RESEARCH INVESTIGATION RI99-012

EVALUATION OF ULTRA-THIN WHITETOPPING

PREPARED BY
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RESEARCH, DEVELOPMENT AND TECHNOLOGY DIVISION

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15. Supplementary Notes
The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract
An asphalt intersection with a history of rutting and shoving problems was selected to determine whether Ultra-Thin Whitetopping (UTW) would be a viable alternative to placing a bituminous overlay. The project selected was the intersection at Route 169(Belt Highway), Route YY, and Mitchell Avenue in St. Joseph, Mo. The UTW project consisted of coldmilling 3 inches of the old asphalt surface, placing a 3-inch concrete overlay, and sawing the concrete overlay into 3 foot by 3 foot squares using early entry saws. The project was completed during a 60-hour period using a high-early strength concrete mix, gradation "F" Bethany Falls limestone and fibrillated polypropylene fibers. The design strength of 3500 psi was monitored using a maturity curve and was achieved prior to 14 hours after placement. Construction practices were monitored, as well as performing concrete tests, molding concrete specimens for later testing, and drilling cores for bond strength tests. Visual surveys were performed prior to and immediately after coldmilling operations and after overlay placement. Falling Weight Deflectometer (FWD) testing was performed prior to asphalt milling and after overlay placement. The FWD testing indicated a dramatic decrease in both the radial strain and the vertical strain following the overlay.
The freeze/thaw resistance was lower than expected, with an average durability factor between 60-65 after 300 cycles. Chloride permeability tests placed the UTW in the moderate range. The air void analysis demonstrated that the air void system contained proper sized and spaced air voids that were evenly distributed through the concrete overlay. The concrete bond to the milled asphalt surface was low, but all cores separated below the concrete and asphalt interface. Visual surveys found no cracking in the concrete overlay until the 3-month survey. Most of the cracking was found in an area where the concrete was less than 3 inches thick.
Based on 6 months of service, the UTW overlay seems to be a viable alternative to an asphalt overlay on an intersection where rutting and shoving has become a problem.

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EXECUTIVE SUMMARY

The objective of this study was to determine the feasibility of Ultra-Thin Whitetopping (UTW) as a viable alternative to placing a bituminous overlay in an area where rutting and shoving has become a problem. The intersection of Missouri Route 169 (Belt Highway) and Route YY in St. Joseph was selected because it had a history of rutting and shoving.

The UTW project consisted of coldmilling 3 inches of the asphalt surface, placing a 3-inch UTW overlay, and sawing the concrete overlay into 3-foot by 3-foot squares using early-entry saws. The project was completed over a 60-hour period using High Early Strength concrete (HES), containing Type I cement, a gradation "F" Bethany Falls limestone, and fibrillated polypropylene fibers. A maturity curve was established prior to construction to monitor the concrete's compressive strength after the concrete overlay had been placed. The specifications required a compressive strength of 3500 psi before opening to traffic. The compressive strength was accomplished before 14 hours had elapsed.

The coldmilling operation started Thursday evening and was completed by early Friday morning. The paving contractor started placing the UTW overlay on Friday evening and the entire overlay of the intersection was completed by Sunday evening. Before the paving operations started, the contractor removed debris from the asphalt surface using high-pressure air. Specifications required that the surface must be clean and dry before the concrete is placed, which helps insure an adequate bond is established between the asphalt and concrete overlay. Once paving operations began, the paving progressed in a smooth fashion.

After the concrete mix design was approved and a maturity curve was established, the maturity curve was used for opening the project to traffic. The use of the maturity curve on this project saved MoDOT time and money by not having to mold cylinders and drive to the Construction office to break compressive strength cylinders. The use of the maturity curve allowed the early entry saws to begin the sawing operation at the earliest possible moment, further reducing down time. Opening the intersection as soon as possible minimized user delay. The Standard Practice for Estimating Concrete Strength by the Maturity Method, ASTM C1074, should continue to be evaluated.

Visual surveys indicate that over 90 percent of the surface cracks in the original asphalt surface were removed during the coldmilling operation. There were no visible cracks or joint problems in the Ultra-Thin Whitetopping overlay during the 1-day, 2-week, or 1-month survey. Nineteen cracks were found during the 3-month survey in a right turn lane where the concrete overlay was less than the 3-inch minimum. A more stringent grade must be maintained during milling operations to help in obtaining the minimum overlay thickness. Two short longitudinal cracks were found in 2 end panels. It is recommended that end panels should be thicker than the overlay to provide a transition zone near the asphalt interface. This project was designed without these transition zones in the end panels.

FWD testing was conducted before milling operations and again after the overlay was placed. FWD testing indicates a significant decrease in both the vertical strain, at the top of the subgrade,

and the radial strain, at the bottom of the asphalt layer, after the placement of the PCC layer.

Air content, slump, and the inverted slump tests were performed at 8 different locations during the paving operations. The average air content was 5.1 percent, the average slump was 3 ½ inches, and the average time of flow through the inverted slump was 5 seconds.

Beams and cylinders were molded at the beginning of each day’s pour. The average compressive strength at 28 days was 5810 psi, while the average flexural strength at 28 days was 818 psi.

The Iowa shear and the pull off test results were fairly low. The 8-core average for the Iowa shear tests was 60 psi while the 8-core average for the pull off tests was 31 psi. The Iowa shear and pull off samples all separated below the concrete and asphalt interface. This is an indication that the bond was stronger than the asphalt being overlaid.

Determination of the air void system in the hardened concrete, ASTM C457, was performed on 8 cores after construction and indicated that air void distribution was good throughout the overlay. Average air content was 4.3 percent and the air voids were of proper size and evenly distributed from the top of the overlay to the bottom.

Chloride permeability was performed on 4 cylinders cast during the construction of the UTW project and the permeability averages placed the UTW overlay in the moderate range.

The project has been open to traffic for only 6 months; so final conclusions cannot be drawn at this time. However, based on construction observations and performance to date, Ultra-Thin Whitetopping could be a viable alternative to asphalt overlays on an intersection were rutting and shoving has become a problem.

TABLE OF CONTENTS

Introduction

MoDOT, like other state DOTs, is facing the same pressure of doing more with less, delivering more value for every tax dollar spent. MoDOT spends millions of dollars annually in asphalt pavement maintenance. In many instances, asphalt pavements and overlays have become prematurely shoved and rutted, requiring additional maintenance while inconveniencing the traveling public. Intersections with an asphalt pavement or overlay are a particular problem, because it is believed that slow moving truck traffic at intersections comprise the most severe loading of an overlay.

An intersection was selected in St. Joseph to test the practice of Ultra-Thin Whitetopping (UTW) as a thin concrete overlay. UTW is a process where a thin layer of concrete (2-4 inches), usually with fibers and often of high early strength, is placed over a prepared surface of distressed asphalt. In addition to the thinness of the concrete overlay, other factors differentiate UTW from conventional concrete overlays of existing asphalt pavement (conventional whitetopping). There is a substantial degree of bond between the concrete overlay and the prepared asphalt surface and a much closer joint spacing.

The site selected for the UTW was the intersection of Rt. 169 (Belt Highway) with Rt. YY to the east and Mitchell Ave. to the west, in Buchanan County. The asphalt at the intersection has a history of rutting and shoving problems. The average daily traffic at this intersection is 12,920 vehicles with eight percent or 1,034 trucks. The speed limit is 40 mph along Belt Highway and the amount of vehicles, especially trucks, that must stop and start again has provided the force necessary to cause the rutting and shoving problem. The existing intersection consisted of four through lanes, each 12 feet wide, and a median or left turn lane that is 14 feet wide. The original intersection included a PCC pavement, 40 feet wide, and two additional lanes that were each 11 feet wide. The additional lanes were constructed in 1964 of 11 inches of Plant Mix Bituminous Base. In 1977, a 3-inch asphalt overlay was placed and in 1989, a ½ inch leveling course, 1 ¾ inches of type B, 1 ¼ inches of type C asphalt mixes were applied to the concrete and bituminous base lanes as an overlay.

This UTW project consisted of coldmilling 3 inches of type B and type C asphalt mix layers. A 3-inch UTW pavement was placed and then saw cut, at the earliest possible time, into 3-foot by 3-foot squares. This intersection project was designed for construction over one weekend, with the east side of the intersection constructed first followed by the west side. “Fast-track” technology was applied to this intersection, which places high early strength (HES) concrete mixtures that can be opened to traffic in a matter of hours instead of days. The maturity concept, a method of monitoring the early age and temperature of concrete to estimate in-place strength, was used to facilitate sawing and opening the pavement to traffic.

Objectives

The objective of this study is to determine the constructability and evaluate the effectiveness of placing an ultra-thin whitetopping overlay using concrete, as a means for pavement rehabilitation, at the intersection of Belt Highway, Route YY, and Mitchell Ave. in St. Joseph. Another objective is to evaluate the Standard Practice for Estimating Concrete Strength by the Maturity Method (ASTM C 1704).

The scope of this report is to evaluate and report on construction methods, tests performed during construction, visual distress surveys, Falling Weight Deflectometer (FWD) data, and performance of the overlay after six months of service.

Present Conditions

For over 20 years, UTW pavement has been used to rehabilitate asphalt structures, such as highways, streets, airports, and parking areas. The procedure of milling and overlaying with asphaltic concrete is the least expensive and most used practice. Other alternatives such as full depth asphalt or Portland cement concrete reconstruction are more expensive and cause more user delay. The development of UTW has offered the potential of an alternative method that may be both cost effective and require minimum user delay. Asphalt pavement has the tendency to shove and rut due to stop and go traffic, especially at intersections. If the shoving and rutting deterioration is severe enough, rehabilitation of the asphalt pavement (patching and asphalt overlays) could become a routine process. Ultra-thin concrete whitetopping pavement should provide an effective non-rutting and durable wearing surface. It is recommended that UTW consist of 2-4 inches of PCC, depending on traffic requirements, and that it is bonded onto a sufficient base of at least 3 inches of sound asphalt pavement. The UTW overlay is sawn into a block system. This block system was designed to reduce the curling and warping stresses that the concrete pavement experiences while curing and in-service. The American Concrete Pavement Association (ACPA) recommends joint spacing to be no more than 12-18 times the depth of the overlay. For example, a 4-inch UTW overlay should have joint spacing of 4-foot by 4-foot to 6-foot by 6-foot squares.

