Evaluation of Pavement Crack Treatments
Literature Review

Final Report

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16. Abstract

The objective of this project was to evaluate existing literature regarding the practice of pavement crack sealing and crack filling. Crack sealing and crack filling consist of the placement of specialized materials into the cracks in pavement surfaces in order to prevent the intrusion of water and foreign objects. It has been suggested that this process extends the life of a pavement surface and can therefore reduce an agency's pavement replacement and rehabilitation costs. The following topics were identified in previous studies, including some conducted in Connecticut, and are discussed in this report: benefits of crack treatment; roadway evaluation; procedures and equipment selection; material placement; treatment materials evaluations; and traffic safety issues. Overall, the previous literature suggests a great deal of variability in opinion regarding the benefits of crack treatment. There is much inconsistency with results from previous studies with respect to location, circumstances and materials employed.

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Asphalt Pavements, Crack sealing, Pavement cracking, Field performance, Hot pour sealants, Cold pour sealants

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INTRODUCTION

Crack treatment involves two types of action: crack sealing and crack filling. Crack treatment is the placement of specialized materials into the cracks of pavement surfaces in order to prevent the intrusion of water and foreign objects that may damage the pavement structure. The Federal Highway Administration (FHWA) Manual of Practice (1) identifies the distinct difference between crack filling and crack sealing. Crack sealing is “the placement of specialized treatment materials above or into *working* cracks using unique configurations to prevent the intrusion of water and incompressibles into the crack.” A working crack is defined as having movement in excess of 3 millimeters. Transverse cracks, cracks perpendicular to the direction of traffic, are typically considered to be working cracks and are often targeted for crack sealing. The Manual further defines crack filling as “the placement of ordinary treatment materials into *non-working* cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement.” Non-working cracks are defined by the FHWA Manual of Practice (1) as “cracks where little movement is occurring between crack edges.” Most longitudinal cracks, cracks parallel to the direction of traffic, are typically considered to be non-working cracks and are often targeted for crack filling. The sections of this report describe the benefits and procedures for crack treatment, and the evaluation procedures used on crack treated roadway sections including both previous Connecticut studies and traffic safety concerns.

BENEFITS OF CRACK TREATMENT

While there are a large number of studies regarding crack sealing, there are very few that have reviewed the overall cost-effectiveness of crack sealing. Most states currently base their crack treatment techniques and practices on a long-standing policy and not on quantitative research (7). Many agencies simply assume that it is cost-effective to seal cracks. The FHWA Manual of Practice (1) indicates that while crack sealing and filling are imperative preventative maintenance tools, the materials used in the past have generally failed to serve their purpose. To some extent this has thwarted the need for individual states to evaluate cost effectiveness of most preventative crack treatments and has also raised into question the overall safety of the roads and highways that have already been treated. Consequently, crack treatment has been applied to the same surfaces repeatedly. A research team, Hand et al, (7) is currently carrying out a study on the cost-effectiveness of crack seals on roadways in Indiana. Their literature review of crack sealing of Portland Cement Concrete (PCC) pavements refers to several studies conducted by the Wisconsin DOT (WDOT) that led to a statewide policy not to treat PCC pavements in Wisconsin (8). Their studies included statistical analyses performed to compare the performance of treated and untreated test sections. The results indicate that crack treatment on PCC pavements did not have a significant effect on pavement distress, ride quality, material integrity, or pavement life. WDOT implemented the “no-seal” policy in 1990 on new PCC pavements and claims to have saved $6,000,000 annually with no loss in pavement performance and with increased customer safety and convenience.

Hall et al. (9) showed that while crack sealing may prevent the intrusion of water and foreign objects into cracks, crack sealing did not demonstrate any beneficial initial or long-term effect with respect to typical pavement distress measurements, such as International Roughness Index (IRI), rutting, or cracking. The information that Hall et al. present was gathered from the SPS-3 experiment, in which long-term pavement performance studies were conducted throughout various test sites in the United States and Canada. These results indicate that new pavement distress measures should be developed to specifically address the effect of cracks on the overall life of the pavement structure.

MATERIALS

In selecting the appropriate material for use, there are specific qualities or properties of the application that should be established. These include preparation time, workability, cure time, adhesiveness, cohesiveness, flexibility, elasticity, resistance to aging, weathering, abrasion, softening and flow. Certain material characteristics perform better in different circumstances. The standards for the finished repair should dictate the material selection. In many cases, individual states have evaluated different materials and each state has developed a list of acceptable or approved products.

The materials used for crack treatment come from many different manufacturers and each provides a list of guidelines for application and usage. There are four distinct types of hot pour crack sealer/filler as defined in American Association of State Highway and Transportation Officials (AASHTO) M324 (20) or ASTM D 6690. Type I is designed for moderate climates tested at a low temperature of –18°C with 50% extension. Type II is designed to be effective in most climates and is tested at a low temperature of –29°C with a 50% extension. Type III is also designed to be effective for most climates. It is tested under the same conditions as Type II with additional special tests. Finally, Type IV is designed to be effective at very cold temperatures and is tested at a low temperature of –29°C with a 200% extension.

Among these different types of hot pour sealant, many variations to a hot pour crack sealant design can be made. For example, merely changing the rubber content of the sealant will affect many key properties of that sealant. In an experiment performed by Qatan and Yildirim (18), three different cold pour sealants and four different hot pour sealants were tested at eight treatment locations in five districts of Texas (Atlanta, El Paso, Lufkin, Amarillo, and San Antonio). Increasing the rubber content in the material reduced its ductility as well as reducing the bond strength in cold temperatures. Other features that were altered included the flow of the treatment material, the resilience of the material, and the softening point of the material. Furthermore, materials with a high softening point are generally used to repair cracks in parking lots to minimize tracking by pedestrians. Adjusting the polymer content of the sealant changes the way in which the sealant will be used.

The following manufacturers and their materials were reviewed:

CRAFCO Inc. (11) manufactures different sealants and treatment products including Hot Applied Asphalt Rubber ®, Asphalt Rubber Plus ®, Polyflex®, and Roadsaver Sealants ®. The materials come in package form and are melted in a heat transfer unit prior to application. CRAFCO Inc. recommends a pressure feed wand application unless the material is of a low viscosity at which point a gravity feed can be used. Application temperatures are specified in order to ensure proper adhesion. Crack cleaning as defined below, is recommended and there is a recommended minimum width to which cracks should be routed prior to treatment.

