FINAL REPORT

EVALUATION OF LATEX-MODIFIED AND SILICA FUME CONCRETE OVERLAYS PLACED ON SIX BRIDGES IN VIRGINIA

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ABSTRACT

Latex-modified and silica fume concrete overlays were placed on six bridges on I-95 south of Emporia, Virginia, in the fall of 1994. The construction was funded with 20% Virginia Department of Transportation maintenance funds and 80% special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial condition of the overlays and to prepare this report.

The overlays are in good condition after 5 years in service and are protecting the reinforcement from further chloride-induced corrosion.

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INTRODUCTION

Latex-modified (LMC) and silica fume (SF) concrete overlays were placed on six bridges on I-95 south of Emporia, Virginia, in the fall of 1994. The construction was funded with 20% Virginia Department of Transportation maintenance funds and 80% special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial condition of the overlays and to prepare this report.

The overlays placed on the six bridges were modified by weight of cementitious material as follows:

- 7% SF, Bridges 1 and 4
- 10% methylmethacrylate LMC (MMLMC), Bridge 2
- 10% microlite (ML)(microlite is 70% SF and 30% aggregate and admixture), Bridge 5
- 15% styrene butadiene LMC, Bridges 3 and 6.

High early strength was achieved by:

- substituting Type III for Type II cement for the LMC overlay placed on Bridge 3
- increasing the cement content for the LMC overlay placed on Bridge 3
- increasing the Type II cement content for the SF concrete overlay placed on Bridge 4.

Table 1 shows the structure number and installation dates for the six overlays.

Table 1. Overlay Technology Description

Project Bridge No.	Structure No.	Overlay Type	Date Overlay Applied	
			Outer Lane	Inner Lane
1R*	2000	SF	9/15/94-9/16/94	N/A
1	2000	SF	9/28/94	10/26/94
2**	2005	MMLMC	9/21/94	10/19/94
3	2003	LMC High Early Strength (LMCHE)	10/5/94	10/13/94
4	2002	Silica Fume High Early (SFHE)	10/4/94	10/12/94
5	2004	ML	9/20/94	10/21/94
6	2001	Styrene Butadiene LMC	9/27/94	10/18/94

*The first overlay placed on Bridge 1 was removed because it developed many full-depth plastic shrinkage cracks that appeared to begin as screed tares.
**Third span of outside lane is ML; inside lane is LMC.

Figure 1 is a site location map for the bridges. Initially, the outside shoulder and travel lane of each bridge were overlayed while traffic used the inside lane. Then, traffic was placed on the outside lane of each bridge while the inside lane and shoulder were overlayed.

PURPOSE AND SCOPE

The objective of this research was to evaluate bridge deck overlays placed using ISTEA Section 6005 funds.

METHODOLOGY

The objective was to be accomplished by completing the following seven tasks with regard to the outside shoulder and travel lane of the six bridges:

1. Evaluate conditions of each deck prior to placement of the overlays.
2. Document the specifications used for each installation.
3. Document the installation of each overlay.
4. Evaluate the initial condition of each overlay.
5. Evaluate the condition of each overlay annually.
6. Evaluate the final condition of each overlay in 1999.
7. Prepare a final report.

