

## **DEEP COLD IN-PLACE RECYCLING WITH EMULSION/CEMENT**

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### ABSTRACT

In 1996, Talon Sebeq Inc. (Division of Miller Paving Ltd.) acquired a Wirtgen WM-400 cement slurry mixer for Deep Cold In-place Recycling with emulsion/cement. In the first year of operation, approximately 100,000 square meters of urban and rural pavement were rehabilitated with this process in Ontario and Quebec where the standard pavement structure consists of an unbound granular base overlaid by one or more courses of bituminous concrete. Thermal cracking and fatigue are the primary causes of pavement distress and failure in both provinces. Instead of adding one or more courses of pavement materials on top of the existing pavement to strengthen it, Deep Cold In-Place Recycling uses the in-place bituminous pavement and unbound granular base (up to a depth of 300 mm) as a source of materials. This process eliminates existing crack patterns and allows restoration of longitudinal and transverse profiles of a deformed roadway. Emulsion/cement treated mixtures obtained from Deep Cold In-place Recycling develop more strength and moisture resistance than emulsion treated mixtures at an early age. This paper presents a brief overview of Deep Cold In-place Recycling and a discussion of project selection, design practices, process equipment, construction procedures and the performance of emulsion/cement recycled mixtures.

### RÉSUMÉ

En 1996, Talon Sebeq inc., division de Miller Paving Ltd., a fait l'acquisition un malaxeur à coulis de ciment Wirtgen WM-400 pour le retraitement en place sur forte épaisseur à l'émulsion avec ajout de ciment. Lors de la première campagne de travaux, 100 000 mètres carrés de chaussées urbaines et rurales ont été réhabilitées à l'aide de ce procédé en Ontario et au Québec. La chaussée type ontarienne et québécoise est constituée de couches de matériaux granulaires non liés recouvertes d'une ou de plusieurs couches d'enrobés bitumineux. La fissuration thermique et la fissuration par fatigue sont les deux principales causes de dégradation de ce type de chaussée. Le retraitement en place sur forte épaisseur permet de réaliser un renforcement de chaussées sans avoir à rajouter de nouvelles couches de matériaux sur la chaussée existante. Les matériaux des couches supérieures de la chaussée sont récupérés et retraités à des épaisseurs pouvant aller jusqu'à 300 mm. Ce procédé permet d'éliminer la fissuration existante et de reprofiler la chaussée. Les matériaux traités à l'émulsion avec ajout de ciment se rigidifient et développent une résistance à l'eau plus rapidement que les matériaux traités à l'émulsion seulement. La présente communication fait un survol du retraitement en place sur forte épaisseur. Les pratiques de conception, le matériel et les procédures de chantier associés à ce procédé y sont traité de même que les performances des matériaux traités à l'émulsion avec ajout de ciment.

## 1.0 INTRODUCTION

### 1.1 Background

Deep Cold In-place Recycling (DCIR) of existing bituminous pavement includes two operations : Full Depth Reclamation and Mixed-in-Place. The Mixed-in-Place operation may be carried out with emulsion or with emulsion/cement. Miller Paving Ltd. introduced DCIR with emulsion in Eastern Canada in 1983. The idea of Deep Cold In-place Recycling with emulsion/cement was introduced in Quebec in 1994 [1]. A different Deep Cold In-place Recycling process with emulsion/cement was introduced in Eastern Canada in 1996 when Talon Sebeq Inc. (Div. of Miller Paving Ltd.) acquired a Wirtgen WM-400 cement slurry mixer (Figure 1).

Cement has been used for many years to control the setting time of emulsion mixtures. Slurry surfacing technologies require the addition of cement or hydrated lime for the slurry to properly flow through the pugmill of slurry spreader. Research carried out in the early 1970s demonstrated that the development of

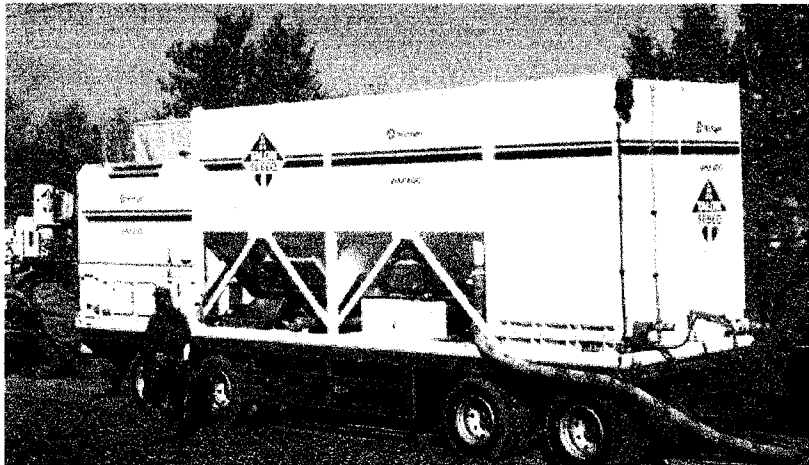


Figure 1. Wirtgen WM-400 cement slurry mixer

strength and moisture resistance was greatly increased with the use of cement in emulsion mixtures [2,3,4]. However, during that period, the relative high cost associated with the addition of cement in emulsion mixtures limited the development of field applications.

The addition of cement to improve the performance of emulsion mixtures is not recent. Yet, the use of this concept in Deep Cold In-place Recycling and the method of dispersion of the cement in the emulsion mixture

may be considered innovative. The method of dispersion of the cement was developed by Wirtgen GmbH of Germany. The cement is transformed into slurry before being mixed with the emulsion mixture. In a slurry form, cement is better dispersed and the dosage of cement as well as water is better controlled. In addition, by mixing the cement with water, no dust is released into the environment. In Deep Cold In-place Recycling, the use of a emulsion/cement binder becomes cost competitive and the performances of the recycled mixtures are improved with respect to the early development of strength and moisture resistance.

### 1.2 Objectives

The objective of this paper is to provide information on how the Deep Cold In-place Recycling operation with a emulsion/cement binder is carried out. The concepts associated with this process are defined and explained. The project selection criteria as well as the project design practices are presented. Information on Deep Cold In-place Recycling equipment and the current construction procedures are provided. Elements of performance to the early development of strength and moisture resistance of the emulsion/cement recycled mixture are discussed.

