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ALTERNATIVE SEALANTS FOR BRIDGE DECKS

Study SD2001-04-D
Final Report

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DISCLAIMER

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16. Abstract

This project investigated potential concrete bridge deck crack and surface sealers, and their optimum application timing. The purpose of this project was to determine if there were better products than what SDDOT was using (i.e. – linseed oil surface sealer and epoxy crack sealer) that can be applied by SDDOT maintenance personnel.

The objectives and tasks for this project were accomplished by gathering and evaluating agency, field, laboratory, and literature data. A major portion of this research project focused on determining the optimum timing for treatment application.

The results indicate the following:

1. SDDOT should discontinue use of linseed oil as a penetrating sealer.
2. SDDOT should adopt penetrating sealers such as silanes/siloxanes/siliconates for surface sealing.
3. SDDOT should continue to use crack sealers such as reactive methacrylates, modified polyurethanes, and epoxies with low viscosity (i.e. - = 15 cp)

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1.0 EXECUTIVE SUMMARY

Early age cracking of new and overlaid Portland Cement Concrete (PCC) bridge decks is widely regarded as a long-term durability and maintenance problem because many of these cracks run through the deck and allow the rapid ingress of moisture and chloride ions into the deck and onto the bridge superstructure and substructure. National Cooperative Highway Research Program (NCHRP) *Report 380 – Transverse Cracking in Newly Constructed Bridge Decks* developed guidelines for reducing transverse deck cracking on new bridge decks, and suggested possible crack and deck sealing strategies. Research is underway looking into the use of Class F fly ash, silica fume, and ground granulated blast furnace slag (GGBFS) as mineral admixtures in structural concrete to reduce concrete permeability and early age cracking.

Currently, SDDOT uses linseed oil/mineral spirit treatments as a penetrating deck sealer on older decks and applies epoxy treatments to random cracking, especially on overlays, where the incidence of cracking is light to moderate. For severe cracking problems SDDOT employs a thin epoxy chip seal it developed for sealing entire decks, which still allows moisture vapor transmission. SDDOT has sufficient tools for sealing cracks on decks, but lacks guidelines as to which particular treatment strategy is appropriate for a given set of circumstances. Numerous product descriptions and studies are available regarding PCC crack/surface treatments. However, as stated in the Request-For-Proposal (RFP), there are few, if any, guidelines describing:

1) When to apply,
2) What to apply, and
3) How to apply the treatments.

The objectives and tasks for this project were accomplished by gathering and evaluating agency, field, laboratory, and literature data. A major portion of this research project focused on determining the optimum timing for treatment application.

FINDINGS & CONCLUSIONS

The following findings and conclusions are presented for this project.

1. It appears that bridge deck cracking is occurring on most of SDDOT's bridge decks.
2. Application of crack and deck sealing treatments after chloride ingress is not the approach most beneficial to extending bridge deck service lives. However, it is acknowledged that slowing additional chloride and water ingress will provide additional life to older bridges. Treating older bridge decks will just not be as effective as treating prior to chloride exposure.
3. Crack and deck sealing products with viscosities less than 15 cp appear to achieve good penetration (i.e. - = 0.10 in.) into cracks and deck surface, respectively.
4. Linseed oil should not be classified or used as a penetrating sealer because its molecular size is bigger than the size of the concrete pore openings. Therefore, it functions primarily as a temporary surface membrane sealer.

IMPLEMENTATION RECOMMENDATIONS

The following implementation recommendations are presented for this project.

1. SDDOT's bridge deck crack and surface sealing activities should be conducted within 3 to 6 months after construction and repeated every 5 years. Existing bridge decks should be treated to minimize further chloride and water ingress, thus reducing corrosion potential.
2. SDDOT should replace linseed oil with penetrating sealers (i.e. – silanes, siloxanes, and siliconates) that incorporate alkyl groups larger than methoxy and ethoxy groups as their concrete bridge deck surface sealing materials.
3. SDDOT should use concrete crack sealing materials (i.e. – Methyl Metacrylate (MMA), Modified Polyurethane (MPU), Epoxy, etc.) with viscosities = 15 cp. If crack widths are = 0.040 in., epoxy should not be used because their extensibility properties are generally less than that of MMA and MPU.

2.0 PROBLEM DESCRIPTION

Early age cracking of new and overlaid Portland Cement Concrete (PCC) bridge decks is widely regarded as a long-term durability and maintenance problem because many of these cracks run through the deck and allow the rapid ingress of moisture and chloride ions into the deck and onto the bridge superstructure and substructure. National Cooperative Highway Research Program (NCHRP) *Report 380 – Transverse Cracking in Newly Constructed Bridge Decks* developed guidelines for reducing transverse deck cracking on new bridge decks, and suggested possible crack and deck sealing strategies. Research is underway looking into the use of Class F fly ash, silica fume, and ground granulated blast furnace slag (GGBFS) as mineral admixtures in structural concrete to reduce concrete permeability and early age cracking.

Many agencies, such as the South Dakota Department of Transportation (SDDOT), employ the use of epoxy-coated reinforcing steel (rebar) to combat the corrosion process. However, there are still concerns regarding the unabated ingress of chloride-bearing water into bridge decks, such as the reduction of freeze-thaw durability and crystalline growth pressure development. Other popular measures to minimize corrosion activity are to apply some type of surface treatment (i.e. – penetrating sealer, waterproof coating/membrane, corrosion inhibitors, etc.) and/or perform crack sealing activities to prevent chloride-bearing water from contacting the rebar.

Currently, SDDOT uses linseed oil/mineral spirit treatments as a penetrating deck sealer on older decks and applies epoxy treatments to random cracking, especially on overlays, where the incidence of cracking is light to moderate. For severe cracking problems SDDOT employs a thin epoxy chip seal it developed for sealing entire decks, which still allows moisture vapor transmission. SDDOT has sufficient tools for sealing cracks on decks, but lacks guidelines as to which particular treatment strategy is appropriate for a given set of circumstances. Numerous product descriptions and studies are available regarding PCC crack/surface treatments. However, as stated in the Request-For-Proposal (RFP), there are few, if any, guidelines describing:

4) When to apply,
5) What to apply, and
6) How to apply the treatments.

This research project addresses these questions as well as provides optimum timing strategies for maintaining serviceability and maximizing deck life.

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3.0 OBJECTIVES

The technical panel charged with oversight of this research project developed a problem statement that summarized issues that the Department has with bridge deck maintenance and long-term performance. To address these issues, the Technical Panel defined the following objectives as minimum requirements at the conclusion of this project. A brief discussion after the objectives summarizes how they were accomplished in this project.

