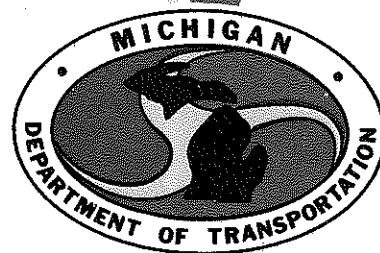


EXPERIMENTAL RESURFACING OF CONCRETE  
BRIDGE DECKS WITH MICROSILICA MODIFIED  
CONCRETE - INITIAL REPORT



**MATERIALS and TECHNOLOGY DIVISION**

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CONCRETE - INITIAL REPORT

H. L. Patterson

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Materials and Technology Division  
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Michigan Transportation Commission  
William Marshall, Chairman;  
Rodger D. Young, Vice-Chairman;  
Hannes Meyers, Jr., Shirley E. Zeller,  
William J. Beckham, Jr., Stephen Adamini  
James P. Pitz, Director  
Lansing, April 1987

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## SUMMARY

The work described in this report involved the development and selection of a microsilica modified concrete (MSMC) mix design, the field application, and the evaluation of that material as an overlay concrete on two bridge decks. The bridges selected for the experimental applications carry Frontenac and Mt. Elliott Ave over I 94 in Detroit. A latex modified concrete (LMC), also placed during the 1986 construction season, on Ferry Ave over I 75 served as the control. Fresh concrete was sampled on the days that both the Ferry and Frontenac Ave bridges were overlaid and test specimens were cast, returned to the Department's Research Laboratory and evaluated. In addition to sampling and evaluating the fresh concrete, cores were taken and corrosion cell surveys were run on both the LMC and the MSMC bridge decks.

Testing of the fresh concrete specimens showed that both concretes have excellent properties, with the MSMC excelling in the strength and rapid chloride permeability tests while the LMC excelled in the consolidation and hardened concrete shrinkage tests. Rapid chloride permeability, run on the concrete cores, showed the permeability characteristics of the MSMC to be improved over the LMC. The corrosion cell survey showed that the Ferry Ave bridge was showing more corrosion activity in the substrate concrete than was the Frontenac bridge deck. It is important to realize this fact initially so that any future problems that are caused by further delaminations of the substrate can be correctly assessed.

Shrinkage or craze cracking, noted to have occurred on both the Frontenac and Mt. Elliott bridges, occurred within two weeks after the overlays were placed. Thirteen days following placement of the overlay, cores were taken from the Frontenac bridge and returned to the laboratory for rapid permeability tests. Although one core had been drilled inadvertently through a full-depth crack, the permeability test results were not altered significantly.

## INTRODUCTION

### Background

The concept of utilizing microsilica or silica fume as a pozzolan in concrete originated in Norway and Denmark, where research work began in the early 1950s. Its early use was in speciality concretes of very high compressive strength (16,000 to 18,000 psi) that had very low permeability.

Originally a waste product, silica fume has now become a useful by-product of both the silicon carbide abrasives industry and the metallic silicon industry. Because of its extreme fineness, its recovery from the exhaust of the electric furnaces is complex; its particle size, finer than that of tobacco smoke, has a specific surface area of 200,000 sq cm/gm. This compares with a specific surface of 1,800 sq cm/gm for Type I portland cement. A comparison of particle sizes of cement and microsilica would be like comparing a watermelon with a radish seed.

Microsilica was introduced to the Department when the Elborg Technology Co. of Pittsburgh, submitted their product Emsac-B for consideration as a new material in February 1984. Because its reputation had preceded its introduction, the New Materials Committee followed the recommendation of the supervisor of the Department's Materials Research Unit and recommended that the Research Laboratory evaluate the material.

### Objective

Because a search for an overlay concrete cheaper than the latex modified concrete (LMC) has been ongoing for several years, the low permeability characteristics of the microsilica concrete were viewed with great interest. Hence, the main objective of the laboratory work associated with Emsac-B was to check the suitability of the material as a bridge deck overlay concrete, and to develop an optimum mix design. To be suitable, the mix design had to be cheaper than the conventional latex overlay, but still maintain its desirable characteristics of low permeability along with low plastic shrinkage and a high shear bond strength. Compressive strengths higher than 4,500 psi were of little interest, since higher strengths are not required for bridge deck overlays.

The objective of the field application was to assess the mixing, placing, consolidating, and finishing of the MSMC mixture as compared to our standard LMC. Monitoring the concrete mixing and placement in the field was accomplished by sampling from the trucks. Measurements of the properties of the fresh concrete were made and test specimens were cast that were returned and tested in the laboratory. Cost data were also analyzed to determine whatever material and labor savings might be realized with the MSMC over the conventional LMC.

### Scope

In addition to the selection of a mix design, the scope of this work was limited to the selection and overlaying of two urban bridge decks

TABLE I  
BRIDGE DECK OVERLAY CONCRETE MIX DESIGNS

Microsilica Modified Concrete (MSMC)

| Mix           | Entrained Air |            | Cement |            | Net $\frac{W}{C}$    |        | Net Mix Water |        | Net $\frac{W+Ad.W}{C}$ |                      | Silica Fume Admixture 46.8% solids |            | Fine Aggregate |      |        | FA/TA ratio, percent by Vol |                             |       | Coarse Aggregate |        |            | A-E Admix MBVR, fl oz |
|---------------|---------------|------------|--------|------------|----------------------|--------|---------------|--------|------------------------|----------------------|------------------------------------|------------|----------------|------|--------|-----------------------------|-----------------------------|-------|------------------|--------|------------|-----------------------|
|               | per-cent      | Vol, cu ft | Wt, lb | Vol, cu ft | ratio, percent by Wt | Wt, lb | Vol, cu ft    | Wt, lb | Vol, cu ft             | ratio, percent by Wt | Wt, lb                             | Vol, cu ft | Grade          | Type | Wt, lb | Vol, cu ft                  | FA/TA ratio, percent by Vol | Grade | Type             | Wt, lb | Vol, cu ft |                       |
| Initial E1&E2 | 5.5           | 1.49       | 658    | 3.36       | 24.7                 | 162.6  | 2.61          | 36.5   | 146                    | 1.75                 | 2NS nat.                           | 1534       | 9.42           | 53.0 | 26A LS | 1389                        | 8.37                        | 8.2   |                  |        |            |                       |
| Adj. E3       | 5.5           | 1.49       | 658    | 3.36       | 24.7                 | 162.6  | 2.61          | 36.5   | 146                    | 1.75                 | 2NS nat.                           | 1550       | 9.52           | 53.5 | 26A LS | 1373                        | 8.27                        | 8.2   |                  |        |            |                       |