### 1.3 Definitions

Cold In-place Recycling (CIR) may be either partial-depth or full-depth [5]. Partial-depth CIR is a process that recycles only the existing bituminous layers. Depth of recycling ranges from 50 to 125 mm. This process is generally performed on thicker, more uniform bituminous pavements. Full-depth CIR may be defined as Deep Cold In-place Recycling. The process incorporates the full bituminous cover and the top portion of the underlying granular material. The in-place material is reclaimed and transformed into a homogeneous mixture of bituminous aggregate and granular material. Consequently, the existing cracking pattern of the bituminous cover is fully eliminated. The reclaimed material is then mixed with a binder. The work is performed with a reclaimer/mixer and the depth of the treatment ranges from 100 to 300 mm. This paper addresses only the Deep Cold In-place Recycling with emulsion/cement as it is represented on Figure 2 by Talon Sebeq Inc.

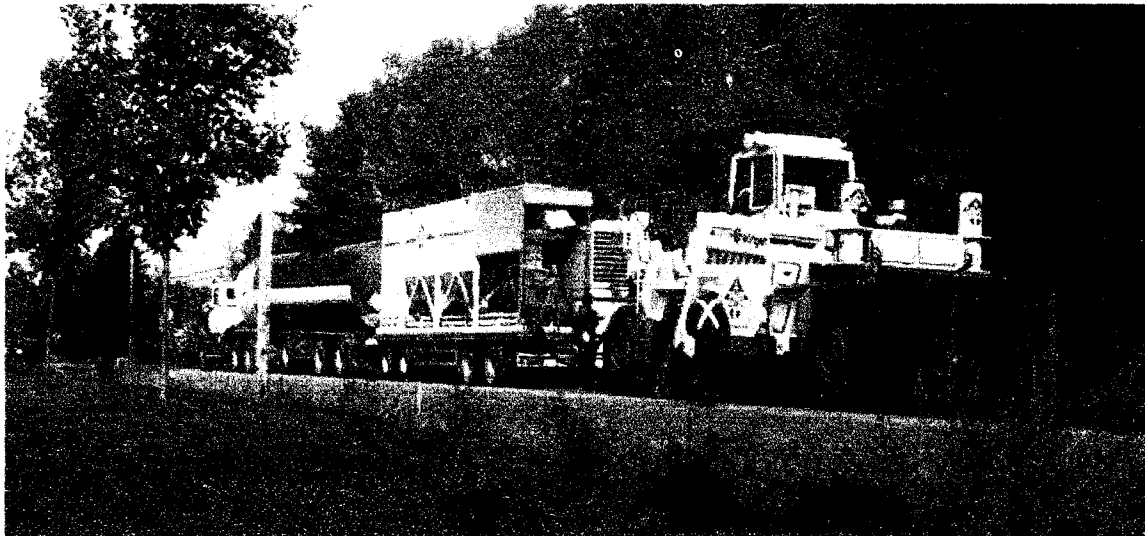


Figure 2. Deep Cold In-place Recycling in District Municipality of Muskoka, Ontario

### 2.0 PROCESS DESCRIPTION

Deep Cold In-place Recycling is based on the principle that the in-place pavement is a source of materials that may be used again to rehabilitate the pavement. Deep Cold In-place Recycling consists of several fundamental operations [5] :

- reclamation of the existing pavement
- transformation of the reclaimed pavement into a calibrated material
- addition of a corrective aggregate if required
- addition of a new binder
- mixing of all the components
- laydown of the new mixture
- compaction of the mixture
- curing of the mixture
- application of a wearing course.

### 3.0 PROJECT SELECTION

Selection of suitable candidates for DCIR requires a detailed field investigation. Field investigation generally includes a work site investigation, and a pavement investigation [6].

#### 3.1 Work Site Investigation

The main objective of the work site investigation is to determine the mode and the severity of pavement distress. Deep Cold In-place Recycling may be carried out on a wide range of deteriorated pavement. This recycling process may be considered a potential rehabilitation technique wherever the following categories of pavement distress occurs :

- pavement cracking
  - age cracking
  - thermal cracking
  - fatigue cracking
  - reflective cracking
- permanent deformation
  - rutting
  - shoving
  - rough pavement
- loss of integrity in the existing bituminous pavement
  - raveling and potholing
  - loss of bond between bituminous layers
  - stripping
  - flushing.

#### 3.2 Pavement Investigation

The pavement investigation provides additional information on the nature and extent of the distresses identified during the visual inspection. This investigation provides layer thickness information, a roughness evaluation of the pavement and an assessment of the presence of base and subgrade problems. Deep Cold In-place Recycling may be carried out on severely deformed and distressed pavements as shown on Figure 3. In certain cases it may also be used to rectify granular base problems. Pavements with extensive subgrade problems are not good candidates for recycling.



**Figure 3. District Municipality of Muskoka - District Road 2 south of Huntsville prior to Deep Cold In-place Recycling with emulsion/cement**

## 4.0 PROJECT DESIGN

The project design involves two distinctive design activities : mixture design and pavement design.

### 4.1 Mixture Design

The laboratory mixture design is carried out in four stages : field sampling and materials testing, additive selection and laboratory mixture design. Field adjustments are a part of the construction procedure and are carried out on the basis of the appearance of the DCIR mat after initial compaction.

#### 4.1.1 Field Sampling and Material Testing

Using the information gathered during the field investigation, DCIR projects are divided into relatively homogeneous sections. A sample of the in-place material is extracted from the pavement in each section.

The laboratory work conducted on the field samples may include the following tests :

- gradation of the in-place material before and after the bitumen extraction
- determination of aged bitumen content.

Along with the field investigation, the test results are used to determine if addition of corrective aggregate is required in the process. The selection of the type of the emulsion/cement binder is also based on the results of these tests.

#### 4.1.2 Additives Selection

Corrective aggregate may be required to strengthen the mineral skeleton of the mixture. Corrective aggregates are usually selected to adjust the existing gradation curve of the mineral aggregate to a shape similar to that of a dense graded material [5,7].

