Improved Preventive Maintenance: Sealing Cracks in Flexible Pavements in Cold Regions

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Cracking of asphalt pavements in cold regions has always presented a problem, because it can directly affect pavement rideability and material behavior and, therefore, service life. If left untreated, cracking will develop into more drastic distresses, such as spalling, potholes, deformation, and even structural failure. These distresses are irreversible and are a major factor in pavement surface roughness. A prime example is the transverse crack that, when left untreated, develops permanent and seasonal deformation in the form of lipping or cupping. Lipping is an upheaval, and cupping is a depression of the pavement profile at the transverse crack. The Ontario Ministry of Transportation has an ongoing preventive maintenance measure, a crack rout-and-seal program, to minimize the effects of cracking. The ministry also seeks to improve rout-and-seal methodology and discover sealant materials that perform better. This paper presents some up-to-date results from these investigations.

When very severe pavement distress results in a very rough surface or deteriorated surface condition that is hazardous for the traveling public, urgent corrective maintenance is undertaken to remedy the situation. Such rough and/or hazardous conditions need not exist, however, if timely preventive maintenance is undertaken. A case in point, sealing the initial transverse crack (Figure 1) at the appropriate time would have stopped or delayed the distress from developing into this impossible situation.

Cracking of asphalt pavement in cold regions has always been a problem because it can directly affect pavement rideability and, therefore, service life. A prime example is the transverse cracks that, if left untreated, will develop permanent deformation in the form of lipping or cupping at the crack. Lipping is the upheaval of the pavement profile at the crack (Figure 2), and cupping is a depression of the pavement profile at the crack (Figure 3). These deformations are irreversible, and they are a major factor in pavement surface roughness.

Until about ten years ago, maintenance of cracks was generally implemented in the Ontario Ministry of Transportation by sealing with "Spray Patch" treatment—that is, spraying emulsion over the crack and blotting with a sand aggregate or stone chips. The success rate of this treatment was much less than acceptable, however, not only because of the treatment itself but because it is inappropriate for the distress (Figure 4). In many instances, the presumed cure is worse than the disease; the treatment can, and generally will, create additional roughness on an otherwise acceptable pavement riding surface, thus lowering its serviceability (Figure 5).

During the early 1970s, the ministry began to seal cracks using the method commonly known as rout-and-seal, using as standard the same rout configuration of 19 mm wide and deep designed for concrete pavement joints and the hot-pour rubberized asphalt sealant developed for the same purpose. Requirements for sealing characteristics of concrete pavement and asphalt pavement, however, are substantially different. Therefore, the results of the early rout-and-seal programs were less than completely successful. This led to questioning the value of crack sealing as a viable maintenance treatment. Is it true, as some advocate, that it is merely a waste of money and time, as cracking will always be with us? Or is it truly beneficial and would it be penny wise and pound foolish to do nothing?

To answer this question, it is essential to know the consequences of deferring sealing of cracks and to know the cost-effectiveness of the rout-and-seal maintenance treatment. For the ministry, it is imperative to know how cost-effective the treatment is, because the ongoing rout-and-seal program has grown from an annual cost of mere tens of thousands to millions of dollars in the latest fiscal years. The ministry began to address this issue in 1980 through a series of studies to improve the rout-and-seal technology as well as to cooperate with the manufacturing sector to produce sealant materials that perform better. This paper provides some up-to-date results of these studies.

CONSEQUENCES OF DEFERRED MAINTENANCE ON CRACKING

Deferred maintenance of cracking is generally accepted, mainly because of budgetary constraints. The pavement designers in the ministry are beginning to be concerned, however, because the majority of asphalt pavement mileage with untreated transverse cracks is developing either lipping or cupping deformations, in many instances very severe. These pavement designers believe their concern is well justified because these deformations are costly to redress under the rehabilitation

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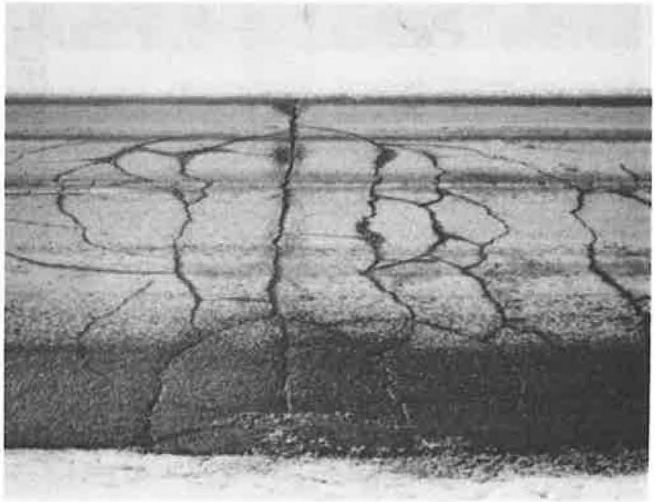

FIGURE 1 Consequence of deferred maintenance of transverse crack.

