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Evaluation of Fiber-Reinforced Unbonded Overlay

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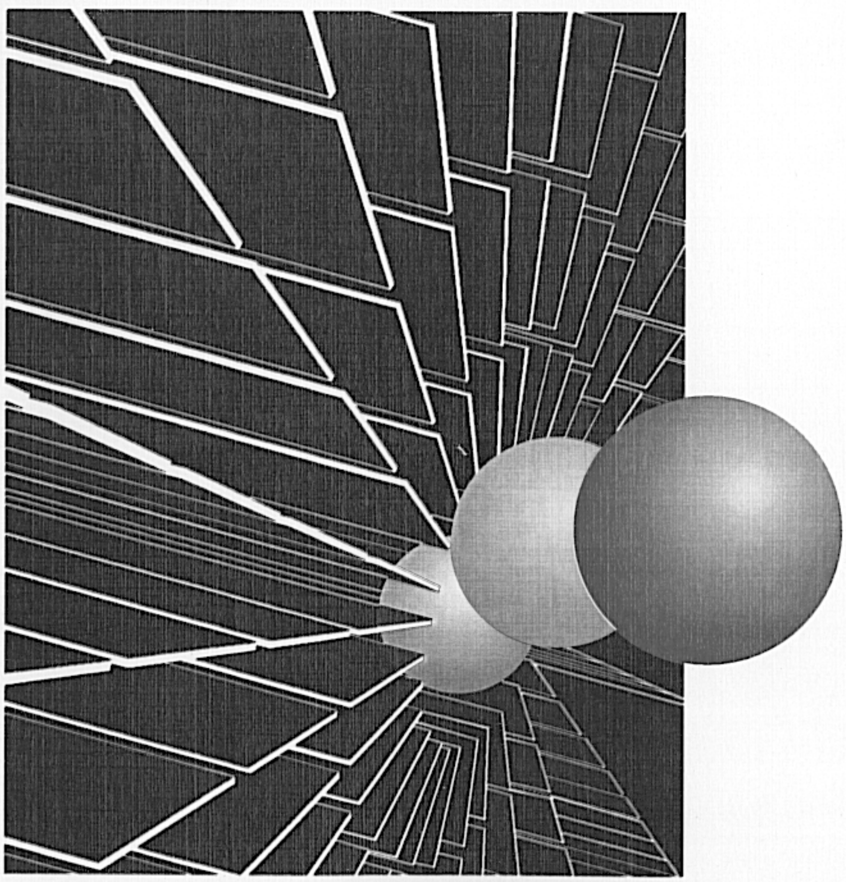

December, 2000

Initial Report
RI97-015

EVALUATION OF FIBER-REINFORCED UNBONDED OVERLAY

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

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16. Abstract

Fiber-reinforced concrete (FRC) is a composite material consisting of Portland cement concrete (PCC) and discontinuous natural, steel or plastic fibers. The inclusion of fibers in concrete results in improved energy absorbing characteristics of the concrete. Energy absorption is directly or indirectly related to properties such as crack propagation resistance, ductility, impact resistance, fatigue performance and durability.

A concrete unbonded overlay was constructed on I-29 in Atchison county. Eight test sections were established in the unbonded overlay. Three of the test sections were reinforced with steel fibers, three of the test sections were reinforced with polyolefin fibers and two of the test sections were non-reinforced PCC. There were fiber-reinforced test sections 9”, 6” and 5” thick for each type of fiber reinforcement. Transverse joint spacing varied in the fiber-reinforced sections from 15’ to 200’. The two non-reinforced PCC test sections were 9” and 11” and all transverse joints were spaced 15’.

The overlay was diamond ground at least 21 days after construction to provide the finished texture. The profilograph readings of the finished pavement measured less than 11 in./mile with a zero blanking band. The International Roughness Index (IRI) averaged 67. Both of these measures are indicative of very smooth pavement.

The compressive and flexural strength of polyolefin fiber-reinforced samples were slightly lower than the non-reinforced concrete. The compressive and flexural strength of the steel fiber-reinforced concrete were comparable to the non-reinforced concrete.

Some transverse cracking has appeared in the fiber-reinforced sections of the unbonded overlay. In general, more cracking has developed in the steel fiber-reinforced sections than the polyolefin fiber-reinforced sections. Thinner sections exhibited more cracking than the thicker sections and longer panels exhibited more cracking than shorter panels.

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EXECUTIVE SUMMARY

Fiber-reinforced concrete (FRC) is a composite material consisting of Portland cement concrete (PCC) and discontinuous natural, steel or plastic fibers. The inclusion of fibers in concrete results in improved energy absorbing characteristics of the concrete. Energy absorption is directly or indirectly related to properties such as crack propagation resistance, ductility, impact resistance, fatigue performance and durability.

Fibers can bridge cracks in concrete and restrain them from opening, thus increasing the load carrying ability of the composite. This increase in load carrying ability could be of great benefit when FRC is used in pavement applications. Once cracks have formed in non-reinforced concrete pavements, environmental factors and traffic loads accelerate the deterioration of the pavement around those cracks. Because the fibers restrain the cracks from opening, the detrimental effects of the environment and traffic loads should be greatly reduced. Fiber-reinforced concrete pavements should have a longer service life and require less maintenance than non-reinforced concrete pavements.

An unbonded Portland cement concrete pavement (PCCP) overlay was designed and built on 1-29 in Atchison County in northwestern Missouri. The location of the project is between Route A and US 136 in the southbound lanes. Eight test sections were established in the unbonded overlay. Three of the test sections were reinforced with steel fibers, three of the test sections were reinforced with polyolefin fibers and two of the test sections were non-reinforced PCC. There were fiber-reinforced test sections 9", 6" and 5" thick for each type of fiber reinforcement. Transverse joint spacing varied in the fiber-reinforced sections from 15' to 200'. The two non-reinforced PCC test sections were 9" and 11" and all transverse joints were spaced 15'.

The initial cost of fiber-reinforced concrete as expected is somewhat higher than conventional non-reinforced concrete. For this project, the cost of furnishing the steel fiber-reinforced concrete was $47.00/cu. yd. more than the non-reinforced concrete. Furnishing the polyolefin reinforced concrete was $60.00/cu. yd. higher than the non-reinforced concrete.

Paving of the unbonded overlay was completed in the summer of 1998. Some clumping of fibers, otherwise known as "fiber balling" was observed during construction of the unbonded overlay. Fiber balls that were visible at the surface of the unbonded overlay were removed before finishing.

In lieu of conventional transverse tine texturing, diamond grinding of the overlay at least 21 days after placement was required for smoothness and rideability. It is believed the smoother a pavement is initially; the longer it will retain an acceptable level of smoothness.

Initial profilograph readings averaged 27 in./mi. with a zero blanking band. Spot grinding to remove bumps brought the average profilograph readings down to 25 in./mi. before diamond grinding for the final surface. After the driving lanes were diamond ground, the profilograph readings averaged less than 11 in./mi. with a zero blanking band. This initial smoothness resulted in a contract bonus based on the final profile index. The International Roughness Index (IRI) averaged 67 for the overlay after diamond grinding. Both of these measures indicate a very smooth pavement. The diamond grinding also produced a surface with good friction characteristics. The presence of fibers in the concrete had little affect on the diamond grinding operation.

The compressive and flexural strengths of the polyolefin fiber-reinforced concrete in this study were significantly lower, 11.5% and 21% respectively, than those of the non-reinforced concrete. The compressive and flexural strengths of the steel fiber-reinforced concrete were within 2% of those of the non-reinforced concrete.

Some transverse cracking has appeared in the fiber-reinforced sections of the unbonded overlay. In general, more cracking has developed in the steel fiber-reinforced sections than the polyolefin fiber-reinforced sections. Thinner sections exhibited more cracking than the thicker sections and longer panels exhibited more cracking than shorter panels.

Based on the average feet of transverse cracking per panel, the 6” polyolefin fiber-reinforced section performed comparably to the 9” polyolefin fiber-reinforced test section. No transverse cracking developed in the polyolefin fiber-reinforced sections where transverse joint spacing was thirty feet. Also, the 9” polyolefin fiber-reinforced section with 60’ panels showed very little transverse cracking.

The location of transverse cracks in the steel fiber-reinforced and polyolefin fiber-reinforced sections has been quite different. Most of the cracks in the steel fiber-reinforced sections are located within 1’ of the transverse joint, seemingly related to the load transfer devices. The cracks in the polyolefin fiber-reinforced sections are located away from the joints in the midpanel.

Spalling at some of the transverse crack locations in the 5” steel fiber-reinforced section developed within the first year of service. Maintenance crews repaired the spalls by patching with cold mix asphalt. The patching material needed to be replaced often. Longitudinal cracks originated and extended from the dowel bars in both the 5” polyolefin and steel fiber-reinforced sections within two years of service. Due to the extensive amount of maintenance expected to be required on these two sections, the decision was made to replace these sections with a full-depth PCCP. This issue will be discussed further in a future report detailing the pavement performance after two years of service.

Future pavement surveys will be completed annually for five years at which time, a decision will be made to continue annual surveys or consider some other time period, such as every two or three years. Following the future pavement surveys, a report will be prepared which includes the latest pavement performance data.

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INTRODUCTION

Fiber-reinforced concrete (FRC) is a composite material consisting of Portland cement concrete (PCC) and discontinuous natural, steel or plastic fibers. The inclusion of fibers in concrete results in improved energy absorbing characteristics of the concrete. Energy absorption is directly or indirectly related to properties such as crack propagation resistance, ductility, impact resistance, fatigue performance and durability.[1]

Fibers can bridge cracks in concrete and restrain them from opening, thus increasing the load carrying ability of the composite.[2] This increase in load carrying ability could be of great benefit when FRC is used in pavement applications. Once cracks have formed in non-reinforced concrete pavements, environmental factors and traffic loads accelerate the deterioration of the pavement around those cracks. Because the fibers restrain the cracks from opening, the detrimental effects of the environment and traffic loads should be greatly reduced. Fiber-reinforced concrete pavements should have a longer service life and require less maintenance than non-reinforced concrete pavements.

An unbonded Portland cement concrete pavement (PCCP) overlay was designed and built on 1-29 in Atchison County in northwestern Missouri. The location of the project is between Route A and US 136 in the southbound lanes. Eight test sections were established in the unbonded overlay. Three of the test sections were reinforced with steel fibers, three of the test sections were reinforced with polyolefin fibers and two of the test sections were non-reinforced PCC. There were fiber-reinforced test sections 9", 6" and 5" thick for each type of fiber reinforcement. Transverse joint spacing varied in the fiber-reinforced sections from 15' to 200'. The two non-reinforced PCC test sections were 9" and 11" and all transverse joints were spaced 15'.

The overlay was designed as an unbonded overlay, using a 1" bituminous interlayer, to decrease the reflective cracking of joints and cracks from the existing pavement into the new overlay.

This report details the construction of the FRC unbonded overlay and discusses the pavement performance up to 1 year after construction.

OBJECTIVE

The objective of this study was to collect data and evaluate the performance of a fiber-reinforced unbonded PCCP overlay placed on Interstate 29 in Atchison County. Test sections were established with varying overlay thickness and varying joint spacing in an attempt to determine the limits of these parameters in fiber-reinforced overlay applications.

MoDOT determined the compressive strength at 7 and 28 days and the flexural strength at 7 and 28 days for the steel fiber-reinforced concrete, the polyolefin fiber-reinforced concrete and the non-reinforced concrete mixes used in the overlay. Pavement distress surveys were performed at 1 day, 2 weeks, 1 month, 3 months, 6 months, 1 year and will be performed annually for at least five additional years to assess the performance of the overlay.

The University of Missouri-Columbia determined toughness and fatigue endurance. The results of the university research will be contained in the report, "Fatigue Performance of Field Specimens from Control and Fiber-reinforced Concrete Pavement Mixes" to be published separately.

DISCUSSION OF PRESENT CONDITIONS

Across the country the aging interstate system and other highways of national and regional importance are in need of major repair. Some of these facilities have been in service longer than their designed service life. The state departments of transportation have the responsibility to repair or replace these facilities to perform under ever increasing traffic loads and volumes. The work must be economically feasible and delay motorists as little as possible.

Unbonded PCCP overlays are one option to repair PCC pavements in advanced stages of distress. The unbonded PCCP overlay increases structural strength of the overall pavement system and provides a new surface that improves the ride quality of the pavement. Minimal pavement repair of the existing pavement is required when using an unbonded overlay.

PROJECT COSTS AND BENEFITS

The primary benefit of adding fibers to the concrete used in the unbonded overlay is to increase the service life of the overlay. Improved energy absorption is expected to lead to an increased service life. The initial cost of fiber-reinforced concrete as expected is somewhat higher than conventional non-reinforced concrete. For this project, the cost of furnishing the steel fiber-reinforced concrete was $47.00/cu. yd. more than the non-reinforced concrete. Furnishing the polyolefin reinforced concrete was $60.00/cu. yd. higher than the non-reinforced concrete. The cost of placing the concrete was the same for same depth sections. *Appendix A* shows a comparison of the actual in-place costs of each of the test sections. If, in fact, the addition of fibers in the overlay increases the energy absorbing properties of the concrete, then perhaps a thinner overlay section could be used to achieve the same service life as a thicker non-reinforced concrete overlay. In this case, the initial costs are very similar. For example, the 11” non-reinforced section costs $321,064.74. The cost of the 6” steel fiber-reinforced section is $319,974.33 and the cost of the 6” polyolefin fiber-reinforced section is $296,857.64. One purpose of this study was to compare the pavement performance of thin fiber-reinforced sections to thicker non-reinforced sections.

TECHNICAL APPROACH

The unbonded PCCP overlay was designed for the southbound lanes of I-29 in Atchison County, with certain sections of the overlay reinforced with either steel or polyolefin fibers. Eight test sections, each 2500' long, were established within the overlay. The test sections are as follows:

Test Section 1	9" Non-reinforced PCCP Unbonded Overlay
Test Section 2	9" Steel Fiber-reinforced PCCP Unbonded Overlay
Test Section 3	9" Polyolefin Fiber-reinforced PCCP Unbonded Overlay
Test Section 4	11" Non-reinforced PCCP Unbonded Overlay
Test Section 5	6" Steel Fiber-reinforced PCCP Unbonded Overlay
Test Section 6	6" Polyolefin Fiber-reinforced PCCP Unbonded Overlay
Test Section 7	5" Steel Fiber-reinforced PCCP Unbonded Overlay
Test Section 8	5" Polyolefin Fiber-reinforced PCCP Unbonded Overlay

Each fiber-reinforced test section contained transverse joint spacings of 15', 30', 60' and 200'. The non-reinforced test sections contained only 15' transverse joint spacing. The layout of test sections, referenced by stationing, can be found in *Appendix B.*

MoDOT in cooperation with the University of Missouri-Columbia previously completed a laboratory evaluation of fiber-reinforced concrete mixes incorporating several fiber types at varying dosage rates. Based on toughness test results from this study and manufacturer's recommendations, the following two fibers were chosen for the I-29 overlay:

3M 50mm polyolefin fibers at a dosage rate of 25 lbs./cu. yd.
Bekaert 60mm hooked-end steel fibers at a dosage rate of 75 lbs./cu. yd.