GER – Hot Pour Sealant (19) designs three types of hot pour material. A low polymer material is typically used for roofing joints. High polymer materials are better suited for roads, floors and roofs. GER also produces a sealant that is jet fuel resistant to be used on runways and gas stations.

Golden Bear Oil (12) manufactures a treatment material known as CRF®, which is an emulsified asphalt material used in cold pour applications. The low-end application temperature is 32°F and the high-end application temperature is 180°F. The reviewed document (12) states that cleaning the crack (as defined later) is not required unless a crack depth between ¼ inch and ½ inch is present. Deeper cracks require sand plugging to reduce the depth to approximately ½ inch so as to prevent the material from running along the inside of the crack and not building up to the surface. The recommended application procedure dictates that the emulsion should be poured into the crack until it is even with the road surface and then covered with unwashed sand to prevent it from tracking during the curing period. One to three weeks are required for complete curing depending on ambient and atmospheric conditions; however, traffic can be introduced as soon as the emulsion is covered with sand. The sand can generally be removed from the road surface within one to two days of the application.

Mr. Allen Watts, of Golden Bear Oil, was contacted on May 26, 2004 by CAP Lab personnel to help inform what standard tests this emulsified product was subjected to in order to ensure its quality and performance. Mr. Watts indicated that there were three basic tests that were specified by American Society of Testing and Materials (ASTM) regulations. The first test being ASTM D244-00: *Standard Test Methods for Emulsified Asphalts*. The second test is ASTM D2006-65: *Method of Test for Characteristic Groups in Rubber Extender and Processing Oils by the Precipitation Method*. Note that this test was withdrawn from the ASTM specifications in 1975, and the results for this test are no longer submitted to the Connecticut DOT. The third test is ASTM D2170-01a: *Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)*. In addition to these tests, there is a “plus” test, or Golden Bear test, that the material is also subjected to. This test is called a *Pumping Stability Test*. In this test, the stability of the material is tested as it passes through a pump. There have been no tests for adhesion.

MulchSEAL ® (13) is a patented cold application process available for the repair of pavement cracks. It is also intended as a preventative tool for reflective cracking on bituminous resurfacing. The manufacturer indicates that the reflection of existing cracks would be delayed for years if the MulchSEAL process were employed prior to resurfacing. Furthermore, the manufacturer suggests that this treatment material becomes more adhesive and strengthens when subjected to traffic loading.

CONNECTICUT APPROVED PRODUCTS AND SPECIFICATIONS

The Connecticut DOT has certain criteria that crack treatment products and their application procedures must meet. The materials that are deemed acceptable include all hot pour materials that meet the AASHTO M301 (ASTM D 3405) standard. This standard was discontinued in the 24th edition of the AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* and replaced by M324 (ASTM D 6690) in year 2004. M324 Type II would be the equivalent of M301. Current ConnDOT specifications do not reflect these changes. In recent years, there has been only one cold pour product used in Connecticut. This product is a liquid petroleum emulsion.

Assuming the products that are to be used fall within the constraints of the approved products for Connecticut, there are certain specifications that must be met for their placement. Most importantly, the contractor is required to submit a certified test report that the material being used meets all specifications of the supplier and state. For highway pavements, the material must be tested and approved by the Director of Research and Materials Testing of the Connecticut Department of Transportation.

Appendix A details the materials and specifications used by states surrounding Connecticut.

SOFTWARE TOOL

During the course of the Federal Highway Administration's Long-Term Pavement Performance (LTPP) program, they noted the important role that the climate plays in the effectiveness of the sealant material. Warm climates require "stiffer" sealants to resist the hot temperatures that would make the sealants too soft and in effect come unbonded from the crack. In contrast, cold climates require a softer and more flexible sealant to compensate for the higher level of widening in the cracks during colder weather as well as the stiffening of sealant caused by the colder temperatures. The LTPPBind (23) software tool determines the high and low temperatures for a given project location based on climate. The program was tested in Fairbanks, AK (cold climate) and Laredo, TX (hot climate) and tested positively with a 98% reliability rate. Therefore, the program is deemed reliable and the temperatures obtained from this program are useful in selecting the appropriate crack-sealing materials for each given project. The temperature ranges produced by this product are used in classifications of materials that meet certain ASTM standards.

EVALUATION, PROCEDURES AND EQUIPMENT SELECTION

The FHWA Manual of Practice (1) recommends certain steps for selecting procedures and equipment in the crack filling/sealing process. For maximum performance, two of these steps are imperative. First, the crack must be cleaned and dry. The other essential step requires the material to be properly prepared and applied. Optional steps in the repair process include cutting or routing the crack, finishing or shaping the material, and blotting. The following subsections outline the crack treatment process according to the FHWA Manual of Practice (1) as well as the ConnDOT standard practice.

ROAD OR ROAD SEGMENT EVALUATION:

Before any crack sealing or filling is recommended, a roadway must first be evaluated to determine the amount of distress in its surface. Correspondence with 4 Connecticut District Maintenance Supervising Planners (21) indicates that roads are evaluated using the PSR (Pavement Serviceability Rating). PSR numbers range from 1 (worst) to 9 (best). Typically, a road with a PSR number of 6 or 7 would be considered for crack treatment as long as resurfacing is not in the foreseeable future. The first consideration for crack treatment of a road or road segment generally takes place four to five years after placement of the wearing surface. This rating is based on the following 5 criteria with their respective weights:

1)	Cracking	25%
2)	Distortion	15%
3)	Disintegration	30%
4)	Drainage	20%
5)	Ride	10%

The evaluation process is based on visual judgment by qualified personnel in the field. The rating is therefore subject to the judgment of the individual or individuals evaluating the roadway. The five criteria listed above represent the facets of distress to be considered. Following the evaluation of the subject area, recommendations for pavement treatment are based on and indicative of the assigned PSR number.

CRACK PREPARATION:

FHWA Manual of Practice (1) notes the cleaning and drying process as the most important part of the sealing/filling process because wet or dirty channels result in adhesion failures between the filler/sealer material and the sidewall(s) of the crack. According to the FHWA Manual of Practice (1), the four typical methods used for cleaning and/or drying cracks are air blasting, hot air blasting, sandblasting and wire brushing. The air blasting equipment consists of portable backpack blowers or higher-pressure air compressors. The portable backpack blowers are not generally recommended in cleaning cracks because they have a lower blast velocity than other methods. Connecticut specifies that adequate air pressure for air blasting be supplied from a unit that "…will have a minimum rated capacity of 90 psi." (22).