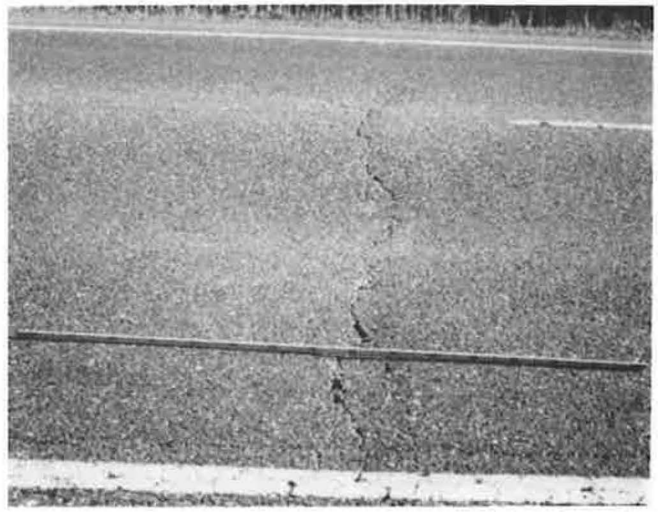

FIGURE 3 Cupping of transverse crack in summer.

program, and simply resurfacing with hot-mix asphalt only perpetuates the cycle of reflection cracking and subsequent cupping or lipping.

Investigation shows that the surface condition of cracking does not necessarily indicate the degree of deterioration (*1*). Deterioration can take place at the bottom of the asphalt layers, as illustrated in Figure 6. On a heavily trafficked highway, deterioration can become so severe that half of the original asphalt layers or more will disintegrate from the bottom upward, creating a pavement of two different structural thicknesses within a matter of 1 m or 3 ft, plus or minus (Figure 7).

The consequences therefore of not sealing cracks are

1. Increased maintenance costs because deteriorated cracks are difficult (see Figure 1) and expensive to repair through corrective maintenance;
2. Increased user costs (vehicle repair and operation);
3. Increased rehabilitation costs, because deteriorated cracks demand special treatment from the designer when pavement rehabilitation is scheduled; and
4. Loss of serviceability and, therefore, service life (*1*).

COST-EFFECTIVE MAINTENANCE OF ASPHALT PAVEMENT CRACKING

The ministry employed two maintenance treatments for cracks—namely, sealing with emulsified asphalt and rout-and-seal with hot-pour rubberized asphalt sealant materials. Of these two treatments, it has been demonstrated that sealing with emulsified asphalt is not only ineffective but can also create undesirable side effects (*2*). On the other hand, rout-and-seal treatment has shown some success in effective maintenance of cracking, although it still is not known how cost-effective this particular maintenance alternative is.

The cost-effectiveness of a maintenance treatment depends on

1. How it will change the existing condition—that is, how effective it corrects the existing distress;

FIGURE 2 Lipping of transverse cracks in winter.

FIGURE 4 Spray patch of crack with emulsion and sand aggregate—crack remains unsealed.

FIGURE 5 Spray patch of cracks with emulsion and sand aggregate—created small ridges at cracks that are detrimental to rideability.

2. How well it can delay the distress's deterioration process and thereby extend the pavement service life; and
3. How much influence time has on its application against the existing distress using the particular maintenance treatment.

Therefore, the information needed to establish the cost-effectiveness of the rout-and-seal maintenance treatment must quantify:

1. The effectiveness of treatment, that is, (a) performance of sealant materials over time and (b) performance of various rout width and depth sizes over time to establish the most efficient rout configuration;
2. The extension of pavement service life that is, (a) retarding of additional crack development and (b) delaying the deterioration process of the existing distress; and
3. The influence of time—that is, at which point of the pavement's life cycle the treatment is applied most cost-effectively.