Special provisions were prepared, which specified the type and dosage rate of fibers to be used in the PCCP overlay, as well as other mix materials and placement requirements. Special provisions for both the "Test Pavement for PCC Unbonded Overlay Without Fibers" and "Test Pavement for PCC Unbonded Overlay With Fibers" can be found in *Appendix C.*

In April of 1998, prior to any construction or pavement repair on the project, a pavement survey was performed to record all distresses in the existing pavement. A large number of low, moderate and high severity transverse cracks were observed in the approximately four-mile section as well as some corner breaks and full depth pavement patches placed by MoDOT maintenance forces.

Between April 13 and May 12, 1998, full depth pavement repair was performed by the contractor on the existing pavement to prepare the pavement for the unbonded overlay. *Appendix D* shows the number of transverse cracks in the pavement before and after repair. Approximately 2% of the low severity transverse cracks were repaired, with 9,816 feet of low severity cracks remaining. Roughly 20% of the moderate severity cracks were repaired, leaving 942 feet of moderate severity cracks. Almost 35% of the high severity transverse cracks were repaired but 1,826 feet remained unrepaired. In addition to the repair of some transverse cracks, 17 out of 330 transverse joints were partially or entirely replaced.

A 1" asphalt interlayer was placed over the existing pavement prior to the PCCP overlay. The interlayer prevents bonding of the new overlay to the existing pavement and provides a stress relief layer; so reflective cracking is limited or prevented. White pigmented curing compound was applied to the asphalt interlayer to further deter bonding and reflect heat so that large temperature differences do not develop between the interlayer and the new overlay.

The PCCP concrete was mixed at a central plant located on the north end of the project. Fibers were placed in the mixing hopper manually at the plant. The mix was then transported to the paver by dump truck.

Placement of the overlay began on June 10, 1998. The 12' passing lane and 4' inside shoulder were paved during the first pass. This pass was completed June 20, 1998. The second pass, which included the 12' driving lane and the 10' outside shoulder, began on June 24, 1998. The second pass was completed on July 9, 1998. Specifications included diamond grinding of the driving surfaces at least 21 days after paving to ensure a smooth ride and possibly extend the pavement life. The pavement was opened to traffic before the diamond grinding operation, so an interim surface texture was provided with an unweighted carpet drag following finishing of the PCCP overlay.

Several test specimens of both the fiber-reinforced mixes and non-reinforced concrete mix were made on-site during construction. The material properties testing of compressive and flexural strength were completed in the MoDOT central laboratory at the designated ages of 7 and 28 days. Beams were made and transported to the University of Missouri-Columbia for toughness and fatigue endurance testing.

Pavement distress surveys were completed at 1 day, 2 weeks, 1 month, 3 months, 6 months and 1 year after paving. Future pavement surveys will be completed annually for five years at which time, a decision will be made to continue annual surveys or consider some other time period, such as every two or three years.

Following the future pavement surveys, a report will be prepared which includes the latest pavement performance data.

RESULTS AND DISCUSSION

Site Preparation

As mentioned previously, minimal pavement repair was performed on the existing pavement. Approximately 2700' of moderate and high severity cracks remained unrepaired in the existing pavement and only 17 of 330 transverse joints were partially or entirely replaced. An asphalt interlayer, 1" thick was placed on top of the existing pavement. This interlayer is intended to cover the deterioration in the existing slab and ensure isolation of the overlay. At 1" thick, the interlayer was believed to be sufficient to prevent the overlay from locking into deterioration in the existing pavement. Other states have indicated a thicker interlayer of 2" or more is preferred. The asphalt interlayer was then treated with white-pigmented curing compound. The white pigmented curing compound reflects heat and prevents heat build-up in the black interlayer surface, reducing shrinkage cracking in the concrete and potential paving problems due to a soft surface.[7]

Dowel bars were used at the transverse joints for the entire overlay width. The dowel bars were epoxy coated steel that had been treated with the debonding agent, Tectyl 506. Dowel bars in section 4, the 11" non-reinforced concrete, were 1 1/2" diameter. All other dowel bars were 1 1/4" diameter. Tie bars were used at the centerline joint and the shoulder joints.

Mix Details

Based on the fiber manufacturers' recommendations, several modifications were made to Missouri's standard PCCP mix. These changes were required through the "Test Pavement for Portland Cement Concrete Unbonded Overlay with Fibers" special provisions located in *Appendix C* for the PCC with both steel and polyolefin fibers. The contractor chose to incorporate many of these changes in the PCC without fibers as well. The special provisions for the "Test Pavement for Portland Cement Concrete Unbonded Overlay without Fibers" are also located *Appendix C*. The mix proportions for all test sections are found in Table 1. Fiber characteristics are found in Table 2.

The coarse aggregate used in the PCCP mixes was Bethany Falls limestone of MoDOT Gradation F (maximum size of 1/2"). The complete gradation can be seen in Table 3.

The ratio of fine aggregate to coarse aggregate (FA/CA), was specified at 45/55. MoDOT's standard PCCP mixes, although not expressly specified, normally have a FA/CA of 38/62.

The Missouri Standard Specifications for Highway Construction requires a minimum cement factor of 6.0 sacks/cu. yd. for PCCP mixes when Class A sand is used, as in this project. "Class A sand includes all sand, except manufactured sand weighing 109 lbs./cu. ft. (having a mass of 1740 kg/m^3) or more."[3] The minimum cement factor for the fiber-reinforced mixes was increased and specified in the job special provisions at 6.6 sacks/cu. yd. to yield an increased volume of paste. When Gradation F coarse aggregate is used, as in this project, the minimum cement factor must be increased by 0.50 sacks/cu. yd., yielding the actual minimum cement factor at 7.1 sacks/cu. yd. It should be noted the increased cement factor was required for only the fiber-reinforced mixes, however the contractor chose to utilize a consistent mix with or without fibers.

Type C fly ash was used, as shown in Table 1, at approximately 15% as allowed by standard specifications. The average cement factor, including the fly ash, for the test sections was 7.19 sacks/cu. yd. Due to the lower specific gravity of fly ash, as compared to cement, replacement of cement with fly ash increases the volume of cementitious paste in the mix. This increased volume of paste provides an improved coating of fibers and aggregate in the mix, leading to improved workability and fiber distribution.[4]

Air entraining agent was used to achieve roughly 6.0% air content in the fresh concrete. A water reducer was also used, with the average water to cementitious materials ratio (w/cm) of 0.39. The w/cm was limited to a maximum of 0.41 in the special provisions.

Both the steel and the polyolefin fibers were packaged in water-soluble materials designed to break down in the mixer and allow the fibers to be evenly dispersed in the mix. The steel fibers "clips" consisted of 16-20 fibers glued together. Several hundred polyolefin fibers were bundled together and wrapped with a water-soluble paper wrapper.

Paving

Paving of the unbonded PCCP overlay began on June 10, 1998. The passing lane and inside shoulder were paved in the first pass. The first section of paving was the 9" thick non-reinforced section. Paving of this first section was completed with few problems.

On June 12, 1998, paving began of the first fiber-reinforced test section, Test Section 2. Test Section 2 is the 9" steel fiber-reinforced section. Some clumping of fibers, otherwise known as "fiber balling" and unevenly distributed fibers were noticed in this test section. Also noticed were a small number of fibers that had failed to be coated with cement paste. The presence of "fiber balling", uneven distribution of fibers and uncoated fibers was very intermittent in this section and mixing procedures were not altered at this time to address the situation.

Throughout the entire overlay, the final surface finish was to be provided by diamond grinding in lieu of standard transverse tining. Because the pavement could be opened to traffic before the diamond grinding operation, an interim texture had to be provided. A burlap drag was initially used to provide this interim surface finish. During finishing of Test Section 2, the steel fibers at the surface of the pavement became entangled in the burlap and began to pull out other fibers and coarse aggregate. A carpet or astro-turf drag was then used to provide the interim surface texture. The carpet was weighted with a 2"x 6" board across the width of the carpet. This weighted carpet drag resulted in a marred, non-uniform surface finish. The 2"x 6" board was removed, and the unweighted carpet drag was then used to provide a satisfactory interim surface finish on the pavement.

Paving of Test Section 3, the 9" polyolefin fiber-reinforced overlay, began on June 13, 1998. The polyolefin fibers appeared to be more prone to non-uniform distribution in the mix than the steel fibers. Areas of "fiber balling" and instances of uncoated fibers were common in this test section. In the locations where the fiber balls could be seen at the surface, they were removed from the overlay before finishing. In some instances remnants of the paper wrapper used to bundle the polyolefin fibers were present in the mix. When noticed, these pieces of paper were also removed from the concrete.

Attempts to reduce or eliminate the fiber balls and uncoated fibers were made at the mixing plant. Introducing the fibers into the mix sooner, increasing the mixing time slightly and reducing the batch size were all approaches taken to eliminate this problem. While some slight improvement was noticed following these alterations, some fiber balls and uncoated fibers were still observed throughout the overlay.

The remaining overlay sections, Test Sections 4 – 8 in the passing lane and Test Sections 1 – 8 in the driving lane were paved from June 16, 1998 to July 9, 1998. As stated above, some fiber balls and uncoated fibers were observed throughout the project. The interim surface finishing with the unweighted carpet drag was acceptable.

Sawing

Transverse contraction joints were sawed with a 65 hp standard diamond saw approximately 10 to 18 hours after paving. The joints were 3/8" wide and the depth was at least 1/4 of the pavement depth. Slight raveling was observed in the fiber-reinforced sections while no raveling occurred in the non-reinforced sections. In December of 1998, a small sample of cores was taken at the transverse joints to confirm that the pavement had cracked through the entire depth. Based on this small sample it appeared as though the pavement had cracked through at the transverse joints.

Longitudinal joints were also sawed at the shoulder line with the same sawing equipment.

Diamond Grinding

In lieu of conventional transverse tine texturing, diamond grinding of the overlay at least 21 days after placement was required for smoothness and rideability. It is believed the smoother a pavement is initially, the longer it will retain an acceptable level of smoothness.[8] *Appendix E* contains the special provisions for diamond grinding of the overlay.

Initial profilograph readings averaged 27 in./mi. with a zero blanking band. Spot grinding to remove bumps brought the average profilograph readings down to 25 in./mi. before diamond grinding for the final surface. After the driving lanes were diamond ground, the profilograph readings averaged less than 11 in./mi. with a zero blanking band. This initial smoothness resulted in a contract bonus based on the final profile index. The International Roughness Index (IRI) averaged 67 for the overlay after diamond grinding. Both of these measures indicate a very smooth pavement. The diamond grinding also produced a surface with good friction characteristics.

During diamond grinding of the polyolefin fiber-reinforced sections, the diamond grinding equipment occasionally had to be stopped so that polyolefin fibers could be removed from the equipment. This “clogging” condition was not severe, but fiber removal was not necessary when grinding the steel fiber-reinforced sections or the non-reinforced sections.

Compressive Strength

The effect of fibers in concrete on its compressive strength generally varies from a negligible increase or decrease to strength gains around 20%.[5,6] As can be seen in Table 4, at the age of seven days the compressive strength of the non-reinforced concrete was higher than both of the fiber-reinforced concretes. At 28 days, however, the compressive strength of the steel fiber-reinforced concrete was comparable to that of the non-reinforced, but the compressive strength of the polyolefin fiber-reinforced concrete was 11.5% lower than the non-reinforced concrete. Failure of the test specimens was not catastrophic as is seen with non-reinforced concrete. The fibers held the cylinder together after failure.

The reason for the lower compressive strength of the polyolefin fiber-reinforced concrete is not obvious. In a previous laboratory evaluation of similar mixes, the 28-day compressive strength of a polyolefin fiber-reinforced concrete was lower than a non-reinforced concrete, but only by about 4%. In that study, the 28-day compressive strength of the steel fiber-reinforced concrete was 1% lower than that of the non-reinforced concrete. The bond between the polyolefin fibers and the cement paste may be responsible for the lower compressive strength seen in this study. Other researchers have observed no significant influence on the compressive strength of concrete when using the same polyolefin fiber at the same dosage rate.[5]

Flexural Strength

While the 28-day flexural strengths of the non-reinforced concrete and the steel fiber-reinforced concrete are nearly equal, the flexural strength of the polyolefin fiber-reinforced concrete is significantly lower, as with the compressive strength. The average flexural strength values for all three mixes at 7 and 28 days can also be found in Table 4. These results are again, somewhat different than previously observed when using these fibers in the laboratory. In the previous laboratory study, the three mixes similar to these mixes had nearly identical flexural strengths at 28 days. Flexural strengths in the previous study were within 20 psi of the flexural strengths for the non-reinforced and the steel fiber-reinforced concrete mixes in this study.

As with the compressive strength cylinders, the flexural strength beams did not experience catastrophic failure, but remained in tact after the initial crack and continued to carry load.

Pavement Performance

Overall pavement performance through the 1-year pavement survey has been good. The smoothness of the overlay, as mentioned earlier, is excellent. Falling Weight Deflectometer (FWD) measurements were recorded before construction of the overlay, shortly after construction of the overlay and 1 year after the overlay was in place.

Deflection measurements recorded before construction of the overlay generally ranged between 10 and 20 mils. After construction of the overlay, deflections were in the range of 2 to 8 mils.

The overlay has exhibited some cracking. The majority of cracking is transverse, while there is one significant longitudinal crack in the outer wheel path of Section 8 approximately 80’ in length. Further discussion of cracking in the unbonded overlay will be limited to the transverse cracks.

Pavement distress surveys were performed after construction of the overlay at the following ages: 1 day, 14 days, 1 month, 3 months, 6 months and 1 year. At the 1 day survey, cracks were observed only in sections 2 and 3. Section 2, the 9” steel fiber-reinforced section, had developed 1.7 feet of transverse cracking per 60’ panel and 24 feet of transverse cracking per 200’ panel. Section 3, the 9” polyolefin fiber-reinforced section, had developed 6 feet of transverse cracking per 200’ panel.

At the time of the 2-week survey, all sections, except section 1, contained some transverse cracking. Section 1 is the non-reinforced 9” section with standard 15’ transverse joint spacing. The amount of transverse cracking in all sections had nearly stabilized after the 6-month survey, with only minor increases in transverse cracking from the 6-month survey to the 1-year survey. A graphical representation of the progression of cracking for all test sections is located on page F-1 of *Appendix F*.

The transverse cracks that have developed do not appear to be reflective. The original pavement had transverse joint spacing of 61.5’. The overlay had variable joint spacing as described previously. While a few of the transverse cracks in the overlay are located above joints or cracks in the existing pavement, the overwhelming majority is not. The one-inch interlayer treated with white curing compound seems to be adequate to isolate the overlay from the underlying pavement.

Three variables were designed into the unbonded overlay to explore the practical limits of an overlay reinforced with fibers. The first variable is the inclusion and type of fiber reinforcement. As mentioned earlier and can be seen in *Appendix B*, test sections were established using non-reinforced concrete, steel fiber-reinforced concrete and polyolefin fiber-reinforced concrete. The next variable was overlay thickness. The overlay was constructed with sections 11”, 9”, 6” and 5” thick. The third variable designed into the overlay was transverse joint spacing. Transverse joint spacings of 15’, 30’, 60’ and 200’ were used in the overlay. The pavement performance will be further discussed with regard to each of these variables.

Type of Reinforcement

Transverse cracking in the non-reinforced sections has been minimal. Section 4, the 11” non-reinforced section has experienced a slightly higher amount of cracking than did Section 1, the 9” section. The progression of transverse cracking of the non-reinforced sections can be seen on page F-2 in *Appendix F*. At 1 year, transverse cracking of about 0.32 feet/panel is present in Section 4, while Section 1 contains about 0.2 feet/panel. The joint spacing in the non-reinforced test sections is 15'. The amount of cracking in these two sections is very small, and these sections are considered to be performing well as expected.

