

SD Department of Transportation Office of Research



# Evaluation of Non-Metallic Fiber Reinforced Concrete Whitetopping

Study SD96-13 Final Report

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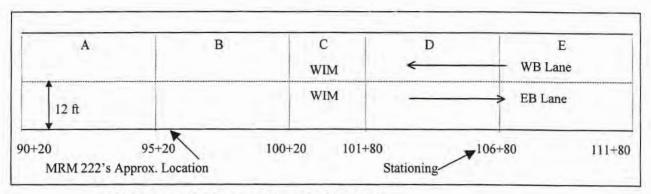
## **Executive Summary**

The relatively short whitetopping sections constructed in an earlier research project SD 94-04 "Evaluation of Non-Metallic Fiber Reinforced Concrete in PCC Pavements and Structures", have performed well for nearly five years, even though the underlying asphalt concrete had severe transverse cracks due to excessive asphalt thickness. Before non-metallic fiber reinforced concrete (NMFRC) whitetopping can be accepted for widespread use, several questions had to be answered. Criteria for design of overlay thickness and joint spacing had to be developed. The constructability of NMFRC overlays had to be demonstrated and the behavior of jointed and unjointed overlays had to be determined. SDDOT desires to minimize joint maintenance by reducing the number of joints through increased joint spacing. Many other states have used joint spacing as small as 1 to 2 m (3 to 6 ft.) squares for ultra-thin whitetoppings (UTW) in their research and demonstration projects. SD wants to minimize joints in whitetoppings and UTW by testing joint spacing of 15.25 m (50 ft.) with a desire of using spacing no less than 6.1 m (20 ft.). High performance fibers are necessary for the longer joint spacing desired by SDDOT. Finally, economic considerations, especially life cycle costs, must be addressed. These issues had to be addressed through construction and evaluation of whitetopping sections large enough to exhibit full-scale behavior. Therefore the proposed research was undertaken in order to find answers for the above stated problems.

## The research objectives were

- 1. To recommend designs for NMFRC overlays of asphalt concrete pavement.
- 2. To evaluate constructability and performance of NMFRC whitetopping.
- 3. To evaluate the economic impacts of using NMFRC in whitetopping applications.

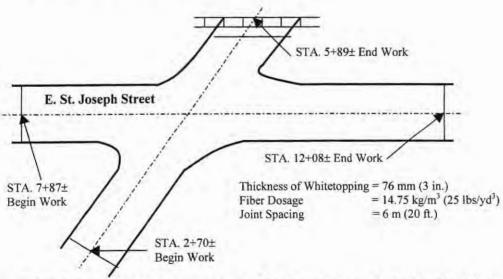
The project involved construction of whitetopping test sections on Highway 14 near MRM 222 west of Pierre, SD. At each lane, the following test and control sections were constructed.



White-topping Layout (Near MRM 222)

Test Section	Length (ft)	Туре	Thickness (in)	Joint Spacing (ft)	Volume of Fiber Concrete (yd³)
A	500	Fiber (25 lbs/yd³)	2.5	50	93
В	500	Fiber (25 lbs/yd³)	3.5	50	129
C	160	Plain	12	20	
D	500	Fiber (25 lbs/yd³)	3.5	No Joints	129
E	500	Fiber (25 lbs/yd³)	2.5	No Joints	93
Asphalt Overlay (Not Shown)	500	Control			
				Total	444

Whitetopping sections were also constructed at the intersection of E.St.Patrick and St. Joe (Highway 79) Rapid City, SD.



Whitetopping at the Intersection of St. Joseph Street and St. Patrick Street, Rapid City, SD

The research activities involved were to review and summarize literature relevant to FRC overlays on asphalt concrete pavements, design the concrete mix, conduct tests on the mix design to ensure desired properties are obtained, conduct quality control tests for both fresh and hardened concrete, evaluate whitetopping test sections from design through construction and subsequent service performance, and periodically conduct condition surveys to evaluate the performance of the whitetopping test sections.

The test program on fresh concrete included slump, concrete temperature, fiber content, air content, vebe time and unit weight. The hardened concrete properties included: compressive strength, static modulus, modulus of rupture, load-deflection curves, first crack toughness strength and post crack behavior, ASTM toughness indices, Japanese toughness index, equivalent flexural strength, fatigue strength, and impact strength. The mixture proportions used, the procedure used for mixing, transporting, placing, consolidating, finishing, and curing during the highway pavement are described.

The polyolefin fibers incorporated in the concrete at a rate of 14.8 kg/m3 (25) lb./cu.yd.) performed well in the mixing operation without causing any balling or segregation. The mean 28-day average compressive strength recorded for concrete placed during four different occasions in Highway 14 was 29.9 MPa (4330 psi for W1), 38.6 MPa (5605 psi for W2), 33.0 MPa (4790 psi for W3), and 33.0 MPa (4785 psi for W4), which was considered, as a considerable variation in the field concrete. The variation in the elastic modulus values was consistent with that of the compressive strength variation. For the whitetopping section at Rapid City, the 28-day average compressive strength recorded was 33 MPa (4780 psi) for WT1, 38.9 MPa (5635 psi) for WT2, 39.5 MPa (5717 psi) for WT3, and 43.5 MPa (6300 psi) for WT4. These variations in the compressive strengths of field concrete were higher than normal. These variations were due to lack of adequate quality control by the concrete suppliers. However all cylinders, tested, failed at a higher strength than the design strength of 27.6 MPa (4000 psi). There was significant enhancement in the impact strength, toughness, post crack load carrying capacity and flexural strength for NMFRC. The most important contribution due to the addition of fibers to concrete is the change in mode of failure to a more desirable ductile failure when subjected to compression, flexure, impact and fatigue loads. The toughness indices showed an enhancement of elasto-plastic behavior of the concrete.

The feasibility of using NMFRC in the construction of whitetopping has been established. The same construction techniques and construction equipment without any permanent modification could be used in the construction of a whitetopping.

Periodic inspections of the whitetopping sections, both on Highway 14 and at Rapid City were made.

On the west bound lane of Highway 14, in the 63.5 mm (2.5 inch) and 88.9 mm (3.5 inch) sections of the unjointed whitetopping, 8 cracks each were observed during the first inspection. Two random cracks (in addition to the control joints) were noticed in the jointed section of the whitetopping. This is believed to be because of the delay in cutting the concrete, by the contractor. After this inspection, the westbound lane was again inspected ten times with the last inspection being on June 19, 1999.

On the eastbound lane of Highway 14, 7 cracks were observed in the 63.5 mm (2.5 inch) section and 4 cracks were observed in the 88.9 mm (3.5 inch) section of the unjointed whitetopping. No cracks were noticed in the jointed section of the whitetopping. After this inspection, the eastbound lane was again inspected eight times with the last inspection being on June 19, 1999. All the cracks were routed and silicone sealed before the second inspection. Very fine corner cracks were first located during the third inspection, in the jointed section of the whitetopping. One corner crack was also noticed in the unjointed section. This was a corner crack to a transverse random crack. There was extensive corner cracking in Highway 14 on the jointed section of the whitetopping. Increased numbers of cracks were noticed during the later inspections. Many cracks were thin hairline cracks and a few wider cracks were also seen. There were more cracks in the thinner section of the whitetopping. The corner cracks occurred at the saw cut joints as diagonal cracks. There was a considerable number of longitudinal and transverse cracks in the unjointed section of the whitetopping. There was also corner cracking in the unjointed section. The fibers seemed to restrict the widening of the cracks and to some extent contain the crack propagation. The cracked concrete was held together by the fibers.

The bond between the milled asphalt surface and the overlay concrete seemed to play a significant role in the performance of whitetopping. Lack of bond and other factors such as smaller thickness of UTW, underlying asphalt, weak base material etc., lead to corner cracking. The extent of the cracking depended on the thickness of the whitetopping and the thickness of the asphalt layer after milling and surface preparation.

Cores taken from highway 14 had indicated that there was very poor bond between the overlay concrete and the asphalt layer below due to poor preparation of the asphalt surface after milling. Considerable amount of dust and sand particles at the interface reduced the bond. It was also noted that the thickness of the asphalt layer was not adequate. In fifty percent of core samples, the thickness of the asphalt layer was less than that of the whitetopping.

The first inspection of the whitetopping at Rapid City was done on June 13, '98 to see whether any plastic shrinkage cracks have occurred. No cracks of any type were noticed. All the joints had been cut. Some of the joints were filled with dust, sand and small aggregate particles making them ineffective. It seemed that some joints were cut too soon causing raveling at the joints. No cracks were found during second and third inspections conducted on June 14<sup>th</sup>, and June 17<sup>th</sup> '98. Traffic was allowed on the whitetopping 4 days after the concrete was placed. The three-day strength was about 20.69 MPa (3000 psi.) No unopened fiber bundles were spotted on the surface of the pavement during any of the inspections. A total of 7 inspections were conducted on the whitetopping section at Rapid City. All the crack dimensions were noted and recorded. During the 4<sup>th</sup> to the 7<sup>th</sup> inspections, extensive corner cracking was observed. However these cracks were thin hairline cracks. It needs continued observation to evaluate the performance of the whitetopping.

The post construction performance of the whitetopping sections was satisfactory. Once the cracks formed, the polyolefin fibers helped to contain the crack propagation and to resist the widening of cracks. In the opinion of the researcher, there was no reduction in the riding quality of the pavements due to thin corner cracking and minor longitudinal and transverse cracking. This opinion was formed by driving my personal vehicle over the sections. SD's profiler was run over the US14 UTW once which did not allow the riding quality to be assessed with age.

The following are the major conclusions and recommendations:

#### Conclusions:

- UTW is a reliable alternative to milling and replacing with HMA frequently in deteriorated and / or damaged asphalt pavements. The procedure is technically sound and it reduces the time required to rehabilitate the roads. It eliminates ruts and provides a safer surface for traffic.
- The NMFRC with enhanced fatigue, impact resistance, modulus of rupture, ductility
  and toughness properties is particularly suitable for the construction UTW overlays.
  Use of NMFRC has eliminated plastic shrinkage cracking and other early age
  cracking in UTW.
- There was considerable corner cracking in both Highway 14 and in Rapid City white toppings. However, the polyolefin fibers helped to contain the crack propagation and restrict the widening of the cracks. UTW, constructed when suitable conditions are available, performs successfully without any cracking and other damage such as in the case of UTW's on Highway 83 Bridge approach road near Vivian and on the intersection of East Blvd. and Main Street in Rapid City, S. D. In general thinner sections 63 mm (2.5 in.) had more cracking than the thicker sections (100 mm (4 in.)). The cracking increased with time with increased traffic.
- Inspection and testing of the cores taken from Highway 14 had shown that there was
  very poor bond between the overlay concrete and the asphalt layer. It was also noted
  that the thickness of the asphalt layer was not adequate. In some core samples, the
  thickness of the asphalt was less than the thickness of the UTW.

#### Recommendations:

• For the construction of UTW, only NMFRC should be used because of its enhanced structural properties, which are desirable for UTW and because of its ability to restrict the widening of the cracks and constrain the crack propagation. A fiber dosage of 14.8 kg/cu.m. (25 lbs /cu.yd.) is recommended. The minimum thickness of the UTW should be 89 mm (3.5 in.). The same construction procedures for mixing, transporting, placing, consolidating, finishing, tining, and curing used for construction with plain concrete, be used for construction of UTW. Some additional mixing time is required for NMFRC, which must be determined by field trials. The

same construction techniques and equipment without major modifications could be used for the construction of NMFRC UTW. The joint spacing can be 6 to 9.2 m (20 to 30 ft.). Joint sawing must be done as soon as the concrete can support the operator and equipment. Brooming and tinning can also be done as early as possible. The milled surface of the asphalt must be thoroughly cleaned with water jets to remove dust and loose sand particles.

Bonded overlay is desirable to provide a composite action for the slab which will reduce the potential tensile stresses and cracking in concrete overlays. A thin layer of cement slurry bonding agent could be used.

- The UTW construction should be organized so that a continuos monolithic construction is possible avoiding cold joints.
- It is recommended that UTW's and whitetoppings should be included as one of SDDOT's design alternatives for rehabilitating severely damaged or deteriorated asphalt pavements.
- It is recommended that reasons for the good performance of the two UTW's constructed in 1994 on Highway 83- approach road to the bridge near Vivian and in Rapid City at the intersection of East Blvd. and Main Street, must be investigated. The former had a joint spacing of 15.25 m (50 ft.) and there were no corner cracks and there were only two very thin hairline cracks. The later one constructed in 1997 was also largely successful without any corner cracks.

The following investigations are suggested to determine the design criteria and construction procedures that will ensure the successful performance and durability of UTW.

- Various procedures for creating an effective bond between the asphalt and the overlay concrete. This should include various surface preparations and bonding agents.
- A study can be conducted (both literature survey and experimental) to determine the optimum minimum thickness of the remaining asphalt layer thickness after milling and preparation to avoid corner cracking.

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## GLOSSARY

The following is a glossary of terms for fiber reinforced concrete (FRC) used in this report.

#### 0.1 General Terms

Balling - When fibers entangle into large clumps or balls in a mixture.

Fiber content - The weight of fibers in a unit volume of concrete.

First Crack - The point on the flexural load-deflection or tensile load-extension curve at which the form of the curve first becomes nonlinear.

First Crack Deflection - The deflection value on the load deflection curve at the first crack.

**First Crack Strength** - The stress obtained when the load corresponding to first crack is inserted in the formula for modulus of rupture given in ASTM Test Method C 78.

First Crack Toughness - The energy equivalent to the area of the load deflection curve up to the first crack.

**Flexural Toughness** - The area under the flexural load-deflection curve obtained from a static test of a specimen up to a specified deflection. It is an indication of the energy absorption capability of a material.

**Toughness Indices** - The numbers obtained by dividing the area under the load-deflection curve up to a specified deflection by the area under the load-deflection curve up to "First Crack" as given in ASTM C 1018.

Toughness Index, I<sub>5</sub> - The number obtained by dividing the area up to 3.0 times the first crack deflection by the area up to the first crack of the load deflection curve, as given in ASTM C 1018.

**Toughness Index, I\_{10}** - The number obtained by dividing the area up to 5.5 times the first crack deflection by the area up to the first crack of the load deflection curve, as given in ASTM C 1018

Toughness Index, I<sub>20</sub> - The number obtained by dividing the area up to 10.5 times the first crack deflection by the area up to the first crack of the load deflection curve, as given in ASTM C 1018

**Residual Strength Factor**  $R_{5,10}$  - The number obtained by calculating the value of  $20(I_{10}$ - $I_5)$ , as given in ASTM C 1018.

Residual Strength Factor  $R_{10,20}$  - The number obtained by calculating the value of  $10(I_{20}\text{-}I_{10})$ , as given in ASTM C 1018.

Flexural Toughness Factor (JCI) - The energy required to deflect the fiber reinforced concrete beam to a mid point deflection of 1/150 of its span.

Equivalent Flexural Strength (JCI) - It is defined by

 $F_c = T_b x s/\delta_{tb} x b x d^2$ 

where

F<sub>c</sub> = equivalent flexural strength, psi

T<sub>b</sub> = flexural toughness, inch-lb

s = span, inches

 $\delta_{tb}$  = deflection of 1/150 of the span, inches

b = breadth at the failed cross-section, inches

d = depth at the failed cross-section, inches

Impact Strength - The total energy required to break a standard test specimen of a specified size under specified impact conditions, as given by ACI Committee 544.

Static Modulus - The value of Young's modulus of elasticity obtained from measuring stress-strain relationships derived from other than dynamic loading.

High Performance Concrete - In this report, High Performance Concrete is defined as a concrete with highly enhanced (or improved) desirable properties for the specific purpose and function for which it is used. It need not necessarily be high-strength concrete. High performance concrete for the bridge deck overlay (pavement and whitetopping) will have highly enhanced ductility, fatigue strength, durability, impact resistance, toughness, impermeability and wear resistance.

**Whitetopping** - Whitetopping is concrete placed over asphalt where the concrete thickness is 101 (4 inch) or more mm thick.

**Ultra-Thin Whitetopping** - Ultra-Thin Whitetopping is concrete placed over asphalt where the concrete is less than 101 mm (4 inch) thick.

## 0.2 Acronyms Used

ACI - American Concrete Institute

FRC - Fiber Reinforced Concrete

HMA - Hot Mixed Asphalt

NMFRC - Non-Metallic Fiber Reinforced Concrete. This acronym refers only to Polyolefin Fiber Reinforced Concrete. These fibers were "supplied" by 3M for the purpose of this study.

PCC - Portland Cement Concrete

SFRC - Steel Fiber Reinforced Concrete.

UTW - Ultra-Thin Whitetopping

## 0.3 ASTM Specifications

- A 820 Specification for Steel Fibers for Fiber Reinforced Concrete
- C 31 Practices for Making and Curing Concrete Test Specimens in the Field
- C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens
- C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Thirdpoint Loading)
- C 94 Specification for Ready-Mixed Concrete
- C138 Test for Unit Weight, Yield and Air Content (gravimetric) of concrete
- C 143 Test Method for Slump of Portland Cement Concrete
- C 172 Method of Sampling Freshly Mixed Concrete
- C 173 Test Method of Air Content of Freshly Mixed Concrete by the Volumetric Method
- C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
- C 469 Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

- C 995 Test Method for Time of Flow of Fiber-Reinforced Concrete Through Inverted Slump cone
- C1018 Test Method for Flexural Toughness and First Crack Strength of Fiber
   Reinforced Concrete (Using beam with Third-point Loading)
- C 1116 Specification for Fiber Reinforced Concrete and Shotcrete

## 0.4 International Standards

- A American Concrete Institute Committee 544 Fiber Reinforced Concrete
   ACI 544.2R.89 Flexural Fatigue Endurance
   Impact Resistance
   Toughness
- B British Standards Institute
  BS1881: Part 2, Methods of Testing Concrete-Vebe Test
- C Japanese Society of Civil Engineers JSCE Standard III-1, Specification of Steel Fibers for Concrete, Concrete Library, No. 50, March 1983.
  - JSCE-SF4 Standard for Flexural Strength and Flexural Toughness, "Method of Tests for Steel Fiber Reinforced Concrete," Concrete Library of JSCE, No. 3, June 1984, Japan Concrete Institute (JCI), pp. 58-66.
  - "Standard Test Method for Flexural Strength and Flexural Toughness of Fiber Reinforced Concrete, (Standard SF4)," JCI Standards for Test Methods of Fiber Reinforced Concrete, Japan Concrete Institute, 1983, pp. 45-51.

## **Problem Description**

Asphalt concrete pavements, like all other constructed pavements deteriorate with age and use. Some forms of deterioration, such as fatigue cracking, rutting under heavy traffic, and shoving at urban intersections, result from certain asphalt concrete mixes' inability to withstand stresses to which they are subjected. This problem has mostly been addressed by strengthening the pavement with an asphalt concrete overlay, but several factors limit the applicability and effectiveness of that technique. First, unless the asphalt overlay is substantially more stable than the original pavement, rutting or shoving will recur. Second, overlay thickness can be limited by, vertical clearances, the need to match curb and gutter elevations, creating excessive cross slopes, and maintaining acceptable roadway widths. On the other hand, thicker overlays may generate other problems, notably severe transverse cracking as the total asphalt concrete thickness exceeds six inches or more.

In such instances, Portland cement concrete (PCC) overlays of asphalt pavements, commonly called "whitetopping", may be a practical way to strengthen pavement without adding excess thickness. By distributing load, a rigid overlay can reduce stress in the underlying asphalt concrete to levels that do not cause fatigue cracking, rutting, and shoving.

As shown in previous work [1], concrete reinforced with non-metallic, 50 mm (2 in.) length and 0.63 mm (0.025 in.) diameter polyolefin fibers appears to be highly suitable as an overlay material. Its impact resistance, toughness, and fatigue resistance permit relatively thin sections to support heavy loads. Unlike conventional concrete, the material continues to withstand load after initial cracking, a property that should reduce risk of serious failure. Finally, the non-metallic fibers have no corrosive potential and are resistant to chemicals. These properties contribute to a long life. UTW sections constructed in earlier research (SD 94-04) have performed well for nearly five years, even though the underlying asphalt concrete had severe transverse cracks due to excessive asphalt thickness [1].

Before non-metallic fiber reinforced concrete (NMFRC) whitetopping can be accepted for widespread use, several questions had to be answered. Criteria for design of

overlay thickness and joint spacing had to be developed. SDDOT desires to minimize joint maintenance by reducing the number of joints through increased joint spacing. Many other states have used joint spacing as small as 1 to 2 m (3 to 6 ft.) squares for ultra-thin whitetoppings (UTW) in their research and demonstration projects. SDDOT wants to minimize joints in whitetoppings and UTW by testing joint spacing of 15.25 m (50 ft.) with a desire of using spacing no less than 6.1 m (20 ft.). High performance fibers are necessary for the longer joint spacing desired by SDDOT. The constructability of NMFRC overlays had to be demonstrated and the behavior of jointed and unjointed overlays had to be determined. Finally, economic considerations, especially life cycle costs, must be addressed. These issues had to be addressed through construction and evaluation of whitetopping sections large enough to exhibit full-scale behavior.

Therefore the proposed research was undertaken in order to find answers for the above stated problems.

## Research Objectives

- 1. To recommend designs for NMFRC overlays of asphalt concrete pavement.
- 2. To evaluate constructability and performance of NMFRC white-topping.
- 3. To evaluate the economic impacts of using NMFRC in white-topping applications.

## Research Task 1: Meet with Technical Panel to discuss the research topic and work plan.

The Principal Investigator (P.I.) and the Research Associate (R.A.) met with the Technical Panel in Pierre on June 6, 1996 and discussed and reviewed the project, the procedures, methods and proposed tasks. Valuable suggestions, and comments were made by the Technical Panel. Details about the maturity testing were discussed during this meeting. The joint spacing for the jointed test section was finalized during this meeting. The Technical Panel informed the research team that the project consisted of suggesting the mixture proportions, providing advice in the construction, monitoring, and evaluating the UTW overlay. It was decided that DOT would conduct the fresh concrete's

quality control tests (acceptance testing) and that testing done by research staff would be done over and above DOT's quality control tests.

The project also consisted of the following: conducting fresh concrete tests during the construction, analyzing and evaluating the test sections and making recommendations. An extensive laboratory investigation would be conducted to recommend the appropriate mixture proportions for the construction of the UTW, and to fully determine the fresh and hardened concrete properties of these recommended concretes.

Research Task 2: Review and summarize literature relevant to FRC overlays on Asphalt Concrete Pavement.

## LITERATURE REVIEW

#### 1.0 Introduction

Plain concrete has two major deficiencies, a low tensile strength and a low strain at fracture. The tensile strength of concrete is very low because plain concrete normally contains numerous microcracks. It is the rapid propagation of these microcracks under applied stress that is responsible for the low tensile strength of the material.

These deficiencies have led to considerable research aimed at developing new approaches to modifying the brittle properties of concrete. Current research has developed a new concept to increase the concrete ductility and its energy absorption capacity, as well as to improve overall durability. This new generation technology utilizes discrete steel or synthetic fibers from 19 to 64 mm (0.75 to 2.5 in.) in length. The fibers are randomly dispersed throughout the concrete matrix providing for better distribution of both internal and external stresses by using a three-dimensional reinforcing network [1-12].

General requirements for these fibers' use as temperature/moisture shrinkage reinforcement include high tensile strength, high bond strength (typically mechanical) and ease to incorporation into the matrix to ensure optimum distribution. The primary role of the fibers in hardened concrete is to modify the cracking mechanism. By modifying the cracking mechanism, the macro-cracking becomes microcracking. The cracks are smaller in width; thus reducing the permeability of concrete and the ultimate cracking strain of the concrete is enhanced. Unreinforced concrete will separate at a crack, reducing the load carrying ability to zero across the crack. The fibers are capable of carrying a load across the crack, if all of the characteristics listed above are met by the fiber [1].

Fiber reinforced concrete specimens, unlike plain concrete specimens, which fail at the point of ultimate flexural strength or first crack, do not fail immediately after the initiation of the first crack. After first crack, the load is transferred from the concrete matrix to the fibers [13].

Because of the flexibility of the method of production, fiber reinforced concrete is an economic and useful construction material. A major advantage of using fiber reinforced concrete besides reducing permeability and increasing fatigue strength is that fiber addition improves the toughness or residual load carrying capacity after the first crack. Additionally, a number of studies have shown that impact resistance of concrete can also improve dramatically with the addition of fibers [1-7, 13].

Extensive research and development has been carried out with FRC materials leading to a wide range of practical applications. In recent years a great deal has been learned regarding the limitations of some FRC materials, and in particular, the importance of good design.

## 2.1 Whitetopping

The construction practice of placing 102 mm (4 in.) or more of concrete over an existing, deteriorated asphalt surface to provide a new riding surface is called whitetopping. Whitetopping specifications, such as mix design and surface thickness, vary according to expected traffic load, strength properties and condition of the existing pavement. This paving technique may be used to rehabilitate everything from driveways to parking lots to interstate highways and is particularly economical in intersections and other areas where maintenance and rutting have been continuous problems [10].

The two main problems limiting its widespread use were:

- Length of construction time (usually three to seven days before traffic can return to the pavement) and
- Increase in surface elevations due to the combined thickness of the old pavement and the new concrete overlay.

To address the first issue Fast-Track Whitetopping was developed with targeted flexural strengths of 2.41-2.76 MPa (350-400 psi) in less than 8 hours and around 5.17 MPa (750 psi) in 24 hours. Concrete pavement which develops flexural strengths this high can support standard traffic loads within 8 hours and heavy traffic within 24 hours after placement of the last cubic yard of concrete. Fast track methods opened many new doors for concrete use in maintenance situations but one drawback still remained: increasing critical elevations [14,15].

Conventional concrete overlays of asphalt pavements (whitetopping) are a well-established rehabilitation technique. The first one was built in 1944 on an airfield at the U.S. Air force Base in Offut, Nebraska. Since then over 189 documented whitetopping projects have been built throughout the United States on all types of highway, street, county road, airport, and parking area pavements. The state of Iowa alone has over 500 km (310 miles) of whitetopped county roads in service.

Typically conventional whitetopping [14] has been used in heavy-truck corridors to combat asphalt rutting. They generally have a minimum thickness of 125 mm (4.9 in.) and are designed with conventional concrete pavement theory that assumes no bond between the existing asphalt and concrete.

## 2.2 Ultra-thin Whitetopping (UTW)

By definition, ultra-thin whitetopping is a process where a layer of concrete less than 102 mm (4 in.) thick is placed over a subbase of milled hot mix asphalt (HMA). UTW combines fast-track technology and an ultra-thin, synthetic fiber-reinforced concrete whitetopping surface to solve both the problem of increased construction time and elevation [15].

UTW is different from conventional whitetopping because specific steps are taken to bond the overlay to the underlying asphalt and short joint spacings are used. They have been developed for low-volume (traffic) pavements such as city streets, intersections, general-aviation taxiways, runways, aprons, and parking areas, where rutting, washboarding, and shoving of the asphalt are a problem. A number of local, state, and federally funded projects have shown that UTW can withstand the loadings expected on these low-volume roads and provide a durable wearing surface.

The first UTW experimental project in the [14] United States was on a landfill disposal facility near Louisville, Kentucky, beginning September 1991. The overlay was constructed on an existing asphalt access road that served 400 to 600 trucks per day, 5.5 days per week. The existing asphalt pavement was milled to obtain a uniform profile. The experiment consisted of two concrete thicknesses- 90 and 50 mm (3.5 and 2.0 in.). The 90 mm (3.5 in.) section had joints at 1.83 m (6 ft.) in one area and at 0.61 m (2 ft.) in another area. Although the test section was monitored only for 13 weeks, it carried truck traffic for approximately 1 year. Field, laboratory, and theoretical study results of the test section indicated that bond developed between the underlying asphalt and the new overlay. It was found that this contributed significantly to the structural capacity of the new concrete overlay. Some of the other significant findings from the Louisville UTW experiment include the following:

- UTW 50-90 mm (2-3.5 in.) thick can carry traffic loadings typical on many low-volume roads, residential streets and parking lots.
- · Corner cracking was the predominant pavement distress.
- Joint spacing has a significant effect on the rate of corner cracking. Pavements
  with joints spaced at 0.61 m (2 ft.) showed considerably less cracking than
  pavement with 1.83 m (6 ft.) joint spacing for 50 mm (2.0 in.) thick
  whitetopping.

#### 2.3 How UTW Pavements Work

The following three basic factors [14] are required for UTW overlays to perform:

Bond between UTW and existing asphalt pavement

Bonding allows the concrete and asphalt layers to perform as a composite section. This causes the layers to act monolithically and share the load. With bonding, the neutral axis in the concrete shifts from the middle of the slab down toward the bottom of the concrete slab. The shifting down of the neutral axis lowers the tensile stresses at the bottom of concrete and brings the stresses into a range the concrete can withstand.

## · Short joint spacing

All pavement systems must absorb the energy of the applied load by either bending or deflecting. Traditional concrete pavements are designed to absorb the energy by bending. The short joint spacing, reduces the moment arm of the applied load and minimizes the stresses due to bending. The short joint spacing also reduces the stresses due to curling and warping by decreasing the amount of slab that can curl or warp. Typical joint spacings that have performed well on UTW projects are somewhere between 0.6 and 1.5 m (2 and 5 ft.).

## · Appropriately thick asphalt layer

After surface preparation, there needs to be enough asphalt present to form a sufficient composite section that can carry the load. There must be enough asphalt to protect the concrete (minimize stresses), and enough concrete must be placed to protect the asphalt.

The main three potential causes for ultra-thin whitetopping failure, according to the conclusions reached from the eight intersection test sections constructed in the state of Tennessee [15-17] are: Hot Mixed Asphalt (HMA) thickness after milling, inadequately prepared asphalt base and insufficient bond between concrete and asphalt.

The following are the conclusions reached from the test sections constructed in Tennessee:

- The best joint spacing appears to be a ratio of 0.3 m/25 mm (1 ft. to 1 in.) of concrete depth.
- The Tennessee DOT has chosen to use a minimum thickness of 75 mm (3 in.) on state maintained roadways. Others have experimented with 50 mm (2 in.) which

needs a joint spacing of 0.61 m (2 ft.). However, the 50 mm (2 in) depth does not seem to be sufficient for most applications and the closer joint spacing is more expensive.

- The sawing of joints must be started as soon as the operator and the equipment
  can be supported by the concrete. Some light foot tracks occur when sawing this
  soon, but they seem to disappear with a few days of wear on the surface.
  Brooming and tining also can be done very early. A deep texturing of the surface
  is desirable for surface traction.
- A concrete mix with a compressive strength of 20.67 MPa (3000 psi) at 24 hours can be achieved by maintaining a low water-cement ratio. Traffic can be allowed on the surface within 18 to 24 hours. The use of a combination of admixtures, such as normal water reducers and high range water reducers, will always cause retardation. This usually causes problems for the finishing crew by extending the time required for sawing by several hours and may also retard enough to lower the strengths at 18 and 24 hours. It is therefore best to use high range water reducers only in achieving slump requirement.
- Using 1.362 kg (3 lb.) of polypropylene fibers per 0.765 m<sup>3</sup> (1 cu.yd.) appears to
  provide superior ductility and strength while improving impact, crack and freezethaw resistance.

Similar test sections were also [16-26] constructed in the states of Iowa, Georgia, North Carolina, South Carolina, Pennsylvania and New Jersey and the following conclusion was reached: Ultra-thin, synthetic fiber-reinforced concrete overlays at urban intersections using the bonded concrete technique are proving to be reliable alternatives to milling and replacing with HMA every two or three years.

Since the early 1970's, Iowa [16] had chosen whitetopping as the preferred rehabilitation method of overlaying rutted, worn-out asphalt pavements. More than 483 kilometers (300 miles) of roads and over 10 airports are now PCC overlays of asphalt. These overlays were designed by the traditional method with no consideration given to the possibility of the new PCC bonding to the old asphalt. As a result, these overlays were built 125+ mm (5+ inches) in depth. After doing research with bonding techniques, and

hearing favorable results from similar projects in other states, Iowa built its first ultra-thin whitetopping. This project, a 11.6 kilometers (7.2 miles) section of Iowa Route 21 between the towns Victor and Belle Plaine, was a joint project of the Iowa DOT, Iowa Concrete Pavement Association, the Federal Highway Administration and the American Concrete Pavement Association (ACPA) and was constructed by Manatt's Inc. of Brooklyn, Iowa.

Sixty-four different test areas were evaluated involving thickness of 51, 102, 152 and 203 mm (2, 4, 6 and 8 in.) and joint spacing combinations of 0.6, 1.2, 1.8 and 3.6 m (2, 4, 6 and 12 ft.). Most areas had 0.885 kg/cu.m. (1.5 lbs/cu.yd.) of fibers although some were not for the sake of experimentation. The existing surface was 89 mm (3.5 in.) of asphalt over 178 mm (7 in.) of cement treated base on a 152 mm (6 in.) granular subbase. The asphalt subbase was prepared three ways before placing the PCC overlay: patch only, patch and scarify, and cold-in-place recycle [16].

The concept of overlaying bituminous pavement [15] with a UTW 89 mm (3.5 in.) bonded layer of PCC has been applied to several projects, including a ramp in Bordertown, NJ, and two intersections in Allentown, PA. The principle concept is to place a thin layer of cement concrete as the wearing course with the primary stress being compression. The tensile stresses associated with structural slabs would be absorbed in the flexible bituminous layer. The concrete is sawed into small slabs (e.g. 1m x 1m [3 ft.x 3 ft.]) to alleviate stresses associated with expansion/contraction. The concrete itself is an accelerated concrete mix with fibers achieving high early strength to allow traffic on the pavement in 24 hours.

In October 1995, PennDOT [18] with the cooperation of the Federal Highway Administration began construction of a whitetop overlay for the maintenance of a curbed reinforced cement concrete ramp, at the interchange of U.S. Route 22 and Interstate 83 in Dauphin County, Engineering District 8-0, that had been overlaid with asphalt concrete. The proposed project was to place whitetopping over the existing bituminous overlay of the concrete ramp.

A thin, Portland cement concrete whitetopping project was constructed on Interstate 20 near Jackson, Mississippi in August 1997 [26], as a test of this technology

on a high traffic, high speed roadway. The primary objective of this project was to evaluate the potential of the 3M fibers to expand UTW applications to compete economically on routine roadways by extending slab length, since sawing and sealing ioints is a significant part of the cost of constructing a UTW. This project contained sections utilizing plain concrete, concrete containing 3M polyolefin fibers, and concrete containing fibrillated polypropylene fibers. Joint spacing for the 3M fiber section ranged from 1.82 m (6 ft.) to 12.2 m. (40 ft.). Joint spacing for the plain and fibrillated fiber sections was 3.65 m (12 ft) and 1.82 m (3 ft.), respectively. The whitetopping was done as an inlay in the truck lane of a hot mix asphalt pavement that had been rehabilitated four times since 1983 and still had unacceptable rutting. Total project size was 1220 m (4026) ft.) long and 3.65 m (12.04 ft.) wide and involved thicknesses of 100 mm, 150 mm, and 200 mm (3.9 in, 5.85 in. and 7.8 in.) This project was a model for thin whitetopping construction as it involved partnering with industry and various branches of government. extensive preconstruction design and trials to test the materials and methods, excellent quality control and quality assurance, and successful construction. Monitoring data included distress surveys, deflection surveys, and skid measurements.

In November 1996, Polyolefin Fiber reinforced concrete was used in the repair of Halifax International Airport Airfield in Nova Scotia, Canada [27]. A comparison of plain, conventional and unreinforced concrete was made with polyolefin fiber reinforced concrete for application of apron repair at the airport. The use of these fibers in the project was initiated through the required repair of the airport airfield and a desire to not use steel fibers, present in an earlier repair job. It was determined that the combination of both fiber reinforcement and an acceptable air voids system were significant in prolonging the freeze-thaw resistance of the concrete and thus increasing the durability. The addition of fibers did not compromise the strength of the composite material and increases in toughness and resistance to environmental conditions were noted. Polyolefin FRC was determined to be an acceptable replacement to both plain concrete and previous sections of steel fiber reinforced concrete.

In September 1994, South Dakota Department of Transportation (SDDOT) constructed a whitetopping [1,5-7] section on an asphalt bridge approach road at Vivian

(the bridge on the U.S. 83 number 43-026-195, over I-90 South of Pierre, SD). Two different fiber contents were used (11.9 kg/m³ [20 lbs./cu.yd.] and 14.8 kg/m³ [25 lbs./cu.yd.]). The depth of the whitetopping varied from 63 mm (2 ½ in.) to 115 mm (4 ½ in.). The dimensions of the whitetopping were 8.5 m (28 ft) wide and 32.6 m (107 ft) long. There was only one transverse and one longitudinal construction joint in the whitetopping. Periodic condition surveys were conducted and the behavior of the whitetopping was monitored. Only two hairline cracks were noticed. No corner cracking was observed. In September 1997, SDDOT constructed a whitetopping section at Rapid City at the intersection of Main Street and East Boulevard [28]. This is a high traffic multi-lane facility located at the east end of the downtown business district. The fiber type used was polyolefin (3M). Dosage rates and sawed joint spacing were as recommended by the fiber supplier.

Two ultra-thin whitetopping projects have been constructed by the Minnesota Department of Transportation [29]. The first was constructed on US-169, in Elk River and the other on I-94 at the Minnesota Road Research (Mn/ROAD) test facility. The US-169 site represents a typical application for the ultra-thin whitetopping. The first 236.4 m (788 ft.) north of each intersection was overlaid with 76.2 mm (3 in.) of fiber reinforced concrete and the following 3.6 m (12 ft.) was paved 203 mm (8 in.) thick. The existing pavement consisted of 228.6 mm (9 in.) of asphalt on a sandy subgrade. Temperature and dynamic and static strain sensors were installed at the intersection. On the I-94 a 342.9 mm (13.5 in.) full depth asphalt pavement at the Mn/ROAD research site was whitetopped with a fiber reinforced concrete overlay. The existing asphalt pavement was previously a transition zone, which separated the 5 and 10 year mainline test cells. The test section was divided up into six separate test cells with various thickness and joint patterns. The test cells were instrumented with strain, temperature and moisture sensors.

Prior to the above-mentioned projects, whitetopping was constructed in May 1995 at North Mankato at the southeast quadrant of the TH-169 and Webster Street intersection. The project was 30.6 m (102 ft.) long and is located on the two northbound lanes of TH-169, which is a four lane divided highway. The original pavement consisted of 304.8 mm (12 in.) of asphalt placed on a 508 mm (20 in.) of an aggregate base material

over a loamy clay subgrade. The whitetopping was a 76.2 mm (3 in.) overlay constructed using fiber reinforced concrete. Adjacent to this section an overlay was constructed using plain concrete. The second was constructed in 1996 on Lorry Drive at the intersection of TH-14 in North Mankato. The existing pavement consisted of 292 mm (11.5 in.) of Asphalt on 0.9 m (3 ft.) of select backfill material. A fiber reinforced concrete overlay of varying thicknesses was used. The overlay was 152.4 mm (6 in.) thick on the south end of the project and 76.2 mm (3 in.) on the north end with a 114.3 mm (4.5 in.) section separating the 152.4 and 76.2 mm (6 and 3 in.) sections.

The work to date has shown the use of Ultra-thin whitetopping overlays at high Average Daily Traffic (ADT) intersections is technically sound and reduces time spent repaving with Hot Mix Asphalt (HMA). The safety advantages are elimination of ruts and ridges, skid resistance and improved light reflection. The 1.36 kg (3 pounds) of synthetic fiber slightly enhances the fatigue strength and modify the cracking mechanism. With the expected life of an ultra-thin whitetopping project now being 8 to 12 years, its use in intersections should prove to be a very economical alternative [15-17].

Research Task 3: Propose the testing program, including lab and field tests and field evaluations that will be performed. In addition to the same lab and field tests that were performed in SD94-04, testing and evaluation should identify the behavior of the white-topping at joints and uncontrolled cracks. This may include measuring crack widths, curling measurements, and visual surveys.

#### Materials

#### **Fibers**

The non-metallic fibers (Polyolefin fibers) were purchased from 3M company, St. Paul, MN. The non-metallic fibers type 50/63 were 50 mm (2 in.) long with a diameter of 0.63 mm (0.025 in.). There were about 20,000 fibers per pound. Several hundred individual fibers were wrapped together in approximately 50 mm (2 in.) diameter bundle, and were packaged 11.3 kg (25 lbs.) per box. Typical physical properties of 3M polyolefin Type 50/63 are given below.

Specific Gravity 0.91

Tensile Strength 275 MPa (40,000 psi) Modulus of Elasticity 2647 MPa (384,000 psi)

Elongation at Break 15 - 17 %
Ignition Point 593°C (1100°F)
Melt Point 160°C (320°F)

Chemical and Salt Resistance Excellent
Alkaline Resistance Excellent
Electrical Conductivity Low

## **Quality Control Tests**

#### **Tests for Fresh Concrete**

The fresh concrete was tested for slump (ASTM C 143), air content (ASTM C 231), fresh concrete unit weight (ASTM C 138) and concrete temperature. The concrete from the unit weight container was washed and the fibers were separated and weighed to determine the actual fiber content in a cubic yard of concrete. The ambient temperature, humidity and wind velocity was also recorded.

#### Tests for Hardened Concrete

## Compressive Strength & Static Modulus

Cylinders were tested for compressive strength at ages 7 and 28 days according to ASTM C 39. Prior to the compression test the cylinders were also tested for the static modulus of elasticity (ASTM C 469) and for dry unit weight. The dry unit weight was obtained by dividing the weight of the specimen by the measured volume of the specimen.

#### Static Flexure Test

The beams were tested for flexural toughness (ASTM C 1018) at ages 7 and 28 days. According to ASTM C 1018, the beams were tested over a simply supported span of 300 mm (12 in.) and third point loading was applied to the beams. The deflection was measured at the mid-span by using a dial gage accurate to 0.00254 mm (0.0001 in.). The deflections were measured using a specially fabricated frame, which made it possible to measure the actual deflections eliminating all extraneous deflections due to the crushing

of concrete and testing machine deformations. This test was a deflection-controlled test. The rate of deflection was kept in the range of 0.05 mm to 0.10 mm (0.002 to 0.004 in.) per minute as per ASTM C 1018. The loads were recorded at every 0.00254 mm (0.0001 in.) increment in deflection till the first crack appeared after which the loads were recorded at regular intervals. The load corresponding to first crack and the maximum load reached were noted for each specimen. From the test results, load-deflection curves were drawn and ASTM toughness indices were calculated. The flexural toughness factor and equivalent flexural strength were also calculated using the Japanese standard method.

## Impact Test

The specimens were tested for impact strength at an age of 28 days by the drop weight test method (ACI Committee 544). In this method, the equipment consisted of a standard manually operated 4.54 kg (10 lbs.) weight with a 457 mm (18 in.) drop (compactor), a 63.5 mm (2-1/2 in.) diameter hardened steel ball, a flat steel base plate with a positioning bracket and four positioning lugs. The specimen was placed on the base plate with its rough surface facing upwards. The hard steel ball was placed on the top of the specimen and within the four positioning brackets. The compactor was placed with its base on the steel ball. The test was performed on a flat rigid surface to minimize the energy losses. The hammer was dropped consecutively, and the number of blows required to cause a visible crack which extended from the specimens center to its edge, was recorded. The impact resistance of the specimen to ultimate failure was also recorded by the number of blows required to open the crack sufficiently so that the pieces of specimen were touching at least three of the four positioning lugs on the base plate.

## Flexural Fatigue Test

In this investigation, the determination of the fatigue strength was quite important as it is one of the main improvements in concrete due to addition of fibers. Fatigue strength was defined as the maximum stress at which the specimen withstood more than 2 million cycles of non-reversed fatigue loading. For most of the fiber reinforced concrete

structures such as airport runways, highway pavements, and bridge decks, the 2 million cycles may represent typical fatigue loading over their life spans.

Similar to the static flexural test, third point loading is used with a span of 300 mm (12 in.) on 100 mm x 100 mm x 350 mm (4 in. x 4 in. x 14 in.) beams. The lower limit for the dynamic loading was set at 10% of the average maximum load from the static flexural test for the same mix category. The upper limit varied from 85% to 50% of the maximum load. If the beam failed before reaching 2 million cycles, then the upper load limit for the next beam was set at a lower percentage. If the beam survived 2 million cycles, then two or more beams were tested at the same percentage.

The frequency of loading used was 20 cycles per second (Hz) for all fatigue tests. The MTS machine was used for both static and flexural fatigue tests. It has a cyclic load capacity of 24950 N (55,000 lbs.). The control and monitor system consists of an MTS 436 control unit, a Hewlett-Packard oscilloscope and a digital multimeter with an MTS load cell. The machine could be operated in any one of the three modes: Load control (force applied to the specimen), strain control (strain induced in the specimen) or deflection control (distance traveled by the ram or deflection of the specimen). Since this test was concerned with stress levels, load control was used for fatigue testing.

There was a choice of three wave forms that could be used: sine wave, square wave and triangular wave. In these experiments the sine wave was used since it is closely related to the actual cyclic loading behavior.

A counter was provided to keep track of the number of cycles to the nearest hundred. When the beam failed, the counter reading was recorded and multiplied by 100 to give the number of cycles the beam had been subjected. A mechanical cut-off switch was provided which could turn off the machine when the beam failed.