In April 1999, the first MoDOT UTW project was placed on U.S. Route 60 from the west Route 60-71 Junction approximately 1.23 miles to the east Route 60-71 Junction in Neosho, Missouri, in Newton County. The original asphalt pavement was 7 inches thick. Two inches of the asphalt pavement was coldmilled, then 4-inches of UTW pavement was placed. The UTW was sprayed with 1.5 times the normal application of curing compound. The UTW was then sawn into 4-foot by 4-foot squares. The UTW pavement reached opening traffic strength of 3500 psi in 7 days. After 2-years of service, the UTW pavement is performing well.

The asphalt pavement at the intersection of Belt Highway and Route YY in St. Joseph exhibited signs of rutting, shoving, and heavy cracking, in both the longitudinal and transverse directions. There had been several attempts at rehabilitation and maintenance repairs over the previous years. As with most asphalt overlays, the cracks continued to reflect and the ruts would reappear. The intersection was located at the base of three hills, which probably contributed to the shoving of the asphalt in addition to the vehicles stopping and starting at the traffic signals.

Technical Approach

The UTW project in St. Joseph was designed to use fast track technology. Paving would start at 6:00 p.m. on a Friday evening and be completed by 6:00 a.m. the following Monday morning. Prior to construction, Herzog Concrete Company of St. Joseph and MoDOT Research, Development, and Technology (RDT) personnel developed a strength-maturity curve for a concrete mix design that would achieve 3500 psi in 12-14 hours. After 4 trial mixes, one was selected and the maturity curve was plotted. Research personnel used a data logger to record the concrete temperatures and broke 2 compressive strength cylinders every 2 hours to establish the maturity curve. The maturity curve was used during the construction process to open the overlay to traffic at the earliest possible moment based on estimated in-place strength, and it was used to determine when the early-entry saws could get on the fresh concrete. A copy of the work plan and a copy of MoDOT's Ultra-Thin Whitetopping specifications can be found in Appendix A.

The mix design selected for the UTW overlay used Bethany Falls gradation "F" limestone for the coarse aggregate and Missouri River sand class "A" for the fine aggregate. An eight-bag type I Portland cement mix was used in place of type III cement. Fibrillated polypropylene fibers were added to the mix at the rate of 3 pounds per cubic yard. This mix design was expected to produce a compressive strength of 3500 psi in less than 16 hours. The mix design can be found in Appendix B.

On September 7, 2000 at 9:00 p.m., APAC Central started the milling operations under traffic in the northbound lanes of Rte. 169. The cold mill machine removed the top 3 inches of the asphalt surface. Each pass of the milling machine removed a strip of asphalt 3 inches thick, 3 feet wide and 530 feet long. The milling operation was performed in the north and southbound lanes of Rte. 169 and the east and westbound lanes of Rte. YY and Mitchell Ave while still open to traffic. Milling operations were completed by 7:00 a.m. on September 8. Traffic was allowed to drive on the milled surface until the UTW paving operations began the evening of September 8.

On September 8, 2000 at 6:00 p.m., the east half of the intersection was closed to traffic, while the west side of the intersection was open to traffic. The paving contractor, Realm Construction, cleaned the milled surface by using high-pressure air. The high-pressure air removed any debris from the milling operation and from the traffic allowed to drive on the milled surface. The UTW paving operation began at 9:00 p.m. and continued until Sunday evening. After the concrete was placed, hand finished, and transversely tined, curing compound was applied to the surface at 1.5 times the normal application rate, as required by the special provisions.

A thermocouple probe was inserted at the beginning of the project and temperatures were recorded and tracked using the maturity chart. When the concrete attained 750-800 psi, the early entry sawing began. The contractor started by sawing the transverse joints, spaced at 3 feet, and finished by sawing the longitudinal joints, also spaced at 3 feet. Minimal raveling was observed during the sawing operations. No cracking was observed before the sawing operations began.

The paving contractor finished placing and finishing the concrete on the east side of Rte. 169 at 2:00 a.m. on September 9. Another thermocouple probe was inserted into the concrete for the maturity curve application. This probe would dictate when the pavement on the east side of the

Rte. 169 intersection could be opened to traffic. The probe was inserted 1-½ inches deep in the center of the paved lane, which was 24 feet wide, approximately 2 feet from the end of the pour. Following completion of the east side of Route 169, the contractor continued to pave on Rte. YY on the east side of the intersection. The paving of the east side of the intersection, except for minor hand work, was completed by 6:00 a.m. on September 9.

The UTW achieved 3500 psi on the east side of the intersection by 3:00 p.m. on September 9, and traffic was allowed to use the east side of the intersection while the west side was being closed to traffic. The west side of the intersection was then cleaned in preparation for the UTW overlay. The contractor began paving the west side of the intersection at 6:30 p.m. and thermocouple probes were inserted in the concrete for maturity testing. The contractor finished paving the west side of Rte. 169 at 8:30 p.m. and the last thermocouple was inserted for maturity monitoring and for opening the pavement to traffic. The UTW overlay achieved 3500 psi at 10:15 a.m. on Sunday, September 10, and was immediately opened to traffic. Opening strengths were achieved within 14 hours.

Research personnel performed concrete tests at 8 locations during the paving operations. These tests included ASTM C 143, Standard Test Method for Slump of Hydraulic Concrete, ASTM C 231, Standard Test Method for Air Content of Freshly Mixed Concrete, and ASTM C 995, Standard Test Method for Time of Flow of Fiber-Reinforced Concrete Through the Inverted Slump Cone. At the beginning of each day's pour, beams and cylinders were molded for later testing. One set of twelve 6-inch by 12-inch cylinders to be broken in sets of 3 at 1-day, 3-day, 7-day, and 28-day was molded for compressive strength testing. One set of nine 6-inch by 6-inch by 20-inch beams to be broken in sets of 3 at 3-day, 7-day, and 28-day were molded for flexural strength testing. Two sets of two 4-inch by 8-inch cylinders were molded for permeability testing. Two sets of three 3 1/2-inch by 4 1/2-inch by 16-inch beams were molded for freeze/thaw testing. In the 8 areas where the concrete tests were performed, 3 cores were drilled. One 4-inch core was used for pavement thickness verification and Iowa Shear testing and a 2-inch core was drilled for a pull-off test.

Visual distress surveys were performed at 1 day, 2 weeks, 1 month, 3 months, and 6 months. These surveys will continue on a yearly basis for a minimum of five years. Beyond 5 years, visual surveys will be conducted as determined appropriate.

Falling Weight Deflectometer (FWD) testing was performed prior to construction and 2 months following the paving operations. FWD testing will continue to be performed on a biennial basis.

Results and Discussion (Evaluation)

The UTW overlay project has been open to the traveling public for 6 months, and test results and observations have been favorable to date. Data and results collected since construction are discussed in the following:

Construction Methods

The milling contractor, APAC Central, milled 3 inches of asphalt from the entire intersection, producing the surface texture necessary for the desired bond. By milling 3 inches down from the top surface, instead of milling down to an established grade line, irregularities such as high and low spots in the surface were not corrected. High spots are a particular concern, because they would result in a thinner than desired overlay. One such high spot was discovered in the right turn lane from northbound Route 169 to eastbound Route YY. A test cap was drilled in the turn lane and verified the overlay was only 1 ¼ inches thick. This turn lane was the only area of the overlay discovered to be less than the 3-inch minimum. The milling operation did uncover 2 sewer covers that had been covered from a previous asphalt overlay.

The paving contractor, Realm Construction Company, employed 2 crews, each working 12-hour shifts. Because the contractor was working with HES concrete and a short deadline, they did not stop until they were finished. The contractor used a slip-form paver to pave two passes, each 24 feet wide. The remaining width of 24 feet was hand poured and finished.

Due to the warm conditions under which the UTW was placed and the specification that the asphalt surface had to be less than 100 degrees Fahrenheit at the time of placement, the paving contractor elected to spray the milled surface with water ahead of the paver. Air temperatures ranged from a high of 92 degrees Fahrenheit to a low of 71 degrees Fahrenheit, while the concrete temperatures ranged from a high of 103 degrees Fahrenheit to a low of 78 degrees Fahrenheit. The contractor continued to spray water onto the milled asphalt surface, even after the asphalt pavement had cooled in the early morning hours. Although the water did not pool, the asphalt surface was wet when the concrete overlay was placed. It is known that an adequate bond between the concrete overlay and the underlying asphalt is essential for the long-term performance of the UTW. Spraying water on the asphalt surface ahead of the paver keeps the surface cooler, but should be kept to a minimum and allowed to dry to a saturated surface condition before the concrete overlay is placed in order to promote a good bond.

Placement of the UTW overlay went relatively smooth. The slump of the concrete was low enough that there was no evidence of the overlay sagging behind the paver, yet it appeared to finish easily with hand tools. After the completion of the hand finishing, transverse tining was performed in a smooth and timely manner. The curing compound was sprayed on the concrete surface immediately following the tining procedure and provided good coverage.

Early entry saws were used on this project with favorable results. The early entry saws were used before internal concrete stresses could build and cause cracking. The narrow joints, 1/8" wide by 1" deep, produced from these saws should minimize incompressibles entering the joints; therefore no joint sealant was used. When the concrete attained 750-800 psi, according to the maturity curve, the early entry sawing was allowed to begin. No cracking in the overlay was observed prior to or following the sawing operation.

Falling Weight Deflectometer(FWD)Data

Falling Weight Deflectometer testing was performed on the intersection before the cold milling operation and again after the placement of the Ultra-thin concrete overlay. There was a major decline in both the vertical strain and the radial strain after the PCC layer was placed. The vertical strain at the top of the subgrade declined from an average of 141(10^{-6} in./in.) before the asphalt was cold milled down to an average of 52.1(10^{-6} in./in.). The radial strain at the bottom of the asphalt dropped from an average of 15.3(10^{-6} in./in.) to an average of 2.9(10^{-6} in./in.). The decline in both the vertical and radial strain would increase the number of loads required for failure from fatigue cracking and rutting in the subgrade. FWD data can be found in Appendix C.