The selection of an emulsion is based on the following requirements :

- compatibility with a cement slurry
- proper coating of both the bituminous aggregate, the granular base material and any added corrective aggregate
- sufficient cohesion and adhesion at an early age to allow traffic and to resist rainfall.

With regards to cement, Portland cement type 10 is usually selected.

#### 4.1.3 Laboratory Mixture Design

A sequence of tests is performed on trial mixtures. The results obtained from these tests provide the necessary information to select an optimum emulsion, cement and water content for proper mix density, air voids and stability. The typical emulsion content for DCIR ranges from 3.5 to 3.8 %. The cement content varies between 0.5 to 2.0 % and the typical total water content ranges from 4.0 to 5.0 %.

The Marshall mixture design method currently used is considered approximate [7]. It does not reproduce well either the effect of the cement or the performance improvement of the mixture in the first weeks of service. The selected mixture design serves as a guideline for an initial job-mix formula. The final mixture

is selected in the field following an evaluation of the mixture quality which includes workability, coating, plasticity and ease of compaction.

## 4.2 Pavement Design

The pavement design must consider the following elements : structural design, traffic and selection of a wearing course.

### 4.2.1 Structural Design

Currently, there is not a universally accepted structural coefficient for emulsion treated DCIR mixtures or emulsion/cement treated mixtures [5]. The structural capacity of recycled mixtures is dependent on the nature of the in-place material, the added binder and the curing time. AASHTO layer coefficients between 0.25 and 0.40 have been assumed for emulsion treated recycled mixtures by many US road agencies. Field observations and laboratory results indicate that emulsion/cement treated mixtures may have a narrow spread of typical stiffness indicating that typical coefficients may be eventually assumed [1,2,3,4,9,10].

### 4.2.2 Traffic

When Deep Cold In-place Recycling with emulsion was introduced in the US, many road agencies recommended that DCIR not be used on pavement carrying heavy traffic. Nonetheless, DCIR has been carried out on roads carrying heavy traffic volume [1,9,10]. An upper limit of traffic volume for Deep Cold In-place Recycling with emulsion/cement may be outmoded, provided an appropriate pavement design is completed.

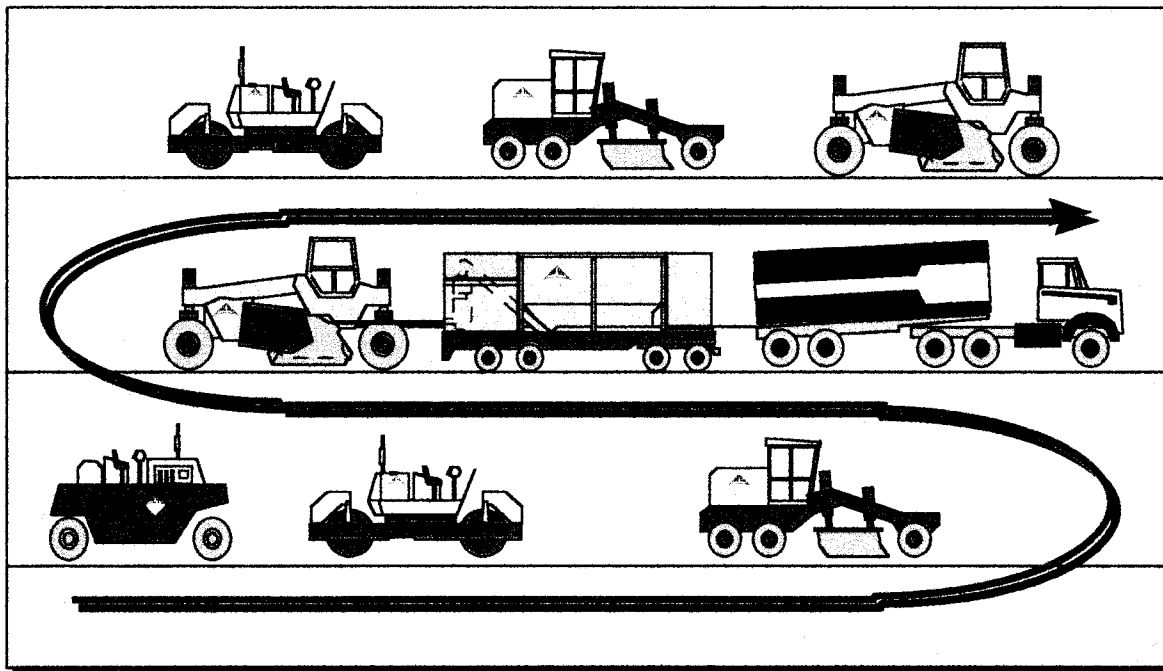


Figure 4. Deep Cold In-place Recycling operations

### 4.2.3 Wearing Course Selection

The final operation of the DCIR process is the placement of a wearing course. The pavement structural design assumptions predicate the selection of the wearing course. The wearing course provides surface sealing and, when required, pavement reinforcement. The selection of the wearing course is determined by local experience. Hot mix overlays as well as open graded emulsion mixes have been used successfully.

## 5.0 EQUIPMENT AND CONSTRUCTION PROCEDURES

### 5.1 Equipment

The machinery required to perform Deep Cold In-place Recycling with emulsion/cement includes a reclaimer/mixer (Figure 5), a slurry mixer, a motor grader and compaction equipment. The DCIR equipment performs the following operations (Figure 4):

- reclamation of the existing top layers of the pavement
- sizing of the reclaimed material into calibrated aggregates
- initial grading and compaction of the calibrated aggregates
- addition of a emulsion/cement binder and mixing of all the components
- final grading and compaction of the recycled layer.

Reclamation and sizing is performed with a reclaimer/mixer. Initial grading and compaction is carried out with standard graders and compaction rollers. The reclaimer/mixer is used again to add and mix-in-place the emulsion as well as the cement slurry. The slurry is produced in-place in a specific machine pushed by the reclaimer/mixer. Final grading and compaction is also carried out with standard graders and compaction rollers.