The progression of cracking in the steel fiber-reinforced and polyolefin fiber-reinforced sections can be seen on pages F-3 and F-4 of *Appendix F*, respectively. The steel fiber-reinforced concrete has developed more cracking overall, than the polyolefin fiber-reinforced concrete. At the one-year survey, the 5" steel fiber-reinforced section had about 11 feet of transverse cracking per panel, while the 5" polyolefin fiber-reinforced section had about 5 feet/panel. Similar trends are present for the 9" and 6" sections. The largest difference in amount of cracking between the steel fiber-reinforced and polyolefin fiber-reinforced concrete is present in the 6" sections. The 6" steel fiber-reinforced section has nearly 8 feet of transverse cracking/panel, while the polyolefin fiber-reinforced section has less than 2 feet/panel. During the cold temperatures (30 – 35 °F) of the 6-month survey in January 1999, the cracks in the steel fiber-reinforced sections were approximately 1/16" wide. The width of the cracks in the polyolefin fiber-reinforced sections was approximately 1/8".

The location of transverse cracks in the steel fiber-reinforced and polyolefin fiber-reinforced sections has been quite different. Most of the cracks in the steel fiber-reinforced sections are located within 1' of the transverse joint. The cracks in the polyolefin fiber-reinforced sections are located away from the joints in the midpanel. If it had not been for the near joint cracks in the steel fiber-reinforced sections, which appear to be related to the load transfer devices, the steel fiber-reinforced sections may have performed as well, or better, than the polyolefin fiber-reinforced sections.

To investigate the cause of these near joint cracks in the steel fiber-reinforced sections, cores were taken at a few locations directly from the joint and from the nearby crack. Inappropriate sawing was initially suspected of causing these near joint cracks. From the few locations cored, it was found that the crack seemed to develop at the end of the dowel bar, and it was confirmed that the transverse saw joint had cracked through the overlay to the interlayer.

Another possible cause of these near joint cracks may be a misalignment of the dowel bars. During construction, the steel fiber-reinforced concrete mix was noted to appear "stiffer" than the polyolefin fiber-reinforced concrete mix. In terms of measured physical properties of the fresh concrete, the steel fiber-reinforced concrete had an average slump lower than that of the polyolefin fiber-reinforced concrete consistent with a "stiffer" mix. However, the inverted slump time for the steel fiber-reinforced concrete was lower than that of the polyolefin fiber-reinforced concrete, indicating better flowability. While it cannot be proven with the data collected to date, the dowel bars may have been lifted at the upstream side, so that the bars are not in a horizontal plane. This misalignment would result in the type of near joint cracks that are present in the steel fiber-reinforced sections.

Pavement repair will be needed in the near future to some of the steel fiber-reinforced sections. When the repair is made, the probable cause of these cracks will likely be able to be determined.

A direct comparison of feet of cracking per panel of the fiber-reinforced concretes and the non-reinforced concrete is not appropriate because the joint spacing of the non-reinforced sections does not vary from 15'. The data shown on pages F-3 and F-4 are an average for the entire test sections, such that cracks in the 15', 30', 60' and 200' panels are all considered to yield the feet of cracking per panel for the test section. In general, the shorter the panels, the less likely they are to develop transverse cracks. A comparison and discussion of only the 15' panels in all sections appears later in this section.

Overlay Thickness
Pages F-5 through F-7 in *Appendix F* show the progression of cracking for the 9", 6" and 5" sections respectively. In each case, it can be seen that the steel fiber-reinforced sections exhibit the largest amount of transverse cracking. The trend is clear that the thicker the overlay, the lower the amount of transverse cracking developed. From the one year survey, for the steel fiber-reinforced sections, the 9" section has about 3.5 feet of transverse cracking/panel, the 6" section has about 7.5 feet/panel and the 5" section has about 11 feet/panel. The one year averages for the polyolefin fiber-reinforced sections are about 1, 2 and 5 feet/panel, for the 9", 6" and 5" thick sections, respectively.

The non-reinforced sections are contrary to the trend cited above. The 11" thick section has actually exhibited a slightly higher amount of transverse cracking than the 9" section. However, the difference (0.32 feet/panel vs. 0.20 feet/panel) in considered insignificant.

The overlay thickness has also affected the deterioration of the overlay at locations where transverse cracks have appeared. At several locations in the 5" steel fiber-reinforced section, where a near joint transverse crack exists, spalling has occurred over the dowel bars. Where the near joint transverse cracks exist in the 9" and 6" steel fiber-reinforced sections, no spalling has occurred as of the 1-year survey. This spalling is most likely attributed to the small amount of concrete cover of the dowel bars. At some of the spalled locations, cover of less than 1 1/2" was observed. The use of 1 1/4" dowel bars in a 5" pavement should be reconsidered.

Transverse Joint Spacing
The degree of pavement movement, curling and warping is related to the length of the slab. Shorter slabs develop lower stresses than longer slabs. The performance of the unbonded overlay in this study has relative performance, with regard to joint spacing, as was expected. For a given concrete mix, the shorter the joint spacing, the fewer transverse cracks developed. The transverse crack data by joint spacing is presented on pages F-8 through F-11 in *Appendix F*. All test sections contained some 15' joint spacing; therefore, they are all shown on page F-8. Only fiber-reinforced test sections contained joint spacings of 30', 60' and 200', so only those sections are included on pages F-9 through F-11.

All of the 15’ panels have performed well. However, the trend has started to develop in the 15’ panels, that the thinner (5” and 6”) steel fiber-reinforced sections are exhibiting higher amounts of transverse cracking than the other sections.

The 5” steel fiber-reinforced section shows significantly greater transverse cracking when evaluating the 30’ panels. In order of most transverse cracking to least, the 5” steel fiber-reinforced section is followed by the 6” steel, the 9” steel, the 6” polyolefin, and the 5” and 9” polyolefin showed no transverse cracking in the 30’ panels. From this project, it appears a 5” to 9” polyolefin reinforced overlay can be built, with 30’ joint spacing, with little or no concern for transverse cracking.

The amount of transverse cracking in the 60’ panels is higher than in the 30’ panels. Along with the three steel fiber-reinforced test sections, the 5” polyolefin fiber-reinforced section is exhibiting a large amount of transverse cracking. The 6” and 9” polyolefin fiber-reinforced sections are performing relatively well, with the 9” section showing an average of less than 1 foot of transverse cracking per 60’ panel.

Two 200’ panels were included at the end of each fiber-reinforced test section to determine the upper limit of transverse joint spacing. The amount of transverse cracking is shown on page E-11, but also of interest was at what interval, or spacing, would the cracks develop. The 9” steel, 9” polyolefin and 6” polyolefin fiber-reinforced sections cracked at approximately the one-third points of the slab. Many more cracks developed in the 200’ panels of the other three sections, the 5” polyolefin, the 6” steel and the 5” steel. Transverse crack spacing in these panels ranged from 10’ to 40’.

Repair and Rehabilitation
Maintenance crews used cold mix asphalt to fill spalls that developed in the overlay within the first year of service. The majority of transverse cracks that developed spalls were in Test Section 7, the 5” steel fiber-reinforced section. The patching material needed to be replaced often. Although not covered in detail by this report, longitudinal cracking was also developing in both the 5” steel and polyolefin fiber-reinforced sections (Test Section 7 and Test Section 8) within two years of service. The longitudinal cracks in both sections were originating and extending from the dowel bar locations. Because a great deal of maintenance was expected to be required on these two 5” sections, the decision was made to replace these sections with a full-depth new PCCP in 2000. This situation will be explained further in a future report detailing the pavement performance after two years of service.

CONCLUSIONS

1. In this study, the use of polyolefin fibers mixed at 25 lbs./cu. yd. in concrete lead to a significant decrease in compressive and flexural strength at 28 days when compared to a non-reinforced concrete of similar mix proportions. The use of steel fibers in concrete had little effect on the compressive and flexural strength at 28 days.

2. The use of a burlap drag to provide the interim surface finish for the fiber-reinforced unbonded overlay resulted in a poor finish because the fibers became entangled in the burlap leading to other fibers and coarse aggregate being pulled from the surface of the pavement. An unweighted carpet drag provided an acceptable interim finish.

3. Both the steel fibers and the polyolefin fibers exhibited some non-uniform distribution of fibers in the concrete. The polyolefin fibers appeared more susceptible to mixing inconsistencies such as fiber balling and the presence of uncoated fibers in the mix than the steel fibers.

4. Diamond grinding of the PCCP overlay provided a smooth profile with no detrimental effect on the friction characteristics of the pavement.

5. Based on data from one year of service, the one inch thick asphalt interlayer appears adequate to prevent major reflective cracking on this project.

6. The steel fiber-reinforced sections of the unbonded overlay exhibited more transverse cracking than the polyolefin fiber-reinforced sections.

7. Based on the one year survey data, the 6” polyolefin fiber-reinforced section has performed nearly as well, in terms of crack development, as the 9” polyolefin fiber-reinforced section.

8. To date, the steel fibers have restricted the opening of cracks more than the polyolefin fibers.

9. The thickness of the overlay greatly impacted the development of transverse cracks in the overlay. In general, the thinner sections developed more transverse cracking than thicker sections.

10. The small coverage of concrete over the dowel bars at transverse joints in the 5” steel fiber-reinforced sections contributed to spalling over those dowel bars.

11. The polyolefin fiber-reinforced sections with transverse joint spacing of thirty feet exhibited nearly no transverse cracking based on the one-year survey. Also, the 9” polyolefin fiber-reinforced section with 60’ panels showed very little transverse cracking.

RECOMMENDATIONS

1. The fiber-reinforced unbonded overlay should be monitored yearly to evaluate and document its performance. Particular attention should be paid to the progression of deterioration of cracks in the fiber-reinforced sections compared to that of the non-reinforced sections.

2. Further study into the near joint transverse cracking in the steel fiber-reinforced sections is warranted. When the failed joints are replaced, Research, Development and Technology personnel should be present to gather data that would detail the probable cause of these cracks.

3. The use or size of dowel bars for load transfer in thin overlays should be reconsidered. The thin overlay provides very little cover for the dowel bars, which can lead to spalling.

4. Additional pavements should be constructed using fiber reinforcement.

5. Unbonded overlays should be further investigated and constructed. A 1" asphalt interlayer treated with the white-pigmented curing compound appears to sufficiently isolate the overlay from the existing pavement

6. The smoothness achieved with the diamond grinding operation is excellent. Diamond grinding should be considered for use on future concrete paving projects.

7. While initial friction properties of the diamond ground overlay are good, the friction properties should continue to be monitored. A comparison of friction values of the fiber-reinforced sections to the non-reinforced sections should be made.

IMPLEMENTATION

The fiber-reinforced unbonded overlay will continue to be monitored on a yearly basis. Maintenance and repairs will be tracked to assess the life cycle costs of the various test sections.

The cause of the near joint transverse cracking in the steel fiber-reinforced sections will be studied. When repairs are made to the failed joints in these sections an attempt will be made to determine the cause of this cracking. A report addendum or letter of finding will be prepared which addresses this issue.

Consideration will be given to future fiber-reinforced concrete pavements. Observations made on this project concerning pavement thickness and joint spacing will be considered in the design of such future projects.

Other concrete pavements that have been diamond ground will be tested with regard to smoothness and friction properties to gain further data to support its use.

Additional reports will be prepared following the annual pavement surveys. Based on pavement performance, PCCP mix designs may be altered to allow or include fiber reinforcement.

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7. ACPA, "Guidelines for Unbonded Concrete Overlays", Technical Bulletin TB-005.0D, 1990.

8. ERES Consultants, Inc., "The Long Term Effects of Initial Pavement Smoothness", Eye on ERES, Vol. 4 No. 3, Champaign, IL, 1997.

Table 1
Mix Proportions and Fresh Concrete Properties

	Test Section 1 9" Non-reinforced	Test Section 2 9" w/ Steel Fibers	Test Section 3 9" w/ Polyolefin Fibers	Test Section 4 11" Non-reinforced	Test Section 5 6" w/ Polyolefin Fibers	Test Section 6 6" w/ Steel Fibers	Test Section 7 5" w/ Steel Fibers	Test Section 8 5" w/ Polyolefin Fibers
Water (lbs/cu. yd)	242	263	261	269	268	279	272	266
Type I Cement (lbs/cu. yd)	574	575	574	574	574	575	575	574
Class C Fly Ash (lbs/cu. yd)	101	102	101	101	101	102	102	101
w/c	0.36	0.39	0.39	0.40	0.40	0.41	0.40	0.39
Class A Platte River Sand (lbs/cu. yd)	1287	1290	1287	1287	1287	1290	1290	1287
Bethany Falls Limestone Gradation F - 1/2" max. (lbs/cu. yd)	1620	1590	1551	1620	1551	1590	1590	1551
3M Polyolefin Fibers 50mm (lbs/cu. yd) *(% by volume)*	0 *0*	0 *0*	25 *1.6%*	0 *0*	25 *1.6%*	0 *0*	0 *0*	25 *1.6%*
Bekaert Hooked End Steel Fibers 60mm (lbs/cu. yd) *(% by volume)*	0 *0*	75 *0.6%*	0 *0*	0 *0*	0 *0*	75 *0.6%*	75 *0.6%*	0 *0*
Daravair 1400 (oz/sack) Air Entraining Agent	0.41	0.28	0.33	0.32	0.34	0.33	0.34	0.4
WRDA 82 (oz/sack) Water Reducer	3.28	3.63	3.29	3.30	3.28	3.46	3.61	3.28
Fresh Air Content (%)	5.9	6.3	6.5	5.6	6.0	5.9	6.1	6.2
Slump (in)	1.75	1.50	1.75	1.75	2.25	2.00	1.50	1.75
Inverted Slump (seconds)	5.9	6.6	7.7	7.4	6.9	5.8	6.1	6.5

Table 2
Fiber Characteristics

Fiber Type	Material	Length	Aspect Ratio (l/d)	Yield Strength	Elastic Modulus	Specific Gravity
3M Type 50/63	Polyolefin	50mm 2.0 in.	79	275 Mpa 40 ksi	2650 Mpa 384 ksi	0.91
Dramix ZC 60/.80	Steel	60mm 2.36 in.	75	1170 Mpa 170 ksi	200000 Mpa 29000 ksi	7.85