1. ***Outline a series of different treatment strategies to reduce water ingress into bridge decks due to existing cracking.***
2. ***Develop recommendations for different systems capable of providing effective sealing of bridge decks under various conditions.***
3. ***Provide bridge deck crack sealing guidelines based on individual bridge deck characteristics.***

Potential treatment strategies were evaluated during the literature review and agency survey (Tasks 1 and 2, respectively). Factors considered during this process included experience; product information; survey responses; and conversations with agency officials, industry consultants, and technical service representatives. Evaluation of these factors revealed that there is no clear consensus on when and how to seal bridge deck cracks, or what material(s) to use. However, before selecting crack treatments, determining crack criteria must be performed first. For decks subject to deicing agents, typical acceptable crack widths ranged from 0.001 to 0.125 in. After evaluating all the information, it was considered reasonable to use the American Concrete Institute (ACI) recommended tolerable crack width for structures exposed to deicing chemicals of 0.007 in. (ACI 224) as a trigger for planned maintenance activities, which most of the deck cracks observed in this project exceeded. This is a realistic tolerance level considering other investigators have found water leakage through cracks as narrow as 0.002 in. (1). Given this information and the widely recognized increase of early age cracking on bridge decks, it is reasonable to recommend crack sealing activities approximately three to six months after construction completion. The most common and successful materials used for crack sealing include epoxies and high molecular weight methacrylates. For this project, reactive methyl methacrylate (MMA), modified polyurethane (MPU), and two-component epoxy sealers were used in field trials. A silicone joint sealer was also installed in two of the three subject bridge decks. The MMA and epoxy had similar crack penetration depths (˜ 0.10 in.) while the MPU penetration was a little less (˜ 0.06 in.). The silicone joint seal used to seal cracks on 2 of the 3 bridge decks appears to be holding up to traffic and snow plows in the shallow reservoirs ground out by the bridge maintenance crew. Although the silicone application may perform well for a long time period, it is extremely labor and time intensive, and aesthetically unpleasing, and is therefore not recommended for bridge deck maintenance.

Sealing deck surfaces appears to be an even more daunting goal than sealing deck cracks due to the numerous systems in the market. However, the following conditions were placed by SDDOT that narrowed the field of deck surface sealing systems:

- The system must be easily applied by SDDOT maintenance personnel.
- The materials should be relatively low cost.
- The materials should have a proven performance history.

Strict adherence to these conditions presents penetrating sealers (i.e. – silanes, siloxanes, and siliconates) as the materials of choice. They can be installed with a common low-pressure garden sprayer, although production field spraying equipment will improve installation time and application uniformity. At a price range of $0.16 to $0.40 per square foot with coverage rates ranging from 150 to 175 square feet per gallon, it is a relatively low cost preventive maintenance material. And finally, the water and chloride repellent performance of these materials are recognized and well documented (1 – 4).

Initially, it was assumed that bridge deck crack and surface sealing guidelines would be developed that take into account the various protective measures employed by SDDOT (i.e. – low slump, polymer modified, silica fume modified concretes; epoxy-coated rebar; etc.). This makes a certain amount of sense because these protective measures do slow water and chloride ingress, and delay the onset of corrosion once threshold levels are achieved. However, it is very important to note that sealing the cracks and deck surface after water and chloride threshold levels are achieved does not immediately, if ever, mitigate the corrosion process. Therefore, delaying the achievement of these water and chloride corrosion thresholds as long as possible is the most cost-effective sealing guideline. In addition, the more aggressive deicing chemicals that are being used (i.e. – sodium chloride, calcium magnesium acetate, magnesium chloride, calcium chloride, and potassium acetate) have a high probability of being detrimental to the concrete matrix. Therefore, early treatment (i.e. – approximately 3 to 6 months after construction, and every 5 years afterward) is recommended to minimize the intrusion of deleterious materials. Five year application intervals are recommended because Taber abrasion test results (2) show that water penetration resistance is good for about 7 years of simulated traffic abrasion. Reducing the interval to 5 years is to take into account application, concrete permeability, and traffic variability.

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4.0 TASK DESCRIPTION

The Technical Panel defined the following tasks as minimum requirements at the conclusion of this project to address the project objectives described in Chapter 3. A discussion after each task summarizes the results.

1. Perform a literature search on crack sealing methods for bridge decks.

Before reviewing the various products that are available for sealing concrete bridge decks, an understanding of performance expectations is required first. Minimizing rebar exposure to water and chlorides by sealing surface cracks is an easy concept to embrace since it is well-known that rebar corrosion is likely in the presence of these components. What is not well understood is the crack width threshold where treatment of any kind is required. The American Concrete Institute (ACI) defines cracking severity in ACI 201 as:

- Fine < 0.04 in.
- Medium 0.04 – to– 0.08 in.
- Wide > 0.08 in.

In ACI 224, the tolerable crack width for structures exposed to deicing chemicals is reported to be 0.007 in., which is six times smaller than the "fine" crack defined in ACI 201. Survey results from this and another project (1) identify typical acceptable crack widths to range from 0.001 to 0.125 in. It is obvious that there is a wide range of opinions regarding tolerable crack widths. For the purpose of evaluating crack and surface sealers in this study, the ACI 201 crack severity definitions will be used.

Although sealing surface opening cracks was the impetus for this project, it is widely acknowledged that deterioration-inducing contaminants also penetrate through the concrete capillary pore structure. The degree of surface permeability is related in large part to the amount of water that migrates to the exposed surfaces (i.e. – bleed water). Therefore, any measures used to reduce water migration to the surface will also reduce the surface permeability [i.e. – low water-to-cementitious (w/c) ratios, moist curing, etc.]. This is one of the reasons why many governing agencies and consultants emphasize low w/c ratios – to reduce capillary porosity. Unfortunately, certain modern construction practices can offset the benefit of low w/c ratios – specifically, curing. It is well known that wet curing (i.e. –

fogging, ponding, wet burlap, etc.) is one of the most effective construction practices for reducing, or eliminating, surface moisture loss, and drying shrinkage – major causes of early-age cracking and other distress. However, project labor and time allotments discourage the regular practice of wet curing. Therefore, the industry developed and promoted the use of spray-applied curing compounds/membranes to reduce, not eliminate, the amount of moisture loss at the surface. Consequently, the degree of surface capillary porosity is somewhere between concrete that was moist cured and concrete that was air cured.

Many different crack and deck sealers were found during the literature search and review, and the agency survey conducted under Task 2. Since it was desired to use existing SDDOT maintenance personnel and equipment to apply these products, membrane/overlay type deck sealers were not included because specialized equipment and training are required, and because of potential installation and durability problems.

Crack Sealers

For crack sealers, high molecular weight methacrylate (HMWM) is cited as demonstrating the best performance with respect to crack penetration, bridging, and sealing (1,3,4). HMWM is a three-component system [monomer resin, cumene peroxide (initiator), and cobalt (promoter)] that requires extra precaution during mixing because a violent reaction may occur if the initiator and promoter are mixed first or improperly. To avoid this problem, some product manufacturers started mixing the promoter directly into the resin before shipping so that field personnel only had to add one component – the initiator. The problem with this solution is that it reduces the shelf life of the product because of slow polymerization. For a product that starts out with a viscosity of 5 – 15 centipoises (cp), it has been reported that after 3 – 4 months the viscosity could be as high as 1,000 – 1,500 cp, resulting in a decrease of the product's crack penetrating capability.

One alternative developed by producers is reactive methyl methacrylate (MMA) catalyzed by a 50% dibenzoyl peroxide powder (BPO/hardener). This two-component crack sealer possesses similar performance characteristics to HMWM – without the volatility potential. Other sealing materials that exhibit good performance are epoxy, modified polyurethane

(MPU), and urethane crack sealers. These sealers exhibit flow characteristics similar to the methacrylates but are reported to have superior extensibility characteristics.