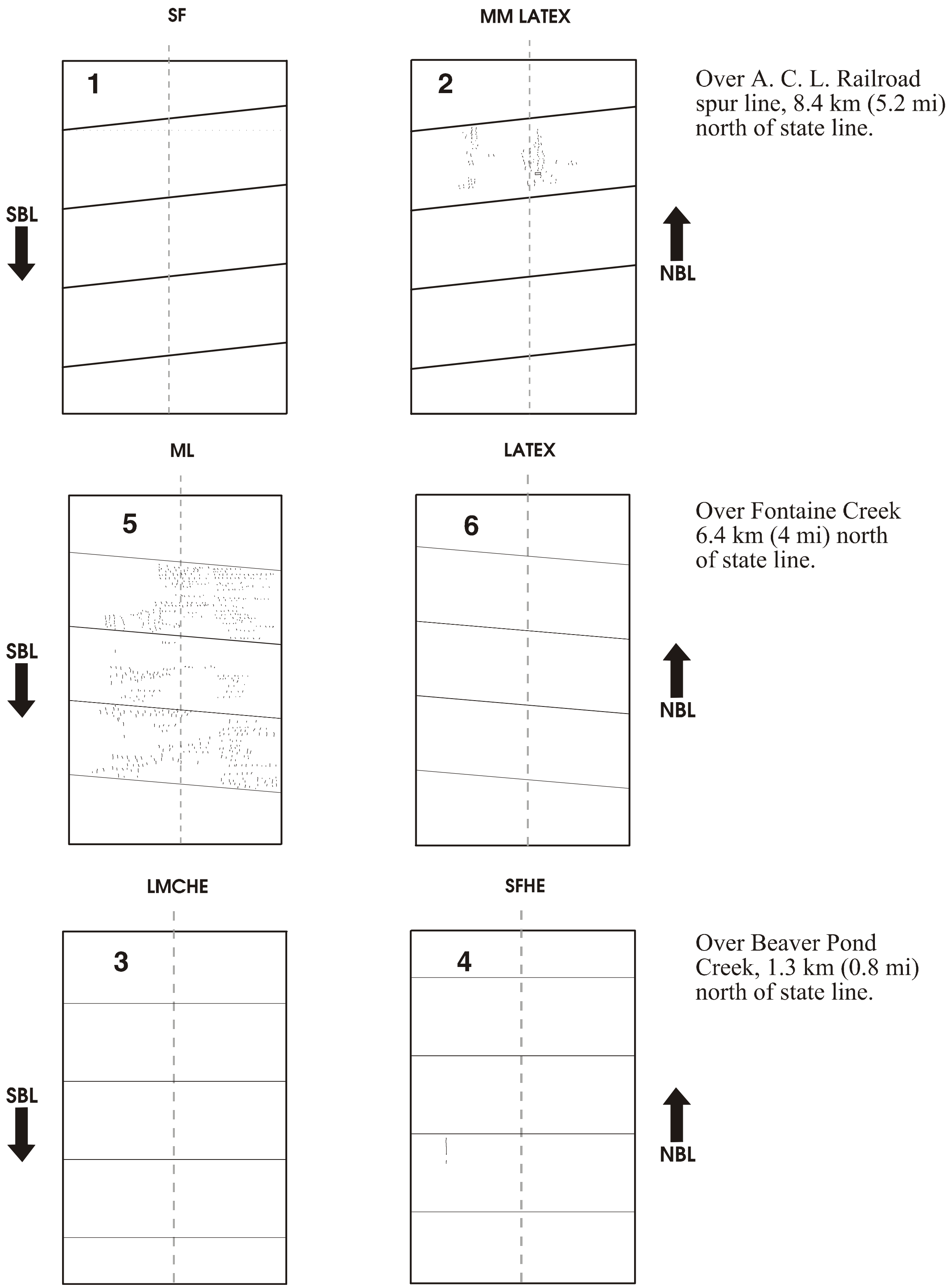

Figure 1. Site Location Map, I-95, 1.3 to 8.4 km (0.8 to 5.2 mi) North of the Virginia-North Carolina State Line

This report covers Tasks 6 and 7. Tasks 1 through 5 were covered in the interim report.[1] When available, information for the inside shoulder and paving lane is presented and included in the evaluation. The mixture planned for Bridge 2 was used only on the outside shoulder and travel lane of the approach slab and Spans 1 and 2, and, therefore, evaluations of the mixture were based on tests done on Spans 1 and 2. Evaluations of the overlays are based on an assessment of how well the overlays are bonded to the base concrete, how well they increase the stiffness of the pavement, how well they are protecting the pavement from the infiltration of chloride ion and corrosion, how well they are providing a skid resistant surface, and their cost-effectiveness.

A modified version of VTM 92 was used to provide an indication of how well the overlays are bonded to the base concrete. Typically, three cores, 57.2 mm (2.25 in) in diameter and approximately 102 mm (4 in) long are tested to evaluate each overlay. The cores are drilled through the overlay and the base concrete and taken to the laboratory for testing. In the laboratory, the cores are saw cut parallel with and approximately 25 mm (1 in) above and below the plane of the bond interface. The machined surfaces of two pipe caps are bonded to the saw cut surfaces of each core with an epoxy. Two hooks are connected to the threaded pipe caps and the hooks and core are pulled in tension using a universal testing machine. Cores are loaded at the rate of 5340 N (1,200 lb) per minute. The failure load and failure location are recorded.

Failures can occur in the base concrete, the bond interface, the overlay, the epoxy used to bond the caps to the core, and a combination of these locations. A 100% failure in the bond interface provides a true indication of bond strength. Failures at other locations indicate that the bond strength is greater than the failure load. However, for practical purposes, failures in the base concrete or overlay provide an indication of the degree to which the overlay is anchored and are considered as indicating bond strength. When a failure occurs in the epoxy, the result may be discarded if it is lower than the average of the other results or included if it is the same or higher. An epoxy failure should be a rare occurrence. Bond strength test results may be qualified as follows:

≥ 2.1 MPa (300 psi), excellent
1.7 to 2.1 MPa (250 to 299 psi), very good
1.4 to 1.7 MPa (200 to 249 psi), good
0.7 to 1.4 MPa (100 to 199 psi), fair
0 to 0.7 MPa (0 to 99 psi), poor.