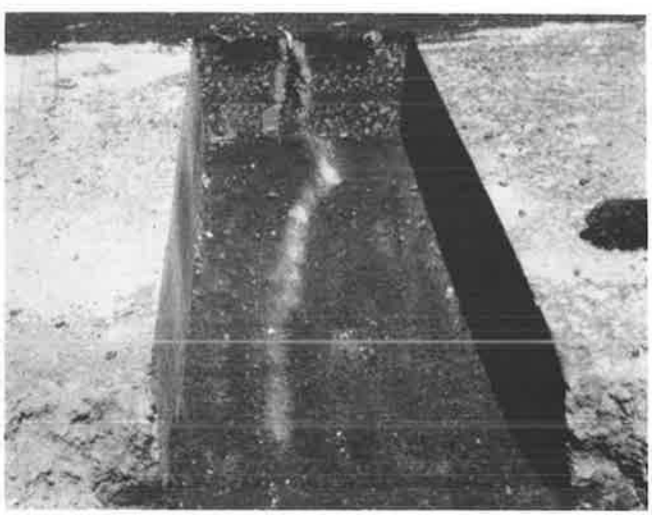

FIGURE 6 Highway 15 investigation site for unsealed transverse crack deterioration.

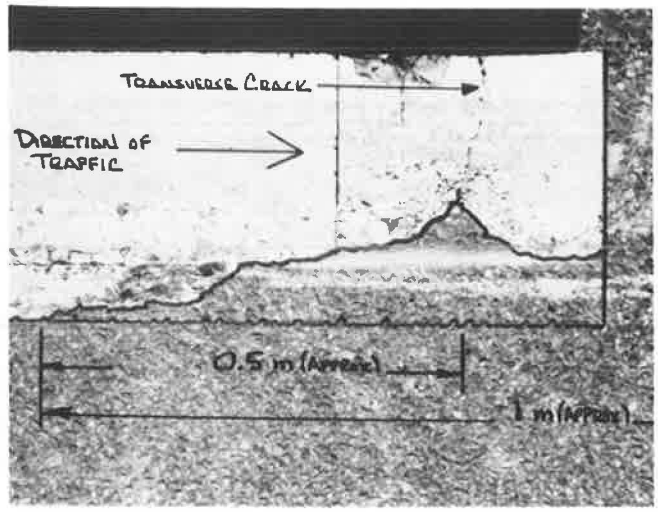

FIGURE 7 Highway 401 investigation site for unsealed transverse crack deterioration.

In Search of Effective Treatment

Effective Sealant Materials

Before 1980, the ministry maintained a designated source list of approved sealant materials that must conform to ASTM D-190 plus the Ministry Specification 1212 requirements. Opinions were expressed in the industry and within the ministry that these materials were evaluated and approved for use on portland cement concrete pavement, and that they were not necessarily effective when used to seal asphalt pavement cracks. In 1980, manufacturers of sealant materials were invited to participate in a field evaluation of their materials under identical and controlled conditions to identify the crack sealant best suited for sealing asphalt pavement cracks (*3–5*).

In 1983, the study identified eight sealant materials as approved products based on their mid-winter performance record. Four "premium" materials were approved for use in asphalt pavements throughout Ontario—namely,

1. Shell Cariphale ELT
2. Bemac Supergook
3. Meadows Hi-Spec
4. Hydrotech Sealz 6165

These materials are of low stiffness modulus and formulated to meet ASTM D-3405 (*6*).

Four other materials considered marginal were approved for use in asphalt pavement located in the southern part of the province only. These were

1. Bakelite 590-13
2. Hydrotech Sealz 6160
3. Meadows 164R
4. Paraseal 2065

These materials are of high stiffness modulus and are formulated to meet ASTM D-1190 (*6*). At this writing, the designated source list had a number of changes due to some additions and deletions (Tables 1 and 2). Deletion from the list means either that the product is no longer marketed by the manufacturer or has been dropped because of unsatisfactory performance observed in continuous monitoring by the Ministry.

Efficient Rout Configuration

Before 1980, the ministry maintained the 19 × 19-mm rout configuration as standard for portland cement concrete pavement joint sealing. This same standard was also used for asphalt concrete pavement joints and cracks (*7*). Opinions were expressed within the ministry that this rout configuration might not be the most efficient for asphalt pavement because of the extensibility. Adhesion at low temperature requirements are not the same for Portland cement concrete pavement and asphalt concrete pavement.