Latex Modified Concrete (LMC)

| Mix | Entrained Air |            | Cement |            | Net $\frac{W}{C}$    |        | Net Mix Water |        | Net $\frac{W+Ad.W}{C}$ |                      | S-B Latex Admixture 48% solids |            | Fine Aggregate |      |              | FA/TA ratio, percent by Vol |                             |       | Coarse Aggregate |        |            | A-E Admix MBVR, fl oz |
|-----|---------------|------------|--------|------------|----------------------|--------|---------------|--------|------------------------|----------------------|--------------------------------|------------|----------------|------|--------------|-----------------------------|-----------------------------|-------|------------------|--------|------------|-----------------------|
|     | per-cent      | Vol, cu ft | Wt, lb | Vol, cu ft | ratio, percent by Wt | Wt, lb | Vol, cu ft    | Wt, lb | Vol, cu ft             | ratio, percent by Wt | Wt, lb                         | Vol, cu ft | Grade          | Type | Wt, lb       | Vol, cu ft                  | FA/TA ratio, percent by Vol | Grade | Type             | Wt, lb | Vol, cu ft |                       |
| L   | 5.0           | 1.35       | 658    | 3.36       | 17.5                 | 115.4  | 1.85          | 33.8   | 206                    | 3.28                 | 2NS nat.                       | 1490       | 9.15           | 53.3 | 26A cr. dol. | 1300                        | 8.01                        | —     |                  |        |            |                       |

with MSMC. The criteria used for the selection of the decks was that they carry commuter and light commercial traffic and be located in the vicinity of a modern central mix batch plant. The depth of the overlay was to be 2 in. and the finishing equipment was to be essentially the same as used for placing conventional LMC overlays.

## CONCRETE DESIGN

### Emsac-B Admixture

The material Emsac-B (now marketed by Elkim Chemicals, Inc. of Pittsburgh) is furnished as a slurry, which is described as containing 45 percent microsilica, 51 percent water, and 4 percent proprietary admixtures. Because of the high adsorption water requirements of the tiny microsilica particles, a great percentage of the "proprietary admixtures" consists of a high range water reducer; this tends to offset the extra water required by the microsilica and maintains the water/cement ratio in a normal range.

### Mix Design Development

Included in the literature supplied by Elkim Chemical were test results of developmental work conducted by a Toronto consulting firm. Their work showed that mixes containing 6 or 7 sacks of cement along with 5 or 10 percent microsilica produced permeability results rivaling the LMC mixes. However, the mix design as advanced by Elkim Chemicals for bridge deck overlays contained 7.5 sacks of cement and 230 lb of Emsac-B; this latter quantity equated to about 104 lb of microsilica or 14.6 percent of the weight of the cement.

Laboratory work began by preparing and testing the recommended mix as supplied by Elkim Chemical, but upon finding that it produced about 3 mils/in. initial plastic shrinkage, it was resolved to modify the design in an attempt to improve the shrinkage characteristics. Considering the Toronto consultants work, both 6 and 7 sack mixes were designed with 10 percent microsilica in hopes of improving the design by trading-off some of the superior compressive strength and permeability characteristics for an improvement in shrinkage. Being successful, the scope of this development work became limited to the testing and evaluation of these three mix designs. Hence, the mix design employed in this work was the 7-sack modification tested in the laboratory; it is shown in Table 1 along with the LMC control mix.

## EXPERIMENTAL BRIDGE OVERLAYS

### MSMC Overlay

The two Detroit bridges selected for application of the microsilica overlay were Frontenac Ave over I 94 (S12 of 82024), and Mt. Elliott Ave over I 94 (S10 of 82024).