Hot air blasting involves use of a hot-air lance (HAL) connected to a compressed air unit. The HAL when used properly, could provide two key benefits. The first benefit of hot air blasting is the rapid dissipation of moisture from the crack. The second benefit is the added bonding capacity that is generated from having heated crack surfaces provided that the treatment takes place immediately after the cleaning and drying procedure while the crack faces are still warm. A study in 1999 by Masson et al. (3) in Montreal, Canada evaluated the use of the HAL method. Their results indicate that normal heat treatment by the HAL has little effect on sealant adhesion, and it may cause the binder to become brittle. Results obtained from laboratory experiments were similar to those obtained from fieldwork.

Sandblasting also has benefits for the treatment application. The sandblasting method leaves a debris free cavity which helps ensure proper bonding. Moreover, the abrasive nature of the sandblasting removes loose particles from the crack sidewall surface, which also helps to ensure proper bonding. The disadvantage to sandblasting is that it involves more labor and effort than other cleaning and drying methods. No studies evaluating the effectiveness of sandblasting were obtained during this literature review.

Wire brushing is another commonly used cleaning mechanism. According to the FHWA Manual of Practice, wire brushing is most useful in removing loose debris from cracks, but is not as effective as sand blasting in the removal of laitance which is a weak layer of asphalt and aggregate fines on the face of the crack. Sand blasting is also more efficient at removing loose asphalt fragments from the crack (1). No studies evaluating the effectiveness of wire brushing were obtained during this literature review.

It has been suggested that by cutting or routing cracks, desirable material shape factors can be achieved improving the ability of the material to withstand greater movement by increasing adhesion (1).

ConnDOT Specifications for cracks deeper than 1 inch specify a backer rod to be installed to a level of at least 1 inch below the driving surface (22). This is to ensure that the treatment material does not adhere to the underlying surface. When the backer rod is installed properly, the treatment material is allowed to expand and contract with the pavement as is desired. The backer rod must be ½ inch and is the only acceptable filler material (22).

In the event crack routing is specified, ConnDOT specifications (22) require the crack routing to be conducted with a vertical spindle or rotary type cutter in order to ensure unnecessary damage does not take place. In some cases, it may be desirable to have cracks widened in order to ensure the material actually enters the crack. Crack widening can be easily performed with routers or saws. However, the FHWA Manual of Practice (1) recommends crack routing over saw cutting because cutting is a rather slow process and cannot conform to the path of the crack as well as a router. It is also suggested that saw crack cutting does further harm to the pavement, as the saw blade cannot follow the irregular path of a crack. A vertical spindle router is then considered the best-suited preparatory repair machine as the slender vertical router can closely follow crack wanderings. While each state has its own policy regarding crack cutting, transverse sawing of new hot-mix asphalt (HMA) pavements above concrete slabs or “saw and seal” practice is common in most states.

PLACEMENT SPECIFICATIONS:

Once the equipment and procedure for preparing the cracks has been selected , the filler/sealer material must be selected. There are multiple options for materials, each with its own application procedure. Standard procedures for applying each of these materials are given in the FHWA Manual of Practice (1).

Hot-Applied – As per ConnDOT specifications, if the crack is to be sealed with hot pour material, a nozzle or hand-pouring pot must be used to ensure proper projection into the constructed joint or random crack (22). Hot-applied thermoplastic bituminous fillers or sealers are usually prepared in a distributing mechanism with a heating kettle or vat. Connecticut specifies that the kettle shall be a “combination melter and pressure applicators. It shall be constructed as a double boiler with space between the inner and outer shells filled with oil or other material for heat transfer.”(22) Also, regardless of the project size, it is recommended that an insulated applicator hose and wand be used when applying the hot pour material. This hose ensures that the crack will be sealed properly in a more accurate manner, than is possible when directly pouring the material into the crack from the kettle. The level of the sealant must not reside below $^1/_8$ inch of the driving surface after cooling as per the contract specifications. (22) If the material is $^3/_{16}$ inch or more below the surface then it must be brought up to the specified level with more hot pour material. Also, the temperature of the material in the melter shall not exceed the temperature specified by the manufacturer by more than 15°C. Furthermore, if there are leftover materials in the melter at the end of the day, no more than 25% of salvaged material shall be mixed with new material for use on the next treatment day. The hot pour contract states that “When traffic conditions or slow drying time occurs – a light application of approved cover material will be required.” (22) The cover material is specified as an “approved liquid or Limestone.”(22)

Cold-Applied – As per ConnDOT specifications, thermoplastic bituminous filler or sealer can be either applied with no heat or may be partially heated. As such, the material may be kept stored in drums or containers and can be directly applied or it may be used with partial or no heat in a distributor with a hose and wand application. If a cover material is to be used on a cold pour material it will be done using either the contractor’s truck which is capable of applying the cover material or hauled by ConnDOT trucks and applied by hand by ConnDOT forces. The contractor will generally apply the material so long as the truck is available.

When the contractor’s truck is not available, ConnDOT trucks are used to haul the material and ConnDOT forces are used to apply the material (21).

PLACEMENT CONFIGURATION -- Four crack sealer and filler material placement configurations and their variations along with four controlling variables are given by the FHWA Manual of Practice (1). The four placement configurations are:

<u>flush fill</u> - material is simply dispensed into the existing, uncut crack and excess material is struck off.

<u>reservoir</u> - material is placed only within the confines of a cut crack (i.e. *crack reservoir*). The material is placed either flush with or slightly below the pavement surface.

<u>overband</u> - the material is placed into and over an uncut crack. If the material over the crack is shaped into a band using a squeegee, then the simple *band-aid* configuration is formed. If the material over the crack is left unshaped, then the *capped* configuration is created.

<u>combination of reservoir and overband</u> - consists of a material placed into and over a cut crack. A squeegee is used to shape the material into a band that is centered over the crack reservoir

Diagrams of these configurations are shown in Appendix A.

The choice of configuration is based on the following parameters: 1) type of application – whether it will be direct or bond-breaker, 2) type of crack channel whether cut or uncut, 3) the finishing characteristics of the repair, and 4) the actual dimensions of the crack and repair. Numerous comparisons have been conducted by different organizations all bearing similar results. Typical outcomes of these studies are presented below.