## Modulus of Rupture Test (Static Flexural Strength)

For fatigue investigation, the beams were tested for static flexural strength (modulus of rupture) according to ASTM C 78 which was a load-control test. The same size beam, 100 mm x 100 mm x 350 mm (4 x 4 x 14 in.) was used with the same third

point loading over a span of 300 mm (12 in.). The specimens were tested at various ages just prior to the commencement of the fatigue testing.

## Static Flexure Test After Fatigue

The beams which survived more than 2 million cycles of non-reversed flexural fatigue loading, were tested again in static flexure, using the same procedure as described above (ASTM C 78).

## **Test Specimens**

A number of test specimens were cast. The following specimens were cast from each mix: 150 mm x 300 mm (6 in. x 12 in.) cylinders for compressive strength and static modulus tests, 100 mm x 100 mm x 350 mm (4 in. x 4 in. x 14 in.) beams for flexural strength, toughness tests and fatigue strength, 150 mm x 65 mm (6 in. x 2-1/2 in.) discs for impact strength.

All the specimens were cast in steel, plastic or wooden molds, which were taken to the job site on the day prior to the construction. The molds were well oiled. A portion of the fresh concrete from the ready-mix truck was discharged into a wheelbarrow to carry out the fresh concrete tests and to make specimens. The specimens were stored in insulated wooden boxes and were covered with plastic sheets and remained at the job-site for a period of 24 hours. They were then transported to the Concrete Technology Laboratory, SDSM&T, where they were demolded and placed in a lime saturated water tank for curing. The specimens remained in the curing tank until they were tested at the appropriate age.

## Mixture and Specimen Designation:

The trial mixes for whitetopping were conducted in the SDSM&T Concrete Laboratory and were labeled as follows:

- T1: Trial mix used for evaluating the performance characteristics of the concrete.
- T2: Trial mix used for the Maturity testing of concrete.
- T5: Trial mix used for the Fatigue testing of concrete.

For cylinder specimens, the second letter is C, for beam specimens, the second letter is B, and for impact specimens, the second letter is I.

Figures and Tables were also labeled as stated above.

Both mixes T1 and T2 were mixed on June 21, 1996 and Mix T5 was mixed on July 12, 1996.

Whitetopping test sections were constructed on Highway 14 near Mileage Reference Number (MRM) 222 west of Pierre, SD. The sampled specimens collected from the paving were designated as follows:

W1: The unjointed section of the west bound lane paved on July 23, 1996.

W2: The jointed section of the west bound lane paved on July 24, 1996.

W3: The jointed section of east bound lane paved on August 7, 1996.

W4: The unjointed section of the east bound lane paved on August 8, 1996.

Additional UTW sections were also constructed on the intersection of E.St.Patrick and St.Joe (Highway 79) Rapid City, SD. The sampled specimens collected from the paving were designated as follows:

WT1: The sample taken from a randomly selected truck during concreting on June 13, 1998.

WT2: The sample taken from a second randomly selected truck during concreting on June 13, 1998.

WT3: The sample taken from a third randomly selected truck during concreting on June 13, 1998.

WT4: The sample taken from a randomly selected truck during concreting on June 23, 1998.

## **Preconstruction Condition Survey**

The preconstruction condition survey of the asphalt pavement (before milling) on Highway 14 was done on June 18, 1996. The P.I., R.A., and two graduate students took part in the condition survey. The DOT engineers assisted the Research team by providing traffic control. The preconstruction condition survey of the asphalt pavement (before milling) on the site at Rapid City was done on June 12, 1998. The P.I., and three graduate

students took part in the condition survey. The condition survey was done according to the guidelines provided by the Strategic Highway Research Program (SHRP) publication "Distress Identification Manual for Long-Term Pavement Performance Project (LTPP)."

#### Cracks:

Fatigue cracking and block cracking was not found in the portion of the asphalt pavement surveyed. Extensive edge cracking, longitudinal cracking (both wheel path and non-wheel path) and transverse cracking were observed. These cracks had been sketched and their lengths and widths were measured. Sketches of these cracks and their location and widths are attached in Appendix F. The severity of transverse cracks is classified as per the SHRP LTPP manual as low (L), moderate (M), and high (H). As per the manual, a crack with mean width  $\leq 6$  mm (0.25 in.) is low severity (L); width  $\geq 6$  mm (0.25 in.) and  $\leq 19$  mm (0.75 in.) is moderate severity (M); and width  $\geq 19$  mm (0.75 in.) is high severity (H).

The location and widths of cracks on the asphalt pavement at Rapid City were noted down and are attached in Appendix F.

#### Patches and Potholes:

No patches were observed in the section surveyed. There was only one pothole on US14 about 0.1 sq. m. (1 sq. ft.) at 90+50 ft as shown in attached sketch [Appendix F]. No patches or potholes were observed on the section in Rapid City.

#### Rutting and Shoving:

No shoving was noticed; however extensive rutting was observed. The details of the depth of rutting measured on US14 are given in the attached Table F1, Appendix F (page F3). The rutting was measured at 30.5 m (100 ft.) intervals with one reading in each wheel path, at each transverse location.

## Bleeding, Polished Aggregates and Raveling:

Bleeding was not extensive, however a few patches of bleeding were noticed at the following locations on Highway 14:

Location	Size
94+35	1.52 m (5 ft.) long and 0.305 m (1 ft.) wide
96+35	0.305 m (1 sq. ft.)
102+75	127 mm (5 in.) by 127 mm (5 in.)
103+90	1.22 m (4 ft.) long and 0.305 m (1 ft.) wide
111+60	4.87 m (16 ft.) long and 1.22 m (4 ft.) wide
109+60 to 109+80	6.7 m (22 ft.) long and 152.4mm (6 in.) wide

Note: These bleedings may be due to the sand seal placed over the pavement in 1990.

Over the entire wheel path surface area some minor polished aggregates were seen; however it was not considered severe. No raveling was noticed.

### Water Bleeding and Pumping:

Traces of fine material left on the surface by pumping was mainly found in the unsealed transverse cracks at the wheel path. No evidence of pumping was found at sealed cracks.

After milling the pavement on Highway 14 was again surveyed on July 23, 1996 by the Research team.

Research Task 4. Evaluate whitetopping test sections from design through construction and subsequent service performance with special attention to the effects of joint spacing and thickness. Whitetopping test sections will be constructed on SD44 near Fish Hatchery in Rapid City and on US14 near MRM 222 west of Pierre. The panel envisions the following test and control sections at each site: two jointed 152 m (500 ft.) test sections each with a different thickness; two unjointed 152 m (500 ft.) test sections each with a different thickness; and one 305 m (1000 ft.) asphalt overlay control section.

Task 4a: In conjunction with SDDOT design personnel, review on the design and plans developed for the white-topping construction.

Throughout the project, the P.I. consulted the SDDOT design personnel and followed the design and plans developed for the UTW construction.

#### **US14 UTW**

In this project SDDOT's goal was to really test the performance of the material by using 63 and 89 mm (2.5 and 3.5 in.) UTW. Each thickness was designed to have two 153 m (500 ft.) test sections one with 15.3 m (50 ft.) joints and the other with no joints. The goal for the unjointed sections was to allow random transverse cracking and then determine the frequency. From this, safe maximum joint spacing could be determined for each thickness. The goal for the jointed sections was to use a large transverse joint spacing to see if any random cracks would occur. More random transverse cracks occurred in the 63 mm (2.5 in.) unjointed section than the 89 mm (3.5 in.) unjointed section. More corner cracking occurred in the 63 mm (2.5 in.) sections than the 89 mm (3.5 in.) sections. The corner cracks are being held tight by the fibers. No section has experienced loss of material preventing hazards to the traveling public.

### Rapid City UTW

As stated in Task 4 of the original project statement, one of the proposed sites for a UTW project was near the Fish Hatchery on SD44 in Rapid City. No UTW was placed at this location due to an insufficient asphalt thickness expected after milling the surface. Once it was found that the Fish Hatchery site was inadequate, attempts were made to find another construction project in which a whitetopping or UTW could be incorporated. Locating a second project (St. Joseph/St. Patrick Intersection) took longer than anticipated causing a time extension for the research project.

As for the St. Joseph/St. Patrick intersection, SDDOT had less control since this section of street would be turned over to the city of Rapid City when the construction was complete. Therefore this project was done with more conservative joint spacing of 6.1 m (20 ft.). Also SDDOT recommended a thickness of 100 mm (4 in.), however, since Rapid City was paying for the UTW only 76 mm (3 in.) was placed.

## Task 4b: In conjunction with SDDOT design personnel, design the concrete mix.

A mixture proportion was selected based on previous laboratory and field experience in the construction of NMFRC UTW prior to the start of the project. Actual aggregates to be used in the project were obtained from the contractor and trial mixes were made at the South Dakota School of Mines and Technology Concrete Laboratory. Based on the trial mixes and in consultation with the Technical Panel, the final mixture proportions were selected.

The following mixture proportions were recommended for the UTW concrete.

Cement (Type II)	341 Kg/m <sup>3</sup>	(575 lb./cu. yd.)
Fly Ash	$68 \text{ Kg/m}^3$	(115 lb./cu. yd.)
Water	$172 \text{ Kg/m}^3$	(291 lb./cu. yd. or 35 gal)
Coarse Aggregate(Size 1)	$830 \text{ Kg/m}^3$	(1400 lb./cu. yd.)
Fine Aggregate	$830 \text{ Kg/m}^3$	(1400 lb./cu. yd.)
Polyolefin Fibers	$14.8 \text{ Kg/m}^3$	(25 lb./cu. yd.)
Water Cementitious Ratio	0.45 max.	
Slump	75 to 140 mm	n (3 to 5½ in.)
Air Content	$6 \pm 1.5 \%$	

The proportions used in the batches gave good workable concrete and the fibers were well distributed in the concrete. The fibers mixed well without causing any balling, segregation, or fiber lumping.

The slump varied depending on the air content, the concrete temperature, ambient temperature and wind condition. Medium or High Range Water Reducers (HRWR) (Superplasticizers) were added at the plant or at the job-site to increase the slump to the 88.9 mm (3 ½ in.) to 101.6 mm (4 in.).

The quantity of air entraining agent required depended on many factors such as type of air entraining agent, the concrete temperature, slump, and ambient weather conditions. It was recommended that the contractor use the appropriate amount of air entraining agent and HRWR to achieve the specified slump and air content.

# Task 4c: Conduct hardened concrete tests on the mix design(s) to ensure desired properties are obtained.

The batches for UTW were conducted in the SDSM&T Concrete Laboratory on June 21, 1996 and July 12, 1996. The batch designated as T1 was used for evaluating the performance characteristics of the concrete. The batch designated as T2 was used for the Maturity testing and batch T5 for the Fatigue testing of concrete. Mixes T1 and T2 were mixed on June 21, 1996 and Mix T5 was mixed on July 12, 1996. The performance characteristics of the batch T1 are included in the Appendix A. The Maturity testing was done as per ASTM C1074-93. For the Maturity testing, two cylinders were tested in compression for one, three, four, five, seven, fourteen and twenty-eight days. Maturity meter readings were taken from two outlets for two cylinders cast from the same mix. Details for the maturity testing are also included in the Appendix E.

## Task 4d. Attend preconstruction meetings and recommend NMFRC construction methods.

#### **US14 UTW**

The P.I. and the R.A. attended the preconstruction meeting on June 11, 1996 in the Pierre Area Office. The meeting was presided by Norman Konechne, Pierre Area Engineer. The personnel attending the preconstruction meeting also included, the representatives of Contractor, Sub-Contractor, Research Panel, and DOT engineers. In this meeting the possible dates for milling and paving were discussed. The aggregates to be used in the paving operation were also finalized. The possible dates for the preconstruction condition survey of the asphalt pavement (before milling) were also discussed.

### Rapid City UTW

The P.I. attended the preconstruction meeting on May 12, 1998 at the SDDOT Regional Office, Rapid City. The personnel attending the preconstruction meeting included the contractor, concrete supplier and three DOT engineers. In this meeting the possible dates for milling and paving were discussed. The aggregates to be used in the

paving operation were also finalized. The possible dates for the preconstruction condition survey of the asphalt pavement (before milling) were also discussed.

Task 4e. Perform quality control testing, record weather conditions, and observe and record construction activities.

#### Quality Control Testing for US14 UTW

For both the lanes on Highway 14, fresh concrete was tested for slump (ASTM C 143), air content (ASTM C 231), and fresh concrete unit weight (ASTM C 138). The temperature of the fresh concrete was also recorded. All results are included in Appendix B.The properties of fresh concrete used in the overlay are given in Tables B1 (page B-1). Also included in Tables B1-A (page B-2) are the results of tests conducted by the DOT personnel. The unit weights calculated did not vary much. The actual measured fiber contents in the samples taken from the field concrete were close to the specified amounts and are recorded in Tables B1. The measured slumps are shown in Figures B1 (page B-16) and the air contents are given in Figures B2 (page B-16). The fresh concrete unit weights are given in Tables B1 (page B-1). B7 (page B-10). The number of specimens cast during each of the quality control sampling is given in Tables B2 (page B-1) and B8 (page B-10).

#### Quality Control Testing for Rapid City UTW

The same quality control tests done for US14 UTW were done for the Rapid City UTWand all results are included in Appendix B.

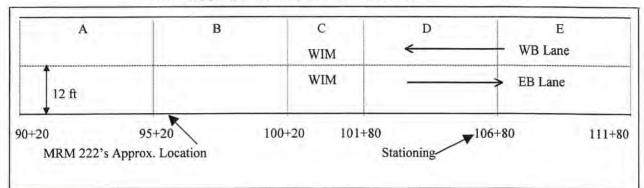
The mixture proportions used are given in Table WR1 (page B-23) and the fresh concrete properties and ambient conditions are given in table WR2 (page B-23). The results of tests conducted by DOT personnel are given in page B-22.

Fresh concrete unit weight did not vary much and the measured fiber contents except for mix WT4 were close to the specified amounts. The measured slumps are shown in Figure WR1 (page B-31) and the air contents are given in Figure WR2 (page B-31).

#### Construction of US14 UTW

UTW test sections were constructed on Highway 14 near MRM 222 west of Pierre. The west bound lane was paved on July 23 and 24, 1996 and the east bound lane was paved on August 7 and 8, 1996. At each lane, the following test and control sections were constructed as shown in the sketch

White-topping Layout (Near MRM 222)



Test Section	Length (ft)	Туре	Thickness (in)	Joint Spacing (ft)	Volume of Fiber Concrete (yd³)
A	500	Fiber (25 lbs/yd³)	2.5	50	93
В	500	Fiber (25 lbs/yd³)	3.5	50	129
C	160	Plain	12	20	
D	500	Fiber (25 lbs/yd³)	3.5	No Joints	129
E	500	Fiber (25 lbs/yd³)	2.5	No Joints	93
Asphalt Overlay (Not Shown)	500	Control			
				Total	444

The unjointed section of the west bound lane was paved on July 23, 1996. The ambient temperature varied from 21°C (69°F) to 35°C (95°F) and humidity varied from 55% to 20%. The concrete temperature varied from 26.2°C (79.2°F) to 28.6°C (83.5°F). The jointed section of the west bound lane was paved on July 24, 1996. The ambient temperature varied from 15.5°C (60°F) to 35°C (95°F) and humidity varied from 70% to 30%. The concrete temperature varied from 24.3°C (75.8°F) to 27.5°C (81.5°F). The jointed section of east bound lane was paved on August 7, 1996. The ambient temperature varied from 26.1°C (79°F) to 33.3°C (92°F) and humidity from 40% to 30%. The

concrete temperature varied from 25.2° C (77.3°F) to 27.4° C (81.3°F). The unjointed section of the east bound lane was paved on August 8, 1996. The ambient temperature varied from 23.8° C (75°F) to 32.2° C (90°F) and humidity from 60% to 30%. The concrete temperature varied from 25.2° C(77.3°F) to 28.9° C (84.8°F). The P.I., R.A., and three graduate students attended the construction of the whitetopping. Concrete was sampled randomly and tested for fresh concrete properties.

Ready-mix concrete was supplied by Morris Redi-Mix. Fibers were mixed with concrete at the batching plant and then the ready-mixed NMFRC was supplied in trucks. The ready-mixed NMFRC was as workable, placeable, and finishable as plain concrete. The curing specifications and procedures were followed as per SD DOT standards.

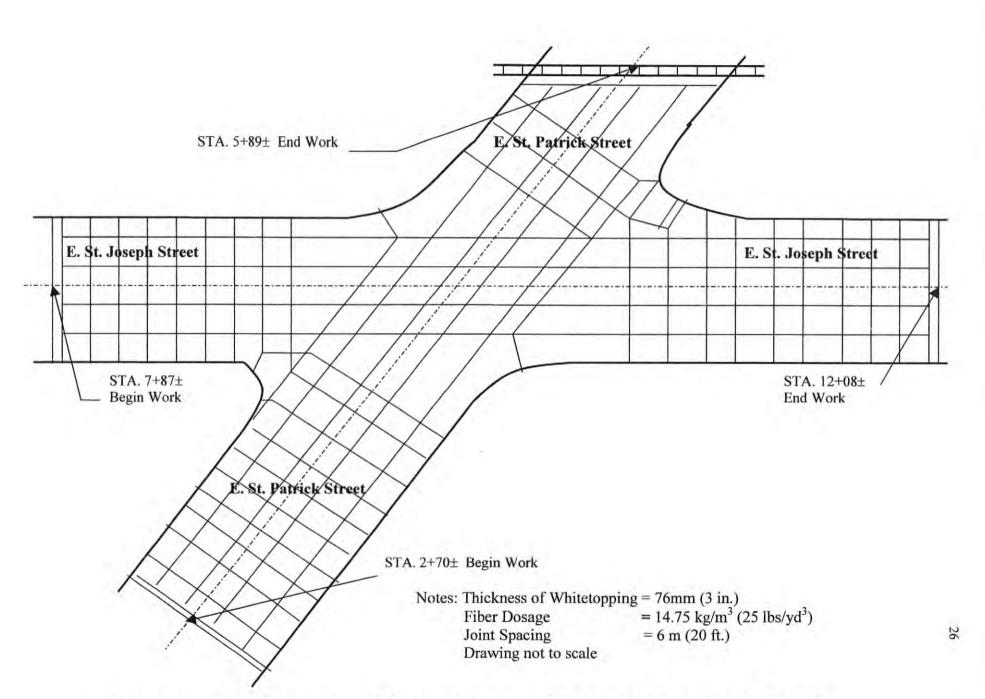
### Construction of Rapid City UTW

Whitetopping sections were also constructed on the intersection of E.St.Patrick and St. Joe (Highway 79) Rapid City, SD as shown in the following sketch.

The section on St. Joe street was paved on June 13, 1998 and the section on E. St. Patrick street was paved on June 23, 1996. On June 13, 1998, the ambient temperature varied between 4°C and 10°C (40°F and 50°F) and humidity varied between 50% and 80%. The concrete temperature varied between 28°C and 30°C (82°F and 86°F). On June 23, 1998, the ambient temperature varied between 7°C and 15°C (45°F and 60°F) and humidity varied between 65% and 80%. The concrete temperature was 30°C (86°F). The P.I. and three graduate students attended the construction of the whitetopping. Concrete was sampled randomly and tested for fresh concrete properties.

#### Construction Procedure - US14 UTW

The following construction procedure was observed. After the concrete was mixed the fibers were added into the truck at the plant and mixed for an additional 5 minutes. Then the ready mix truck delivered the concrete to the site. A Bidwell Paving machine was used. As soon as the concrete was placed in front of the paver, two persons moved the concrete and distributed it properly. There was one person to guide the chute.



Whitetopping at the Intersection of St. Joseph Street and St. Patrick Street, Rapid City, SD

After the paving machine passed, the concrete was bull floated and finished with a straight edge. Before bull floating, the edges were hand finished by two finishers one at each side. Then Astro-turf was dragged over the concrete surface in the direction of traffic. Then the tining was done in the transverse direction. The curing compound was applied about 15 to 20 minutes after the finishing operation before the concrete surface completely dried.

The DOT engineer and his assistants were checking the string lines, and were also marking the location of the saw-cut joints. They were also stamping the stationing on the road.

After the tining operation, it was noticed that the tining was too deep or too shallow in two locations. Each of these areas were about 30 m (100 ft.) long. The explanation given by the tining operator for the shallow tining, was that the concrete set up fast due to the high wind. Then as he caught up to the paving operation, he moved back into fresher concrete.

One typical day, the number of persons involved in the concrete placement and finishing operation was as follows:

Concrete Spreaders 4 persons
Chute Regulator 1 person
Water Sprayer to moisten asphalt surface 1 person
Paving Operator 1 person
Edge finishing behind the machine 2 or 3 persons
Bull Floating, Straight Edge and Carpet Drag 2
Tining and Curing Compound Spraying 1 person
Guide Rail moving 2 persons

## Construction Procedure - Rapid City UTW

Concrete was supplied by Hills Red-E-Mix Co. Fibers were mixed with concrete at the batching plant and then the NMFRC was supplied in trucks. The NMFRC was as workable, placeable, and finishable as plain concrete. The curing specifications and procedures were followed as per SD DOT standards.

The construction procedure was similar to that used in US14 UTW.

## Task 4f. Conduct performance tests of hardened concrete on the collected field samples.

## For Section on Highway 14

The compressive strengths and elastic modulus values are given in Table B3 and B9 pages B-4 and B-11, respectively. A comparison of the compressive strengths for different batches is shown in Figure B3 page B-18. The 7-day average compressive strength recorded was 23.2 MPa (3370 psi for W1), 28.8 MPa (4175 psi for W2), 24.3 MPa (3530 psi for W3), and 26.3 MPa (3810 psi for W4). The 28-day average compressive strength recorded was 29.9 MPa (4330 psi for W1), 38.6 MPa (5605 psi for W2), 33.0 MPa (4790 psi for W3), and 33.0 MPa (4785 psi for W4), which was a considerable variation in the field concrete. The variation in the elastic modulus values was consistent with that of the compressive strength variation. These variations were due to lack of adequate quality control by the concrete suppliers. However all cylinders tested failed at a higher strength than the design strength of 27.6 MPa (4000 psi).

The first crack strength and the modulus of rupture values are given in Table B4 and B10 (pages B-5 and B-12) and Figures B4 (page B-17) and B5 (page B-18). There was not a significant variation in the modulus of rupture for different batches.

The toughness indices calculated according to the ASTM standard procedures are given in Tables B5 and B11 (pages B-6 and B-13). The first crack toughness is compared in Figure B6 (page B-18) and the toughness indices I5, I10, and I20 are compared in Figure B7 and B8 (page B-19). The ratios of I10/I5 and I20/I10 are compared in Figure B9 and B10 (page B-20).

The ASTM toughness indices were approximately the same at 7 and 28 days which was normally expected. Toughness indices I5, I10 and I20 were respectively 4, 8, and 15 times higher than that of plain concrete because for plain concrete these values were 1. The ratios I10/I5 and I20/I10 indicated a very ductile behavior.

The Japanese standard toughness and equivalent flexural strengths are shown in Tables B5 and B11 (pages B-6 and B-13) and Figure B11 and B12 (page B21), respectively. The comparisons also confirmed the increase in ductility and toughness of the concrete due to the addition of polyolefin fibers.

The impact resistance of the concretes are given in Table B13 page B-15. There was high impact strength due to the addition of polyolefin fibers. The number of blows for ultimate failure in NMFRC was above 200.

### Fatigue Strength and Fatigue Life

Flexural Fatigue Tests were conducted and all the results have been included in a previous report (Study SD96-15 Final Report, December 1998). A summary of the tests conducted and results are as follows:

To predict the fatigue life for concrete, S-N curves (the fatigue stress vs. the number of cycles or log number of cycles) were used. The flexural fatigue strength ( $f_f$ ) vs. the log number of cycles for all four concretes (plain, SFRC, NMFRC and NMFRC-2) were plotted. There was a linear relationship between the fatigue stress ( $f_f$ ) and the log number of cycles, until the fatigue strength ( $f_{max}$ ) of that particular concrete was reached, then the line became parallel to the x-axis indicating that there was an endurance limit for concrete. The same type of behavior was observed for all concretes. There was an increase in fatigue strength and fatigue life with the addition of polyolefin fibers.

All beams, which had withstood 2 million cycles, were further tested for static flexural strength ( $f_r$ ). There was an increase in the static flexural strength ( $f_r$ ) for both plain and FRC after they were tested for fatigue. This observed increase (from 10 to 20%) was higher than the strength gain that could be attributed to the aging of the test specimens. The same phenomenon was observed in all our earlier extensive fatigue testing of plain and fiber reinforced concretes. The amount of increase in  $f_r$  seemed to depend on the flexural fatigue stress ( $f_r$ ) to which the specimens were subjected during the fatigue testing. With lower  $f_r$  values, the increase in  $f_r$  was higher. It was suggested that this post fatigue increase in  $f_r$  compared to the pre-fatigue  $f_r$  was due to densification of concrete caused by initial low stress level cycling, in a manner similar to the improvement in strength under moderate sustained loading.

All the available fatigue test results from the three studies (SD 94-04, SD96-13, and SD96-15) were combined together and an extensive statistical analysis was done. All concretes with the same fiber dosage (14.8 kg/m<sup>3</sup> – 25 lb/cu.yd.) and varying compressive

strengths were selected and using statistical and probabilistic concepts, a multiregression analysis was conducted. A constitutive model was developed to predict the fatigue life and endurance limit for NMFRC concrete with compressive strengths varying from 27.6 Mpa to 55.2 Mpa (4000 psi to 8000 psi) and having fiber content of 14.8 kg/m³ (25 lb/cu.yd.). The detailed analysis and the equations were included in a paper, which was reviewed and accepted for presentation and published by the American Concrete Institute (ACI). The paper was presented as a keynote paper in the International Conference on High-Performance Concrete in Gramado, RS, Brazil and published in ACI special publication, No.186. [30]

## For Section at Rapid City

The compressive strengths at 3, 5, 7 and 14 days are given in Tables WR3, WR4 (pages B-24 and B-25) and the compressive strengths and elastic modulus values at 28 days are given in Table WR5 (page B-26). Comparison of the compressive strengths for different batches at 14 and 28 days are shown in Figures WR5 and WR6 (page B-33). The 3-day average compressive strength recorded was 21.5 MPa (3115 psi) for WT1 and 23.1 MPa (3338 psi) for WT4. The 5-day average compressive strength recorded was 27.4 MPa (3970 psi) for WT1 and 32.3 MPa (4678 psi) for WT4. The 7-day average compressive strength recorded was 30.7 MPa (4438 psi) for WT1 and 35.4 MPa (5123 psi) for WT4. The 14-day average compressive strength recorded was 32.0 MPa (4630 psi) for WT1, 31.4 MPa (4545 psi) for WT2, 35.8 MPa (5182 psi) for WT3 and 37.9 MPa (5483 psi) for WT4 .The 28-day average compressive strength recorded was 33 MPa (4780 psi )for WT1, 38.9 MPa (5635 psi) for WT2, 39.5 MPa (5717 psi) for WT3, and 43.5 MPa (6300 psi) for WT4, which was a tolerable variation in the field concrete. The variation in the elastic modulus values was consistent with that of the compressive strength variation. These variations were also higher than normal for field concrete. However all strengths obtained were higher than the design strength of 27.6 MPa (4000 psi).

The modulus of rupture values at 14 and 28 days are given in Tables WR6 (page B-27) and WR7 (page B-28) and Figures WR8 and WR9 (page B-34 and B-35)

respectively. There was not a significant variation in the modulus of rupture for different batches.

The toughness indices calculated according to the ASTM standard procedures are given in Table WR8 (page B-29). The first crack toughness is compared in Figure WR10 (page B-35) and the toughness indices I5, I10, and I20 are compared in Figure WR11 (page B-36). The ratios of I10/I5 and I20/I10 are compared in Figure WR14 (page B-37).

Toughness indices I5, I10 and I20 were respectively 4, 8, and 15 times higher than that of plain concrete because for plain concrete these values were 1. The ratios I10/I5 and I20/I10 indicated a very ductile behavior.

The Japanese standard toughness and equivalent flexural strengths are shown in Table WR9 (page B-29) and comparisons of the same are shown in Figures WR12 and WR13 (page B-36 and B-37) respectively. The comparisons also confirmed the increase in ductility and toughness of the concrete due to the addition of polyolefin fibers.

The impact resistance of the concretes is given in Table WR10 (page B-30). There was high impact strength due to the addition of polyolefin fibers. The number of blows for ultimate failure in NMFRC was above 150 on an average. The impact test for plain concrete was not done. But based on the knowledge of the previous research experiments it would be between 20 to 30 (1).

## Task 4g: Periodically conduct condition surveys to evaluate the field performance of the constructed whitetoppings.

Throughout the project, the work was done in consultation and with approval from the Technical Panel. Periodic condition surveys were conducted to evaluate the performance of the constructed UTW. These condition surveys were conducted at two weeks, one month, 3 months, 6 months, 1 year, and at the latest possible date prior to the end of the contract (June 19,1999). In addition detailed observations were made about the behavior of the UTW at joints and uncontrolled cracks. The lengths and widths of these cracks were accurately measured and recorded over the contract period.

#### US14 UTW

#### West Bound Lane

After the paving on July 23 and 24, 1996, the west bound lane was inspected on July 29, 1996. In the 63.5 mm (2.5 in.) section of the unjointed whitetopping, 8 cracks were observed. Also in the 88.9 mm (3.5 in.) section of the unjointed whitetopping, 8 cracks were observed. Two random cracks (in addition to the control joints) were noticed in the jointed section of the Whitetopping. This is believed to be because of the delay in the cutting of the concrete, by the contractor. The west bound lane was again inspected on August 6 and 7, 1996. The third inspection of the west bound lane was done on August 14, 1996. The fourth, fifth, and sixth inspections of the west bound lane were done respectively on August 25, September 7, and October 15, 1996. All the cracks were routed and silicone sealed before the fifth inspection. Very narrow corner cracks were first noticed during the fifth inspection, in the jointed section of the whitetopping. There was not much change in the corner cracks during the sixth inspection. The details of the inspection are given in Appendix C.

#### **East Bound Lane**

The east bound lane was paved on August 7 and 8, 1996, the pavement was inspected on August 14, 1996. In the 63.5 mm (2.5 in.) section of the unjointed whitetopping, 7 cracks were observed. Also in the 88.9 mm (3.5 in.) section of the unjointed whitetopping, 4 cracks were observed. No cracks were noticed in the jointed section of the Whitetopping. The second, third, and fourth inspections of the east bound lane were done respectively on August 25, September 7, and October 15, 1996. All the cracks were routed and silicone sealed before the second inspection. Very fine corner cracks were first noticed during the third inspection, in the jointed section of the whitetopping. One corner crack was also noticed in the unjointed section. This was a corner crack to a transverse random crack. There was not much change in the corner cracks during the later inspections. During the fourth inspection, one longitudinal crack was noticed in the 63.5 mm (2.5 in.) jointed section of the whitetopping. The crack extended over the entire panel length. Details of the inspection are given in Appendix C

Four additional inspections were done on May28 and 29, 1997; July 28,1997; November 7, 1997 and April 17, 1998. During each of these inspections the P.I and two graduate students participated in the survey. Both east bound and west bound lanes were carefully observed for corner cracks, new transverse and longitudinal cracks, cracks in asphalt shoulders and exposed fiber bundles. All the cracks, new and old, were mapped and the widths were measured by a crack-measuring gage. The exposed fiber bundles and their locations were noted down. The exposed fiber bundles area appeared as small holes on the surface of the pavement as the fibers in the bundles were without any bond and got washed away. All the details of the cracks, their widths and locations are shown in the figures given in the Appendix C. The figures are shown separately for each inspection with the newly observed cracks in dotted lines so that the progress and development of the cracking could be clearly seen.

The last inspection was done by the P.I on June 19, 1999 in order to assess the overall performance of the whitetopping and status of the cracking. There were no new cracks observed. The old cracks seemed to have stabilized. They did not widen or expand. Only the initial transverse cracks were routed and sealed. All cracks appearing after the 3<sup>rd</sup> inspection were not sealed. In the locations where unopened bundles were located, a photograph (Photo 1, page 35) was taken to show the current status of these bundles. Most of the fibers are intact in the holes.

There was rain in the previous night. Hence water-pumping action was seen. Water was oozing out of the transverse cracks in the shoulder asphalt and along the longitudinal edge of the whitetopping. Water was also seen in some of the corner cracks (Photos 2 and 3, pages 35 and 36). The worst of the corner cracks and longitudinal cracks are shown in Photos 2 and 3. The worst corner cracks noticed in the centerline of the pavement are shown in Photo 4 (page 36). (Pennies are placed on the pavement for size comparison)

#### **UTW** at Rapid City

The first inspection of the UTW was done at 6 p.m. on June 13, 1998 to see whether any plastic shrinkage cracks have occurred. No cracks of any type were noticed.

All the joints had been cut. Some of the joints were filled with dust, sand and small aggregate particles making them ineffective. It seemed that some joints were cut too soon causing raveling at the joints.

The second inspection was done on June 14<sup>th</sup> at 11 am. Again the entire UTW was inspected. No Cracks were found.

The third inspection was done on June 17, 1998. Traffic was allowed on the UTW, which was placed on June 13, 1998, that is 4 days after the concrete was placed. The three-day strength was about 20.69 Mpa (3000 psi). During the inspection, no shrinkage or other cracks were found.

The fourth inspection of the UTW was done on Sunday, July 12, 1998, from 3 to 5 p.m. Sunday was selected because of the low traffic volume. The P.I and two graduate students did the inspection.

No unopened fiber bundles were spotted on the surface of the pavement. Also no plastic shrinkage cracks were found on the pavement. Only a few fibers per square yard (10 to 15) were visible on the top surface.

Two diagonal cracks were noted approximately 0.81 mm (0.032 in.) wide on St. Joseph Street (Street Highway 79). These cracks were on the either side of a sawed joint, 457.2 mm (18 in.) long on one side and 787.4 mm (31 in.) long on the other. These cracks were not sealed. The cracks are located next to a drainage inlet and may have been caused by settlement of the inlet due to lack of consolidation. Additionally, there was a smaller diagonal crack inside the larger diagonal crack.

There was a smaller diagonal crack about 0.3 m (1 ft.) long at the junction of the two saw cut joints joining at an acute angle. The average width of the crack was 0.5 mm (0.02 in.) and it was not sealed. There were two small diagonal cracks, which were sealed at the junction of saw cut joints. They were about 254 mm (10 in.) long.

The fifth inspection of the UTW was done on Sunday, August 30, 1998, from 3 to 5 p.m. No unopened fiber bundles were spotted on the surface of the pavement. Also no plastic shrinkage cracks were found on the pavement. Only a few fibers per square yard (10 to 15) were visible on the top surface.



Photo 1. Seven unopened bundles imbedded in the pavement as seen on June 19, 1999. Most fibers are intact in the holes. (Pennies are shown for size comparison.)



Photo 2. Water pumping action due to a previous night rain. Water was oozing out of the transverse cracks in the shoulder asphalt and along the longitudinal edge of the UTW. This was also the most severe longitudinal crack observed (Pennies are shown for size comparison.)



Photo 3. Water was oozing out of a corner crack due to pumping action. This was also the most severe corner cracking observed.

(Pennies are shown for size comparison.)



Photo 4. The most severe corner crack noticed in the centerline of pavement. (Pennies are shown for size comparison.)

There was a longitudinal crack approximately 0.81 mm (0.032 in.) wide on St. Joe street. This crack was very near and along the curb and 2.5 m (8 ½ ft.) long. This crack was not sealed and it had two smaller cracks branching out which were the same widths as the main crack. These smaller cracks extended from the main crack into the curb. There was also a diagonal crack approximately 0.81 mm (0.032 in.) wide at the end of the main crack which was 203.2 mm (8 in.) long on one side and 177.8mm (7 in.) long on the other.

There was a smaller diagonal crack about 0.38 m (1'3") long on E. St. Patrick street. The average width of the crack was 0.81 mm (0.032 in.) and it was not sealed.

There were two new diagonal cracks, branching from the old crack on Highway 79 which were both about 0.81 mm (0.032 in.) wide and they were about 0.50 m (1'8") and 254 mm (10 in.) long respectively. There was another diagonal crack on Highway 79 which was also 0.81 mm (0.032 in.) wide and 0.3 m (1 ft.) long on one side and about 228.6 mm (9 in.) on the other.

There was a new diagonal crack approximately 0.81 mm (0.032 in.) wide at the junction of E. St. Patrick and St. Joe streets which was about 0.3 m (1 ft.) long on one side and 254 mm (10 in.) on the other.

There were three other diagonal cracks on St. Joe Street, which were about 0.76 mm (0.030 in.) wide and were about 0.3 m (1 ft.) long on either side.

The sixth inspection of the UTW was done on Sunday, November 29, 1998. No unopened fiber bundles were spotted on the surface of the pavement. Only a few fibers per square yard (10 to 15) were visible on the top surface.

All the cracks observed and mapped earlier did not widen or extend in length.

There was no further damage around the cracks. It looked like the fibers were holding the cracks together and did not allow further widening.

Two new diagonal cracks were found on both sides of a joint on St. Joseph Street. The first of these cracks was about 0.45 m (1'6") long on one side and 0.68 m (2'3") long on the other and had an average width of 0.25 mm (0.009 in.). The crack on the other side of the same joint was 0.56 m (1'10") long on one side and 0.69 m (2'3") long on the other side. This crack was also about 0.25 mm (0.009 in.) wide on an average. The other two

diagonal cracks had formed on the adjacent slab and had lengths of 0.48 m (1'7") on one side and 0.76 m (2'6") on the other and 0.3mm (0.011 in.) and 0.5 mm (0.019 in.) wide respectively. Other than these cracks a new crack had developed from the older one on St. Joe and was about 0.6 m (2 ft.) long on either side and had an average width of 0.80 mm (0.031 in.). All of these cracks were not sealed. All the new cracks have been marked on the map. Quite a few cracks were observed on the old curb and gutter.

A thorough final inspection of the UTW was done on Saturday, February 28, 1999. The P.I and three graduate students did the inspection.

No unopened fiber bundles were spotted on the surface of the pavement. Also no plastic shrinkage cracks were found on the pavement. A number of fibers per square yard (25 to 30) were visible on the top surface.

There was development of quite a number of new cracks as compared to the previous inspections. More cracks were noticed on the St. Joe Street. There was a longitudinal crack approximately 1.01 mm (0.04 in.) wide on left lane of St. Joe street and very near the junction of St. Joe and E. St. Patrick Streets. This crack was very near and along the curb and 3.3 m (11 ft.) long and was not sealed. There were diagonal cracks at almost all the junction points of joints along the centerline of the pavement on St. Joe Street. These cracks were not sealed and they were about 0.6 m (2 ft.) long on an average and were approximately 0.81 mm (0.032 in.) wide.

About nine diagonal cracks were noticed at the junction on St. Joe and E. St. Patrick Street on the lane heading east. These cracks had an average length of about 0.6 m (2 ft.) and their widths varied between 0.63 mm (0.025 in.) to 1.52 mm (0.06 in.). There were no new cracks on the E. St. Patrick Street away from the junction area. Diagonal cracking was also noticed on Highway 79 on both the lanes. There were three new cracks on the right lane. The first one was 0.91 m (3 ft.) long on one side and 482 mm (19 in.) long on the other (approximate average width of 1.27 mm - 0.05in.). The other two diagonal cracks were on either side of a joint and were 533.4 mm (21 in.) long on one side and about 508 mm (20 in.) long on the other side. Their average width was 0.81 mm (0.032 in.). On the left lane of Highway 79 ten new cracks were noted out of which two of the cracks had developed from older cracks. About seven of these cracks had average

lengths of about one foot and widths of about 1.01 mm (0.04 in.) The rest of the cracks were about 0.6 m (2 ft.) long on either side and were of the same average width as the other cracks.

On the left lane of St. Joe Street two new diagonal cracks were noted on one side of a joint. One was a branch of the other. The main crack was two feet long on either side and the branch was about 0.3 m (1 ft.) long on one side and about 0.6 m (2 ft.) long on the other. The average crack width of the main crack was about 1.01 mm (0.04 in.) and that of the branch crack was about 0.51 mm (0.02 in.)

All details of the crack widths and locations are given in tables and maps in Appendix C.

## General discussion and comments about the performance of UTW Corner Cracking:

There was extensive and considerable corner cracking (diagonal cracking) in both Highway 14 and Rapid City UTW. These cracks increase in number with time as the traffic increases. The corner cracks in Highway 14 are more in number and some are wider. There were more corner cracks on the thinner section of the US14 UTW than the thicker section. The corner cracks occurred mostly at the junctions of saw cut joints. In Highway 14, there was also corner cracking in the unjointed section of the UTW. The crack frequency was the same for both jointed and unjointed 63 mm (2.5 in.) sections and the crack frequency for both the 89 mm (3.5 in.) sections was also the same.

The cracks, once formed, did not widen very much and the fibers seemed to restrict the widening of the cracks and to some extent contained the crack propagation. The cracked concrete was held together by the fibers. The extensive, but narrow cracks did not seem to effect the riding quality of the pavement. Wider cracks might deteriorate the riding quality and would lead to progressive and extensive damage.

Personal observations by the author and literature review had shown that corner cracking occurred when the UTW's were opened for traffic in various parts of the country such as Virginia, Mississippi, Minnesota, Pennsylvania and Tennessee. The extent of the cracking depended normally on the thickness of the whitetopping and the thickness of the

asphalt layer after milling and surface preparation. The base and/or sub-base conditions had an influence on the corner cracking. It was interesting to note that shorter joint spacing did not eliminate corner cracking.

It is believed that lack of adequate bond and composite action leads to corner cracking. The bond between the milled asphalt surface and the overlaid concrete seems to play a significant role in the performance of whitetopping. Bond between the asphalt and the concrete would create a composite action and reduce the tensile stresses in the concrete.

#### Longitudinal and Transverse Cracks:

In Highway 14, transverse cracking occurred in the unjointed section of the UTW. However there were no significant transverse cracking in the jointed section even with 15 m (50 ft.) joint spacing. Extensive longitudinal cracking occurred in the thinner section.

## Fiber's Ability to Prevent Loss of Material

Even though the UTW's might have areas where extensive cracking occurred, the NMFRC was holding together and minimized the large cracks, spalling, and loss of material (reducing potential hazards to the public) than a plain concrete UTW or a UTW with a lower performance fiber.

#### Case Study:

Based on a five-year observation, it can be stated that the UTW constructed on the Highway 83 bridge approach road near Vivian is a very successful application. The joint spacing was 15m (50 ft.) and there were no corner cracks. Except two very narrow hairline cracks, there were no other cracks. The extensive cracking in the asphalt did not reflect through to overlay concrete. The UTW is performing very well. The UTW done in Rapid City at the intersection of East Blvd. and Main Street is also largely successful in voiding corner cracking. There are only a few hairline cracks now. The conditions that contributed to the success of these two cases must be investigated. Full depth cores must

be taken and bond tests must be conducted. A detailed analysis could indicate reasons for the good performance of these two UTW.

### **Evaluation of Cores and Testing for Bond**

Coring was done for the US14 UTW to determine the remaining asphalt thickness, UTW thickness, and bond strength at the asphalt/concrete interface. A total of eight cores were taken, 1 core in each test section (4 test sections) in each lane (2 lanes). The locations, measured dimensions, and details of visual inspection are given in Tables D1 (page D-1) and D2 (page D-2) in Appendix D and Photos 5 through 8 (pages 43 and 44 ).

There was a wide variation in the thickness of the asphalt layer after milling and the UTW thickness. In fifty percent of the cores the asphalt layer thickness was less than the depth of the concrete overlay. The fiber distribution across the depth was uniform and good.

These cores were tested in tension in order to determine the bond stress between the concrete and the asphalt surface. Before testing, the cores were trimmed using a Hillquist saw, then the dimensions were accurately measured by a vernier. The top and bottom were cut perpendicular to the sides. This allowed the testing plate to be attached in such a way as to eliminate any eccentricity. A 19 mm (0.75 in.) diameter steel rod was welded to a 2.5 mm (0.1 in.) thin steel plate that was cut in the shape of 100 mm (4 in.) diameter circle. Two of these plates were attached to the trimmed core samples, one at each end of the sample as shown in Photo 9 to 15 (pages 45 and 46). The plates were attached to the specimen using a two-part epoxy (PC-11) manufactured by Protective Coating Co, Allentown, PA. PC-11 remained workable for 30 minutes allowing time to attach the plates. This epoxy was chosen for its ability to bond and fill any voids between the steel plate and the core sample. The load was evenly distributed to the entire cross sectional area of the sample.

The specimen was tested in direct tension using the standard procedure for testing steel rods in tension (shown in Photo 9, page 45).

In some samples the bond was very poor. In two samples the concrete and asphalt parts separated while the specimens were being prepared by fixing the steel plates. Only in one specimen (Photo 9 and 10) the fracture was in the asphalt layer indicating that the bond strength was greater than the tensile strength of the asphalt. All other specimens failed at the interface of the concrete and the asphalt. The average failure stress was about 0.03 MPa (5 psi.) as shown in the table below. The inspections of the surfaces after failure showed that there was dust and unbonded sand particles on the scarified asphalt surface (Photo 11). It seemed that after sand blasting, the sand was not completely removed which resulted in poor bond between the concrete and asphalt.