In 1981 and 1983, studies were initiated to identify the most efficient rout configurations from various combinations of width and depth (*2*, *6*, *7*). The result was that the new configuration of 40 mm width by 10 mm depth (Figure 8) was put into the Ministry *Maintenance Operation Instruction* guide as an option beside the standard 19 × 19-mm configuration for asphalt concrete pavement rout-and-seal guidelines (*8*).

The logic for this configuration is that the shape factor is at a ratio of 4 to 1 rather than the standard configuration of 1 to 1. Therefore, under low temperature the extensibility required of the sealant materials induced much less strain on the sealant and minimized the cohesion failure in the material. In addition, the shape factor provides a greater bonding area horizontally instead of the vertical bond faces for the standard square configuration. Therefore, since the extension force is less, it will in turn induce smaller adhesion stress on the sealant materials, thus minimizing the chance of bond failure.

Added benefits of the 40 × 10-mm configuration are that it is easier for the routing machine operator to follow the meandering cracks, which are the usual condition of asphalt pavement cracking. Also, there is less stress on the routing machine and router bits, which means higher productivity at lower cost. To date, although this configuration is optional, most of the in-house and contractual works were done using this 40 × 10-mm rout.

Efficient Work Procedures

Before 1980, rout-and-seal work procedure was the same standard as rout-and-seal Portland cement concrete pavement joints. That is, it was routed with a vertical router, cleaned with compressed air, and flush-filled with a hand pouring cone or garden watercan. The process is slow because of the vertical router's low productivity; considerable adhesion failure was also experienced from the flush-filled procedure. This was due to shrinkage of the sealant materials upon cooling, and it resulted in actual underfilling (*7*).

Since 1980, a number of studies were undertaken to establish the most efficient rout-and-seal procedure with the best possible long-term performance of sealing the cracks (*1*, *2*, *6*, *7*, *9*). The manufacturing sector also brought onstream some improved equipment designed for rout-and-seal operation (*6*, *7*, *9*). As a result, a number of processes were added or discarded based on their suitability. For example, the ministry

TABLE 1 MTO-DESIGNATED SOURCES LIST FOR ENGINEERING MATERIALS: PRODUCTS SUITABLE FOR USE IN ALL DISTRICTS

Manufacturer	Product	Supplier
Bakelite Thermosets Ltd 284 Watline Ave. Mississauga, Ontario L4Z 1P4 (416) 890-4800	590-13A Pouring Temp. 175-185°C	Manufacturer
Hydrotech Membrane Corp 100 Amber Street, Unit #12 Markham, Ontario L3R 3A2 (416) 475-3880	Hot Poured Sealz Sealz 6165 Pouring Temp. 190-215°C	Manufacturer
W.R. Meadows of Canada Ltd 130 Toryork Drive Weston, Ontario M9L 1X6 (416) 741-2220	Hi-Spec. Hot Poured Rubberized Asphalt Pouring Temp. 195-205°C	Manufacturer
Tremco (Canada) Ltd. 220 Wicksteed Ave. Toronto, Ontario M4H 1G7 (416) 421-3300	THC-200 Pouring Temp. 190-205°C	Manufacturer

NOTE: For all of the above products, method of application is either by pressure or gravity feed.