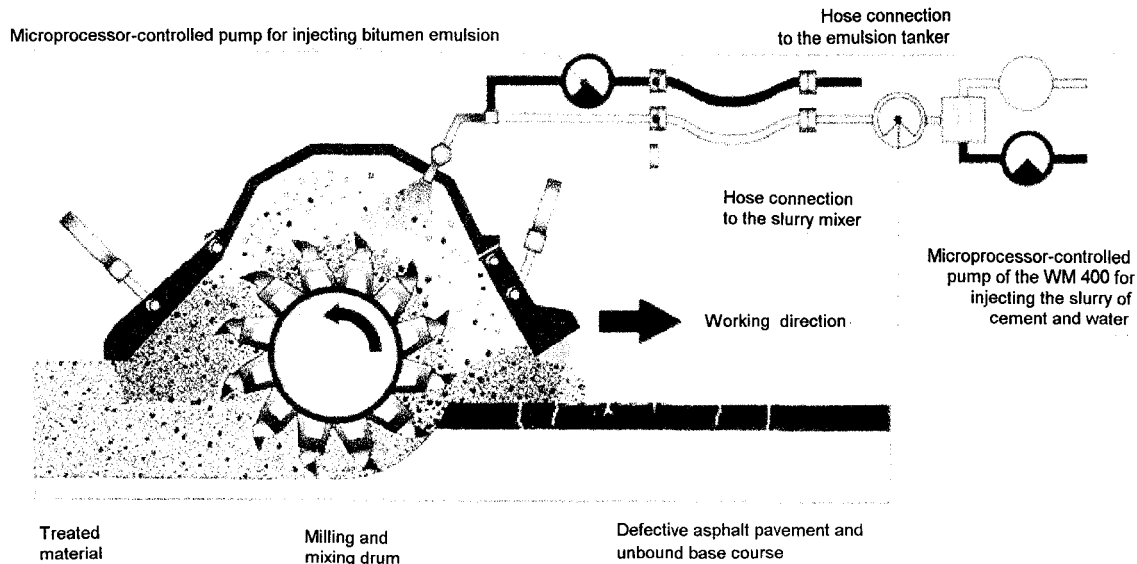


Figure 5. Wirtgen WR-2500 reclaimer/mixer

### 5.2 Gradation of the In-place Material

The intent of sizing is to separate the aggregate particles from one another at the bitumen/aggregate interface. A gradation control system consisting of an adjustable bar positioned in the front of the drum to promote fragmentation is commonly used to achieve acceptable sizing. The forward speed of the reclaimer/mixer as well as the rate of rotation of the drum influence the gradation of the in-place material. Specifications requiring trial strips to establish optimum settings of the reclaimer/mixer are widely used.





**Figure 6 Schematic drawing of the mixing process of the emulsion and the cement slurry**

### 5.3 Mixing

Mixing of the additives with recycled aggregate occurs in the cutting drum of the reclaimer/mixer (Figure 6). Micro-processor control systems are used to properly regulate the injection of emulsion and slurry to the travel speed of the reclaimer/mixer. The pumping and metering system is calibrated to deliver within a tolerance of  $\pm 3.0\%$  by volume. A self-cleaning nozzle system is commonly used to promote uniform application and mixing.

### 5.4 Compaction

A successful DCIR operation is highly dependent on the compaction of the mixture. The use of one heavy pneumatic roller combined with one double drum vibrating roller is typically sufficient to achieve compaction. The rolling patterns to achieve compaction are established on trial sections. Nuclear gauges are used to monitor the moisture content as well as the density of the mixture during the compaction operation.

The mixture moisture content is critical for compaction. On one hand, if there is not enough water, the mixture is harsh and will not compact. On the other hand, if there too much water, the mixture may not compact because of excess fluids and no air voids. The field optimum total water content for compaction ranges between 4.0 to 5.0 %. The minimum compaction requirement most commonly used is 96 % of the Marshall laboratory density.

### 5.5 Field Adjustments

Field adjustments are carried out on a continuous basis during a Deep Cold In-place Recycling operation to account for the variability of the field conditions [7]. Although field adjustments of the emulsion, slurry and

water content are relatively minor, they are very important to obtain a uniform performance of the mat. Field adjustments are based on the appearance of the mat after the initial rolling.

### 5.6 Curing

A certain time period is necessary to allow the recycled mixture to cure and build up some internal cohesion before being covered with a wearing course. The curing of emulsion/cement treated DCIR mixtures is rapid. However, a criteria to determine adequate curing has not been established [1,2,3,4,9,10]. Contrary to standard emulsion treated mixtures, moisture content may not be an adequate criteria to evaluate the curing of a emulsion/cement treated mixture. Field observations are suggesting that build up of internal cohesion may not be related to moisture content. Bearing capacity measurements using a Dynaflect have been used to determine whether or not the mixture has built up sufficient internal cohesion to be overlaid. As a rule of thumb, whenever a saw cut core can be extracted from the mat relatively easily, the recycled mix has built up enough internal cohesion to be covered.

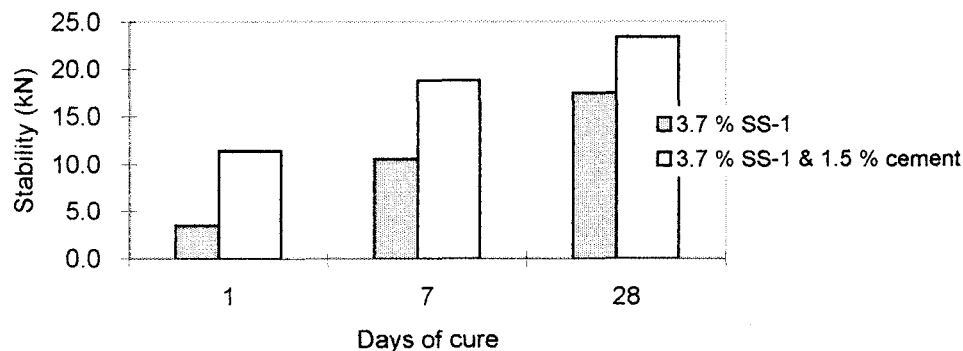
### 5.7 Weather Limitations

When rain is imminent, DCIR operations must be stopped. However, wet pavement with no standing water does not affect the process providing that the moisture content of the in-place material is monitored and field adjustments are carried out. Emulsion/cement treated DCIR mixtures are not affected as much as other emulsion applications by low temperature or rainfalls. In the fall of 1996, Deep Cold In-place Recycling operations were carried out in relatively low temperatures with success. Nevertheless, close monitoring of the mat stability is recommended whenever the air temperature is less than 5° C during operations.