Tests Performed During Construction

(Maturity Testing ASTM C 1704)

The intent of maturity testing is to predict in-situ concrete strength in lieu of cylinders, because cylinders are not always considered representative of actual in-place strength. In-place strength is felt to be higher because of the increased heat generated by a larger volume of concrete. Increased heat means a higher rate of hydration and hence, higher strengths. When time is of the essence, maturity testing can save time and money, while minimizing the inconvenience to the traveling public.

The maturity curve was established prior to construction using the approved mix design at an off site location. An 8-foot by 8-foot by 3-inch test slab was poured and a thermocouple was inserted 1 ½ inches into the center of the slab. Two cylinders had a thermocouple inserted into the center of each cylinder and each thermocouple reading was recorded. The thermocouples were used to measure temperatures in the slab for comparison to cylinder temperatures. The temperature in the test slab peaked at 132.8° F, 7 ½ hours after placement. The temperature in the cylinders peaked at 136.8° F four hours after placement. Two compressive strength cylinders were broken at 2-hour intervals until the concrete had attained 3500 psi. After the concrete had attained 3500 psi, a maturity curve was established using the temperatures of the 2 cylinders that were probed at the time the compressive strength cylinders were broken. No other compressive strength cylinders were broken and no temperatures were recorded after the concrete had reached 3500 psi.

After Herzog Concrete Company selected the concrete mix to be used and a maturity curve was established, the use of the maturity curve on the project went well. No problems occurred during construction with the thermocouple probes or the data loggers. Two additional compressive strength cylinders were molded and cured next to the pavement when the last thermocouple probe was inserted to verify the estimated compressive strength according to the maturity curve. The 2 extra compressive strength cylinders were broken 1 ½ hours after the maturity curve indicated that the overlay had attained 3500 psi and the compressive strength of the cylinders as 3250 psi. The intersection was opened according to the maturity curve. Application of the maturity curve saved MoDOT time and money by not having to mold cylinders and then drive to the Resident Engineer’s office every hour to break cylinders for compressive strength. The other benefits of the maturity testing were opening the intersection as soon as possible to minimize user delay and ensuring sawing at the optimum time. The maturity curve and the projected compressive strength chart from the project can be found in Appendix D.

(Concrete Tests Performed)

Air content, slump, and inverted slump tests were performed at 8 locations during paving operations. The average air content was 5.1 percent, the average slump was 3 ½ inches, and the average time through the inverted slump was 5 seconds. Beams and cylinders were molded at the start of each day's pour for compressive strength and flexural strength testing at a later time.

Tests Performed After Construction

The average compressive strength at 28 days was 5810 psi and the average flexural strength at 28 days was 818 psi. Compressive strength data can be found in Table E-1. Flexural strength data can be found in Table E-2.

The Iowa shear and the pull off tests, ACI 503R-80, results were fairly low. The Iowa shear tests averaged 60 psi, but most cores separated just below the concrete and the asphalt interface. Iowa shear data can be found in Table E-3. The pull off tests averaged 31 psi, but they also separated below the interface. Results of the pull off tests can be found in Table E-4. The low results from the Iowa shear and pull off tests did not seem to be related to the water being sprayed on the asphalt surface ahead of the paver because of the separation just below the concrete and asphalt interface. The average overlay thickness was 3 5/8 inches. Core data can be found in Table E-5.

Rapid chloride permeability testing, AASHTO T-277, was performed on the 4 cylinders molded during the paving operations. The permeability averages were 3342 coulombs passing and placed the UTW overlay in the moderate chloride permeability range (2000-4000 coulombs passing). Chloride permeability data can be found in Table E-6.

Air void structure of the hardened concrete was determined in accordance with ASTM C-457 using the linear traverse method on cores drilled from the project. Results indicate good air void distribution throughout the overlay with an average air content of the eight cores at 4.3 percent. The average number of air voids per inch was 7.95 and the average spacing factor was 0.0095 inches. The air voids were of the proper size and were distributed evenly from the top of the overlay to the bottom. Linear traverse data can be found in Table E-7.

Freeze/thaw tests, ASTM C-666, Method B, were performed on 2 sets of three 3 1/2-inch by 4 1/2-inch by 16-inch beams. Each set represented one day's pour, with the east side having an average durability factor of 60.5 and the west side having an average durability factor of 65.8. MoDOT typically requires a durability factor of 90 or above for good freeze/thaw resistance. All beams were subjected to 300 freeze/thaw cycles. Air void structure evaluation was performed on 3 of the freeze/thaw beams after completion of 300 cycles. Average air content was 4.8 percent, but the average spacing factor was a little higher than desired. Freeze/thaw test results can be found in Table E-8.

The cores evaluated for air void structure and the beams tested for freeze/thaw were both viewed under low magnification to determine the condition of the coarse aggregate, Bethany Falls limestone. The core specimens exhibited a high percentage of cracked aggregate (75 percent).

These cores were drilled approximately 16 hours after the overlay was placed. The freeze/thaw specimens exhibited over 90% percent of the aggregate cracked. The cracks in the aggregate in the freeze/thaw specimens were more open and quite large when compared to the cored specimens. It is felt that the Bethany Falls limestone, which has a history of poor resistance to freeze/thaw conditions, is likely the source of the poor freeze/thaw results, despite the limited maximum size (1/2" max.) gradation used.

Visual Distress Surveys

Prior to milling operations, a visual distress survey was performed of the intersection. Several high severity transverse and longitudinal cracks were observed in all the travel lanes. Most of the transverse cracks spanned all 5 lanes with several of the transverse and longitudinal cracks containing high severity block cracking. Immediately after the milling operations were completed, another visual distress survey was performed. Only 18 transverse cracks were observed, but no longitudinal cracks or block cracking could be found. The transverse cracks were all of moderate severity.

A 1-day, 2-week, and a 1-month survey were performed after the UTW overlay had been placed. There were no cracks or joint problems visible during these surveys.
Nineteen corner cracks were found in the middle of the right turn lane from northbound Route 169 onto eastbound Route YY during the 3-month survey. This is the area where the overlay is less than 3 inches thick. One corner crack was found in the driving lane of southbound Route 169 in the inner wheel path. All corner cracks were approximately 3 inches long. Two short longitudinal cracks were observed in the southbound driving lane of Route 169 located in the wheel paths of the end panels. There was no extra concrete thickness allowed for transition from or onto the asphalt on this project and these cracks are located in the area were the transition should have been located. During the 6-month survey, only 1 new crack was observed and it was located in the eastbound driving lane of Mitchell Avenue. This new crack was approximately 4 feet in length and was located in the outer wheel path.

A 1-year survey is scheduled for the fall of 2001, with yearly surveys scheduled after that.

Photographs of the project and construction can be found in Appendix F.

Conclusions

1. Based on construction observations and 6-month performance, Ultra-Thin Whitetopping appears to be a viable alternative to asphalt overlays on intersections where rutting and shoving is a problem.

2. The use of the maturity concept to estimate the in-place concrete strength worked well and saved time and money on this project.

3. A few corner cracks were observed during the 6-month visual survey, but most were in the area where the overlay was less than the 3-inch minimum required.

4. FWD tests indicate a decrease in the average vertical strain and in the average radial strain. Due to the dramatic decrease in the vertical and radial strain, an increase in the number of loads will be required for failure from fatigue cracking and rutting in the subgrade.

5. Average air content monitored was 5.1 percent, with an average slump of 3 1/2 inches. Average air content according to the air void analysis was 4.3 percent. The air voids were of proper size and evenly distributed in the concrete.

6. Iowa shear tests and pull off tests were low, but most of the specimens separated below the concrete and asphalt interface, indicating a sufficient bond.

7. Average rapid chloride permeability tests placed the UTW overlay in the moderate chloride permeability range.

8. Early entry sawing performed very well on this project. The early entry saws were used before internal concrete stresses could build and cause cracking. The narrow joints produced by the early entry saws should minimize the incompressibles entering the joints; therefore no joint sealant was used.

Recommendations

1. Visual distress surveys should be performed yearly for at least 5 years. If the overlay is still performing well after 5 years, the surveys should be continued as determined appropriate.

2. The Standard Practice for Estimating Concrete Strength by the Maturity Method, ASTM C1704, should continue to be evaluated. This practice could prove to be both time and cost effective.

3. A more stringent grade must be maintained during milling operations in preparation for UTW overlay placement. The minimum overlay thickness requirement must be met for successful performance.

4. As no significant problems in construction were observed and preliminary performance and rideability is good, it is recommended that additional UTW test projects be considered.

Bibliography

1. American Concrete Pavement Association and National Ready Mixed Concrete Association, "Ultra-Thin Whitetopping-Today's Choice for Durable Pavement Overlays", pamphlet and video.
2. Tritsch, Steve, P.E., "Whitetopping Technique Revives Burgeoning Kansas Thoroughfare".
3. MoDOT, "Ultra-Thin Portland Cement Overlay, Route 60, Newton County", construction draft report and work plan.
4. Kentucky Ready-Mixed Concrete Association, "Thin High Strength Whitetopping Research", video

Appendix A
Work Plan

WORK PLAN

Date: 5/16/00

Project Number: RI99-012

Title: Evaluation of Ultra-Thin Whitetopping at Belt Highway and Rte. YY, Buchanan County

Research Agency: Research, Development and Technology

Principle Investigator: David R. Amos, Intermediate Research and Development Assistant

Objective: The objective of this study is to determine the constructability and evaluate the effectiveness of placing an ultra-thin whitetopping overlay, as a means for pavement rehabilitation, at the intersection location of Belt Highway and Rte. YY (St. Joseph), Buchanan County.

Background and Significance of Work: This project will be Missouri's second ultra-thin concrete whitetopping pavement (UTW) constructed, but will be Missouri's first "fast track" ultra-thin concrete whitetopping pavement.