Epoxy product hazards include skin irritation, dermatitis, and other allergic responses due to prolonged exposure. Cornea damage may occur with eye contact. Many silicon-based crack/joint sealing products release acetic acid (vinegar) during curing – an irritant to skin, eyes, and respiratory tissues. With all material types, make sure area is adequately ventilated.

Surface Sealers

For this project, surface sealers were limited to those products that could be relatively easily spray, squeegee, brush, or roller applied to the bridge deck. From an economic and performance standpoint, it was desired to use SDDOT maintenance personnel instead of contractors to install the products. Therefore, membrane-type products that require a protective overlay/wear course were not evaluated.

A number of manufacturers claim their products penetrate the surface of cementitious substrates (i.e. – penetrating sealers) to seal the pore structure. The linseed oil used by SDDOT is touted as a penetrating sealer, but its molecular size and viscosity make it more of a membrane sealer rather than a penetrating sealer. True penetrating sealers are produced in both water-based and volatile organic compound (VOC) releasing formulations. The surface sealers reportedly react in two fashions. One group (silanes/siloxanes/siliconates) "wets" the surface and limits the penetration of chlorides and water into the concrete. The second group (silicates) reacts chemically with concrete components and forms precipitates to seal the pores at or below the surface of the concrete. This second group of products also claims to improve freeze/thaw damage resistance, and reduce efflorescence and dusting.

The Nevada Department of Transportation (NDOT) still references the use of linseed oil for sealing roadways, but they cited silanes as exhibiting the greatest degree of concrete permeability reduction of products they have used. Other suppliers and users also report that silanes are the best overall penetrating surface sealer for the following reasons

- Low viscosity (10 – 50 cps)
- Low molecular size (2 – 4 x 10^{-5} in.) –versus– concrete pore size (5 – 50 x 10^{-5} in.)

– Resistance to alkaline environments – depending on chemistry

Silanes and siloxanes have reportedly achieved up to a quarter of an inch penetration into concrete surfaces – depending on their chemistry, and concrete quality, porosity, and moisture content. Siloxanes have larger molecular sizes that may reduce their concrete penetrating capability in comparison to silanes. However, after penetrating into the concrete and "wetting" the pore structure surfaces, both materials polymerize in the presence of moisture and bond to silica-containing materials to reduce the surface tension of the substrate concrete [i.e. – if the substrate surface tension is less than water, it will be water-repellant (2)] and reduce the moisture and chloride penetration that accelerates concrete and rebar deterioration. There are indications that silanes and siloxanes may be effective at waterproofing cracks as large as 0.010 in. (1-3). It is important to note that all silanes and siloxanes are not created equal. Those products that have larger molecular weight alkyl groups (i.e. – iso-butyl and n-octyl groups versus methyl and ethyl groups) will exhibit better water and chloride repellency, and better stability in an alkaline environment (2).

Most of the products described in this section have a pH above 7 and are considered alkaline in nature and are an irritant to skin and eyes. Safe handing of all these products would minimally require eyeglasses with safety shields or goggles. An eyewash station should also be provided. Skin protection requires rubber or neoprene gloves, an apron, and full-length shirt and pants. Most of the products need to be protected from freezing because they contain water. Some products do have volatile components and need to be kept away from open flames or other ignition sources.

2. Conduct a survey of northern tier states and Canadian provinces with respect to current bridge deck crack sealing strategies.

Forty (40) states and Canadian provinces were sent surveys regarding their crack and deck sealing practices. Of these agencies, 25 responded for this project. Attempts were made to contact the non-respondents by telephone to get their information. The survey did not reveal any consensus with respect to bridge deck crack sealing strategies, but it did contain general tendencies toward the use of the crack and deck sealing materials used in this project (See Table 1).

Table 1 – Agency Survey Summary

#1	Which of the following cracking types do your bridge decks experience?			
	Transverse	=	19	(76%)
	Random	=	20	(80%)
	Other	=	8	(32%)
#2	Does your agency consider bridge deck cracking an adverse problem?			
	Yes	=	20	(80%)
	No	=	3	(12%)
	Other	=	2	(8%)
#3	Does your agency have a bridge deck maintenance program?			
	Yes	=	20	(80%)
	No	=	6	(24%)
	Other	=	1	(4%)
#4	What deicing technology do you use?			
	NaCl	=	22	(88%)
	CaCl	=	11	(44%)
	MgCl	=	11	(44%)
	Other	=	3	(12%)
	N/A	=	0	(0%)
#5	Do you require epoxy-coated rebar in your bridge deck design specifications?			
	Yes	=	21	(84%)
	No	=	4	(16%)
	Other	=	0	(0%)
#6	What methods of bridge deck failure detection does your agency use?			
	Sounding	=	21	(84%)
	Coring	=	19	(76%)
	Non-Destructive	=	9	(36%)
	Visual	=	22	(88%)
	Other	=	3	(12%)
#7	Does your agency have a policy for sealing cracks on bridge decks?			
	Methacrylate	=	6	(24%)
	Epoxy	=	6	(24%)
	Polyesters	=	0	(0%)
	No	=	15	(60%)
	Yes for AC Sealant	=	1	(4%)

Table 1 (Continued) – Agency Survey Summary

#8a	What is your criteria to begin surface crack repair?			
	1/16" or less	=	5	(20%)
	1/8" or less	=	4	(16%)
	Other	=	5	(20%)
	N/A	=	11	(44%)
	Don't for PCC	=	1	(4%)
	No Policy	=	1	(4%)
	Crack width: 1/16" or less, 1/8" or less, Other			
#8b	Extent over bridge deck surface: Low, Medium, High			
	Low	=	6	(24%)
	Medium	=	3	(12%)
	High	=	3	(12%)
	N/A	=	14	(56%)
	No Policy	=	1	(4%)
#9	Which restorative products do you use to seal and/or restore failed bridge decking?			
	Methacrylate	=	7	(28%)
	Epoxy	=	8	(32%)
	Other	=	7	(28%)
	N/A	=	9	(36%)
#10	What bridge overlay products does your agency use?			
	Low Slump Concrete	=	10	(40%)
	Polymer Concrete	=	4	(16%)
	Latex Modified Concrete	=	10	(40%)
	Asphalt	=	11	(44%)
	Other	=	12	(48%)
#11	Does your agency use sealing products on bridge decks?			
	Barrier	=	4	(16%)
	Penetrating	=	11	(44%)
	Other	=	1	(4%)
	No	=	13	(52%)
#12	Does your agency use membranes?			
	Yes	=	12	(48%)
	No	=	11	(44%)
	Other	=	3	(12%)

3. Meet with the Technical Panel to discuss the project and scope of work.

A brief meeting was held with the Technical Panel in conjunction with the field survey conducted in Task 4. Comments from the Panel included the desire to halt the use of linseed oil as a "penetrating" sealer.

4. Obtain detailed information with regard to bridge deck cracking in South Dakota, conduct a survey of existing crack sealing applications statewide and interview appropriate Departmental personnel.

During the state bridge deck tour conducted by Dan Johnston (Research/Technical Panel Chair), a general understanding of bridge deck cracking types, severity, and frequency was obtained. Crack sealing applications, namely epoxy crack sealing and the SDDOT single coat epoxy chip seal, were observed for apparent performance. The epoxy chip seal in particular exhibited outstanding performance after 3 to 5 years. Interviews and data collection were conducted with Rapid City Region, Pierre Region, and Mitchell Region bridge maintenance personnel; the Bridge Maintenance Engineer; and Operations Support.