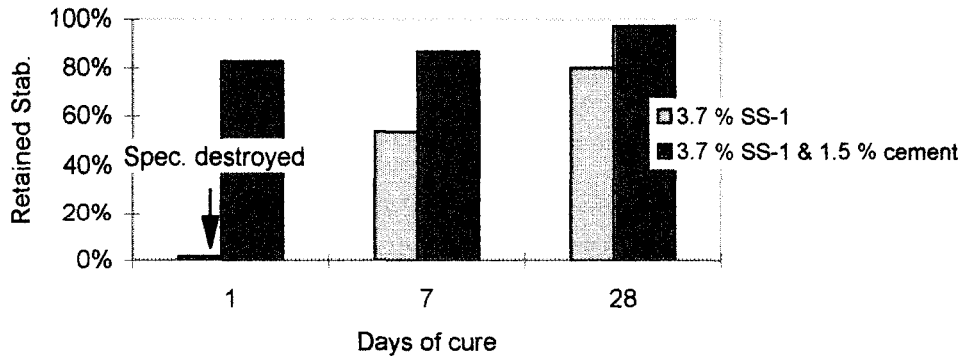
## 6.0 PERFORMANCE OF EMULSION/CEMENT MIXTURE

### 6.1 Pre-construction Period Laboratory Testing

The performance of emulsion/cement mixtures was assessed by Talon Sebeq Inc. during the winter of 1996. Laboratory testing was performed to determine the effect of cement slurry in emulsion mixture. Reclaimed material collected on a typical DCIR project in 1995 was used to perform the testing. An anionic slow



**Figure 7. Stability of Deep Cold In-place Recycled Mixes using Slow Setting (SS-1) emulsion with and without cement**



**Figure 8. Moisture resistance of Deep Cold In-place Recycled Mixes using Slow Setting (SS-1) emulsion with and without cement**

setting type emulsion (SS-1) was selected because of favourable cement stability test results [8]. With regards to cement, Portland cement type 10 was selected.

The laboratory Marshall stability tests were performed as well as moisture resistance tests on Marshall specimens [11]. The specimens were air cured in a laboratory at ambient temperature. In order to reproduce the field conditions, only the top face of the specimens was exposed. The purpose of the stability tests was to evaluate the build up of internal strength while the objective for the moisture resistance tests was to assess the contribution of the cement. The tests were performed on emulsion/cement treated specimens as well as on emulsion treated specimens. The results are shown on Figures 7 and 8.

The results from the stability tests and the moisture resistance tests obtained in 1996 corroborate the results of similar tests carried out in other studies from the early 1970s. The laboratory test results indicate that the early strength and moisture resistance of the emulsion/cement mixture are significantly higher than those of the emulsion treated mixture. The most impressive difference is the comparison of the moisture resistance of the two types of mixtures after a one day curing period. Eighty percent of the dry stability is retained after immersion in water for the emulsion/cement mixture whereas the other mixture does not have any retained stability. As curing occurs, the value of the spread between the results of the stability and the moisture resistance for the two types of mixtures remain significant, but the spread progressively decrease.

In light of the pre-construction laboratory testing results, it was decided to carry out the first 1996 Deep Cold In-place Recycling projects with an anionic SS-1 emulsion and a regular type 10 cement. However, Deep Cold In-place Recycling with emulsion remains popular and the best results are obtained with a cationic emulsion [8]. Consequently, the use of an anionic emulsion with cement implicated a passage back and forth between anionic and cationic emulsion. The operational inconveniences associated with use of an SS-1 emulsion were significant since both operations, DCIR with emulsion/cement and DCIR with emulsion were carried out with the same equipment. The operational inconveniences as well as the better adhesive characteristics of cationic emulsion [8] soon spurred field trials of cationic type emulsion with cement. Trials were carried out and the results were satisfactory and equivalent to those obtained with an anionic emulsion. Thus, it was decided to continue subsequent Deep Cold In-place Recycling projects with a cationic slow setting type emulsion (CSS-1) and a type 10 cement.

## 6.2 Ste-Agathe Test Site

The Ste-Agathe test site is located on the northbound lanes of Highway 117 near Ste-Agathe, Quebec, approximately 175 km north of Montreal. The traffic volume is 15,000 AADT and the percentage of commercial vehicles is 15% [9]. The Deep Cold In-place Recycling project was carried out in the month of June 1997.

The depth of the initial reclamation and sizing operation varied between 300 and 350 mm. The addition of binder and mixing was performed over a thickness of 150 mm. The test site included four test sections and one reference section. The reference section was treated with a cationic slow setting emulsion (CSS-1) while the other sections included the same type of emulsion as well as cement.

Deflection tests using a Dynaflect were performed before and after the Deep Cold In-place Recycling operation. Measurements of deflections were taken every two days for twelve days following the DCIR treatment. The purpose of the measurements was to compare the short term development of bearing capacity as curing occurred. A laboratory testing program of field samples was also implemented to compare the Marshall stability and the moisture resistance of the different mixtures as curing occurred.

### 6.2.1 Mixture Designs

The emulsion and cement contents for each section are shown on Table 1. The quantity of added emulsion varied from one location to another in order to maintain a constant total bitumen content in the Deep Cold In-place Recycling mixture. Yet, a significant lower total bitumen content was found in section four because of a lower ratio of bituminous pavement/granular material in the reclaimed material. The cement contents were 0.4% in section one, 0.8% in section two, 1.1% in section three and 1.6% in section four.