DS: 143.4

Designated Sources for: JOINT SEALING COMPOUNDS FOR USE IN ASPHALTIC CONCRETE PAVEMENT - HOT-POURED RUBBERIZED ASPHALT

Specification(s): (1) EMO BITUMINOUS SECTION (ii) OPSS-1212

Standards: OPSD 508.01, 508.02, 508.03

TABLE 2 MTO-DESIGNATED SOURCES LIST FOR ENGINEERING MATERIALS: PRODUCTS SUITABLE FOR USE IN DISTRICTS 1–8 ONLY

Manufacturer	Product	Supplier
Bakelite Thermosets Ltd 284 Watline Ave. Mississauga, Ontario L4Z 1P4 (416) 890-4800	590-13M Pouring Temp. 175-185°C	Manufacturer
Hydrotech Membrane Corp 100 Amber Street, Unit #12 Markham, Ontario L3R 3A2 (416) 475-3880	Hot Poured Sealz 6160 Pouring Temp. 195-215°C	Manufacturer
W.R. Meadows of Canada Ltd 130 Toryork Drive Weston, Ontario M9L 1X6 (416) 741-2220	No. 164 Hot Poured Rubberized Asphalt Pouring Temp. 195-215°C	Manufacturer
Tremco (Canada) Ltd. 220 Wicksteed Ave. Toronto, Ontario M4H 1G7 (416) 421-3300	THC-205 Pouring Temp. 190-205°C	Manufacturer
Globe Asphalt Products Ltd. 3300 Steeles Ave. West Suite 201 Concord, Ontario L4K 2Y4 (416) 738-4306	W.I. 317 Pouring Temp. 195-210°C	Manufacturer
Koch Materials Co. 43 Industrial St. Toronto, Ontario M4G 1Z2 (416) 421-2252	#9001 Pouring Temp. 200-215°C	Manufacturer

NOTE: For all of the above products, method of application is either by pressure or gravity feed.

DS: 143.4

Designated Sources for: JOINT SEALING COMPOUNDS FOR USE IN ASPHALTIC CONCRETE PAVEMENT - HOT-POURED RUBBERIZED ASPHALT

Specification(s): (1) EMO BITUMINOUS SECTION (ii) OPSS-1212

Standards: OPSD 508.01, 508.02, 508.03

will not advocate a "Band-Aid" process because snow-plowing in the winter has made this process unacceptable. Similarly, the overfilled to 80 mm and squeezed method was also discarded because of additional labor, waste of sealant materials, and snowplow shearing of excess materials (*2*, *6*, *7*). The ministry recommends that whether 19 × 19 mm or the optional 40 × 10 mm is used, sealant materials should be overfilled sufficiently to cover both edges of the routed crack, leaving the sealing materials standing slightly proud of the pavement surface (Figure 9). This additional material will provide sufficient coverage to compensate for shrinkage during the cooling process (*6*, *7*).

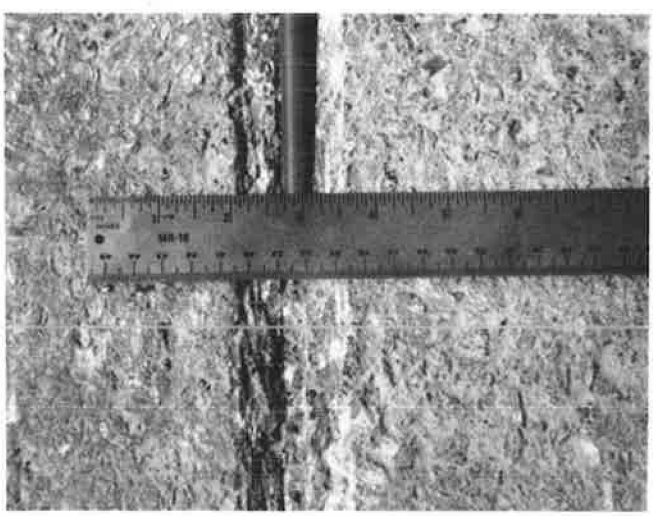

FIGURE 8 Rout configuration 40 mm × 10 mm.

For equipment, the ministry recommends the use of the Crafco and Marathon routers (both with cutter wheels) as the most efficient and productive of available routers. Use of a hot-compressed-air lance rather than compressed blowers is also recommended because it will remove dust and moisture efficiently to ensure a better bond between the pavement and the sealant materials (*6*, *7*, *9*).

The most efficient and productive operation arrangement was put together by the Ottawa District Maintenance staff of the ministry. Their method is now the standard for all in-house operations (Figure 9). The train of manpower and equipment is set up as follows. Two Crafco or Marathon routers with the operator operating ahead of the equipment train. A hot-compressed-air lance, connected to a tow-vehicle and supplied by the tow-vehicle with propane and compressed air, operates approximately 5 m (15 ft) for drying and clean-

FIGURE 9 Recommended sealant materials overfilled sufficiently to cover edges of routed crack.

ing the rerouted crack of dust and debris. A double-jacket oil kettle for sealant materials is towed behind the tow-vehicle; the heat is supplied by propane from the vehicle. Sealant is dispersed into routed crack by a pump-wand that maintains the sealant at a constant pouring temperature. The distance is approximately 5 m (15 ft) from the tow-vehicle. That is, the maximum distance between the cleaning and sealing phases is only about 20 to 25 m (60–80 ft), thus ensuring that no dust or debris will enter the routed crack prior to the sealant being poured.