5. Develop a listing of promising candidate sealing strategies and evaluate their effectiveness and cost.

The following products were selected for field trials after evaluating several crack and deck sealing products in Tasks 1 and 2:

Table 2 – Selected Crack And Surface Sealer Products

Product	**Application**
100% Silane – Degussa	Surface Sealer
40% Silane – Hydrozo	Surface Sealer
40% Silane – Masterbuilders	Surface Sealer
Penetron Waterproofing*	Crack/Surface Sealer
Reactive Methyl Methacrylate – Degussa	Crack Sealer
Modified Polyurethane – Roadware	Crack Sealer
Two-Component Epoxy	Crack/Surface Sealer
Dow 888 Silicone	Crack Sealer

* - Not applied during field trials

A silicate crack and surface sealer (Penetron Waterproofing) was requested for this project, but did not arrive on-site for the trial applications. Therefore, it was decided to apply Dow 888 silicone joint seal in hand-routed cracks on bridge decks based on the positive performance of an accidental rout-and-seal bridge application in the Rapid City Region.

The average cost for treating bridge decks with linseed oil was $0.021 per square foot from fiscal year 1995 to 1997 in the Aberdeen Region. At an interest rate of 4 percent over 5 years, the cost in 2002 would be about $0.026 per square foot. This is only the cost for applying the linseed oil. It does not take into account bridge deck deterioration costs due to an ineffective sealer against moisture and chlorides. As noted earlier, linseed oil cannot really be considered a penetrating sealer due to its molecular size and viscosity. Therefore, it should be considered a membrane type of sealer that is easily abraded by traffic and snow removal activities.

The following are the costs for the materials used in this project.

Table 3 – Product Materials Costs

Product	Cost
100% Silane – Degussa	$0.35 - $0.40/SF
40% Silane – Hydrozo	$0.16 - $0.20/SF
40% Silane – Masterbuilders	$0.16 - $0.20/SF
Penetron Waterproofing	NA
Reactive Methyl Methacrylate – Degussa	$0.45/SF
Modified Polyurethane – Roadware	$1.40/SF
Two-Component Epoxy – Unitex Pro-Seal	$0.70/SF
Dow 888 Silicone	$1.25/LF

From a labor standpoint, all of these products are quick-curing (= 1 hour) with the exception of Dow 888. For the average SDDOT bridge deck (approximately 130 ft. x 26 ft. = 3,380 sf.), traffic control, deck preparation, application, and curing will take approximately 4 to 6 hours.

6. ***Apply these sealing strategies to several structures statewide (with the aid of SDDOT maintenance forces) and evaluate their effectiveness.***

On October 1 and 2, 2001, AEC, SDDOT, and supplier representatives applied various concrete deck and surface crack sealers to three (3) different bridge decks that represent three (3) levels of surface preparation (See the following table).

Table 4 – Bridge Identification and Surface Preparation

Bridge Number	**Bridge Name**	**Location**	**Surface Preparation Level**
1	Foster Street Bridge	Mitchell, SD	Sand Blast
2	I-90 WB (#50275165)	MRM 406.12 / 0.42 miles west of Brandon Exit	Power Broom/Forced Air
3	I-90 EB (#50275166)	MRM 406.12 / 0.42 miles west of Brandon Exit	Do Nothing

Figure 1 – Bridge #1/Section #1

Six (6) product test sections were placed on each bridge deck with assistance from supplier representatives. As noted previously, three (3) surface preparation levels were used (i.e. – sand blasting, power broom/forced air, and do-nothing). Figure 1 shows the first test section on Bridge #1 after members of the research team mapped and measured the width of existing cracks at various locations. The Mitchell Region Bridge Maintenance Crew (MRBMC) subsequently sandblasted and cleaned each test section after the research team documented the crack information.

Fig. 2 – Bridge #2/Crack Pattern

Figure 2 shows the general deck condition for Bridges #2 and #3. The concrete block sections defined by the cracking are approximately $1^{1}/_{2}$ ft. square. Instead of tracing the cracks with chalk and transferring the crack patterns to field sketches, numerous photographs and crack width measurements, with a crack comparator (See Figure 3), were taken to document the test sections. Figure 4 shows test section schematics for the 3 bridges.

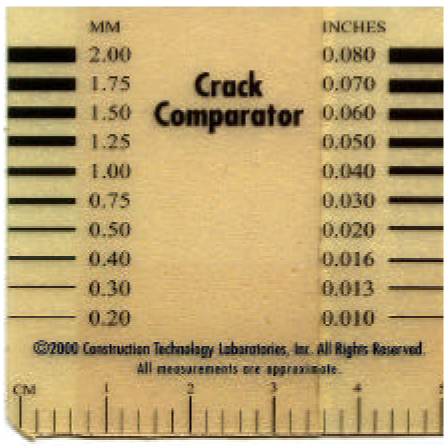

Figure 3 – Crack Comparator

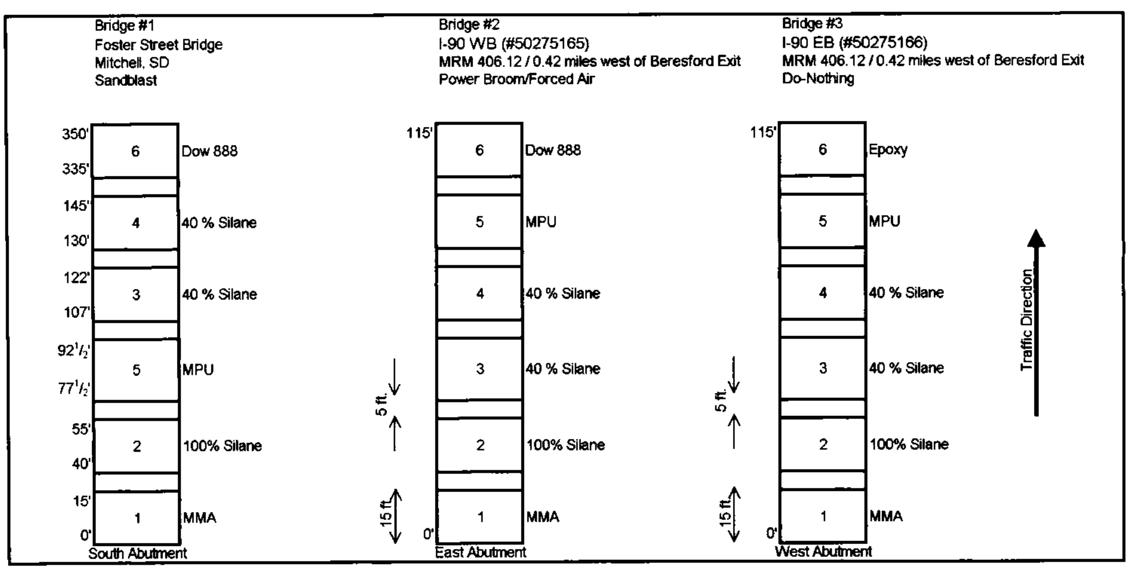

Figure 4 – Test Section Schematic

The layout for Bridge #1 is not the same as Bridges #2 and #3 because the crack pattern was not uniform. Therefore, the research team selected test section locations based on the intended use of the product (i.e. – medium crack density area/crack sealers application and low crack density area/surface sealers application). The following figures show the installation of the various crack/surface sealer products.