Smith and Romine (2) report on the result of a comprehensive pavement surface maintenance study. The SHRP H-106 experiment and subsequent FHWA Long Term Maintenance (LTM) project included: 1) the installation of 31 unique crack treatments (i.e., combinations of sealant/filler materials and installation method) at 5 different test sites. Each treatment was employed on a section totaling 10 cracks. Abilene, TX; Wichita, KS; Elma, WA; Des Moines, IA; and Prescott, ON were the 5 locations, 2) the laboratory testing of experimental sealant/filler materials, and 3) the 7-year performance monitoring of the various crack treatments. Their efforts included cost-effectiveness analysis that considered the total installation cost and estimated service life of each treatment. The most cost-effective treatments were found to be those consisting of rubberized asphalts that were placed in a standard or shallow recessed band-aid configuration. The least cost-effective sealants were the fiberized asphalt and proprietary emulsion sealants. The products of the said investigation are included in the FHWA Manual of Practice along with other data, review material and defining information (1).

In another study, Eli Cuelho and Reed B. Freeman (4a) report on the cost-effectiveness of crack sealing materials and techniques for asphalt pavements. The State of Montana Department of Transportation Research Section and the U.S. Department of Transportation Federal Highway Administration funded the study (4). Four test sections in Montana were selected (Conrad, Dutton, Tarkio, and Helena). Eleven sealant materials were selected for use including one cold pour (Witco CRF-MP) and ten hot pour (Crafco 221, Crafco 231, Crafco 299, Crafco 516, Crafco 522, Deery 101 ELT, Deery 1101, Maxwell 60, Maxwell 71, and Maxwell 72). Six different sealing procedures were used to apply these various materials. The procedures included: simple band-aid (BA), capped (CAP), square reservoir and flush (SQ-F), square reservoir and recessed (SQ-R), square reservoir and band-aid (SQ-BA), shallow reservoir and flush (SH-F).

The materials and procedures were used in various combinations throughout the four test sites. Of the results reported by Cuelho and Freeman, several conclusions can be drawn. In Conrad, the band-aid and capped configuration as well as the square reservoir and recess performed worst of all for treating both transverse and longitudinal cracks. Maxwell 60 was very ineffective material. It should be noted, however, as stated by the authors, that the materials for this site were commonly applied in unfavorable conditions, which may have contributed to the overall poor performance of crack sealing in this section. In Dutton, only the square-flush and shallow-flush configurations were tested, with the latter performing favorably. In this section, Crafco 516 was the least effective material. Tarkio showed that again the square reservoir and recess was the least effective method for both longitudinal and transverse cracking. Crafco 221 and Maxwell 72 were the least effective materials reported for this section. Of note is the fact that the band-aid configuration performed exceptionally well for sealing longitudinal cracks in this section.

The final section evaluated was located in Helena. The authors state that this section has the most valid results, because evaluations were performed seasonally to gain a broader range of behavior patterns for the materials and application procedures. Only transverse cracks were treated in this section. Six months after application, during the winter season, the test site in Helena showed the band-aid configuration to be the weakest method with Maxwell 72 to be the least effective material. For evaluations at 32 months (spring), 42 months (winter) and 57 months (summer) after the initial application of material; all showed the band-aid configuration and Deery 101 ELT to be the least effective procedure and material respectively. It is important to note, however, that performance varied based on the season the evaluation was performed in. The materials all performed better when the climate was warmer rather than when the climate was colder. This fact can be attributed to the shrinkage effects that cold temperature has on the asphalt pavement, causing it to pull away effectively widening the crack. The breakdown of failure rates for both the material and procedures for this site are shown in Appendix C.

Overall, all test sites in this study indicated that it is more effective to have a square reservoir, except when using a recess configuration. Also, it was common that the band-aid, capped, and square reservoir with recess configurations had most of their failure caused by adhesion and cohesion losses, whereas the other configurations' failures were primarily caused by secondary cracking. In addition, Cuelho and Freeman determined that the most cost effective material/procedure combination for use was the Crafco 522 with a shallow reservoir and flush. The combination of Crafco 231 with a square reservoir and flush was also highly cost effective. The least effective combination was deemed to be Deery 101 ELT with a square reservoir and recess.

FINISHING:

Finishing of crack treatments is generally performed with a squeegee (1) during hot pour applications and is not required on capped and recessed configurations where the treatment material surface is purposely left at a height above or below the driving surface. When a cover or blotting material is required for hot pour treatments as described above, a light application of an approved cover material, such as an approved liquid or Limestone, is applied (22). This cover material serves as a bond breaker to prevent vehicle tires from pulling the treatment material from the crack.

PERFORMANCE EVALUATION CRITERIA

Guidelines have been established by the FHWA Manual of Practice (1) to help evaluate the performance of crack treatments. These guidelines include an eight-step crack treatment program involving analysis, treatment determination and performance of treatment. The analysis sequence includes review of the existing pavement maintenance history as well as a physical quantification of the crack severity. Local conditions such as traffic intensity, percent trucks, and climate are also considered. The Manual offers a crack survey worksheet to assist in this evaluation. Based on this survey, the appropriate maintenance procedure can then be determined along with the materials to be used. The maintenance is then to be carried out and periodically evaluated as to its performance

The Manual of Practice (1) also recommends that an evaluation be made at least once every year and that this evaluation should take place in the middle of the cold season when the crack is near the maximum opening. A small representative sample should be examined to establish the performance level of the treatment material. The following conditions indicate failure of the treatment material:

- loss of full depth adhesion
- cohesion loss
- material pull out
- spalling
- secondary cracks
- potholes

The manual offers a comprehensive method to estimate the percentage of failure that the material exhibits and to approximate the effectiveness of the material versus time.

The SHRP H-106 crack treatment study performed by Smith and Romine (2) examined the performance of many different crack treatment materials as well as methods of placement in several locations in the United States and Canada. During the study Smith and Romine (2) developed their own criteria for deciphering material distress from material distress failure and used the established guidelines while performing their evaluations. The following paragraph was extracted from Smith and Romine (2), page 47.