Cost-Effectiveness of Rout-and-Seal Treatment as a Preventive Maintenance Measure

The cost-effectiveness of a treatment can be measured by how long it can delay the distress's deterioration process and by its additional ability to retard development of other distresses related to or consequent of the original distress.

In 1981, a small-scale study was initiated by the Ottawa District Maintenance Office to look into the consequences of sealing pavement cracks with rout-and-seal versus deferred maintenance (*1*, *7*). A section of Highway 17 near Ottawa was selected since it was originally constructed in 1965 with 115 mm (4 1/2 in.) of hot-mix asphalt and was rehabilitated in 1979 with 65 mm (2 1/2 in.) of hot-mix asphalt because of extensive cracking. In 1981, two years after resurfacing, extensive transverse cracks reappeared, and the pavement was rout-and-sealed as a preventive maintenance measure. Part of this pavement was used for the experimental study. In 1985, an investigation was made on the deferred maintenance control section and the rout-and-seal study section, which are adjacent to each other.

A summary of the findings and observations (*1*) follows. When transverse crack maintenance was deferred in the control section, cupping deformation occurred and progressed to the "moderate" category six service years after rehabilitation (Figure 10). Deterioration of the transverse crack continues upward from the original pavement and into the base course of the resurfacing layers after six service years (Figure 11). Also, transverse cracks began to develop multiple cracks and spalling after six service years (Figure 12).

When transverse cracks were routed and sealed, cupping deformation developed after six service years but is in the "slight" category (Figure 13). Deterioration of the transverse crack upward from the original pavement was halted or retarded even after six service years (Figure 14), and the transverse crack surface condition remains static with no spalling or secondary crack development (Figure 15).

Therefore, although the project is still active and monitoring continues, the interim conclusions are as follows:

1. Rout-and-seal treatment of transverse cracks effectively retards internal and external deterioration.
2. Rout-and-seal treatment of transverse cracks effectively slows down the progress of cupping deformation.
3. Comparison of the treated sections with the control section indicates that rout-and-seal treatment of transverse cracks can extend the serviceability of the pavement by at least four years.

FIGURE 10 Standard ministry equipment train for in-house rout-and-seal operations.

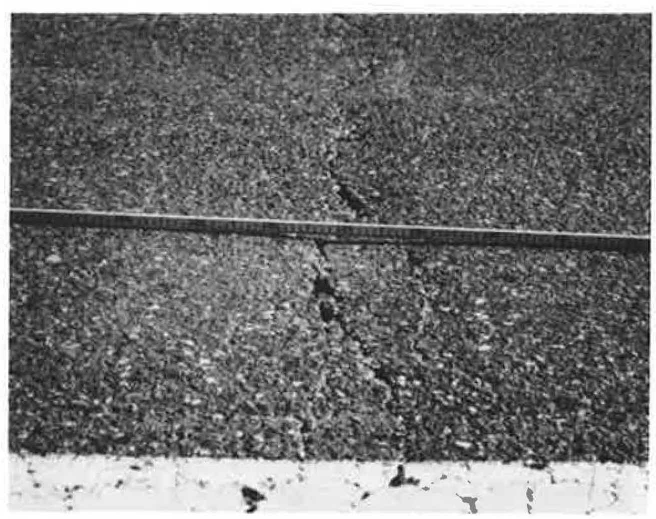

FIGURE 11 Moderate cupping of transverse crack on Highway 17, control section.

FIGURE 12 Unsealed transverse crack deterioration continues upward unchecked on Highway 17, control section.

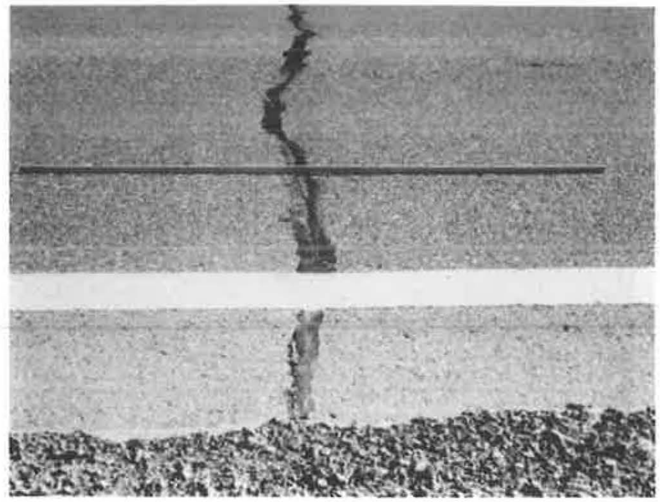

FIGURE 14 Slight cupping of transverse crack on Highway 17, sealed test section with Hydrotech 6160.