Core Location	Length in inches		Diameter	Area	Ultimate	Bond	Failure
	Concrete	Asphalt	(inches)	(in²)	Load (lbs)	Strength (psi)	Туре
East Bound at 92 + 02 8 ft. from shoulder	2.85	4.75	4.00	12.56	440	35	Tension failure in asphalt
East Bound at 98 4 ft. from shoulder	3.80	2.30	4.01	12.57	72	6	Bond at interface
West Bound at 109 + 50 4.6 ft. from shoulder	3.40	3.40	4.00	12.56	34	3	Bond at interface
West Bound at 104 + 30 8.9 ft. from shoulder	4.40	2.10	4.02	12.67	81	6	Bond at interface

Conversions: 1 inch = 25.4 mm, 1 lb = 0.4536 kg

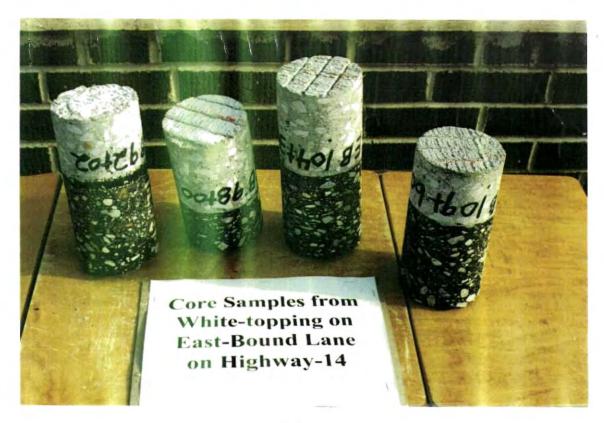


Photo 5



Photo 6



Core Sample #2 from White-topping on East-Bound Lane on Highway-14



Core Sample #2 from White-topping on West-Bound Lane on Highway-14

Photo7

Photo 8



Photo 9

Bond Test Set-up

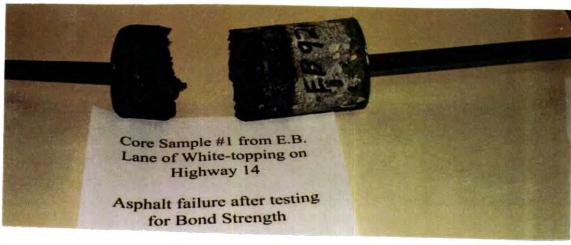


Photo 10



Photo 11



Photo 12



Photo 13



Photo 14



Photo 15

## Research Task 5: Recommend design, testing and construction guidelines for using NMFRC in whitetopping applications based on the results from the test sections.

Based on the performance evaluation of the ultra-thin whitetopping constructed in Highway 14, Highway 83 approach road to bridge near Vivian, in the intersection of East Boulevard and Main Street, the intersection of St. Patrick Street and Main Street in Rapid City, and observation of other UTW constructed in Virginia, Mississippi, Minnesota and Tennessee, the following guidelines are recommended.

At the time these projects were constructed, design procedures were not available for determining the thickness of NMFRC whitetopping. It is recommended that the minimum thickness of the UTW should be 89 mm (3.5 in.) for heavy- traffic intersections and for State and National Highways. The joint spacing can be 6 to 9.2 m (20 to 30 ft.). Bonded overlay is desirable to provide a composite action for the slab which will reduce the potential tensile stresses and cracking in concrete overlays. The milled surface of the asphalt must be thoroughly cleaned with water jets to remove dust and loose sand particles, to ensure proper bond between the concrete and the asphalt surfaces. A thin layer of cement-slurry could be used as a bonding agent.

The UTW construction should be organized so that as much as possible, a continuos monolithic construction is possible avoiding cold joints. It is also desirable to have 4.2 m (14 ft.) lanes allowing 0.6m (2 ft.) overlay extending into the shoulder which will reduce the corner cracking.

When UTW's are needed, only NMFRC should be used with a fiber dosage of 14.8 kg/m<sup>3</sup> (25 lb/cu.yd.) which will have the required structural properties such as higher fatigue strength, flexural strength, impact resistance, toughness and ductility compared to plain concrete (PCC). The addition of fibers would reduce the plastic shrinkage cracking and other early age cracking. When cracks occur due to traffic or other causes, the fibers would contain the crack propagation and restrict the widening of the cracks and minimize the loss of material reducing hazards to the public.

The same construction procedures for mixing, transporting, placing, consolidating, finishing, tinning, and curing used for construction with plain concrete, be used for construction of NMFRC whitetopping. Some additional mixing time is required for NMFRC, which must be determined by field trials. The same construction techniques and equipment without major modification could be used for the construction of NMFRC whitetopping. Joint sawing must be done as soon as the concrete can support the operator and the equipment. Brooming and tinning can also be done as early as possible.

When NMFRC is used, the following quality control tests should be conducted using ASTM test procedures for the fresh concrete: slump, unit weight, and air content. In addition the fiber content by weight should be determined by washing the concrete from the unit weight container and separating the fibers carefully and weighing them. The concrete temperature, the ambient temperature, humidity and the wind velocity be recorded during placing of the concrete.

The following hardened concrete control tests should be conducted on field samples collected and cured according to ASTM standard procedures for NMFRC at 28 days: compressive strength, elastic modulus, flexural strength, fatigue strength and toughness values (ASTM and Japanese Standards).

The standard test procedures to be followed are described in Task 3.

The procedure for adding fibers to the mix may vary depending on the field conditions. This could be determined by trial mixing.

Research task 6: Using cost data available from SDDOT and others, compare the performance and life cycle costs of NMFRC whitetopping and asphalt overlays. NMFRC cost estimates should assume that its use becomes common construction practice and is no longer experimental.

#### Life Cycle Cost Analysis

Life cycle cost analysis is an economic evaluation of all current and future costs associated with investment alternatives. It will be very useful to the transportation officials in selecting the most appropriate solution among the various alternatives available for the construction of new transportation structures and for the repair, renovation and/or rehabilitation of bridges, pavements and other structures. Life cycle

cost analysis is an important technique for assisting with decisions for infrastructure investments. However, a commonly acceptable, comprehensive methodology for UTW life cycle cost analysis is not currently available. Therefore, a comprehensive life cycle cost analysis for whitetopping is not attempted.

The constructed white toppings are experimental projects and the quantities of materials involved are comparably small. Further, NMFRC is a new material for the construction of whitetopping and the contractors did not have previous experience in using NMFRC. Hence the bid-prices for this project were exceedingly high compared to what it should actually cost if the job is a routine construction job. In realistic estimates, the cost increase in NMFRC construction should be equal to the cost of fibers and the additional effort required to add the fibers to the concrete. However, the bid-prices were much higher than the anticipated cost.

There are a number of unknown factors, such as the life expectancy of structures built with NMFRC, type and frequency of maintenance needed and the maintenance cost for whitetoppings. Therefore, it may not be possible to calculate the life cycle cost without making some assumptions. Further, it may not be possible to assign a cost for the behavioral efficiency of NMFRC whitetopping compared to the non-fiber reinforced concrete whitetopping. Hence instead of regular life cycle cost analysis, a discussion of the comparable cost is included.

#### **UTW Costs**

The whitetoppings constructed were ultra-thin with thickness 64 mm and 89 mm (2.5 in. and 3.5 in.) PCC ultra-thin whitetopping may not last long unless the panel size is unreasonably small. For ultra-thin whitetopping, technical consideration would result in the use of FRC, when a 6-9 m (20-30 feet) joint spacing is to be used. The choice would be between steel fibers and polyolefin fibers due to the enhanced performance. Since the overall cost is the same for SFRC and NMFRC, the NMFRC was selected because of its advantages such as non-corrosive, non-magnetic, and non-hazardous projections if any.

Based on Highway 14 project unit costs, per mile of NMFRC whitetopping 64 mm (2.5 in.) thickness would cost \$615,800 and 89 mm (3.5 in.) thickness would cost

\$783,000. These costs do not look reasonable and are probably inflated for several reasons:

- Both whitetopping projects constructed to date have been associated with other projects. The Vivian whitetopping was included in a bridge deck overlay project, whereas, the US14 whitetopping was included in a large asphalt project.
- The US14 and Vivian UTW projects were relatively small and located in rural areas.
- 3. Concrete paving projects normally have only one bid item which is "Finished Concrete Per Square Yard". However, for the whitetopping projects, an additional bid item (furnished concrete/yd³) was added to the bid list to protect the contractor. This additional bid item was used to protect the contractor, but it can also decrease the contractors incentive to not exceed the design thickness.
- Concrete was mixed using redi-mix trucks rather than a portable central batch plant.

Using the cost from the US14 whitetopping, the cost per square yard is approximately \$35.42 (\$581,800 per mile/16,427 yd²) and \$40.98 (\$673,100 per mile/16,427 yd²) for the 64 mm and 89 mm (2.5 in. and 3.5 in.) thicknesses, respectively. What would a more realistic cost be? The department can place its typical 203 mm (8in.) doweled PCCP with 6 m (20 ft.) joints for approximately \$18.14/yd² (\$298.000 per mile/16,437 yd² per mile). This clearly indicates that whitetopping costs do not compare. Since the US83 NMFRC full depth paving costs seem to be realistic, maybe a more realistic whitetopping cost could be delivered by either of the following simplified options. Both of the options below assume the cost to mill the asphalt surface prior to whitetopping is equal to the cost for trimming the base material prior to placing PCC.

Prorating the costs observed from the full depth NMFRC paving costs seen on US83. Using the cost for the 203 mm (8 in.) NMFRC doweled pavement with 7.5 m (25ft.) joints we can compute that a 89 mm (3.5 in.) whitetopping might cost approximately \$215,000/mile or \$13.10/yd² (\$490,000/mile x (3.5)/8 = \$214,800/mile of whitetopping and \$214,800 per mile/16,427yd² per mile =

- \$13.10/yd<sup>2</sup>). Similar costs can be computed for the 64 mm (2.5 in.) whitetopping.
- 2. Normally, PCC paving is bid on a square yard finished basis. A cost model, which includes the cost of finishing per yd2 as well as the cost of the concrete per yd3, can be developed. This cost model will assume that the cost to finish concrete will remain the same regardless of the thickness of the concrete. The model be similar to  $f_c$  per  $yd^2 = fg_c$  per  $yd^2 + m_c$  per  $yd^3 \times t/36$ ", where;  $f_c$  is the cost per yd2 for finished concrete (this includes finishing and material costs), fgc is the cost to finish a yd2 concrete regardless of thickness (this is the finishing costs only), mc is the cost of the concrete based on yd3, and t is the thickness in inches. Knowing the average cost for SD's typical 203 mm (8 in.) plain doweled PCCP with 6 m (20 ft.) joints is \$18.14/yd2 and assuming that the concrete costs \$70/yd3, the finishing cost for one yd2 of concrete can be determined (\$18.14/yd2 =  $fg_c + 8^{\circ\prime}/36^{\circ\prime} \times \$70/yd^3$ ). Solving the equation for  $fg_c$  gives a cost of  $\$2.58/yd^2$ . Now by assuming that the finishing cost remains constant and adding the cost of the fibers to the cost of the concrete we can determine fc for varying thickness of fiber concrete ( $f_c = $2.58/yd^2 + 3.5^{\circ\prime\prime}/36^{\circ\prime\prime} \times 120/yd^3$ ). Solving the equation for  $f_c$ yields finished cost of \$14.25/yd2. Note: the costs per yd3 of concrete may range anywhere from \$50 to \$80. This cost varies based on several factors, some of which include quantity, location, 2 lane, 4 lane, urban, rural, etc. For this analysis the cost of a cubic yard of concrete is taken as \$70.00.

Clearly it is difficult to determine a realistic whitetopping cost from the costs seen on the constructed whitetopping projects. Lastly, if whitetopping continues to be expensive, then the determination of its use should be evaluated on a case by case basis.

## Cost of Asphalt Overlays

In doing the cost analysis of the full depth pavement in Highway 83 (study SD96-15), the cost of "Mill and AC overlay" (1 in. milled and 2 in. AC overlay) was assumed at \$150,000/mile. This is equivalent to \$9.13/yd<sup>2</sup>. This is only for 2" overlay and the expected life is 10 years.

The Rapid City Engineer Jagodzinski who was in charge of the NMFRC-UTW in Rapid City, reported that a 50mm (2 in.) asphalt overlay in Rapid City intersection would cost \$3.75 to 5.25 per yd<sup>2</sup>. Prorating this for 89 mm (3.5 in.) asphalt overlay would be \$6.56 to 9.18 per yd<sup>2</sup>. He reported that the asphalt overlays in heavy traffic intersections would last 5 to 7 years and then they have to be rehabilitated. In Rapid City the Main Street and East Boulevard intersection was badly deteriorated with 76 mm (3 in.) rut depths and distress cracking with an unsafe surface for traffic when it was rehabilitated at 7 years. He felt that it should have been overlaid 2 to 3 years earlier.

#### Cost of NMFRC - UTW

Five ultra thin whitetoppings were constructed in South Dakota with NMFRC from July 1994 to May 1999. The design thickness varied from 64 mm to 100 mm (2.5 in. to 4 in.). The actual thickness varied considerably because the milling operations were not properly controlled. Two UTW were constructed in Highway 14 and Highway 83 near Pierre and Vivian and two were constructed at heavy traffic intersections in Rapid City in 1997 and 1998. One UTW was constructed in Huron in 1999. The actual bid costs for four UTW are compared in the following table.

The comparison of the unit costs for one cubic yard of concrete had shown that the cost reduced from \$200 in 1996 to \$126 in 1999. The cost per square yard of finished UTW 89 mm (3.5 in.) thick reduced from \$35.97 to \$23.35 as the contractors had more experience with NMFRC whitetoppings. There was a 35 percent reduction in cost in 3 years. It is hoped that in a few years, the bid prices would become more realistic.

The life-cost comparison can be made with unproved assumptions. For this comparison, based on the performance of UTW in Highway 83, it is assumed that NMFRC 89 mm (3.5 in.) thick UTW would have a life expectancy of 40 years. The unit cost per square yard would be \$23.35.

Location of UTW		NMFRC BI	D COST	Bid Cost for	Total Cost (\$)
		For Cu.yd (\$)	For Sq.yd (\$)	Placing and Finishing (\$)	
Highway 14	2.5 inch thick	200	13.89	16.53	30.42
1996	3.5 inch thick	200	19.44	16.53	35.97
Rapid City,					
St.Patrick St. &	4 - 1 - 1				
Main intersection	3.0 inch thick	135	11.25	15.25	26.50
(1998) (Prorated)	3.5 inch thick	135	13.40	15.25	28.65
Rapid City,					
East Boulevard and	V c I		1 / 1		
Main intersection	3.0 inch thick	126	10.50	12.45	22.95
1997 (Prorated)	3.5 inch thick	126	12.25	12.41	24.66
Huron UTW (1999)	4.0 inch thick	No.		26.69	26.69
(Prorated)	3.5 inch thick		- 2	-	23.35

Based on the Huron whitetopping finished cost for 101 mm (4 in.) thick overlay, a cost comparison is given below for various projects. It is assumed that the finished cost for US14 and St. Joseph/St. Patrick UTW will remain the same regardless of thickness. Therefore the fraction of a cubic yard of furnished concrete will be added to the finished cost.

US14 finish cost for 101 mm (4 in.) = 
$$16.53 + 200 (4/36) = $38.75/sq$$
. yd. St. Joseph/St. Patrick (4 in.) =  $15.25 + 135 (4/36) = $30.25/sq$ . yd. Huron (4 in.) =  $$26.69/sq$ . yd. East Blvd/Main (4 in.) =  $12.45 + 126 (4/36) = $26.45/sq$ . yd.

It is clearly seen that as contractors gain experience in using NMFRC, the cost had reduced. In less than 3 years there was a reduction of 32 percent in the cost.

It is assumed that the asphalt overlay would last 10 years and hence four overlays must be done to achieve 40 years of service. The unit cost would be \$36.48 (4 x 9.12). Therefore NMFRC-UTW can be considered as economical over the lifetime of the overlay.

In the heavy traffic street intersection, the life expectancy of 89mm (3.5 in.) NMFRC-UTW can be taken as 20 years. The asphalt overlays must be done four times to achieve the same service life. Taking the unit price of asphalt overlay 75 mm (3 in.) thick in city intersections at \$7.88 per sq.yd., the total cost would be \$31.50 per sq.yd., whereas the cost of NMFRC-UTW would be \$22.95. In the above comparison, the inflation costs are not considered. The above analysis did not take into account the inconvenience caused to the public by closing the Highway and/or slowing of the traffic during the numerous repair and maintenance operations due to asphalt overlays.

Research Task 7: Provide an interim report 90 days after each section is constructed. The interim report should document the construction evaluation, material properties, early performance of the test and control sections, and should include sketches showing relative locations of each test section along with descriptive text. Therefore, two interim reports should be submitted, each being 90 days after the completion of its respective construction completion date. Careful planning of each interim report will allow incorporation of each into the final report.

An interim report was submitted to the SDDOT, 90 days after the US14 UTW was constructed. The report included all the required information.

Research Task 8: Submit a final report summarizing relevant literature, research methodology, test results, specifications, design standards, conclusions and recommendations.

The final report has been submitted which summarized all aspects of the study.

Research Task 9: Make an executive presentation to the SDDOT Research Review Board summarizing the findings and conclusions.

An executive presentation was made at the August 19, 1999 SDDOT Research Review Board Meeting.

### CONCLUSIONS

Based on the performance evaluation of the Ultra-Thin whitetoppings constructed in Highway 14, Rapid City, and Highway 83 (Vivian), and observation of other UTW constructed in Virginia, Mississippi, Minnesota, and Tennessee, the following conclusions are made:

- Ultra-thin whitetopping is a reliable alternative to milling and replacing with HMA
  frequently in deteriorated and / or damaged asphalt pavements. The procedure is
  technically sound and it reduces the time required to rehabilitate the roads. It
  eliminates ruts and provides a safer surface for traffic.
- The new NMFRC with enhanced fatigue, impact resistance, modulus of rupture, ductility and toughness properties is particularly suitable for the construction UTW overlays.
- Use of NMFRC has eliminated plastic shrinkage cracking and other early age cracking in UTW.
- 4. There was considerable corner cracking in both Highway 14 and in Rapid City UTW's. However, the polyolefin fibers helped to contain the crack propagation and restrict the widening of the cracks.
- 5. Even though the UTW's might have areas where extensive cracking occurred, the NMFRC was holding together and minimized the large cracks, spalling, and loss of material (potential hazards to the public) than a plain concrete UTW or UTW with a lower performance fiber.
- UTW, constructed when suitable conditions are available, performs successfully
  without any cracking and other damage such as in the case of UTW's on Highway 83
  Bridge approach road near Vivian and on the intersection of East Blvd. and Main
  Street in Rapid City, S. D.
- 7. When suitable conditions are not available, the predominant distress is corner cracking in the pavements as seen in UTW's constructed on Highway 14 and on the intersection of St. Joseph Street (Highway 79) and St. Patrick Street in Rapid City. There was extensive corner cracking in both these UTW's.

- In general thinner sections 63mm (2.5 in.) had more cracking than the thicker sections (100 mm (4 in.)). The cracking increased with time with increased traffic.
- 9. Observations by the author and the literature review had shown that most of the UTW's constructed in various parts of the country had corner cracking ranging from minimum to severe cracking. The extent of the cracking depended on the thickness of the whitetopping. Shorter joint spacing did not eliminate corner cracking.
- 10. An evaluation of the performance of UTW in Highway 14 and in Rapid City, and other projects around the country indicate the following two main reasons for the corner cracking and poor performance of the UTW:
  - Insufficient thickness of the asphalt layer and inadequate base and / or subbase thickness.
  - b. Poor or no bond between the overlaid concrete and the asphalt surface was possibly due to improper surface preparation of the asphalt layer after milling. Lack of bond reduces composite action and increases the potential for higher tensile stresses in the concrete.
- 11. Inspection and testing of the cores taken from Highway 14 had shown that there was very poor bond between the overlay concrete and the asphalt layer. After testing for bond, a considerable amount of sand particles was noticed at the interface between the concrete and asphalt. It was also noted that the thickness of the asphalt layer was not adequate. In some core samples, the thickness of the asphalt was less than the thickness of the UTW.

#### Recommendations

 For the construction of UTW, only NMFRC should be used because of its enhanced structural properties, which are desirable for UTW and because of its ability to restrict the widening of the cracks and constrain the crack propagation. A fiber dosage of 14.8 kg/cu.m. (25 lbs /cu.yd.) is recommended.

- It is recommended that UTW's and whitetoppings should be included as one of SDDOT's design alternatives for rehabilitating severely damaged or deteriorated asphalt pavements
- 3. The same construction procedures for mixing, transporting, placing, consolidating, finishing, tining, and curing used for construction with plain concrete, be used for construction of UTW and whitetopping. Some additional mixing time is required for NMFRC, which must be determined by field trials. The same construction techniques and equipment without major modifications could be used for the construction of NMFRC UTW and whitetopping. The joint spacing can be 6 to 9.2 m (20 to 30 ft.). Joint sawing must be done as soon as the concrete can support the operator and equipment. Brooming and tining can also be done as early as possible.
  - Bonded overlay is desirable to provide a composite action for the slab, which will reduce the potential tensile stresses and cracking in concrete overlays. A thin layer of cement-slurry bonding agent could be used.
  - 4. The minimum thickness of the UTW should be 89 mm (3.5 in.). The UTW construction should be organized so that a continuos monolithic construction is possible avoiding cold joints. The milled surface of the asphalt must be thoroughly cleaned with water jets to remove dust and sand particles to ensure proper bond between the concrete and the asphalt.
  - 5. When NMFRC is used, the following quality control tests be conducted for the fresh concrete: slump, unit weight, air content, and fiber content. The concrete temperature, the ambient temperature, humidity and the wind velocity be recorded during placing of the concrete.
    - The following hardened concrete control tests be conducted on field samples collected and cured according to ASTM standard procedures for NMFRC at 28 days: compressive strength, elastic modulus, flexural strength, fatigue strength and toughness values (ASTM and Japanese Standards)
  - Fast-Track construction could be easily adopted for UTW overlays. Traffic could be allowed within 24 hours of placing of concrete. The NMFRC mix could be designed

- to give a flexural strength 93 MPa (435 psi) within 8 hours and 5.5 MPa (800 psi) in 24 hours for Fast-Track construction.
- 7. The riding quality of the UTW with extensive, but with tolerable thin cracking has not been significantly reduced. Therefore, the UTW need not be considered as failed or need to be replaced. A criterion should be developed to assess the serviceability of the UTW and when it would be considered to have failed. Based on this criterion the cracked UTW should be continuously evaluated to determine its service life.
- 8. The following additional investigations are suggested to determine the design criteria and construction procedures that will ensure the successful performance and durability of UTW:
  - Cores should be taken and tested, and a detailed analysis should be made to determine the reasons for the successful performance of the whitetopping in Vivian and Rapid City.
  - Various procedures for creating an effective bond between the asphalt and the overlay concrete must be experimented. This should include various surface preparations and bonding agents.
  - A study can be conducted (both literature survey and experimental) to determine the optimum minimum thickness of the remaining asphalt layer thickness to avoid corner cracking.

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# APPENDIX A

**Details of Laboratory Batches** 

## **DOT Trial Mixes for White-topping**

**Table A1: Mixture Proportions** 

Mixture #				Proportions cu. yd.			
	Cement	Fly Ash	Coarse Agg.	Fine Agg.	Water	Fiber	AEA oz/cu. yd
DOT-T1	575	115	1400	1400	291	25	12.0
DOT-T2	575	115	1400	1400	291	25	10.1
DOT-T5	575	115	1400	1400	291	25	10.1

**Table A2: Fresh Concrete Properties** 

Mixture #	Te	oom emp. nidity	Conc. Temp.	Unit Weight	Air Content	Slump	Ve Slump	be Time
	(°F)	(%)	(°F)	(lb/cu ft)	(%)	inches	inches	Sec.
DOT-T1	80	40	75.2	140.4	9.4	5.5	4.5	2.0
DOT-T2	80	50	76.7	141.4	8.2	5.0	4.0	1.2
DOT-T5	80	30	80.1	140.4	6.0	3.0	2.25	2.0

Table A3: Number of Specimens

Mixture #	Nun	nber of Speci	mens	
	Beams	Cylinders	Impac	
DOT-T1	8	6	15	
DOT-T2	- W	14	-	
DOT-T5	23	2	-	

Conversion table:

1 inch = 25.4 mm 1 pcf = 16.02 kg/cu m 1 sq. in. = 645.2 sq mm 1 psi = 0.006895 Mpa 1 pcy = 0.5933 kg/cu m

°F to °C: T(°C) = [T(°F) - 32]/1.8 1 inch-pound = 0.1130 Nm

1 lb = 0.4536 kgf = 4.448 N

**Table A4: Compressive Strength** 

Specimen #	Age (days)	Date of Testing	Length (inches)	Diameter (inches)	Area (Sq. Inches)	Unit Weight (pcf)	Compressive Strength (psi)
DOT-T1-C1	7	06/28/96	12.08	5.99	28.16	140.11	3745
DOT-T1-C2	7	06/28/96	12.13	5.97	28.01	140.2	4085
DOT-T1-C3	7	06/28/96	12.13	5.99	28.18	141.0	3865
Average							3900
DOT-T1-C4	28	07/19/96	12.18	5.98	28.10	139.2	4980
DOT-T1-C5	28	07/19/96	12.24	5.99	28.22	139.0	4960
DOT-T1-C6	28	07/19/96	12.26	5.98	28.09	139.5	5020
Average							4990

Table A5: First Crack Strength and Maximum Flexural Strength

Specimen #	Age (Days)	Load (lbs)	First Crack Deflection (inches)	Stress (psi)	Maximum Load (lbs)	Flexural Strength (psi)
DOT-T1-B1	7	2298	0.0004	412	2747	492
DOT-T1-B2	7	2719	0.0005	453	2916	485
DOT-T1-B3	7	2309	0.0002	406	2775	488
DOT-T1-B4	7	3153	0.0003	512	3153	512
Average				446		494
DOT-T1-B5	28	2927	0.0008	498	3697	630
DOT-T1-B6	28	2536	0.0005	431	3469	589
DOT-T1-B7	28	2982	0.0006	504	3739	632
DOT-T1-B8	28	3205	0.0003	518	3243	524
Average				488		594

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m1 sq. in. = 645.2 sq mm 1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcy = 0.5933 kg/cu m1 lb = 0.4536 kgf = 4.448 N 1 inch-pound = 0.1130 Nm

Table A6: Japanese Standard - Toughness & Equivalent Flexural Strength

Specimen #	Age (Days)	Toughness (Inch-lbs)	Equivalent Flexural Strength (psi)
DOT-T1-B1	7	104	232
DOT-T1-B2	7	159	331
DOT-T1-B3	7	90	198
DOT-T1-B4	7	166	338
Average		130	275
DOT-T1-B5	28	219	466
DOT-T1-B6	28	174	369
DOT-T1-B7	28	215	455
DOT-T1-B8	28	183	369
Average		198	415

**Table A7: ASTM Toughness Indices** 

Specimen	Age	First Crack		Toughness	Indices	Toughne	ss Ratios
#	(Days)	Toughness (inch-lbs)	15	110	120	110/15	120/110
DOT-T1-B1	7	0.52	4.95	10.07	19.69	2.04	1.96
DOT-T1-B2	7	0.84	4.40	8.58	16.32	1.95	1.90
DOT-T1-B3	7	0.29	4.64	9.25	18.07	1.99	1.95
DOT-T1-B4	7	0.69	3.71	7.01	13.32	1.89	1.90
Average		0.59	4.43	8.73	16.85	1.97	1.93
DOT-T1-B5	28	1.52	4.72	9.27	17.49	1.97	1.89
DOT-T1-B6	28	0.73	5.65	11.34	22.07	2.01	1.95
DOT-T1-B7	28	1.10	4.85	9.76	18.94	2.01	1.94
DOT-T1-B8	28	0.65	3.97	7.61	14.62	1.92	1.92
Average		1.00	4.80	9.49	18.28	1.98	1.92

1 inch = 25.4 mm

1 psi = 0.006895 Mpa

°F to °C: T(°C) = [T(°F) - 32]/1.8 1 inch-pound = 0.1130 Nm

1 pcf = 16.02 kg/cu m 1 sq. in. = 645.2 sq mm 1 pcy = 0.5933 kg/cu m

1 lb = 0.4536 kgf = 4.448 N

Table A8: 28 Days Impact Strength

Specimen #	Number o	of Blows	Difference
	First Crack	Failure	
DOT-T1-I1	47	322	275
DOT-T1-I2	36	307	271
DOT-T1-I3	51	355	304
DOT-T1-I4	13	186	173
DOT-T1-I5	25	327	302
DOT-T1-I6	47	665	618
DOT-T1-I7	27	273	246
DOT-T1-I8	89	571	482
DOT-T1-I9	194	550	356
DOT-T1-I10	25	185	160
DOT-T1-I11	41	585	544
DOT-T1-I12	62	270	208
DOT-T1-I13	33	341	308
DOT-T1-I14	36	655	619
DOT-T1-I15	36	300	264
Average	51	393	342

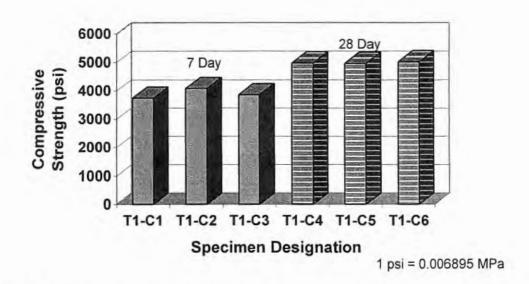


Fig A1: Comparison of Compressive Strength for Different Specimens of the Same mix

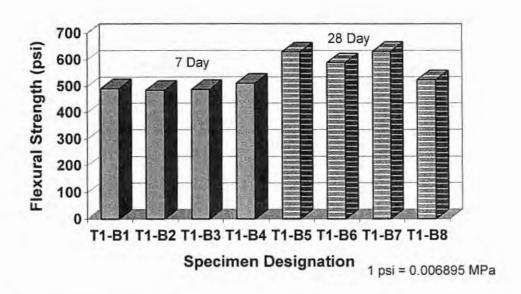


Fig A2: Comparison of Flexural Strength for Different Specimens of the Same Mix

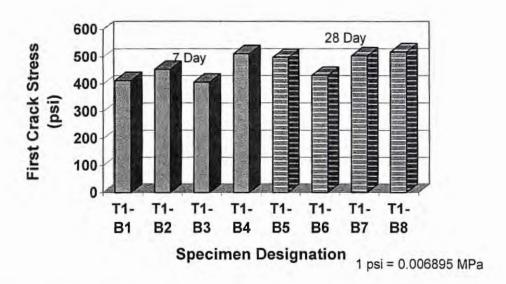


Fig A3: Comparison of First Crack Stress for Different Specimens of the Same Mix

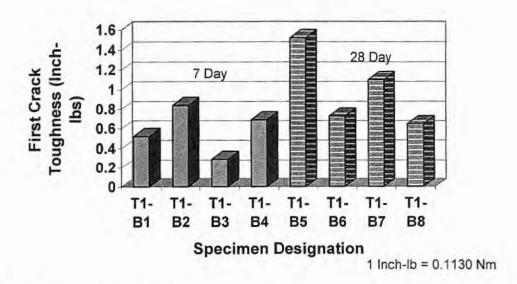


Fig A4: Comparison of ASTM First Crack Toughness for Different Specimens of the Same Mix

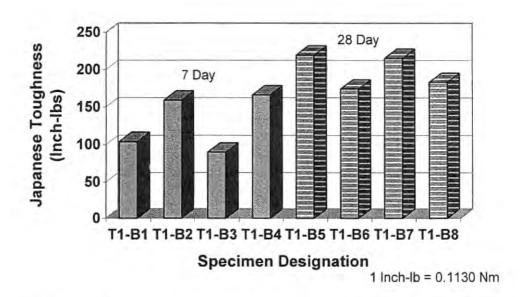


Fig A5: Comparison of Japanese Toughness for Different Specimens of the Same Mix

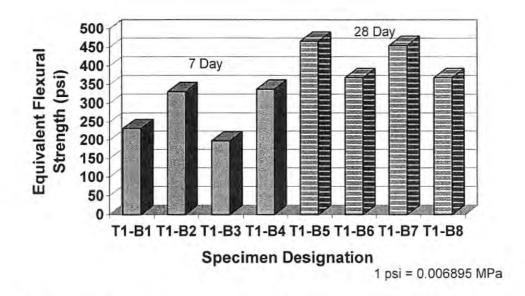


Fig A6: Comparison of japanese Standard Flexural Strength for Different Specimens of the Same Mix

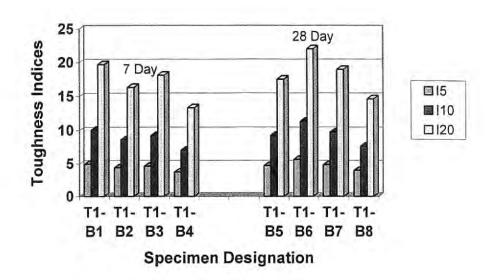


Fig A7: Comparison of ASTM Toughness Indices for Different Specimens of the Same Mix

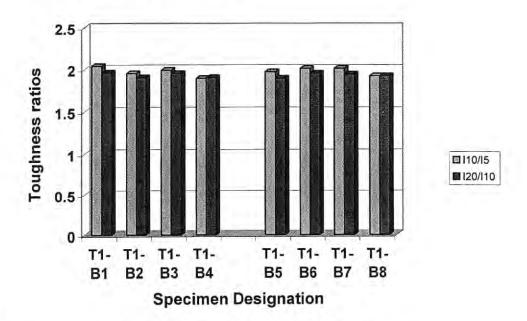


Fig A8: Comparison of ASTM Toughness Ratios for Different Specimens of the Same Mix

# APPENDIX B

Details of Fresh and Hardened Concrete Properties for NMFRC White-topping For

- 1. Highway 14
- 2. Rapid City

### Specimens made from the paving done on July 23 and 24, 1996 for White-topping on Highway 14 (West Bound Lane)

**Table B1: Fresh Concrete Properties** 

Mixture #	Time	Ar	nbient	Conc. Temp.	Unit Weight	Air Content	Slump	Actual Fiber
		Temp.	Humidity	12022	W. C. Carlott			Content
		(°F)	(%)	(°F)	(lb/cu ft)	(%)	Inches	(lb/cu yd)
W1	7:30	69	55	79.2	143.3	6.4	5.00	- ATT
(7/23/96)	8:30	85	40	79.2	141.7	6.8	3.75	24.11
	9:30	90	30	79.8	141.3	8.2	2,50	7
	10:30	90	25	81.8	143.7	7.5	4.50	24.61
	11:30	90	25	83.4	142.1	7.8	4.00	
	12:30	95	20	83.5	145.4	1.6	2.00	
W2	7:35	60	70	75.8	146.2	4.2	1.50	
(7/24/96)	8:30	65	65	78.7	145.8	2.0	0.50	27.05
	9:30	75	50	78.3	136.7	10.2 *	6.25	
	10:40	80	40	81.5	146.2	5.4	1.75	
	11:30	95	30	78.9	145.4	5.4	1.00	

<sup>\*</sup> Truck was rejected

**Table B2: Number of Specimens** 

Mixture #	Nun	aber of Speci	mens
	Beams	Cylinders	Impact
W1	12	9	18
W2	8	6	-
W1-Fatigue	26	3	

Conversion table:

1 inch = 25.4 mm1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 inch-pound = 0.1130 Nm1 lb = 0.4536 kgf = 4.448 N

Table B1-A: Fresh Concrete Tests done by DOT Personnel for the paving done on July 23 and 24, 1996

Concrete Type: NMFRC Tests done on 7/23/96

Test #	Time	Air Temp.	Conc. Temp.	Air Content (%)	Slump (Inches)
1	7:30	60	76	6.2	3.25
2	8:37	68	78	6.9	2.50
3	9:41	79	82	7.5	2.50
4	10:47	82	82	5.4	2.25
5	12:10	83	84	7.9	3.00
6	1:32	89	86	8.0	3.25

Concrete Type: A-45 Test done on 7/23/96

Test #	Time	Air Temp.	Conc. Temp.	Air Content (%)	Slump (Inches)
1	2:48	86	86	5.8	2.25
2	4:45	84	86	6.0	2.25

Concrete Type: NMFRC Tests done on 7/24/96

Test #	Time	Air Temp.	Conc. Temp.	Air Content (%)	Slump (Inches)
_1	7:19	56	76	5.2	1.25
2	8:55 64		80	6.0	1.50
3	10:56	70	84	6.2	1.12
4	12:44	82	86	5.1	1.25

Note: Spec. Limits for NMFRC are:

Air Content:  $6.5 \pm 1.5 \%$ 

Slump: 1 to 4 -1/2 inches

Concrete Temp.: NTE 90 °F

Spec. Limits for Class A-45 Concrete are:

Air Content:  $6.5 \pm 1.5 \%$ 

Slump: 1 to 3 inches

Concrete Temp.: NTE 90 °F

Table B1-B Climatic Conditions During Construction of White-topping on Highway - 14

July 23, 1996

Time	Temperature (°F)	Humidity (%)	Wind Velocity (mph)
7:30	65	60	4.0
8:00	70	55	2.0
8:30	75	48	4.0
9:00	75	49	5.0
9:30	80	39	7.0
10:00	84	30	8.5
10:30	80	35	10.5
11:00	83	25	24.0
11:30	95	25	20.0
12:00	95	22	22.0
13:30	96	20	24.0

July 24, 1996

Time	Temperature (°F)	Humidity (%)	Wind Velocity (mph)
7:30	60	60	5.5
9:30	70	60	7.0
11:00	80	45	10.0
12:00	85	45	8.0

Temperature Conversion:

 $^{\circ}$ F to  $^{\circ}$ C:  $T(^{\circ}$ C) =  $[T(^{\circ}$ F)-32]/1.8

**Table B3: Compressive Strength** 

Specimen #	Age (days)	Date of Testing	Length (inches)	Diameter (inches)	Area (Sq. In.)	Unit Wt. (pcf)	Static Modulus	Comp. Str. (psi)
W1-C1	7	07/30/96	11.97	5.98	28.07	145.6	3.85 x 10 <sup>6</sup>	3490
W1-C2	7	07/30/96	12.13	6.00	28.24	144.3	$3.40 \times 10^6$	3365
W1-C3	7	07/30/96	12.10	6.00	28.27	144.5	3.82 x 10 <sup>6</sup>	3255
Average								3370
W1-C4	28	08/20/96	12.01	6.02	28.50	143.1	3.46 x 10 <sup>6</sup>	4175
W1-C5	28	08/20/96	12.09	6.05	28.75	141.2	3.48 x 10 <sup>6</sup>	4350
W1-C6	28	08/20/96	12.01	6.03	28.56	142.6	3.50 x 10 <sup>6</sup>	4465
Average								4330
W2-C1	7	07/31/96	12.06	6.02	28.50	144.3	4.21 x 10 <sup>6</sup>	4070
W2-C2	7	07/31/96	11.98	6.01	28.33	144.6	4.24 x 10 <sup>6</sup>	4165
W2-C3	7	07/31/96	12.01	5.98	28.10	144.9	4.27 x 10 <sup>6</sup>	4290
Average	7							4175
W2-C4	28	08/21/96	11.95	5.99	28.20	144.6	4.26 x 10 <sup>6</sup>	5410
W2-C5	28	08/21/96	12.03	5.99	28.21	143.5	4.25 x 10 <sup>6</sup>	5760
W2-C6	28	08/21/96	11.99	5.99	28.18	144.2	4.26 x 10 <sup>6</sup>	5645
Average								5605

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 inch-pound = 0.1130 Nm

1 lb = 0.4536 kgf = 4.448 N

Table B4: First Crack Strength and Maximum Flexural Strength

Specimen	Age	First Crack			Maximum	Flexural
#	(Days)	Load (lbs)	Deflection (inches)	Stress (psi)	Load (lbs)	Strength (psi)
W1-B1	7	2500	0.0005	451	2500	451
W1-B2	7	2709	0.0007	490	2823	510
W1-B3	7	3066	0.0012	529	3149	543
W1-B4	7	2595	0.0007	464	2657	475
Average				484		495
W1-B5	28	3673	0.0009	672	3751	686
W1-B6	28	3229	0.0008	596	3375	623
W1-B7	28	3308	0.0009	594	3700	664
W1-B8	28	3376	0.0008	606	3400	610
Average				617		646
W2-B1	7	2843	0.0012	527	2945	546
W2-B2	7	3229	0.0009	609	3300	622
W2-B3	7	3160	0.0009	565	3175	568
W2-B4	7	3146	0.0008	565	3158	568
Average		-		567		576
W2-B5	28	3538	0.0009	645	3776	688
W2-B6	28	3828	0.0012	704	3837	705
W2-B7	28	3875	0.0014	727	3903	732
W2-B8	28	3762	0.0016	710	3835	724
Average	2 2 2 1			697		712

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m 1 sq. in. = 645.2 sq mm 1 psi = 0.006895 Mpa 1 pcy = 0.5933 kg/cu m °F to °C: T(°C) = [T(°F) - 32]/1.8 1 inch-pound = 0.1130 Nm

1 lb = 0.4536 kgf = 4.448 N

Table B5: ASTM Toughness Indices

Specimen	Age	First Crack		Toughne	ss Indices	Toughne	ss Ratios
#	(Days)	Toughness (inch-lbs)	15	I10	120	110/15	120/110
W1-B1	7	1.02	3.40	6.28	11.66	1.85	1.86
W1-B2	7	1.39	3.77	7.00	12.64	1.86	1.81
W1-B3	7	2.21	4.33	8.18	14.80	1.89	1.81
W1-B4	7	1.28	3.85	7.21	13.26	1.87	1.84
Average		1.48	3.84	7.17	13.09	1.87	1.83
W1-B5	28	2.28	3,89	7.25	13.16	1.87	1.82
W1-B6	28	1.83	3.84	7.10	12.58	1.85	1.77
W1-B7	28	1.93	4.38	8.42	15.81	1.92	1.88
W1-B8	28	2.13	3.51	6.52	12.07	1.86	1.85
Average		2.04	3.91	7.32	13.41	1.88	1.83
W2-B1	7	2.18	4.13	7.65	13.30	1.85	1.74
W2-B2	7	1.83	4.18	7.95	14.76	1.90	1.86
W2-B3	7	1.62	4.45	8.48	15.64	1.91	1.84
W2-B4	7	1.44	4.42	8.40	15.42	1.90	1.84
Average		1.77	4.30	8.12	14.78	1.89	1.82
W2-B5	28	1.88	4.50	8.55	15.50	1.90	1.81
W2-B6	28	2.61	3.18	6.33	12.19	1.99	1.93
W2-B7	28	3.57	3.96	7.36	13.09	1.86	1.78
W2-B8	28	3.42	4.52	8.72	16.46	1.93	1.89
Average		2.87	4.04	7.74	14.31	1.92	1.85

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m 1 sq. in. = 645.2 sq mm 1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 1 inch-pound = 0.1130 Nm

1 lb = 0.4536 kgf = 4.448 N

Table B6: Japanese Standard - Toughness & Equivalent Flexural Strength

Specimen #	Age (Days)	Toughness (Inch-lbs)	Equivalent Flexural Strength (psi)
W1-B1	7	85	191
W1-B2	7	73	165
W1-B3	7	133	287
W1-B4	7	128	287
Average		105	233
W1-B5	28	108	248
W1-B6	28	79	183
W1-B7	28	125	281
W1-B8	28	107	241
Average		105	238
W2-B1	7	119	276
W2-B2	7	164	387
W2-B3	7	148	331
W2-B4	7	154	346
Average		146	335
W2-B5	28	188	429
W2-B6	28	188	431
W2-B7	28	187	439
W2-B8	28	250	590
Average		203	472

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m

1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcy = 0.5933 kg/cu m 1 sq. in. = 645.2 sq mm

1 lb = 0.4536 kgf = 4.448 N

1 inch-pound = 0.1130 Nm

Table B6-A: Impact Strength

Specimen #	Number	Difference	
	First Crack	Failure	First Crack- Failure
W1-I1	26	190	164
W1-I2	38	150	112
W1-I3	28	154	126
W1-I4	28	162	134
W1-I5	12	140	128
W1-I6	29	173	144
W1-I7	30	150	120
W1-I8	11	190	179
W1-I9	17	120	103
W1-I10	25	175	150
W1-I11	12	115	103
W1-I12	21	140	119
W1-I13	86	171	85
W1-I14	20	132	112
W1-I15	95	150	55
W1-I16	86	191	105
W1-I17	29	141	112
W1-I18	28	146	118

# Table B7-A: Climatic Conditions During Construction of White-topping on Highway - 14

### August 7, 1996

Time	Temperature (°F)	Humidity (%)	Wind Velocity (mph)
8:00	74	30	6
8:30	76	30	6
9:00	79	30	7
9:30	81	35	8
10:00	82	35	8
10:30	82	35	9
11:00	85	32	9
11:30	87	33	9
12:00	87	32	9
12:30	88	32	9
13:00	92	28	9
13:30	93	22	8
14:00	93	21	8

## August 8, 1996

Time	Temperature (°F)	Humidity (%)	Wind Velocity (mph)
8:00	75	60	1 to 2
8:30	82	48	1 to 2
9:00	90	43	1 to 2
9:30	90	35	1 to 2
10:00	90	33	1 to 2
10:30	90	30	1 to 2
11:00	90	30	1 to 2
11:30	90	30	1 to 2
12:00	90	30	1 to 2

Conversion table:

1 inch = 25.4 mm 1 psi = 0.006895 Mpa °F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$  1 pcf = 16.02 kg/cu m 1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N