"*Most of the distresses represented a reduction in a treatment's ability to perform its function (i.e., to keep water and incompressibles out of the crack channel). Examples of these distresses include partial-depth adhesion and cohesion loss, and overband wear. On the other hand, some distresses, such as full-depth pull-outs and full-depth adhesion and cohesion loss, signified a treatment's failure to perform its function. These distresses were termed "failure distresses." The total amount of failure distress observed in a treatment formed the basis for performance comparison."*

A study conducted by D.R. Johnson et al. (4) included an analysis of four test locations where several different crack treatment materials and techniques were used. These sections were constructed and then analyzed after one, six and twelve months had passed since treatment ensued. The report states that evaluations were "generally" consistent with the procedures outlined in SHRP Experiment H-106. Modes of failure included material failure as well as any other condition that permitted the intrusion of water into the pavement. Material failure included the breakdown of adhesion and cohesion integrity. Cohesion failure was stated as a condition where fracture was evident within the treatment material itself. Adhesion failure was stated as being the loss of bonding between the treatment material and the crack reservoir wall.

The report also indicated that there were failure mechanisms that would be the result of “a combination of factors.” These conditions involved pullouts as well as secondary cracking. Pullouts were defined as “the complete removal of sections of sealant from the pavement.” Secondary cracking was defined as “the formation of short cracks generally parallel to a sealed crack.” The report indicated that secondary cracking could be caused by routing or sealants that do not effectively relieve stress in the pavement.

During the analyses of the sealed sections, failures were quantified on a per crack basis as a percentage of total crack length. The percentages were then assigned a rating per SHRP H-106 using the following logic extracted from page 34 of the report:

- 0 to 10 percent failure, excellent;
- 11 to 20 percent failure, good;
- 21 to 35 percent failure, fair;
- 36 to 50 percent failure, poor; and
- 51 to 100 percent failure, very poor.

Superficial pavement distresses were also recorded at the time of each analysis but were not deemed failures at the time because their conditions did not allow water to intrude into the pavement. The report indicated that these conditions were recorded because they could lead to problems in the future. These conditions included bubbling, extrusion, tracking, stone intrusion, weathering and wear. The classification of these conditions was inconsistent with the failure modes because they were not yet considered failures. Instead, the superficial distresses fell into one of the following three categories:

- Less than one-third crack length
- One-third to two-thirds crack length
- Greater than two-thirds crack length

Only distresses thought to be moderate to high in severity were recorded.

A study conducted by Yildirim et al. (5) evaluated the field performance of hot pour sealants and cold pour sealants. The evaluation of performance was carried out via visual analyses of several treated sites. The report states that the failure rate was determined by calculating the ratio of the length of the treated section subjected to distresses to the original length. The distresses observed in the sections included full-depth pullout and full-depth cohesion or adhesion loss.

The evaluation process also included a procedure (AASHTO PP20-94) for calculating effectiveness percentages. The failure modes primarily consisted of opening of sealed cracks, full-depth adhesion or cohesion loss as well as spalls. Bleeding was also assessed at test sections which were covered with a chip seal. For this evaluation, the process used was that depicted in SHRP-LTPP/FR-90-001. This evaluation method classifies bleeding severity into the following categories:

- Low
- Moderate
- High

Shober (8), states that Wisconsin DOT evaluates pavement distress using an index that takes into account all types of distresses. This index is the pavement distress index (PDI). PDI weighs the severity as well as the extent of the distress and their relative effect on overall pavement performance. These weights are then combined into one index. The range of the index scale is 1 – 100 with 100 being the worst possible rating. Shober also states that pavement distresses are evaluated using a ride factor and quantified via the International Roughness Index (IRI). The IRI ranges from 0 (perfectly smooth) to 5 (very rough). The report does not specify exactly what values would indicate failure.

RESULTS OF PERFORMANCE EVALUATIONS

Three comprehensive studies of performance evaluations for crack sealing were found. The first, a study conducted by Yildirim et al. (2003) completed in eight different locations in Texas (5), investigated the feasibility of using hot pour crack treatment materials as well as emulsified crack treatment materials by comparing the short-term performance of each material. The evaluation team examined the test locations six times; three months after application, one year after application, and approximately every 6 months there after for a total of 36 months. The intermediate results of this study indicate excellent performance for the hot pour crack treatment and a drastic decline in performance of the emulsified crack treatment during the second and third evaluations.

The draft final report for the study conducted by Yildirim et al. (2004) in Texas yielded results that showed the hot-pour sealants had a better performance throughout the duration of the three-year study as compared to cold pour sealants. (26) The overall average treatment effectiveness for the hot pour material was found to be 42.95 percent as compared to 0.52 percent for the cold pour materials at the end of three-year study. This study also found that the average annual cost for hot pour materials was less than half that of the cold pour materials.

A study conducted by the Ministry of Transportation of Ontario (MTO), Canada in 1996 (6) was performed to evaluate the performance of crack treatment materials. In this study, a life cycle cost analysis compared treated and untreated sections of roadway on 37 test sites. Each of the test sites consisted of 5 150m long sections. The test sites spanned Ontario and covered all levels of traffic. The results of this study indicate that treating pavement cracks is a viable and cost-effective preventive maintenance, which can extend the service life of asphalt pavements by at least two years.

Smith and Romine (2) investigated material types combined with sealant configurations and crack preparation procedures. 15 material products, 8 placement configurations and 7 crack preparation procedures were employed in the study totaling 31 distinct treatment types and 82 treatment applications. 22,000 feet of cracking was treated. They reported that only 9 of the 31 distinct crack-seal treatments in their study (1999) exhibited “favorable” performance after the final round of evaluations was completed (about 6 ½ years) on test sections placed across the United States and Canada.

PREVIOUS STUDIES IN CONNECTICUT

The Connecticut Department of Transportation has conducted studies to test the feasibility of using cold applied crack treatments versus hot pour crack treatments. Four tests throughout Connecticut have been highlighted. In an internal study by the Connecticut DOT in 2003, *A Study on Hot Pour and Cold Pour Joint Sealer* (14), roads were observed after having been treated with both treatment methods. Three areas were evaluated during this process. Three 100 foot long sections per area were evaluated. Two of the areas evaluated had been treated with a cold applied material and the third area was treated with a hot pour material. According to the study report, in the first area which was cold pour, the failure rates after 18 months were 90%, 99% and 99% on the three sections respectively. On the second area which was also cold pour, the failure rates after 29 months were 95%, 90% and 95% on the three sections respectively. On the third area, which was hot pour, the failure rates after 27 months were 50%, 30% and 10% on the three sections respectively. Failure was defined as the ability of water to penetrate the crack and was determined by physical in-field examination. The document states that the cold applied material had flowed through the cracks and was no longer present. There were no details included in the report regarding the specific hot or cold materials used or the methods of their application.