A chain drag of the overlay is used to provide an indication of areas that are delaminated (0 bond strength). A survey of the overlay for areas that are spalled and patched provides an indication of bond strengths that were not high enough to prevent failure because of stress caused by shrinkage, traffic, temperature change, moisture, and freeze-thaw action.

Protection against the infiltration of chloride ion is evaluated based on pavement surveys and mapping cracks and tests of two or three cores for permeability to chloride ion (AASHTO T 277). Permeability test results are based on tests of the top 51 mm (2 in) of cores 102 mm (4 in) in diameter and are typically the average of tests on two or three cores. Results are expressed as follows:

> 4000, high
2000-4000, moderate
1000-2000, low
100-1000, very low
< 100 negligible.

Protection against corrosion is indicated by electrical half-cell potential measurements (ASTM C 876). Readings are typically taken on a 1.5-m (5-ft) grid and are interpreted as follows:

0 to –0.19 V_{cse}, 90% probability of no corrosion
-0.20 to –0.35 V_{cse}, uncertain as to corrosion
more negative than –0.35 V_{cse}, 90% probability of corrosion.

Protection against corrosion is also indicated by the chloride ion content at the level of the reinforcing steel. Contents that are 0.77 kg/m^3 (1.3 lb/yd^3) or greater are sufficient to cause corrosion. Samples are typically taken and analyzed in accordance with AASHTO T 260. Most departments of transportation use 1.18 kg/m^3 (2 lb/yd^3) as the threshold for decisions.

Skid resistance is typically measured with a skid test trailer that is pulled at 64 km/h (40 mph). Tests are done with a treaded tire (ASTM E501) or a bald tire (ASTM E524). Results are reported based on the average of three tests. The treaded tire provides a good indication of microtexture, and the bald tire, macrotexture. Departments of transportation do not publish standards for numbers, but asphalt and concrete pavements and bridge decks typically have numbers between 30 and 50. Cost-effectiveness is typically based on life cycle costs. Unfortunately, it is difficult to get representative costs for demonstration projects because of the unique nature and small size of typical projects. Relative comparisons of the costs of traffic control, construction, materials, and mobilization for various overlay systems can provide an indication of relative cost-effectiveness.

RESULTS

Cracks

Prior to placement of the hydraulic cement concrete overlays, all six bridge decks were covered with epoxy overlays**,** and, thus, no cracks or patches were visible. The condition of the EP5 modified epoxy concrete overlay on Bridge 2 was excellent. The epoxy and sand Class I waterproofing on the other bridges was in very poor condition. The waterproofing on the bridges was worn away over much of the traveled surface but in place over most of the shoulder areas.

Table 2 provides a summary of the cracks, delaminations, and patches in the outside lane and shoulder of the overlays in 1994 after the overlays were placed and in 1999 after 5 years in service. The overlays on Bridge 1 (1R) were removed in 1994 because of the plastic shrinkage cracks initiated by screed tares. The overlays on Bridge 5 and Span C of Bridge 2 were treated with high-molecular-weight methacrylate in 1994 to seal the plastic shrinkage cracks.

After 5 years in service, the overlays had cracked. Cracks are reported in units of length because the bridges are similar in size. The length of crack was the greatest for the bridges with the silica fume overlays, Bridges 1, 4, and 5. The least cracking occurred on Bridge 6, with the conventional LMC overlay.

Table 2. Summary of Cracks, Delaminations, and Patches After Overlay Placements

		Bridge Number							
		1R	**1**	**2 A/B**	**2 C**	**3**	**4**	**5**	**6**
Cracks m (ft)	1994	Numerous plastic shrinkage	None	None	Numerous plastic shrinkage	None	3.7 (12)	Numerous plastic shrinkage	None
	1999	No overlay	58.4 (192)	25.3 (83)	12.2 (40)	39.5 (129.5)	83.7 (274.5)	165.2 (541.5)	20.6 (67.5)
Delaminations m^2 (ft^2)	1994	0	0	0	0	0	0	0	0
	1999	No overlay	0.37 (4.0)	0	0	0	0	0	0
Patches m^2 (ft^2)	1994	0	0	0	0.093 (1)	0	0	0	0
	1999	No overlay	0	0	0.093 (1)	2 (21.75)	4.9 (52.5)	0	0

Delaminations

Table 2 shows that Bridge 1 had 0.37 m^2 of delamination in 1999. Otherwise, no delaminations were found.