Timing for Cost-Effective Application of Rout-and-Seal Treatment

In 1986, the ministry's Maintenance Branch initiated a comprehensive study program to further investigate the rout-and-seal treatment of cracks as a cost-effective preventive maintenance procedure (*1*). The scope of the study is provincewide to ensure complete coverage of the different climatic and environmental conditions that exist in Ontario. One of the objectives is to establish the influence of timing of treatment. That is, answers are sought to the question, At which point of the pavement's life cycle is the treatment most cost-effectively applied? To answer this question, pavement test sites were selected from several pavement age groups: those with less than 3 yr, 4 to 6 yr, and 7 to 9 yr of service life since last constructed or rehabilitated.

It is recommended, however, that rout-and-seal treatment of asphalt pavement cracking be carried out within the first five years of service life. Meanwhile, the ministry has also recently developed an expert system, with the acronym ROSE, for recommending rout-and-sealing of asphalt concrete pavement in cold areas (*10*). ROSE encodes expertise derived from recent research and development studies and from experience gathered within the ministry.

SUMMARY

The rout-and-seal treatment is designed to seal asphalt concrete pavement cracks to prevent water from entering and damaging the pavement structure. This is doubly important for pavements in cold areas because of the combination of low temperature-induced crack opening and the winter maintenance of snow and ice removal with salt.

Routing is used to open up the crack to accommodate enough sealant to provide an effective seal even after the pavement

FIGURE 13 Unsealed transverse crack develops multiple cracking and spalling on Highway 17, control section.

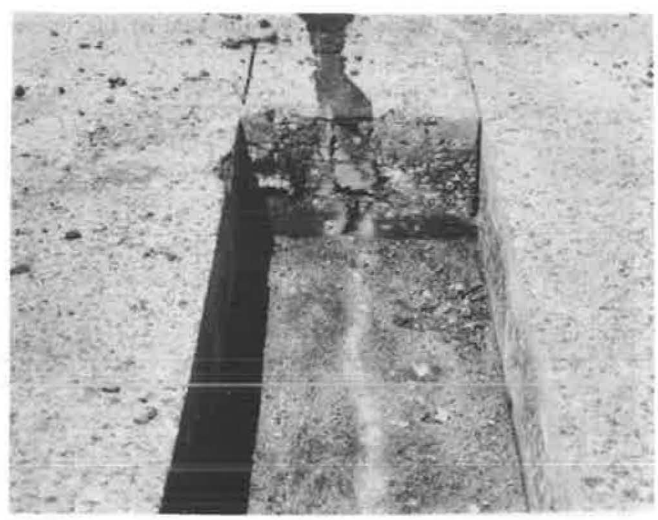

FIGURE 15 Sealed transverse crack original deterioration stopped or retarded from progressing upward on Highway 17, sealed test section with Hydrotech 6160.

crack opens due to contraction at low temperature during the winter months. Sealing is water-proofing the crack by bonding to the pavement surface and extending without fracture over the opened crack during the critical winter period. The ministry realized, however, that even the best sealant materials available would not perform in the field if they were not properly installed in clean, dry conditions and in the correct routing configuration. Therefore, the ministry has expended considerable effort to bring together the total package—that is:

1. The best performing sealant materials designed for the job,
2. The proper work procedure and equipment to ensure a well-laid seal, and
3. The proper timing for execution of this treatment.

The ministry considered these efforts worthwhile because past studies have indicated that rout-and-seal treatment, executed in a timely and proper fashion, can prolong pavement life by about five years for asphalt concrete pavement (*7*). This can be economically significant since the cost to rout and seal a two-lane highway is about $1,000 per kilometer, and typical resurfacing cost is about $40,000 per kilometer. The additional benefit is that when rehabilitation is scheduled, the pavement designer will not have a badly deteriorated pavement to deal with if timely maintenance has been performed.

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