Performance of Cold In-Place Recycling in Ontario

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In today's climate of environmental and economic constraints coupled with a limited aggregate supply, in-place recycling provides a feasible alternative to conventional pavement rehabilitation. Several state agencies have employed the cold in-place recycling (CIR) process for low-to-moderate traffic volume roads since the mid-1980s with reported favorable results. The Ministry of Transportation of Ontario was interested in determining whether these benefits could be realized on Ontario's highways. CIR consists of partial milling the existing pavement, processing the material to a suitable size, treating with an emulsion, and placing this recycled cold mix using conventional paving and compaction equipment. In the summer of 1990 the ministry decided to use CIR on a major rehabilitation project. The location chosen was Highway 15, 40 km southwest of Ottawa. The ride on this road was considered uncomfortable, with major distresses consisting of extensive, moderate transverse and longitudinal wheel track cracking and slight rutting throughout the project length. The design details, construction procedures, mix test results, and pavement performance of this project are described. Conclusions and recommendations are made for further development of CIR in Ontario.

As we become more conscious of the need for construction techniques that not only rehabilitate to acceptable standards but are also environmentally friendly, cold in-place recycling (CIR) is proving to be an economical rehabilitation technique that conserves granular materials and energy and results in zero waste. It had been used in the states of Oregon and New Mexico with progressive success since the 1980s (*1–5*). Although it had been used on two local roads in the Ottawa area in 1989, it had never been tried on a highway in Ontario.

Cold mix recycling is a process in which reclaimed asphalt pavement is combined with new emulsified asphalts or recycling agents, or both, either in place on the roadway or at a central plant to create a cold mix (*6*).

CIR is an alternative to off-site central plant recycling for highways with lower traffic volumes and moderate to severe distresses. CIR involves milling the existing pavement to a maximum depth of 150 mm; screening and crushing, if necessary, to meet a specific gradation; adding a polymer-modified asphalt emulsion and mixing; then placing it on the roadway in a windrow as one continuous operation. The processed material is then picked up by a slat elevator, laid down with a conventional paver, and compacted.

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ADVANTAGES AND DISADVANTAGES

Besides the environmental advantages to in situ recycling, CIR can be used on severely cracked but structurally sound pavement. Unlike hot in-place recycling, it is not limited to pavements exhibiting only surficial defects. The cold mix tends to be self-healing and therefore helps to retard reflection cracking and localized roughness.

Traffic disruptions are also minimized with CIR. Vehicles can drive on the recycled mat immediately after compaction and need only be detoured around the CIR train and uncured mat as it makes its way down the highway.

As with all rehabilitation techniques, there are also some disadvantages to CIR:

- It must be placed in warm, dry weather and therefore is limited to the summer months for construction.
- The cold mix is also susceptible to moisture intrusion and abrasion, so it requires a separate wearing surface such as a hot mix overlay or surface treatment.
- Since cold in-place recycling is a relatively new technique, there is no widely accepted mix design or thickness design methodology. Typically treatment depths range from 50 to 100 mm.

BACKGROUND

In 1990 the Ministry of Transportation of Ontario decided to award a demonstration project on a provincial highway to determine whether CIR is a feasible rehabilitation technique with regard to economics, performance, and preservation of resources (*7*).

Highway 15 from Smith Falls north to just north of Frankton, a length of 15.6 km, was chosen as the demonstration site. Highway 15 is a two-lane, rural King's highway that serves as a collector route southwest of Ottawa in eastern Ontario. It was chosen as the trial project because of its moderate traffic volumes and fair to poor pavement condition.

Traffic on this section of highway has an AADT of 4,000 with commercial traffic between 10 and 15 percent.

The existing pavement structure consisted of 150 mm hot mix over 150 mm granular base and 150 mm granular subbase. The subgrade is typically a silty sand to silty clay. The surface course was placed in 1980 and was one of the first central plant recycled hot mixes placed in eastern Ontario. At that time the two-lane pavement was widened from 6.1 to 7.3 m, and a 0.6-m partial paved shoulder was added on both sides.

The pavement condition before construction was fair to poor. The major distresses were slight wheel track rutting throughout, extensive moderate longitudinal wheel track cracking, and extensive moderate center line cracking. There was also moderate coarse aggregate loss (raveling) and multiple transverse cracking over most of the highway.

The extensive longitudinal and transverse cracking contributed to an uncomfortable ride, especially during the spring.