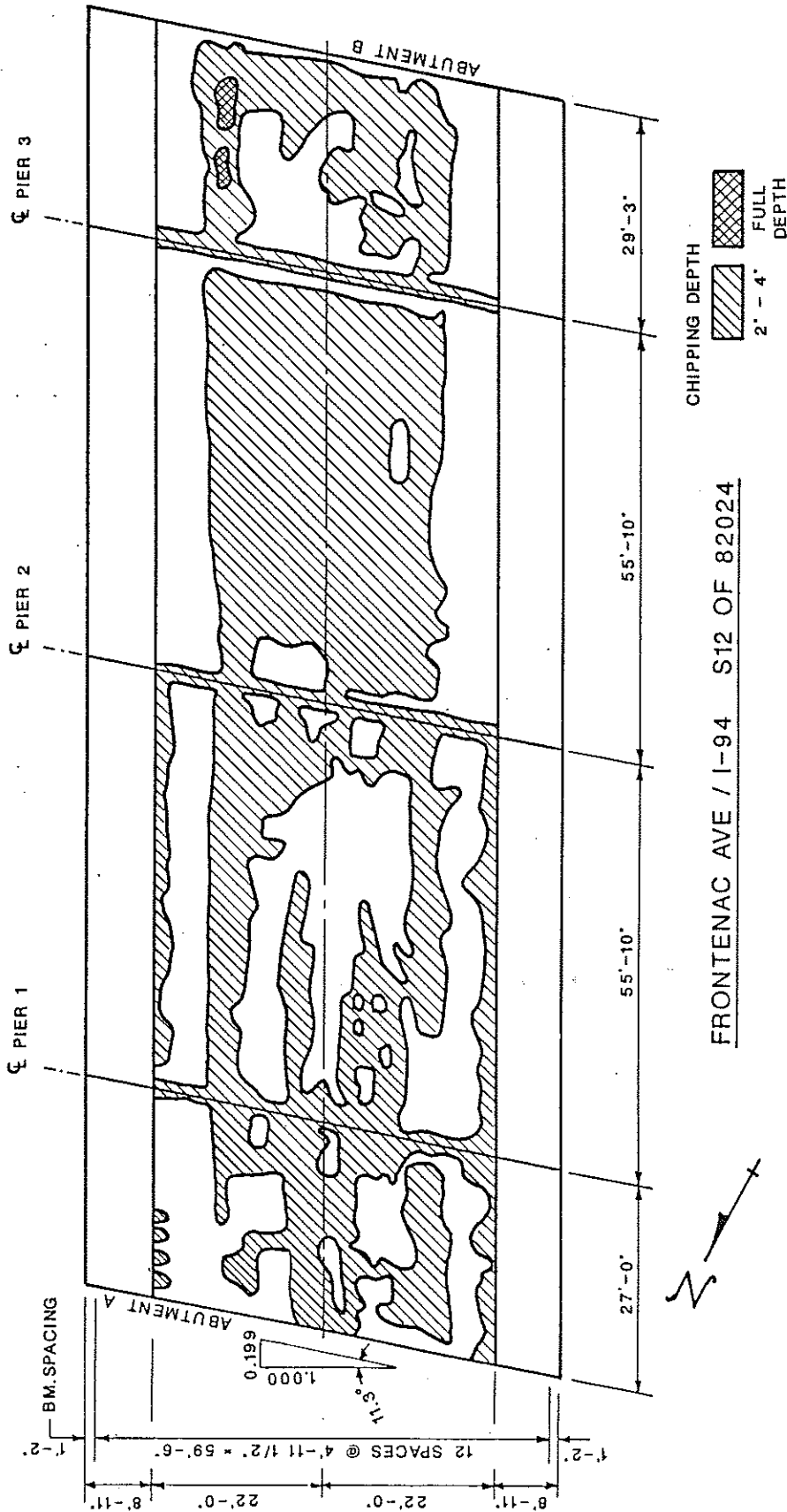


Figure 1. Areas of distressed concrete removal in substrate preparation.



The Frontenac Ave bridge has four spans and carries a low traffic volume which is mostly commuter and light commercial. This bridge was selected for monitoring because it carries light traffic and because it was closed to traffic during the construction of the overlay. The original deck showed low cover over the steel bars and was delaminated over large areas in all four spans, especially extensive in Span 3. Figure 1 is a scale diagram of the deck showing the locations of all chipped out areas. Because the original deck had construction joints and bar laps at 11 ft on either side of the bridge centerline, many of the badly corroded bars in the center section of heavily distressed Span 3 were completely freed; this allowed them to be removed and replaced with epoxy coated reinforcing bars.

The Mt. Elliott Ave bridge also has four spans, but carries a high traffic volume which includes the full range of light to heavy commercial vehicles. The contractor was required to maintain traffic on half of the bridge throughout the construction of the overlay. The deck repair of this bridge was not closely monitored by laboratory personnel.

#### Control LMC Overlay

The Detroit bridge selected for the control application of the latex modified concrete (LMC) overlay was Ferry Ave over I 75 (S20 of 82251). This bridge has five spans, carries light traffic, and was closed to traffic during the construction of the overlay. The original deck showed low cover over the steel bars, was moderately delaminated in Spans 1, 2, and 5, and lightly delaminated in Spans 3 and 4. Figure 2 is a scale diagram of the deck showing the locations of all chipped out areas.

## OVERLAY PLACEMENT

#### Batching Arrangements

The contractor delivered the concrete in 7 cu yd loads with transit-mix trucks, with about a 15-minute haul time, to the Frontenac Ave bridge. A 6,000-gal tank of microsilica Emsac-B was located at the plant. It was necessary to continuously agitate the product to keep it from gelling in the tank; it was pumped directly from the tank to the central mix drum with controls located in the batch house.

#### Construction Dates and Placement Details

The pouring of the overlay on the Frontenac bridge took place on June 6, and progressed from south to north with a single roller screed machine spanning the full deck width. Concretmobile mixers were used to produce the water-cement-sand bonding slurry which was broomed into the moistened substrate prior to two side-by-side transit-mix trucks discharging overlay concrete in front of the screeding machine. It was observed that extra hand finishing was required across Span 4 and into Span 3 before