Patches

Table 2 shows that after 5 years in service only the overlays on Bridges 3 and 4 (LMCHE and SFHE) had to be patched. These overlays would be the most likely to fail because they were opened to traffic after only 24 hours of cure. The small patch on span C of Bridge 2 was done shortly after the overlay was placed and prior to opening it to traffic.

Skid Tests

The results of the skid tests conducted with a trailer in 1994 and 1999 are shown in Table 3. The tests were conducted on the outside lane of the overlays. All the overlay concretes achieved acceptable skid resistance. A tined texture was placed on Bridges 3 and 4. Grooves were saw cut into the other overlays. After 5 years in service, all numbers are good.

Table 3. **Skid Testing on Travel Lane**

Bridge No.	Overlay Type	1994 Bald Tire	1994 Treaded Tire	1999 Bald Tire	1999 Treaded Tire
1	SF	46	45	45	41
2	MMLMC	45	45	45	41
3	LMCHE	42	42	48	45
4	SFHE	51	51	51	51
5	ML	38	41	46	43
6	LMC	33	31	49	46

Electrical Half-Cell Potential Results

Electrical half-cell potential measurements (ASTM C876) were taken on a 1.2-meter grid over the outside shoulder and travel lane. Table 4 shows the results of the electrical half-cell potential tests performed prior to placement of the overlays, at 8 to 16 days after placement, and in 1999 after 5 years in service. All the results except for Bridge 5 were more negative 8 to 16 days after the overlays were placed. The researcher believes this is due to the moisture in the new overlays, which improves the conductivity of the concrete, and to the epoxy on the surface prior to placement of the overlays, which tends to resist current flow. In 1999, all measurements were less negative than the earlier readings and no measurements were more negative than –0.35, indicating that the overlays are protecting the reinforcement in the decks and that the small areas in Bridges 1 and 5 that had potentials more negative than –0.35 no longer are.

Table 4. **Electrical Half-cell Potentials Prior to and After Placement of Overlay (%)**

Bridge No.	Prior to Overlay, $-V_{CSE}$			After Overlay, $-V_{CSE}$			October 1999, $-V_{CSE}$		
	<0.20	0.20-0.35	>0.35	<0.20	0.20-.35	>0.35	<0.20	0.20-.35	>0.35
1	44	50	6	2	81	17	92	8	0
2	97	3	0	44	50	6	99	1	0
3	88	12	0	81	19	0	94	6	0
4	73	27	0	57	43	0	100	0	0
5	55	43	2	80	20	0	100	0	0
6	84	16	0	66	34	0	97	3	0

Tensile Bond Strength

Table 5 shows the results of the tensile adhesion tests conducted on the outside travel lane and shoulder in accordance with a modified version of ACI 503A and VTM 92. The modification is that cores approximately 102 mm long are removed from the deck and saw cut in the laboratory to provide a specimen with approximately 25 mm on each side of the bond line, a pipe cap is bonded to both sawn surfaces, and the specimen is subjected to tension using a universal testing machine in the laboratory. The bond strengths were in the fair to poor range in

Table 5. Tensile Bond Strength

Bridge No.	94 Overlay Thick., cm	99 Overlay Thick., cm	94 Bond Strength MPa	99 Bond Strength MPa	94 Overlay Failure Area, %	99 Overlay Failure Area, %	94 Bond Failure Area, %	99 Bond Failure Area, %	94 Base Failure Area, %	99 Base Failure Area, %
1	3.4	3.1	1.0	1.0	3	3	94	3	0	97
2	3.7	3.4	0.7	1.0	10	7	83	3	3	94
2C*	3.3	3.2	0.4	1.3	0	15	85	10	0	90
3	4.2	4.0	0.6	1.3	2	0	98	0	2	98
4	4.0	3.9	0.8	1.1	0	7	93	17	0	83
5	3.3	3.0	0.9	0.9	8	0	92	0	2	98
6	3.8	3.5	0.8	1.4	0	2	98	0	0	100

*Span 3 was overlaid with ML.

1994 and in the fair range in 1999. The failures are predominately in the base concrete below the bond line. The researcher believes the failures occurred in the base concrete because of the damage done by the milling machine. The results are not representative of the bond strengths of the six overlay concretes. The overlay may fail prematurely because of the weak base to which they are bonded.