# Specimens made from the paving done on August 7 and 8, 1996 for White-topping on Highway 14 (East Bound Lane)

**Table B7: Fresh Concrete Properties** 

Mixture #	Time	Aı	mbient	Conc. Temp.	Unit Weight	Air Content	Slump	Actual Fiber
4	. 4	Temp.	Humidity	( 300.5		1		Content
		(°F)	(%)	(°F)	(lb/cu ft)	(%)	Inches	(lb/cu yd)
W3	9:00	79	30	77.3	145.8	5.1	2.75	27.78
(8/7/96)	10:00	82	40	77.0	144.6	4.5	2.75	2
	11:00	85	30	77.5	144.6	5.4	2.50	
	11:55	87	25	81.3	145.4	5.0	3.25	24.28
	1:00	92	30	81.2	144.6	8.1	4.50	
W4	8:00	75	60	79.5	145.8	5.0	2.37	26.39
(8/8/96)	9:00	90	43	77.3	145.0	6.6	3.00	-
	10:00	90	30	79.6	145.0	6.1	2.75	TV
	11:00	90	30	82.0	140.5	9.1	4.25	-
	11:55	90	30	84.8	145.8	1.6	2.75	1-1-

Table B8: Number of Specimens

Mixture #	Number of Specimens				
	Beams	Cylinders	Impact		
W3	8	6	15		
W4	8	6			

Conversion table:

1 inch = 25.4 mm 1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m 1 lb = 0.4536 kgf = 4.448 N

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 inch-pound = 0.1130 Nm

**Table B9: Compressive Strength** 

Specimen #	Age (days)	Date of Testing	Length (inches)	Diameter (inches)	Area (Sq. In.)	Unit Weight (pcf)	Static Modulus (psi)	Comp. Str. (psi)
W3-C1	7	08/17/96	12.01	6.01	28.416	143.3	3.52 x 10 <sup>6</sup>	3715
W3-C2	7	08/17/96	12.01	6.01	28.388	142.4	3.52 x 10 <sup>6</sup>	3380
W3-C3	7	08/17/96	12.10	6.00	28.274	142.6	3.53 x 10 <sup>6</sup>	3500
Average								3530
W3-C4	28	09/04/96	12.25	6.01	28.416	141.5	4.22 x 10 <sup>6</sup>	4665
W3-C5	28	09/04/96	12.11	5.99	28.237	143.0	4.24 x 10 <sup>6</sup>	4850
W3-C6	28	09/04/96	12.15	5.99	28.255	143.5	$4.24 \times 10^6$	4850
Average								4790
W4-C1	7	08/17/96	12.10	6.02	28,444	142.6	3.52 x 10 <sup>6</sup>	3710
W4-C2	7.	08/17/96	12.15	6.01	28.378	141.1	3.52 x 10 <sup>6</sup>	4055
W4-C3	7	08/17/96	12.12	6.01	28.369	141.7	$3.52 \times 10^6$	3660
Average	ix-c-;							3810
W4-C4	28	09/05/96	12.06	6.00	28.237	143.6	4.25 x 10 <sup>6</sup>	4850
W4-C5	28	09/05/96	12.08	6.04	28.653	141.3	4.19 x 10 <sup>6</sup>	4605
W4-C6	28	09/05/96	12.00	5.98	28.133	143.8	4.27 x 10 <sup>6</sup>	4905
Average			100			The		4785

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 inch-pound = 0.1130 Nm

1 lb = 0.4536 kgf = 4.448 N

Table B10: First Crack Strength and Maximum Flexural Strength

Specimen #	Age (Days)	Load (lbs)	First Crack Deflection (inches)	Stress (psi)	Maximum Load (lbs)	Flexural Strength (psi)
W3-B1	7	3166	0.0010	570	3391	610
W3-B2	7	3090	0.0012	555	3112	559
W3-B3	7	3144	0.0008	564	3179	570
W3-B4	7	3134	0.0010	576	3179	584
Average				566		581
W3-B5	28	3303	0.0009	594	3343	601
W3-B6	28	3828	0.0008	675	3839	677
W3-B7	28	3995	0.0009	709	4007	711
W3-B8	28	3389	0.0012	600	3597	636
Average				645		656
W4-B1	7	2951	0.0009	538	3071	560
W4-B2	7	2856	0.0009	508	2954	526
W4-B3	7	2957	0.0008	522	3300	583
W4-B4	7	3258	0.0010	596	3262	596
Average				541		566
W4-B5	28	3729	0.0012	672	3790	683
W4-B6	28	3260	0.0008	593	3316	604
W4-B7	28	3433	0.0010	622	3662	664
W4-B8	28	3607	0.0010	626	3991	693
Average				628		661

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa

u m

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

I pcy = 0.5933 kg/cu m

1 lb = 0.4536 kgf = 4.448 N

1 inch-pound = 0.1130 Nm

Table B11: Japanese Standard - Toughness & Equivalent Flexural Strength

Specimen #	Age (Days)	Toughness (Inch-lbs)	Equivalent Flexural Strength (psi)		
W3-B1	7	113	253		
W3-B2	7	141	317		
W3-B3	7	109	245		
W3-B4	7	138	317		
Average		125	283		
W3-B5	28	151	339		
W3-B6	28	193	425		
W3-B7	28	197	437		
W3-B8	28	171	378		
Average		178	395		
W4-B1	7	169	385		
W4-B2	7	118	262		
W4-B3	7	157	348		
W4-B4	7	155	354		
Average		150	337		
W4-B5 28		178	401		
W4-B6	28	145	330		
W4-B7	28	127	287		
W4-B8	28	170	369		
Average		155	347		

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m1 lb = 0.4536 kgf = 4.448 N

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 inch-pound = 0.1130 Nm

Table B12: ASTM Toughness Indices

Specimen	Age	First Crack	Toughness Indices			Toughness Ratios	
#	(Days)	Toughness (inch-lbs)	15	110	120	I10/I5	120/110
W3-B1	7	1.94	4.37	8.22	14.66	1.88	1.78
W3-B2	7	2.48	3.92	7.28	13.01	1.86	1.79
W3-B3	7	2.05	3.41	6.21	11.11	1.82	1.79
W3-B4	7	1.97	4.15	7.81	14.22	1.88	1.82
Average		2.11	3.96	7.38	13.25	1.86	1.80
W3-B5	28	2.22	3.65	6.76	12.33	1.85	1.82
W3-B6	28	2.12	3.83	7.15	13.05	1.87	1.82
W3-B7	28	2.12	4.31	8.16	14.86	1.89	1.82
W3-B8	28	2.68	4.12	7.69	13.73	1.87	1.78
Average		2.29	3.98	7.44	13.49	1.87	1.81
W4-B1	7	1.93	3.81	7.21	13.56	1.89	1.88
W4-B2	7	1.68	4.09	7.71	14.12	1.88	1.83
W4-B3	7	1.83	3.83	7.24	13.59	1.89	1.88
W4-B4	7	2.18	3.93	7.41	13.72	1.88	1.85
Average		1.90	3.92	7.39	13.75	1.88	1.86
W4-B5	28	3.21	3.75	6.91	12.29	1.84	1.78
W4-B6	28	2.12	3.45	6.36	11.68	1.84	1.84
W4-B7	28	2.42	3.94	7.32	13.10	1.86	1.79
W4-B8	28	2.14	4.64	8.91	16.50	1.92	1.85
Average		2.47	3.95	7.38	13.39	1.87	1.82

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m

1 sq. in. = 645.2 sq mm

1 psi = 0.006895 Mpa °F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcy = 0.5933 kg/cu m

1 inch-pound = 0.1130 Nm

1 lb = 0.4536 kgf = 4.448 N

Table B13: Impact Strength
[Specimens made from the paving done on August 7 and 8, 1996 for White-topping on Highway 14 (East Bound Lane)]

Specimen #	Number	of Blows	Difference
	First Crack	Final Failure	First Crack- Final Failure
W3-I1	338	475	137
W3-I2	29	263	234
W3-I3	33	820	787
W3-I4	32	236	204
W3-I5	11	204	193
W3-I6	21	437	416
W3-I7	184	515	331
W3-I8	18	151	133
W3-I9	226	444	218
W3-I10	89	490	401
W3-I11	96	415	319
W3-I12	13	236	223
W3-I13	75	337	262
W3-I14	49	337	288
W3-I15	325	1050	725
Average	103	427	325

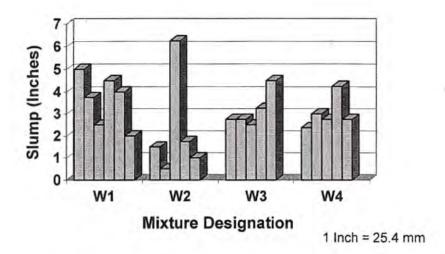


Fig B1: Comparison of Slump Measured During Quality Control Tests

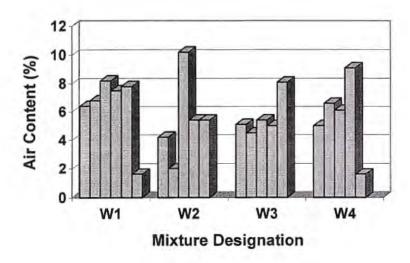


Fig B2: Comparison of Air Content Measured During Quality Control Tests

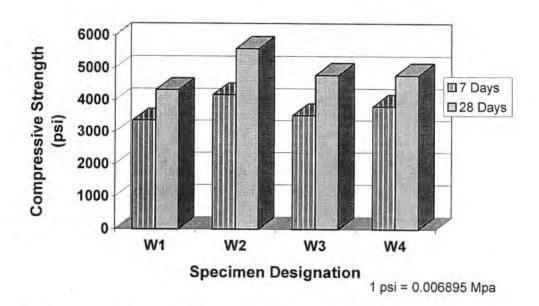


Fig B3: Comparison of Compressive Strength for Different Sections

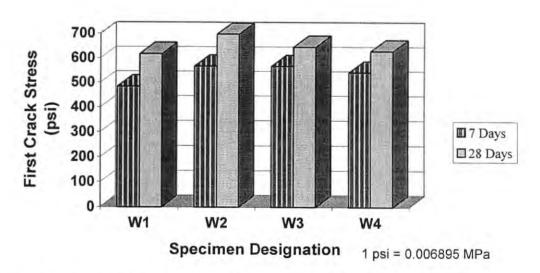


Fig B4: Comparison of First Crack Stress for Different Sections

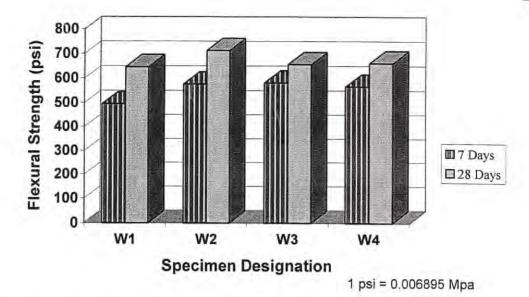


Fig B5: Comparison of Flexural Strength for Different Sections

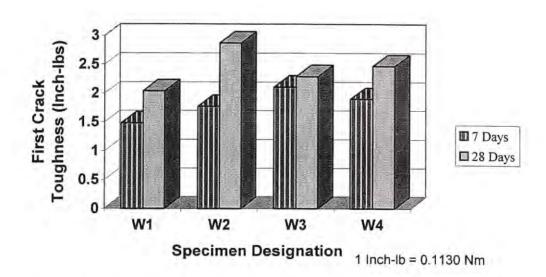


Fig B6: Comparison of ASTM First Crack Toughness for Different Sections

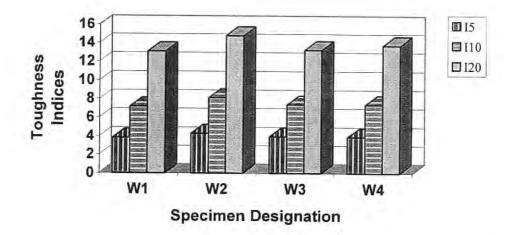


Fig B7: Comparison of 7 Day ASTM Toughness Indices, I5, I10, I20 for Different Sections

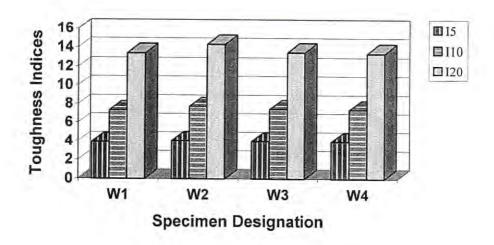


Fig B8: Comparison of 28 Day ASTM Toughness Indices, I5, I10, I20 for Different Sections

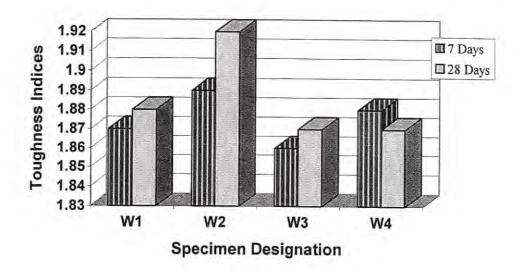


Fig B9: Comparison of 7 and 28 Day ASTM Toughness Ratio I10/I5 for Different Sections

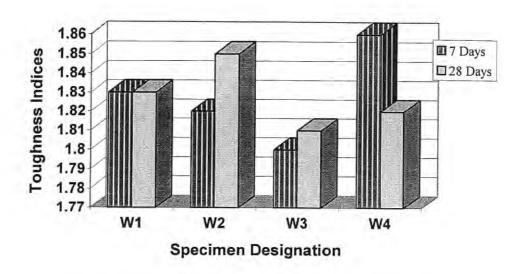


Fig B10: Comparison of 7 and 28 Day ASTM Toughness Ratio I20/I10 for Different Sections

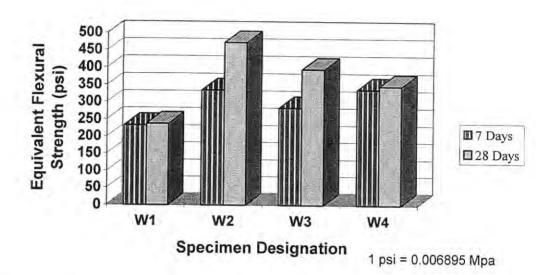


Fig B11: Comparison of Japanese Standard Equivalent Flexural Strength for Different Specimens

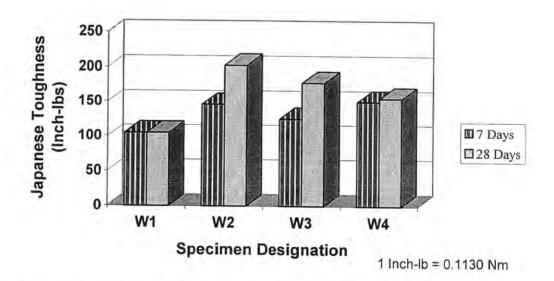


Fig B12: Comparison of Japanese Toughness for Different Sections

Table WR: Summary of Tests Conducted by SD-DOT

SI.No:	Mix Date	Age Hardened Properties		Fresh Concrete Properties		
			Strength	Air	Slump	
1	16-Jun-98	3	3695	6.2	2	
		6	4620			
		28	5870			
2	24-Jun-98	3	4080	5.8	1.75	
		5	4260			
		28	6370			
3	24-Jun-98	1	2720	6.2	2.25	
		5	4650			
		28	6400			

Table WR1 : Mixture Proportions for concrete used at Rapid City White Topping

Mixture	Mixture Proportions (lbs/cubic yard)											
Designation	Coarse Aggregate pcy	Fine Aggregate pcy	Cement	Fly Ash pcy	Water	w/c	w/(c+f)					
WT1	1425	1425	570	113	267.0	0.47	0.39					
WT2	1425	1425	570	113	267.0	0.47	0.39					
WT3	1425	1425	570	113	267.0	0.47	0.39					
WT4	1385	1385	670	113	269.5	0.40	0.34					

<sup>\*</sup> Conversion Factor: pcy x 0.59 = kg/m<sup>3</sup>

for water: gallons\*8.345 = pounds

Table WR2 : Fresh Concrete Properties and Ambient Conditions for concrete used at Rapid City Whitetopping

Mix ID Properties	WTI	WT2	WT3	WT4
Slump (inches)	2.50	3.25	2.25	3.00
Air Content (%)	8.0	8.2	7.6	6.4
Unit Weight (pcf)	136.4	133.6	134.0	142.8
Fiber Content (pcy)	25.1	24.6	24.0	21.2
Temperature (F)	86	86	82.4	86
Ambient Conditions				
Temperature (F)	50	50	45	60
Relative Humidity	80	80	75	65
Wind Velocity (mph)	< 5	< 5	< 5	< 5
Date of Casting	6/13/98	6/13/98	6/13/98	6/23/98

Conversion table:

1 inch = 25.4 mm 1 psi = 0.006895 Mpa °F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m 1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N

Table WR3: Compressive Strength of Concrete used at Rapid City

Spec.	Age	Ler	ngth	Dian	neter		nit ight	Compr	
ID#	days	in.	mm	in.	mm	pcf	Kg/m <sup>3</sup>	psi	Mpa
WT1-C3	3	8.00	203.3	4,02	102.0	144.9	2320.5	2970	20.5
WT1-C4	3	8.01	203.3	4.00	101.7	137.3	2198.8	3260	22.5
Averag	jes	8.00	203.3	4.01	101.8	141.1	2259.7	3115	21.5
WT4-C13	3	8.02	203.6	4.02	102.2	144.3	2310.9	3270	22.6
WT4-C11	3	8.02	203.6	4.02	102.1	144.4	2312.9	3405	23.5
Averag	jes	8.02	203.6	4.02	102.1	144.3	2311.9	3338	23.1
WT1-C5	5	8.00	203.3	4.01	101.9	145.2	2325.3	3840	26.5
WT1-C8	5	8.00	203.3	4.02	102.1	144.7	2318.0	4100	28.3
Averag	jes	8.00	203.3	4.02	102.0	145.0	2321.7	3970	27.4
WT4-C1	5	8.01	203.5	4.02	102.1	144.5	2313.8	4450	30.7
WT4-C2	5	8.01	203.5	4.03	102.3	143.9	2304.5	4905	33.9
Averaç	jes	8.01	203.5	4.02	102.2	144.2	2309.2	4678	32.3
WT1-C2	7	8.00	203.3	4.02	102.0	144.9	2320.4	4145	28.6
WT1-C6	7	8.01	203.5	4.02	102.1	136.1	2179.3	4730	32.7
WT1-C1	7	8.01	203.4	4.02	102.1	144.8	2319.1	3945	27.3
Averag	jes	8.01	203.4	4.02	102.0	140.5	2249.8	4438	30.7
WT4-C10	7	8.03	203.9	4.02	102.2	144.0	2306.1	4720	32.6
WT4-C12	7	8.01	203.4	4.02	102.0	144.8	2318.9	5525	38.2
WT4-C5	7	8.01	203.6	4.02	102.1	144.7	2316.9	4850	33.5
Averag	ges	8.02	203.6	4.02	102.1	144.4	2312.5	5123	35.4

1 inch = 25.4 mm

1 pcf = 16.02 kg/cu m 1 sq. in. = 645.2 sq mm 1 psi = 0.006895 Mpa

 $^{\circ}F$  to  $^{\circ}C$ :  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcy = 0.5933 kg/cu m 1 inch-pound = 0.1130 Nm 1 lb = 0.4536 kgf = 4.448 N

Table WR4: Compressive Strength of Concrete used at Rapid City at 14 days

Spec.	Age	Lei	ngth	Diar	neter		nit ight	Compressive Strength		
ID#	days	in.	mm	in.	mm	pcf	Kg/m <sup>3</sup>	psi	Mpa	
WT1-C13	14	8.01	203.5	4.01	101.9	145.0	2322.0	4860	33.6	
WT1-C12	14	8.01	203.5	4.02	102.0	136.3	2183.3	4540	31.4	
WT1-C9	14	8.01	203.4	4.02	102.2	144.4	2313.5	4490	31.0	
Averag	jes	8.01	203.4	4.02	102.0	141.9	2272.9	4630	32.0	
WT2-C6*	14	8.01	203,5	4.03	102.3	143.8	2303.1	2430	16.8	
WT2-C5	14	8.01	203.4	4.02	102.2	144.3	2311.1	4600	31.8	
WT2-C4	14	8.01	203.5	4.02	102.2	144.3	2311.9	4490	31.0	
Averaç	es	8.01	203.5	4.02	102.2	144.1	2308.7	4545	31.4	
WT3-C3	14	8.01	203.5	4.02	102.1	144.5	2314.3	4925	34.0	
WT3-C3	14	8.01	203.5	4.02	102.1	144.4	2312.4	5510	38.1	
WT3-C6	14	8.01	203.5	4.03	102.2	144.2	2308.9	5110	35.3	
Averag	es	8.01	203.5	4.02	102.2	144.3	2311.8	5182	35.8	
WT4-C7	14	8.02	203.7	4.02	102.0	144.6	2315.6	5525	38.2	
WT4-C8	14	8.00	203.3	4.02	102.1	144.5	2315.1	5395	37.3	
WT4-C9	14	8.01	203.5	4.03	102.3	143.8	2303.2	5530	38.2	
Averag	jes	8.01	203.5	4.02	102.2	144.3	2311.3	5483	37.9	

<sup>\*</sup> Specimen not considered for calculation of average value as it is an outlier.

I inch = 25.4 mm

1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m 1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm

1 lb = 0.4536 kgf = 4.448 N

Table WR5: Compressive Strength of Concrete used in Rapid City at 28-day

Spec.	Age	Ler	ngth	Diar	neter	U	nit	Static	Mod.	Compr	essive
		-	2-			We	ight	psi	Mpa	Stre	ngth
ID#	days	in.	mm	in.	mm	pcf	Kg/m <sup>3</sup>	(x10 <sup>6</sup> )	$(x10^4)$	psi	Mpa
WT1-C7	28	8.01	203.5	4.04	102.5	143.3	2295.9	4.9	3.4	5550	38.4
WT1-C11	28	8.01	203.5	4.02	102.2	144.2	2310.3	4.7	3.3	4010	27.7
WT1-C10*	28	8.01	203,4	4.03	102.3	144.0	2306.0	4.3	3.0	3220	22.3
Averag	jes	8.01	203.5	4.03	102.3	143.9	2304.0	4.8	3.2	4780	33.0
WT2-C3	28	8.01	203,5	4.03	102.3	143.8	2303.1	4.9	3.4	5725	39.6
WT2-C1	28	8.01	203.5	4.03	102.4	143.8	2303.2	4.9	3.4	5060	35.0
WT2-C2	28	8.01	203,4	4.03	102.3	144.0	2306.0	4.9	3.4	6120	42.3
Averag	jes	8.01	203.5	4.03	102.3	143.9	2304.1	4.9	3.4	5635	38,9
WT3-C1	28	8.01	203.5	4.03	102.3	143.9	2305.0	4.9	3.4	5810	40.1
WT3-C4	28	8.01	203.4	4.04	102.5	143.5	2298.6	4.9	3.4	6340	43.8
WT3-C5	28	8.02	203.8	4.04	102.5	143.0	2290.9	4.9	3.4	5000	34.6
Averag	jes	8.01	203.6	4.03	102.4	143.5	2298.2	4.9	3.4	5717	39.5
WT4-C6	28	8.01	203.4	4.01	101.8	145.4	2328.4	5.0	3.4	6575	45.4
WT4-C4	28	8.00	203.3	4.01	101.8	145.4	2329.5	5.0	3.4	6540	45.2
WT4-C3	28	8.01	203.4	4.01	101.8	145.4	2328.6	5.0	3.4	5785	40.0
Averag	es	8.01	203.3	4.01	101.8	145.4	2328.8	5.0	3.4	6300	43.5

<sup>\*</sup> Specimen not considered for calculation of average value as it is an outlier.

1 inch = 25.4 mm

1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m 1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N

Table WR6: Flexural Strength of Concrete used in Rapid City at 14 day

Spec. ID#	Age	Len	gth	Bre	adth	De	pth	1000	nit eight	X2. 7.5.5.6	mum ad	Flex	ural
	days	in.	mm	in.	mm	in.	mm	pcf	kg/m <sup>3</sup>	lbs	kgs	psi	Mpa
WT1-B4	14	14.00	355.6	4.02	102.1	4.02	102.2	137.3	2200.0	3990.0	1809.8	735	5.1
WT1-B5	14	14.00	355.6	4.02	102.2	4.02	102.1	137.3	2200.0	4265.0	1934.6	790	5.5
WT1-B1	14	14.00	355.6	4.03	102.2	4.02	102.1	137.3	2199.1	4240.5	1923.5	785	5.4
WT1-B6*	14	14.00	355.6	4.02	102.1	4.02	102.2	137.4	2200.7	3476.0	1576.7	640	4.4
Averag	ges	14.00	355.6	4.02	102.2	4.02	102.2	137.3	2199.9	3992.9	1811.1	770	5.3
WT2-B5	14	14.00	355.6	4.03	102.3	4.03	102.2	137.0	2194.6	4279.6	1941.2	785	5.4
WT2-B8	14	14.00	355.6	4.03	102.3	4.03	102.3	137.0	2194.3	3595.1	1630.7	660	4.6
WT2-B6	14	14.00	355.6	4.03	102.3	4.03	102.4	136.9	2193.5	3937.0	1785.8	725	5.0
WT2-B7*	14	14.00	355.6	4.02	102.1	4.02	102.0	141.3	2263.9	4491.2	2037.2	830	5.7
Averag	ges	14.00	355.6	4.02	102.2	4.03	102.2	138.1	2211.6	4075.7	1848.7	723	5.2
WT3-B2	14	14.00	355.6	4.03	102.3	4.02	102.2	137.2	2197.3	4676.4	2121.2	860	5.9
WT3-B6*	14	14.00	355.6	4.02	102.1	4.02	102.1	137.5	2202.8	5004.4	2270.0	925	6.4
WT3-B3	14	14.00	355.6	4.02	102.1	4.02	102.2	137.4	2200.7	4359.0	1977.2	805	5.6
WT3-B5	14	14.00	355.6	4.02	102.2	4.02	102.2	137.3	2198.9	4531.3	2055.4	830	5.7
Averag	ges	14.00	355.6	4.02	102.2	4.02	102.1	137.3	2199.9	4642.8	2105.9	832	5.9
WT4-B3*	14	14.00	355.6	4.01	101.8	4.03	102.5	145.0	2322.9	6443.0	2922.5	1180	8.2
WT4-B7	14	14.00	355.6	4.03	102.3	4.04	102.6	144.0	2307.4	4800.0	2177.2	875	6.0
WT4-B6	14	14.00	355.6	4.03	102.4	4.03	102.3	144.5	2314.7	4554.0	2065.7	835	5.8
WT4-B5	14	14.00	355.6	4.01	101.9	4.03	102.3	148.9	2385.8	4120.0	1868.8	755	5.2
Averag	ges	14.00	355.6	4.02	102.2	4.03	102.5	144.5	2315.0	5265.7	2388.5	822	6.7

<sup>\*</sup> Specimen not considered for calculation of average value as it is an outlier. Conversion table:

 $\begin{array}{lll} 1 \text{ inch} = 25.4 \text{ mm} & 1 \text{ psi} = 0.006895 \text{ Mpa} & ^{\circ}\text{F to } ^{\circ}\text{C} \colon \text{T(}^{\circ}\text{C}) = [\text{T(}^{\circ}\text{F}) - 32]/1.8 \\ 1 \text{ pcf} = 16.02 \text{ kg/cu m} & 1 \text{ pcy} = 0.5933 \text{ kg/cu m} & 1 \text{ inch-pound} = 0.1130 \text{ Nm} \\ \end{array}$ 

1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N

Table WR7: Flexural Strength of Concrete used in Rapid City at 28-day

Spec. ID#	Age	Len	gth	Bre	adth	De	pth		nit eight	Maxi Lo		Flex	ural
	days	in.	mm	in.	mm	in.	mm	pcf	kg/m <sup>3</sup>	lbs	kgs	psi	Mpa
WT1-B2	28	14.00	355.6		102.3	4.02	102.0	137.3		4256.0	1930.5	790	5.5
WT1-B3*	28	14.00	355.6	4.02	102.1	4.02	102.0	141.5	2267.3	3715.0	1685.1	680	4.7
WT1-B7	28	14.00	355.6	4.02	102.1	4.01	102.0	141.5	2266.8	5220.0	2367.8	965	6.7
WT1-B8*	28	14.00	355.6	4.03	102.3	4.01	102.0	137.4	2200.5	3853.0	1747.7	710	4.9
Averag	jes	14.00	355.6	4.02	102.2	4.01	102.0	139.4	2233.7	4261.0	1932.8	878	6.1
WT2-B4*	28	14.00	355.6	4.03	102.3	4.02	102.2	137.2	2197.9	3508.0	1591.2	645	4.5
WT2-B1	28	14.00	355.6	4.02	102.2	4.01	101.8	141.7	2270.2	4926.0	2234.4	795	5.5
WT2-B2	28	14.00	355.6	4.02	102.2	4.02	102.1	141.3	2262.8	3905.0	1771.3	720	5.0
WT2-B3	28	14.00	355.6	4.02	102.1	4.01	102.0	137.8	2206.8	4097.0	1858.4	760	5.3
Averaç	jes	14.00	355.6	4.02	102.2	4.02	102.0	139.5	2234.4	4109.0	1863.8	758	5.2
WT3-B4*	28	14.00	355.6	4.02	102.0	4.01	101.8	141.9	2272.9	3849.0	1745.9	710	4.9
WT3-B8	28	14.00	355.6	4.03	102.3	4.02	102.2	137.2	2197.3	4270.0	1936.8	785	5.4
WT3-B1	28	14.00	355.6	4.03	102.3	4.02	102.2	137.2	2197.3	5185.0	2351.9	955	6.6
WT3-B7	28	14.00	355.6	4.03	102.4	4.01	101.8	137.6	2203.4	4297.0	1949.1	795	5.5
Averag	jes	14.00	355.6	4.02	102.2	4.02	102.0	138.4	2217.7	4400.3	1995.9	845	5.8
WT4-B4	28	14.00	355.6	4.02	102.1	4.02	102.2	137.4	2201.1	6089.7	2762.2	1125	7.8
WT4-B8	28	14.00	355.6	4.01	101.9	4.01	101.8	144.0	2307.4	5291.6	2400.2	985	6.8
WT4-B2	28	14.00	355.6	4.02	102.1	4.03	102.2	144.9	2321.6	5530.4	2508.5	1020	7.0
WT4-B1	28	14.00	355.6	4.01	101.9	4.01	101.9	145.8	2335.5	5065.5	2297.7	945	6.5
Averag	jes	14.00	355.6	4.02	102.0	4.02	102.1	142.1	2276.7	5637.2	2557.0	1019	7.0

<sup>\*</sup> Specimen not considered for calculation of average value as it is an outlier.

1 inch = 25.4 mm 1 psi = 0.006895 Mpa °F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

 $\begin{array}{lll} 1 \ pcf = 16.02 \ kg/cu \ m & 1 \ pcy = 0.5933 \ kg/cu \ m & 1 \ inch-pound = 0.1130 \ Nm \\ 1 \ sq. \ in. = 645.2 \ sq \ mm & 1 \ 1b = 0.4536 \ kgf = 4.448 \ N \end{array}$ 

Table WR8: ASTM Toughness Indices and Residual Strength Factors for Concrete used in Rapid City

Spec.	First C	Crack nness		Toughne	ss Indices		Tou	ghness l	Ratios	R 5,10	R10,20
	inlbs	Nm	15	110	120	130	110/15	120/110	130/120		,
WT1-2	3.60	34,20	3.80	6.60	11.30	16.10	1.76	1.71	1.42	56	94
WT1-3	3.30	31.35	4.00	7.10	12.70	18.50	1.76	1.79	1.45	62	112
WT1-8*	2.50	23.75	3,80	7.10	12.50	17.90	1.83	3.78	1.20	66	108
WT1-7	5.20	49.40	4.00	6.50	10.80	15.30	1.64	1.68	1.41	50	86
Averages	4.03	38.32	3.93	6.73	11.60	16.63	1.72	1.73	1.43	56	97
WT2-4	4.20	39.90	3,30	5.90	10.90	16.20	1.80	1.84	1.48	52	100
WT2-1*	3.00	28.50	3.40	5.60	8.50	15.80	1.63	1.52	1.87	44	58
WT2-2	3,00	28.50	3,90	6.90	12.10	17.40	1.79	1.74	1.44	60	104
WT2-3	3.10	29.45	3.80	6.80	11.80	17.00	1.78	1.73	1.44	60	100
Averages	3.43	32.62	3.67	6.53	11.60	16.87	1.79	1.77	1.45	57	101
WT3-4*	3.40	32.30	3,60	6.40	7.60	11.20	1.79	1.18	1.48	56	24
WT3-1	3.00	28.50	4.00	7.30	12.60	16,90	1.83	1.71	1.35	66	106
WT3-7*	4.00	38.00	3,10	4.90	7.50	10.30	1.59	1.53	1.37	36	52
WT3-8	3.10	29.45	3.80	7.00	12.20	16.70	1.85	1.75	1.37	64	104
Averages	3.05	28.98	3.90	7.15	12.40	16.80	1.84	1.73	1.36	65	105
WT4-8	4.70	44.65	3.00	5.30	9.80	14.40	1.76	1.86	1.47	46	90
WT4-1	3.10	29.45	4.00	7.30	12.40	16.70	1.83	1.71	1.35	66	102
WT4-5	5.20	49.40	5.10	7.90	11.40	14.80	1.54	1.45	1.29	56	70
WT4-2	5.20	49.40	4.00	6.50	10.80	15.30	1.64	1.68	1.41	50	86
Averages	4.55	43.23	4.03	6.75	11.10	15.30	1.69	1.68	1.38	55	87

<sup>\*</sup> Specimen not considered for calculation of average value as it is an outlier.

Table WR9 : Japanese Standard - Toughness and Equivalent Flexural Strength of concrete used in Rapid City

Spec. Id.	Age	Tou	hness	Equivaler Stre	nt Flexural
	(days)	Nm	inlbs	Мра	psi
WT1-2	28	23	206	3.3	475
WT1-3	28	22	199	3.2	460
WT1-8	28	23	200	3.2	461
WT1-7	28	25	221	3.5	511
Averages		23	206	3,3	477
WT2-4	28	24	209	3.3	480
WT2-1	28	21	184	2.9	424
WT2-2	28	25	218	3.5	504
WT2-3	28	22	192	3.1	444
Avera	iges	23	201	3.2	463
WT3-4	28	24	211	3.3	485
WT3-1	28	25	224	3.6	515
WT3-7	28	19	167	2.7	386
8-ETW	28	24	216	3.4	498
Avera	iges	23	204	3.2	471
WT4-8	28	24	213	3.4	496
WT4-1	28	25	224	3.6	520
WT4-5	28	25	224	3,6	516
WT4-2*	28	56	496	7.9	1141
Avera	Averages		289	4.6	511

 $\begin{array}{lll} I \; inch = 25.4 \; mm & 1 \; psi = 0.006895 \; Mpa & {}^{\circ}F \; to \; {}^{\circ}C ; \; T({}^{\circ}C) = [T({}^{\circ}F) \; - \; 32]/1.8 \\ 1 \; pef = 16.02 \; kg/cu \; m & 1 \; pey = 0.5933 \; kg/cu \; m & 1 \; inch-pound = 0.1130 \; Nm \\ \end{array}$ 

1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N

Table WR10: Impact Test Results for concrete used in Rapid City

Age of specimen: 28 day

Specimen ID:	First Crack	Failure	Difference		
WT1-1	48	182	134		
WT1-2	57	206	149		
WT1-3	60	200	140		
*WT1-4	74	180	106		
WT1-5	42	182	140		
WT1-6	54	201	147		
Average	52	194	142		
*WT2-1	22	78	56		
*WT2-2	47	100	53		
WT2-3	60	168	108		
WT2-4	84	174	90		
*WT2-5	100	185	85		
WT2-6	78	180	102		
Average	74	174	100		
WT3-1	16	78	62 64		
WT3-2	20	84			
Wt3-3	27	90	63		
WT3-4	15	80	65		
*WT3-5	90	197	107		
*WT3-6	100	185	85		
Average	20	83	64		
WT4-1	102	262	160		
WT4-2	100	250	150		
WT4-3	109	274	165		
WT4-4	108	235	127		
*WT4-5	95	160	65		
WT4-6	127	294	167		
Average	109	263	154		

<sup>\*</sup> Specimen not considered for the calculation of average

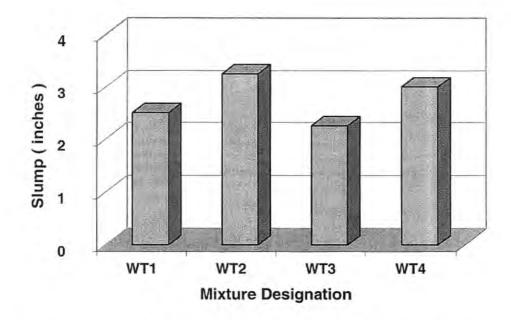


Fig WR1: Comparision of Slump of concrete used in Rapid City

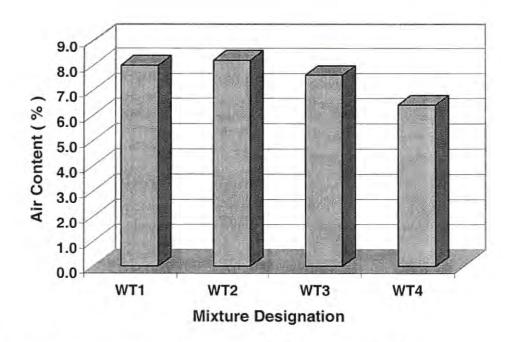


Fig WR2:Comparision of Air Content of Concrete used in Rapid City

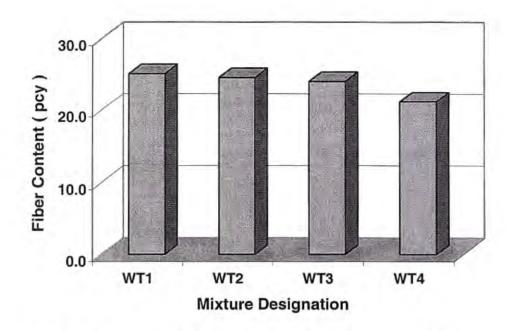


Fig. WR3: Comparision of Fiber Content of Concrete used in Rapid City

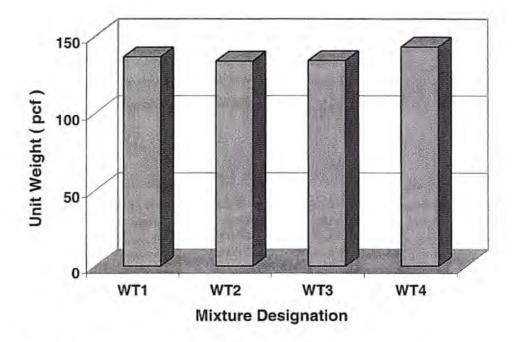


Fig. WR4: Comparision of Unit Weight of Concrete used in Rapid City

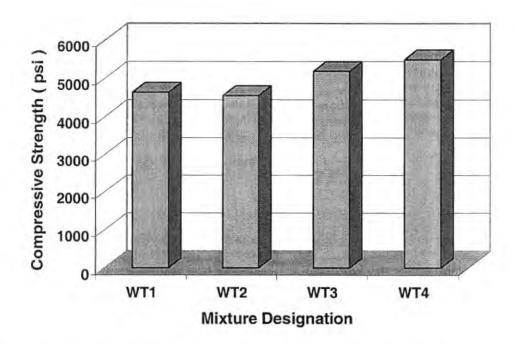


Fig. WR5: Comparision of Compressive Strength at 14 day of Concrete used in Rapid City

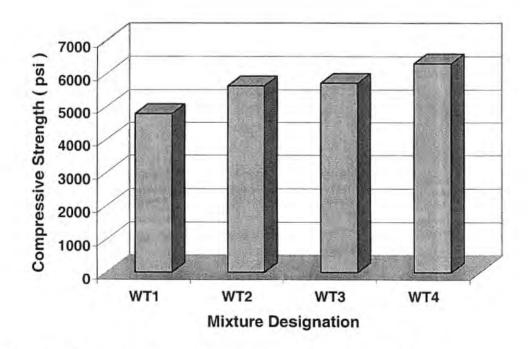


Fig. WR6: Comparision of Compressive Strength at 28 day of Concrete used in Rapid City

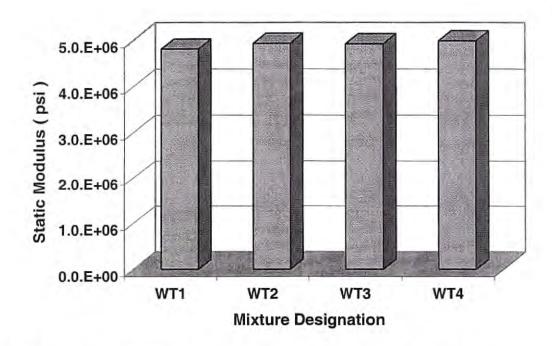


Fig. WR7: Comparision of Static Modulus of concrete used in Rapid City

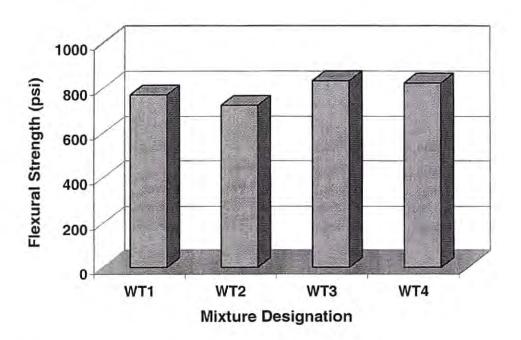


Fig. WR8: Comparision of Flexural Strength at 14 day of Concrete used in Rapid City

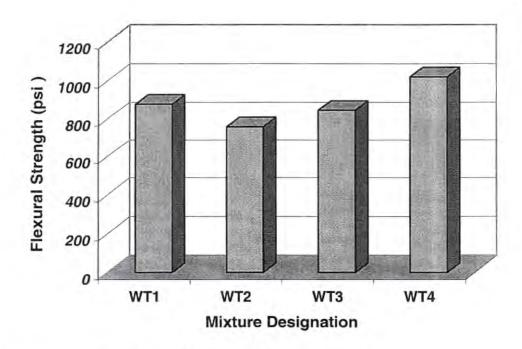


Fig. WR9: Comparision of Flexural Strength at 28 day of Concrete used in Rapid City

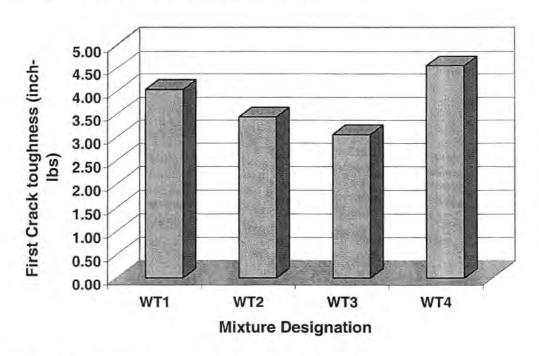


Fig. WR10: Comparision of First Crack Toughness of Concrete used in Rapid City

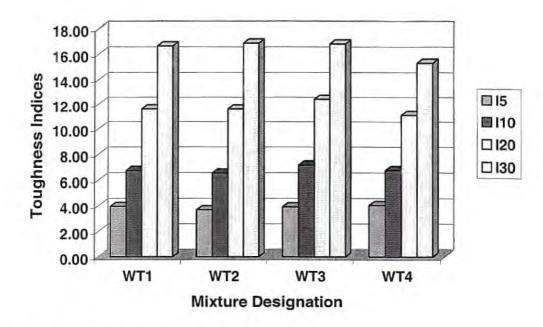


Fig. WR11: Comparision of Toughness Indices of Concrete used in Rapid City

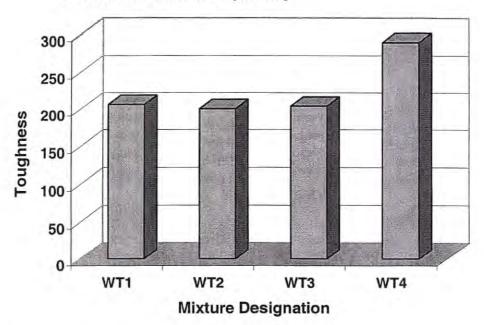


Fig. WR12: Comparision of Japanese Standard Toughness of Concrete used in Rapid City

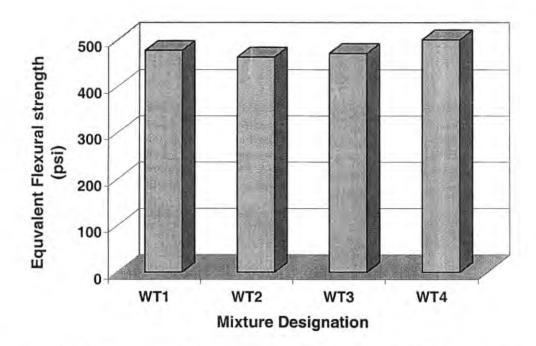


Fig. WR13: Comparision of Japanese Standard Equivalent Flexural Strength of Concrete used in Rapid City