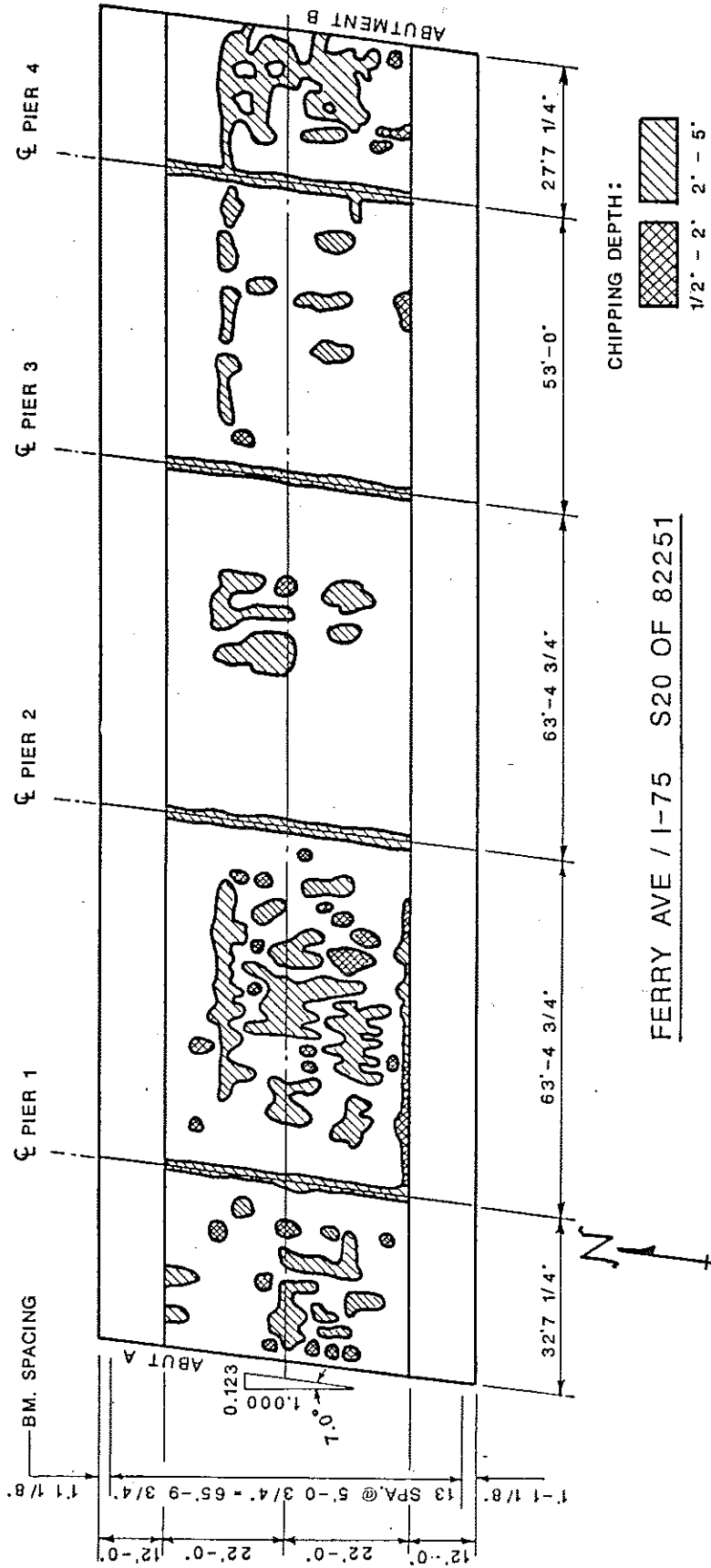


Figure 2. Areas of distressed concrete removal in substrate preparation.

wet burlap and polyethylene curing could be placed as fissures and open cracks were being left by the screed roller. Previous experience has shown that this is characteristic of the finishing of superplasticized concrete, but it was thought that an upward adjustment of the fine aggregate/total aggregate ratio might be helpful. The Research Laboratory engineer visited the plant and effected the change which is shown as the adjusted mix design in Table 1. The change had the effect of increasing the slump but none of the adjusted concrete went onto the deck until work had progressed to the middle of Span 2. The mix adjustment helped but did not completely solve the problem; however, the float pan pulled along behind the roller did a fairly good job of closing these fissures. On this bridge it was noticed that the pan vibrator, which was suspended in front of the screed roller, was ineffective in consolidating the concrete. The Department's bridge staff technician requested that it be removed and the concrete consolidated with a probe vibrator dragged through the concrete in front of the screed roller. Moist curing was maintained for four days in compliance with the special provision.

On the Mt. Elliott bridge, the east half of the deck was poured on June 11 from south to north with the adjusted mix design shown in Table 1. When work had progressed to about 15 ft from the north end it began raining and rained so hard that mortar was washed off of the concrete that had just been placed. The concrete further back had already been covered and was unaffected. The rain also washed the bonding slurry off of the uncovered substrate at the north end. After the rain stopped, the water was blown out of the chipped out areas and because the mobile mixers had already left the area, the assistant project engineer requested that the substrate be reprimed by brooming overlay concrete into the surface in the same manner as is done with LMC. The screeding machine was then backed up over the rain washed area, fresh concrete placed, and the surface refinished.

After the traffic was switched over and the chipping completed, the west half of the deck was overlaid on June 26.

After the Ferry Ave bridge was chipped out, placement of the LMC overlay, which is serving as the control for this work, began on May 27 from the west end of the bridge. By mid-morning, when work had progressed into Span 2, it began to rain; a header was placed, and work stopped. The remainder of the deck was overlaid the next day. Two mobile concrete mixers, positioned side-by-side, discharged immediately in front of the screed machine which spanned the full deck width. Wet burlap was placed on the finished concrete and moist curing maintained for 48 hours.

Joints for all three subject bridges were selected to accommodate the expansion requirements of their simple spans: those accommodating the expansion of one span were reconstructed with joint filler material and the hardened concrete sawed out for preformed neoprene; those accommodating the expansion of two spans were reconstructed with a prefabri-

cated proprietary joint that was installed with patching concrete to the finished elevation prior to the overlayment.

MSMC vs. LMC Cost Comparison

The same contractor did the overlay work on all three of the subject bridges. The material cost for the experimental application of the MSMC was bid at \$250/cu yd while the LMC was bid at \$290. Under routine construction conditions, the price of the MSMC would probably be reduced further to a level under \$200/cu yd. The changes that would have the effect of lowering the prices might be: 1) the increased competition afforded by additional suppliers, 2) the delivery in bulk quantities to ready mix plants who installed facilities for handling microsilica, and 3) greater familiarity with the product by the contractor.

SAMPLED FRESH CONCRETE

Test Specimens Cast

In addition to the fresh concrete measurements, shown in Table 2, of slump, entrained air, temperature, unit weight, and age at time of sampling, test specimens were cast of both the MSMC and LMC to yield information on the properties of the hardened concrete.