Another test was conducted in Connecticut on GSB-88®, an emulsified sealer and rejuvenator manufactured by Russell Standard. This cold applied treatment was applied to a section of Rte. 372 in Berlin (15) in 1996. There were questions within ConnDOT with regard to whether the frictional properties of the roadway had been altered by the treatment. As a result, ConnDOT tested the section for pavement friction in June 1997. The tests conducted included ASTM E501, *Standard Ribbed Test Tire* and ASTM E524, *Standard Smooth Test Tire*. The results of this test yielded substantial evidence that the emulsified treatment reduced the frictional properties of the roadway considerably. The reported results went as far as to include a statement that corrective measures may be necessary in this particular location.

The Research Liaison Committee of the Bureau of Engineering and Highway Operations and ConnDOT (16) evaluated two crack treatment materials in 1994: CRF ® and CRF-PM ®. These are both cold applied products. CRF is a cold pour emulsion, while CRF-PM is a polymer-modified cold pour emulsion. It is stated in the document by Dr. Charles Dougan of ConnDOT that the advantages of the CRF emulsion are the ability to apply the material at nearly any temperature and in most weather conditions. The advantage of the polymer modified CRF-PM is the increased bond strength that the polymer modification offers. The Research Liaison Committee recommended that the two materials be approved for use as crack filler, joint filler, and restorative seal and pothole patch.

Several hot and cold crack treatment projects were field evaluated using photography in each of the four Districts in Connecticut from 1998 to 2000 (24). Connecticut Department of Transportation Maintenance Division conducted a study comparing the condition of these treatments and noting the type of material used, the cover material and an evaluation of the condition of both the pavement as well as the treatment material. Images of each of the locations are given in the report. The conclusions at the end of the report indicate that both cold and hot applications adequately seal joints and cracks. The sealing capabilities of cold pour materials were stated as being superior to those of hot pour materials because of several characteristics noted in the field. The hot pour was evaluated to have a tendency to shrink and re-crack with freeze – thaw cycles. It was also suggested that the hot pour material was not as useful on wider cracks where a wider application was required. The report also concludes that bleeding is a problem with hot materials in times of resurfacing while cold applied materials did not exhibit any tendency to bleed through newly placed pavements. There is a stated increase in cost per daily operation from hot pour to cold pour, however, the report indicates that the added benefits that are associated with cold pour products more than compensate for the said price differential and justify the use of the cold pour material.

Overall, the studies undertaken to date in Connecticut indicate that there are both advantages and disadvantages to both hot-pour and cold-pour materials for crack sealing. Depending on the project objectives when selecting a material more research may be required.

SAFETY

Safety is a concern during the placement of crack treatment for the workers as well as the traffic. Traffic issues are present both during the placement of crack treatment as well as after the road or road segment has been treated. Crack treatment safety issues include concerns about the temperature of hot-applied sealants (over 250^{o} F), total time of sealant application on roadway (and thus increased time of lane closure), and the texture of the pavement surface after sealant application. To avoid possible burns and skin damage from the high temperature of hot-applied sealants, cold pour emulsified crack treatments can be recommended. However, this often requires longer setting times, curing times and application of a cover material creating traffic issues in areas with high traffic volumes.

An article in TranSafety Reporter (10) discusses a possible link between the over-application of treatment material for joints or cracks in paved roadways and motorcycle accidents. The article claims that when the asphalt crack treatment applications become too wide, friction between the motorcycle tires and the road is decreased. Consequently tires can skid and the driver can lose control of the vehicle, possibly resulting in injury or death. The article includes an account of a fatal crash of an experienced motorcycle driver in Ohio, where the cause may have been directly related to asphalt cement crack treatment. Following this incident, the Federal Highway Administration (FHWA) alerted field representatives in all fifty states about the potential danger to motorcyclists caused by wide patches of crack treatment (10). The American Motorcycle Association (AMA) has expressed serious concerns to the FHWA about dangerous crack repairs in states including New York, California, Ohio, Oregon, Pennsylvania, and Utah (10).

These questions about the safety of the sealed road and the findings of the study in Berlin, CT provide further evidence that there is more knowledge needed regarding crack sealing materials.

SUMMARY OF REVIEWED LITERATURE

The documents that have been examined during the course of this literature review indicate a general assumption that cracks in pavements facilitate the intrusion of water into the pavement structure and that this intrusion has detrimental and unfavorable effects. These effects include secondary cracking, spalling, edge deterioration and potholes as well as other distresses. It is generally accepted that crack treatment inhibits the intrusion of water and thus slows the deterioration and further distress of the pavement.

The FHWA Manual of Practice (1) has established guidelines for evaluating a road or highway for potential treatment. ConnDOT conducts preliminary evaluations based on the PSR (pavement serviceability rating) system. The PSR system assigns a serviceability rating based on five performance conditions. These conditions are cracking, distortion, disintegration, drainage and ride. Each condition carries a weighted percentage of the overall serviceability rating as described above.

The FHWA Manual of Practice (1) also offers guidelines for evaluating the performance of in place treatment materials. The treatment conditions examined in determining performance are loss of full depth adhesion, cohesion loss, material pull out, spalling, secondary cracks and potholes. Smith and Romine (2) have developed a failure rating procedure based on failure of treatment as a percentage of crack length.

Review of experiments and investigations conducted by several agencies and organizations present discrepancies as to the cost effectiveness of treating cracks. Hall et al. (9) express that while the intrusion of water into cracks is hindered by treatment, there is no significant benefit of treating cracks with respect to the overall long term quality of the structure. Most states in the U.S. simply assume that crack treatment contributes to the life of the pavement structure and thus their roads and highways receive crack treatment. A study conducted by the Ministry of Transportation, Ontario (MTO), Canada, (6) indicates that crack treatment can extend the service life of the structure by 2 years. This cost effectiveness discrepancy is the subject of ongoing research. A study conducted in Indiana by Purdue University in cooperation with Indiana Department of Transportation and Federal Highway Administration (25) collected data on 19 test sites in Indiana. The objective of the project was: *"… to provide adequate evidence to determine if joint and crack sealing is cost effective and under what conditions."*

Only one year of data was collected on the performance of the treatments, and the authors were able to draw no conclusions regarding material performance or cost effectiveness of crack and joint treatment.