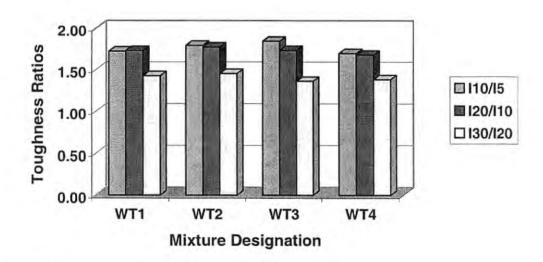


Fig. WR14: Comparision of Toughness Ratios of Concrete used in Rapid City

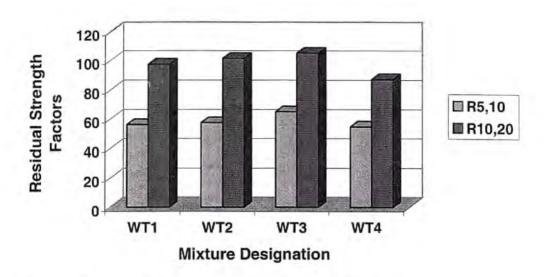


Fig. WR15: Comparision of Residual Strength Factors of Concrete used in Rapid City

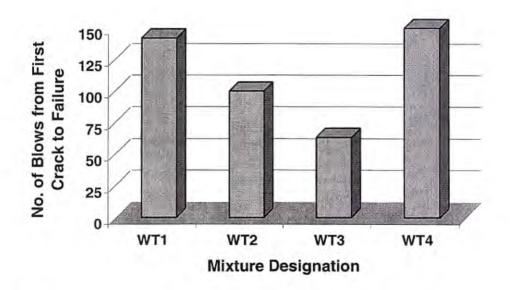


Fig. WR16: Impact Test Results of Concrete used in Rapid City

# APPENDIX C

Details of the Inspections for Crack Measurement For

- 1. Highway 14
- 2. Rapid City

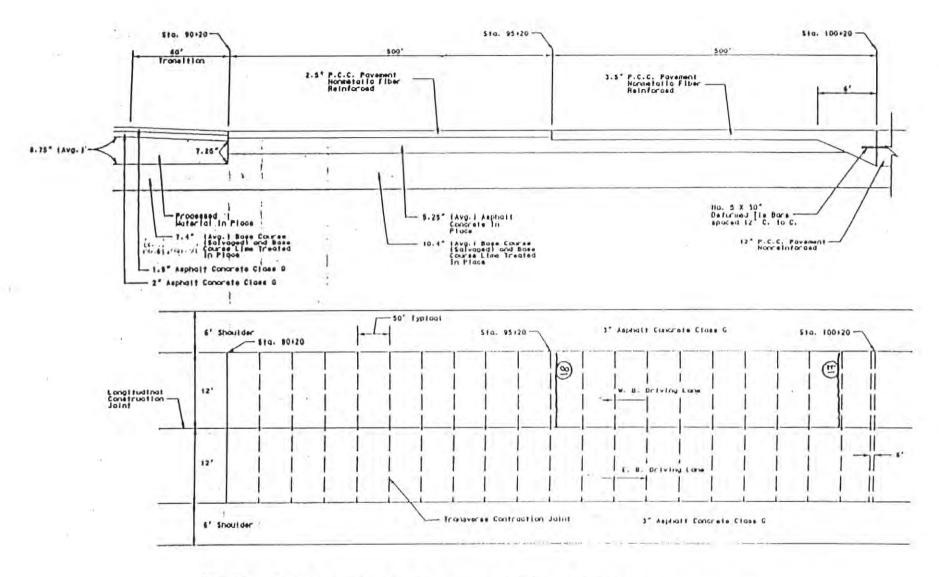


Fig C1: Crack Location for 2.5 inch and 3.5 inch NMFRC White-topping in the Jointed Section

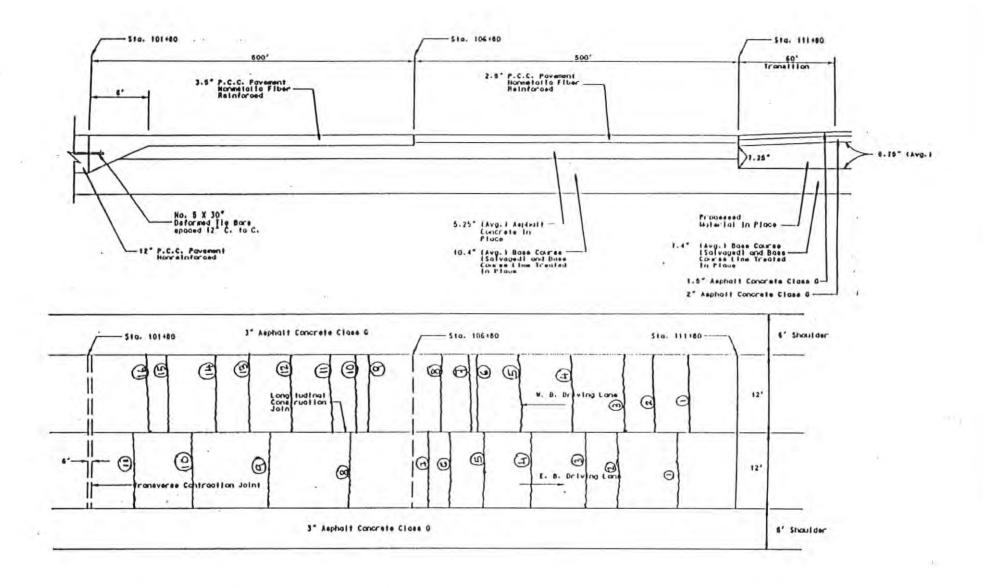


Fig C3: Crack Location for 2.5 inch and 3.5 inch NMFRC White-topping in the Unjointed Section

### Crack Number and Maximum Width on East Bound White-Topping on Highway 14

(First Inspection of East-Bound Lane) Pavement inspected on 08/14/96

(Refer to attached Plan for crack numbers)

Thickness of Whitetopping	Crack Numbe r	Distance between	Crack Width	Maximum Crack Width me at surface		measured
(mm)		consecutive cracks (m)	Measured at Edge	South Edge	Center Edge	North Edge
63.5	1	9.	4 mm	5 mm	6 mm	5 mm
63.5	2	28.35	3 mm	4 mm	3 mm	4 mm
63.5	3	12.80	3 mm	4 mm	3 mm	3 mm
63.5	4	26.82	4 mm	5 mm	6 mm	4 mm
63.5	5	21.49	0.5 mm	0.8 mm	0.6 mm	1 mm
63.5	6	16.61	3 mm	3 mm	2 mm	3 mm
63.5	7	10.97	1.5 mm	2 mm	2 mm	3 mm
	Saw- Cut @106+ 80	6.70	0.08 mm		*	
88.9	8	30.02	3 mm	5 mm	8 mm	7 mm
88.9	9	38.86	4 mm	6 mm	8 mm	6 mm
88.9	10	34.75	2 mm	3 mm	5 mm	5 mm
88.9	11	25.60	2 mm	5 mm	5 mm	5 mm
	Saw- Cut @101+ 80	23.16	No Crack		I+	

#### Conversion table:

1 inch = 25.4 mm

I pcf = 16.02 kg/cu m I sq. in. = 645.2 sq mm 1 psi = 0.006895 Mpa

1 pcy = 0.5933 kg/cu m

1 lb = 0.4536 kgf = 4.448 N

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 inch-pound = 0.1130 Nm

Thickness of whitetopping (mm)	Location of Saw-cut	Crack Width	Remarks
	Saw-cut @ 101+74	No Crack	Transition Zone between White- topping & 12" thick PCC pavement
304.8	Saw-cut @ 101+60	No Crack	
304.8	Saw-cut @ 101+40	1 mm	
304.8	Saw-cut @ 101+20	1 mm	
304.8	Saw-cut @ 101+00	1.5 mm	
304.8	Saw-cut @ 100+80	1.5 mm	
304.8	Saw-cut @ 100+60	1.5 mm	
304.8	Saw-cut @ 100+40	2 mm	
304.8	Saw-cut @ 100+20	Not visible*	
304.8	Saw-cut @ 100+16	Not visible*	
304.8	Saw-cut @ 99+66	2 mm	
304.8	Saw-cut @ 99+20	3 mm	
304.8	Saw-cut @ 98+70	3 mm	
304.8	Saw-cut @ 98+20	2 mm	
304.8	Saw-cut @ 97+70	2 mm	
304.8	Saw-cut @ 97+20	2 mm	
88.9	Saw-cut @ 96+70	3 mm	
88.9	Saw-cut @ 96+20	4 mm	
88.9	Saw-cut @ 95+70	3 mm	
88.9	Saw-cut @ 95+20	5 mm	
88.9	Saw-cut @ 94+70	5 mm	
88.9	Saw-cut @ 94+20	4 mm	
88.9	Saw-cut @ 93+70	3 mm	
88.9	Saw-cut @ 93+20	3 mm	
88.9	Saw-cut @ 92+70	2 mm	
88.9	Saw-cut @ 92+20	4 mm	
63.5	Saw-cut @ 91+70	3 mm	
63.5	Saw-cut @ 91+20	3 mm	
63.5	Saw-cut @ 90+70	4 mm	
63.5	Saw-cut @ 90+20	14	

W.B. - West Bound Traffic.

Note: All the cracks were transverse to the direction of traffic and extended over the full width of the west bound lane.

Crack was not visible due to wooden form obstruction.

Conversion table: 1 inch = 25.4 mm

# Crack Number and Maximum Width on East Bound White-Topping on Highway 14 (Second Inspection of East-Bound Lane)

(Measurement done on 8/25/96)

Thickness of whitetopping (mm)	Crack Number and Location	Crack Width measured on top surface
63.5	1 @ 110+86	Routed
63.5	2 @ 109+93	Routed
63.5	3 @ 109+51	Routed
63.5	4 @ 108+63	Routed
63.5	5 @ 107+92'6"	Routed
63.5	6 @ 107+38	Routed
63.5	7 @ 107+02	Routed
88.9	8 @ 105+81*6"	Routed
88.9	9 @ 104+54	Routed
88.9	10 @ 103+40	Routed
88.9	11 @ 102+56	Routed
	Saw-Cut Jt. Location	Crack measaured at Edg
304.8	Saw-cut @ 99+66	5 mm
304.8	Saw-cut @ 99+20	2 mm
304.8	Saw-cut @ 98+70	3 mm
304.8	Saw-cut @ 98+20	2 mm
304.8	Saw-cut @ 97+70	3 mm
304.8	Saw-cut @ 97+20	3 mm
88.9	Saw-cut @ 96+70	4 mm
88.9	Saw-cut @ 96+20	3 mm
88.9	Saw-cut @ 95+70	5 mm
88.9	Saw-cut @ 95+20	3 mm
88.9	Saw-cut @ 94+70	4 mm
88.9	Saw-cut @ 94+20	4 mm
88.9	Saw-cut @ 93+70	4 mm
88.9	Saw-cut @ 93+20	3 mm
88.9	Saw-cut @ 92+70	4 mm
88.9	Saw-cut @ 92+20	3 mm
63.5	Saw-cut @ 91+70	6 mm
63.5	Saw-cut @ 91+20	3 mm
63.5	Saw-cut @ 90+70	5 mm

Note: All the cracks were transverse to the direction of traffic and extended over the full width of the east bound lane.

Conversion table: 1 inch = 25.4 mm

### Crack Number and Maximum Width on East Bound White-Topping on Highway 14

(Third Inspection of East-Bound Lane) Pavement inspected on 09/07/96

Thickness of whitetopping (mm)	Crack Number and Location	Remarks
63.5	1 @ 110+86	Routed
63.5	2 @ 109+93	Routed
63.5	3 @ 109+51	Routed
63.5	4 @ 108+63	Routed
63.5	5 @ 107+92'6"	Routed
63.5	6 @ 107+38	Routed
63.5	7 @ 107+02	Routed
88.9	8 @ 105+81'6"	Routed
88.9	9 @ 104+54	Routed
88.9	10 @ 103+40	Routed
88.9	11 @ 102+56	Routed

#### Measurements of Corner Cracks for East Bound Lane

Thickness of whitetopping (mm)	Crack Location	Maximum Width	Remarks
63.5	90+20	0.6 mm	North Edge towards East
63.5	90+20	0.5 mm	North Edge towards East
63.5	90+70	0.3 mm	North Edge towards West
63.5	90+70	0.5 mm	South Edge towards East
63.5	90+70	0.5 mm	South Edge towards West
63.5	91+20	0.33 mm	South Edge towards West
88.9	92+20	0.5 mm	North Edge towards East
88.9	92+20	0.5 mm	North Edge towards West
88.9	93+20	0.3 mm	South Edge towards East
88.9	93+20	0.4 mm	South Edge towards West
88.9	93+70	0.2 mm	South Edge towards East
88.9	93+70	0.2 mm	South Edge towards West
88.9	94+20	0.4 mm	North Edge towards East
88.9	94+20	0.033 mm	South Edge towards East
88.9	94+20	0.5 mm	South Edge towards West
88.9	94+70	0.6 mm	South Edge towards East
88.9	94+70	0.6 mm	South Edge towards West
304.8	98+20	0.3 mm	North Edge towards East
63.5	108+63	1.5 mm	Corner crack to transverse crack in Unjointed section at North Edge towards East

Conversion table: 1 inch = 25.4 mm

## Crack Number and Maximum Width on East Bound White-Topping on Highway 14

#### (Fourth Inspection of East-Bound Lane) Pavement inspected on 10/15/96

Thickness of whitetopping (mm)	Crack Number and Location	Remarks
63.5	1 @ 110+86	Routed
63.5	2 @ 109+93	Routed
63.5	3 @ 109+51	Routed
63.5	4 @ 108+63	Routed
63.5	5 @ 107+92'6"	Routed
63.5	6 @ 107+38	Routed
63.5	7 @ 107+02	Routed
88.9	8 @ 105+81'6"	Routed
88.9	9 @ 104+54	Routed
88.9	10 @ 103+40	Routed
88.9	11 @ 102+56	Routed

## **Longitudinal Crack**

Thickness of whitetopping (mm)	Location	Width	Remark
63.5	90+20 to 90+70 @ 1.5' from the edge	0.3 mm 0.25 mm 0.3 mm	Extended over the entire panel length but was not continuos

#### Measurements of Corner Cracks for East Bound Lane

Thickness of whitetopping (mm)	Crack Location	Maximum Width	Remarks
63.5	90+20	0.6 mm	North Edge towards East
63.5	90+20	0.5 mm	North Edge towards East
63.5	90+70	0.5 mm	North Edge towards West
63.5	90+70	0.5 mm	South Edge towards East
63.5	90+70	0.5 mm	South Edge towards West
63.5	91+20	0.33 mm	South Edge towards West
63.5	92+20	0.5 mm	North Edge towards East
63.5	92+20	0.5 mm	North Edge towards West
88.9	93+20	0.3 mm	South Edge towards East
88.9	93+20	0.4 mm	South Edge towards West
88.9	93+70	0.2 mm	South Edge towards East
88.9	93+70	0.2 mm	South Edge towards West
88.9	93+70	0.33 mm	North Edge towards West
88.9	93+70	0.2 mm	North Edge towards East
88.9	94+20	0.4 mm	North Edge towards East
88.9	94+20	0.033 mm	South Edge towards East
88.9	94+20	0.5 mm	South Edge towards West
88.9	94+70	0.6 mm	South Edge towards East
88.9	94+70	0.6 mm	South Edge towards West
88.9	94+70	0.2 mm	North Edge towards East
304.8	97+20	0.2 mm	North Edge towards East
304.8	98+20	0.3 mm	North Edge towards East
63.5	110+86	0.5 mm	Corner crack to transverse crack in Unjointed section at North Edge towards East
63.5	110+86	0.5 mm	Corner crack to transverse crack in Unjointed section at North Edge towards West
63.5	109+51	0.33	Corner crack to transverse crack in Unjointed section at North Edge towards East
63.5	108+63	1.5 mm	Corner crack to transverse crack in Unjointed section at North Edge towards East
63.5	107+38	0.5 mm	Corner crack to transverse crack in Unjointed section at North Edge towards East
63.5	107+02	0.5 mm	Corner crack to transverse crack in Unjointed section at North Edge towards East
63.5	107+02	0.33 mm	Corner crack to transverse crack in Unjointed section at North Edge towards West

## Crack Number and Maximum Width on West Bound White-Topping on Highway 14

(First Inspection of West-Bound Lane) Pavement inspected on 07/29/96

(Refer to attached Plan for crack numbers)

Crack Number	Distance between consecutive cracks	Maximum Crack Width	
1		2.0 mm	
2	56' 2"	1.0 mm	
3	47' 6"	1.5 mm	
4	82' 10"	2.0 mm	
5	82' 8"	1.5 mm	
6	65' 8"	0.33 mm	
7	13' 3"	1.0 mm	
8	50' 11"	0.4 mm	
Saw-Cut between 2.5" and 3.5" thick white-topping (W.B.)	45' 0"	-	
9	74' 2"	0.33 mm	
10	21' 4"	0.4 mm	
11	38' 8"	1.25 mm	
12	66' 10"	1.0 mm	
13	68' 0"	1.25 mm	
14	56' 0"	0.8 mm	
15	81' 6"	0.8 mm	
16	30' 6"	1.0 mm	
Saw-Cut between 3.5" white- topping and transition zone between White-topping and 12" PCC pavement (W.B.)	56' 0''		
Saw-Cut at transition between 12" PCC pavement and 3.5" thick white-topping at the transition zone (W.B.)	160' 0''		
17	54' 2"	1.25 mm	
18	432' 4"	0.8 mm	
Saw-Cut at transition between 3.5" and 2.5" thick White-topping (W.B.)	13' 6"	+	

W.B. - West Bound Traffic.

Note: All the cracks were transverse to the direction of traffic and extended over the full width of the west bound lane.

1 Inch = 25.4 mm

# Crack Number and Maximum Width on West Bound White-Topping on Highway 14 (Second Inspection of West-Bound Lane)

(Measurement done on 8/6/96 and 8/7/96)

Crack Number	Depth of Overlay at the Crack	Crack width measured on side	Crack Width measured on top surface
1	3.75"	3.0 mm	4.0 mm
2	3.625"	3.0 mm	3.0 mm
3	3.75"	4.0 mm	4.0 mm
4	3.00"	4.0 mm	5.0 mm
5	3.00"	2.0 mm	2.0 mm
6	2.50"	1.5 mm	1.5 mm
7	2.75"	2.0 mm	2.0 mm
8	3.00"	1.5 mm	1.5 mm
Saw-Cut between 2.5" and 3.5" thick white-topping (W.B.)	3.50"	3.0 mm	-
9	4.50"	1.5 mm	1.5 mm
10	4.00"	1.5 mm	1.5 mm
11	3.75"	1.5 mm	1.5 mm
12	4.00"	2.0 mm	2.0 mm
13	3.75"	3.0 mm	3.0 mm
14	4.125"	2.0 mm	2.0 mm
15	4.00"	3.0 mm	3.0 mm
16	3.875"	1.5 mm	1.5 mm
Saw-Cut between 3.5" white- topping and transition zone between White-topping and 12" PCC pavement (W.B.)	6.50"	1.0 mm	
Saw-Cut at transition between 12" PCC pavement and 3.5" thick white-topping at the transition zone (W.B.)	6.50"	No Crack	
Saw-cut @ 99+70	4.50"	No Crack	
17	4.375"	1.5 mm	1.5 mm
Saw-cut @ 99+20	4.00"	3.0 mm	~
Saw-cut @ 98+70	4.50"	3.0 mm	
Saw-cut @ 98+20	4.125"	2.0 mm	
Saw-cut @ 97+70	4.25"	3.0 mm	
Saw-cut @ 97+20	3.625	3.0 mm	
Saw-cut @ 96+70	4.50"	2.0 mm	
Saw-cut @ 96+20	4.25"	3.0 mm	

Crack Number	Depth of Overlay at the Crack	Crack width measured on side	Crack Width measured on top surface
Saw-cut @ 95+70	4.00"	3.0 mm	-
18	4.00"	1.5 mm	1.5 mm
Saw-cut @ 95+20	4.00"	No Crack	-
Saw-cut @ 94+70	3.875	2.0 mm	3-
Saw-cut @ 94+20	3.50"	2.0 mm	4
Saw-cut @ 93+70	3.00"	4.0 mm	_
Saw-cut @ 93+20	3.25"	4.0 mm	3
Saw-cut @ 92+70	2.875"	3.0 mm	1
Saw-cut @ 92+20	2.75"	5.0 mm	4
Saw-cut @ 91+70	3.25"	5.0 mm	\
Saw-cut @ 91+20	3.125"	5.0 mm	
Saw-cut @ 90+70	3.00"	5.0 mm	

W.B. - West Bound Traffic.

Note: All the cracks were transverse to the direction of traffic and extended over the full width of the west bound lane.

1 Inch = 25.4 mm

## Crack Number and Maximum Width on West Bound White-Topping on Highway 14

(Third Inspection of West-Bound Lane) (Measurement done on 8/14/96)

Crack Number	Crack Width measured on top surface		
	South Edge	Center	North Edge
	(mm)	(mm)	(mm)
1	2	2	3
2	2	3	3
3	4	2	2

0.8

1.5

Note: All the cracks were transverse to the direction of traffic and extended over the full width of the west bound lane.

Conversion table: 1 inch = 25.4 mm

## Crack Number and Maximum Width on West Bound White-Topping on Highway 14

(Fourth Inspection of West-Bound Lane)

(Measurement done on 8/25/96)

Crack Number	Crack Width measured on top surface		
	South Edge	Center	North Edge
	(mm)	(mm)	(mm)
1	2	2	3
2		Crack Routed	
3	5	3	3
4	3	3	5
5	4	3	5
6	4	2	4
7	6	4	5
8	4	2	3
9	5	5	6
10	4	5	5
11	4	5	5
12	5	5	7
13	2	2	4
14	5	5	6
15	3	4	5
16	4	5	5
17	5	5	3
18	5	4	3

Note: All the cracks were transverse to the direction of traffic and extended over the full width of the west bound lane.

Conversion table: 1 inch = 25.4 mm

### Crack Number and Maximum Width on West Bound White-Topping on Highway 14

(Fifth Inspection of West-Bound Lane) (Measurement done on 9/7/96)

Crack Number	Crack Width measured on top surface			
	South Edge Center		North Edge	
	(mm)	(mm)	(mm)	
1		Crack Routed		
2		Crack Routed		
3		Crack Routed		
New Crack @ 109+76	8	6	4	
4	Crack Routed			
5	Crack Routed			
6	Crack Routed			
7	Crack Routed			
8	Crack Routed			
9	Crack Routed			
10	Crack Routed			
11	Crack Routed			
12	Crack Routed			
13	Crack Routed			
14	Crack Routed			
15	Crack Routed			
16	Crack Routed			
17	Crack Routed			
18	Crack Routed			

#### Measurements of Corner Cracks for West Bound Lane

Thickness of whitetopping	Crack Location	Maximum Width	Remarks	
63.5	90+20	0.5 mm	South Edge towards East	
63.5	91+70	0.4 mm	South Edge towards East	
63.5	91+70	0.25 mm	South Edge towards West	
88.9	92+20	0.4 mm	South Edge towards East	
88.9	92+20	0.4 mm	South Edge towards West	
88.9	92+70	0.33 mm	South Edge towards East	
88.9	93+20	0.4 mm	South Edge towards East	
88.9	93+20	0.33 mm	South Edge towards West	

Conversion table: 1 inch = 25.4 mm

# Crack Number and Maximum Width on West Bound White-Topping on Highway 14 (Sixth Inspection of West-Bound Lane)

(Measurement done on 10/15/96)

Crack Number	Crack Width measured on top surface			
	South Edge	Center	North Edge	
	(mm)	(mm)	(mm)	
1		Crack Routed		
2		Crack Routed		
3		Crack Routed		
Crack @ 109+76	8	6	6	
4	Crack Routed			
5		Crack Routed		
6	Crack Routed			
7	Crack Routed			
8	Crack Routed			
9	Crack Routed			
10		Crack Routed		
11	Crack Routed			
12	Crack Routed			
13	Crack Routed			
14	Crack Routed			
15	Crack Routed			
16	Crack Routed			
17	Crack Routed			
18	Crack Routed			

#### Measurements of Corner Cracks for West Bound Lane

Thickness of whitetopping (mm)	Crack Location	Maximum Width	Remarks
63.5	90+20	0.5 mm	South Edge towards East
63.5	91+70	0.4 mm	South Edge towards East
63.5	91+70	0.25 mm	South Edge towards West
88.9	92+20	0.5 mm	South Edge towards East
88.9	92+20	0.4 mm	South Edge towards West
88.9	92+70	0.4 mm	South Edge towards East
88.9	93+20	0.5 mm	South Edge towards East
88.9	93+20	0.4 mm	South Edge towards West

Conversion table: 1 inch = 25.4 mm

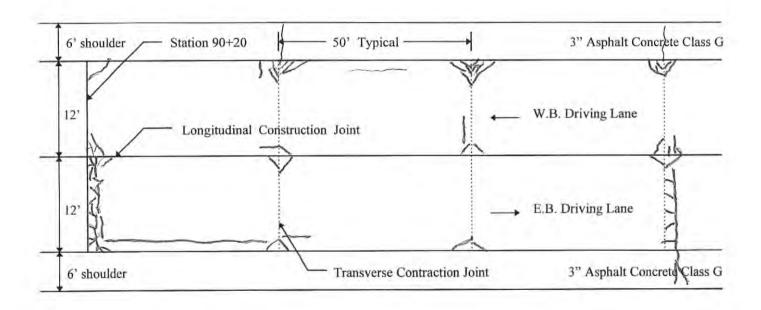


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

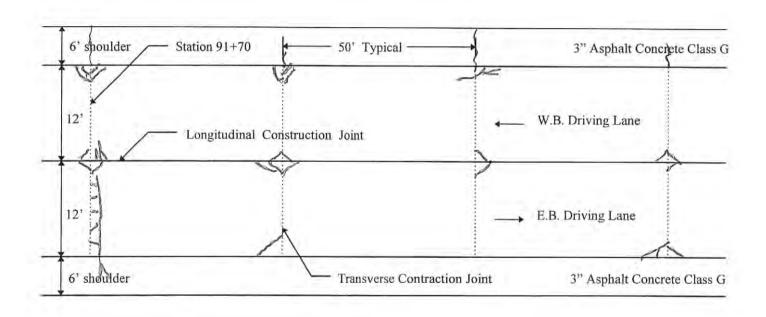


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

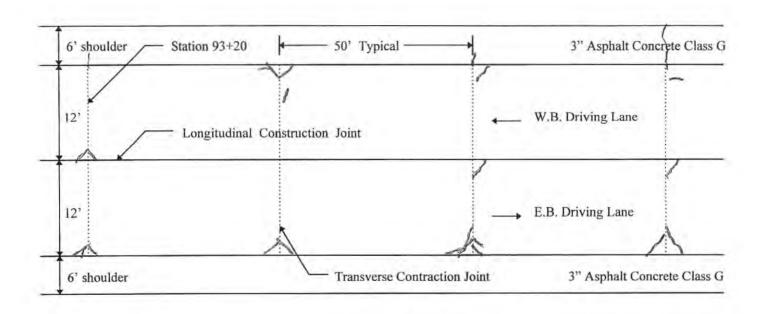


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

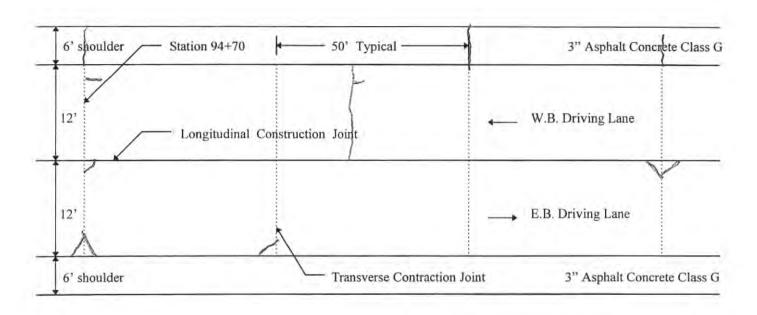


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

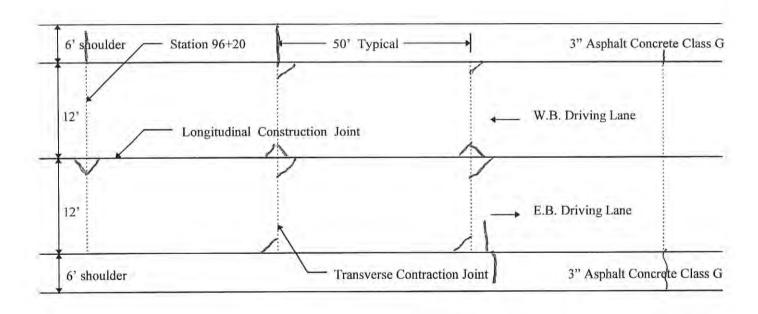


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

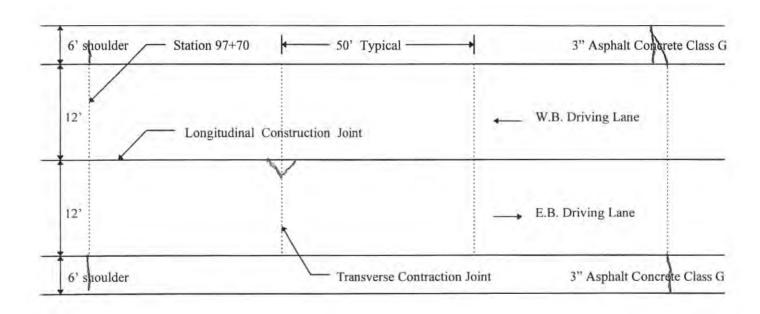


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

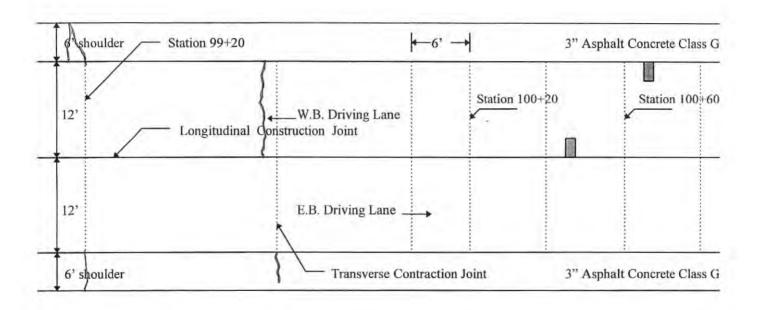


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on May 28, 1997.

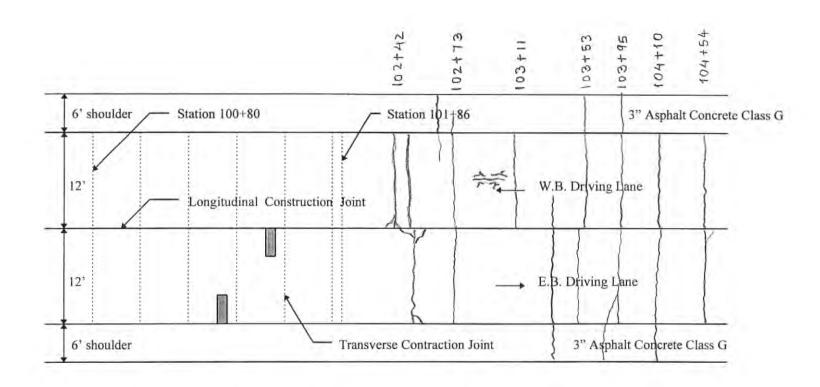


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on May 28, 1997.

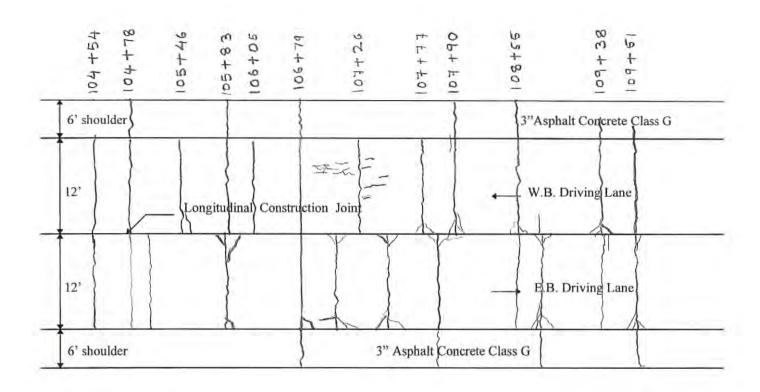


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on May 28, 1997.

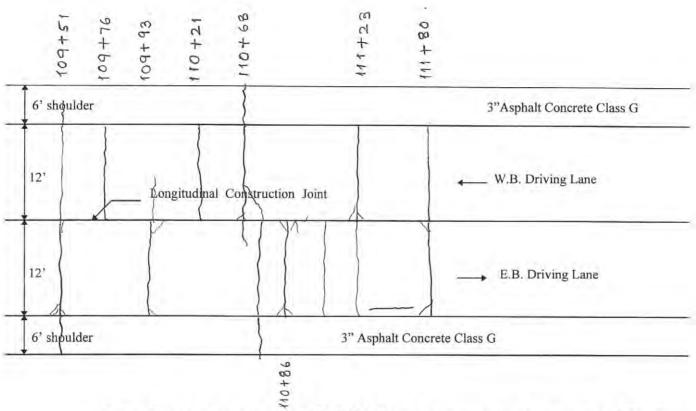


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on May 28, 1997.

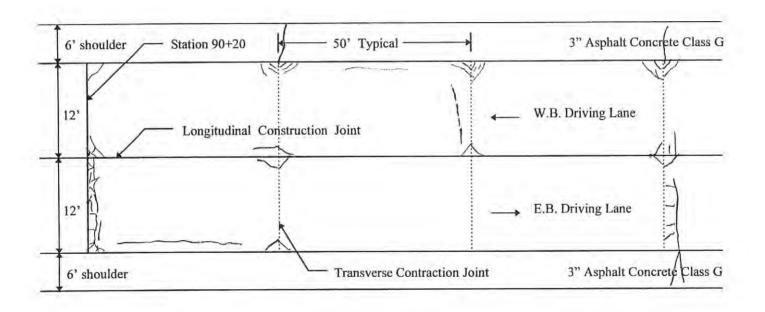


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

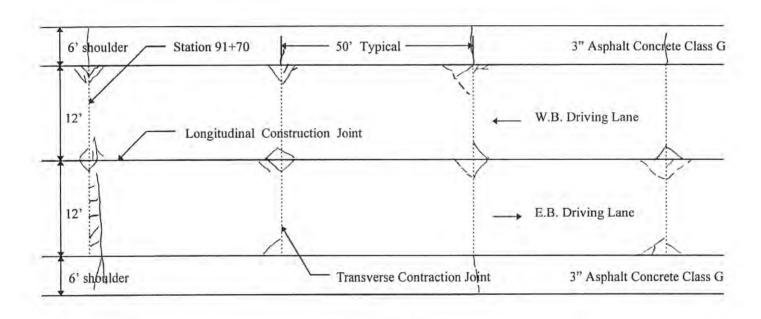


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

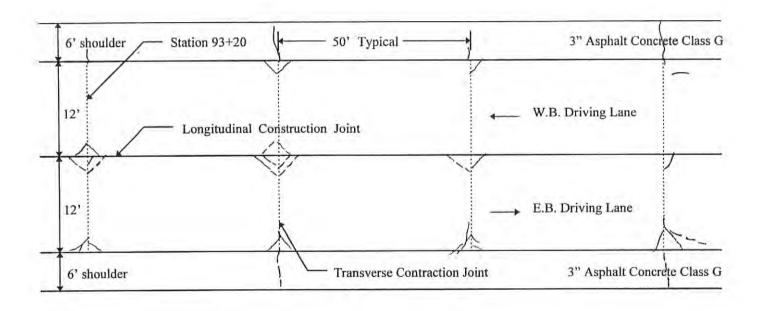


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

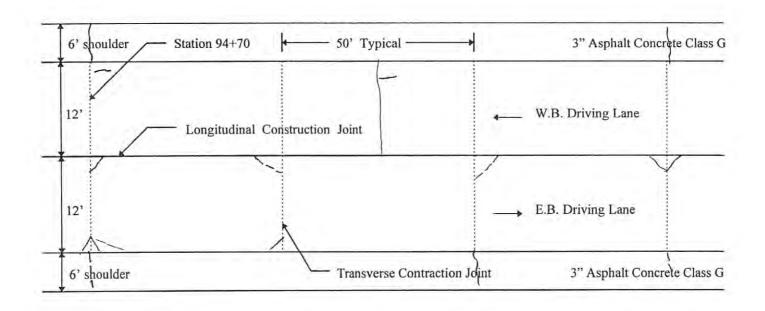


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

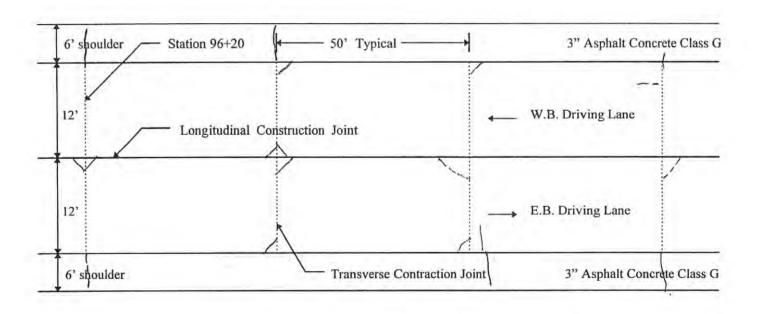


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

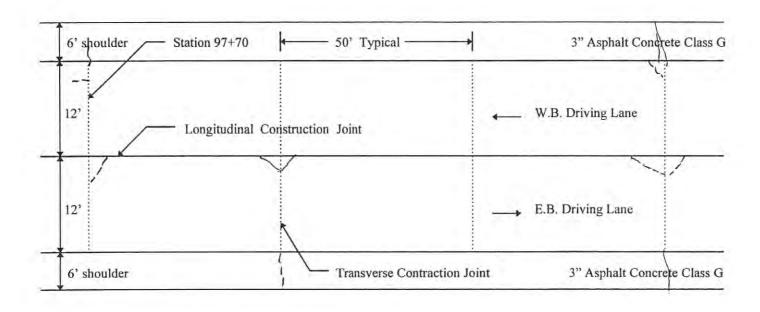


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

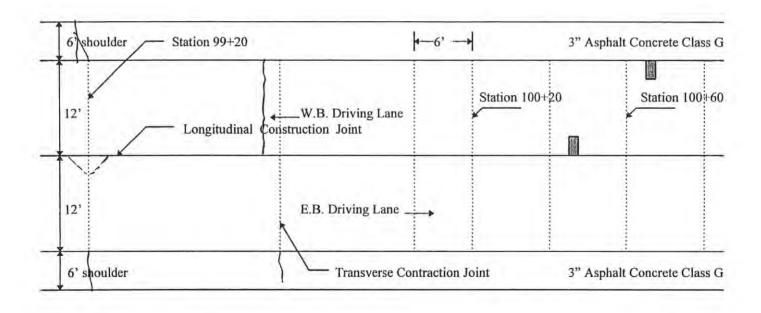


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on July 28, 1997.

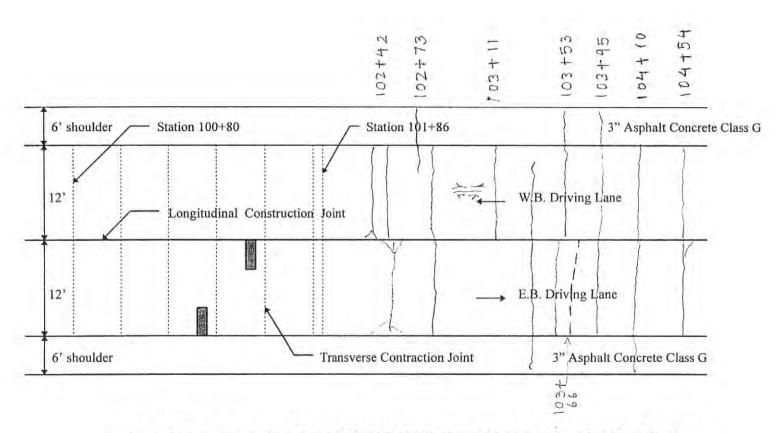


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on July 28, 1997.

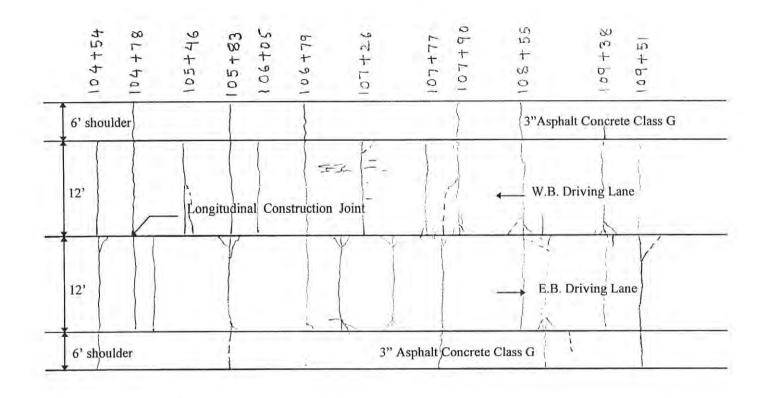


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on July 28, 1997.

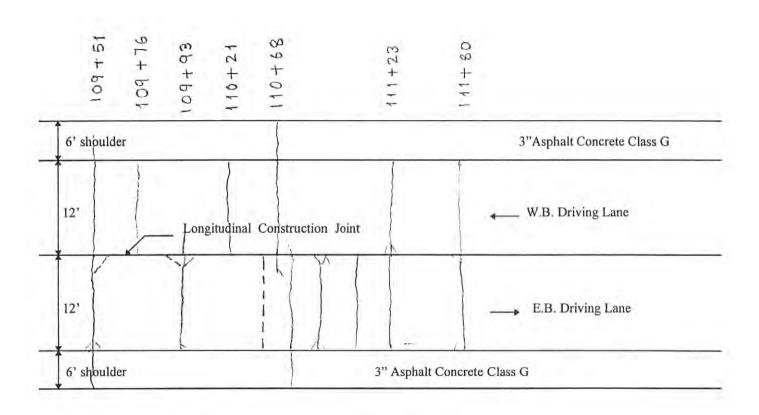


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on July 28, 1997.

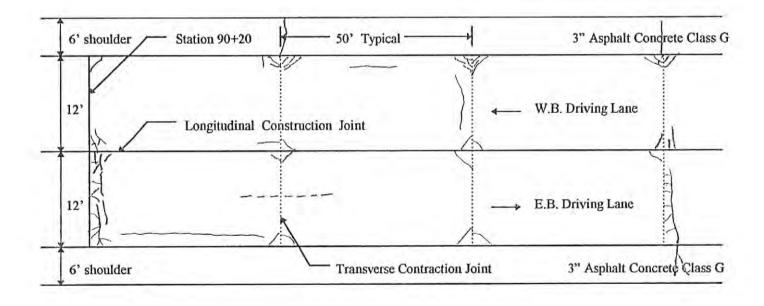


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

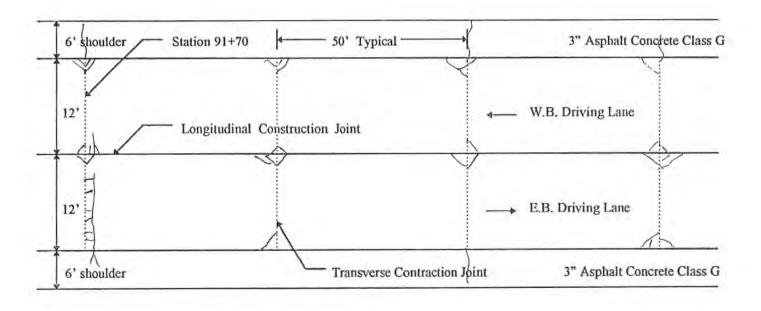


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

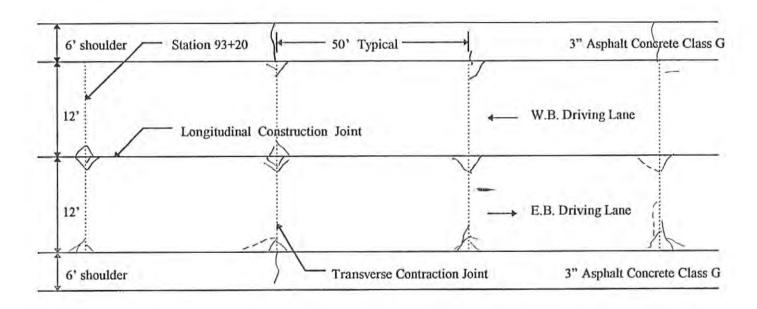


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

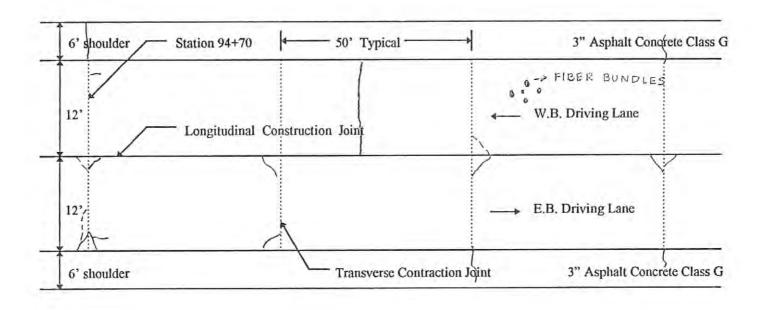


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

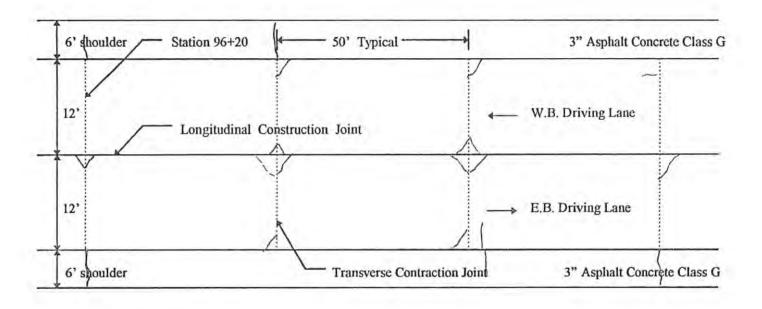


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

**New Crack Observed** 

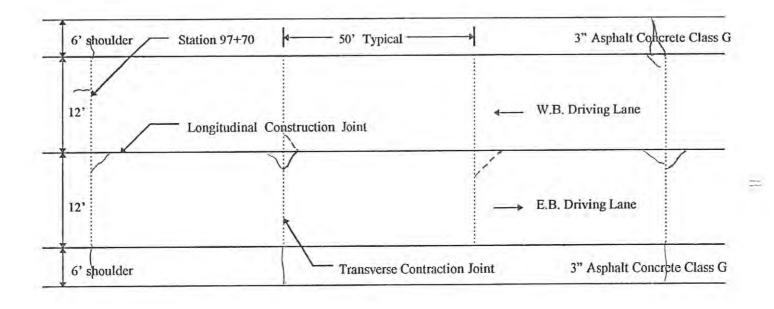


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

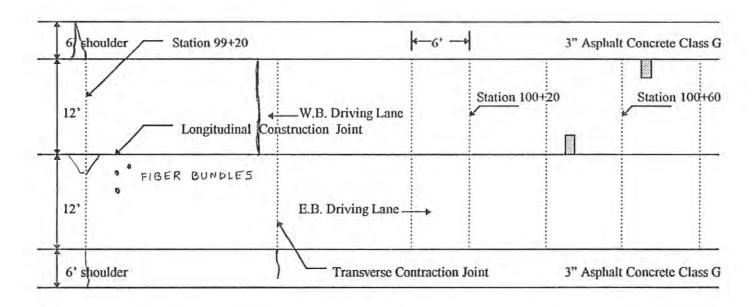


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on November 7, 1997.