TABLE 2  
FRESH CONCRETE MIX DATA

| Mix                                  | Pour Date | Mix Details |            |                         | Measurements |                    |         |                |
|--------------------------------------|-----------|-------------|------------|-------------------------|--------------|--------------------|---------|----------------|
|                                      |           | Vol, cu yd  | Mixer Type | Mix Plus Haul Time, min | Slump, in.   | Entr. Air, percent | Temp, F | Unit Wt, cu ft |
| Microsilica Modified concrete (MSMC) |           |             |            |                         |              |                    |         |                |
| E1                                   | 6-6-86    | 7.0         | Central    | 30                      | 3.5          | 4.0                | 73      | 147            |
| E2                                   | 6-6-86    | 7.0         | Central    | 30                      | 4.8          | 5.0                | 76      | 143            |
| E3                                   | 6-6-86    | 7.0         | Central    | 30                      | 6.2          | 5.1                | 80      | 145            |
| Latex Modified Concrete (LMC)        |           |             |            |                         |              |                    |         |                |
| L                                    | 5-28-86   | N/A         | Mobile     | 5                       | 4.3          | 7.4                | 80      | 142            |

The following specimens were moist cured continuously and tested in groups of three at the stated time intervals.

- 1) Nine 4 by 8-in. cylinders - tested in compression at 3, 7, and 28 days.

2) Six 4 by 4 by 16-in. beams - tested in flexure at 7 and 28 days.

The following specimens were moist cured for four days, allowed to air dry through 28 days, and then tested as described.

1) Three 3 by 3 by 15-in. shrinkage prisms - measured at 1 and 28 days and at 6 months.

2) Three 4 by 8-in. Rapid Chloride Permeability Cylinders - tested in accordance with AASHTO T 277-831.

3) Three 9 by 12 by 2.5-in. salt penetration slabs - had dikes cast on them the second day and a 3 percent NaCl solution ponded for 90 days within those dikes beginning at 28 days.

4) Three 3 by 4 by 16-in. freeze-thaw (F-T) beams - were tested through 336 cycles in rapid F-T testing in accordance with Procedure B of ASTM C666.

5) Three 3 by 6-in. initial plastic shrinkage cylinders - were measured initially and at 24 hours in accordance with the Corps of Engineers Standard CRD-C621-80.

### Test Results

Test values in Table 3 indicate that the performance of both materials compared with conventional bridge deck concrete was excellent. The MSMC mix excelled in strength and rapid chloride permeability while the latex excelled in consolidation and the shrinkage of the hardened concrete. The initial plastic shrinkage of both materials was equal at the very low value of 0.5 mils/in.; good quality bridge deck concrete normally sustains around 3.0 mils/in.

## POST-CONSTRUCTION EVALUATION

### Cores

Figures 3 and 4 in addition to showing where the fresh concrete was sampled also show the location where cores were taken in deep chipped areas. From the recovered cores, which exceeded 3.5 in. in depth, a 2-in. section was cut from the center and tested for rapid chloride permeability. These results are shown below:

| <u>Core</u> | <u>MSMC</u>  | <u>LMC</u>     |
|-------------|--------------|----------------|
| A           | 213 coulombs | 1,051 coulombs |
| B           | 487 coulombs | 851 coulombs   |
| C           | 228 coulombs | 1,004 coulombs |

Core B from the MSMC material, though not intentionally drilled at a cracked location was discovered to have a full-depth incipient hairline

TABLE 3  
CONCRETE SPECIMEN TEST RESULTS

| Mix                                  | Pour Date | Strength, psi |        |             | Consolidation    |                             | Cl <sup>-</sup> Penetration           |   | Composite Modulus of Elasticity x 10 <sup>6</sup> , psi | Shrinkage (mils/in.) |                |            |       |
|--------------------------------------|-----------|---------------|--------|-------------|------------------|-----------------------------|---------------------------------------|---|---|----------------------|----------------|------------|-------|
|                                      |           | Flexural      |        | Compression | Dry Bulk Sp. Gr. | Permeability voids, percent | Rapid Chloride Permeability, coulombs | 90-Day Ponding w/3% NaCl, Cl <sup>-</sup> cu yd |   | Initial              | 28 Day Dry Out | 6 Mo. Max. |       |
|                                      |           | 7 Day         | 28 Day |             |                  |                             |                                       |   |   |                      |                |            | 3 Day |
| E1                                   | 6-6-86    | 1180          | 1205   | 4800        | 6240             | 7610                        | 2.30                                  | 7.9   | 261   | 0.0<br>(1.5")        | 0.35           | 0.53       |       |
| E2                                   | 6-6-86    | 1160          | 1200   | 4770        | 6480             | 7770                        | 2.27                                  | 8.6   | 302   | 0.0<br>(1.5")        | 0.35           | 0.55       |       |
| E3                                   | 6-6-86    | 1200          | 1230   | 4660        | 6640             | 8140                        | 2.29                                  | 7.2   | 216   | 0.0<br>(1.5")        | 0.5            | 0.32       |       |
| Microsilica Modified Concrete (MSMC) |           |               |        |             |                  |                             |                                       |   |   |                      |                |            |       |
| Latex Modified Concrete (LMC)        |           |               |        |             |                  |                             |                                       |   |   |                      |                |            |       |
| L                                    | 5-28-86   | 700           | 930    | 3450        | 4190             | 5360                        | 2.28                                  | 3.2   | 749   | 0.3<br>(1.5")        | 0.5            | 0.20       | 0.41  |