Figures 5 – 7 show the mixing and roller application of the MMA.

Figure 5 – MMA Proportioning

Figure 6 – MMA Mixing

Figure 7 – MMA Roller Application

Figures 8 – 10 show the MPU crack sealer packaging, cartridge preparation and installation.

Figure 8 – MPU Packaging

Figure 9 – MPU Cartridge Preparation

Figure 10 – MPU Installation

Figure 11 shows the installation of the silanes and two-component epoxy.

Figure 11 – Silanes & Epoxy Installation

Figures 12 – 13 show the preparation and installation of the silicone crack/joint seal.

Figure 12 – Crack Preparation

Figure 13 – Silicone Installation

To evaluate the materials' performance, three (3) cores from each test section (i.e. – 3 decks x 6 products x 3 cores = 54 samples) were obtained for laboratory testing (test reports located in appendices). Only 30 cores were tested because some of the cores contained surface cracks and they broke during transport and laboratory preparation. A 56-day ponding test was performed with a fluorescence dye so that water, as well as sealer, penetration could be measured. Chloride ponding was not conducted because obtaining dust samples with a drill may have destroyed the core samples prior to observing sealer penetration in polished saw cut sections. Discussions with industry and agency representatives indicated that observation of water penetration with a fluorescence dye would be a good indicator for evaluating water and chloride penetration resistance.

In general, sealer penetration was greatest on the bridge deck that was given a brush blast with a sandblasting apparatus. The MMA product had the best crack penetration, probably due to its roller application. One of SDDOT's crack sealing products [i.e. – a two-part epoxy crack/penetrating sealer (Unitex Pro-Seal)] was applied with a garden sprayer to Bridge #3. Its penetration depth was similar to the methyl methacrylate and exhibited similar results in the water ponding test. As expected, the 100 percent silane exhibited slightly better penetration than the 40 percent silanes.

Since the penetration depth of both sealers and water is affected by the substrate concrete quality, full petrographic examinations were performed on representative concrete samples from each bridge deck. The following table shows the results for the three bridges.

Table 5 – Petrographic Evaluation Summary

Bridge Number	W/C Ratio	Percent Air, %	Paste Hardness
1	0.38 – 0.43	7.9	Medium
2	0.33 – 0.38	4.9	Hard
3	0.37 – 0.42	5.3	Medium – Hard

The petrographic examinations indicate that the concrete substrates are dense and in good overall condition. Therefore, it may be inferred that the concrete in the 3 bridge decks would exhibit similar permeability characteristics.

The results of the laboratory testing indicated the following:

- In general, the crack sealers exhibited good penetration and appeared to be well-bonded to the crack walls.
- Although the cracks were sealed, water ingress occurred around the cracks through the unsealed concrete surface.
- The 100 percent silane exhibited better water repelling performance versus the 40 percent silanes.
- Sandblasting may not be warranted prior to application because the sealers exhibited similar penetration among the 3 bridge decks. In fact, the sandblasted deck exhibited greater overall water penetration.
- In the absence of excessive debris, the "Do-Nothing" deck preparation appears to provide the overall best sealer performance.

7. ***Develop a series of protocols for crack sealing with guidelines for locating and evaluating the severity of cracks on a tined surface and any surface preparation required prior to sealing.***

Different materials were used to attempt to highlight crack patterns on the bridge decks (i.e. – light water mist and dye penetrant). However, the research team and MRBMC personnel resorted to crawling on hands and knees to locate cracks because the highlighting materials were not consistent in revealing cracks and sometimes masked them. For the cracks that were located, crack width measurements were obtained through the use of a crack comparator (See Figure 3). The tool is easy and quick to use as opposed to crack scopes. Crack width measurements should be used for product selection as opposed to triggering sealing activities. Use the following ACI 201 crack definitions for product selection:

Table 6 – Product Selection Based On Crack Width

Crack Definition	Crack Width	Recommended Products
Fine	< 0.04 in.	MMA, MPU, Epoxy
Medium	0.04 = x = 0.08 in.	MMA, MPU, Epoxy
Wide	> 0.08 in.	MMA and MPU

The reason for this distinction is that epoxies are generally more rigid than the other two materials. Therefore, for cracks widths larger than about 0.08 in. there is an increased likelihood of adhesion failure due to crack movement. Conventional crack sealing activities (i.e. – roller application, squirt bottles, etc.) may be used for crack frequencies greater than approximately 5 feet. If surface cracking is more frequent, then the SDDOT developed epoxy chip seal treatment should be considered. All of these activities are predicated on the bridge deck surface being relatively sound (i.e. – no large delamination, scaling, and/or spalling areas).

The laboratory tests indicate that crack and deck sealer penetration is similar for the three preparation levels used in this project. However, water ingress measurements were significantly worse for the sandblasted deck – probably due to the opening and widening of the surface pore structure. For good performance and cost-effectiveness, it appears that the do-nothing approach is the best alternative. If excessive debris (i.e. – dirt/sand piles, garbage, etc.) is present, then power-brooming/forced air is the best approach.

8. ***Develop stratified guidelines for crack sealing of bridge decks based on deck condition (cracking severity), deicer usage patterns, geographic and environmental considerations and age and type of structure.***

   It is already established that placing a sealing system after chloride ingress has occurred is not very effective, which means prevention of chloride and water ingress from the beginning is recommended. Therefore, placement of crack and deck sealing treatments within 3 to 6 months after bridge deck construction with reapplication at 5-year intervals is the best approach. Existing bridge decks should also be treated to reduce further chloride and water ingress, thus reducing the bridge decks' corrosion potential.

9. ***Meet with the Technical Panel to discuss results and recommendations prior to drafting the final report.***

   Due to scheduling conflicts, a pre-draft report meeting was not possible. However, communication with the Technical Panel Chairman was maintained and any concerns regarding the draft report were addressed.

10. ***Prepare a final report and executive summary of the literature review, research methodology, findings, conclusions, guidelines and recommendations.***

    This document fulfills the requirements for this task.

5.0 FINDINGS & CONCLUSIONS

The following findings and conclusions are presented for this project.

1. It appears that bridge deck cracking is occurring on most of SDDOT's bridge decks.
2. Application of crack and deck sealing treatments after chloride ingress is not the approach most beneficial to maximizing bridge deck service lives. However, it is acknowledged that slowing additional chloride and water ingress will provide additional life to older bridges. Treating older bridge decks will just not be as effective as treating prior to chloride exposure.
3. Crack and deck sealing products with viscosities less than 15 cp appear to achieve good penetration (i.e. - = 0.10 in.) into cracks and deck surface, respectively.
4. Linseed oil should not be classified or used as a penetrating sealer because its molecular size is bigger than the size of the concrete pore openings. Therefore, it functions primarily as a temporary surface membrane sealer.

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6.0 IMPLEMENTATION RECOMMENDATIONS

The following implementation recommendations are presented for this project.