For over 20 years, the UTW pavement has been used to rehabilitate asphalt structures, such as highways, streets, airports and parking areas. Asphalt pavement has the tendency to shove and rut due to the stop and go traffic, especially at intersections. If the rutting and shoving deterioration is severe enough rehabilitation of the asphalt pavement could become a routine process. Ultra-thin concrete whitetopping pavement should provide an effective non-rutting and durable wearing surface. UTW recommends 2 to 4-inches of PCC, depending on traffic requirements, bonded onto a sufficient base of at least three inches of asphalt pavement. The pavement is sawn into a block system. This block system was designed to reduce the curling and warping stresses that the concrete pavement experiences while curing. American Concrete Pavement Association (ACPA) recommends joint spacing to be no more than 12–18 times the depth of the overlay. For example, a four-inch UTW pavement could have joint spacing of four foot by four foot to six foot by six-foot squares. A copy of the Missouri Specifications for Ultra-Thin Whitetopping can be found in Attachment A.

In April 1999, the first UTW was placed on Route 60 from the West Rt. 60-71 Junction east about 1.23 miles to the East Rt. 60-71 Junction in Neosho, Missouri in Newton County. The original asphalt pavement was seven inches thick, two inches of the asphalt pavement was coldmilled and four inches of UTW pavement was then placed. The UTW was sprayed with 1.5 times the normal application of curing compound. The UTW was then sawn into four foot by four-foot squares. The UTW pavement reached opening traffic strength of 3500 psi seven days. After one-year, the UTW pavement is performing well.

In St. Joseph at the intersection of Belt Highway and Rte. YY, an UTW project will be constructed to rid the intersection of rutting and shoving of the asphalt pavement. The average daily traffic at the intersection is 12,920 vehicles with eight percent or 1034 trucks. The speed limit is 40 mph along Belt Highway, and the amount of vehicles especially trucks that must stop and start again provides the force to cause the rutting and shoving. The existing intersection consists of four – 12 foot lanes and a 14-foot median or left turn lane. The existing pavement consists of 40 foot of concrete lanes plus two – 11 foot outer lanes constructed of 11 inches of Plant Mix Bituminous Base. Then a ½ inch minimum leveling course, 1 ¾ inches type B, and 1 ¼ inches type C asphalt mixes were applied to the concrete and bituminous base lanes. The typical sections are located in Attachment B.

The UTW project will consist of coldmilling three inches of type B and C asphalt mix layers. A three-inch UTW pavement will be placed then saw cut in three-foot by three-foot squares. The intersection project will be constructed over a weekend; with the east side of the intersection constructed first then the west side. Fast track technology will be applied to this intersection, which places high early strength (HES) concrete mixtures that can be opened in a matter of hours instead of days. The use of HES concrete mixtures will have the St. Joseph traffic back on the intersection for early Monday morning traffic.

Action Plan: Data collection will be obtained by the following items:

Pre-Construction:

1. Falling Weight Deflectometer (FWD) deflection data
2. Rut depth measurements
3. Drill depth verification cores
4. The pavement will be rated by utilizing SHRP "Distress Identification Manual for the Long-Term Pavement Performance Project"

Construction:

1. Evaluate the cold-milled surface by following the SHRP distress identification manual guidelines
2. Perform Air, Slump, and Inverted Slump tests on the PCC
3. Mold cylinders and beams for strength testing
4. Monitor air temperature, wind speed, humidity
5. Monitor the UTW pavement temperature
6. Monitor joint sawing
7. Evaluate all aspects of the construction process

Post-Construction:

1. Drill cores for Shear Tests and Air Void Structure testing by Linear Traverse
2. Drill cores before first freeze/thaw cycle for SEM Analysis and again after a couple winters for chemical analysis
3. Conduct Pull Off tests to ascertain bond strength
4. Conduct Shear tests to ascertain bond strength

5. Perform cracking survey utilizing SHRP distress manual
6. Run FWD deflection tests
7. Prepare construction and 60-day analysis, four annual memorandum, five-year and ten-year reports

Literature Search: A literature search provided the following literature and videos:

1. "Ultra-Thin Whitetopping – Today's Choice for Durable Pavement Overlays" pamphlet and video by American Concrete Pavement Association and National Ready Mixed Concrete Association
2. "Whitetopping Technique Revives Burgeoning Kansas Thoroughfare" by Steve Tritisch, P.E.
3. "Ultra-thin Portland Cement Concrete Overlay, Route 60, Newton County" construction draft report and workplan by MoDOT
4. "Thin High Strength Whitetopping Research" video presented by Kentucky Read-Mixed Concrete Association.

A literature search will continue throughout the investigation.

Method of Implementation: A construction report will be given for internal MoDOT use. The specifications for fast track construction and materials for UTW pavement will be reevaluated based on the study results. The Technology Transfer Department of Research, Development and Technology will deliver the construction report and any additional information.

Anticipated Benefits: A successful construction and performance of the fast track UTW pavement will provide an excellent alternative option to the traditional asphalt overlay. As stated in the pamphlet "Ultra-Thin Whitetopping Today's Choice for Durable Pavement Overlay", presented by the National Ready Mixed Concrete Association and ACPA, "research indicates that Ultra-Thin Whitetopping can last 2-3 times longer than asphalt overlays. With fast track properties, the UTW will also reduce construction time at highly traveled intersections such as Belt Highway and Rt. YY. Reducing the construction time and the 2-3 possible future asphalt overlays will protect the traveling public from traffic delays and possible safety risks.

Research or Evaluation Period: The research period will be a ten-year study from summer 2000 to summer 2010.

Funding: The construction testing, travel expenses, and personnel salaries will be MoDOT state funded.

Procedure:

Pre-Construction

1. FWD crew will perform the following deflection tests: 20 - deflection tests in the outer wheel path (OWP) of the 11 foot 11inch plant mix bituminous base lane in (outside and turning lanes) 9 – deflection tests in the (OWP) of the inside Portland cement concrete pavement (PCCP) lane (locations of FWD deflection test can be located in the intersection diagram in Attachment C)
2. District 1 Construction personnel will measure the rut depths.
3. RDT personnel will drill depth verification cores at locations selected by FWD crew leader.
   Two – cores in the outer wheel path (OWP) of the 11 foot 11inch plant mix bituminous base lane in (outside and turning lanes) two – cores in the (OWP) of the inside Portland cement concrete pavement (PCCP) lane
4. Two RDT personnel will implement the SHRP distress identification manual to survey the existing asphalt pavement prior to coldmilling. This survey will be conducted from the sidewalk or shoulder without traffic control.

Construction

1. RDT personnel will evaluate the coldmilled surface following the SHRP distress identification manual guidelines.
2. Research personnel will perform air, slump, and inverted slump tests. Eight tests will be performed within the intersection. The approximate test locations can be located on the intersection diagram located in Attachment D. The amount of concrete needed for the tests is 1.4 cu.ft.
3. One location on the east and west side of the project will be sampled. The following cylinder and beams will be molded for strength testing.
   Two sets of twelve six-inch by twelve-inch cylinders to be broken in sets of three at 1 day, 3 days, 7 days and 28 days for compressive strength.
   Two sets of nine 6-inch by 6-inch by 20-inch beams to be broken in sets of three at 3 day, 7 days and 28 days for flexural strength. Two sets of three 3 1/2-inch by 4 ½-inch by 16-inch beams to be used for freeze/thaw analysis. Two sets of two four-inch by eight-inch cylinders for permeability testing. The approximate strength samples location can be located on the intersection diagram located in Attachment D. The amount of concrete required for sample fabrication is approximately 12.6 cubic feet.
4. RDT personnel will monitor the air temperature, wind speed and humidity at least every half-hour for the first 24-hours of pavement curing. RDT personnel will use the Kestral®3000 Pocket Weather Meter to monitor the air temperature, wind speed and humidity.
5. The contractor may develop a strength-maturity relationship for the UTW design mix. Then the contractor will equate a maturity of °C-hour with a compressive strength of 3500 psi. Research personnel would like to have the contractor monitor the air

temperature, top, and bottom concrete pavement temperature for over a 24-hour period. One temperature probe can be inserted ½ inch from the top of pavement and the other probe located at the UTW pavement and asphalt interface. Tests have shown that a temperature difference of more than 7 to 10°F may lead to shrinkage cracking. If the contractor cannot obtain temperatures, then RDT personnel will measure the temperature.

6. RDT personnel will monitor the joint sawing
7. RDT personnel will evaluate all aspects of the construction process.

Post-Construction

1. Research personnel will drill four-inch cores for Shear Tests and Air Void Structure testing by Linear Traverse, which one core can be used for both tests.
2. If a high early strength cement mix is used in the UTW pavement mix, four-inch cores will be cored before the first freeze/thaw cycle for future SEM analysis for chemical analysis. After a few years with a number of freeze/thaw cycles, four-inch cores will be drilled and have SEM analysis performed for chemical analysis.
3. Two-inch pull-off tests will be performed to compare with the shear tests.
4. All shear, SEM analysis and pull off core samples will be drilled at four of the air, slump and inverted slump construction test sites and will be performed at 24 hours or when 3500 psi is obtained.
5. Research personnel will make pavement distress surveys at 1day, 2 week, 1 month, 3 month, 6 month, 1 year and each year after that for first five years. After five years if there is no appreciable deterioration, the continuation of yearly surveys should be reevaluated. The final survey will be at ten years, unless a continuation of the project is recommended at the time.
6. The FWD deflection testing will be performed post-construction and annually thereafter at the pre-construction deflection test sites.

Report Schedule

Fall 2000: The construction and 60 day analysis report will be finalized.
Fall 2001-2004: A brief memorandum of the yearly surveys will be finalized.
Fall 2005: A five-year interim report will be finalized.
Fall 2010: A ten-year and final report will be finalized.

Staffing: The FWD testing will require four RDT personnel. The following vehicles for FWD testing require one person each, FWD van, sign van and two crash trucks.

A Senior R&D Assistant and Senior R&D Technician will be needed to perform distress surveys of the pavement.

A Senior R&D Assistant, Intermediate R&D Assistant and Senior R&D Technician will be needed during the construction period to make the testing samples.
A Senior R&D Assistant, Intermediate R&D Assistant and Senior R&D Technician will be needed during the pre-construction and post-construction period to drill and perform the various tests.

Equipment:

Pre-Construction The equipment needed is the FWD van, sign van, two crash trucks and a rut depth gage.