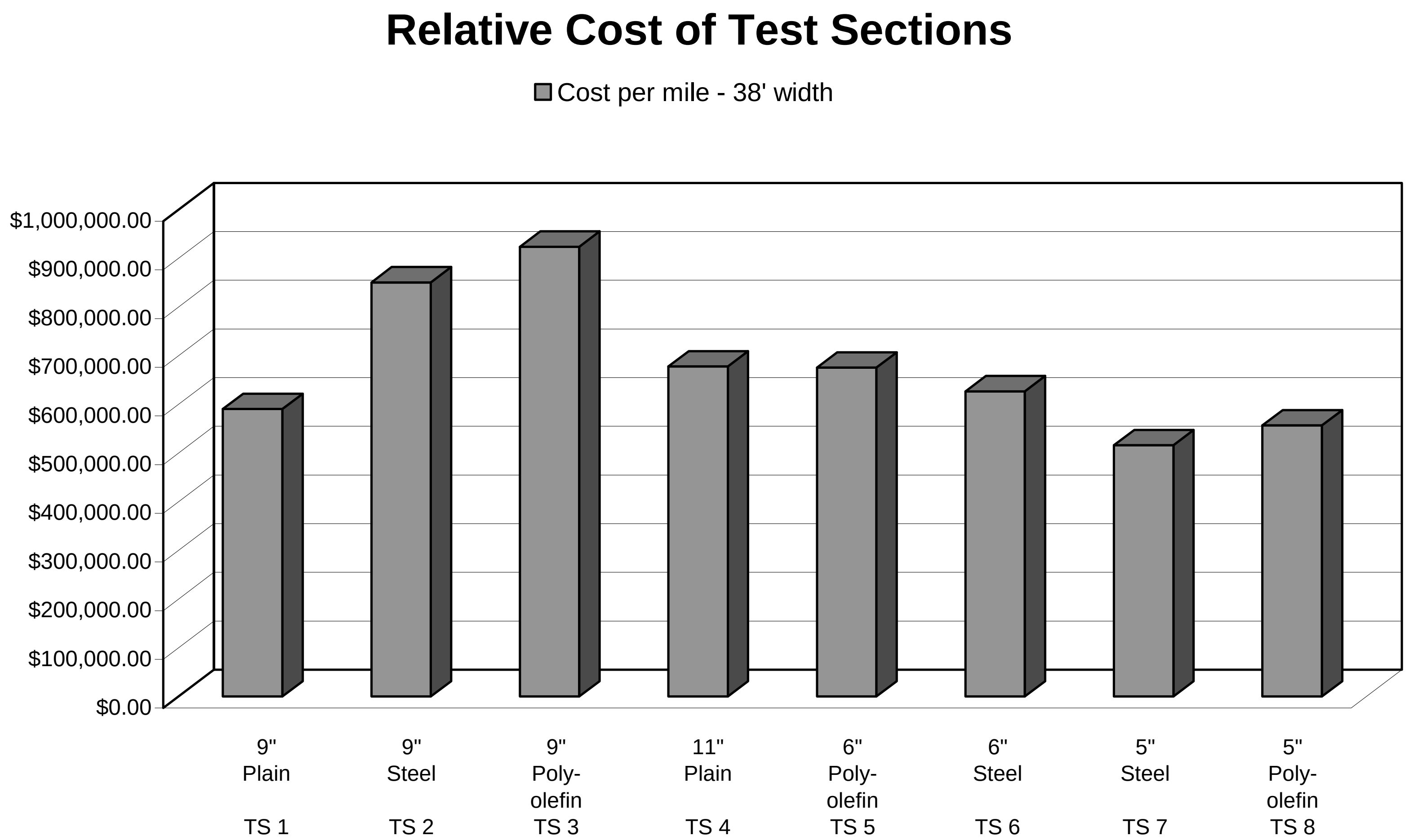
Table 3
Gradation for Coarse Aggregate (MoDOT Gradation F)

Gradation F	Percent by Weight (Mass)
Passing 1/2" (12.5mm) sieve	100
Passing 3/8" (9.5 mm) sieve	85-100
Passing No. 4 (4.75 mm) sieve	10-30
Passing No. 8 (2.36 mm) sieve	0-10
Passing No. 16 (1.18 mm) sieve	0-5

Table 4
Hardened Concrete Properties

	Non--Reinforced Concrete Sections 1 and 4	Steel Fiber-Reinforced Concrete Section 2, 6 and 7	Polyolefin Fiber-Reinforced Concrete Sections 3, 5 and 8
7 day Average Compressive Strength (psi)	4840	4500	4370
28 day Average Compressive Strength (psi)	5730	5760	5070
7 day Average Flexural Strength (psi)	740	650	590
28 day Average Flexural Strength (psi)	760	770	600

APPENDIX A


Relative Cost of Test Sections
Cost per mile - 38' width
$1,000,000.00
$900,000.00
$800,000.00
$700,000.00
$600,000.00
$500,000.00
$400,000.00
$300,000.00
$200,000.00
$100,000.00
$0.00
9" Plain TS 1
9" Steel TS 2
9" Poly-olefin TS 3
11" Plain TS 4
6" Poly-olefin TS 5
6" Steel TS 6
5" Steel TS 7
5" Poly-olefin TS 8

APPENDIX B

Test Sections - Concrete Unbonded Overlay

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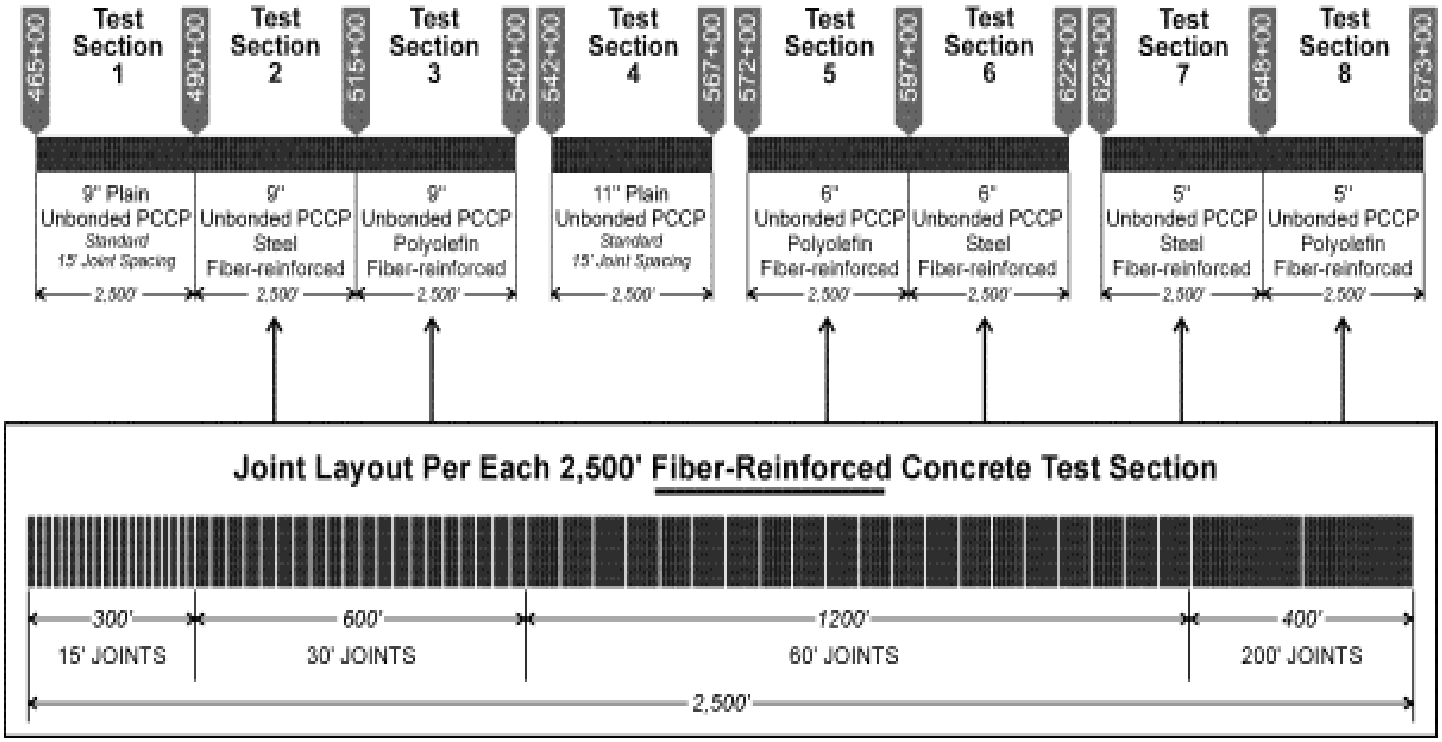
S.B.L. I-29 - Atchison County



Note: Non-fiber-reinforced concrete test sections and transition areas will have standard 15' joint spacing.
Longitudinal joint with tie bars, according to standard, will be placed full length of the unbonded overlay.

APPENDIX C

TEST PAVEMENT FOR PORTLAND CEMENT CONCRETE UNBONDED OVERLAY WITHOUT FIBERS

1.0 DESCRIPTION OF MSP-97-11. This work shall consist of applying a debonding material and constructing a portland cement concrete unbonded overlay as required in this special provision and in accordance with details and locations shown on the plans. Work also includes minor surface pavement repair, joint filling, and other associated operations.

1.1 Unless otherwise stated, specification section references are from the version, in effect at the time of this contract, of the Missouri Standard Specifications for Highway Construction and its supplements.

2.0 GENERAL.

2.1 All procedures and materials for the concrete unbonded overlay shall meet applicable provisions of Sec 502 for non-reinforced concrete pavement except as herein described.

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

3.1 The debonding material between the asphalt surface leveling overlay and the new concrete pavement overlay shall be one of the following.

3.1.1 A white pigmented curing compound meeting Sec 1055 and applied at the rate of 200 square feet per gallon.

3.1.2 Whitewash, a mixture of hydrated lime and water mixed at the rate of 100# of lime per 12.5 gallons of water, applied at a rate of 200 square feet per gallon of mixture.

3.1.3 An alternate material will be considered provided it can be demonstrated to provide a) lack of bond between asphalt concrete and portland cement concrete overlay, b) a white coloration to reflect and control heat buildup in the base pavement, c) no detrimental effect to the asphalt and/or concrete overlay as a result of the use, and d) reasonable durability under traffic resisting removal prior to overlay. Upon request, the contractor shall provide any testing necessary to demonstrate these properties. Approval shall be obtained from the Division Engineer, Materials, prior to use. Requests for approval shall include a specific description of the proposed material, applicable material safety data sheets, and the proposed application rate and are subject to uniform and satisfactory application.

3.2 Dowel bars shall be 1 1/4 inch for concrete pavement overlay sections less than 10 inch thicknesses and 1 1/2 inch for concrete pavement overlay sections greater than 10 inch thicknesses. All dowel bars shall meet 1057.1.

3.3 Tie bars shall be epoxy coated and meet Sec 1057.1.

3.4 Material sources and mix designs for unbonded portland cement concrete pavement overlay placed throughout this project shall not change, unless otherwise specified in this contract, without prior written approval of the engineer.

4.0 CONSTRUCTION. Preliminary work, including joint sealing, may be done under traffic as allowed elsewhere in the contract. Prior to placement of the asphalt surface leveling overlay, the traffic shall be diverted as noted else where in the contract, and the remaining operations shall commence.

4.1 Surface Preparation.

4.1.1 Pavement repair to the existing pavement shall be performed as indicated in this contract.

4.1.2 Prior to placement of the asphalt surface leveling overlay, all existing pavement cracks and joints shall be sealed or re-sealed where required and all pavement repairs completed.

4.1.3 Prior to placement of the asphalt surface leveling overlay, all holes greater than 2 inches in width and 1 inch in depth, in the surface of the traffic lanes (not shoulders), shall be patched by filling with a bituminous patching material. It shall be compacted to a flat, tight surface.

4.1.4 Prior to placement of the concrete overlay, the base surface shall be free of loose material and relatively flat, without bumps or indentations.

4.1.5 Debonding material, as indicated in Sec 3.1 is to be applied uniformly at the designated rate. If the material is removed by rain, wear, or other means to the extent that the reflective or bond-breaking properties are not effective, it shall be re-applied.

4.1.6 In order to properly locate the saw cuts in the concrete overlay, the location of all transverse expansion joints and longitudinal lane joints in the existing pavement shall be identified by a reliable method. The contractor shall receive approval from the engineer for the procedure to be used to mark and relocate existing joints.

4.2 Placement.

4.3 Tie bar, dowel, and joint saw depths are as shown on plans. Tie bars are required for both the centerline and shoulder longitudinal joints.

4.4 Dowel bars shall be installed the full concrete unbonded overlay width and the baskets firmly anchored to the existing surface.

4.5 While transverse joints are not required to match the existing joints, transverse expansion joints and longitudinal lane joints shall be cut or placed to match the underlying joint configuration.

4.6 Any transverse expansion joints in the existing pavement shall be specifically marked and identified as such. The expansion joint shall be precut in the plastic concrete, to allow for any slab movement until sawing can be started. As soon as sawing is possible, the contractor shall saw two full-depth cuts on each side of the precut joint following the edges of the underlying expansion joint, as shown on the details. The contractor shall remove and dispose the concrete between the sawcuts at a location meeting the approval of the engineer and at the contractor's expense.

4.7 Concrete pavement overlay shall be placed at the depths and locations shown on the plans.

4.8 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.

5.0 Surface Finish.

5.1 In lieu of a wire comb surface finish, the concrete overlay surface shall be textured in accordance with the requirements of PCCP Diamond Grind Texturing specified in this contract.

6.0 METHOD OF MEASUREMENT.

6.1 Measurement of furnishing full depth unbonded overlay concrete within the limits shown on the plans will be to the nearest 0.1 cubic yard, using the count of batches incorporated into the unbonded overlay.

6.2 Measurement for placing full depth unbonded overlay concrete within the limits shown on the plans will be computed to the nearest 0.1 square yard.

6.3 Measurement for furnishing and placing unbonded concrete overlay within transitions areas as specified in the plans will be in accordance with the requirements of Pavement Depth Transition specified in this contract.

6.4 Final measurement of the completed 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.

6.5 Measurement for furnishing and placing asphalt surface leveling overlay will be made in accordance with Sec 403. Final measurement will not be made except for authorized changes during construction or where appreciable errors are found in the contract quantity.

6.6 Measurement for full depth and partial depth pavement repair will be made in accordance with Sec 613.

7.0 BASIS OF PAYMENT.

7.1 The accepted quantity of portland cement concrete for the unbonded overlay will be paid for the contract unit price of "Furnishing 9" PCCP (plain)," "Furnishing 11" PCCP (plain)," "Placing 9" PCCP (plain)," or "Placing 11" PCCP (plain)," as appropriate.

7.2 Payment for furnishing unbonded portland cement concrete will be paid for at the contract unit price for "Furnishing 9" PCCP (plain)" or "Furnishing 11" PCCP (plain)," as appropriate, per cubic yard. No direct payment will be made for furnishing labor, equipment, and other materials necessary to furnish the concrete.

7.3 Payment for placement of the portland cement concrete unbonded overlay will be paid for at the contract unit price for "Placing 9" PCCP (plain)" or "Placing 11" PCCP (plain)," as appropriate, per square yard. No direct payment will be made for furnishing labor, equipment, reinforcement, and other materials necessary to place, finish, and cure the overlay including sawing and sealing the joints, in accordance with the plans and specifications.

7.4 Payment for furnishing and placing asphalt surface leveling overlay will be in accordance with Sec 403.

7.5 Unless specified otherwise, no direct payment will be made for surface preparation, including joint filling of the existing surface, application of the debonding material, and any other incidental work and material necessary to complete this work.

7.6 Payment for full depth and partial depth pavement repairs will be in accordance with Sec 613.

TEST PAVEMENT FOR PORTLAND CEMENT CONCRETE UNBONDED OVERLAY WITH FIBERS

1.0 DESCRIPTION OF MSP-97-12. This work shall consist of applying a debonding material and constructing a fiber-reinforced portland cement concrete unbonded overlay as required in this special provision and in accordance with details and locations shown on the plans. Work also includes minor surface pavement repair, joint filling, and other associated operations.