1. SDDOT should eliminate the use of linseed oil as its penetrating bridge deck sealer because it is not a true penetrating sealer and has a short effective life.
2. SDDOT should replace linseed oil with penetrating sealers (i.e. – silanes, siloxanes, siliconates) that incorporate alkyl groups larger than methoxy and ethoxy groups as their concrete bridge deck surface sealing materials. The products used in this study (See Table 7), or functional equivalents, should be used.
3. SDDOT should use concrete crack sealing materials (i.e. – MMA, MPU, Epoxy, etc.) with viscosities = 15 cp. If crack widths are = 0.080 in., epoxy should not be used because their extensibility properties are generally less than that of MMA and MPU. The products used in this study (See Table 7), or functional equivalents, should be used.
4. SDDOT's bridge deck crack and surface sealing activities should be conducted within 3 to 6 months after construction and repeated every 5 years. Existing bridge decks should be treated at 5 year intervals to minimize further chloride and water ingress, thus reducing corrosion potential.
5. SDDOT should follow the product and application time guidelines shown in Tables 8, 9, and 10. In all cases where surface and crack sealers are combined, the crack sealer should be applied first, then the surface sealer. Refer to Table 7 for product recommendations.

Table 7. – Recommended Products

Product Number	Product	Application
1	100% Silane – Degussa	Surface Sealer
2	40% Silane – Hydrozo	Surface Sealer
3	40% Silane – Masterbuilders	Surface Sealer
4	Reactive Methyl Methacrylate – Degussa	Crack Sealer
5	Modified Polyurethane – Roadware	Crack Sealer
6	Two-Component Epoxy – Unitex Pro-Seal	Crack/Surface Sealer
7	SDDOT Epoxy Chip Seal	Crack/Surface Sealer

Table 8 – Product Guidelines (Crack Frequency > 10 Feet)

Crack Width, in.	Bridge Deck Age, Years		
	0 to 5	**6 to 10**	**> 10**
< 0.04	(1, 2, or 3)	(1, 2, or 3)	(1, 2, or 3)
0.04 to 0.08	(1, 2, or 3) **OR** (1,2, or 3) and (4, 5, or 6)	(1, 2, or 3) **OR** (1,2, or 3) and (4, 5, or 6)	(1, 2, or 3) **OR** (1,2, or 3) and (4, 5, or 6)
> 0.08	(1,2, or 3) and (4 or 5)	(1,2, or 3) and (4 or 5)	(1,2, or 3) and (4 or 5)

Table 9 – Product Guidelines (Crack Frequency 5 – 10 Feet)

Crack Width, in.	Bridge Deck Age, Years		
	0 to 5	**6 to 10**	**> 10**
< 0.04	(1, 2, or 3) **OR** (1,2, or 3) and (4, 5, or 6)	(1, 2, or 3) **OR** (1,2, or 3) and (4, 5, or 6)	(1, 2, or 3) **OR** (1,2, or 3) and (4, 5, or 6)
0.04 to 0.08	(1,2, or 3) and (4, 5, or 6) **OR** 7	(1,2, or 3) and (4, 5, or 6) **OR** 7	(1,2, or 3) and (4, 5, or 6) **OR** 7
> 0.08	(1,2, or 3) and (4 or 5) **OR** 7	(1,2, or 3) and (4 or 5) **OR** 7	(1,2, or 3) and (4 or 5) **OR** 7

Table 10 – Product Guidelines (Crack Frequency < 5 Feet)

Crack Width, in.	Bridge Deck Age, Years		
	0 to 5	**6 to 10**	**> 10**
< 0.04	(1,2, or 3) and (4 or 6) **OR** 7	(1,2, or 3) and (4 or 6) **OR** 7	(1,2, or 3) and (4 or 6) **OR** 7
0.04 to 0.08	(1,2, or 3) and (4 or 6) **OR** 7	(1,2, or 3) and (4 or 6) **OR** 7	(1,2, or 3) and (4 or 6) **OR** 7
> 0.08	(1,2, or 3) and (4) **OR** 7	(1,2, or 3) and (4) **OR** 7	(1,2, or 3) and (4) **OR** 7

7.0 REFERENCES

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LABORATORY REPORTS

REPORT OF CONCRETE TESTING

PROJECT:

SEALER TESTING

REPORTED TO:

AEC ENGINEERING INC.
400 FIRST AVENUE NORTH, SUITE 400
MINNEAPOLIS, MN 55401

ATTN: ARIEL SORIANO

APS JOB NO: 10-01983

DATE: MARCH 6, 2002

INTRODUCTION

This report presents the results of laboratory work performed by our firm on three concrete core samples submitted to us by Mr. Ariel Soriano of AEC Engineering on February 19, 2002. We understand the concrete cores were obtained from exterior concrete bridge decks currently under evaluation. The scope of our work was limited to performing petrographic analysis testing to document the overall quality of the concrete.

CONCLUSIONS

Based on our observations, test results, and past experience, our conclusions are as follows:

1. The overall quality of the concrete was good. The cement paste was relatively dense and hard with carbonation up to 9/32". The crushed quartzite aggregate was hard, appeared sound, and durable. We did observe minor silica gel deposits lining air voids adjacent to several reactive fine aggregate shale particles. The concrete was placed with a low slump.

2. The concrete has good durability. The concrete contained an air void system that is consistent with current technology for resistance to freeze-thaw deterioration.

SAMPLE IDENTIFICATION

Sample Number:	1-2-3	2-2-2	3-2-2
Sample Type:	Hardened Concrete Core		
Original Sample Dimensions, in:	4" diameter by 2-5/8" long	4" diameter by 3-1/4" long	4" diameter by 3-1/2" long

TEST RESULTS

Our complete petrographic analysis test results appear on the attached sheets entitled 00 LAB 001 "Petrographic Examination of Hardened Concrete, ASTM:C856." A brief summary of these results is as follows:

1. The coarse aggregate in the cores was comprised of **2**" to 3/4" maximum sized crushed quartzite that was fairly well graded with good overall uniform distribution.

2. Pozzolanic admixtures were not observed in any of the concrete samples.

3. The paste color of the cores was medium gray with the slump estimated to be low (1" to 3").

4. The paste hardness of the cores was judged to be medium to hard with the paste/aggregate bond considered fair.

5. The depth of carbonation was up to 9/32".

6. The water/cement ratio of the cores was estimated at between 0.33 to 0.42 with approximately 10-16% unhydrated cement particles.

Air Content Testing

Sample Identification:	1-2-3	2-2-2	3-2-2
Total Air Analysis - Air Void Content, % Spacing Factor, in	 7.9 0.003	 7.9 0.004	 6.8 0.005
Entrapped Air (%)	0.6	1.0	0.5
Entrained Air (%)	7.3	4.9	5.3

TEST PROCEDURES

Laboratory testing was performed on February 19, 2002, and subsequent dates. Our procedures were as follows:

Petrographic Analysis

A petrographic analysis was performed in accordance with APS Standard Operating Procedure 00 LAB 001, APetrographic Examination of Hardened Concrete,@ ASTM:C856-latest revision. The petrographic analysis consisted of reviewing cement paste and aggregate qualities on a whole basis as well as on a cut/polished section. The depth of carbonation was documented using a phenolphthalein indicator solution applied on a freshly cut and polished surface of the concrete samples. The water/cement ratio of the concrete was estimated by viewing a thin section of the concrete under an Olympus BH-2 polarizing microscope at magnification up to 1000x. Thin section analysis was performed in accordance with APS Standard Operating Procedure 00 LAB 013, ADetermining the Water/Cement of Portland Cement Concrete, APS Method.@ The samples are first highly polished, then epoxied to a glass slide. The excess sample is cut from the glass and the slide is polished until the concrete reaches 25 microns or less in thickness.