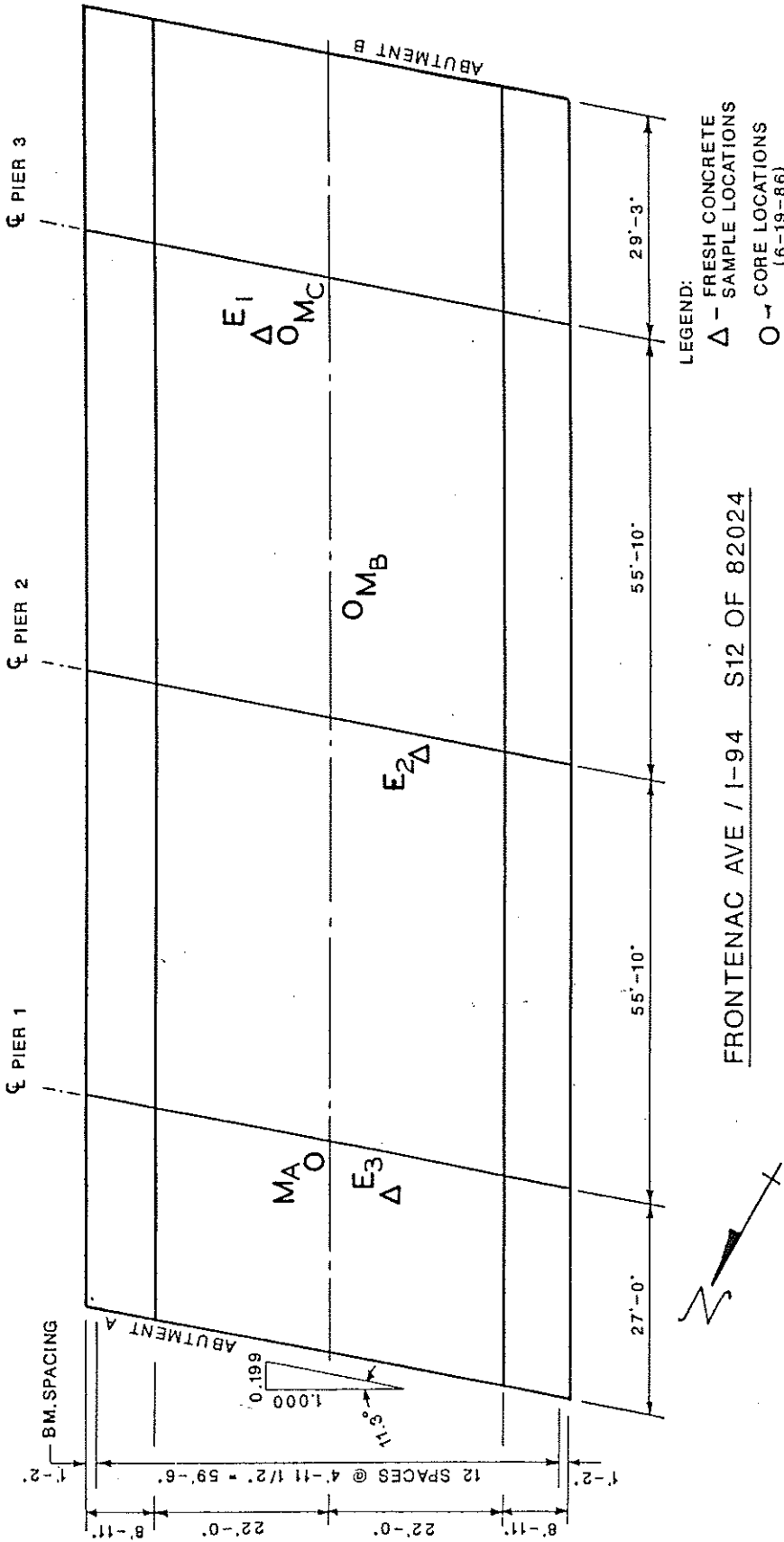


Figure 3. Locations where fresh concrete (MSMC) was sampled on pour date and cores were cut later.





fracture; however, this had a minimal effect on its performance. Since this crack passed through and not around coarse aggregate particles it was realized that it was not caused by plastic shrinkage.

#### Initial Deck Condition Survey

In mid-July 1986, reports were received from the Project Engineer's office that shrinkage cracks had appeared in the decks of both the Frontenac and Mt. Elliott bridges. Immediately following a rain on July 25, crack patterns were plotted on Span 4 and the south half of Span 3 of the Frontenac bridge before the moisture source dried up and the cracks were no longer visible. Since the crack patterns were roughly rectangular instead of hexagonal, it was surmised that their formation was influenced by the pattern of the reinforcing steel and possibly by traffic-induced stresses, since flexural cracks are normally transverse. The same type cracking was typical of all spans. The general area and close up views in Figure 5 show the appearance of these cracks in Span 1; their width was measured to vary between 0.004 and 0.008 in. Later, cores cut through these cracks revealed their prominence to vary with depth, but all extended full depth through the overlay and a short distance into the substrate. No evidence of distress was noted in the LMC of the Ferry Ave bridge.

#### Initial Corrosion Cell Survey

This survey was conducted in accordance with ASTM C876, "Half Cell Potentials of Reinforcing Steel in Concrete," and was limited to the entire southbound traffic lane of the Frontenac Ave bridge and the eastbound traffic lane over Spans 1, 2, and 3 on the Ferry Ave bridge. The equipment was grounded on the lower flange of the fascia beam. Readings were taken at 5-ft intervals over a grid system where transverse lines were parallel to the substructure reference lines and with longitudinal lines 2, 7, and 12-ft from the curblines. Results are plotted on the bridge diagrams and are shown in Figures 6 and 7 as an equipotential contour map. Figure 7 shows several locations on the surveyed area of the Ferry Ave bridge that apparently are sustaining low level corrosion of the reinforcing bars. Reading locations were not prewetted prior to taking the measurements.