1.1 Unless otherwise stated, specification section references are from the version, in effect at the time of this contract, of the Missouri Standard Specifications for Highway Construction and its supplements.

2.0 GENERAL.

2.1 All procedures and materials for the fiber-reinforced concrete unbonded overlay shall meet applicable provisions of Sec 502 for non-reinforced concrete pavement except as herein described.

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

3.1 The debonding material between the asphalt surface leveling overlay and the new fiber-reinforced concrete pavement overlay shall be one of the following.

3.1.1 A white pigmented curing compound meeting Sec 1055 and applied at the rate of 200 square feet per gallon.

3.1.2 Whitewash, a mixture of hydrated lime and water mixed at the rate of 100# of lime per 12.5 gallons of water, applied at a rate of 200 square feet per gallon of mixture.

3.1.3 An alternate material will be considered provided it can be demonstrated to provide a) lack of bond between asphalt concrete and fiber-reinforced portland cement concrete overlay, b) a white coloration to reflect and control heat buildup in the base pavement, c) no detrimental effect to the asphalt and/or concrete overlay as a result of the use, and d) reasonable durability under traffic resisting removal prior to overlay. Upon request, the contractor shall provide any testing necessary to demonstrate these properties. Approval shall be obtained from the Division Engineer, Materials, prior to use. Requests for approval shall include a specific description of the proposed material, applicable material safety data sheets, and the proposed application rate and are subject to uniform and satisfactory application.

3.2 Dowel bars shall be 1 1/4 inch for fiber-reinforced concrete pavement overlay sections less than 10 inch thicknesses and 1 1/2 inch for fiber-reinforced concrete pavement overlay sections greater than 10 inch thicknesses. All dowel bars shall meet Sec 1057.1.

3.3 Tie bars shall be epoxy coated and meet Sec 1057.1.

3.4 Steel fibers, for use in fiber-reinforced concrete overlay as shown on the plans, shall be Dramix® ZC 60/.80 Steel Fibers manufactured by Bekaert Corporation, Marietta, GA. Steel fibers shall be added to the concrete mix at a rate of 75# per cubic yard. Polyolefin fibers, for use in fiber-reinforced concrete overlay as shown on the plans, shall be 3M Polyolefin Type 50/63 Fibers manufactured by 3M, St. Paul, MN. Polyolefin fibers shall be added to the concrete mix at a rate of 25# per cubic yard.

3.4.1 All fibers shall be measurable by weight. 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 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.

3.5 No material changes will be allowed during placement of the fiber-reinforced unbonded concrete overlay.

4.0 CONCRETE MIX DESIGN.

4.1 Fiber-reinforced concrete shall comply with the requirements for pavement concrete in Sec 501, with the following exceptions. Type I cement shall be used and the minimum sacks per cubic yard shall be in accordance with the following requirements:

Class of Sand	Minimum Cement
A	6.60
B	6.80
C	7.00
D	7.40

4.1.1 The maximum water cement ratio by weight shall not exceed 0.41 and Type F high range water-reducer will be allowed. The cement requirement shall be increased 0.50 sacks per cubic yard of concrete if coarse aggregate, Gradation F conforming to Sec 1005.1.4.5 is used. Class C flyash may be used to replace a maximum of 15 percent of Type I cement.

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

4.3 The ratio of fine aggregate to coarse aggregate for the fiber-reinforced concrete mix design shall be 45/55 by volume content.

4.4 The contractor shall assure that a workable mix is obtained within these specifications. Prior to the first day of placement of the steel fiber-reinforced concrete mix and the polyolefin fiber-reinforced concrete mix in the work, the contractor shall provide a minimum 3 cubic yard trial batch of each mix. The trial batches shall be mixed and agitated in accordance with the specifications to replicate haul and discharge time and placed at a contractor chosen location to demonstrate suitable workability and general specification compliance. Any specification deviations or indicated placement problems shall be satisfactorily resolved to the engineer's satisfaction prior to starting initial paving. No additional payment will be made for providing trial batches as required.

4.5 No mix design changes will be allowed during placement of fiber-reinforced concrete in the work without the approval of the engineer.

5.0 CONSTRUCTION. Preliminary work, including joint sealing, may be done under traffic as allowed elsewhere in the contract. Prior to placement of the asphalt surface leveling overlay, the traffic shall be diverted as noted elsewhere in the contract, and the remaining operations shall commence.

5.1 Surface Preparation.

5.1.1 Pavement repair to the existing pavement shall be performed as indicated in this contract.

5.1.2 Prior to placement of the asphalt surface leveling overlay, all existing pavement cracks and joints shall be sealed or re-sealed where required and all pavement repairs completed.

5.1.3 Prior to placement of the asphalt surface leveling overlay, all holes greater than 2 inches in width and 1 inch in depth, in the surface of the traffic lanes (not shoulders), shall be patched by filling with a bituminous patching material. It shall be compacted to a flat, tight surface.

5.1.4 Prior to placement of the fiber-reinforced concrete overlay, the base surface shall be free of loose material and relatively flat, without bumps or indentations.

5.1.5 Debonding material, as indicated in Sec 3.1 is to be applied uniformly at the designated rate. If the material is removed by rain, wear, or other means to the extent that the reflective or bond-breaking properties are not effective, it shall be re-applied.

5.1.6 In order to properly locate the saw cuts in the fiber-reinforced concrete overlay, the location of all transverse expansion joints and longitudinal lane joints in the existing pavement shall be identified by a reliable method. The contractor shall receive approval from the engineer for the procedure to be used to mark and relocate existing joints.

5.2 Placement.

5.3 Tie bar, dowel, and joint saw depths are as shown on plans. Tie bars are required for both the centerline and shoulder longitudinal joints.

5.4 Dowel bars shall be installed the full fiber-reinforced concrete unbonded overlay width and the baskets firmly anchored to the existing surface.

5.5 Transverse joints are variably spaced and shall be placed at the locations shown on the plans.

5.6 While transverse joints are not required to match the existing joints, transverse expansion joints and longitudinal lane joints shall be cut or placed to match the underlying joint configuration.

5.6.1 Any transverse expansion joints in the existing pavement shall be specifically marked and identified as such. The expansion joint shall be precut in the plastic concrete, to allow for any slab movement until sawing can be started. As soon as sawing is possible, the contractor shall saw two full-depth cuts on each side of the precut joint following the edges of the underlying expansion joint, as shown on the details. The contractor shall remove and dispose the concrete between the sawcuts at a location meeting the approval of the engineer and at the contractor's expense.

5.7 Fiber-reinforced concrete pavement overlay shall be placed at the depths and locations shown on the plans.

5.8 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.

5.9 Fiber-reinforced concrete shall be free of fiber balls when placed in the work.

6.0 Surface Finish.

6.1 In lieu of a wire comb surface finish, the fiber-reinforced concrete overlay surface shall be textured in accordance with the requirements of PCCP Diamond Grind Texturing specified in this contract.

7.0 METHOD OF MEASUREMENT.

7.1 Measurement of furnishing full depth fiber-reinforced unbonded overlay concrete within the limits shown on the plans will be to the nearest 0.1 cubic yard, using the count of batches incorporated into the unbonded overlay.

7.2 Measurement for placing full depth fiber-reinforced unbonded overlay concrete within the limits shown on the plans will be computed to the nearest 0.1 square yard.

7.3 Measurement for furnishing and placing fiber-reinforced unbonded concrete overlay within transition areas as specified in the plans will be accordance with the requirements of Pavement Depth Transition specified in this contract.

7.4 Final measurement of the completed 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.

7.5 Measurement for furnishing and placing asphalt surface leveling overlay will be made in accordance with Sec 403. Final measurement 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.

7.6 Measurement for full depth and partial depth pavement repair will be made in accordance with Sec 613.

8.0 BASIS OF PAYMENT.

8.1 The accepted quantity of fiber-reinforced portland cement concrete for the unbonded overlay will be paid for at the contract unit price of "Furnishing 9" PCCP With Steel Fibers," "Furnishing 9" PCCP With Polyolefin Fibers," "Furnishing 6" PCCP With Steel Fibers," "Furnishing 6" PCCP With Polyolefin Fibers," "Furnishing 5" PCCP With Steel Fibers," "Furnishing 5" PCCP With Polyolefin Fibers," "Placing 9" PCCP With Steel Fibers," "Placing 9" PCCP With Polyolefin Fibers," "Placing 6" PCCP With Steel Fibers," "Placing 6" PCCP With Polyolefin Fibers," "Placing 5" PCCP With Steel Fibers," or "Placing 5" PCCP With Polyolefin Fibers," as appropriate.

8.2 Payment for furnishing fiber-reinforced unbonded portland cement concrete will be paid for at the contract unit price for "Furnishing 9" PCCP With Steel Fibers," "Furnishing 9" PCCP With Polyolefin Fibers," "Furnishing 6" PCCP With Steel Fibers," "Furnishing 6" PCCP With Polyolefin Fibers," "Furnishing 5" PCCP With Steel Fibers," or "Furnishing 5" PCCP With Polyolefin Fibers," as appropriate, per cubic yard. No direct payment will be made for furnishing labor, equipment, and other materials necessary to furnish the concrete.

8.3 Payment for placement of the fiber-reinforced portland cement concrete unbonded overlay will be paid for the contract unit price for "Placing 9" PCCP With Steel Fibers," "Placing 9" PCCP With Polyolefin Fibers," "Placing 6" PCCP With Steel Fibers," "Placing 6" PCCP With Polyolefin Fibers," "Placing 5" PCCP With Steel Fibers," or "Placing 5" PCCP With Polyolefin Fibers," as appropriate, per square yard. No direct payment will be made for furnishing labor, equipment, reinforcement, and other materials necessary to place, finish, and cure the overlay including sawing and sealing the joints, in accordance with the plans and specifications.

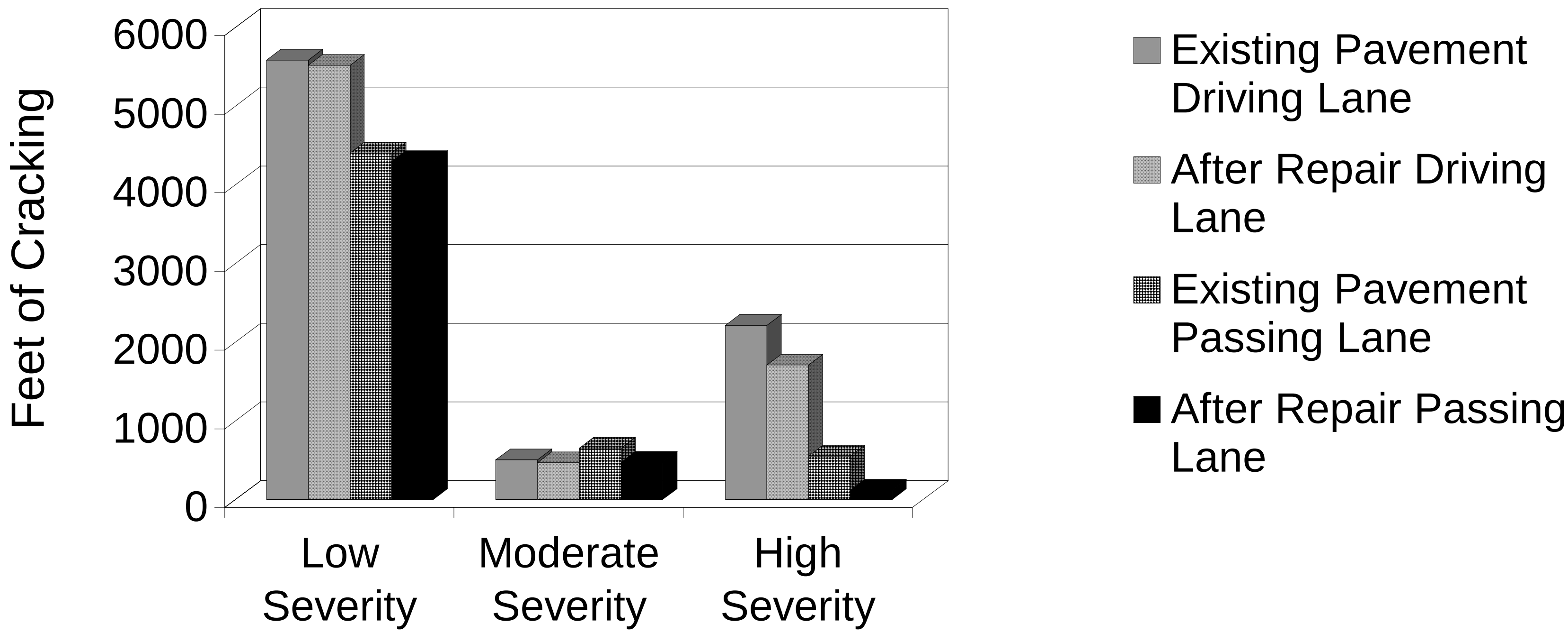
8.4 Payment for furnishing and placing asphalt surface leveling overlay will be in accordance with Sec 403.

8.5 Unless specified otherwise, no direct payment will be made for surface preparation, including joint filling of the existing surface, application of the debonding material, and any other incidental work and material necessary to complete this work.

8.6 Payment for full depth and partial depth pavement repairs will be in accordance with Sec 613.

APPENDIX D

Transverse Cracking
Before and After Pavement Repair



APPENDIX E

PCCP DIAMOND GRIND TEXTURING MSP-96-19A

1.0 DESCRIPTION OF MSP-96-19A. This specification covers diamond grinding the roadway surface of new PCCP in lieu of a wire comb surface finish.

1.1 Unless otherwise stated, specification section references are from the English version, in effect at the time of this contract, of the Missouri Standard Specifications for Highway Construction and its supplements.

2.0 Construction Requirements. All concrete paving on this job shall be in accordance with the standard specifications except as noted herein.

2.1 Paving.

2.1.1 Surface Finish. A wire comb surface finish shall not be provided for the specified mainline or adjacent shoulders. Instead, a burlap drag finish shall be provided for, in accordance with the following. After surface irregularities have been removed and while the concrete is still plastic, the concrete shall be given a uniformly roughened surface of gritty texture by use of a seamless burlap fabric drag. The damp fabric shall be dragged in a longitudinal direction. The dragging shall be completed before the concrete is in a condition that it will be torn or unduly roughened and before the concrete has attained its initial set. The fabric shall be maintained clean and free of encrusted mortar. It shall be replaced as often as necessary to obtain the required surface texture. Upon completion of dragging, the surface of the pavement shall be uniform in appearance and shall be free from surplus water, rough or porous spots, irregularities, depressions, and other objectionable features.

2.1.2 Joint Sealing. All PCCP joint sealing shall be completed, prior to any adjacent surface being diamond ground. It is mandatory that all joints in diamond ground areas have the sealant recessed 1/4 - 3/8 inch below the surface so that the grinding process does not encounter the joint material. Adjoining areas with joints filled at the same time, such as the shoulders, may also be filled to those limits. Any remaining joints filled at separate times shall be filled according to the plans.

2.1.3 Diamond Grinding. Following curing of the PCCP, all traffic lanes shall also be diamond ground as specified herein for the 12 foot lane width. Diamond grinding shall be in accordance with Sec 622.30 except as follows.

2.1.3.1 No diamond grinding shall be done until the pavement has attained strength sufficient to be opened to all types of traffic, and no sooner than 21 days after being placed.