Air Content Testing

Air content testing was performed using APS Standard Operating Procedure 00 LAB 003, AMicroscopical Determination of Air Void Content and Parameters of the Air Void System in Hardened Concrete, ASTM:C457-latest revision.@ The linear traverse method was used. The concrete cores were cut perpendicular with respect to the horizontal plane of the concrete as placed and then polished prior to testing.

REMARKS

The test samples will be retained for a period of at least thirty days from the date of this report. Unless further instructions are received by that time, the samples may be discarded.

Report Prepared By:

Scott F. Wolter, P.G.
President MN Reg. No. 12856
MN License No. 30024

Richard D. Stehly, P.E., FACI

PROJECT:

SD DOT ALTERNATIVE
SEALERS FOR BRIDGE DECKS
AEC 201514-3283

REPORTED TO:

AEC ENGINEERING INC.
400 FIRST AVENUE NORTH, SUITE 400
MINNEAPOLIS, MN 55401

ATTN: ARIEL SORIANO

APS JOB NO: 10-01983a

DATE: MARCH 19, 2002

INTRODUCTION

This report presents the results of laboratory work performed by our firm on thirty concrete core samples submitted to us by Mr. Ariel Soriano of AEC Engineering on February 26, 2002. We understand the concrete cores were obtained from exterior concrete bridge decks currently under evaluation. The scope of our work was limited to measuring the width of existing microcracks at various depths in twenty four of the cores and measuring the depth of sealer penetration in thirteen of the cores.

TEST RESULTS

MEASUREMENT OF MICROCRACK AND SEALER - DECK #1

Sample ID	Width of Crack @ Top of Core (mm)	Width of Crack @ Lower Limit of Sealer (mm)	Sealer Depth (mm)
1-1-1	**2.29**	**1.02**	**1.22**
1-1-2	**1.83**	**0.13**	**2.08**
1-1-3	**0.05**	**0.05**	**2.06**
1-3-1	**0.08**	**0.08**	**3.07**
1-3-2	**0.03***	**N/A***	**N/A***
1-3-3	**0.05***	**N/A***	**N/A***
1-1-1a	**0.91**	**0.05**	**10.67**
1-3-1a	**0.05***	**N/A***	**N/A***

MEASUREMENT OF MICROCRACK AND SEALER - DECK #2

Sample ID	Width of Crack @ Top of Core (mm)	Width of Crack @ Lower Limit of Sealer (mm)	Sealer Depth (mm)
2-1-1	2.79	1.65	3.68
2-1-2	0.48	0.05	0.89
2-5-2	0.30	0.18	2.92
2-5-3	0.10*	N/A*	N/A*
2-1-1a	0.13	0.08	2.54
2-5-1a	0.33	0.08	0.33

MEASUREMENT OF MICROCRACK AND SEALER - DECK #3

Sample ID	**Width of Crack @ Top of Core (mm)**	**Width of Crack @ Lower Limit of Sealer (mm)**	**Sealer Depth (mm)**
3-1-1	0.43	0.15	1.27
3-1-3	1.65	0.13	4.19
3-5-1	0.08	0.08	7.14
3-5-2	0.36	0.15	3.73
3-5-3	0.20	0.13	2.41
3-6-1	0.05*	N/A*	N/A*
3-6-3	0.08*	N/A*	N/A*
3-1-1a	0.51	0.20	3.30
3-5-1a	0.13	0.13	1.85
3-6-1a	0.05*	N/A*	N/A*

* The sealer was observed only partially covering the top surface and was not observed within the subvertical microcrack.

MEASUREMENT OF SILANE SEALER PENETRATION - DECK #2 & DECK#3

Sample ID	Width of Crack @ Top of Core (mm)	Sealer Depth (mm)
2-2-1a	0.03	Negligible penetration into concrete, sealer observed within microcrack to full depth of core (50mm).
2-3-1a	0.03	Negligible penetration into concrete, sealer observed within microcrack to full depth of core (47mm).
2-4-1a	0.05	Negligible penetration into concrete, sealer observed within microcrack to full depth of core (45mm).
3-2-1a	N/A**	Negligible penetration into concrete, sealer observed within microcrack to full depth of core (48mm).
3-3-1a	0.002	1mm up to 4mm penetration into concrete, sealer observed within microcrack to full depth of core (49mm).
3-4-1a	0.05	Negligible up to 2mm penetration into concrete, sealer observed within microcrack to full depth of core (45mm).

** Core is fractured along microcrack.

TEST PROCEDURES

Laboratory testing was performed on February 26, 2002, and subsequent dates. Our procedures were as follows:

Measurement of Crack Width and Penetration of Film Forming Sealers

The cores were saw cut perpendicular to the microcrack and polished smooth. Observations were made using an Olympus stereozoom microscope with magnification up to 130x.
Photographs are included to illustrate our work and conclusions.

Measurement of Silane Sealer Penetration

The cores were saw-cut perpendicular to microcrack, rinsed and allowed to dry. Observations of sealer penetration were made using an ultra-violet light source.

REMARKS

The test samples will be retained for a period of at least thirty days from the date of this report. Unless further instructions are received by that time, the samples may be discarded.

Report Prepared By:

Christine Tillema
Geologist/Petrographer

Report Reviewed By:

Gerard Moulzolf, P G
Vice President/Geologists/Petrographer
MN License No. 30023

REPORT OF AIR VOID ANALYSIS

PROJECT:

SEALER TESTING

REPORTED TO:

AEC ENGINEERING INC.
400 FIRST AVENUE NORTH, SUITE 400
MINNEAPOLIS, MN 55401

ATTN: ARIEL SORIANO

APS JOB NO: 10-01983

DATE: MARCH 4, 2002

Sample No:	1-2-3	2-2-2	3-2-2
Conformance:	The samples contain an air void system consistent with current technology for freeze-thaw resistance.		
Sample Data:			
Description:		Hardened Concrete Core	
Dimensions:	4" diameter by 2e" long	4" diameter by 33" long	4" diameter by 32" long
Test Data ASTM:C457 Linear Traverse Method, APS Standard Operating Procedure 00 LAB 003			
Air Void Content, %	7.9	5.9	6.8
Entrained, % ≤ 0.040"	7.3	4.9	5.3
Entrapped, % > 0.040"	0.6	1.0	0.5
Air Voids/inch	26.10	16.26	16.22
Specific Surface, in^2/in^3	1330	1110	960
Spacing Factor, inches	0.003	0.004	0.005
Paste Content, %	26.0	26.0	26.0
Magnification	50x	50x	50x
Traverse Length, inches	90"	90"	81"
Test Date	2/20/02	2/20/02	2/20/02

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-01983	Date:	2-20-02/3-4-02
Sample Identification:	1-2-3	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on both sides of a 102 mm (4") x 67 mm (2-5/8") x 25 mm (1") thick polished section that was cut from the original 102 mm (4") diameter x 67 mm (2-5/8") long core.