Permeability

Table 6 shows the results of permeability tests conducted on cores 102 mm (4 in) in diameter removed from the outside lane and shoulder of the decks in 1994 and 1999. In 1994, cores were taken at an overlay age of about 8 to 16 days and tested at an age of 6 weeks. Tests were conducted on the top 51 mm (2 in). Three cores were taken from the following locations on each bridge:

- center of the outside shoulder of Span A
- right wheel path of the outside travel lane of Span B
- center of the outside travel lane of Span C.

Table 6. Permeability to Chloride Ion, Coulombs

Bridge	1994	1999
1	1081	911
2	2533	795
2C	327	670
3	1665	513
4	815	780
5	1211	696
6	1296	454

All three samples were taken at midspan. The results were in the low (1000 to 2000) to very low (100 to 1000) range, indicating that all of the overlays are providing good protection. In general, the permeability of the LMC overlays (2, 3, 6) has decreased with age, and the permeability of the SF overlays (1, 2C, 4, 5) has stayed the same. Most important, all overlays had a permeability in the very low range in 1999.

Cost of Overlay

Cost data for the six bridge overlay installations are shown in Table 7. The unit costs of the concretes were slightly different because of the costs of the ingredients and the relative difficulties and ease with which the overlays can be constructed. The cost of bridge preparation and traffic control exceeds the cost of the overlays.

Table 7. Cost Description of Project

Bridge No.	Type of Overlay	Cost of Bridge Preparation and Traffic Control, $	Unit Cost of Concrete, $/m^3	m^3 of Concrete Placed	Total Cost, $
1	SF	120,293	850	62*	172,943
2	MMLMC	104,074	850	43**	140,854
3	LMCHE	81,774	948	47	125,999
4	SFHE	75,019	889	44	113,779
5	ML	93,503	900	46	134,783
6	LMC	79,376	850	43	116,101
					804,459

*15 m^3 included for replaced span.
**19 m^3 MMLMC + 16 m^3 LMC + 8 m^3 ML.

Estimate of Remaining Service Life of Overlays

Data obtained during the evaluation indicate the overlays have many properties that are similar to those of overlays that have lasted 20 years.[2] Unfortunately, the bond strengths are lower than those of long-lasting overlays, and premature spalling may occur.

Evaluation of Cost-Effectiveness

The overlays differ slightly with respect to cost because of the differences between the cost of the ingredients and the equipment and procedures required for the installation. The cost of mobilization, traffic control, joint replacement, backwall construction, and approach slab construction exceeds the cost of the overlays.

Assessment of Project's Objectives Using Section 6005(e)7

In the spirit of the ISTEA funding, this project demonstrated the viability LMC and SF concrete overlays and revealed areas for improvement.

CONCLUSIONS

- Styrene butadiene LMC and MMLMC and 7% SF and ML concrete overlays are viable deck protective systems that can provide low permeability to chloride ions and good skid resistance.

- High-early-strength concrete overlay mixtures with styrene butadiene latex and 7% SF can be opened to traffic at 24 hours of age. However, opening to traffic early may contribute to some reduction in service life.

- A low surface strength for the old base concrete leads to tensile bond strengths in the fair to poor ranges for overlays. Milling likely damages the old concrete surface.

- The permeability to chloride ion generally decreases with age for the LMC overlays and stays about the same over 5 years for SF overlays. Both types of overlays have a very low permeability at 5 years.

- The concretes differ slightly with respect to cost because of the difference between the cost of the ingredients and the equipment and procedures required for the installation.

- The cost of mobilization, traffic control, joint replacement, backwall construction, and approach slab construction exceeds the cost of the overlays, suggesting that minor differences in the cost of materials has minimal impact on the total cost of the project. Major cost savings can be achieved by using systems that minimize the cost of traffic control.

RECOMMENDATIONS

1. Styrene butadiene LMC and 7% SF concrete overlays should continue to be used as deck protective systems. MMLMC, which is not currently available, and ML concrete overlays can be used as alternatives to the standard LMC and SF overlays.

2. LMC and SF overlays made with high-early-strength mixtures as described herein may be opened to traffic after only 24 hours of curing, but cracks will occur because of the reduced cure time. The cracks may cause minor reductions in the life of the deck.

3. More emphasis and care should be placed on concrete removal and surface preparation so that higher bond strengths can be obtained. Research needs to be done to identify milling machines that cause damage.

4. To reduce the total cost of the overlays, an effort should be made to identify ways to reduce the cost of traffic control necessary to construct the overlays.

ACKNOWLEDGMENTS

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