2.1.3.2 The grinding head shall be a minimum of 3 feet wide and provide 55 to 60 evenly spaced grooves per foot.

2.1.3.3 All grooves and adjacent passes shall be parallel to each other and the roadway, with no variation. Adjacent passes shall completely lap with no unground surface between, however they shall not overlap more than 1 1/2". Adjacent passes shall be within 1/8 inch of the same height as measured with a 3-foot straightedge. Not less than 98 percent of the specified surface shall be textured by grinding. It is preferable that all specified surface be textured. There shall be no ridge between lanes. Any remaining ridges on the outside edge next to the shoulder greater than 1/8 inch in height shall be feathered out to the satisfaction of the engineer in a separate operation.

2.1.3.4 Grinding operations will be limited only by other contractor operations and the remainder of the contract, and not restricted to daytime closures.

2.1.3.5 Any deficiencies in the final surface due to improper contractor operations and/or equipment shall be corrected by the contractor at no additional expense to the department. This includes, but is not limited to: a) corrugation of the pavement due to "out of round" wheels or improper cutting operations, b) depressions created due to improper starting or stopping operations, or c) unground ridges due to defective blades. All corrections shall be parallel to, and match, existing operations.

3.0 Basis of Payment.

3.1 Pavement Thickness. Pavement thickness determination will be made after all diamond grinding has been completed. The following table applies to adjacent PCCP shoulder as well as the diamond ground traffic lanes. The table in Sec 502.19.1 shall be modified as follows:

Deficiency in Thickness	Deductions Percent of Contract Unit Price
0 inch to 4/10 inch	None
Over 4/10 inch and not over 6/10 inch	15
Over 6/10 inch and not over 8/10 inch	60
Over 8/10 inch	100

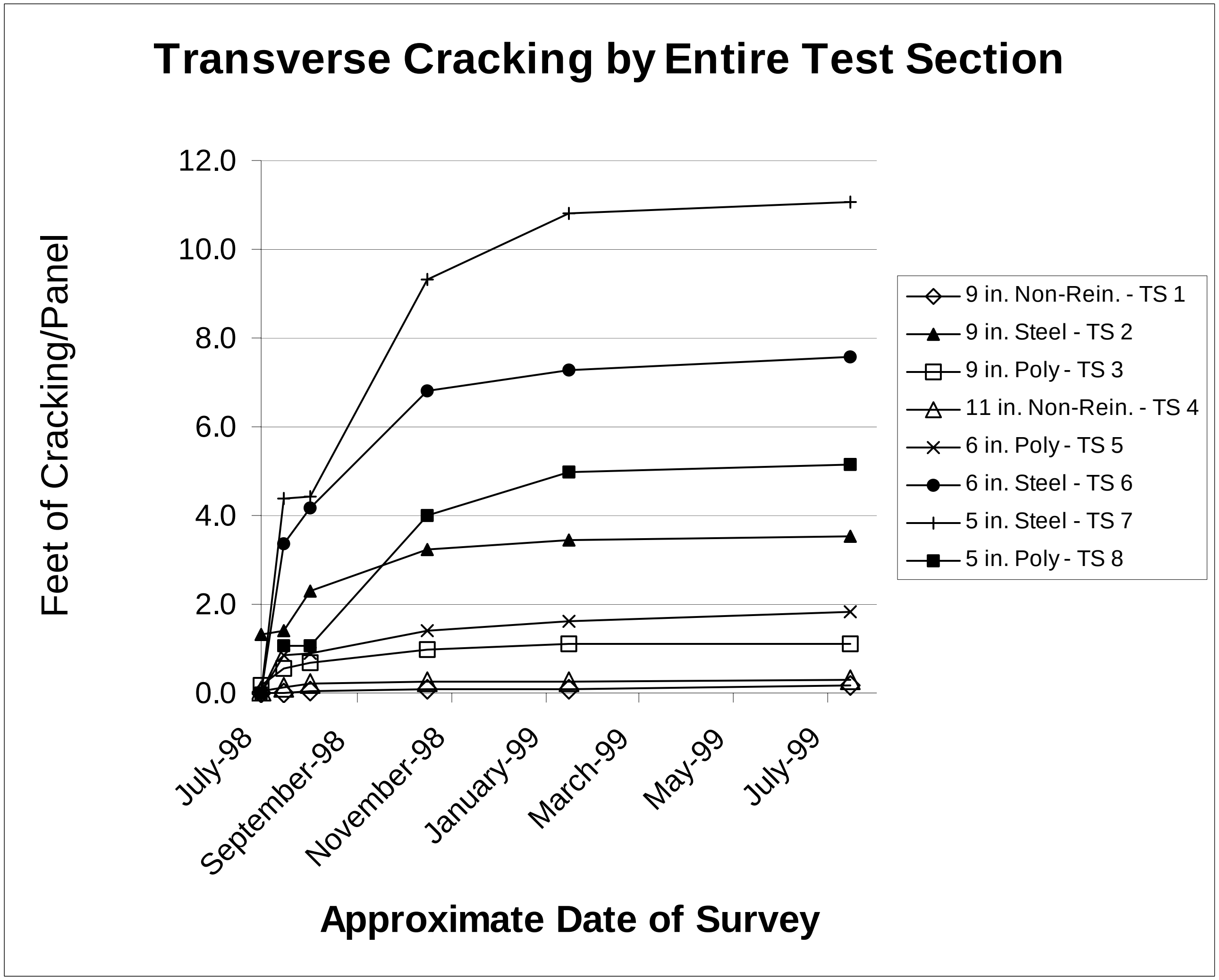
Pavement deficient in thickness by more than 8/10 inch will be considered under Sec 502.19.2.

3.2 Profile.

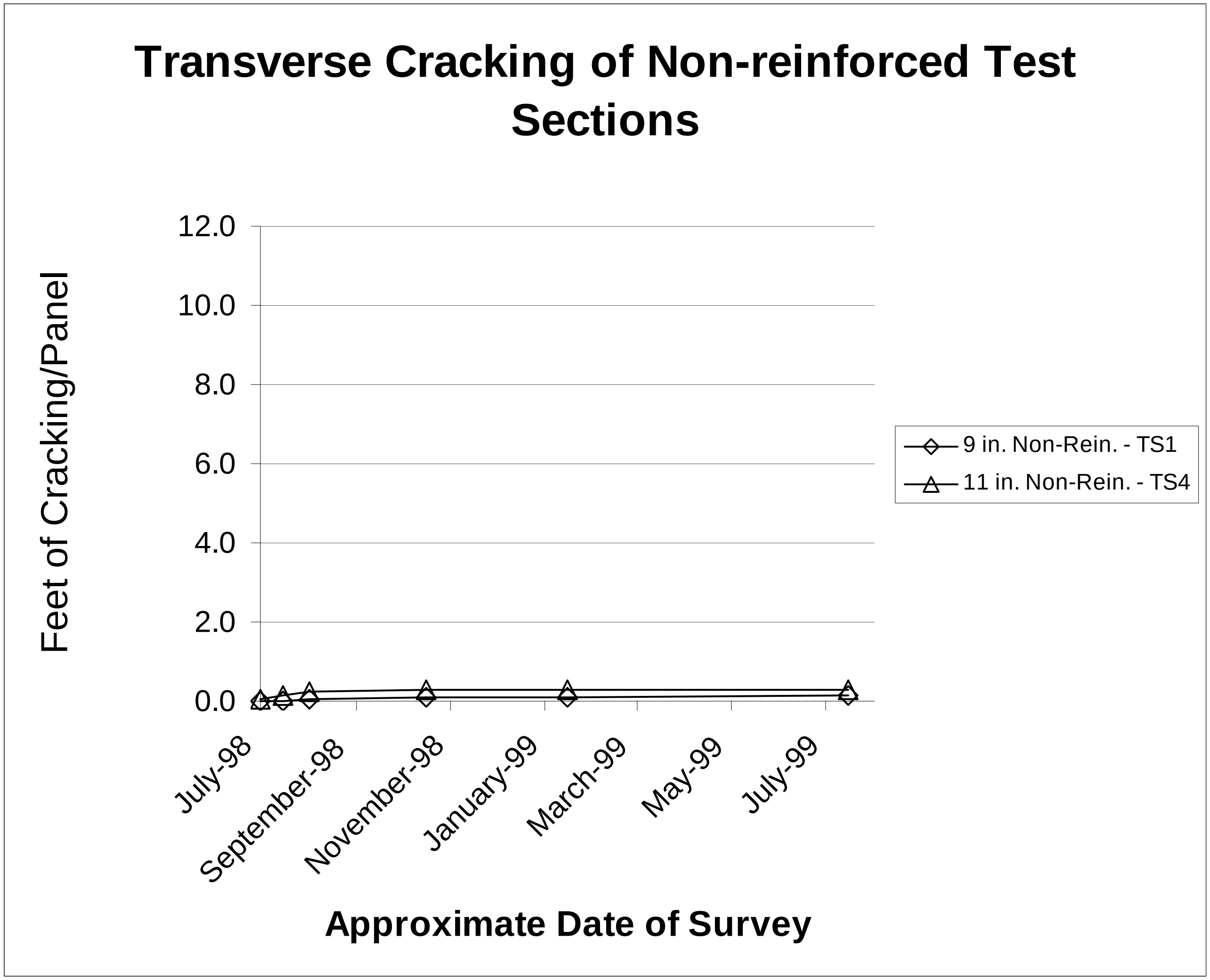
3.2.1 Initial Profile. Based on profilograph measurements made prior to diamond grinding operations, the contract price for square yard of PCCP paid will be reduced by 7 percent for sections of pavement having measurements of 45.1 or greater, prior to bump correction. Any subsequent bump correction in order to improve the final profile is at the option of the contractor.

3.2.2 Final Profile. Delete the table in Sec 502.19.5 and replace with the following table, which applies to the diamond ground surface in addition to any initial profile payment deductions.

APPENDIX F



Transverse Cracking by Entire Test Section
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Feet of Cracking/Panel
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Non-Rein. - TS 1
9 in. Steel - TS 2
9 in. Poly - TS 3
11 in. Non-Rein. - TS 4
6 in. Poly - TS 5
6 in. Steel - TS 6
5 in. Steel - TS 7
5 in. Poly - TS 8