DESIGN

The design used for this project was to cold in-place recycle 75 mm of the existing pavement and resurface with 50 mm of hot mix. Normally the rehabilitation scheme for this type of highway would consist of milling one lift and replacing with two 40-mm lifts of recycled hot mix and a 40-mm virgin surface course mix. A short section (850 m) at the south end, which exhibited fewer distresses than the rest of the project, was repaired with a 50-mm overlay with no recycling. Two 1-km test sections, one to be cold in-place recycled to a depth of 100 mm and the other to a depth of 50 mm, were incorporated into this project.

No formal mix designs were available for this project. Emulsion and water contents were established in the field using trial and error procedures by experienced paving personnel. Field adjustments were based on softness of extracted asphalt, gradation of millings, and percentage of recovered asphalt.

CONSTRUCTION

A 3.8-m-wide cold milling machine was used at the start of the paving train; it pulled a mobile screen deck and pugmill behind it. The pavement was milled to the required depth in a single pass, leaving the existing partially paved shoulder in place (P. Bound, memorandum). Water was added to the drum of the milling machine, resulting in a 2 to 3 percent moisture content of the reclaimed asphalt pavement (RAP).

A conveyor belt then sent the RAP to a screening deck to ensure that no oversize material got into the mix. Any oversize material was sent to a portable hammer mill for crushing, then placed back on the conveyor belt for screening. From here the processed material was weighed and introduced into a continuous flow computerized pugmill where a metering system added the required amount of emulsion, which was mixed into the RAP. The mix was then placed in a windrow behind the pugmill. If necessary, water could be added at the pugmill to facilitate mixing.

The RAP in the windrow was picked up by a slat elevator and placed into a conventional paver. The mix was then placed on the highway at the appropriate depth.

Automatic longitudinal grade controls were not used on the paving machine for the CIR mat, since this could result in overloading or emptying of the paver hopper.

The mat was left in place before compaction for 15 to 30 min to allow the emulsion to break and the curing process to start.

Compaction was accomplished with a 30-ton pneumatic breakdown roller followed by a steel wheel roller usually in the static mode.

The texture of the mat was open and inconsistent with slight to moderate segregation throughout and a few areas of localized severe segregation.

Previous experience by various state agencies has shown that a mat with open texture and segregation is common for CIR. Once traffic was on the roadway, the center of the lane and edges appeared more segregated because of the lack of kneading action by traffic (*2*).

Traffic was allowed to run on the CIR material about 1 hr after compaction. This caused a small amount of loose material to be picked up from the pavement by traffic and moved eventually onto the shoulder. This is a normal occurrence on CIR projects, as reported by several state agencies (*2*).

The specifications called for a minimum of 14 days curing before placement of the overlay, but because of wet, cool weather the overlay was not placed until after the curing was complete at about 22 to 26 days after placement. To remove any interim rutting, secondary compaction was allowed after 10 days of curing, but this had no effect on the traveled surface and was discontinued. The overlay consisted of 50 mm of HL-4 hot mix.

SPECIFICATIONS

The following requirements from the special provision controlling the cold in-place operation are highlighted:

- The maximum size of the reclaimed asphaltic pavement shall be 100 percent passing the 37.5-mm sieve.
- The binder shall be a polymer modified high float emulsified asphalt.
- The cold in-place recycled mix shall cure for a minimum of 14 calendar days before being covered with the hot mix overlay.
- One and three-tenths percent binder total emulsion by mass of reclaimed asphalt pavement shall be used.
- The cold in-place shall be compacted to a minimum of 97 percent of the laboratory density.
- The surface shall be free from any deviation exceeding 6 mm as measured in any direction with a 3-m straightedge.

CIR MIX TEST RESULTS

Compaction

To test for compaction before overlay, the contractor first attempted to core the cold in-place recycled material, but the mix had not cured enough and could not withstand the pressure of coring. The resulting samples were not acceptable for testing. The contractor then decided to use dry saw cut samples (100 mm × 100 mm) for both the compaction and moisture tests.

The contract required a minimum compaction of 97 percent of the laboratory density. A compaction procedure similar to Oregon's sample preparation and modified Marshall procedure was specified (*4*).

