjacent to a pour until at least one hour after a pour is completed.

(d) Placement procedures: The Contractor shall furnish a minimum of two transverse work bridges, not counting the finishing machine.

(d-1) Preceding placement - The finishing machine shall be test run over the deck or pavement before each day's paving to ensure the required thickness of pavement will be achieved. FRLMC shall be placed working down grade, unless otherwise approved by the Engineer.

(d-2) Joints - At transverse and longitudinal joints, the surface course previously placed shall be sawed to a straight, vertical edge before the adjacent course is placed. Sawing of joints may be omitted if the bulkhead produces a straight, smooth, vertical surface. The face of the joints whether sawed or formed shall be sand or water blasted to remove loose material.

(a) Longitudinal joint - A longitudinal construction joint will be permitted only at the centerline of roadway or at lane lines unless otherwise permitted by the plans.

(b) Transverse joint - In case of delay in the placement operation exceeding one-half hour in duration, an approved construction joint shall be formed by removing all material not up to finish grade and sawing the edge in a straight line. Further placement is permitted only after 12 hours, unless a gap is left between placements, wide enough for the finishing machine to clear the formed construction joint. During minor delays of one-half hour or less, the end of the placement may be protected from drying with several layers of wet burlap.

(d-3) Placing - The latex-modified mortar phase of the mixture shall be brushed onto the wetted, prepared surface, and any coarse aggregate shall be removed and disposed of by the Contractor. Care shall be taken to ensure that all vertical as well as horizontal surfaces receive a thorough, even coating and that the rate of progress is limited so that the material brushed on does not change color before further FRLMC placement.

All placing operations shall stop when it starts to rain. The Contractor shall protect fresh, previously placed FRLMC from rain. The Engineer may order removal of any concrete material damaged by rain.

(d-4) Roadway finish - After the roadway has been struck off with a finishing machine as described in 509.21(b-2), it shall be floated if necessary to produce a uniform tight texture. Quality of workmanship shall be such that the finished work meets 509.16(b). After the FRLMC has hardened sufficiently, it shall be textured with:

- A steel-lined tool with 1/8-inch wide tines at 3/4-inch centers shall be used prior to a plastic film forming on the surface. It shall mark the finished concrete to a depth of 1/8-inch to 3/16-inch, or

- A finned float having a single row of fins. The grooving shall be approximately 3/16-inch in width at 3/4-inch centers and the groove depth shall be 1/8-inch to 3/16-inch. This operation shall be done before a plastic film forms and at such time and in such manner that the desired texture will be achieved while minimizing displacement of the larger aggregate particles, or

- Saw cut grooving that shall be 0.1-inch wide, spaced at 3/4-inch centers and 1/8-inch to 3/16-inch deep. Grooving must occur after curing duration and before the roadway is opened to traffic. Residue from the grooving operation shall be continuously removed while grooving and disposed of in a manner satisfactory to the Engineer.

Overlaps of the texturing shall be avoided. Texturing shall be transverse to the roadway centerline and full roadway width except for strips 16 inches wide along curb faces, which shall be left unmarked.

(d-5) Curing:

a. Wet cure - For the initial wet cure cover, the surface shall be covered with a single layer of clean, presoaked wet burlap immediately after texturing. As an additional wet cure cover, within 10 minutes of covering with wet burlap, a layer of 4-mil, white, reflective, polyethylene film, or wet burlap-polyethylene sheets, shall be placed on the wet burlap, and the surface continuously cured with water for 36 hours. The wet burlap-polyethylene sheets shall not replace the initial wet burlap.

b. Air cure - The curing material shall then be removed for an additional 60 hours air cure.

c. Additional cure time - If during the wet or air curing period the ambient temperature falls below 45°F, the 96-hours curing period will be increased by the number of hours the temperature is below 45°F as determined by the 24-hour recording thermometer.

509.33 Crack Survey and Repair - Immediately after the air cure period, the surface will be checked for cracks. If cracks are found, cores will be required unless the Engineer determines coring is not necessary.

All visible cracks shall be sealed with a methacrylate sealer from the Division's Approved Products Listing, except that Concresive 2075 shall not be used, unless the Engineer determines removal and replacement is required.

All corrective measures, including cutting, preparing and filling of core holes, as required in 509.16, will be at the Contractor's expense. All corrective measures shall be completed before opening to traffic, unless otherwise directed by the Engineer.

509.34 Use of New Surface:

(a) Vehicles - No vehicles or construction equipment shall be allowed on the new FRLMC surface until curing is compete in accordance with 509.32(d-5).

(b) Traffic - No section of FRLMC may be opened to traffic until the pavement meets all the requirements in 509.16, 509.31, 509.32 and 509.33 unless otherwise approved in writing by the Engineer.

Measurement

509.81 Measurement - Measurements will be in accordance with the following:

(a) Preparation - The area of Class 1 preparation will be the number of square yards prepared as specified.

The area will be determined by horizontal width and length measurements taken to the nearest 0.1-foot. The area will be computed to the nearest full square yard.

(b) Resurfacing - Measurement of FRLMC resurfacing shall be:

(b-1) The volume of furnish FRLMC placed as specified will be determined in place from cross sections taken before placement at 10-foot maximum intervals. Horizontal width and length measurements will be taken to the nearest 0.1 foot, and depth measurements to the nearest 0.01-foot. The volume of FRLMC will be computed to the nearest 0.1-cubic yard by the average end area method or methods of equivalent accuracy.

(b-2) Square yards of construct FRLMC resurfacing complete in place will be measured as described in (a) above.

Payment

509.91 Payment - Preparation and resurfacing of bridge decks will be paid at the contract unit price per unit of measurement for each item listed below that is shown in the bid schedule:

Item	Unit of Measurement
(a) Class 1 Preparation	Sq. Yd.
(b) Furnish Fiber Latex Modified Concrete	Cu. Yd.
(c) Construct Fiber Latex Modified Concrete Resurfacing	Sq. Yd.

Payment for item (a) above will include payment for removal and disposal of any existing asphalt concrete overlay and the top surface of the portland cement concrete deck as specified and cleaning and preparing all surfaces which are to receive the FRLMC.

Payment for item (b) above will include payment for furnishing the FRLMC used above the lower limit of deck preparation.

Payment for item (c) above will include payment for placing and finishing the FRLMC resurfacing.

Payment, when made at the contract unit prices for the above items (a) through (c), shall be complete compensation for furnishing all labor, materials, equipment, tools and incidentals required to complete the work as specified.

509.92 Class 2 and Class 3 Deck Preparation - Class 2 and Class 3 preparation will be paid for on an Extra Work basis as set forth in 109.07.

SECTION 510
STEEL STRUCTURES

Structural steel shall be furnished, fabricated, and erected in conformance with Section 510 of the Standard Specifications supplemented and/or modified as follows:

510.11 Materials - Supplement or modify Section 733 as follows:

733.01 Structural Steel - In 733.01(a), (b) and (c), include the following paragraphs as appropriate:

Change the designations for the following structural steels:

Old Designation		New Designation	
AASHTO	ASTM	AASHTO	ASTM
M 183	A 36	M 270, Grade 36	A 709, Grade 36
M223, Grade 50	A 572, Grade 50	M 270, Grade 50	A 709, Grade 50
M222	A588	M 270, Grade 50W	A 709, Grade 50W

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