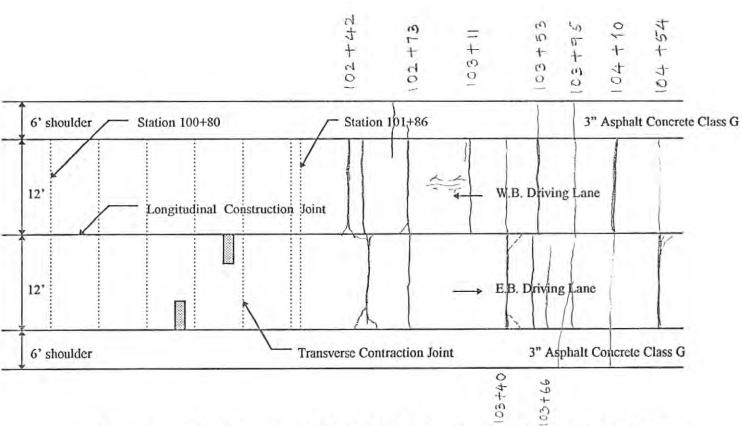


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on November 7, 1997.

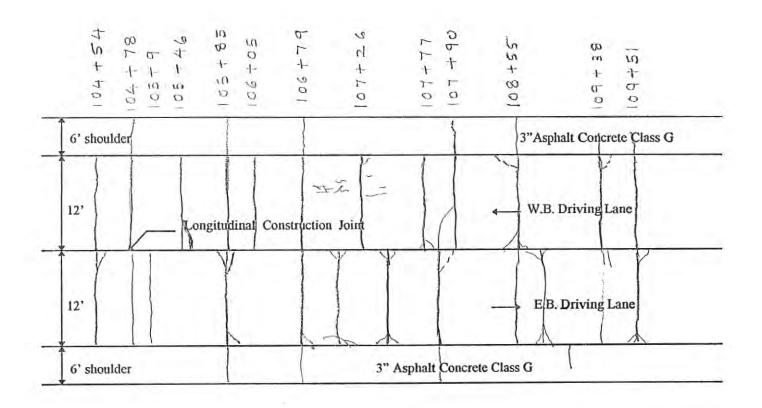


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on November 7, 1997.

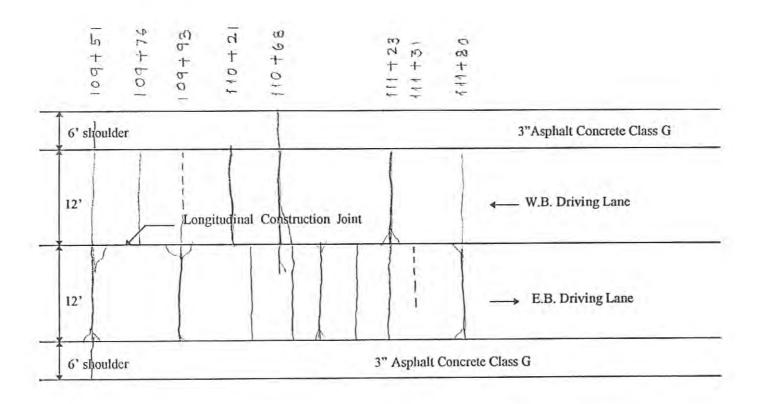


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on November 7, 1997.

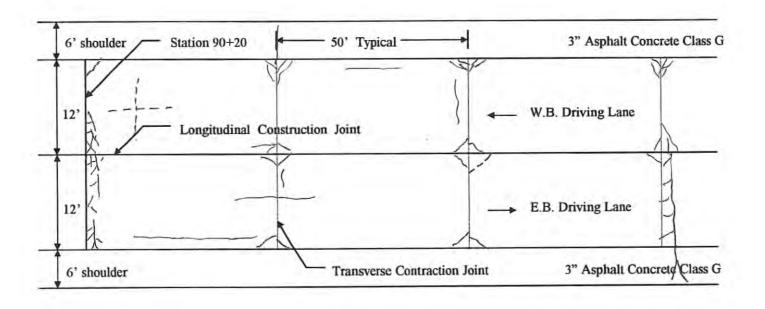


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

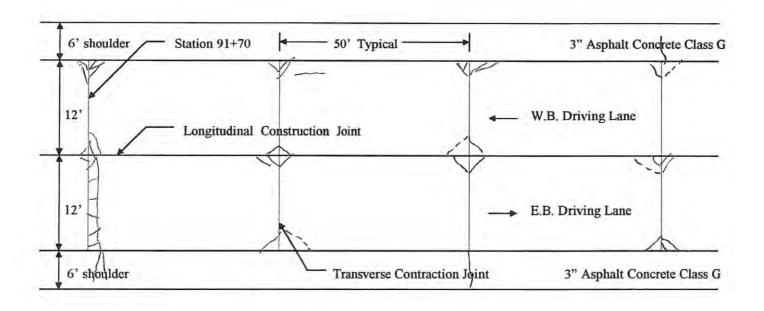


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

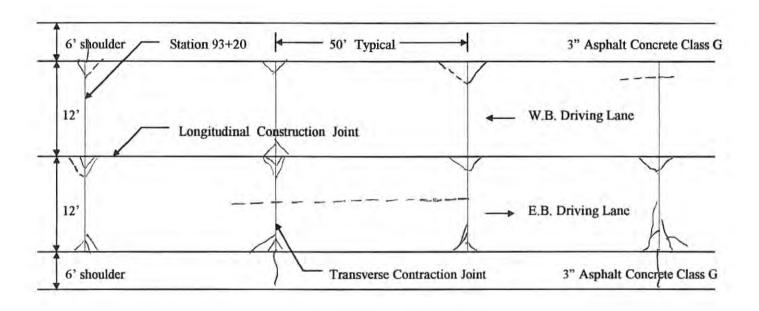


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

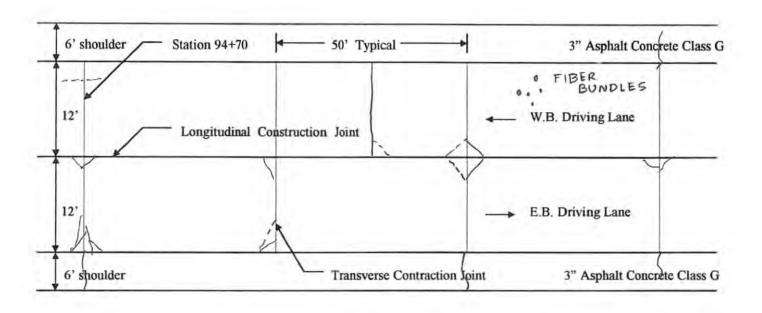


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

**New Crack Observed** 

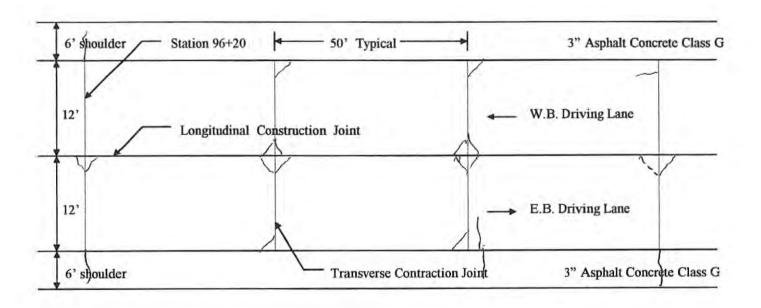


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

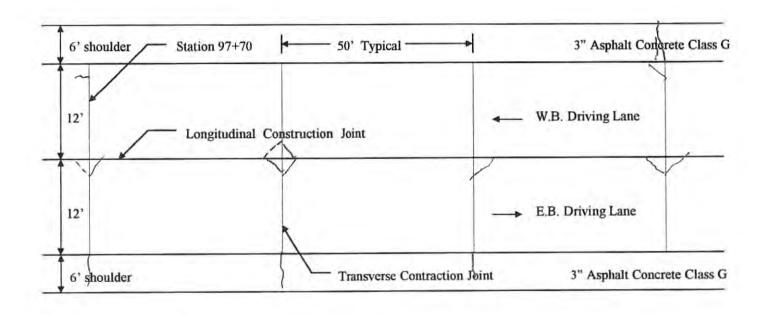


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

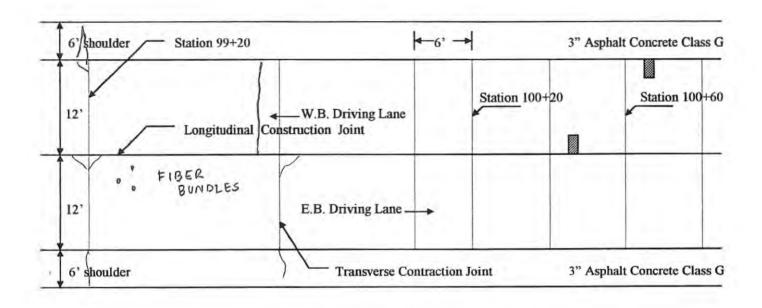


Fig: Crack Location for NMFRC Whitetopping in the Jointed Section as observed on April 17, 1998.

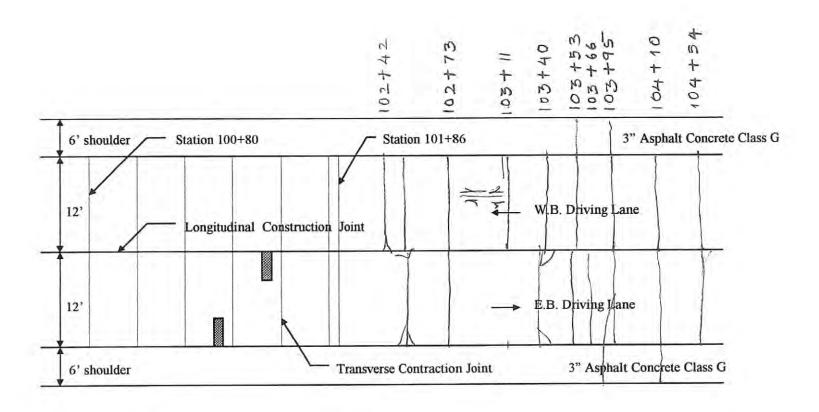


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on April 17, 1998.

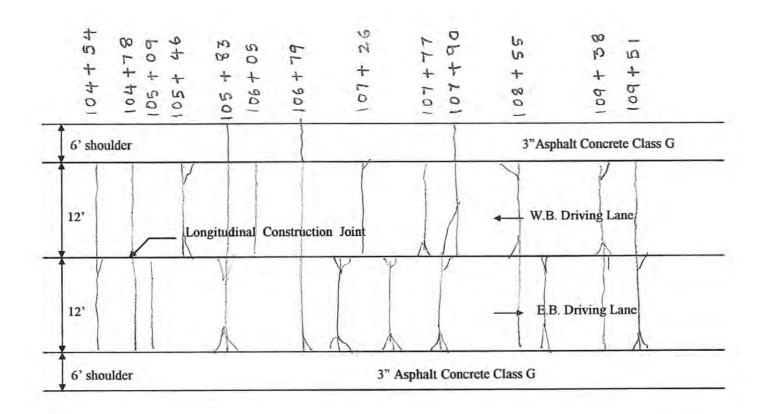


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on April 17, 1998.

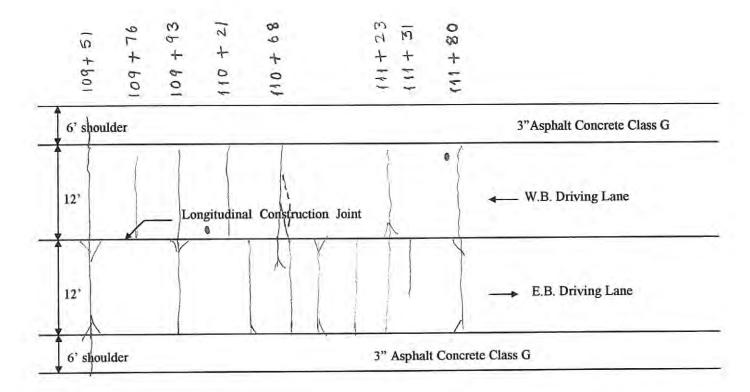


Fig: Crack Location for NMFRC Whitetopping in the unjointed Section as observed on April 17, 1998.

#### Rapid City Whitetopping Crack Number and Average Crack Width

Inspection Date: 7/12/98 (Refer Map No.1)

Crack No.	Width (inches)	Average Width (inches)	Remarks
1	0.014	4.74.53	
	0.022	0.018	New Crack
2	0.026		
	0.018	0.022	New Crack
3	0.026	2 3 3 3 3 3 3	
	0.026	0.026	New Crack
4	0.022		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	0.022	0.022	New Crack
5	0.026		
	0.022	0.024	New Crack
6	0.026		1000
	0.022	0.024	New Crack

Inspection Date: 8/30/98 (Refer Map No.2)

Crack No.	Width (inches)	Average Width (inches)	Remarks	
1	0.032			
	0.014	0.023	Old Crack	
2	0.026		1000	
	0.022	0.024	Old Crack	
3	0.026	75.5		
	0.032	0.029	Old Crack	
4	0.022	1 2 3 1 4		
	0.063	0.042	Old Crack	
5	0.026	177.37.3		
	0.032	0.029	Old Crack	
6	0.026			
	0.030	0.028	Old Crack	
7	0.030			
	0.032	0.031	New Crack	
8	0.032			
	0.030	1. 23.50	2.000	
	0.030	0.031	New Crack	
9	0.030			
	0.032	0.000		
	0.063	0.042	New Crack	
10	0.032	1 - 6.000	2.V 6E-1	
	0.032	0.032	New Crack	
11	0.032			
	0.032	1,135	100.249	
	0.032	0.032	New Crack	
12	0.030	1.72.07	11000	
	0.032	0.031	New Crack	

Inspection Date: 8/30/98 (Refer Map No.2)

Crack No.	Width (inches)	Average Width (inches)	Remarks
13	0.030		
	0.030	0.030	New Crack
14	0.026		
	0.032		
	0.032	0.030	New Crack
15	0.030		
	0.030	0.030	New Crack
16	0.022		
	0.032	1	
	0.032	0.029	New Crack
17	0.014		
	0.032	0.023	New Crack
18	0.018		
	0.030	0.024	New Crack
19	0.063		
	0.022	0.042	New Crack
20	0.030	1 1	
	0.026	0.028	New Crack
21	0.002		
	0.018		
	0.014	0.011	New Crack
22	0.014		
	0.022	0.018	New Crack

## **Rapid City Whitetopping** Crack Number and Average Crack Width Inspection Date : 11/30/98 (Refer Map No.3)

Crack No.	Width (inches)	Average Width (inches)	Remarks
1			Old Ossals Ossals
	*	•	Old Crack Sealed
2			Old Crook Soolo
3	-		Old Crack Sealed
3		6.25	Old Crack Sealed
4			Old Oldon Gealer
7	- V-	.2	Old Crack Sealed
5	0.030		Old Oldon Oddio
	0.063	0.046	Old Crack
6	0.026		7.5
	0.032	0.029	Old Crack
7	0.030		
· ·	0.032	0.031	Old Crack
8	0.032		
	0.250	2.0	
	0.063	0.115	Old Crack
9	0.030		
	0.032		
- 1	0.063	0.042	Old Crack
10	0.032		7-2-0
	0.032	0.032	Old Crack
11	0.032		
	0.032	a see	27.0
	0.032	0.032	Old Crack
12	0.030		0.10
	0.032	0.031	Old Crack
13	0.030	0.000	0110
	0.030	0.030	Old Crack
14	0.026		
	0.032	0.000	Old Coast
15	0.032	0.030	Old Crack
15	0.063 0.030	0.030	Old Crack
16	0.026	0.030	Old Olack
10	0.032		
	0.032	0.030	Old Crack
17	0.014	0.000	Old Oldon
	0.032	0.023	Old Crack
18	0.018		
	0.030	0.024	Old Crack
19	0.063		
	0.032	0.047	Old Crack
20	0.030		
	0.026	0.028	Old Crack

Inspection Date : 11/30/98

(Refer Map No.3)

Crack No.	Width (inches)	Average Width (inches)	Remarks
21	0.026		
	0.018		
	0.014	0.019	Old Crack
22	0.014		
	0.022	0.018	Old Crack
23	0.032		
	0.063	0.047	New Crack
24	0.014		
	0.026	0.020	New Crack
25	0.018		
	0.014	0.016	New Crack
26	0.014		
	0.018	0.016	New Crack
27	0.032		
	0.030		
	0.022	0.022	New Crack

### Rapid City Whitetopping Crack Number and Average Crack Width

Inspection Date: 2/27/99

(Refer Map No.4)

Crack No.	Width (inches)	Average Width (inches)	Remarks
1	-		
	•		Old Crack Sealed
2	15		
		No.	Old Crack Sealed
3			
			Old Crack Sealed
4	-		
-		•	Old Crack Sealed
5	0.250	0.456	Old Crook
6	0.063 0.026	0.156	Old Crack
ь	0.032	0.029	Old Crack
7	0.032	0.029	Old Clack
	0.032	0.031	Old Crack
8	0.063	0.031	Old Clack
0	0.250		
	0.063	0.125	Old Crack
9	0.030	0.125	Old Oldok
9	0.032		
	0.063	0.042	Old Crack
10	0.032		
	0.032	0.032	Old Crack
11	0.032		
	0.063		1 7 0.7
	0.032	0.042	Old Crack
12	0.030		1275
	0.032	0.031	Old Crack
13	0.030		A CONTRACTOR
	0.063	0.046	Old Crack
14	0.026		
	0.032	2.2	0110
	0.250	0.103	Old Crack
15	0.063	0.000	Old Canal
40	0.030	0.030	Old Crack
16	0.032 0.032		
	0.032	0.105	Old Crack
17	0.030	0.105	Old Clack
17	0.030	0.031	Old Crack
18	0.032	0.001	Old Order
10	0.030	0.030	Old Crack
19	0.063	0.000	Old Oldon
	0.032	0.047	Old Crack

Inspection Date: 2/27/99

(Refer Map No.4)

Crack No.	Width (inches)	Average Width (inches)	Remarks	
20	0.030			
	0.026	0.028	Old Crack	
21	0.032			
	0.032			
	0.026	0.030	Old Crack	
22	0.032			
	0.250	0.141	Old Crack	
23	0.032			
	0.063	0.047	Old Crack	
24	0.030			
	0.026	0.028	Old Crack	
25	0.026			
	0.014	0.020	Old Crack	
26	0.014			
2 -7	0.018	0.016	Old Crack	
27	0.032			
1	0.030		10.77	
	0.063	0.063	Old Crack	
28	0.014			
	0.014			
	0.022	0.017	New Crack	
29	0.030			
	0.006	0.018	New Crack	
30	0.032			
	0.032	0.032	New Crack	
31	0.030			
	0.032	0.031	New Crack	
32	0.032			
	0.063	1.00	4-67	
	0.030	0.030	New Crack	
33	0.032	1 454-11		
	0.018	0.025	New Crack	
34	0.016	1,000	113, 4	
	0.032	0.024	New Crack	
35				
	0.063	2476	10.002392	
	0.030	0.046	New Crack	
36	0.022	2.000	W. G. V	
	0.018	0.020	New Crack	
37	0.018			
	0.032	1,1533	Carlo and	
	0.030	0.027	New Crack	
38	0.032	4.254	40.00	
	0.030	0.031	New Crack	

Inspection Date: 2/27/99

(Refer Map No.4)

Crack No.	Width (inches)	Average Width (inches)	Remarks	
39	0.018			
	0.022			
	0.022	0.022	New Crack	
40	0.032			
14	0.018			
	0.030	0.030	New Crack	
41	0.032			
	0.032		1.50	
	0.063	0.042	New Crack	
42	0.032			
	0.063			
	0.063	0.052	New Crack	
43	0.063			
	0.063			
	0.030	0.052	New Crack	
44	0.063			
V-7	0.063			
	0.032	0.052	New Crack	
45	0.018			
	0.026			
	0.032	0.025	New Crack	
46	0.026			
	0.063			
	0.032			
	0.032			
	0.030		100 TO 100	
	0.032	0.036	New Crack	
47	0.032			
	0.063			
	0.063	0.052	New Crack	
48	0.026		- No. 1	
	0.030	0.028	New Crack	
49	0.030		1	
	0.030	0.030	New Crack	
50	0.026			
	0.016	0.021	New Crack	
51	0.018	1.3	PG-64	
	0.030	0.024	New Crack	
52	0.032			
. 77.	0.063	0.047	New Crack	
53	0.063			
	0.063	F gas it	A	
	0.032	0.052	New Crack	
54	0.032			
	0.018	200		
	0.026	0.025	New Crack	

Inspection Date : 2/27/99 (Refer Map No.4)

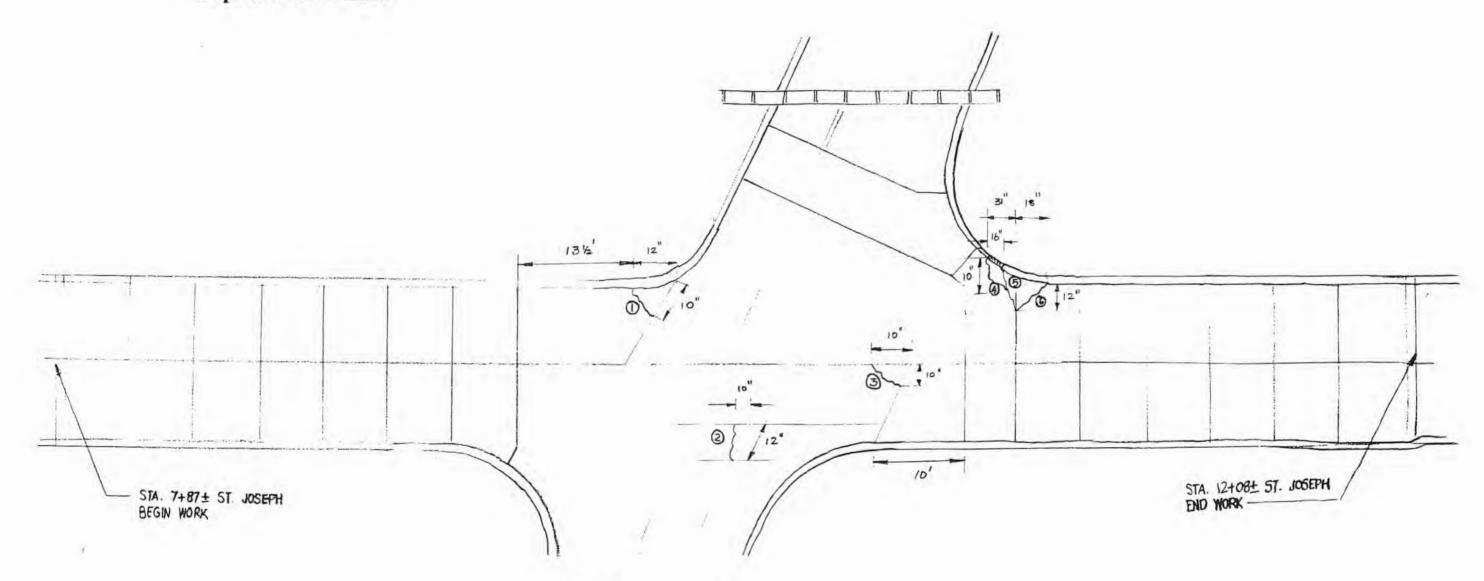
Crack No.	Width (inches)	Average Width (inches)	Remarks	
55	0.032			
	0.063			
	0.063	0.052	New Crack	
56	0.032			
7.7	0.250	1 7 7 7 4		
	0.063	0.115	New Crack	
57	0.032			
	0.018	7.00	Annual Control	
	0.063	0.038	New Crack	
58	0.063			
	0.018	0.040	New Crack	
59	0.018			
	0.018		100	
	0.006	0.014	New Crack	
60	0.030	3		
_4	0.026	0.028	New Crack	
61	0.063			
	0.032	1.7279		
	0.032	0.042	New Crack	
62	0.063			
	0.063	18.00		
	0.026	0.050	New Crack	
63	0.026			
	0.018	0.022	New Crack	
64	0.026			
	0.018	0.022	New Crack	
65	0.032			
	0.032	5, 5 10		
	0.063	0.042	New Crack	
66	0.032	2.50		
	0.026	0.029	New Crack	
67	0.018	2.5.5	( II DETAIL	
	0.006	0.012	New Crack	

Map No :1

Inspection Date: 7/12/98

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SCALE: 1" = 30"



E. ST. PATRICK

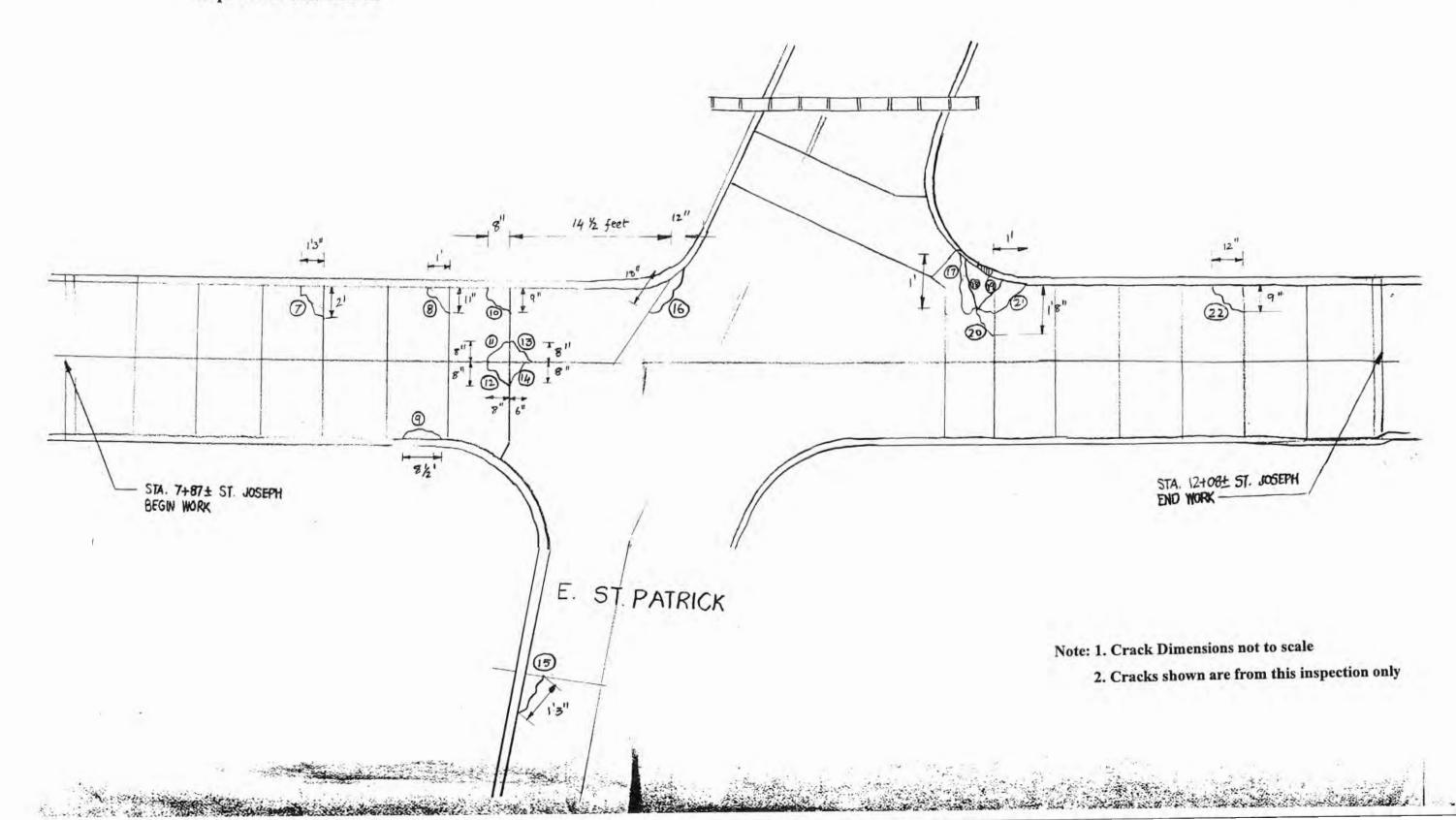
Note: 1. Crack Dimensions not to scale

2. Cracks shown are from this inspection only

Map No : 2

Inspection Date: 8/30/98

SCALE: 1" = 30"



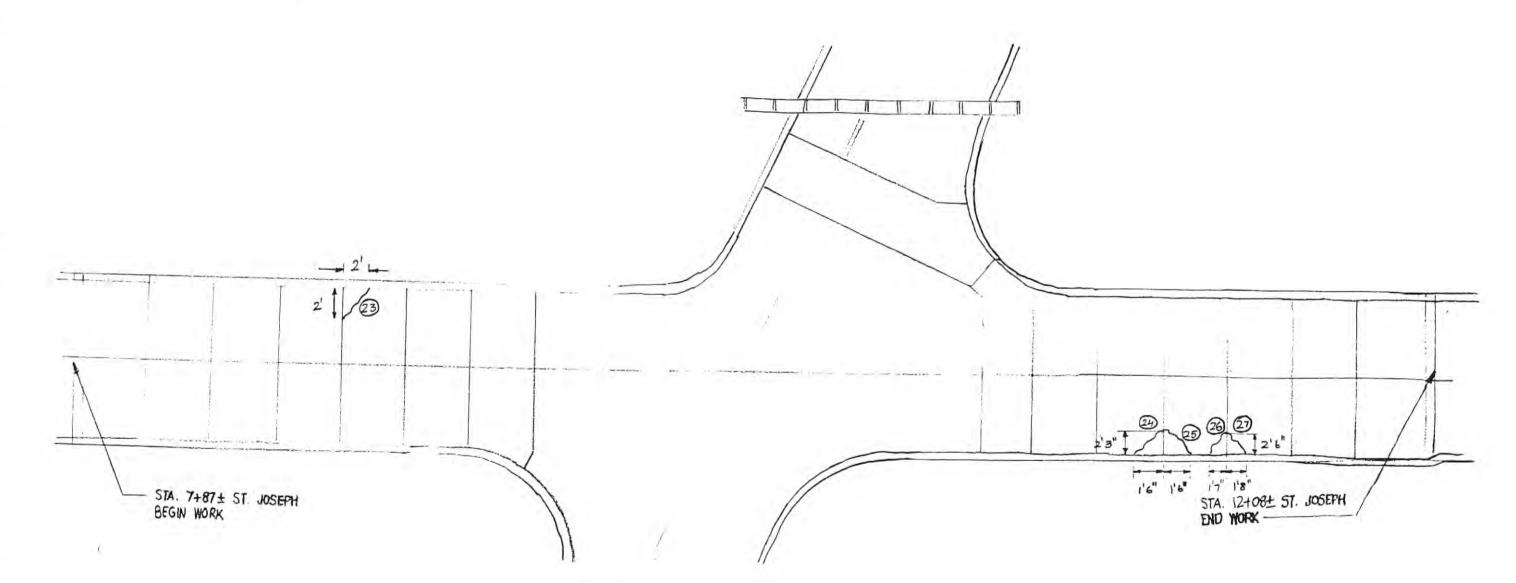
Map No

Inspection Date: 11/30/98

: 3

The second section of the second seco

SCALE: 1" = 30"



E. ST. PATRICK

Note: 1. Crack Dimensions not to scale

A CONTRACTOR OF THE CONTRACTOR

2. Cracks shown are from this inspection only

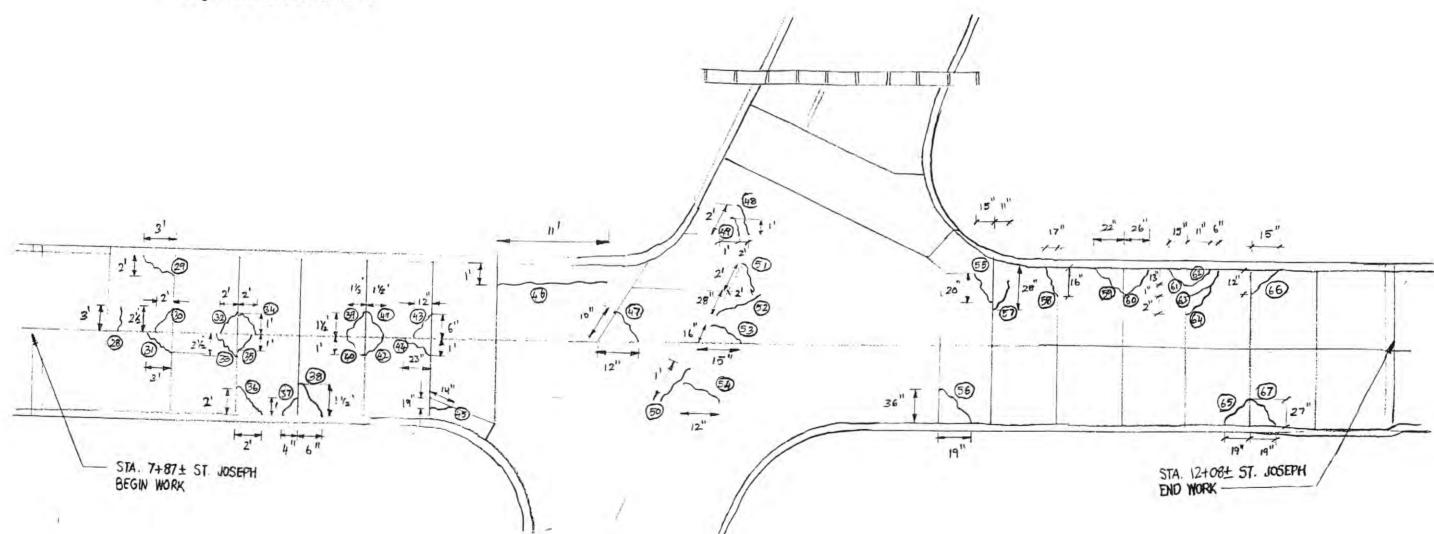
SCALE: 1" = 30'

P

Map No : 4

The state of the second st

Inspection Date: 02/27/99



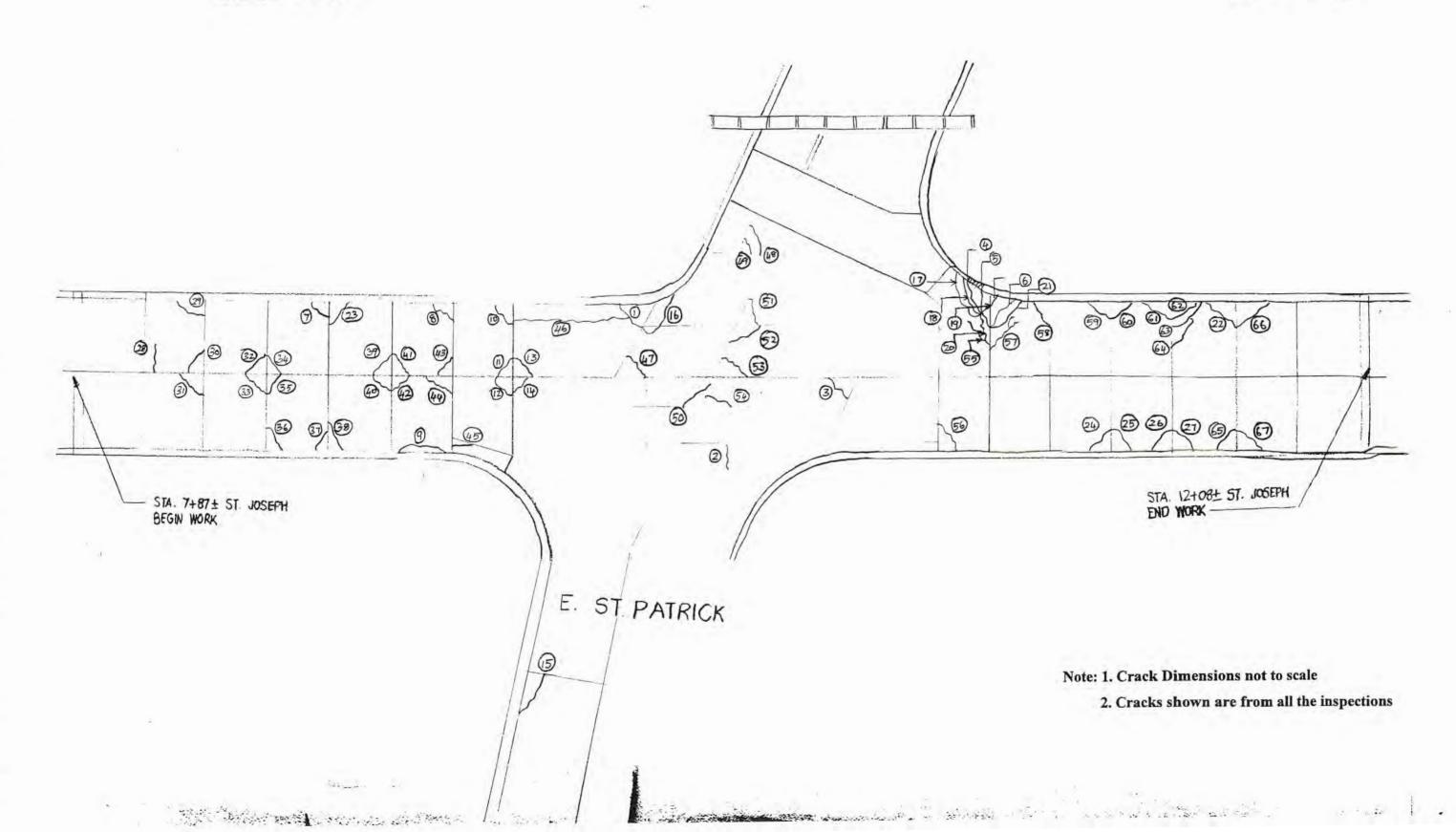
E. ST. PATRICK

Note: 1. Crack Dimensions not to scale

2. Cracks shown are from this inspection only

Map No : 5
Crack Summary

SCALE: 1" = 30"



# APPENDIX D

**Details of Core Testing** 

### Cores on NMFRC White-topping Research East Bound Lane (US-14)

Core #	Location	Diameter (Inches)	Length of Concrete portion (Inches)	Total Length of Core (Inches)	Remarks
1	92+00	4,000	3.000	8.281	About 4 %
		4.000	3.094	8.125	honey-combing
		4.000	3.094	8.125	Good Fiber
			3.125	8.125	Distribution
	Average	4.000	3.078	8.164	
2	98+00	4.000	3.906	6.531	About 7 %
		4.000	4.281	7.156	honey-combing
		4.000	4.156	7.063	Good Fiber
		1 2 1	4.156	6.906	Distribution
	Average	4.000	4.125	6.914	
3	104+30	4.000	4.313	9.375	About 8 %
		4.000	4.313	9.438	honey-combing
		4.000	4.313	9.500	Good Fiber
		1427274	4.313	9.500	Distribution
	Average	4.000	4.313	9.453	
4	109+50	4.000	2.813	7.750	About 5 %
		4.000	2.844	7.750	honey-combing
		4.000	2.938	7.719	Good Fiber
			2.938	7.750	Distribution
	Average	4.000	2.883	7.742	

Conversion Table: 1 Inch = 25.4 mm

### Cores on NMFRC White-topping Research West Bound Lane (US-14)

Core #	Location	Diameter (Inches)	Length of Concrete portion (Inches)	Total Length of Core (Inches)	Remarks
1	109+50	4.000	3.188	6.785	About 5 %
		4.000	3.250	6.790	honey-combing
		4.000	3.313	6.850	Good Fiber
			3.281	6.830	Distribution
	Average	4.000	3.258	6.814	
2	104+30	4.000	5.094	7.685	About 4 %
		4.000	5.219	7.535	honey-combing
		4.000	4.781	7.550	Good Fiber
			5.000	7.640	Distribution
	Average	4.000	5.024	7.603	
3	98+00	4.000	4.000	8.063	About 5 %
		4.000	4.063	8.125	honey-combing
		4.000	4.063	8.094	Good Fiber
			4.094	8.000	Distribution
	Average	4.000	4.055	8.071	
4	92+00	4.000	3.094	7.750	About 3 %
		4.000	3.156	7.656	honey-combing
		4.000	3.063	7.719	Good Fiber
		- 4 ==	3.094	7.625	Distribution
	Average	4.000	3.102	7.688	

Conversion Table: 1 Inch = 25.4 mm

## APPENDIX E

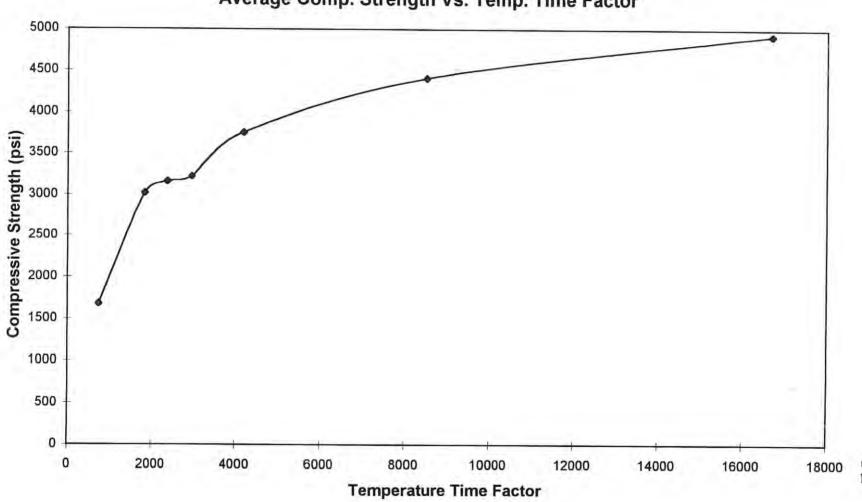
**Details of Maturity Testing** 

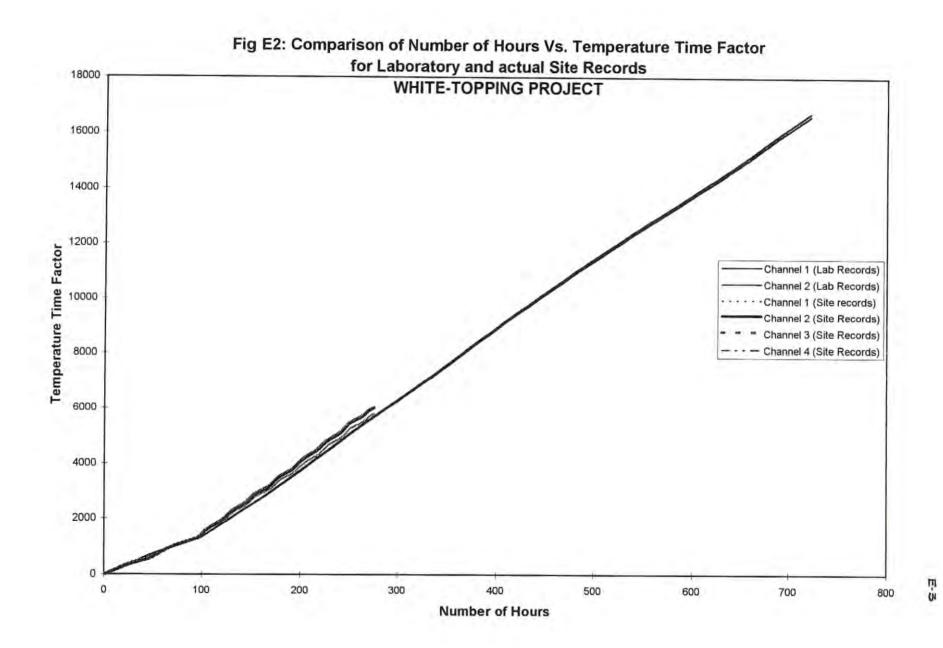
## **Maturity Testing for DOT Project**

### White-topping Overlay

Day	Date	Sp. Nos.	Comp. Strength	Maturity Meter Readings				
			(psi)	Outlet	Hours	Internal Temp.	Age (hours)	TTF
1	6/22/96	DOT-T2-C1	1690	1	24	28	44.5	743
		DOT-T2-C2	1665	2	24	28	44.6	740
		Average	1680					742
3	6/24/96	DOT-T2-C3	2920	1	72	22	100	1831
		DOT-T2-C4	3115	2	72	22	100	1822
		Average	3020					1827
4	6/25/96	DOT-T2-C5	3140	1	96	23	129	2380
		DOT-T2-C6	3190	2	96	23	128	2365
		Average	3165					2373
5	6/26/96	DOT-T2-C7	3230	1	120	25	160	2967
		DOT-T2-C8	3220	2	120	25	158	2946
		Average	3225	52.24			150	2957
7	6/28/96	DOT-T2-C9	3685	1	168	26	226	4202
		DOT-T2-C10	3825	2	168	26	224	4171
		Average	3755					4187
14	7/5/96	DOT-T2-C11	4505	1	336	27	460	8535
		DOT-T2-C12	4315	2	336	27	456	8480
		Average	4410					8508
28	7/19/96	DOT-T2-C13	4990	1	(70	24	905	16745
20	1113130	DOT-T2-C13	4855	2	672 672	24	895	16742
		Average	4925	2	672	24	887	16633 16688