Briefly the sample preparation procedure involved

1. Air drying the processed millings (26.5 mm minus) for 4 hr to determine air content;

2. Heating sample to 60°C for 1 hr and adding sufficient water to raise moisture content of mixture to 4.5 percent of dry weight;
3. Adding and mixing emulsion at the design application rate, spreading it, and allowing it to cure for 1 hr at 60°C;
4. Compacting samples using 50 blows/side for Marshall procedure in preheated molds, curing for 20 ± 4 hr at 60°C and recompacting at 25 blows/side; and
5. Curing specimens for 24 hr at 60°C in the molds, extruding, and curing for 72 hr at room temperature before normal testing.

The majority of samples did not reach the compaction requirement of 97 percent; the average was only 95.1 percent with a standard deviation of 1.84. These results and the following graphs only apply to samples taken in the areas where the pavement was CIR to a depth of 75 mm. Four samples were taken in the section of 100-mm-deep CIR and one in the area of 50-mm-deep CIR. All results are given in Table 1.

Figure 1 shows the percent compaction versus moisture content. The trend indicates that as the moisture content decreases, the compaction increases, which is expected.

The weather seems to have the greatest effect on compaction: the higher the degree days, the higher the compaction; also, the longer the cure time, the greater the compaction (see Figures 2 and 3). Degree days is the summation of the high temperature of the day from time of paving to coring.

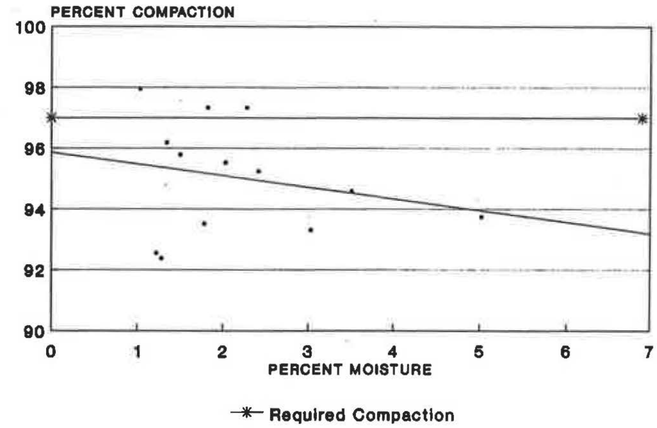


FIGURE 1 Compaction versus moisture content, CIR material.

Moisture Content

Moisture content was analyzed on all but one of the samples taken for compaction testing. The graphs only refer to samples taken in the areas of 75-mm-deep CIR treatment. All test results are given in Table 1.

The moisture content of the cold in-place recycled material appeared to be unaffected by the number of degree days or

TABLE 1 CORE DATA

Core Number	Days Cured Before Coring	% Compaction	% Moisture	Degree Days
Cores from 75 mm CIR				
3	20	95.9	N/A	501
4	24	78.0	2.83	598
R4-B	28	98.0	1.03	688
5	22	Too Loose	3.68	549
R5-B	26	94.6	3.51	639
6	27	95.8	1.50	663
7	26	96.2	1.34	606
8	22	97.3	1.82	526
9	21	97.3	2.28	504
10	20	92.6	1.22	484
R10-B	25	95.2	2.42	579
11	19	92.4	1.28	460
R11-B	24	93.8	5.02	578
12	14	93.3	3.03	339
R12-B	16	93.5	1.78	387
R12-c	21	95.5	2.03	505
Cores from 100 mm CIR				
1	22	97.3	N/A	545
2	21	97.0	N/A	525
14	29	95.7	1.75	703
R14-B	33	99.1	1.83	793
Core from 50 mm CIR				
13	17	95.8	N/A	N/A

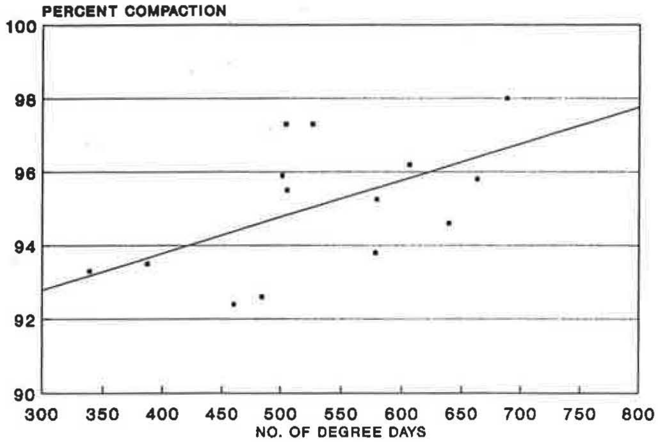


FIGURE 2 Compaction versus degree days, CIR mix.