Transverse Cracking of Non-reinforced Test Sections
Feet of Cracking/Panel
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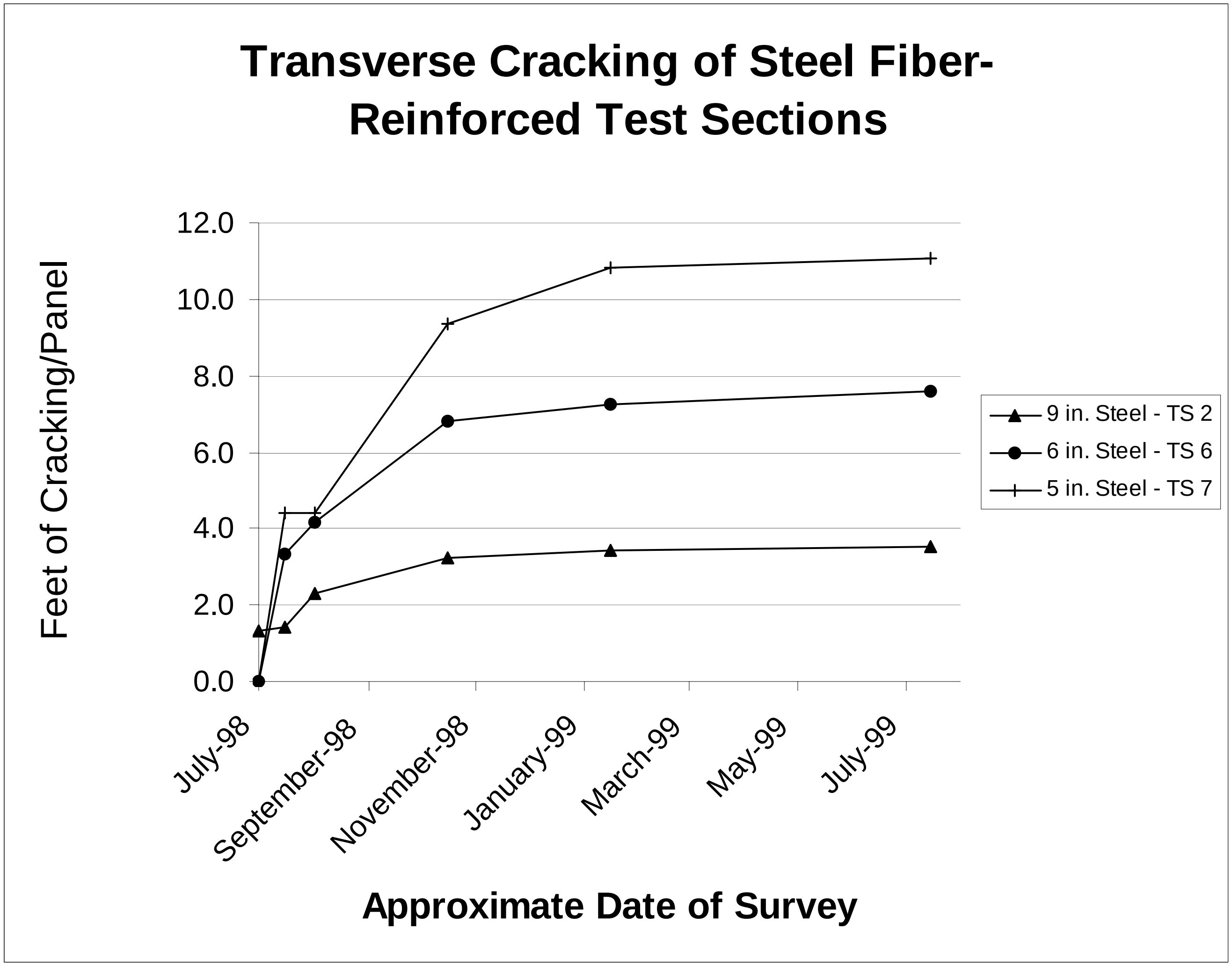
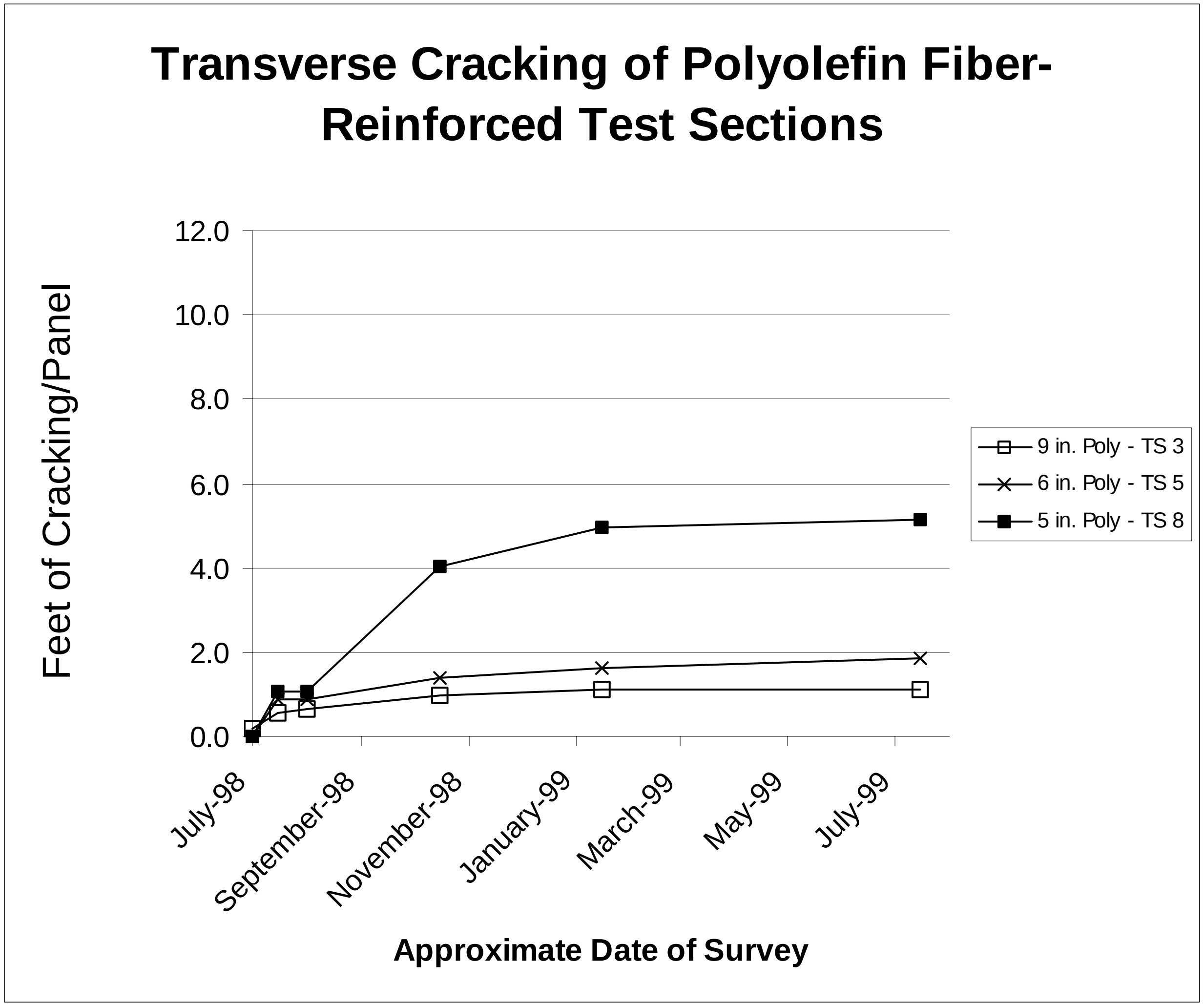
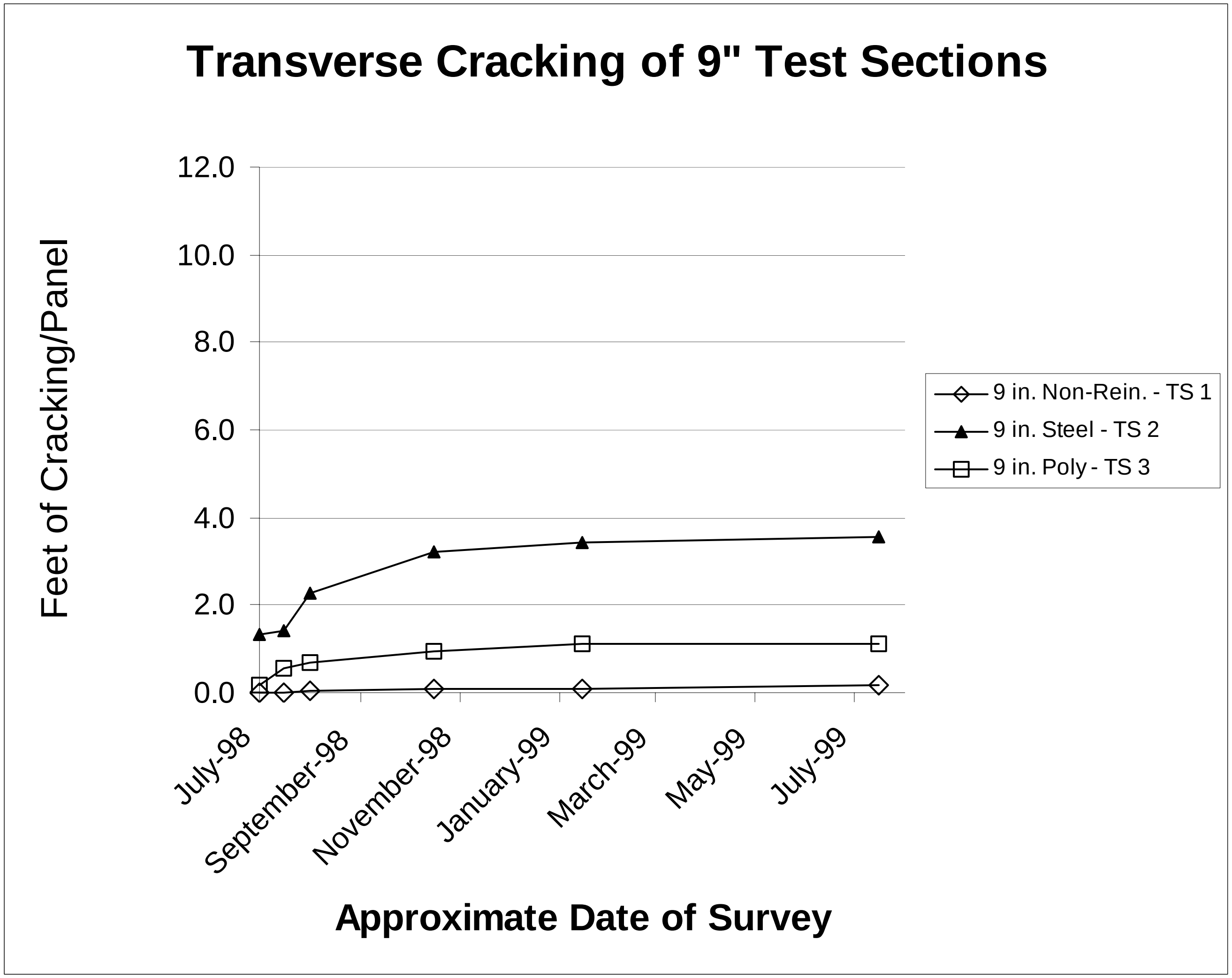
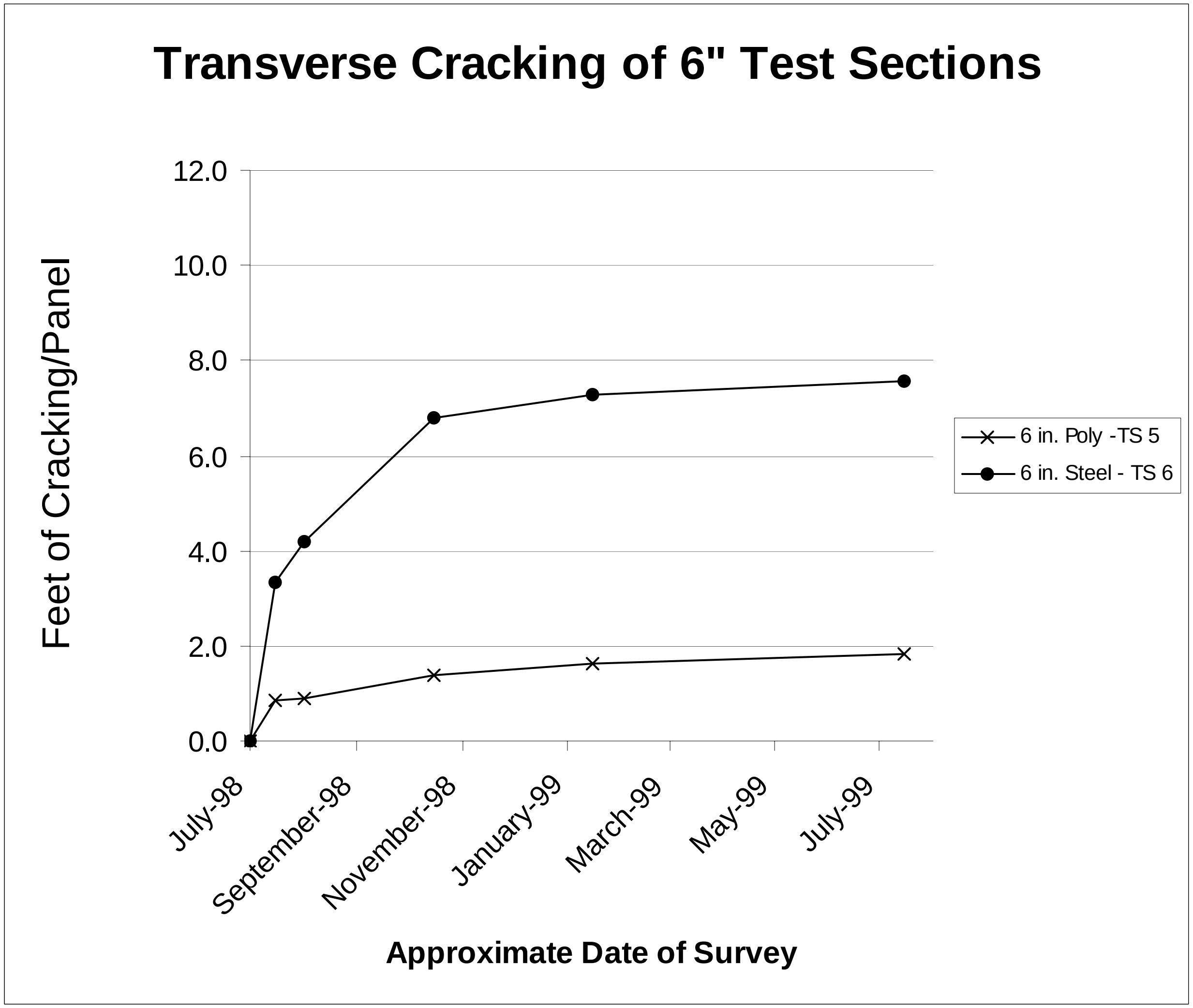
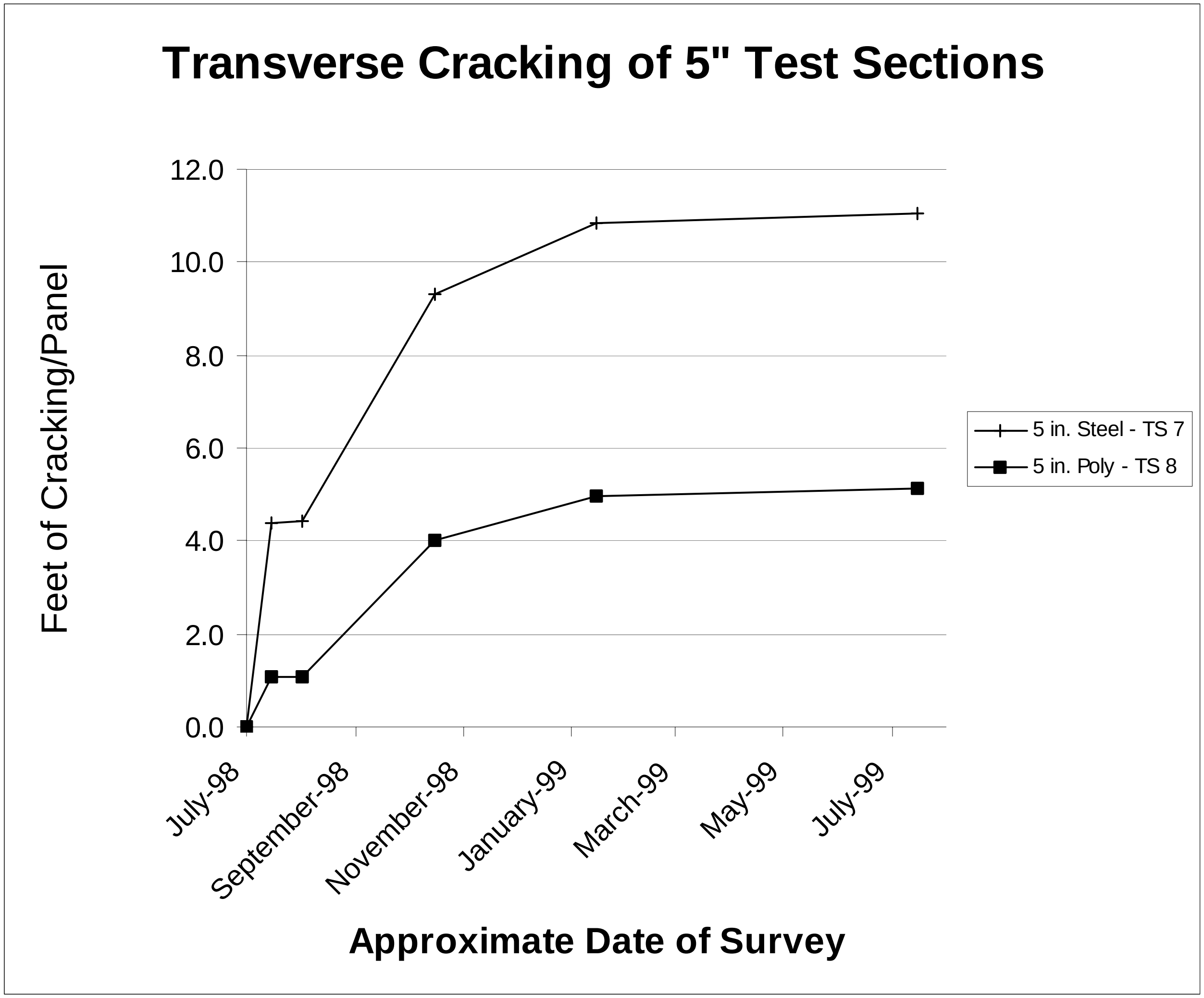
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Non-Rein. - TS1
11 in. Non-Rein. - TS4