Fig E1: Maturity Testing for DOT white-topping project Average Comp. Strength Vs. Temp. Time Factor





	n 4101 ID#		d at luna 20/06	07:14 D		
		als Recording started			2.00 D	
		dings, Recording wa				
or La	boratory tria	als Printout at July 2	2/96 03:58 P a	nd for site A	ug 05/96 1	1:18 P
					100	
		re: 0 deg C	TTF - Tem	perature tim	e Factor	
		5000 deg K				
Equiv.	Age Temp:	20 deg C				
		ORY RECORDS	-		TE RECOR	
Hour		Channel 2		Channel 2		
#	TTF	TTF	TTF	TTF	TTF	TTF
0	0	0	0	0	0	0
0.5	13	12	16	13	13	13
1	26	25	32	27	27	27
1.5	39	37	49	41	40	42
2	52	50	65	56	55	56
2.5	65	63	83	70	69	71
3	78	77	100	85	85	86
3.5	91	90	119	100	100	102
4	105	104	137	116	116	118
4.5	119	118	156	131	132	134
5	133	132	175	147	147	149
5.5	148	147	194	162	163	165
6	163	162	213	178	178	180
6.5	179	178	232	193	194	196
7	195	193	250	209	209	211
7.5	211	210	268	224	225	227
8	228	226	286	239	240	242
8.5	245	243	303	253	255	256
9	262	260	320	267	269	270
9.5	280	277	336	281	283	284
10	297	295	351	294	296	297
10.5	315	312	366	307	309	309
11	333	330	380	319	321	321
11.5	350	347	394	331	333	332
12	368	365	407	343	345	344
12.5	385	383	420	355	356	355
13	403	400	432	367	368	366
13.5	420	417	444	379	379	377
14	437	434	456	390	390	388
14.5	453	451	467	401	401	398
15	470	468	478	412	412	409
15.5	486	484	489	423	423	419
16	502	500	500	434	433	429
16.5	518	516	510	445	444	439
17	534	532	520	456	454	449
17.5	549	547	530	466	464	459
18	565	563	540	476	474	468
18.5	580	578	549	486	483	478
19	596	593	558	496	493	487

19.5	611	608	567	506	503	496
20	626	623	576	516	512	506
20.5	641	638	586	526	522	515
21	656	653	595	537	532	525
21.5	671	668	605	548	543	537
22	685	683	615	560	555	549
22.5	700	698	626	574	569	563
23	714	712	638	588	583	577
23.5	729	726	650	604	599	593
24	743	740	664	620	615	609
24.5	757	754	678	638	633	627
25	769	766	693	655	650	644
25.5	781	778	709	673	668	662
26	793	790	725	692	688	680
26.5	805	801	742	711	707	699
27	817	813	759	730	727	719
27.5	828	824	776	750	747	738
28	840	836	794	770	767	758
28.5	851	847	812	790	787	778
29	863	859	830	810	807	798
29.5	874	870	847	829	827	818
30	886	882	865	848	847	838
30.5	897	893	883	867	866	857
31	909	905	901	885	885	876
31.5	920	916	919	902	903	894
32	932	928	936	919	920	911
32.5	943	939	953	935	937	927
33	955	951	970	951	953	943
33.5	966	962	986	966	968	958
34	978	974	1002	981	983	972
34.5	989	985	1017	995	997	986
35	1001	997	1032	1009	1011	999
35.5	1012	1008	1046	1023	1024	1012
36	1024	1020	1059	1036	1037	1025
36.5	1035	1031	1072	1049	1050	1037
37	1047	1043	1084	1062	1063	1049
37.5	1058	1054	1096	1074	1075	1061
38	1070	1066	1108	1087	1087	1073
38.5	1081	1077	1120	1099	1099	1084
39	1093	1089	1131	1111	1111	1096
39.5	1104	1100	1142	1123	1123	1107
40	1116	1112	1153	1135	1135	1119
40.5	1127	1123	1164	1147	1147	1130
41	1139	1135	1174	1159	1158	1142
41.5	1150	1146	1185	1171	1170	1153
42	1162	1158	1195	1183	1181	1164
42.5	1173	1169	1205	1194	1193	1175
43	1184	1180	1215	1206	1204	1186
43.5	1195	1191	1225	1217	1216	1197
44	1206	1202	1235	1229	1227	1208
	1217	1213	1245		1239	1220
44.5	1/1/	1213	1745	1240	1734	1220

45.5	1239	1235	1266	1264	1263	1244
46	1250	1246	1277	1276	1274	1255
46.5	1261	1257	1287	1288	1286	1266
47	1272	1268	1298	1299	1297	1278
47.5	1283	1279	1308	1312	1309	1290
48	1294	1290	1319	1324	1322	1302
49	1316	1312	1341	1350	1347	1327
50	1338	1334	1365	1378	1376	1355
51	1360	1356	1391	1411	1410	1388
52	1382	1378	1420	1446	1445	1423
53	1404	1400	1451	1482	1481	1459
54	1426	1422	1484	1518	1518	1495
55	1448	1444	1519	1554	1554	1531
56	1470	1466	1552	1586	1585	1561
57	1492	1488	1580	1614	1613	1587
58	1515	1510	1605	1640	1638	1612
59	1538	1532	1629	1664	1662	1635
60	1561	1554	1651	1687	1684	1656
61	1584	1577	1671	1709	1706	1677
62	1607	1600	1691	1730	1727	1698
63	1630	1623	1710	1751	1748	1719
64	1653	1646	1728	1772	1768	1739
65	1676	1668	1746	1792	1788	1758
66	1699	1690	1764	1812	1808	1777
67	1721	1712	1782	1831	1827	1796
68	1743	1734	1800	1850	1846	1815
69	1765	1756	1817	1870	1865	1834
70	1787	1778	1835	1890	1885	1854
71	1809	1800	1854	1910	1906	1874
72	1831	1822	1873	1933	1928	1897
73	1853	1844	1895	1959	1954	1923
74	1875	1866	1919	1988	1984	1953
75	1897	1888	1946	2020	2016	1985
76	1919	1910	1974	2054	2049	2018
77	1941	1932	2003	2088	2084	2052
78	1963	1954	2034	2123	2119	2087
79	1986	1976	2065	2158	2154	2122
80	2009	1998	2097	2192	2188	2155
81	2032	2020	2128	2224	2220	2187
82	2055	2043	2158	2254	2249	2215
83	2078	2066	2187	2281	2276	2241
84	2101	2089	2213	2306	2301	2266
85	2124	2112	2237	2329	2325	2289
86	2147	2135	2259	2352	2347	2310
87	2170	2158	2279	2374	2369	2331
88	2193	2181	2299	2395	2389	2352
89	2216	2204	2317	2416	2409	2371
90	2239	2227	2335	2435	2429	2390
91	2262	2250	2352	2454	2448	2409
92	2285	2273	2368	2473	2467	2427
93	2308	2296	2385	2493	2486	2447
94	2332	2319	2405	2514	2508	2470

95	2356	2342	2427	2539	2532	2495
96	2380	2365	2453	2567	2560	2524
97	2403	2388	2481	2598	2591	2556
98	2426	2411	2512	2631	2624	2589
99	2450	2434	2545	2664	2658	2622
100	2474	2457	2578	2696	2690	2654
101	2498	2481	2610	2729	2723	2688
102	2522	2505	2643	2765	2759	2724
103	2546	2529	2678	2800	2795	2761
104	2570	2553	2712	2834	2830	2795
105	2594	2577	2746	2865	2860	2825
106	2618	2601	2775	2891	2886	2850
107	2642	2625	2800	2914	2910	2873
108	2667	2649	2822	2937	2932	2894
109	2692	2673	2842	2958	2954	2915
110	2717	2697	2862	2979	2974	2935
111	2742	2721	2880	3000	2994	2954
112	2767	2746	2898	3019	3014	2973
113	2792	2771	2916	3038	3032	2991
114	2817	2796	2932	3057	3050	3009
115	2842	2821	2948	3075	3068	3026
116	2867	2846	2964	3093	3086	3044
117	2892	2871	2981	3112	3105	3063
118	2917	2896	3001	3133	3126	3084
119	2942	2921	3023	3156	3148	3107
120	2967	2946	3047	3181	3173	3132
121	2992	2971	3073	3209	3201	3161
122	3017	2996	3101	3240	3233	3192
123	3042	3021	3131	3274	3267	3226
124	3067	3046	3162	3310	3302	3261
125	3092	3071	3194	3346	3338	3297
126	3117	3096	3227	3381	3374	3333
127	3142	3121	3260	3416	3409	3368
128	3167	3146	3292	3449	3442	3401
129	3192	3171	3324	3481	3473	3432
130	3217	3196	3354	3510	3502	3460
131	3242	3221	3383	3536	3528	3486
132	3267	3246	3409	3561	3552	3509
133	3292	3271	3433	3584	3575	3532
134	3318	3296	3455	3607	3597	3553
135	3344	3321	3475	3628	3618	3574
136	3370	3346	3495	3649	3638	3593
137	3396	3371	3513	3668	3658	3612
138	3422	3396	3531	3687	3676	3631
139	3448	3421	3547	3706	3694	3649
140	3474	3446	3563	3724	3712	3667
141	3500	3471	3579	3743	3731	3686
142	3526	3496	3598	3764	3752	3707
143	3552	3521	3620	3788	3776	3732
	3578	3547	3645	3815	3803	3759
144			AT 144.		(1011.1.7)	37.734
144	3604	3573	3672	3844	3833	3790

147	3656	3625	3732	3912	3903	3859
148	3682	3651	3765	3948	3941	3897
149	3708	3677	3798	3986	3979	3936
150	3734	3703	3833	4023	4016	3973
151	3760	3729	3867	4058	4052	4008
152	3786	3755	3901	4091	4086	4041
153	3812	3781	3933	4123	4117	4073
154	3838	3807	3963	4152	4146	4101
155	3864	3833	3991	4179	4173	4128
156	3890	3859	4017	4206	4199	4153
157	3916	3885	4042	4231	4223	4178
158	3942	3911	4066	4254	4247	4201
159	3968	3937	4088	4277	4269	4224
160	3994	3963	4110	4300	4291	4245
161	4020	3989	4130	4321	4312	4266
162	4046	4015	4150	4342	4333	4287
163	4072	4041	4168	4363	4353	4306
164	4098	4067	4186	4383	4373	4325
165	4124	4093	4204	4403	4392	4345
166	4150	4119	4223	4423	4413	4365
167	4176	4145	4244	4445	4435	4388
168	4202	4171	4267	4470	4459	4413
169	4228	4197	4293	4497	4487	4442
170	4254	4223	4323	4528	4519	4473
171	4280	4249	4354	4560	4551	4506
172	4306	4275	4387	4592	4584	4538
173	4332	4301	4420	4624	4617	4571
74	4358	4327	4453	4658	4652	4605
175	4384	4353	4487	4691	4686	4639
176	4410	4379	4521	4724	4719	4672
177	4436	4405	4554	4755	4750	4703
178	4462	4431	4585	4784	4779	4732
179	4488	4457	4614	4811	4806	4759
180	4514	4483	4641	4837	4832	4785
181	4540	4509	4667	4862	4856	4810
182	4566	4535	4691	4887	4880	4835
183	4592	4561	4715	4910	4904	4858
184	4618	4587	4736	4932	4926	4880
185	4644	4613	4756	4953	4946	4900
186	4670	4639	4774	4972	4966	4919
187	4696	4665	4792	4991	4986	4938
188	4722	4691	4809	5010	5006	4957
189	4748	4717	4826	5029	5025	4976
190	4774	4743	4844	5050	5045	4997
191	4800	4769	4864	5073	5068	5020
192	4826	4795	4888	5098	5093	5046
193	4852	4821	4914	5125	5121	5075
194	4878	4847	4942	5156	5152	5107
195	4904	4873	4973	5189	5186	5142
196	4930	4899	5005	5224	5222	5178
197	4956	4925	5039	5260	5259	5216
198	4982	4951	5075	5297	5297	5254

199	5008	4977	5112	5334	5335	5291
200	5034	5003	5150	5370	5371	5328
201	5060	5029	5187	5404	5406	5362
202	5086	5055	5221	5434	5435	5392
203	5112	5081	5249	5460	5460	5416
204	5138	5107	5272	5483	5482	5439
205	5164	5133	5293	5505	5504	5460
206	5190	5159	5313	5526	5524	5481
207	5216	5185	5331	5547	5544	5501
208	5242	5211	5349	5567	5564	5520
209	5268	5236	5367	5586	5583	5539
210	5294	5261	5384	5605	5601	5558
211	5319	5286	5401	5624	5619	5576
212	5344	5311	5418	5642	5637	5594
213	5369	5336	5435	5662	5656	5613
214	5394	5361	5453	5682	5676	5633
215	5419	5386	5473	5705	5699	5656
216	5444	5411	5499	5732	5727	5684
217	5469	5436	5529	5762	5758	5716
218	5494	5461	5561	5794	5792	5749
219	5519	5485	5596	5829	5828	5786
220	5544	5509	5629	5861	5861	5819
221	5569	5533	5656	5889	5887	5845
222	5594	5557	5680	5914	5911	5868
223	5619	5581	5702	5937	5933	5891
224	5644	5606	5725	5960	5955	
225	5669			1 - 3 - 3 - 1 - 5 - 5 - 5 - 5 - 5 - 5 - 5 - 5 - 5		5913
226	5694	5631 5656	5747 5769	5983 6006	5977	5935
227	5719	5681	5792	6029	5999	5957
228	5744	5706	3792	0029	6022	5979
229	5769	5731				-
230	5794	5756				
231	5819					
		5781 5806				
232	5844					
	5869	5831				
234	5894	5856				
235	5919 5944	5881 5906				
236 237					·	
	5969	5931				
238	5994	5956				
239	6019	5981				
240	6044	6006				
241	6069	6031				
242	6094	6056				
243	6118	6081				
244	6142	6105				
245	6166	6129				
246	6190	6153			10	
247	6214	6177				
248	6238	6201				
249	6262	6225				
250	6286	6249			1	

## APPENDIX F

Pre-Construction Condition Survey
For

- 1. Highway 14
- 2. Rapid City

# PRE-CONSTRUCTION CONDITION SURVEY

The pre-construction condition survey of the asphalt pavement on Highway 14 was done on June 18, 1996. The Principal Investigator (P.I.), the Research Associate (R.A.) and two graduate students took part in the condition survey. The DOT engineers assisted the research team by providing traffic control during the condition survey. They had also clearly marked the starting point and the end of the white-toppings.

The condition survey was done according to the guidelines provided by the Strategic Highway Research Program (SHRP) publication "Distress Identification Manual for the Long-Term Pavement Performance Project (LTPP)".

#### Cracks:

Fatigue cracking and block cracking were not observed in the portion of the asphalt pavement surveyed. Extensive edge cracking, longitudinal cracking (both wheel path and non-wheel path) and transverse cracking were observed. These cracks have been sketched and their lengths and widths were measured. Sketches of these cracks and their location and widths are attached. The severity of transverse cracks is classified as per the SHRP LTPP manual as low (L), moderate (M) and high (H). As per the manual, a crack with mean width  $\leq 6$  mm (0.25 in.) is low severity (L); width  $\geq 6$  mm (0.25 in.) and  $\leq 19$  mm (0.75 in.) is moderate severity (M); and width  $\geq 19$  mm (0.75 in.) is high severity (H).

#### Patches and Potholes:

No patches were observed in the section surveyed. There was only one pothole about 0.1 sq. m. (1 sq. ft.) at 90+50 ft as shown in the attached sketch.

# Rutting and Shoving:

No shoving was noticed; however extensive rutting was observed. The details of the depth of rutting measured are given in the attached Table. The rutting was measured at 100 ft. intervals and four readings were taken at each transverse location.

# Bleeding, Polished Aggregates and Raveling:

Bleeding was not extensive, however a few patches of bleeding were noticed at the following locations:

Location	Size
94+35	5 ft. long and 1 ft. wide
96+35	1 sq. ft.
102+75	5 in. by 5 in.
103+90	4 ft. long and 1 ft. wide
111+60	16 ft. long and 4 ft. wide
109+60 to 109+80	22 ft. long and 6 in. wide

Over the entire wheel path surface area some minor polished aggregates were seen; however it is not considered severe. No raveling was noticed.

# Water Bleeding and Pumping:

Some traces of pumping action was found at the unsealed transverse cracks, with no evidence of pumping at sealed cracks. Traces of fine material left on surface by water bleeding and pumping was mainly found in the unsealed transverse cracks at the wheel paths.

# Rapid City Whitetopping

The P.I. attended the preconstruction meeting for this project on May 12, 1998 at the SDDOT Regional office, Rapid City.

On June 11, 1998, a trial mix was done at the Hills Red.E.Mix Plant in Rapid City between 2:30 and 4:00 p.m. The trial mix was done so that DOT engineers, the concrete suppliers and the contractor would become familiar with the mix and its performance, such as slump, air content, unit weight, workability and finishability. All present (DOT engineers – 3, the concrete supplier, and the contractor) were satisfied with the performance and the workability of the mix.

# **Pre-construction Condition Survey**

On June 12, 1998 the P.I. and three graduate students inspected the surface that was prepared to receive the whitetopping. All the observed cracks in the scarified asphalt surface were mapped. The details of the cracks are given in the Appendix F. Mostly transverse cracks running over the entire width of the pavement were noted. There was a diagonal crack at the middle of the intersection.

# **EVALUATION OF NMFRC WHITE-TOPPING (SD 96-13)**

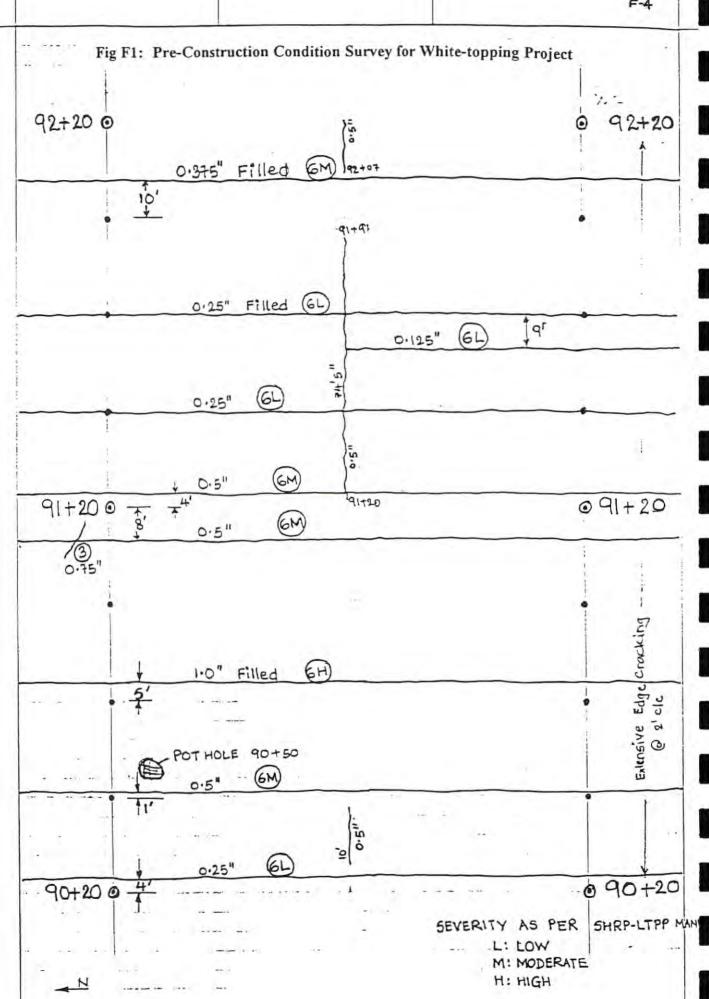
# CONDITION SURVEY BEFORE MILLING (JUNE 18, 1996)

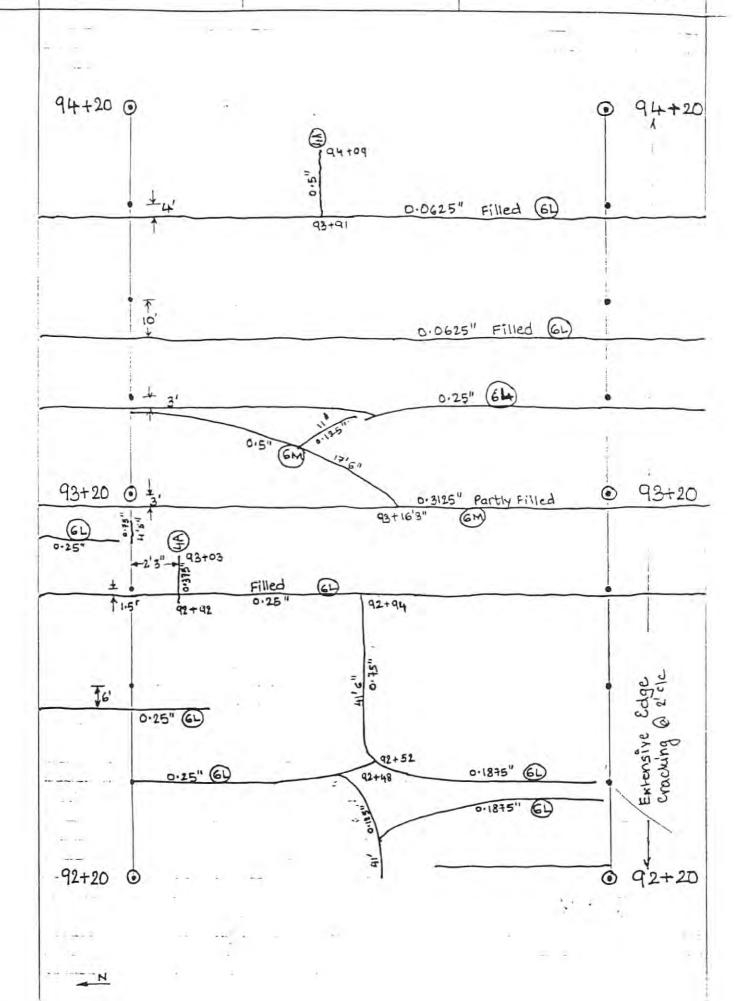
Table F1: Rutting Measurements as per SHRP LTPP Manual

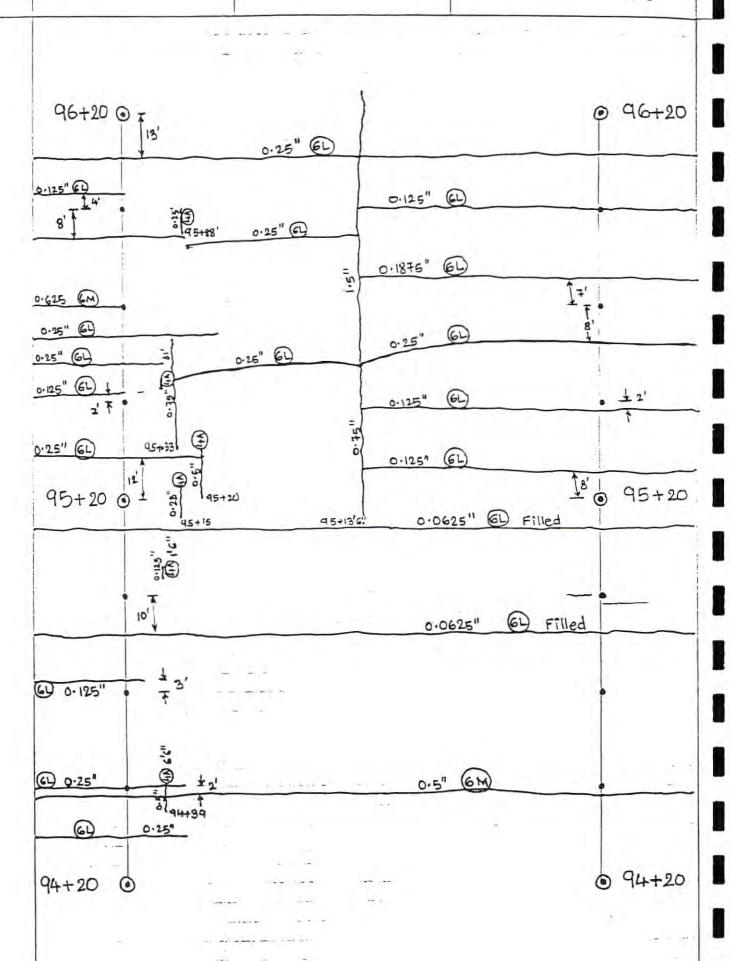
Sr. No.	Station		nd Traffic end lane)	East Bound Traffic (South end lane)						
		Inner Wheel Path (mm)	Outer Wheel Path (mm)	Inner Wheel Path (mm)	Outer Wheel Path (mm)					
1.	90+20	14	8	17	25					
2.	91+20	13	12	14	20					
3.	92+20	13	12	19	27					
4.	93+20	12	14	18						
5.	94+20	10	16	12	20					
6.	95+20	15	12	14	25					
7.	96+20	14	12	15	20					
8.	97+20	15	11	13	24					
9.	98+20	9	12	10	15					
10.	99+20	13	11	9	12					
11.	100+20	10	10	15	14					
12.	101+80	10	6	14	17					
13.	102+80	9	10	12	20					
14.	103+80	8	11	15	17					
15.	104+80	10	10	14	23					
16.	105+80	10	8	13	20					
17.	106+80	15	6	18	15					
18.	107+80	16	10	16	18					
19.	108+80	15	14	13	13					
20.	109+80	14	11	11	15					
21.	110+80	13	7	10	9					
22.	111+80	11	9	11	10					

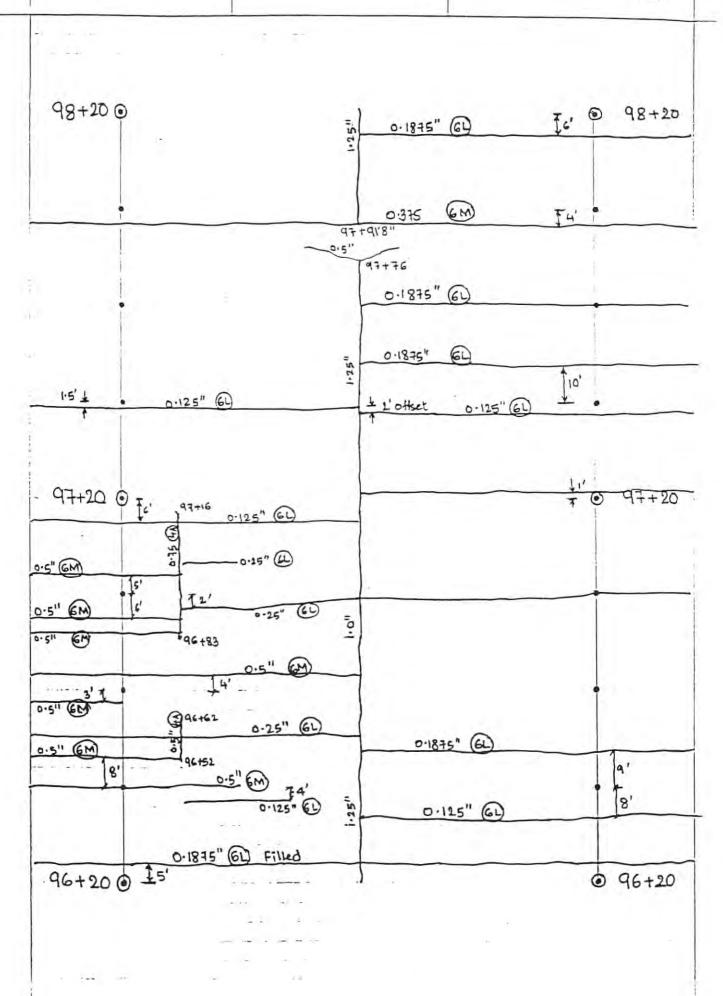
Conversion table:

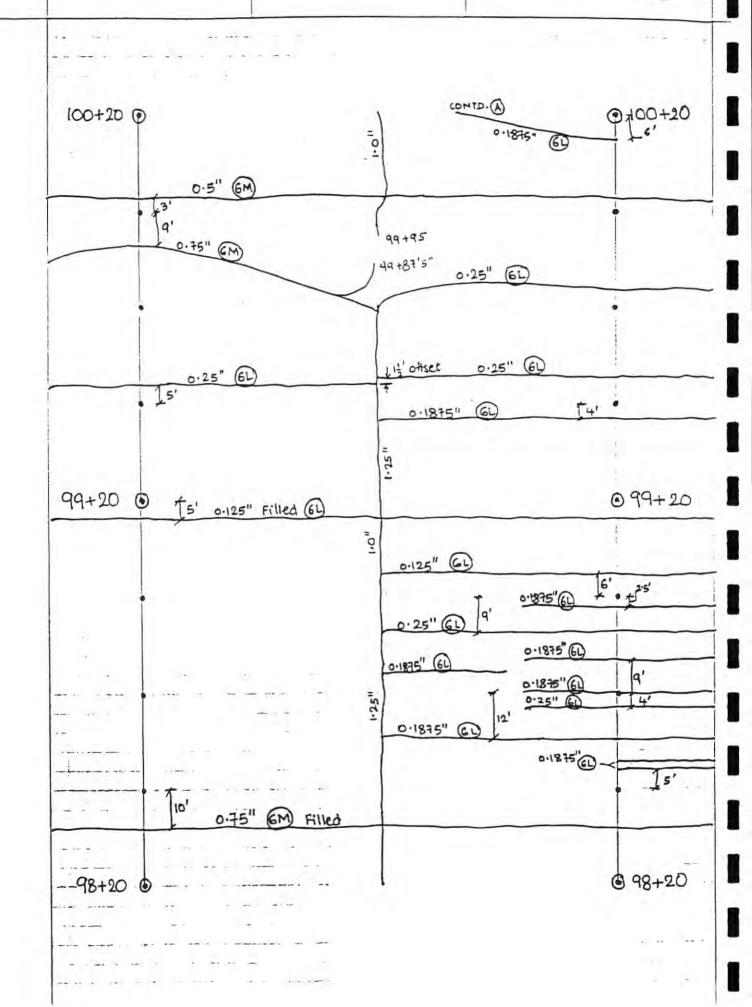
1 inch = 25.4 mm

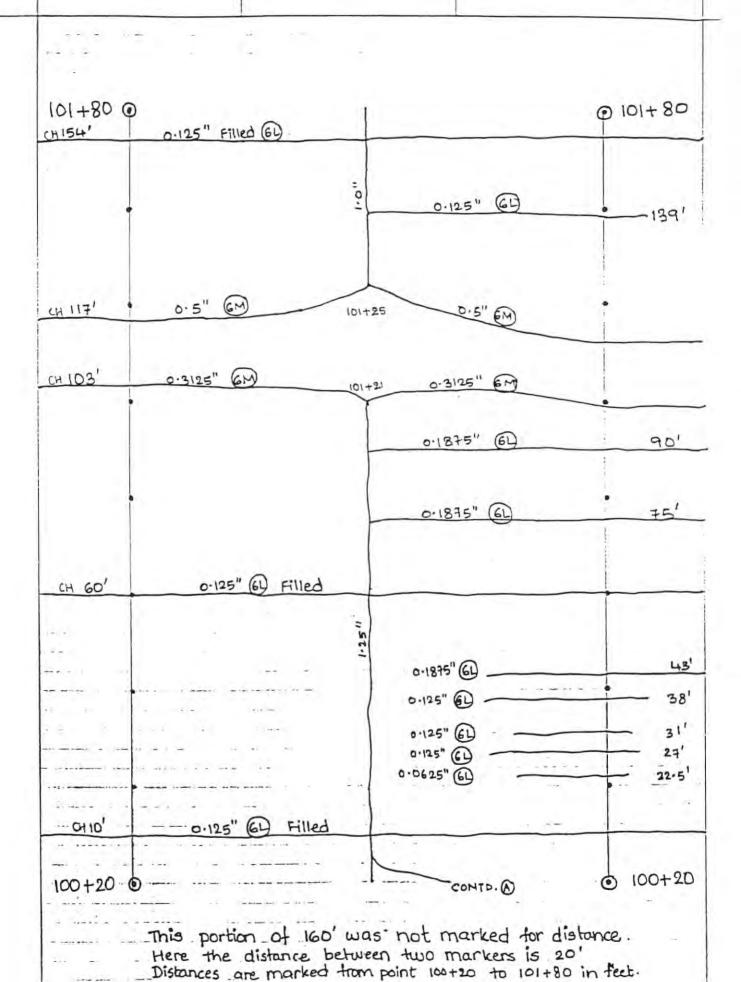












107+80 0 0.125" (1) Filled	) +F01 <b>©</b>	80
13'		
· ¥		
	0·1875" (EL)	
	0.1875" 60	
A' 0.25" 60	A' 1.	
A' 0.25" 60	0-1875" (61)	
+	0.1845.0	
1.	0.1875" (61)	
[5' 0-25' @	10/	
	0·125" (E)	
0.25" (61)		
106+80 @ \$51	⊙ 106÷	-80
lus i		Ī
0.1875" (6)	7 1'btfset	
0.1875" (61)		
+ + -	•	
0.1813 (65)		_
0·125" (6L)		_
n'		
18' 0-1875" (6b)	1	
		_
0-25" (6)		
16'		
$\int u'$	\ .	
		_
0.375" (6M)	\	
0·375" (6M)		
105+80 @	O 105+	80
114	0 105+	80
100	0 105+	80

# Rapid City White Topping Preconstruction Survey - Crack Details Date: 6/12/98

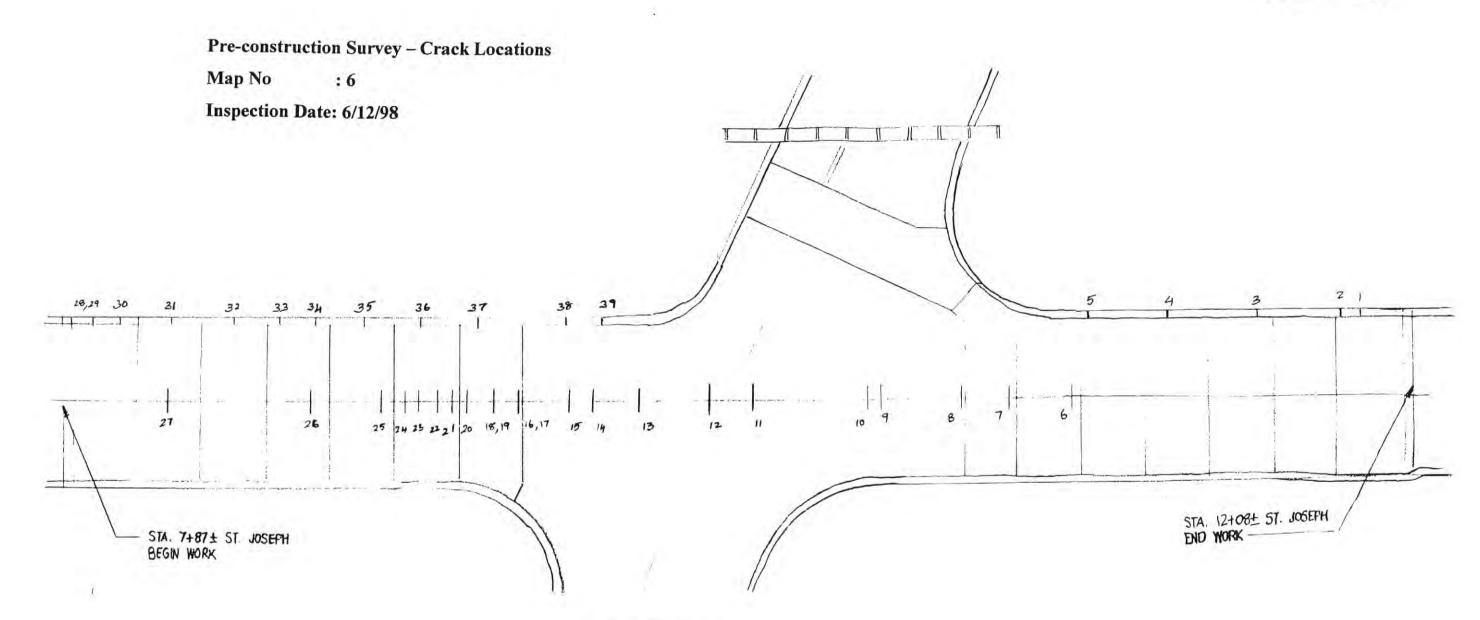
SI.No:	Crack Position	Width of Crack	Avg.Width of Crack	Comment							
	Frm 12+08										
1	14'	0.032 0.25 0.125 0.032	0.1098	Crack also extends the kerb							
2	20'	0.01 0.01 0.02	0.0133	Crack on kerb;located adjacent to expansion joint							
3	49'	0.375 0.125 0.03	0.1767	Crack extends onto kerb and also onto other side of the road							
4	74'	0.125 0.03	0.1250 0.0300	this crack on kerb only longitudinal crack on road							
5	99'	0.375 0.375	0.3750	Crack extends onto other side of road; this crack has an approx. length of 4 ft.							
6	105'	0.032 0.032	0.0320	Crack only on kerb							
7	124.5'		3,0020	PVC pipes (3 nos.) running across the street							
8	145'	0.25 0.25	0.2500	starts middle of road							
9	169'	0.25 0.125 0.375	0.2500	running for 7' from middle into width of road							
10	172'			No cracks; diagonal joint							
11	208'	0.04 0.03 0.04	0.0367	crack running in zig-zag pattern; extends through out width of road							
12	222'	0.25 0.125 0.375	0.2500	crack running throughout width of road							
13	249'	0.5 0.5	0.5000	crack on kerb only; both ends of manhole							
14	263'	0.5 0.5 0.125	0.3750	Crack only on kerb							
15	269'	0.5 0.25 0.125	0.2917	Crack only on kerb							
16	279'	0.5 0.5	0.5000	joint on kerb							

SI.No:	Crack Position	Width of Crack	Avg.Width of Crack	Comment							
17	280'	0.375 0.5	0.4375	crack on road 4 ft. long; starts middle of road							
18	287'	0.5 0.25	0.3750	crack on road							
19	289'	0.25	0.2500	Crack only on kerb							
20	294'			4' long exposure of under- ground cable							
21	299'		11 - 1 -	4' long exposure of under- ground cable							
22	305'	0.5 0.25 0.25	0.3333	running for 15' length across from middle of road							
23	312'	0.25 0.125	0.1875	crack on road							
24	319'	0.125 0.25 0.125	0.1667	running throughout width of road							
25	322'	0.125 0.25	0.1875	crack no:24 forks out from middle of road							
26	349'	0.125 0.25	0.1875	crack on road; also from this crack there exists a longitudinal crack on road of avg.width 0.125 in.							
27	392'			slab removed							
-	Frm 7+87										
28	8'	0.125 0.375	0.2500	crack on kerb							
29	8'	0.032 0.03	0.0310	crack on road							
30	16'	0.25 0.5	0.3750	crack on kerb only							
31	31'	0.25 0.25 0.125	0.2083	crack on kerb only							
32	50'	0.25 0.125	0.1875	crack on kerb only							
33	65'	0.25 0.125 0.75	0.3750	crack on kerb only							
34	75'	0.125 0,25	0,5000	crack on kerb only							
35	90'	0.375 0.25	0.3125	crack on kerb only							

SI.No:	Crack Position	Width of Crack	Avg.Width of Crack	Comment
36	107'	0.25 0.25 0.375	0.2917	crack on kerb only
37	128'	0.5 0.5 0.25	0.2917	crack on kerb only
38	149'	0.25 0.25 0.125	0.2083	crack on kerb only
39	160'	0.125 0.25	0.1667	crack on kerb only

Rapid City White Topping
Preconstruction Survey - Depth Details Date: 6/12/98

SI.No:	Location		inches)				
	From 12+08	Edge	Center				
1.	0	2 1/8	3 1/4				
2	20	3	3 1/4				
3	40	2 7/8	3				
4	60	2 7/8	3 1/8				
5	80	2 1/2	3 1/8				
6	100	2 1/2	3 1/4				
7	120	2 1/2	3 3/8				
8	140	NA	3 1/4				
9	160	NA	3				
10	180	NA	3 1/8				
11	200	2 3/8	3 1/8				
12	220	2 1/2	3 1/8				
13	240	2 7/8	3 1/4				
14	260	2 3/4	3				
15	280	2 5/8	3 1/8				
16	300	2 1/2	3 1/8				
17	320	2 3/8	3 1/8				
18	340	2 5/8	3 1/8				
19	360	2 1/2	3 1/8				
20	380	2 3/8	3				
21	400	2 1/4	3 3/4				
22	420	2 1/4	4 1/2				



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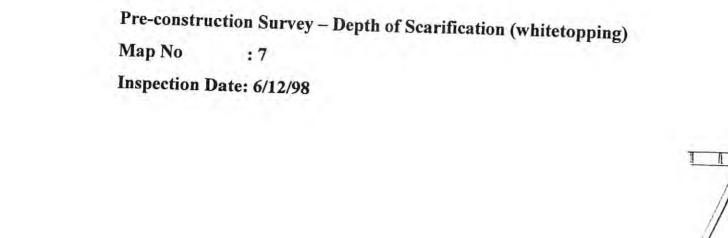
E. ST. PATRICK

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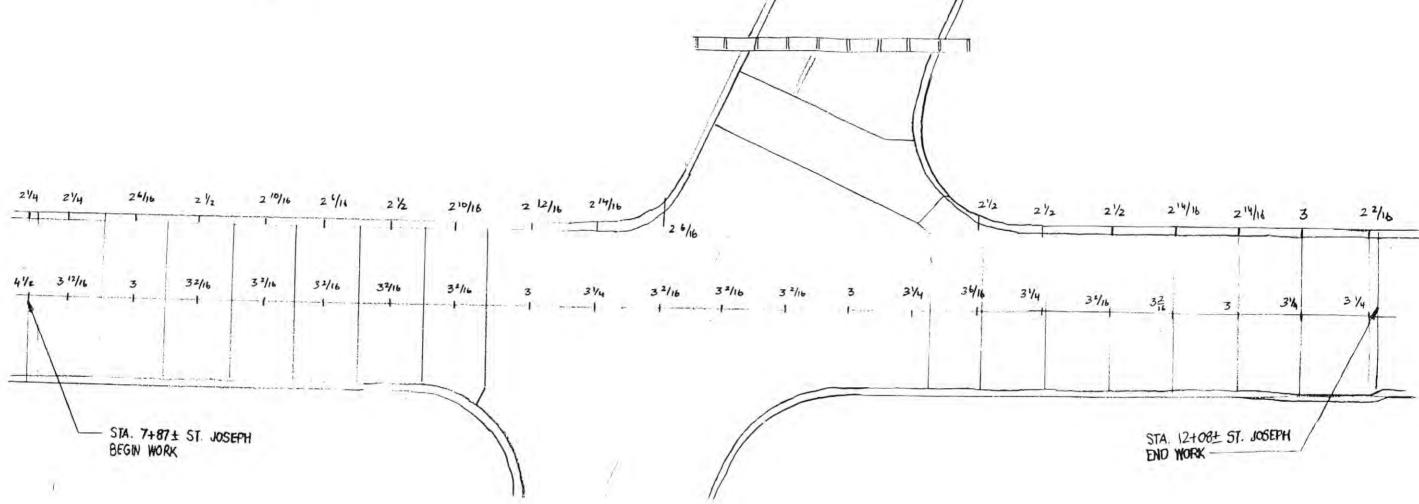
Note: Locations not to scale