Construction The equipment that is needed will be:

24 - 6-inch by 12-inch cylinder molds
4 - 3 ½-inch by 4 ½-inch by 16-inch beam molds
18 - 6-inch by 6-inch by 20-inch beam molds
3 - 4-inch by 8-inch cylinder molds
One Air Meter
Small hand tools for finishing fresh concrete
Drill truck to supply power for the vibrators for the testing specimens
Tow vehicle and trailer to transport test specimens
One Inverted Slump Cone
One External Vibrator
One Internal Vibrator
2 Two Wheel Carts

Post-Construction: The equipment needed will be the FWD van, core drill with two inch and four inch bits, Cap Pull Off apparatus and supplies, and Shear Test apparatus. The void analysis, compressive and flexural strength testing will be analyzed by using the General Headquarter Laboratory equipment and personnel.

Budget:

FWD Testing (4 RDT personnel, 2 – 10 hour days, 1 overnight stay, and 4 vehicles)

Salary (includes 1.693 benefit factor, 4% inflation) –	$33,220
Vehicle Expense (0.28 dollars/mile, 4% inflation) -	$14,865
Lodging and Food (4% inflation) -	$ 7,142
Total FWD cost -	$55,227

Distress Survey (2 RDT personnel, 1 – 10 hour day, and 1 vehicle)

Salary (includes 1.693 benefit factor, 4% inflation) –	$ 8,992
Vehicle Expense (0.28 dollars/mile, 4% inflation) -	$ 1,638
Food (4% inflation) -	$ 787
Total Distress Survey cost -	$ 11,417

Construction Testing (3 RDT personnel, 60 hour weekend, 3 nights and 2 vehicles)

Salary (includes 1.693 benefit factor) –	$ 6,371
Vehicle Expense (0.28 dollars/mile) -	$ 125
Lodging and Food -	$ 810
Total Construction cost -	$ 7,306

Drilling and Testing (2 RDT personnel, 6 – 10 hour days, 4 nights and 2 vehicles)

Salary (includes 1.693 benefit factor) –	$ 3,858
Vehicle Expense (0.28 dollars/mile) -	$ 250

Lodging and Food -	$ 690
Total Drilling and testing cost -	$ 4,798

SEM Analysis (1 RDT personnel, 3 day, 2 nights and 1 vehicle)	
Salary (includes 1.693 benefit factor, 4% inflation) –	$ 1,919
Vehicle Expense (0.28 dollars/mile, 4% inflation) -	$ 1,040
Lodging and Food (4% inflation) -	$ 520
Sample Preparation (70 dollar/sample, 4% inflation) -	$ 583
Laboratory Analysts (60 dollars/hour, 4% inflation) -	$ 1,998
Total SEM Analysis cost -	$ 6,060

Reports (1RDT personnel, 1.693 benefit factor)	
Construction and 60-Day Analysis (1month) -	$6,913
Yearly Brief (2 weeks per brief, and 4% inflation) -	$12,763
5 Year Report (1month, and 4% inflation) -	$8,411
10 Year Report (1month, and 4% inflation) -	$10,232
Total Report Cost -	$38,319

Total Research Investigation Cost -	$123,127

Work plan-Attachment A

Ultra-thin concrete whitetopping MSP-98-09E

ULTRA-THIN CONCRETE WHITETOPPING MSP-98-09E

1.0 Description. This specification covers materials and construction requirements for producing and placing an Ultra-Thin Concrete Whitetopping (UTW) pavement to be placed in conformance with the lines, grades, and typical cross sections shown on the plans, or as established by the engineer.

1.1 UTW pavement is a fiber reinforced concrete pavement, ranging from 2 to 4 inches (50 to 100 mm) in thickness, placed over a prepared asphalt surface. Unless otherwise specified in the plans, the minimum UTCW pavement thickness shall be 4.0 inches (100 mm). The prepared base asphalt must have a minimum thickness of 3 inches (75 mm). The UTCW pavement shall meet all the applicable requirements of Sec 502, except as modified herein.

1.2 Note to engineer and contractor: UTW is intended to be placed in a uniform thickness on a final grade which has been established by other means, such as coldmilling. Payment for the quantity of concrete is intended to compensate for rough surfaces, and not for grade adjustments.

2.0 Materials. All materials shall conform to Division 1000, Materials Details, unless otherwise noted.

2.1 Fibrillated polypropylene fibers shall be added at a rate of 3.0 pounds per cubic yard (1.8 kilograms per cubic meter).

2.1.1 All fibers shall be measurable by weight (mass). Fibers may be measured in bags, boxes, or like containers with the approval of the engineer. Such bags, boxes, or containers shall be sealed by the fiber manufacturer, shall have the weight (mass) contained therein clearly marked, and shall be in a like new condition. No fraction of an unsealed bag, box or like container delivered unsealed, or left over from previous work, shall be used unless weighed. Fibers shall be added to the concrete mix and mixed according to their respective manufacturer's recommendations.

2.2 When requested by the contractor, an approved high range water-reducing admixture may be used, subject to approval of the engineer. When a high range water-reducing admixture is used, the slump of the concrete, achieved with water, shall not exceed 3 inches (75 mm) before the high range water-reducing admixture is added to the mix. After the high range water-reducing admixture is added to the mix, the slump may be a maximum of 6 inches (150 mm) at the time of placement. No re-dosing of high range water-reducing admixture will be allowed.

2.3 Other admixtures for the purpose of otherwise reducing the water, retarding or accelerating the set may be used with the approval of the engineer, however they shall meet applicable specifications.

2.4 Type 3 cement, accelerators and/or blankets may be used to enhance curing for fast track paving, provided the final concrete product is not harmed.

3.0 Mix Design.

3.1 The contractor shall develop the job mix formula, meeting Sec 501 Pavement Concrete, and furnish certified test results from an independent testing laboratory for the engineer's approval. Approved MoDOT Sec 1005 paving aggregate gradations shall be used. The minimum cement factor specified for pavement concrete shall apply. The maximum cement requirement may be increased up to an additional 141 pounds per cubic yard (64 kg per cubic meter) at the contractor's option. The mixture shall be designed to develop a minimum compressive strength of 3500 psi (24 MPa). The maximum aggregate size shall not be more than 1/3 the thickness of the UTW pavement. The engineer will approve the design mix and all materials and methods prior to use.

3.2 Any admixtures used shall require certification from the fiber manufacturer for compatibility with fibers used in concrete.

3.3 No mix design changes will be allowed during placement of the UTW pavement without the approval of the engineer.

4.0 Construction Requirements.

4.1 Surface Preparation. The existing bituminous surface shall be coldmilled in accordance with applicable requirements of Sec 622.10 and as indicated elsewhere in the contract.

4.1.1 Immediately prior to applying the UTW pavement, the surface shall be dry, and thoroughly cleaned of all vegetation, dirt, mud, and other objectionable materials. All dust and loose particles shall be completely removed just prior to paving by vacuum or air blowing.

4.1.2 The asphalt surface temperature shall be less than 100 F (38 C) at the time of UTW application. This may require night placement, water fogging or other approved means of obtaining a cooler surface, however there shall be no puddled water or other contamination to prevent bonding to the asphalt surface.

4.2 Placement. UTW pavement shall be placed at the depths and locations shown on the plans.

4.2.1 Trucks used for transporting concrete will be permitted to drive on the pavement being overlaid and deposit concrete directly in front of the concrete spreader, provided no loose foreign material is tracked onto the surface.

4.2.2 UTW pavement shall be free of fiber balls when placed in the work.

4.2.3 The concrete temperature shall not exceed 90 F (32 C) when delivered to the site. THE CONTRACTOR IS ADVISED THAT HIGH WATER EVAPORATION CONDITIONS SHOULD BE AVOIDED UNDER ALL CONCRETE POURING CIRCUMSTANCES.

4.3 Surface Finish. The surface of the UTW pavement shall be tined with a wire comb as specified in Sec 502. At the option of the contractor, in lieu of wire tinning, the contractor may perform PCCP diamond grind texturing in accordance with MSP-96-19 included in this contract. If PCCP diamond grind texturing is used, the specified twenty one day time delay shall not apply and grinding may proceed as soon as 3500 psi (24 MPa) has been attained, and thickness deficiency and profile requirements shall be revised as shown for PCCP diamond grind texturing.

4.4 Joints. Sawing of the joints shall commence as soon as the UTW pavement has hardened sufficiently to permit sawing without excessive raveling. The UTW pavement joints may be cut utilizing an "early entry" or "green-cut" saw. The joints shall be spaced equidistant longitudinally and transversely, and at a distance in inches approximately equal to twelve times the specified UTW thickness. Slight adjustments may be made in the joint spacing to equalize the longitudinal joints between pavement cast edges. All sawed UTW units shall be square except as necessary in pavement width transitions. In that instance slight field adjustments may be necessary to maintain relatively square units. Joint spacing for any adjustments shall not exceed 1 foot (300 mm) greater than the intended “12 times specified UTW thickness”. Transverse joints on adjoining lanes shall match. The minimum depth of the joints shall be thickness/4 and the width of the joint shall be 1/8 inch (3 mm) maximum. The joints are not to be sealed but shall be cleaned of all deleterious material after sawing. Cracking as a result of late sawing may require replacement, at the option of the engineer, by the contractor with no additional reimbursement. THE CONTRACTOR IS ADVISED THAT DUE TO THE THINNESS AND TEMPERATURE SUSCEPTIBILITY OF UTW, SEVERAL JOINT SAW UNITS MAY BE REQUIRED TO AVOID CRACKING.

4.5 Curing. Curing compound shall be applied at 1.5 times the normal application rate. If blankets are used for fast tracking, they shall be light in color and shall not take the place of a curing compound. The temperature under the blanket shall not exceed 160 F (71 C). Blankets shall not be removed until the temperature under the blanket is within 40 F (20 C) of the ambient temperature.

4.6 Opening to Traffic. The UTW pavement shall not be opened for light traffic until the concrete has attained a minimum compressive strength of 3000 psi (21 MPa). UTW pavement, including fast tracked, shall not be opened to all types of traffic until the concrete has attained a minimum compressive strength of 3500 psi (24 MPa). Compressive strength will be determined by tests made in accordance with MoDOT methods.

5.0 Method of Measurement.

5.1 Measurement for furnishing UTW concrete will be made to the nearest 0.1 cubic yard (meter), for material incorporated into the UTW pavement.