### 6.2.2 Bearing Capacity

The bearing capacity of the various sections was determined by the Ministry of Transportation of Quebec using Dynaflect measurements. The bearing capacity evolution and variation is shown on Figures 9 and 10. The bearing capacity before the Deep Cold In-place Recycling operation ranged between 11 and 12 tonnes. Bearing capacity measurements were taken approximately 48 hours after the DCIR operation and lower

Section	Location	Bitumen before (%)	Mix-Design			Mixture Analysis	
			Bitumen (%)	Cement added (%)	B/C* Ratio	Total Res. Bit. (%)	Final B/C* Ratio
CSS-1	5+100 - 5+300	2.94	2.5	0.0	N/A	5.44	N/A
Test Sect. 1	5+300 - 5+500	3.26	2.4	0.4	6.1	5.69	14.2
Test Sect. 2	5+900 - 6+100	2.25	3.2	0.8	4.3	5.45	7.3
Test Sect. 3	6+240 - 6+440	2.16	2.9	1.1	2.6	5.06	4.6
Test Sect. 4	6+440 - 6+640	1.28	2.9	1.6	1.8	4.18	2.6

\*Bitumen to Cement ratio

Table 1. Ste-Agathe test site - Location, Mix-design and Mixture analysis

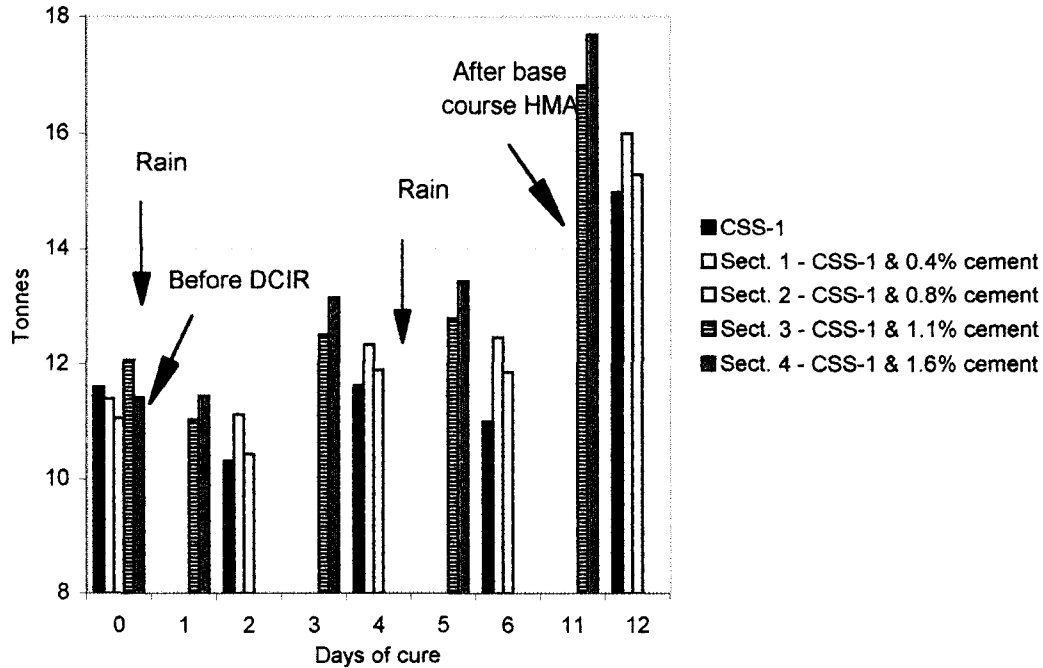


Figure 9. Bearing capacity of Deep Cold In-place Recycling test sections using Cationic Slow Setting (CSS-1) emulsion with and without cement

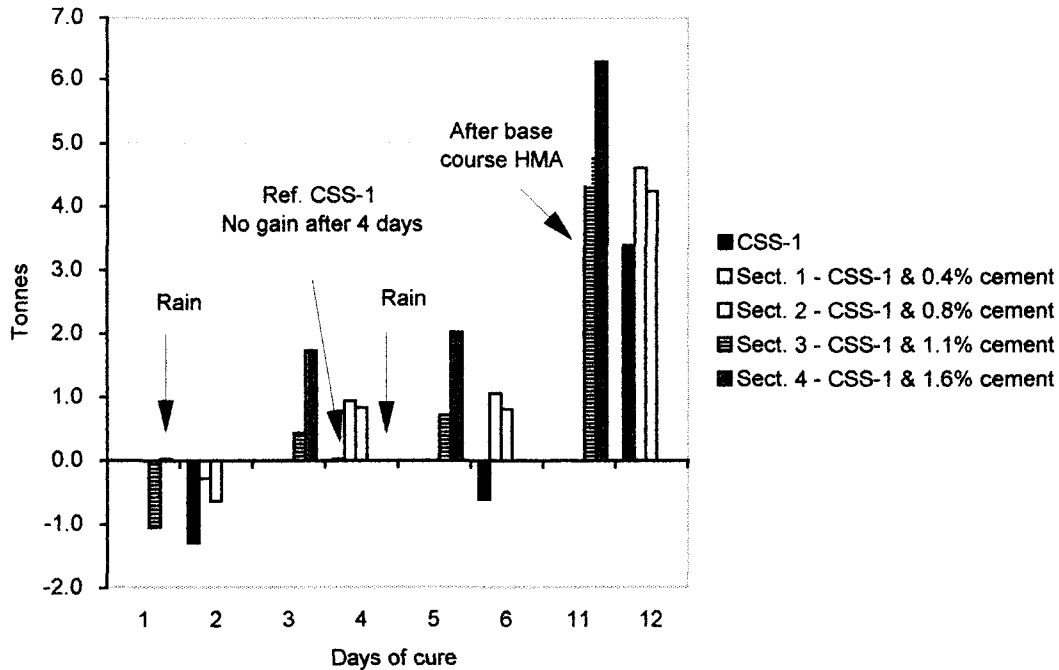


Figure 10. Bearing capacity gains/loss of Deep Cold In-place Recycling test sections using Cationic Slow Setting (CSS-1) emulsion with and without cement

values were obtained for all of the sections. Yet, the loss of bearing capacity was greater for the CSS-1 reference section than for the emulsion/cement treated sections. Furthermore, the bearing capacity had still not increased for the CSS-1 section after four days of curing. It rained between the second and third series of measurements and a loss of bearing capacity was recorded on the third set of measurements for the CSS-1 section whereas the bearing capacity was increasing for the other emulsion/cement treated sections.