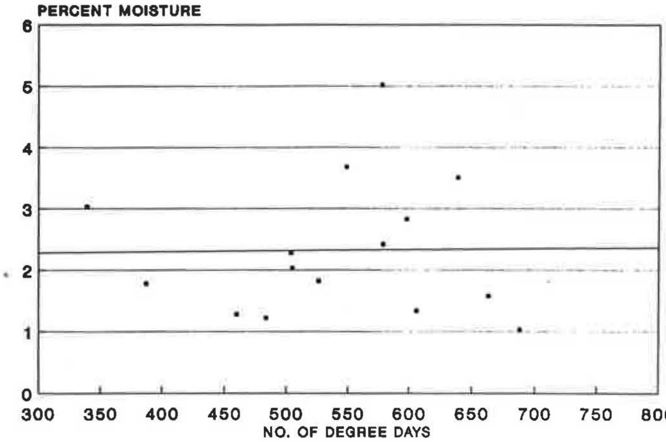


FIGURE 4 Moisture content versus degree days, CIR mix.

amount of curing time (see Figures 4 and 5). This probably was due in large part to the very wet weather experienced during construction, with 13 cloudy and rainy days and an average daily maximum temperature of 24°C until the CIR mat was overlaid.

Permeability

Permeability testing was done using the Johns-Manville field permeability test. Results indicated that the CIR material was very permeable (i.e., greater than 25 ml/min). The inconsistency of the mix resulted in varying test results, ranging from 145 to more than 500 ml/min (see Table 2).

Tests were also carried out on the existing partially paved shoulder, which indicated that it was impermeable. There was some concern during construction that this would cause drainage problems by restricting the lateral drainage of the CIR material. But observation and coring at the interface between the partially paved shoulder and the CIR lift did not indicate any problems with trapped water, since the partial paved shoulder was only 50 mm thick and drainage occurred into the adjacent granular materials.

Marshall Stability Testing

Limited stability testing was done during construction. The specification did not have any stability requirements for the CIR material (see Table 3 for the results).

The limited testing done indicates an initial low stability for the CIR mix in all three sections. Normally for this type of highway an HL-4 or HL-8 would be used for the binder course. Both of these types of mixes call for a Marshall stability of 5800 N at 60°C. Although no retesting was done for stability, the falling weight deflectometer (FWD) testing indicates an increase in strength with time that would be reflected in increased stabilities as the mix continued to cure.

Recovered Penetration

Testing for recovered penetration on the original hot mix was done in 1987, 2 years before construction. The tests had an average value of 31 at 25°C. The contract specifications called for a recovered penetration of 50 at 25°C after CIR, but of the 13 tests taken during construction only one sample met this requirement.

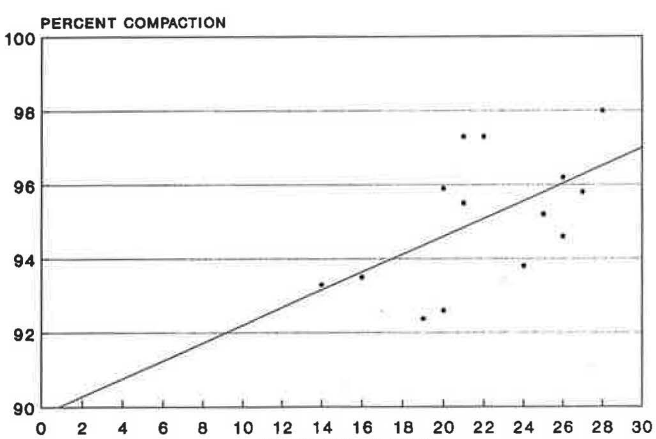


FIGURE 3 Compaction versus curing time, CIR mix.