5.2 Measurement for placing UTW pavement will be computed to the nearest 0.1 square yard (meter).

5.3 The final pavement will be cored in accordance with Sec 502 and all pavement thickness deficiencies will apply, except that any pavement deficient enough in thickness to require 100 percent reduction in contract price shall be replaced and will not be allowed to remain in place. All profile index requirements will apply.

5.4 Otherwise, final measurement of the complete UTW pavement will not be made except for authorized changes during construction, or where appreciable errors are found in the contract quantity. The revision or correction will be computed and added to or deducted from the contract quantity.

5.5 Measurement for coldmilling bituminous pavement for removal of surface will be made in accordance with Sec 622.

6.0 Basis of Payment.

6.1 The accepted quantity of UTW concrete will be paid for at the contract unit price for UTW concrete, per cubic yard (meter).

6.2 Payment for the placement of UTW pavement will be made at the contract unit price for UTW pavement, per square yard (meter), to include all surface preparation following cold milling of the bituminous surface. No direct payment will be made for furnishing labor, equipment, reinforcement, and other materials to place, finish, texture, and cure the UTW pavement including sawing the joints, in accordance with the plans and specifications.

6.3 Any adjustments in payment as a result of the profilograph index or pavement thickness deficiency of the UTW pavement will be made to the unit contract prices for UTW pavement, per square yard (meter), and UTW pavement placed, per cubic yard (meter). For this purpose, the volume of UTW pavement placed per cubic yard (meter) price will be adjusted to a square yard (meter) price based on the plan UTW pavement thickness.

6.4 Payment for coldmilling bituminous pavement for removal of surface will be made in accordance with Sec 622.

Work plan-Attachment B

Typical Sections

Work plan-Attachment C

FWD Test Locations

Work plan-Attachment D

Construction Test Locations

Appendix B
Mix Design

Mix Proportions and Fresh Concrete Properties

Water (lbs. /yd.^{3})	277.8
Type I cement (lbs. /yd.^{3})	751
Water/cement	0.370
Fine Aggregate (lbs. /yd.^{3}) Class A Missouri River	1109
Coarse Aggregate (lbs. /yd.^{3}) Bethany Falls-Gradation “F”	1783
Daravair 1000 (oz./sack) Air Entraining Agent	0.95
ADVA (oz./sack) High Range Water Reducer	4.69
Air Content (%)	5.1
Slump (in.)	2 3/4

Appendix C
FWD Data

Summary of FWD data on RT. 169/YY Ultra-Thin Project

Falling weight deflectometer (FWD) data was collected at eight locations within the ultrathin whitetopping project limits. Eight sensors, interspersed within a 5' radius, provided deflection readings at each location. The same locations were tested before and after construction. FWD testing after construction occurred when the pavement layers were frozen or partially frozen.

The deflection files were pulled through the EVERCALC backcalculation software program, which was originally developed for the Washington State DOT. Drop loads were normalized to 9000 pounds (typical half axle or single tire weight). Coring provided the exact AC thicknesses before construction and exact PCC thicknesses after construction. It was assumed that the AC layers were reduced by 3" at all locations after milling. The BELLS3 equation was used to predict mid-depth AC temperatures. The program output files yielded stress and strain information.

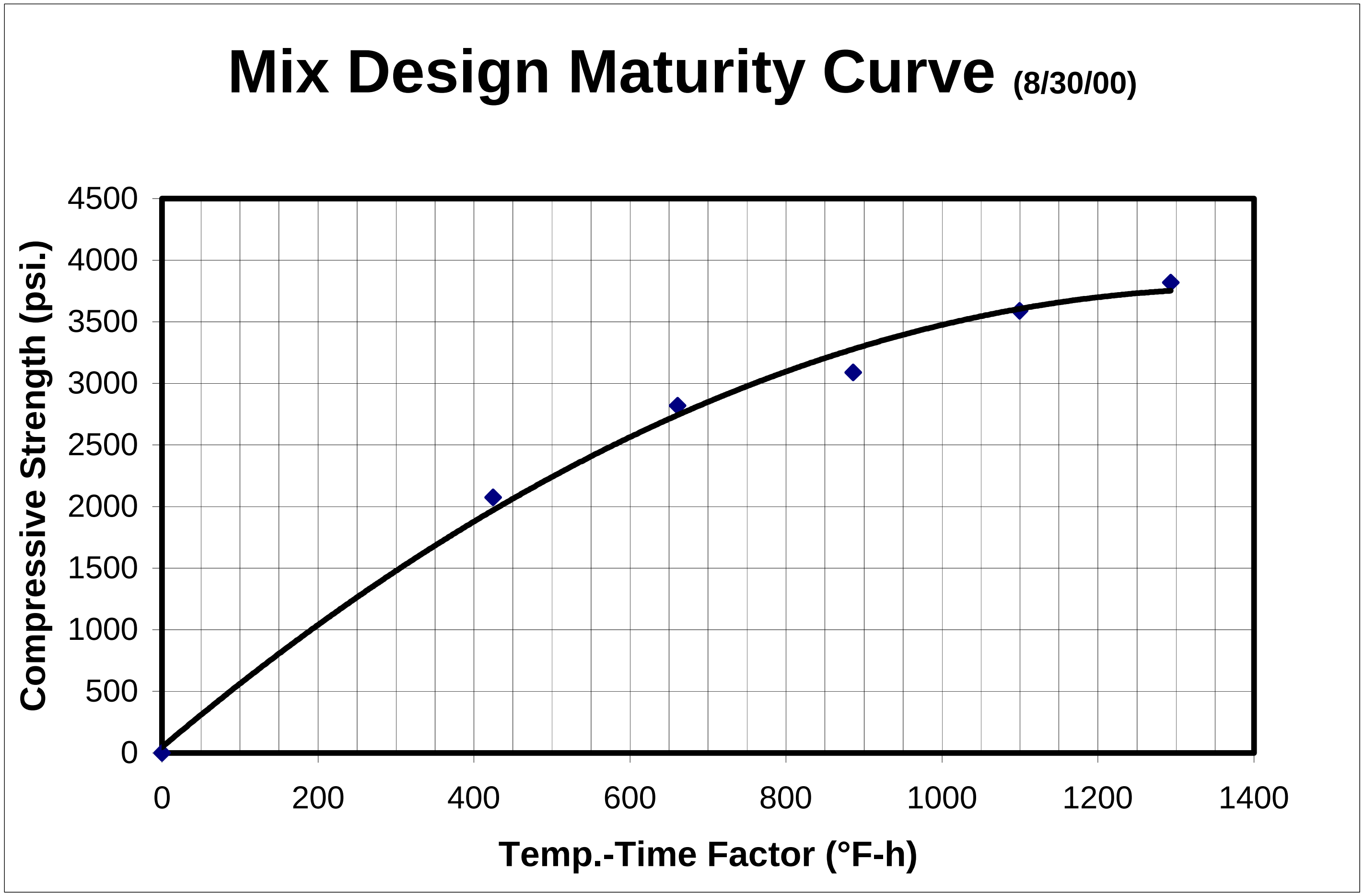
Critical strain types and locations in a flexible pavement are radially or in tension at the bottom of the asphalt concrete layer and vertically or in compression on the base/subgrade surface. Excessive radial strains under the AC layer lead to fatigue cracking. Heavy vertical strains on the base/subgrade surface lead to rutting deformation.

The following table clearly shows the reduction in radial and vertical strains after the PCC layer was placed. Bear in mind, however, strain values after construction were lowered by the frozen conditions and should not be taken at face value. Also, some actual program inputs for the layers, such as the 3" milling reduction, would have varied from location to location. Still, the strains shown before and after construction have relative importance. The stiffness of the PCC overlay, regardless of frozen testing conditions, will increase the number of loads required for failure from fatigue cracking and rutting of the subgrade.

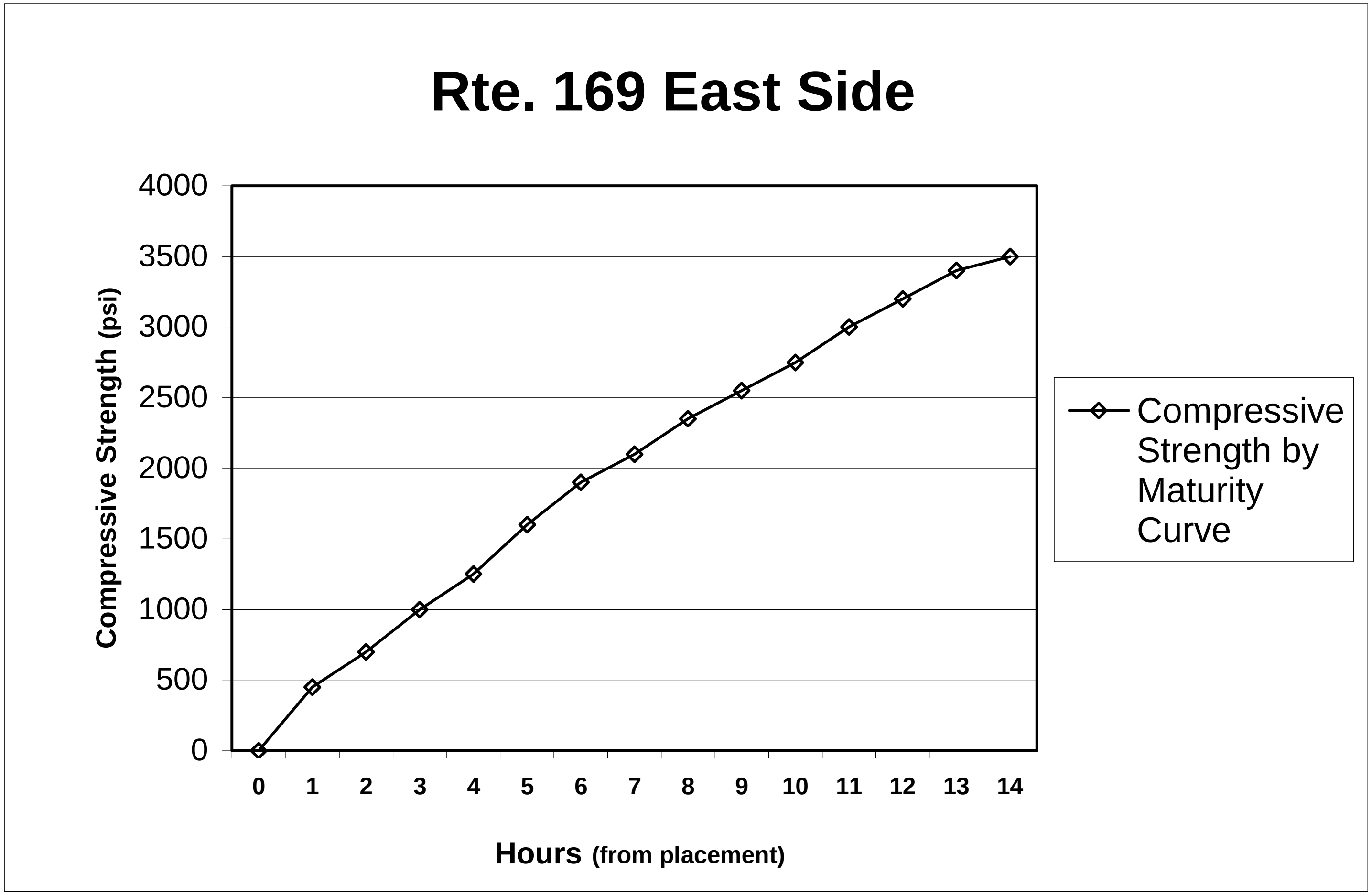
Location	Before Ultrathin		After Ultrathin **	
	Vertical Strain @ Top of Subgrade (10^{-6})	**Radial Strain @ Bottom of AC Layer (10^{-6})**	**Vertical Strain @ Top of Subgrade (10^{-6})**	**Radial Strain @ Bottom of AC Layer (10^{-6})**
Rt. 169 SB @ 100'	151	56	13	2
Rt. 169 SB @ 197'	198	73	18	3
Rt. 169 NB @ 100'	124	45	14	2
Rt. 169 NB @ 197'	106	38	19	<1
Rt. YY WB @ 100'	149	56	*	*
Rt. YY WB @ 200'	122	45	13	<1
Rt. YY EB @ 100'	86	30	12	1
Rt. YY EB @ 200'	192	74	18	10