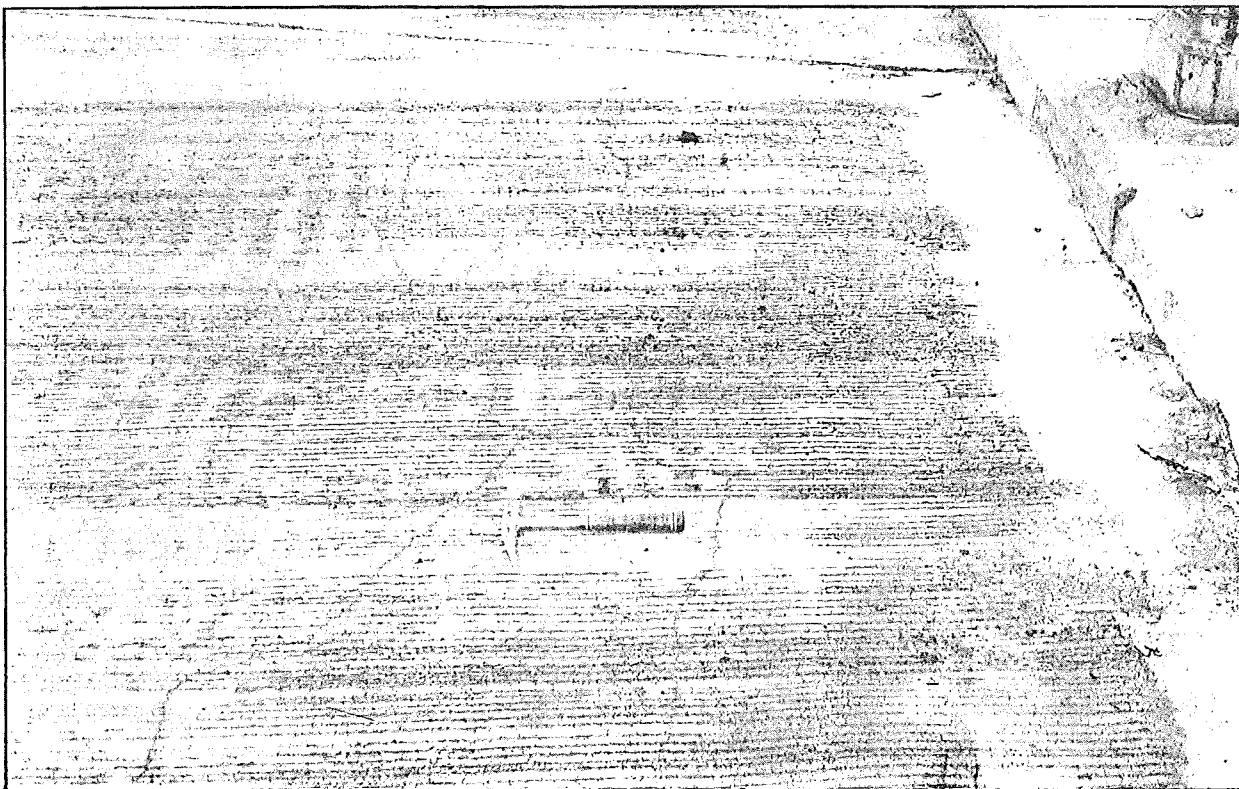


Figure 5. General area and close up views of shrinkage cracks in Span 1 of the bridge that carries Frontenac Ave over I 94 in Detroit.