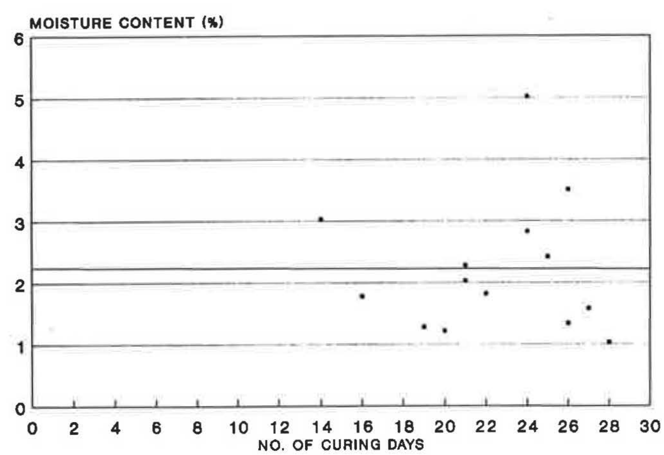


FIGURE 5 Moisture content versus curing time, CIR mix.

TABLE 2 PERMEABILITY TEST RESULTS

Station	Test No.	Pavement Age(Days)	Permeability * (ml/min)	Comments
14+625	1	29	>500	500 mm from Edge of Pav't
(Montague)	2	29	180	Centre of Lane
Northbound Lane	3	29	>500	250 mm from Centreline
16+150	1	11	>500	Outer Wheel Path
(Montague)	2	11	>500	Inner Wheel Path
	3	11	>500	Centreline
Northbound Lane	4	11	22	Partial Paved Shoulder
16+150	1	23	N/A	Leak Detected
(Montague)	2	23	>500	Outer Wheel Path
Southbound	3	23	145	Inner Wheel Path
Lane	4	23	>500	Outer Wheel Path

* Permeability = Volume (30 secs)- Volume (90 secs)

The average recovered PEN was 40.8 with a standard deviation of 7.5. This represents a 29 percent improvement in recovered penetration as a result of the CIR process. Test results are given in Table 4.

Binder Material

The binder used was a polymer-modified high float emulsified asphalt Styrelf HF-150-P. Because of problems in shipping and receiving, the contractor did not ensure that the laboratory testing samples were received within the required 7 days. The emulsion had broken and the samples were not suitable for testing.

Polymer modified emulsions are not necessarily used by other agencies, except when pavements are highly weathered and oxidized (a penetration of less than 10) (*8*).

PERFORMANCE EVALUATION

Pavement Condition Evaluation

Before construction the ride on Highway 15 was classified as uncomfortable. A pavement condition index of 50 for this type of highway facility would necessitate rehabilitation within the 5-year program. Presently, the major distresses are frequent moderate midlane cracking in the surface courses, which was caused by a defective paver. Centerline cracking associated with moderate to severe frequent segregation is also present in the overlay, probably caused by poor paving operation. There were few distress manifestations associated with the CIR, since most of the visual distresses are associated with surficial distresses in the overlay.

Load Deflection Characteristics

The FWD is a nondestructive test in which a dynamic load impulse strikes the surface of the pavement. The resultant deflections are measured by seven sensors. The loads used in this testing were 40, 60, and 80 kN in sequence. The results discussed have all been normalized to 40 kN and 21°C (*9*).

FWD testing was performed on May 30, 1990, before construction, on June 26, 1990, after CIR but before the hot mix overlay, and on August 22, 1990, September 24, 1990, and in October 1991 after construction was completed. Table 5 gives the results of the testing.

Readings were taken in the control section, where there was no CIR but a 50-mm hot mix overlay was placed. Test

TABLE 3 MARSHALL STABILITY TESTING

	Immediately after Secondary Compaction			72 hr after Secondary Compaction		
Design Depth	Marshall Stability (N @ 60°C)	Flow (0.25 mm)	Percent Air Voids	Marshall Stability (N @ 60°C)	Flow (0.25 mm)	Percent Air Voids
50 mm	3005	15.0	6.4	2390	15.0	6.5
75 mm	2159	12.0	9.0	1465	10.0	7.2
100 mm	2695	15.0	7.9	2625	15.0	7.8

TABLE 4 RECOVERED PENETRATION RESULTS

	Date Tested	Recovered Penetration at 25°C
Existing Pavement	Sept 30, 1987	31
	Oct. 1, 1987	32
	Oct. 5, 1987	30
Cold In-Place Recycled Material	June 7, 1990	35
	June 8, 1990	49
	June 13, 1990	40
	June 14, 1990	59
	June 14, 1990	37
	June 22, 1990	30
	June 22, 1990	39
	June 22, 1990	36
	June 22, 1990	42
	July 3, 1990	49
	July 3, 1990	40
	July 4, 1990	37
	July 4, 1990	38

Sections 1, 2, and 3 are areas where 50, 75, and 100 mm of CIR were carried out, respectively.