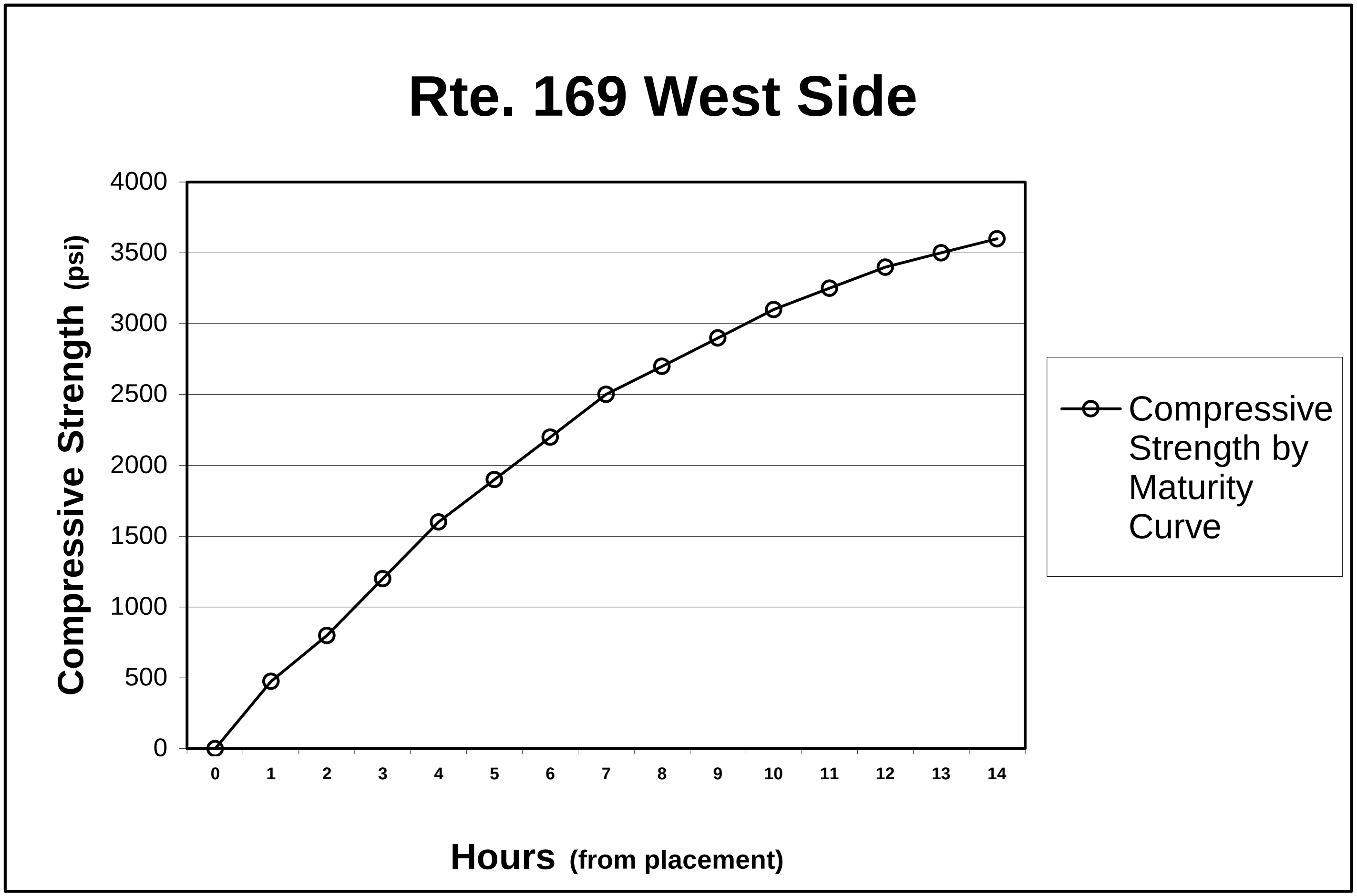
* Data unavailable due to erroneous sensor reading
** Pavement layers were frozen or partially frozen

Appendix D
Maturity Tests



Mix Design Maturity Curve (8/30/00)
Compressive Strength (psi.)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
Temp.-Time Factor (°F-h)


Rte. 169 East Side
Compressive Strength (psi)
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Hours (from placement)
Compressive Strength by Maturity Curve


Rte. 169 West Side
Compressive Strength (psi)
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Hours (from placement)
Compressive Strength by Maturity Curve

Appendix E
Tests Performed During Construction

Figure E-1

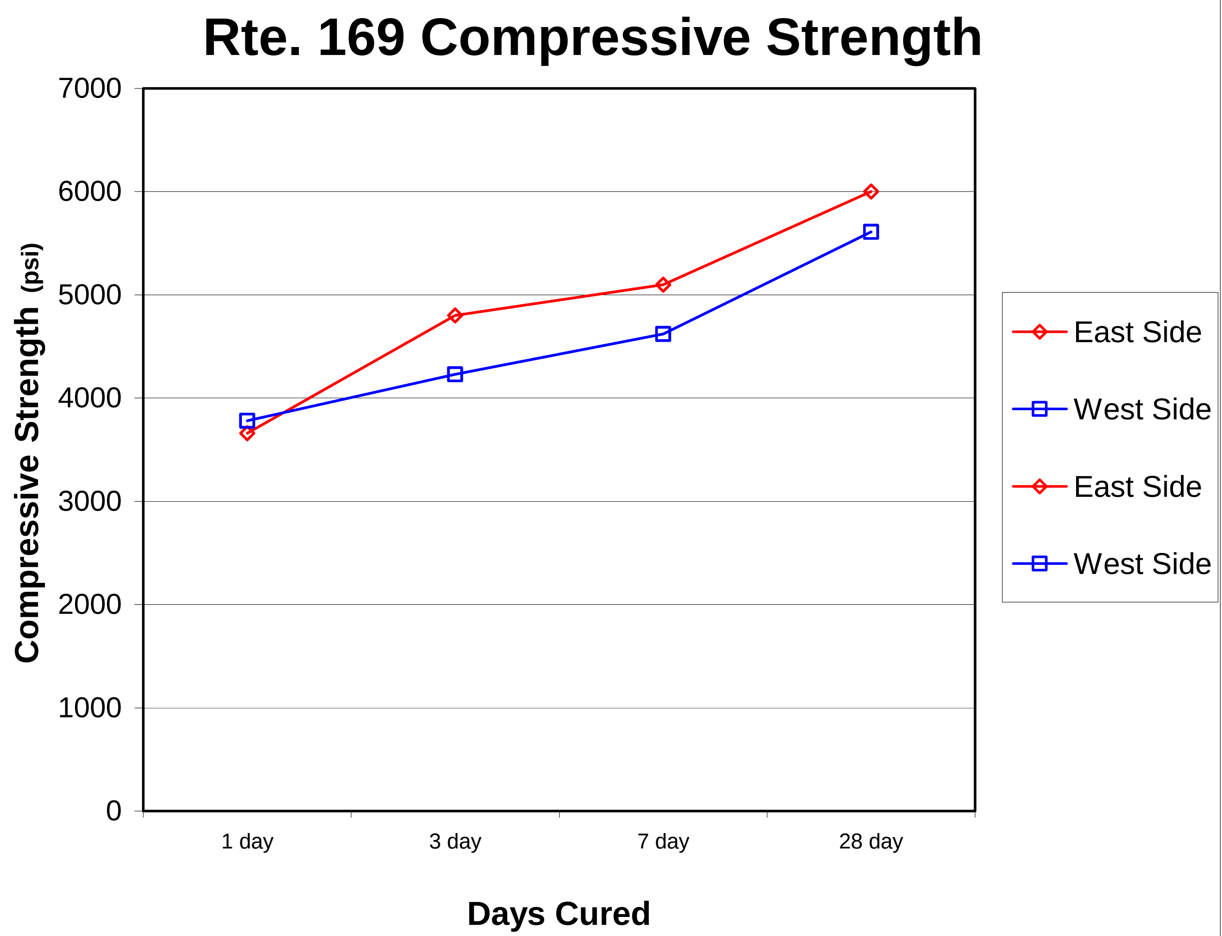


Table E-1

Compressive Strength

	1 Day	3 Day	7 Day	28 Day
East Side	3820	4950	5200	6100
	4060	4700	5120	5860
	3095	4740	4980	6040
	3660 AVG.	4800 AVG.	4800 AVG.	6000 AVG.