There are two categories of crack treatment materials, namely hot and cold. The material properties of all treatment products are different depending on the intent of their application. The available treatment materials are standardized by several ASTM tests. Some products are subject to additional tests by their manufacturer. ConnDOT accepts hot applied crack treatment materials that conform to the AASHTO M301 (ASTM D 3405). This standard was discontinued in the 24th edition of the AASHTO *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* and replaced by M324 (ASTM D 6690) in the year 2004. Current ConnDOT specifications do not reflect these changes. There are several incongruities as to which type of material, hot or cold, is superior. Several investigated experiments and documents that indicate that hot applied materials have a longer lasting performance than those of cold applied materials, while there are some cited documents that indicate the contrary. Research continues in Connecticut to explore these theories and develop guidelines and criteria for the materials as well as their uses.

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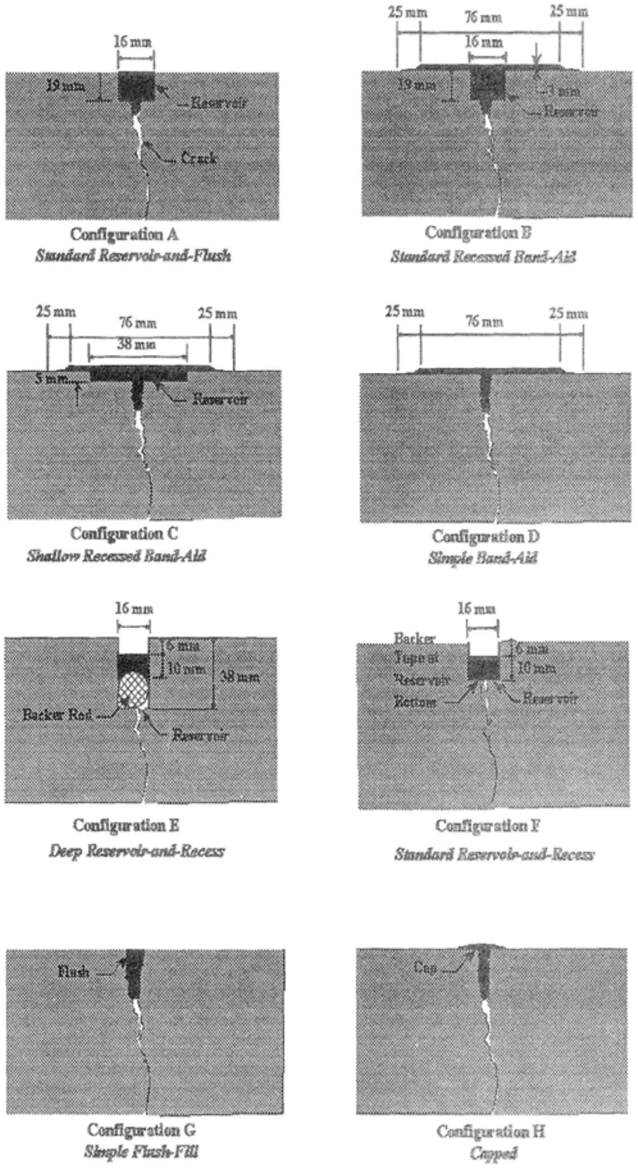
APPENDIX A.

SURROUNDING STATES ACCEPTED MATERIALS AND SPECIFICATIONS

STATE	CONTACT	MATERIALS / SPECS
Connecticut	Terri Thompson	- ASTM 3405 is spec used for approved sealant materials - Sample of materials used must be submitted to ensure products meet specs - Joints shall be cut to dimensions of 1/2 in. deep x 3/8 in. wide or 1 1/2 in. deep x 3/8 in. wide and must be cut in straight line - All cracks should be thoroughly cleaned with compressed air - Backer rod is required for a crack with depth greater than 1 in. - If sealant is more than 3/16 in. below pavement surface, it must be brought up to surface - All equipment must be approved by inspector and be kept in satisfactory working conditions
Maine	Jamie Andrews	- ASTM 3405 is spec used for approved sealant materials - Application not allowed when: pavement surface is wet, after sunset or before sunrise, temperature is below 10C in shaded area of project, or other unfavorable weather conditions exist - Cracks of width 5 mm to 20 mm will routed to dimensions of 12 mm to 19 mm x 12 mm to 19 mm - Cracks larger than 20 mm do not require routing but must be thoroughly cleaned - Routed cracks will be filled flush to pavement surface and any excess sealant must be removed to satisfy the requirements of the authorized representative - Overband of the sealant shall not exceed 50 mm to 100 mm depending on severity of crack and thickness must be minimized - Hot Air Lance is used to warm cracks and dry off any moisture - All equipment must be approved by inspector and be kept in satisfactory working conditions
Massachusetts	Bruce Noyes	- ASTM 1401 used as spec for approved hot-applied crack sealing materials - AC20 with a polyester fiber is the commonly used material - A ruberized joint sealer is also a common material used - Crack sealant materials are dusted with "black beauty" for frictional purposes
New Hampshire	Alan Perkins	- ASTM D 3405 is spec used for approved crack sealing materials - Modified materials are sometimes used - Only hot pour crack sealing materials are used
New York	Jim Klotz	- ASTM D 6690 Type II (formerly ASTM 3405) is spec used for approved crack sealing materials - Looking into use of Type IV for PCC applications - Fiber reinforced binders with a performance grading of 64-22 or 64-28 are required - Materials samples must be provided in blocks to be tested and placed on approved products' list - Overbanding is allowed with maxima set at 50 mm wide and 1 mm deep - Hot Air Lance is used to dry and clean cracks in preparation for sealing - In routing applictations, cracks should have the minimum dimensions of 16 mm wide and 13 mm deep - Routed cracks are sealed with a flush fill configuratoin and sealant is applied using a sealing shoe
Rhode Island	Jose Lima	- Two types of sealant materials are used: a.) hot applied materials that meet ASTM D 6690 Type III and b.) Fiber reinforced asphalt compound with PG grading of 64-34 or 70-34 with 5% rubber content (more common) - Filler material is either Bituminous Concrete Class I-2 or High Performance Bituminous Cold Patch - "Black Beauty is used as a blotter material to prevent lifting and tracking of sealant material - Hot Air Lance is used to dry and heat crack surfaces that will be sealed - All equipment used for installation must be approved by engineer and kept in satisfactory working conditions - For application purposes, ambient temperature must be < 90F and > 40F and the pavement must be dry - Banding is allowed with a 2 inch width maximum and a middle of band depth between 1/16 inch and 3/16 inch
Vermont	Bill Ahearn	**No Response**

APPENDIX B.