The bearing capacity measurements performed on the reference section and the cement treated sections indicate that even a relatively small amount of cement still contributes to an acceleration of the strengthening of the mat during the first days of curing. The loss of strength after the rainfall for the CSS-1 section may also confirm that even a cement content of 0.4 % still improves the moisture resistance of the mixture.

### 6.2.3 Surface Curvature Index (SCI) Values

Surface Curvature Index values represent the difference in deflection between sensor one and sensor two of the Dynaflect. This value provides an appreciation of the shape of the deflection basin of the pavement induced by the Dynaflect. The SCI value is used to evaluate the stiffness of the top layer of a pavement. Lower SCI values indicate higher stiffness, while higher SCI values suggest the opposite.

Surface Curvature Index values were determined for each test section in order to assess the stiffness of the various mixtures. The results are presented in Figures 11 and 12. The SCI values obtained for the various test sections follow the same pattern observed with the bearing capacities evaluated for each section.

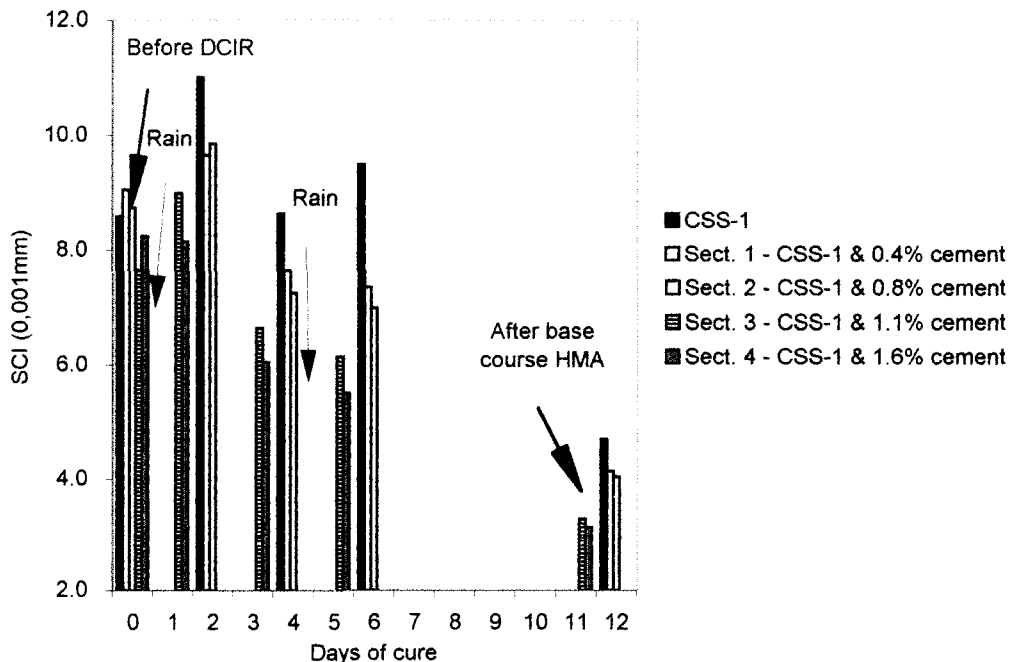
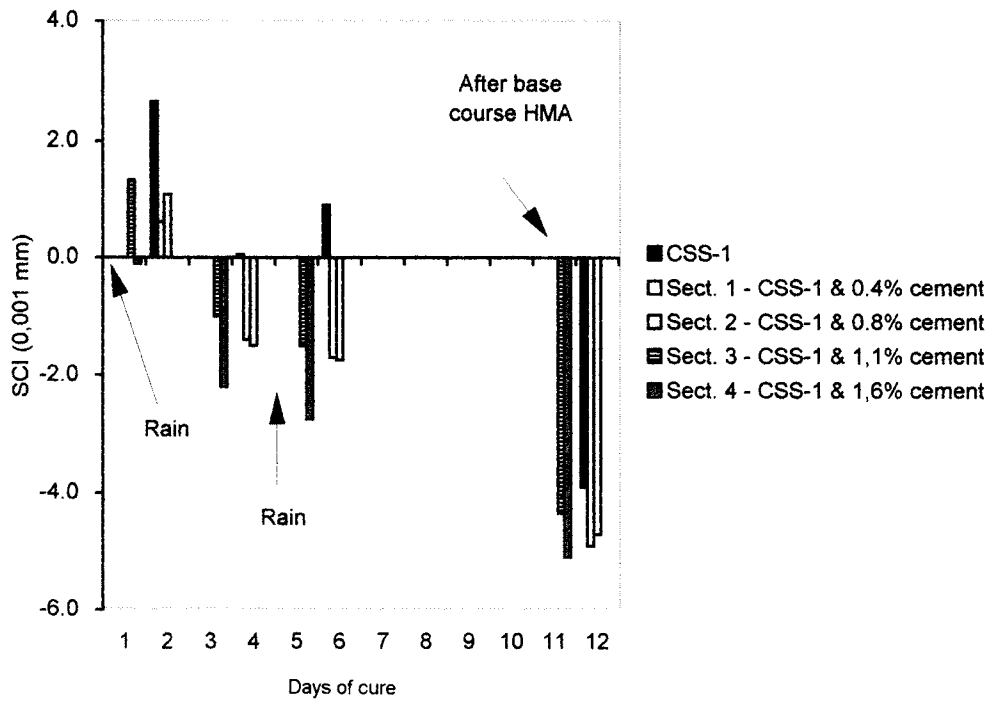


Figure 11. Surface Curvature Index Values of Deep Cold In-place Recycling test sections using Cationic Slow Setting (CSS-1) emulsion with and without cement



**Figure 12 Surface Curvature Index gain/loss of Deep Cold In-place Recycling Test sections using Cationic Slow Setting (CSS-1) emulsion with and without cement**

#### 6.2.4 Laboratory Testing

Two samples of recycled material were extracted from each section. Each set of two samples were combined to provide a representative material for testing. Identical Marshall type specimens were moulded within four hours of field sampling. The specimens were air cured at ambient temperature with only the top face of the specimens being exposed. For each test section, Marshall stability tests were performed on dry and vacuum soaked specimens after 1, 3, 7 and 28 days of curing. The results of these tests are presented on Figures 13 and 14.