West Side	3820	4240	4620	5540
	3590	4180	4690	5670
	3930	4280	4540	5610
	3780 AVG.	4230 AVG.	4620 AVG.	5610 AVG.

Figure E-2

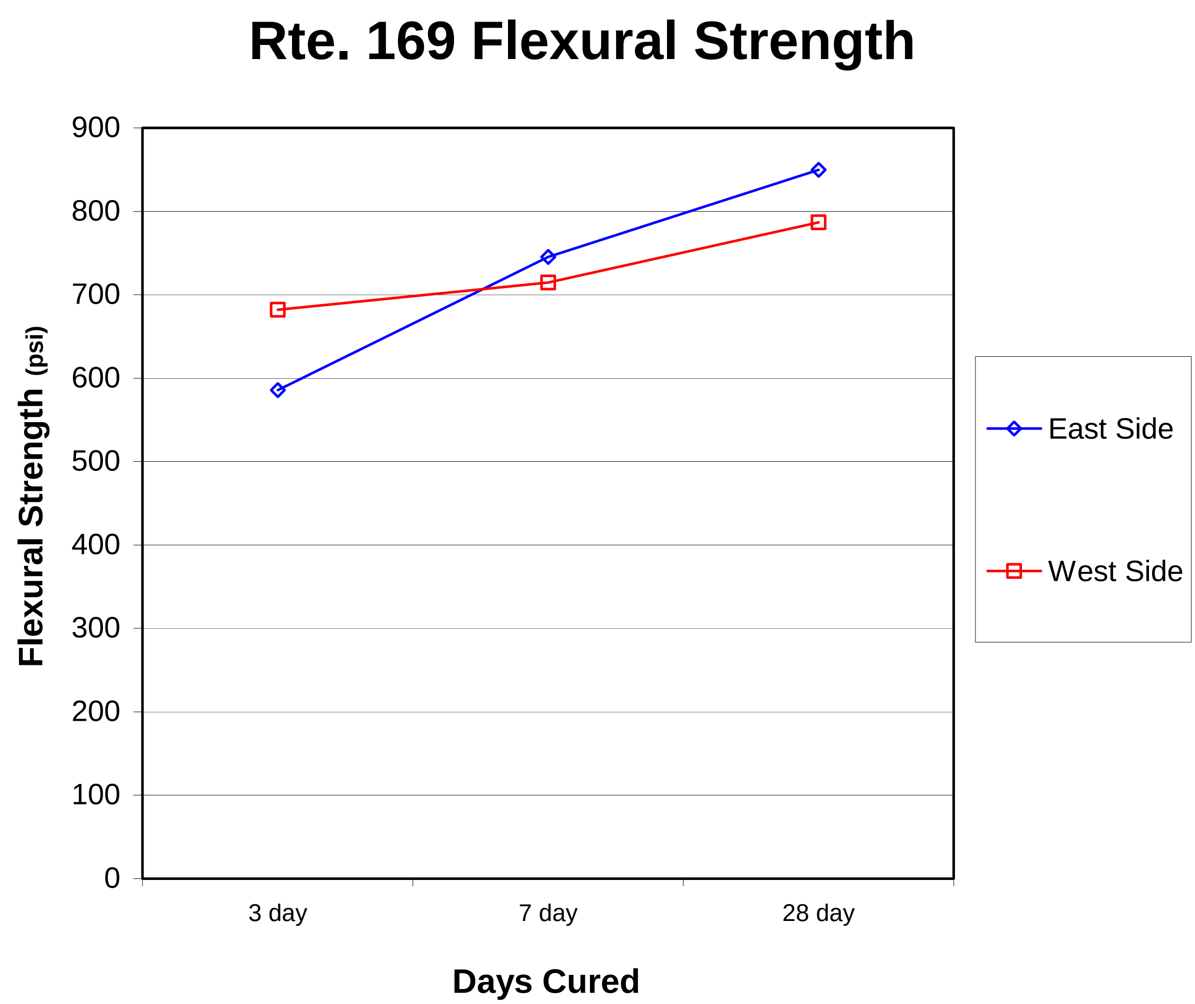


Table E-2

Flexural Strength

	3 Day	7 Day	28 Day
East Side	601.7 633 522.5 585.7 AVG.	772.3 740.6 723.3 745.4 AVG.	789.3 885 875.5 849.9 AVG.
West Side	680.8 656.4 709.1 682.1 AVG.	709.1 736.2 699.2 714.8 AVG.	796.8 786.8 776.4 786.7 AVG.

Table E-3

Iowa Shear

Core #	Date	Location	Force (lbf)	Area (sq. In.)	Strength (psi.)
1	09/09/2000	N.B. Rt.169 (N.of Mitchell)	604	12.57	48
2	09/09/2000	N.B. Rt.169 (S.of Mitchell)	738	12.57	59
3	09/10/2000	S.B. Rt.169 (N.of Mitchell)	1124	12.57	89
4	09/10/2000	S.B. Rt.169 (S.of Mitchell)	498	12.57	40
5	09/10/2000	E.B. Rt.YY (E.of Rt.169)	1004	12.57	80
6	09/10/2000	E.B. Mitchell (W.of Rt.169)	655	12.57	52
7	09/10/2000	W.B. Rt.YY (E.of Rt.169)	576	12.57	46
8	09/10/2000	W.B. Mitchell (W.of Rt.169)	810	12.57	64
					60 AVG.

Table E-4

Pull Off Tests

Date	Location	Force (lbf)	Area (sq. In.)	Strength (psi.)
09/09/2000	N.B. Rt.169 (N.of Mitchell)	0	3.14	0
09/09/2000	N.B. Rt.169 (S.of Mitchell)	120	3.14	38
09/10/2000	S.B. Rt.169 (N.of Mitchell)	200	3.14	64
09/10/2000	S.B. Rt.169 (S.of Mitchell)	40	3.14	13
09/10/2000	E.B. Rt.YY (E.of Rt.169)	80	3.14	25
09/10/2000	E.B. Mitchell (W.of Rt.169)	120	3.14	38
09/10/2000	W.B. Rt.YY (E.of Rt.169)	120	3.14	38
09/10/2000	W.B. Mitchell (W.of Rt.169)	100	3.14	32
				31 AVG.

Table E-5

Core Depths

Core #	Date	Location	Overlay Depth (inch)	Asphalt Depth (inch)	Concrete Depth (inch)
1	09/09/2000	N.B. Rt.169 (N.of Mitchell)	2.750	5.250	8.750
2	09/09/2000	N.B. Rt.169 (S.of Mitchell)	3.375	3.000	8.750
3	09/10/2000	S.B. Rt.169 (N.of Mitchell)	3.500	2.000	*
4	09/10/2000	S.B. Rt.169 (S.of Mitchell)	4.250	1.750	12.000
5	09/10/2000	E.B. Rt.YY (E.of Rt.169)	4.125	2.625	7.750
6	09/10/2000	E.B. Mitchell (W.of Rt.169)	3.500	13.000	**
7	09/10/2000	W.B. Rt.YY (E.of Rt.169)	4.000	2.250	8.250
8	09/10/2000	W.B. Mitchell (W.of Rt.169)	4.000	1.000	8.125

*Unable to measure concrete depth
** Full depth asphalt

Table E-6

Rapid Chloride Permeability

Core ID	Lift 1	Lift 2	Lift 3	**Average**	Permeability
WB1	2316	3481	3118	**2972**	Moderate
WB2	2055	3833	3322	**3070**	Moderate
EB1	3913	4105	3412	**3810**	Moderate
EB2	3211	3764	3566	**3514**	Moderate

Table E-7

Linear Traverse

Core #	Percent Air	Average Air Void	Paste/Void Ratio	Voids per Inch	Spacing Factor Range: 0.004-0.008	Specific Surface Range: 600-1100
1	4.293	0.0052	13.27	8.25	0.00935	768.95
2	3.898	0.00484	14.35	8.05	0.00901	825.83
3	5.203	0.00556	10.42	9.36	0.00989	719.61
4	3.033	0.00544	18.59	5.58	0.01132	735.44
5	3.833	0.00539	13.8	7.11	0.00985	742.36
6	6.332	0.00720	9.14	8.79	0.01097	555.42
7	4.544	0.00528	12.12	8.61	0.00911	757.76
8	2.954	0.00372	18.48	7.94	0.00772	1074.97

Table E-8

Freeze/Thaw

Westbound	Number of Cycles	Weight Change	Length Change	Durability Factor	Relative Dynamic Modulus
1	300	0.532	0.3006	49.92	49.92
2	300	0.385	0.1944	78.66	78.66
3	300	0.510	0.2981	52.78	52.78
Average	**300**	**0.476**	**0.2644**	**60.45**	**60.45**

Eastbound					
1	300	0.352	0.1875	62.36	62.36
2	300	0.356	0.1988	65.57	65.57
3	300	0.320	0.2100	69.59	69.59
Average	**300**	**0.343**	**0.1988**	**65.84**	**65.84**

Appendix F
Project and Construction Photographs

Texture of milled asphalt surface prior to concrete overlay placement.

Contractor cleaning milled asphalt surface of debris using high-pressure air.

MoDOT Research Technician performing ASTM C231, air content of fresh concrete.

Contractor finishing fresh concrete behind paver.

Contractor hand pouring a turn lane.

Application of the curing compound.

MoDOT Research Technician inserting thermocouple probe for maturity testing.

Early entry saws used on this project.

Another view of the early entry sawing.

MoDOT Research personnel drilling cores for Iowa shears, SEM analysis, and pull off tests.

View from the east showing finished product.

View from the south end of project.

View of the 3-foot by 3-foot joint pattern.

View showing the continuation of the joint pattern in the turn lane.