TREATMENT CONFIGURATIONS



Configuration A
Standard Reservoir-and-Flush

Configuration B
Standard Recessed Band-Aid

Configuration C
Shallow Recessed Band-Aid

Configuration D
Simple Band-Aid

Configuration E
Deep Reservoir-and-Recess

Configuration F
Standard Reservoir-and-Recess

Configuration G
Simple Flush-Fill

Configuration H
Capped

Figure 2. Material placement configurations for AC crack treatments.

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Crack treatment configuration diagrams, courtesy of FHWA RD-99-143. Reference (2)

APPENDIX C.

RESULTS OF MONTANA STUDY. TRANSPORTATION RESEARCH RECORD #1697.

I. Individual Failure Percentages

		Transverse Cracks (% Failure)						Longitudinal Cracks (% Failure)					
Site	Material	BA	CAP	SQ-F	SQ-R	SQ-BA	SH-F	BA	CAP	SQ-F	SQ-R	SQ-BA	SH-F
Conrad	Crafco 221	100.0	100.0	42.7	68.6	54.9		33.7	36.0	0.0	23.4	24.3	
	Maxwell 60	100.0	100.0	43.0	100.0	84.7	37.3	100.0	100.0	60.1	100.0	3.7	6.8
	Crafco 231	100.0	100.0	17.9	100.0	22.0	21.2	100.0	100.0	23.3	100.0	4.7	0.5
Dutton	Crafco231			9.0			13.9						
	Crafco 299			8.9			14.1						
	Crafco 516			68.2			50.1						
	Crafco 522			16.1			11.9						
Tarkio	Crafco 231	13.7		7.2	49.0	0.0	7.2	1.2		11.3	9.4	1.9	31.6
	Crafco 522	5.1		0.4	19.3	0.5	0.4	0.1		4.4	37.0	6.6	2.9
	Maxwell 72				43.1		1.5				25.8		4.4
	Crafco 221	42.4			43.1	0.5							
Helena 6	Crafco 231	3.6		10.8	16.5	3.0	6.6						
	Crafco 522	4.5		9.2	16.4	4.3	5.9						
	Maxwell 71	32.7		10.7	16.2	6.0	4.6						
	Maxwell 72	49.4		7.3	20.4	14.5	4.4						
	Deery 101 ELT	56.1		4.9	22.1	4.3	2.5						
Helena 32	Crafco 231	37.9		13.0	21.7	5.5	9.5						
	Crafco 522	19.0		10.2	24.0	6.5	6.0						
	Maxwell 71	99.8		16.0	61.8	11.6	6.9						
	Maxwell 72	95.3		12.7	50.6	84.7	6.5						
	Deery 101 ELT	99.1		77.6	75.6	60.0	49.7						
Helena 42	Crafco 231	69.6		10.6	29.1	8.7	11.2						
	Crafco 522	26.2		11.5	25.3	6.7	8.3						
	Maxwell 71	99.4		19.4	55.9	38.8	6.5						
	Maxwell 72	99.0		19.0	50.7	19.3	7.2						
	Deery 101 ELT	98.0		71.7	66.4	61.4	78.0						
Helena 57	Crafco 231	48.5		27.5	12.1	4.3	8.2						
	Crafco 522	47.3		11.5	30.3	6.9	8.3						
	Maxwell 71	100.0		33.9	44.9	50.7	19.2						
	Maxwell 72	97.9		10.4	45.7	12.3	4.9						
	Deery 101 ELT	59.8		64.7	58.0	56.1	59.3						

BA – Band aid
CAP – Capped
SQ-F – Square and Flush
SQ-R – Square and recessed
SQ-BA – Square and band aid
SH-F – Shallow and flush

APPENDIX C. RESULTS OF MONTANA STUDY. TRANSPORTATION RESEARCH RECORD #1697.

II. Average Failure Percentages

		Average Transverse (% Failure)							Average Longitudinal (% Failure)						
Site	Material	BA	CAP	SQ-F	SQ-R	SQ-BA	SH-F	Material	BA	CAP	SQ-F	SQ-R	SQ-BA	SH-F	Material
Conrad	Crafco 221	100.00	100.00	34.53	89.53	53.87	29.25	73.24	77.90	78.67	27.80	74.47	10.90	3.65	23.48
	Maxwell 60							77.50							61.77
	Crafco 231							60.18							54.75
Dutton	Crafco231	N/A	N/A	25.55	N/A	N/A	22.50	11.45	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Crafco 299							11.50							N/A
	Crafco 516							59.15							N/A
	Crafco 522							14.00							N/A
Tarkio	Crafco 231	20.40	N/A	3.80	38.63	0.33	3.03	15.42	0.65	N/A	7.85	24.07	4.25	12.97	11.08
	Crafco 522							5.14							10.20
	Maxwell 72							22.30							15.10
	Crafco 221							28.67							N/A
Helena 6	Crafco 231	29.26	N/A	8.58	18.32	6.42	4.80	8.10	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Crafco 522							8.06							N/A
	Maxwell 71							14.04							N/A
	Maxwell 72							19.20							N/A
	Deery 101 ELT							17.98							N/A
Helena 32	Crafco 231	70.22	N/A	25.90	46.74	33.66	15.72	17.52	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Crafco 522							13.14							N/A
	Maxwell 71							39.22							N/A
	Maxwell 72							49.96							N/A
	Deery 101 ELT							72.40							N/A
Helena 42	Crafco 231	78.44	N/A	26.44	45.48	26.98	22.24	25.84	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Crafco 522							15.60							N/A
	Maxwell 71							44.00							N/A
	Maxwell 72							39.04							N/A
	Deery 101 ELT							75.10							N/A
Helena 57	Crafco 231	70.70	N/A	29.60	38.20	26.06	19.98	20.12	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Crafco 522							20.86							N/A
	Maxwell 71							49.74							N/A
	Maxwell 72							34.24							N/A
	Deery 101 ELT							59.58							N/A