The effect of cement on the mixture strength is significant. After a cure time of one day, the Marshall stability of the different mixtures ranged from 5.0 kN to 10 kN for the cement treated mixtures while the reference CSS-1 mixture stability was approximately 2.5 kN.

The cement also contributes to the moisture resistance of the mixture. The retained stability after one day of curing was between 80% and 90% for the cement treated mixtures while the retained stability for the reference CSS-1 mixture was nil. The soaked CSS-1 mixture specimen crumbled before being tested. However, after 28 days of curing, the retained stability values were equivalent for the CSS-1 reference specimens and the cement treated mixtures.

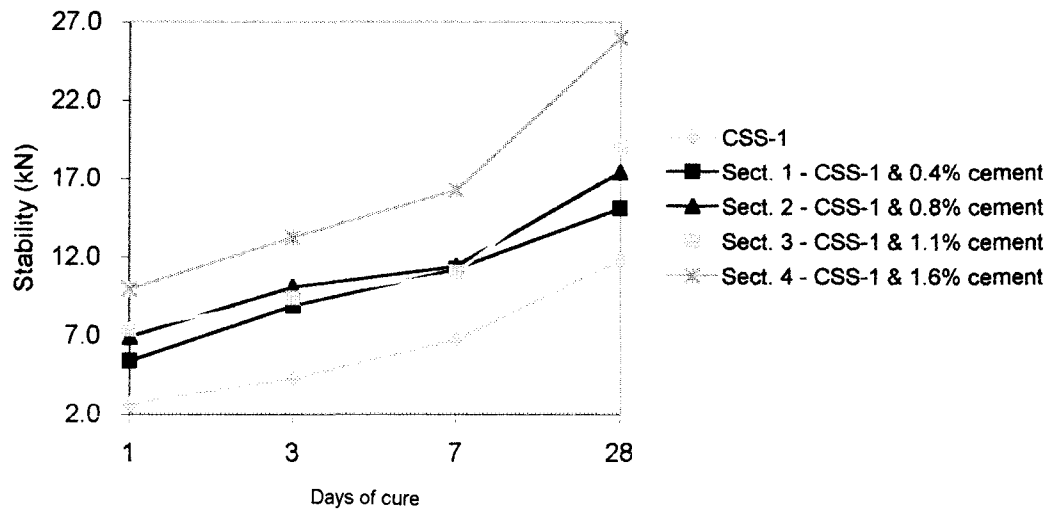


Figure 13. Stability of CSS-1 mixes with and without cemen

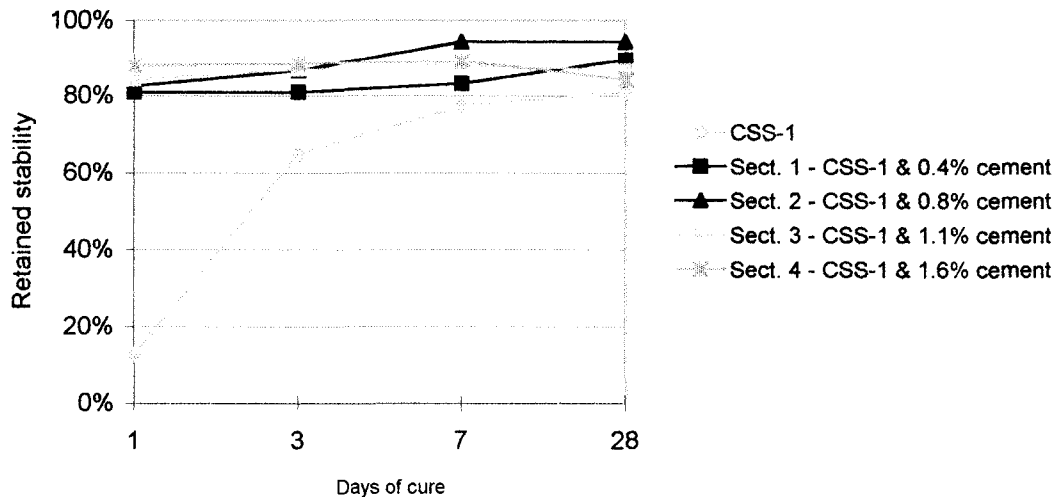


Figure 14 Moisture resistance of CSS-1 mixes with and without cement

### 6.2.5 Field Observations and Laboratory Testing

Parallels between the field observations and the laboratory testing may be established. The bearing capacity and the Marshall stability for the emulsion/cement mixtures are always greater than the reference emulsion treated mixture. Field observations and the laboratory testing also indicate a moisture resistance improvement for the emulsion/cement mixtures. The loss of bearing capacity recorded after a rainfall for the CSS-1 section, when the bearing capacity for the emulsion/cement sections was stable or increasing, may confirmed the laboratory testing that indicates that cement improves the moisture resistance of the mixture.





**Figure 15 Deep Cold In-place Recycling with emulsion/cement in Montréal-Nord**

## 7.0 CONCLUSION

A wide range of severely distressed pavement may be Deep Cold In-place Recycled. This process reuses all of the existing materials, allowing the preservation of aggregates and bitumen. The Deep Cold In-place Recycling operation may be executed with minimal disturbance to traffic. This process fully eliminates existing cracking patterns. The need to raise the surface elevation of the pavement is minimized. The cold nature of the process and the control of dust reduces the impact on the environment and preserves energy [6].

Addition of as little as 0.4% cement to a Deep Cold In-place Recycling mixture with emulsion results in a dramatic increase in early strength and moisture resistance. Late season work or high traffic conditions are no longer imposing limitations for Deep Cold In-place Recycling. Consequently, the use of a emulsion/cement binder with pavement recycling broaden the application options of Deep Cold In-place Recycling.

The laboratory and field results obtained from the Ste-Agathe test site confirm the findings published in the early 1970s with respect to the build-up of early strength and the added resistance to moisture. Yet, more research work is required to fully optimize and better understand the chemical and physical properties of recycled emulsion/cement treated mixtures. The monitoring of the Ste-Agathe test site undertaken by the Ministry of Transportation of Quebec will provide more information on the long term performance of Deep Cold In-place Recycling with emulsion/cement.

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