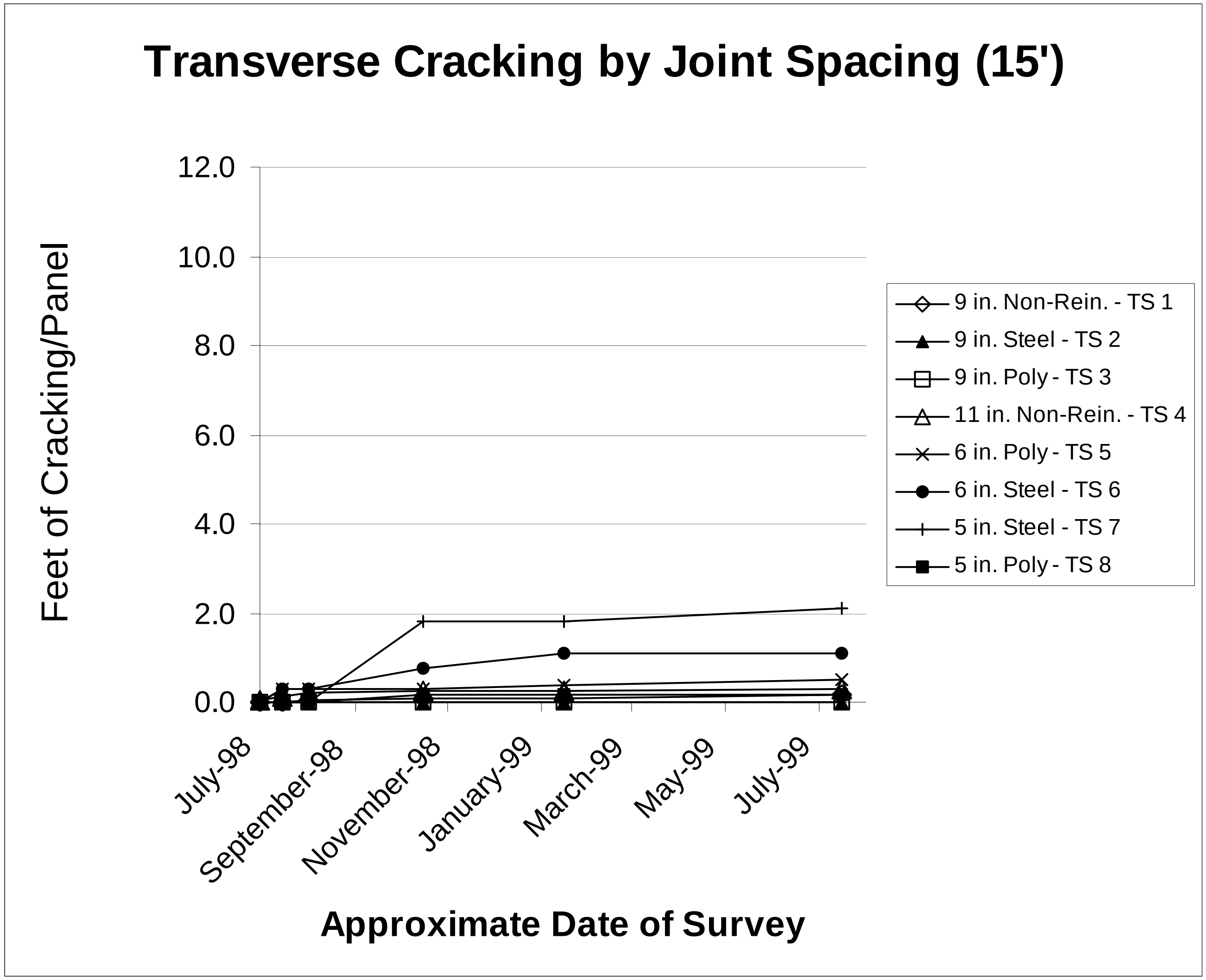

Transverse Cracking of Steel Fiber-Reinforced Test Sections
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Steel - TS 2
6 in. Steel - TS 6
5 in. Steel - TS 7


Transverse Cracking of Polyolefin Fiber-Reinforced Test Sections
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Poly - TS 3
6 in. Poly - TS 5
5 in. Poly - TS 8

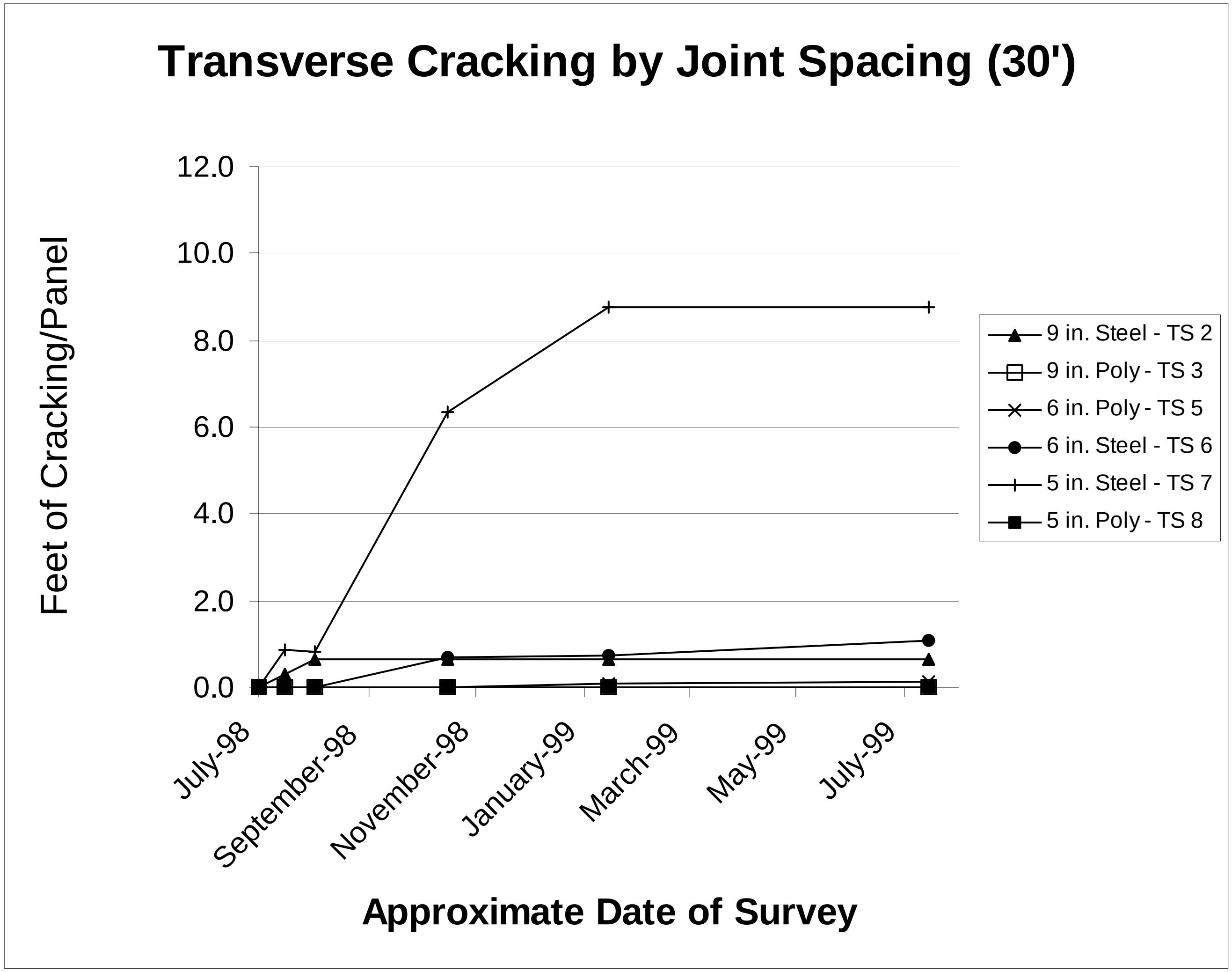

Transverse Cracking of 9" Test Sections
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Non-Rein. - TS 1
9 in. Steel - TS 2
9 in. Poly - TS 3

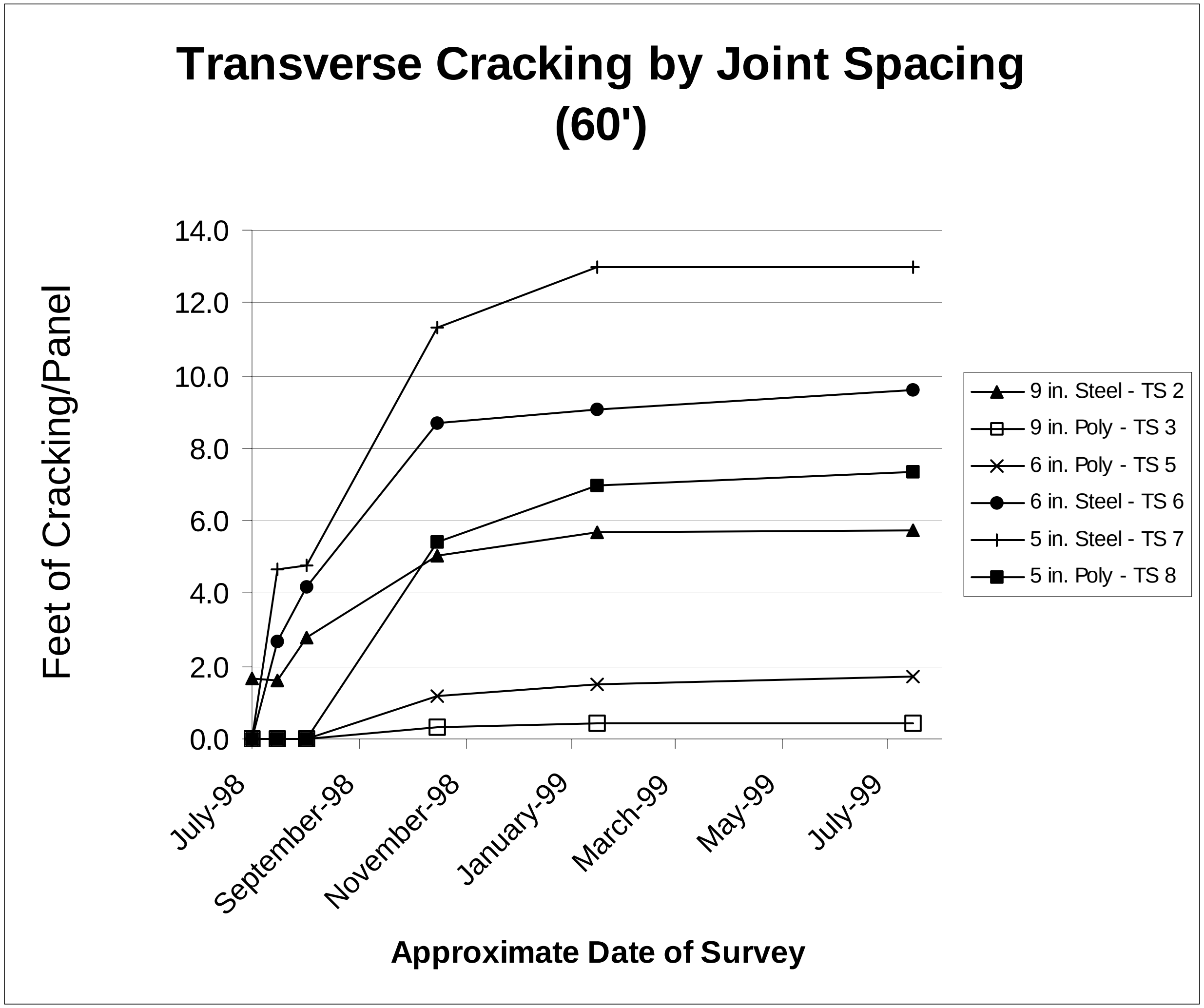

Transverse Cracking of 6" Test Sections
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
6 in. Poly -TS 5
6 in. Steel - TS 6

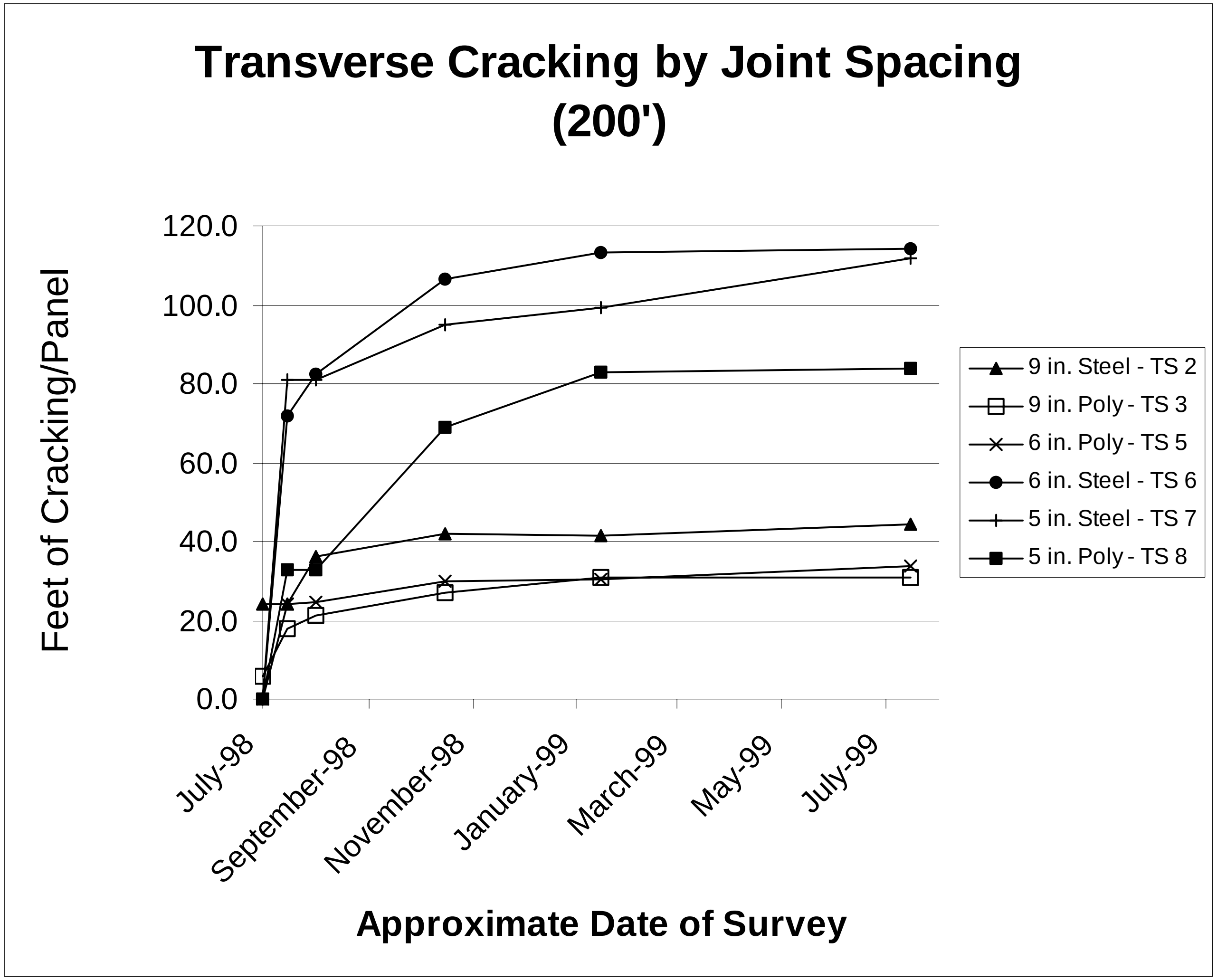

Transverse Cracking of 5" Test Sections
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
5 in. Steel - TS 7
5 in. Poly - TS 8



Transverse Cracking by Joint Spacing (15')
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Non-Rein. - TS 1
9 in. Steel - TS 2
9 in. Poly - TS 3
11 in. Non-Rein. - TS 4
6 in. Poly - TS 5
6 in. Steel - TS 6
5 in. Steel - TS 7
5 in. Poly - TS 8


Transverse Cracking by Joint Spacing (30')
Feet of Cracking/Panel
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Steel - TS 2
9 in. Poly - TS 3
6 in. Poly - TS 5
6 in. Steel - TS 6
5 in. Steel - TS 7
5 in. Poly - TS 8


Transverse Cracking by Joint Spacing (60')
Feet of Cracking/Panel
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Steel - TS 2
9 in. Poly - TS 3
6 in. Poly - TS 5
6 in. Steel - TS 6
5 in. Steel - TS 7
5 in. Poly - TS 8



Transverse Cracking by Joint Spacing (200')
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Feet of Cracking/Panel
July-98
September-98
November-98
January-99
March-99
May-99
July-99
Approximate Date of Survey
9 in. Steel - TS 2
9 in. Poly - TS 3
6 in. Poly - TS 5
6 in. Steel - TS 6
5 in. Steel - TS 7
5 in. Poly - TS 8