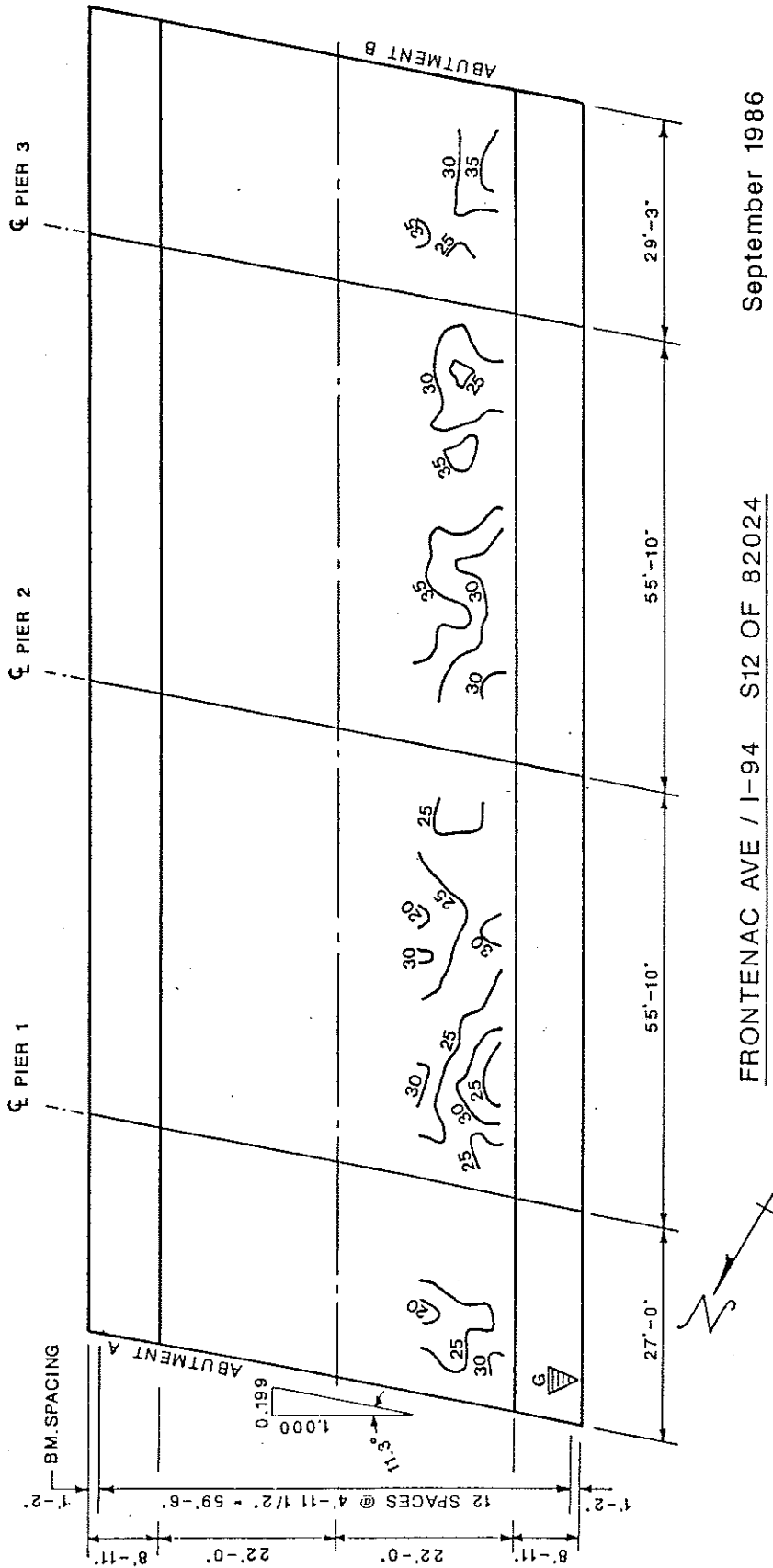
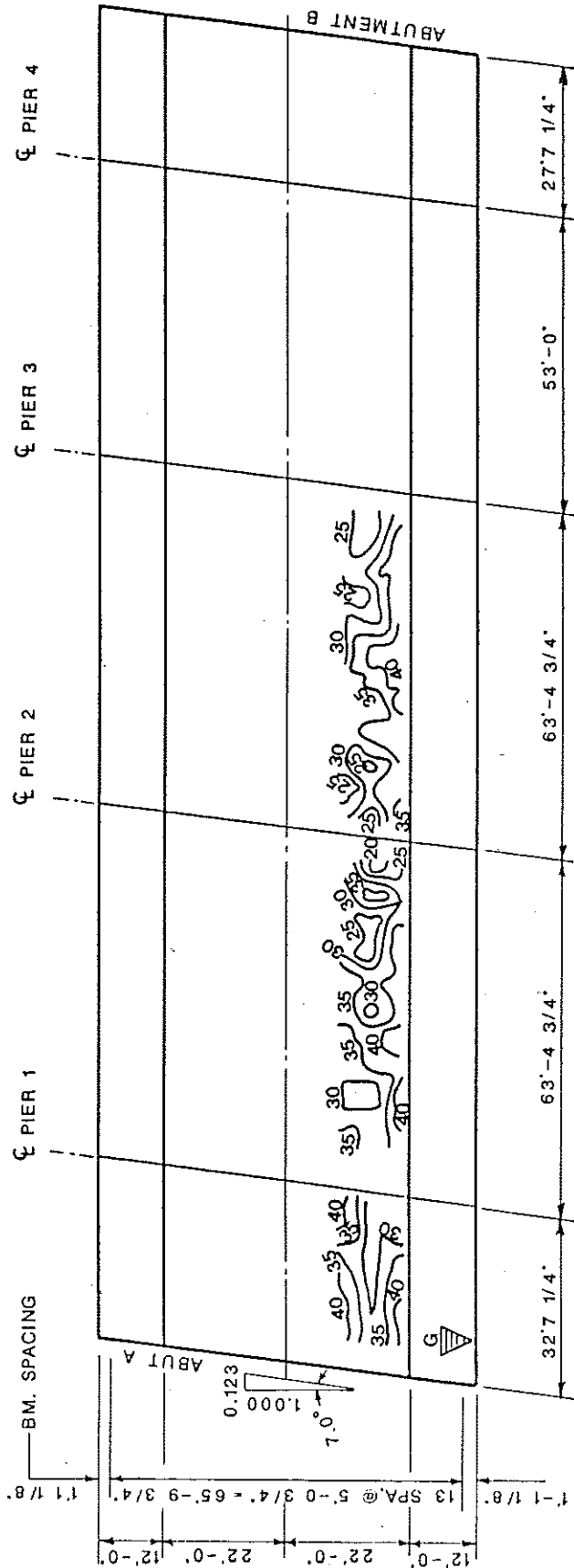


Figure 6. Initial half cell corrosion survey shown as an Equipotential Contour Map. All values are negative and are in units equal to centivolts. Active corrosion is probably occurring where numerical values are greater than 35 centivolts.



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Figure 7. Initial half cell corrosion survey shown as an Equipotential Contour Map. All values are negative and are in units equal to centivolts. Active corrosion is probably occurring where numerical values exceed 35 centivolts.

## CONCLUSIONS

Although the initial test results of the MSMC indicate that it possesses excellent properties in strength, initial plastic shrinkage, and permeability, it still falls short of the LMC in the critical properties of post-set shrinkage and resilience; the latter being indicated by the compressive modulus of elasticity.

The crack observed in core MB revealed it to be very fine and to run full-depth through the overlay. It will be noted from the test results in Table 3 that the average hardened concrete shrinkage of the MSMC is 70 percent greater than that of the LMC while its compressive modulus of elasticity is 24 percent greater; this indicates that it not only shrinks more, but that it is also stiffer. Unpublished data from a previous study (High Density Concrete Deck with Superplasticizer; S10 of 54014) indicates that this greater shrinkage of hardened concrete is typical of superplasticized concrete. Apparently the mechanism that imparts the increased fluidity to the plastic concrete also results in greater shrinkage of the hardened concrete.

With respect to permeability, the quality of the MSMC exceeds that of the LMC, but its development of shrinkage cracks could present future problems. These cracks will provide avenues of surface water access to the substrate and thus detract from the function of the overlay. However, the outstanding reduction in permeation that is obtainable with microsilica should provide sufficient incentive for further laboratory experimentation and development work to minimize or eliminate the shrinkage problem from future MSMC overlays. It appears that lower dosages of the microsilica/superplasticizer may provide adequately low permeability with less shrinkage. Additional laboratory work along these lines will be done.

An interim report describing the first year's performance of this material will be written following the 1987 construction season.