Refer to Appendix F for Crack Widths

and Locations







E. ST. PATRICK

Note: Locations not to scale Refer to Appendix F for Details

# APPENDIX G Data Supplied By SDDOT

FT. PIERRE WEIGH-IN-MOTION SITE: US14 MRM Average Daily Traffic (ADT) For Each Class For Each Month in 1999

FHWA		nuary	Fel	bruary	N.	March		April	10	May	June		July	-	August	Se	ptember	0	ctober	No	vember	De	cember	Year	Average
Vehicle Class	ADT S	% of ADT	ADT % of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT								
1	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0.00%		0.00%		0.00%		0.00%		0.00%	-	0.00%		0.00%		0.009
2	245	53.85%	349	60.07%	306	61.45%	321	50.23%	340	49.93%	0.00%		0.00%		0.00%		0.00%	1	0.00%		0.00%		0.00%	312	49.329
3	120	26.37%	195	33.56%	163	32.73%	192	30.05%	193	28.34%	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	173	27.279
4	2	0.44%	1	0.17%	2	0.40%	- 1	0.16%	2	0.29%	0.00%		0.00%		0.00%		0.00%	-	0.00%		0.00%		0.00%	2	0.259
5	14	3.08%	20	3.44%	17	3.41%	21	3.29%	22	3.23%	0.00%	1	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	19	2.979
6	5	1.10%	5	0.86%	5	1.00%	5	0.78%	6	0.88%	0.00%		0.00%	-	0.00%		0.00%	1 - 1	0.00%		0.00%		0.00%		0.829
7	0	0.00%	- 1	0.17%	0	0.00%	1	0.16%	2	0.29%	0.00%	1	0.00%		0.00%		0.00%	1	0.00%		0.00%		0.00%	1	0.139
8	3	0.66%	3	0.52%	3	0.60%	3	0.47%	7	1.03%	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	4	0.60
9	24	5.27%	36	6.20%	33	6.63%	25	3.91%	24	3,52%	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	28	4.49
10	2	0.44%	3	0.52%	3	0.60%	3	0.47%	3	0.44%	0,00%	,	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	3	0.44
11	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0.00%		0.00%		0.00%	1	0.00%	-	0.00%		0.00%		0.00%	- 0	0.009
12	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%		0.00%		0.009
13	8	1.76%	17	2.93%	13	2.61%	9	1.41%	21	3.08%	0.00%		0.00%		0.00%		0.00%		0.00%		0.00%		0.00%	14	2.159
	423		630	1 - 7	545		581		620		0	1 0		1	0	0		0		0		0	1000	560	
Heavy Trucks	177	12.7%		14.8%		15.3%		10.6%		12.8%	0.0%	)	0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		11.89

#### FT\_PIERRE WEIGH-IN-MOTION SITE: US14 MRM Average Daily Traffic (ADT) For Each Class For Each Month in 1998

FHWA	Ja	nuary	Fe	bruary		March		April		May		June		July	1	August	Se	ptember	0	ctober	No	ovember	De	ecember	Year A	Average
Vehicle Class	ADT 9	% of ADT	ADT	% of ADT																						
1	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
2	258	56.70%	332	57.14%	273	54.82%	385	60.25%	377	55.36%	429	56.30%	491	55.17%	431	57.39%	361	60.27%	372	59.33%	253	48,75%	311	52.36%	356	56.25%
3	134	29.45%	186	32.01%	152	30.52%	192	30.05%	216	31.72%	262	34.38%	289	32.47%	219	29.16%	174	29.05%	195	31.10%	193	37.19%	193	32.49%	200	31.669
4	2	0.44%	2	0.34%	2	0.40%	2	0.31%	2	0.29%	2	0.26%	2	0.22%	2	0.27%	2	0.33%	2	0.32%	1	0.19%	. 2	0.34%	2	0,30%
5	17	3.74%	17	2.93%	19	3.82%	20	3.13%	25	3.67%	25	3.28%	40	4.49%	31	4.13%	22	3.67%	19	3.03%	22	4.24%	21	3.54%	23	3.66%
6	4	0.88%	3	0.52%	5	1.00%	3	0.47%	6	0.88%	5	0.66%	10	1.12%	18	2.40%	5	0.83%	3	0.48%	4	0.77%	8	1.35%	6	0.97%
7	0	0.00%	0	0.00%	0	0.00%	0	0.00%	1	0.15%	1	0.13%	2	0.22%	1	0.13%	1	0.17%	0	0.00%	0	0.00%	1	0.17%	1	0.09%
8	3	0.66%	4	0.69%	4	0.80%	3	0.47%	5	0.73%	6	0.79%	9	1.01%	7	0.93%	4	0.67%	4	0.64%	4	0.77%	5	0.84%	5	0.76%
9	28	6.15%	29	4.99%	33	6.63%	27	4.23%	37	5.43%	23	3.02%	37	4.16%	27	3.60%	21	3.51%	23	3.67%	33	6.36%	43	7.24%	30	4.75%
10	2	0.44%	2	0.34%	4	0.80%	2	0.31%	5	0.73%	2	0.26%	3	0.34%	3	0.40%	2	0.33%	2	0.32%	3	0.58%	3	0.51%	3	0.439
11	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	. 0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
12	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0,00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
13	7	1.54%	6	1.03%	6	1.20%	5	0.78%	7	1.03%	7	0.92%	7	0.79%	12	1.60%	7	1.17%	7	1.12%	6	1.16%	7	1.18%	7	1.119
	455		581		498	KE WE	639	and the	681		762		890	1	751	E	599		627		519		594		633	
& Heavy Trucks		13.8%		10.8%		14.7%		9.7%		12.9%		9.3%		12.4%		13.4%		10.7%		9.6%		14.1%		15.2%		12.1%

FT. PIERRE WEIGH-IN-MOTION SITE: US14 MRM Average Daily Traffic (ADT) For Each Class For Each Month in 1997

FHWA	J	anuary	Fe	ebruary		March	II	April	1.1.1	May		June		July	P	August	Se	ptember	(	October	No	vember	De	cember	Year A	Average
Vehicle Class	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT	ADT	% of ADT		W	200	% of ADT		% of AD						
4	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00
2	184	52.87%	288	59.50%	234	55,58%	259	54.99%	327	54.23%	381	54.66%	421	55.98%	483	55.52%	392	54.29%	382	55.85%	317	51.54%	300	56.07%	331	
3	101	29.02%	132	27.27%	133	31.59%	157	33.33%	196	32.50%	234	33.57%	239	31.78%	281	32.30%	240	33.24%	228	33.33%	222	36.10%	166	31.03%	194	1
4	2	0.57%	2	0.41%	2	0.48%	2	0.42%	2	0.33%	2	0.29%	2	0.27%	1	0.11%	2	0.28%	2	0.29%	-	0.33%	2	0.37%	2	0.3
5	21	6.03%	16	3.31%	15	3,56%	22	4.67%	24	3.98%	29	4.16%	37	4.92%	41	4.71%	26	3,60%	19	2.78%		3.41%	16	2.99%	24	
6	4	1.15%	- 5	1.03%	3	0.71%	3	0.64%	7	1.16%	6	0.86%	5	0.66%	7	0.80%	6	0.83%	4	0.58%		0.98%	4	0.75%	5	0.8
7	0	0.00%	0	0.00%	1 3	0.24%	0	0.00%	-1	0.17%	1	0.14%	0	0.00%	1 1	0.11%	- 1	0.14%	. 1	0.15%		0.16%	0	0.00%	1	0.1
8	5	1.44%	4	0.83%	4	0.95%	4	0.85%	5	0.83%	6	0.86%	9	1.20%	8	0.92%	6	0.83%	6	0.88%	4	0.65%	3	0.56%	- 5	0.8
9	24	6.90%	31	6.40%	22	5.23%	19	4.03%	33	5.47%	24	3.44%	25	3.32%	36	4.14%	31	4.29%	33	4.82%	35	5.69%	35	6.54%	29	
10	3	0.86%	2	0.41%	- 1	0.24%	1	0.21%	3	0.50%	7	1.00%	5	0.66%	4	0.46%	7	0.97%	3	0.44%	2	0.33%	2	0.37%	3	0.5
11	0	0.00%	C	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.0
12	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0,00%	0	0.00%	0	0.00%	0	0.0
13	4	1.15%	4	0.83%	6	1.43%	4	0.85%	5	0.83%	7	1.00%	9	1.20%	8	0.92%	11	1.52%	6	0.88%	- 5	0.81%	7	1.31%	6	1.0
(V) (1) (***) (***)	348		484		421		471		603		697		752		870		722		684		615		535		600,1667	
Heavy Trucks		18,1%		13.2%		12.8%		11.7%	* 100	13.3%		11.8%		12.2%		12.2%		12.5%		10.8%		12.4%		12.9%	(1.	12.6

#### Notes:

- The spread sheet does not include any data for 1996. Therefore, the traffic shown on the sheet includes all of 1998, and January through May of 1999.
- 2. This sheet gives the average Daily Traffic (ADT) for one lane (or by direction which is the same thing).
- 3. From this traffic, it was estimated that each lane (direction) has withstood 95,300 equivalent single axle loads (ESAL's). To get this number it was assumed that the traffic for August through December of 1996 to be that same as that seen in the same months for 1997. Therefore, this ESAL estimate would include all traffic from August 1996 through May of 1999.
- 4. Several large trucks have driven over the US14 UTW. Many 13 axle trucks hauling aggregate have weighed in at 146,000lbs. These are very large trucks and their weights were confirmed with a static scale. The truck configurations were a semi-tractor with two trailers. There are other trucks that have also driven over the US14 UTW which have as many as 15 axles. Clearly, these trucks would have a larger load, possibly as high as 155,000 to 160,000 lbs.

Table 2: ARAN014W tested 11/6/1996 Cls/Hwy/Sfx 1014 WB

DLW 221 aran v. 4.28 sride v. 1.14a

				Foot Sensitiv	
MRM	Disp. (miles)	Driver	Passenger	Driver SDI	Passenge SDI
004	0.000	IRI (m/km)	IRI (m/km)		
224	-0.993	0.57	0.51	4.91	4.91
224	-1.043	0.57	0.51	4.91	4.91
224	-1.093	0.59	0.63	4.95	4.91
224	-1.143	0.52	0.43	4.95	4.97
224	-1.193	0.56	0.51	4.78	4.78
224	-1.243	0.62	0.61	4.79	4.48
224	-1.293	0.65	0.53	4.95	4.98
224	-1.343	0.64	0.62	4.55	4.64
224	-1.393	0.62	0.66	4.71	4.57
224	-1.443	0.46	0.43	4.97	4.98
224	-1.493	0.50	0.41	4.99	5.00
224	-1.543	0.54	0.41	4.98	4.98
224	-1.593	0.56	0.56	4.80	4.77
224	-1.643	0.67	0.62	4.84	4.88
224	-1.693	1.30	1.27	4.10	4.03
224	-1.743	0.94	0.91	4.70	4.67
224	-1.793	0.88	1.02	4.83	4.84
224	-1.843	0.93	0.88	4.79	4.76
224	-1.893	0.93	0.92	4.39	4.46
224	-1.943	1.04	1.01	4.83	4.82
224	-1.993	1.19	0.76	4.36	4.86
222	-0.050	1.14	1.07	3.82	3.84
222	-0.100	1.14	0.87	4.42	4.72
222	-0.149	1.05	1.13	3.91	3.79
222	-0.199	0.54	0.67	4.72	4.53
222	-0.249	0.68	0.65	4.55	4.49
222	-0.299	0.53	0.54	4.74	4.63
222	-0.348	0.53	0.50	4.74	4.97
					4.54
222	-0.398	0.71	0.71	4.85	10,3
222	-0.448	0.46	0.55	4.99	4.95
222	-0.498	0.68	0.68	4.88	4.72
222	-0.547	0.50	0.43	4.99	4.99
222	-0.597	0.57	0.60	4.84	4.58
222	-0.647	0.57	0.55	4.71	4.58
222	-0.697	0.81	0.73	4.64	4.59
222	-0.746	0.66	0.64	4.58	4.51
222	-0.796	0.50	0.49	4.84	4.90
222	-0.846	0.58	0.55	4.76	4.75
222	-0.896	0.69	0.71	4.75	4.71
222	-0.945	0.65	0.66	4.67	4.63
222	-0.995	0.67	0.65	4.94	4.93
221	-0.048	0.64	0.68	4.96	4.95
221	-0.098	0.75	0.51	4.91	5.00
221	-0.148	0.67	0.52	4.93	4.99

Table 3: ARAN014E Cls/Hwy/Sfx 1014 EB

tested 11/6/1996

DLW

aran v. 4.28 111 sride v. 1.14a 2 Foot Sensitivity

MRM	disp (miles)	Driver IRI (m/km)	Passenger IRI (m/km)	Driver SDI	Passenge SDI
220.39	0.585	0.47	0.60	4.62	4.53
220.39	0.635	0.61	0.56	4.96	4.97
220.39	0.685	0.60	0.44	4.66	4.60
220.39	0.735	0.59	0.46	4.71	4.65
220.39	0.785	0.49	0.46	4.47	4.29
220.39	0.835	0.50	0.50	4.84	4.75
220.39	0.885	0.57	0.60	4.71	4.60
220.39	0.935	0.69	0.72	4.74	4.49
220.39	0.985	0.56	0.52	4.86	4.88
220.39	1.035	0.53	0.66	4.92	4.85
220.39	1.085	0.66	0.69	4.91	4.78
220.39	1.135	0.67	0.65	4.96	4.89
220.39	1.185	0.48	0.61	4.96	4.84
220.39	1.235	0.55	0.62	4.97	4.85
220.39	1.285	0.83	0.79	4.80	4.79
220.39	1.335	0.49	0.47	4.98	4.79
	1.385	0.49	0.66	4.37	
220.39					4.26
220.39	1.435	0.59	0.68	4.78	4.61
220.39	1.485	0.83	0.89	4.22	4.36
220.39	1.535	1.61	1.45	3.51	3.72
222.00	0.001	1.26	0.97	4.27	4.67
222.00	0.051	1.22	1.17	4.21	4.29
222.00	0.101	1.02	0.99	4.78	4.83
222.00	0.150	1.04	1.03	4.67	4.67
222.00	0.200	0.85	0.80	4.80	4.92
222.00	0.250	1.14	1.15	4.83	4.79
222.00	0.300	0.88	1.31	4.92	4.68
222.00	0.350	1.41	1.41	3.95	4.18
222.00	0.399	0.67	0.74	4.78	4.56
222.00	0.499	0.60	0.63	4.71	4.75
222.00	0.499	0.46	0.43	4.87	4.87
222.00	0.549	0.62	0.58	4.94	4.89
222.00	0.599	0.59	0.69	4.95	4.84
222.00	0.648	0.62	0.65	4.90	4.80
222.00	0.698	0.59	0.61	4.51	4.27
222.00	0.748	0.55	0.62	4.92	4.76
222.00	0.798	0.48	0.52	4.96	4.92
222.00	0.848	0.56	0.55	4.63	4.41
222.00	0.897	0.72	0.66	4.84	4.74
222.00	0.947	0.69	0.71	4.91	4.76
222.00	0.997	0.56	0.54	4.98	4.90
222.00	0.050	0.66	0.66	4.85	4.72

#### Table 4: P.C.C.P. PROFILOGRAPH SMOOTHNESS SUMMARY AFTER GRINDING

PROJECT: P0014 (130)202

COUNTY: STANLEY PCEMS: 4446

ROUTE: US 14 0.4 miles LANES: RIGHT (eastbound)

UNIT PRICE: S.Y. LANE WIDTH: 12 FT.

BEGIN STATION	END STATION	SEGMENT LENGTH	0.00	LANE PASS Inside1 count x 10	LANE PASS outside (2) count x 10	P.I. LANE AVG (in/mi)
90+37.00	95+65.00	528	704	4.5	0.5	2
95+65.00	100+93.00	528	704	3.5	0.5	2
100+93.00	106+21.00	528	704	2.5	1.5	2
106+21.00	111+49.00	528	704	1.0	3.0	2

#### Table 5: P.C.C.P. PROFILOGRAPH SMOOTHNESS SUMMARY AFTER GRINDING

PROJECT: P0014 (130)202

COUNTY: STANLEY PCEMS: 4446

ROUTE: US 14 0.4 miles LANES: LEFT (westbound)

UNIT PRICE: S.Y. LANE WIDTH: 12 FT.

BEGIN STATION	END STATION		100 100 100 100		LANE PASS outside (2) count x 10	P.I. LANE AVG (in/mi)
90+37.00	95+65.00	528	704.0	6.0	3.0	4
95+65.00	100+93.00	528	704.0	6.0	3.5	4
100+93.00	106+21.00	528	704.0	4.5	3.0	4
106+21.00	111+49.00	528	704.0	1.0	2.0	-1

Table 6:

PROJECT: P0014 (130)202

COUNTY: STANLEY Elevation: Milled Surface

Station	11' Rt	6' Rt	1' Rt	1' Lt	6' Lt	11' LT
90+20	1001.10	1001.23	1001.34	1001.36	1001.24	1001.08
90+45	1001.23	1001.34	1001.45	1001.48	1001.40	1001.27
90+70	1001.36	1001.49	1001.58	1001.63	1001.53	1001.36
90+95	1001.51	1001.64	1001.70	1001.71	1001.67	1001.52
91+20	1001.69	1001.81	1001.87	1001.89	1001.83	1001.68
91+45	1001.79	1001.93	1002.02	1002.05	1001.95	1001.81
91+70	1001.91	1002.02	1002.12	1002.18	1002.09	1001.94
91+95	1002.03	1002.13	1002.23	1002.28	1002.21	1002.07
92+20	1002.15	1002.26	1002.37	1002.42	1002.32	1002.17
92+45	1002.26	1002.39	1002.50	1002.55	1002.45	1002.28
92+70	1002.42	1002.53	1002.62	1002.67	1002.58	1002.43
92+95	1002.57	1002.68	1002.78	1002.83	1002.74	1002.60
93+20	1002.71	1002.84	1002.93	1002.97	1002.89	1002.74
93+45	1002.84	1002.96	1003.06	1003.10	1003.01	1002.87
93+70	1002.96	1003.09	1003.21	1003.24	1003.15	1003.01
93+95	1003.12	1003.22	1003.32	1003.37	1003.28	1003.15
94+20	1003.23	1003.33	1003.42	1003.47	1003.42	1003.30
94+45	1003.39	1003.51	1003.62	1003.66	1003.61	1003.48
94+70	1003.57	1003.69	1003.80	1003.86	1003.81	1003.69
94+95	1003.72	1003.83	1003.93	1004.02	1003.95	1003.82
95+20	1003.91	1004.04	1004.14	1004.18	1004.13	1003.98
95+45	1004.00	1004.11	1004.23	1004.27	1004.15	1004.02
95+70	1004.12	1004.22	1004.31	1004.35	1004.25	1004.12
95+95	1004.26	1004.37	1004.28	1004.52	1004.41	1004.26
96+20	1004.39	1004.49	1004.59	1104.64	1004.56	1004.42
96+45	1004.52	1004.62	1004.72	1104.77	1004.69	1004.57
96+70	1004.72	1004.81	1004.90	1004.95	1004.87	1004.74
96+95	1004.87	1004.97	1005.09	1005.13	1005.03	1004.91
97+20	1004.97	1005.10	1005.21	1005.24	1005.14	1005.04
97+45	1005.07	1005.19	1005.30	1005.32	1005.22	1005.12
97+70	1005.17	1005.28	1005.38	1005.40	1005.28	1005.19
97+95	1005.27	1005.38	1005.48	1005.51	1005.40	1005.27
98+20	1005.33	1005.47	1005.58	1005.62	1005.51	1005.39
98+45	1005.44	1005.55	1005.65	1005.71	1005.61	1005.50
98+70	1005.53	1005.64	1005.75	1005.80	1005.71	1005.61
98+95	1005.64	1005.74	1005.85	1005.90	1005.80	1005.70
99+20	1005.74	1005.85	1005.96	1006.01	1005.92	1005.81
99+45	1005.83	1005.94	1006.06	1006.03	1006.03	1005.91
99+70	1005.93	1006.03	1006.13	1006.19	1006.12	1006.00
99+95	1005.99	1006.08	1006.17	1006.23	1006.19	1006.07
102+05	1006.28	1006.40	1006.54	1006.57	1006.46	1006.35
102+30	1006.30	1006.41	1006.55	1006.58	1006.47	1006.34
102+55	1006.30	1006.43	1006.57	1006.59	1006.48	1006.34

Station	11' Rt	6' Rt	1' Rt	1' Lt	6' Lt	11' LT
102+80	1006.30	1006.42	1006.53	1006.57	1006.46	1006.35
103+05	1006.25	1006.42	1006.55	1006.59	1006.49	1006.37
103+30	1006.18	1006.37	1006.50	1006.55	1006.46	1006.32
103+55	1006.25	1006.30	1006.42	1006.48	1006.39	1006.29
103+80	1006.18	1006.23	1006.39	1006.40	1006.30	1006.20
104+05	1006.08	1006.14	1006.27	1006.33	1006.22	1006.11
104+30	1005.93	1006.05	1006.14	1006.20	1006.15	1006.01
104+55	1005.87	1005.97	1006.08	1006.14	1006.06	1005.93
104+80	1005.77	1005.89	1005.99	1006.05	1005.96	1005.83
105+05	1005.63	1005.81	1005.96	1006.01	1005.91	1005.79
105+30	1005.59	1005.76	1005.85	1005.90	1005.82	1005.71
105+55	1005.53	1005.71	1005.83	1005.86	1005.77	1005.64
105+80	1005.43	1005.63	1005.75	1005.79	1005.69	1005.55
106+05	1005.23	1005.53	1005.63	1005.67	1005.60	1005.48
106+30	1005.13	1005.45	1005.54	1005.53	1005.46	1005.34
106+55	1004.96	1005.37	1005.46	1005.39	1005.32	1005.22
106+80	1004.76	1005.24	1005.33	1005.29	1005.21	1005.04
107+05	1004.53	1005.10	1005.17	1005.20	1005.11	1004.98
107+30	1004.33	1004.88	1004.95	1004.98	1004.91	1004.78
107+55	1004.14	1004.67	1004.77	1004.81	1004.72	1004.59
107+80	1003.96	1004.50	1004.61	1004.66	1004.55	1004.44
108+05	1003.75	1004.29	1004.41	1004.45	1004.33	1004.23
108+30	1003.52	1004.08	1004.16	1004.22	1004.13	1004.03
108+55	1003.31	1003.87	1003.99	1004.03	1003.91	1003.81
108+80	1003.12	1003.65	1003.74	1003.79	1003.70	1003.58
109+05	1003.31	1003.44	1003.54	1003.56	1003.50	1003.39
109+30	1003.12	1003.27	1003.38	1003.41	1003.31	1003.20
109+55	1002.95	1003.07	1003.16	1003.22	1003.12	1002.99
109+80	1002.72	1002.83	1003.92	1002.99	1002.90	1002.76
110+05	1002.48	1002.60	1002.70	1002.75	1002.70	1002.56
110+30	1002.26	1002.42	1002.50	1002.53	1002.48	1002.32
110+55	1002.10	1002.23	1002.33	1002.36	1002.26	1002.13
110+80	1001.93	1002.05	1002.16	1002.18	1002.11	1001.96
111+05	1001.75	1001.85	1002.95	1001.99	1001.90	1001.79
111+30	1001.50	1001.63	1001.75	1001.78	1001.69	1001.59
111+55	1001.32	1001.43	1001.52	1001.57	1001.50	1001.39
111+80	1001.09	1001.21	1001.27	1001.36	1001.28	1001.19

Table 7:

PROJECT: P0014 (130)202 COUNTY: STANLEY

Elevation: Whitetopping Surface after grinding

Station	Inst Elev	11' Rt	6' Rt	1' Rt	1' Lt	6' Lt	11' LT
90+20	1008.24	1001.36	1001.44	1001.56	1001.59	1001.49	1001.39
90+45	1008.24	1001.48	1001.58	1001.69	1001.72	1001.61	1001.50
90+70	1008.24	1001.59	1001.69	1001.81	1001.84	1001.74	1001.63
90+95	1008.24	1001.73	1001.83	1001.95	1001.98	1001.89	1001.82
91+20	1008.24	1001.89	1001.99	1002.12	1002.15	1002.04	1001.95
91+45	1008.24	1002.01	1002.11	1002.24	1002.26	1002.17	1002.06
91+70	1008.24	1002.16	1002.26	1002.38	1002.40	1002.30	1002.20
91+95	1008.24	1002.27	1002.38	1002.49	1002.52	1002.42	1002.31
92+20	1008.24	1002.38	1002.48	1002.59	1002.61	1002.51	1002.42
92+45	1008.24	1002.52	1002.62	1002.72	1002.75	1002.65	1002.56
92+70	1008.24	1002.65	1002.75	1002.85	1002.88	1002.79	1002.70
92+95	1008.24	1002.81	1002.93	1003.05	1003.06	1002.97	1002.87
93+20	1008.24	1002.97	1003.08	1003.18	1003.21	1003.10	1002.99
93+45	1008.24	1003.12	1003.22	1003.32	1003.34	1003.25	1003.15
93+70	1008.24	1003.23	1003.34	1003.45	1003.48	1003.39	1003.29
93+95	1008.24	1003.37	1003.49	1003.61	1003.62	1003.51	1003.43
94+20	1008.24	1003.52	1003.63	1003.74	1003.76	1003.67	1003.58
94+45	1010.93	1003.74	1003.86	1003.97	1003.98	1003.87	1003.78
94+70	1010.93	1003.90	1004.03	1004.14	1004.16	1004.04	1003.93
94+95	1010.93	1003.04	1004.18	1004.29	1004.31	1004.21	1004.12
95+20	1010.93	1004.04	1004.37	1004.49	1004.50	1004.39	1004.29
95+45	1010.93	1004.26	1004.45	1004.57	1004.58	1004.50	1004.41
95+70	1010.93	1004.33	1004.56	1004.65	1004.66	1004.58	1004.50
95+95	1010.93	1004.45	1004.71	1004.83	1004.83	1004.74	1004.63
96+20	1010.93	1004.60	1004.82	1004.93	1004.97	1004.87	1004.76
96+45	1010.93	1004.72	1004.97	1005.09	1005.10	1005.01	1004.91
96+70	1010.93	1004.87	1005.13	1005.24	1005.27	1005.16	1005.07
96+95	1010.93	1005.03	1005.28	1005.39	1005.40	1005.31	1005.20
97+20	1010.93	1005.28	1005.39	1005.51	1005.52	1005.44	1005.33
97+45	1010.93	1005.38	1005.48	1005.60	1005.61	1005.52	1005.43
97+70	1010.93	1005.46	1005.56	1005.68	1005.70	1005.62	1005.53
97+95	1010.93	1005.58	1005.69	1005.80	1005.82	1005.72	1005.63
98+20	1010.93	1005.71	1005.81	1005.92	1005.95	1005.84	1005.74
98+45	1010.93	1005.81	1005.91	1006.04	1006.05	1005.94	1005.84
98+70	1010.93	1005.91	1006.02	1006.12	1006.14	1006.03	1005.93
98+95	1010.93	1006.03	1006.12	1006.22	1006.24	1006.13	1006.03
99+20	1012.42	1006.15	1006.23	1006.32	1006,36	1006.26	1006.16
99+45	1012.42	1006.28	1006.36	1006.46	1006.48	1006.38	1006.29
99+70	1012.42	1006.39	1006.45	1006.54	1006.57	1006.48	1006.36
99+95	1012.42	1006.48	1006.54	1006.64	1006.65	1006.55	1006.46
102+05	1012.42	1006.68	1006.79	1006.90	1006.93	1006.81	1006.70
102+30	1012.42	1006.69	1006.79	1006.91	1006.92	1006.82	1006.72
102+55	1012.42	1006.67	1006.77	1006.87	1006.91	1006.81	1006.71
102+80	1012.42	1006.65	1006.74	1006.86	1006.90	1006.80	1006.72

Station	Inst Elev	11' Rt	6' Rt	1' Rt	1' Lt	6' Lt	11' LT
103+05	1012.42	1006.70	1006.81	1006.94	1006.94	1006.83	1006.73
103+30	1011.86	1006.65	1006.78	1006.94	1006.91	1006.81	1006.71
103+55	1011.86	1006.56	1006.68	1006.90	1006.83	1006.73	1006.63
103+80	1011.86	1006.48	1006.60	1006.81	1006.75	1006.65	1006.54
104+05	1011.86	1006.41	1006.51	1006.73	1006.66	1006.56	1006.46
104+30	1011.86	1006.35	1006.45	1006.64	1006.60	1006.49	1006.38
104+55	1011.86	1006.24	1006.34	1006.57	1006.48	1006.38	1006.30
104+80	1011.86	1006.15	1006.25	1006.47	1006.39	1006.30	1006.20
105+05	1011.86	1006.07	1006.18	1006.36	1006.32	1006.22	1006.12
105+30	1011.86	1006.00	1006.10	1006.30	1006.25	1006.14	1006.04
105+55	1011.86	1005.94	1006.04	1006.23	1006.17	1006.06	1005.96
105+80	1011.86	1005.88	1005.98	1006.14	1006.11	1006.00	1005.89
106+05	1011.86	1005.81	1005.92	1006.09	1006.04	1005.93	1005.80
106+30	1011.86	1005.72	1005.84	1006.03	1005.93	1005.82	1005.70
106+55	1011.86	1005.58	1005.69	1005.93	1005.79	1005.68	1005.57
106+80	1011.86	1005.41	1005.53	1005.78	1005.65	1005.54	1005.41
107+05	1011.86	1005.27	1005.38	1005.63	1005.48	1005.37	1005.25
107+30	1011.86	1005.07	1005.18	1005.47	1005.29	1005.18	1005.06
107+55	1011.86	1004.85	1004.97	1005.28	1005.07	1004.97	1004.87
107+80	1011.86	1004.66	1004.77	1005.07	1004.90	1004.79	1004.68
108+05	1008.78	1004.49	1004.59	1004.87	1004.70	1004.59	1004.48
108+30	1008.78	1004.29	1004.39	1004.70	1004.50	1004.39	1004.28
108+55	1008.78	1004.07	1004.18	1004.49	1004.30	1004.19	1004.08
108+80	1008.78	1003.87	1003.98	1004.29	1004.08	1003.98	1003.88
109+05	1008.78	1003.67	1003.77	1004.08	1003.88	1003.76	1003.66
109+30	1008.78	1003.44	1003.55	1003.88	1003.66	1003.55	1003.44
109+55	1008.78	1003.25	1003.36	1003.66	1003.47	1003.36	1003.24
109+80	1008.78	1003.02	1003.13	1003.46	1003.26	1003.15	1003.04
110+05	1008.78	1002.83	1002.94	1003.25	1003.06	1002.96	1002.84
110+30	1008.78	1002.66	1002.76	1003.05	1002.88	1002.77	1002.67
110+55	1008.78	1002.46	1002.57	1002.67	1002.67	1002.57	1002.46
110+80	1008.78	1002.29	1002.39	1002.48	1002.50	1002.39	1002.28
111+05	1008.78	1002.11	1002.21	1002.31	1002.33	1002.21	1002.10
111+30	1008.78	1001.89	1001.99	1002.08	1002.11	1002.00	1001.89
111+55	1008.78	1001.69	1001.80	1001.91	1001.91	1001.80	1001.69
111+80	1008.78	1001.50	1001.61	1001.71	1001.73	1001.61	1001.50

Table 8: Thickness of whitetopping after grinding (inches)

Station	11' LT	6' Lt	1' Lt	1' Rt	6' Rt	11' Rt
90+20	3.7	3.0	2.8	2.6	2.5	3.1
90+45	2.8	2.5	2.9	2.9	2.9	3.0
90+70	3.2	2.5	2.5	2.8	2.4	2.8
90+95	3.6	2.6	3.2	3.0	2.3	2.6
91+20	3.2	2.5	3.1	3.0	2.2	2.4
91+45	3.0	2.6	2.5	2.6	2.2	2.6
91+70	3.1	2.5	2.6	3.1	2.9	3.0
91+95	2.9	2.5	2.9	3.1	3.0	2.9
92+20	3.0	2.3	2.3	2.6	2.6	2.8
92+45	3.4	2.4	2.4	2.6	2.8	3.1
92+70	3.2	2.5	2.5	2.8	2.6	2.8
92+95	3.2	2.8	2.8	3.2	3.0	2.9
93+20	3.0	2.5	2.9	3.0	2.9	3.1
93+45	3.4	2.9	2.9	3.1	3.1	3.4
93+70	3.4	2.9	2.9	2.9	3.0	3.2
93+95	3.4	2.8	3.0	3.5	3.2	3.0
94+20	3.4	3.0	3.5	3.8	3.6	3.5
94+45	3.6	3.1	3.8	4.2	4.2	4.2
94+70	2.9	2.8	3.6	4.1	4.1	4.0
94+95	3.6	3.1	3.5	4.3	4.2	3.8
95+20	3.7	3.1	3.8	4.2	4.0	4.2
95+45	4.7	4.2	3.7	4.1	4.1	4.0
95+70	4.6	4.0	3.7	4.1	4.1	4.0
95+95	4.4	4.0	3.7	4.2	4.1	4.1
96+20	4.1	3.7	4.0	4.1	4.0	4.0
96+45	4.1	3.8	4.0	4.4	4.2	4.2
96+70	4.0	3.5	3.8	4.1	3.8	3.7
96+95	3.5	3.4	3.2	3.6	3.7	3.7
97+20	3.5	3.6	3.4	3.6	3.5	3.7
97+45	3.5	3.6	3.5	3.6	3.5	3.7
97+70	4.1	4.1	3.6	3.6	3.4	3.5
97+95	4.3	3.8	3.7	3.8	3.7	3.7
98+20	4.2	4.0	4.0	4.1	4.1	4.6
98+45	4.1	4.0	4.1	4.7	4.3	4.4
98+70	3.8	3.8	4.1	4.4	4.6	4.6
98+95	4.0	4.0	4.1	4.4	4.6	4.7
99+20	4.2	4.1	4.2	4.3	4.6	4.9
99+45	4.6	4.2	4.3	4.8	5.0	5.4
99+70	4.3	4.3	4.6	4.9	5.0	5.5
99+95	4.7	4.3	5.0	5.6	5.5	5.9
102+05	4.2	4.2	4.3	4.3	4.7	4.8
102+30	4.6	4.2	4.1	4.3	4.6	4.7
102+55	4.4	4.0	3.8	3.6	4.1	4.4
102+80	4.4	4.1	4.0	4.0	3.8	4.2
103+05	4.3	4.1	4.2	4.7	4.7	4.8
103+30	4.7	4.2	4.3	4.8	4.9	4.8

Station	11' LT	6' Lt	1'Lt	1' Rt	6' Rt	11' Rt
103+55	4.1	4.1	4.2	4.7	4.6	4.6
103+80	4.1	4.2	4.2	4.1	4.4	4.8
104+05	4.2	4.1	4.0	4.4	4.4	4.7
104+30	4.4	4.1	4.8	5.2	4.8	5.0
104+55	4.4	3.8	4.1	4.7	4.4	4.4
104+80	4.4	4.1	4.1	4.4	4.3	4.6
105+05	4.0	3.7	3.7	4.1	4.4	4.4
105+30	4.0	3.8	4.2	4.6	4.1	4.4
105+55	3.8	3.5	3.7	3.7	4.0	4.2
105+80	4.1	3.7	3.8	4.1	4.2	4.2
106+05	3.8	4.0	4.4	4.8	4.7	4.6
106+30	4.3	4.3	4.8	4.7	4.7	4.6
106+55	4.2	4.3	4.8	3.8	3.8	4.2
106+80	4.4	4.0	4.3	3.6	3.5	3.4
107+05	3.2	3.1	3.4	3.6	3.4	3.7
107+30	3.4	3.2	3.7	4.0	3.6	3.7
107+55	3.4	3.0	3.1	3.6	3.6	3.8
107+80	2.9	2.9	2.9	3.1	3.2	4.0
108+05	3.0	3.1	3.0	3.5	3.6	4.2
108+30	3.0	3.1	3.4	4.0	3.7	4.0
108+55	3.2	3.4	3.2	3.6	3.7	3.8
108+80	3.6	3.4	3.5	4.1	4.0	4.2
109+05	3.2	3.1	3.8	4.1	4.0	4.3
109+30	2.9	2.9	3.0	3.4	3.4	3.8
109+55	3.0	2.9	3.0	3.6	3.5	3.6
109+80	3.4	3.0	3.2	4.0	3.6	3.6
110+05	3.4	3.1	3.7	4.2	4.1	4.2
110+30	4.2	3.5	4.2	4.7	4.1	4.8
110+55	4.0	3.7	3.7	4.1	4.1	4.3
110+80	3.8	3.4	3.8	3.8	4.1	4.3
111+05	3.7	3.7	4.1	4.3	4.3	4.3
111+30	3.6	3.7	4.0	4.0	4.3	4.7
111+55	3.6	3.6	4.1	4.7	4.4	4.4
111+80	3.7	4.0	4.4	5.3	4.8	4.9

Table 9: FALLING WEIGHT DEFLECTOMETER TEST RESULTS

#### US 14 Polyolefin Fiber Concrete Research Site Near MRM 222 BEFORE FIBER CONCRETE WHITETOPPING

Item	Section A	Section B	Section D	Section E
Deflection Sensor 1 (Mils)	1-11			
Average	35.9	32.6	35.8	40
Range	27.1 to 50.7	25.8 to 40.1	25.9 to 50.9	27.2 to 55.9
Elastic Modulus Asphalt Concrete			1 1	
(Ksi)			3.34	
Average	281.2	318.7	278.4	250.7
Range	60 to 710	72 to 928	75 to 890	60 to 682
Elastic Modulus Base (Ksi)	7 3 3			
Average	5.2	6	5.1	4.6
Range	1 to 16	1 to 20	1 to 17	1 to 15
Elastic Modulus Soil (Ksi)				
Average	14	14.4	14	13.5
Range	6 to 27	7 to 27	6 to 26	5 to 26

Table 10: FALLING WEIGHT DEFLECTOMETER TEST RESULTS
US 14 Polyolefin Fiber Concrete Research Site Near MRM 222
AFTER FIBER CONCRETE WHITETOPPING

Item	Section A	Section B	Section D	Section E	
Deflection Sensor 1 (Mils) Average Range	13.3 11.8 to 16	12.5 9.9 to 15.5	12 10.0 to 13.8	12.3 10.3 to 15.4	
Load Transfer (Ave %)	79.6	90.4	*		
Delta Deflections (Mils)	1.09	0.42	*	*	
K/Kc at X.22 (Average)	0.99	0.99	*	*	
Subgrade Properties EvField CBR (FWD)	14.1 3.1	14.4 3.2	14.1 3.1	13.6 3.0	

<sup>\*</sup> Test Section's D and E were designed with no transverse joints

Table No:11 Date: 7/23/96

Supplier: Morris Inc.

Type of Concrete: NMFRC

Test		2	3	4	5	6	Spec. Limits
% Air Content	6.2	6.9	7.5	5.4	7.9	8	6.5 <u>+</u> 1.5
Slump (in.)	3 1/4	2 1/2	2 1/2	2 1/4	3	3 1/4	1 - 4 1/2
Concrete Temp (F)	76	78	82	82	84	86	90 F
Air Temp (F)	60	68	79	82	83	89	
Time	7:30	8:37	9:41	10:47	12:10	1:32	
Truck#	213	213	207	207	208	213	
Cylinder#/Beam#			1-A, 1-B, 1-C	No.			1
Location	Lt. 111+80	Lt. 110+15	Lt.109+21	Lt.106+75	Lt.104+80	Lt.102+40	
Unit Weight							
Design Strength	A						
Quantity Represented	110/11.5 cu.yd.	172.75/27.5 cu.yd.	226.75/28 cu.yd.	294/28 cu.yd.	290/32 cu.yd.	240/37 cu.yd.	

Conversion table:

1 inch = 25.4 mm

1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 1 inch-pound = 0.1130 Nm

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m

1 sq. in. = 645.2 sq mm

Table No:11a Date: 7/23/96

Supplier: Morris Inc. Type of Concrete: A-45

Test		2	3	4	5	6	Spec. Limits
% Air Content	5.8	6					6.5 <u>+</u> 1.5
Slump (in.)	2 1/4	2 1/8					1 - 3"
Concrete Temp (F)	86	86					90 F
Air Temp (F)	86	84					
Time	2:48	4:45			1		
Truck#	213	213					
Cylinder#/Beam#	1, 1A				/-		
Location	Lt. 101+65	est.Lt. 100+50					
Unit Weight							
Design Strength							
Quantity Represented	97 sq.yd.	117 sq.yd.			+ 4		

Conversion table:

1 inch = 25.4 mm

1 psi = 0.006895 Mpa

 $^{\circ}$ F to  $^{\circ}$ C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m

1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm

Table No: 11b Date: 8/8/96

Supplier: Morris Inc.

Type of Concrete: NMFRC

Test		2	3	4	5	6	Spec. Limits
% Air Content	5.5	2.5	6.9	7	8		5-8%
Slump (in.)	2 1/4	2 5/8	2 3/8	3	3		1 - 4 1/2
Concrete Temp (F)	74	74	80	80	82		90 F
Air Temp (F)	60	68	78	81	87		4
Time	8:25	10:00	10:37	11:44	1:15		
Truck#	213	207	213	213	213		
Cylinder#/Beam#							
Location	102+20	105+05	106+10	108+30	111+15		
Unit Weight							
Design Strength							
Quantity Represented		36 cu.yd./ 300 sq.yd.		140 cu.yd.			

### Conversion table:

1 inch = 25.4 mm

1 psi = 0.006895 Mpa

 $^{\circ}$ F to  $^{\circ}$ C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m

1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm

Table No:11c Date: 8/8/96

Supplier: Morris Inc.

Type of Concrete: NMFRC

Test	1	2	3	4	5	6	Spec. Limits
% Air Content	5.5	2.5	6.9	7	8		5-8%
Slump (in.)	2 1/4	2 5/8	2 3/8	3	3		1 - 4 1/2
Concrete Temp (F)	74	74	80	80	82		90 F
Air Temp (F)	60	68	78	81	87		
Time	8:25	10:00	10:37	11:44	1:15		
Truck#	213	207	213	213	213		
Cylinder#/Beam#							II. A
Location	102+20	105+05	106+10	108+30	111+15		
Unit Weight							
Design Strength					<u> </u>		
Quantity Represented		36 cu.yd./ 300 sq.yd.		140 cu.yd.			

#### Conversion table:

1 inch = 25.4 mm

1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m

1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm

Table No:11d Date: 8/7/96

Supplier: Morris Inc. Type of Concrete: A-45

Test	10 - 10 - 10	2	3	4	5	6	Spec. Limits
% Air Content	7.4						6.5±1.5
Slump (in.)	2 1/2						1 - 4 1/2
Concrete Temp (F)	82						90 F
Air Temp (F)	86						
Time	14:45						
Truck#	208			- 1)			
Cylinder#/Beam#							
Location	sta. 101+10 Rt.						
Unit Weight	1						
Design Strength	4 5 7 1						
Quantity Represented	63, 25						1

#### Conversion table:

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 1 inch = 25.4 mm1 psi = 0.006895 Mpa

1 inch-pound = 0.1130 Nm1 pcf = 16.02 kg/cu m1 pcy = 0.5933 kg/cu m

1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N

Table No: 11e Date: 8/7/96

Supplier: Morris Inc.

Type of Concrete: NMFRC

Test	- 11 -	2	3	4	5	6	Spec. Limits
% Air Content	6.8	5	6.4	8			5-8%
Slump (in.)	2 1/4	2 1/4	2 1/8	1 1/2			1 - 4 1/2
Concrete Temp (F)	64	68	78	80			90 F
Air Temp (F)	58	70	78	86			
Time	8:48	9:50	11:35	13:30			
Truck#	213	203	208	208			
Cylinder#/Beam#		3, 3A, 3B, 3C					
Location	sta. 90+40 Rt.	sta. 93+40 Rt.	sta 96+20 Rt.	sta. 99+60 Rt.			
Unit Weight		140 cu.yds					
Design Strength							
Quantity Represented							

Conversion table:

1 inch = 25.4 mm 1 psi = 0.006895 Mpa

°F to °C:  $T(^{\circ}C) = [T(^{\circ}F) - 32]/1.8$ 

1 pcf = 16.02 kg/cu m

1 pcy = 0.5933 kg/cu m

1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm

Table No:11f Date: 7/24/96

Supplier: Morris Inc.

Type of Concrete: NMFRC

Test		2	3	4	5	6	Spec. Limits
% Air Content	5.2	6	6.2	5.1			6.5±1.5
Slump (in.)	1 1/4	1 1/2	1 1/8	1 1/4			1 - 4 1/2
Concrete Temp (F)	76	80	84	86			90 F
Air Temp (F)	56	64	70	82			
Time	7:19	8:55	10:56	12:44			
Truck#	213	208	208	208			
Cylinder#/Beam#		2, 2A, 2B					
Location	Lt.100+15	Lt.97+70	Lt.93+45	Lt.90+70			
Unit Weight							
Design Strength							
Quantity Represented	170 sq.yd.	447/15540 cu.yd.	467	250			
cu.yd.	31.0	55.0	43.5	25.5			

Conversion table:

1 inch = 25.4 mm 1 psi = 0.006895 Mpa  $^{\circ}$ F to  $^{\circ}$ C:  $T(^{\circ}$ C) =  $[T(^{\circ}$ F) - 32]/1.8 1 pcf = 16.02 kg/cu m 1 inch-pound = 0.1130 Nm

1 sq. in. = 645.2 sq mm 1 lb = 0.4536 kgf = 4.448 N