2. Surface Conditions:

   Top: Rough, tined surface with mortar erosion exposing few coarse aggregate surfaces
   Bottom: Rough, irregular, fractured surface

3. Reinforcement: None observed.

4. General Physical Conditions: The sample is characterized by a rough, tined, top surface which has undergone mortar erosion exposing few coarse aggregate surfaces. The concrete is purposefully air-entrained and contains an air void system considered freeze-thaw durable. Fair to good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized traprock made up of quartzite. Fairly well graded with good overall uniform distribution.

2. Fine: Natural quartz feldspar sand that was fairly well graded. The grains were mostly sub-angular with many rounded particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 7.9% total, 0.6% entrapped, 7.3% entrained
2. Depth of carbonation: Ranged from negligible up to 7 mm (9/32")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair to poor
5. Paste color: Medium gray, stained brown in the top 1 mm, up to 4 mm in one area
6. Paste hardness: Medium
7. Paste proportions: 26% to 28%
8. Microcracking: A few subvertical microcracks proceed up to 13 mm depth from the top surface. A subhorizontal microcrack swarm was observed in the approximately 32 mm (1-1/4") depth from the top surface. Microcracking was observed in the paste subparallel and proximate to the fractured bottom surface.
9. Secondary deposits: Ettringite thinly lines some of the smallest void spaces scattered in the sample.
10. Slump: Estimated, low (1-3")
11. Water/cement ratio: Estimated at between 0.38 to 0.43 with approximately 10-12% unhydrated or residual portland cement clinker particles.
12. Cement hydration: Alites - well to fully, belites - moderate to well

IV. Conclusions

The general overall quality of the concrete was good.

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-01983	Date:	2-21-02/3-4-02
Sample Identification:	2-2-2	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on the 76 mm (3") thick topping portion of a 100 mm (3-15/16") x 83 mm (3-1/4") x 25 mm (1") thick polished section that was cut from the original 102 mm (4") diameter x 83 mm (3-1/4") long core.

2. Surface Conditions:
   Top: Rough, tined and screeded surface which is traffic worn exposing many fine aggregate surfaces
   Bottom: Rough, irregular, formed surface placed as a topping

3. Reinforcement: None observed.

4. General Physical Conditions: The core sample includes an approximately 50 mm (2") thick topping placed over an approximately 25 mm (1") thick layer of similar concrete which was placed upon a lightweight base concrete. The first layer of topping appears well bonded to the base concrete. The top surface of this concrete appears rough, irregular and fractured, and contains some microcracking subparallel and proximate to the surface. The second layer of topping contains a purposefully entrained air void system considered freeze-thaw resistant under severe exposure. The first layer of topping contains a much lower percentage of purposeful air entrainment. Many soft and deleterious fine shale and iron oxide particles were observed scattered throughout the two toppings. Clear to white alkali silica gel was observed lining and partially filling several void spaces proximate to reactive fine aggregate particles. Good overall condition.

II. Aggregate

1. Coarse: 19 mm (3/4") maximum sized traprock made up of quartzite. Fairly well graded with good overall uniform distribution.

2. Fine: Natural quartz feldspar, carbonate and shale sand with some other lithic particles that was fairly well graded. The grains were mostly sub-angular with many rounded particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 5.9% total, 1.0% entrapped, 4.9% entrained
2. Depth of carbonation: Ranged from negligible up to 2 mm (1/16")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Dark gray, becoming darker in the top up to 8 mm (5/16") of the sample
6. Paste hardness: Hard
7. Paste proportions: 26% to 28%
8. Microcracking: Few subvertical drying shrinkage microcracks proceed up to 3 mm (1/8") depth from the top surface. A subvertical microcrack proceeds from the top of the first layer of the topping to the bottom of the sample. Microcracking was observed within many reacted and desiccated fine shale particles throughout the sample.
9. Secondary deposits: Clear to white alkali silica-gel was observed lining and partially filling several void spaces proximate to reactive fine aggregate particles.
10. Slump: Estimated, low (1-3")

11. Water/cement ratio: Estimated at between 0.33 to 0.38 with approximately 14-16% unhydrated or residual portland cement clinker particles.

13. Cement hydration: Alites - moderate to well, belites - low to well

IV. Conclusions

The general overall quality of the concrete was good.

00 LAB 001 Petrographic Examination of Hardened Concrete
ASTM: C-856

Job #:	10-01983	Date:	2-20-02/3-5-02
Sample Identification:	3-2-2	Performed by:	S. Malecha/G. Moulzolf

I. General Observations

1. Sample Dimensions: Our analysis was performed on both sides of a 100 mm (4") x 89 mm (3-1/2") x 22 mm (7/8") thick polished section that was cut from the original 102 mm (4") diameter x 89 mm (3-1/2") long core.

2. Surface Conditions:

   Top: Rough, tined screeded surface which is traffic worn exposing several fine aggregate surfaces
   Bottom: Rough, irregular, fractured surface

3. Reinforcement: None observed.

4. General Physical Conditions: The sample is characterized by a rough, screeded and tined top surface which is traffic worn exposing several fine aggregate surfaces. A macrocrack orientated subvertically, bisects the sample. The subvertical fracture plane is dirty and stained brown up to 57 mm (2-1/4") depth from the top surface. The crack proceeds through the paste only, where stained, but appears to bisect a few coarse aggregate particles at further depth. Many soft and deleterious fine shale and iron oxide particles were observed scattered throughout the sample. Clear to white alkali silica-gel (ASR) was observed lining and partially filling many void spaces proximate to reactive fine aggregate particles. The concrete is purposefully air entrained and overall contains an air void system considered freeze-thaw durable. However, the air void system was poorly distributed throughout the sample. Fair to good overall condition.

II. Aggregate

1. Coarse: 13 mm (1/2") maximum sized traprock made up of quartzite. Fairly well graded with good overall uniform distribution.

2. Fine: Natural quartz, feldspar, carbonate, and shale sand with some other lithic particles that were fairly well graded. The grains were mostly sub-angular with many rounded particles. Good overall uniform distribution.

III. Cementitious Properties

1. Air Content: 6.8% total, 1.5% entrapped, 5.3% entrained
2. Depth of carbonation: Ranged from 1 mm (1/32") up to 3 mm (1/8")
3. Pozzolan presence: None observed
4. Paste/aggregate bond: Fair
5. Paste color: Medium gray becoming darker in the top up to 6 mm (1/4") of the sample
6. Paste hardness: Hard to medium
7. Paste proportions: 29% to 31%
8. Microcracking: Few subvertical microcracks were observed subparallel and proximate to the subvertical fracture. Microcracking was observed within many desicated fine shale particles throughout the sample.
9. Secondary deposits: Clear to white alkali silica-gel was observed lining and partially filling many void spaces proximate to reactive fine aggregate particles. Some scattered void spaces are thinly lined with ettringite.
10. Slump: Estimated, low (1-3")

11.	Water/cement ratio:	Estimated at between 0.37 to 0.42 with approximately 11-13% unhydrated or residual portland cement clinker particles.
14.	Cement hydration:	Alites - well to fully, belites - low to well

IV. Conclusions

The general overall quality of the concrete was good.