Figures 6 and 7 show the mean deflection of each of the three test sections of the CIR mix and the control section, which was only overlaid. Immediately after CIR the deflections increased, indicating a drop in strength characteristics compared with the original. But after the overlay and additional curing time, the strength of the pavement has progressively increased to such an extent that it is greater than the original pavement.

Test Sections 2 and 3, with 75- and 100-mm-deep CIR treatments, tended to have a greater reduction in strength just after the CIR took place, compared with the 50-mm-deep section.

The control section results show a nominal progressive drop of deflection, reflecting the normal drying of the granular and subgrade over the summer months.

Rutting

Surveys were initially taken along Highway 15 with the Automatic Road Analyzer (ARAN) to determine the size and extent of the rutting before construction. The ARAN uses a

TABLE 5 FWD TEST RESULTS

Section	Initial Mean Deflection (mm) May 30, 1990	Mean Deflection After CIR (mm) June 26, 1990	Mean Deflection After Overlay (mm) August 22, 1990	Mean Deflection(mm) Sept. 24/25 1990
Control Section				
NBL	0.31	0.30	0.26	0.21
SBL	0.27	0.27	0.23	0.19
Test Section #1				
NBL	0.48	0.56	0.36	0.29
SBL	0.48	0.61	0.39	0.29
Test Section #2				
NBL	0.50	0.59	0.37	0.32
SBL	0.37	0.55	0.36	0.26
Test Section #3				
NBL	0.33	0.46	0.29	0.25
SBL	0.27	0.44	0.29	0.22

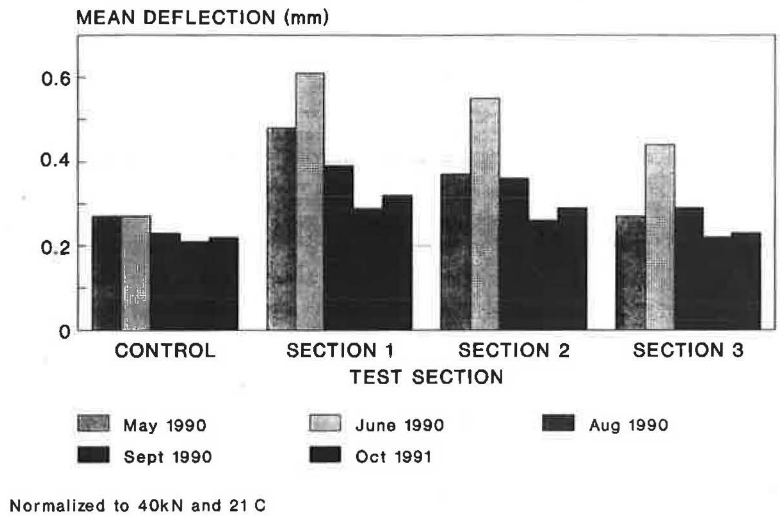


FIGURE 6 FWD testing, southbound lanes.

3.75-m-long "smart bar" mounted on its front bumper equipped with ultrasonic sensors spaced at 100-mm intervals. The sensors bounce signals off the pavement and record the relative distance between the bar and the surface. These data are interpreted to give a transverse profile of the pavement lanes (*10*).

Rut surveys were also taken in December, April, and August 1991, 6, 10, and 14 months after construction. The surveys indicate that any initial severe rutting was alleviated; slight rutting, however, is apparent throughout after CIR with some increase between the last surveys.

Before rehabilitation, the average rut depth was 13 mm. The 6-, 10-, and 14-month average rut depth readings were 5.4, 5.7, and 6.2 mm, respectively. This increase in rutting may be the result of minor consolidation of the CIR material under traffic loading due to the low levels of compaction achieved during construction.

Detailed rut survey results for the northbound and southbound lanes are shown in Figures 8 and 9, respectively. The results are similar for the two lanes. A summary of the rut survey comparing both directions is shown in Figure 10.

Roughness

Roughness surveys were taken using a portable universal roughness device (PURD) before and just after construction, then 10 and 16 months after rehabilitation.

The PURD is a trailer-mounted, accelerometer-based measuring device operated at a constant speed on the highway. It uses the root mean square of vertical acceleration of the trailer axle to measure roughness. The data are converted into a ride condition rating (RCR) as follows (*10*):

$$RCR = 26.64 - 7.38 * \log_{10} (PURD)$$

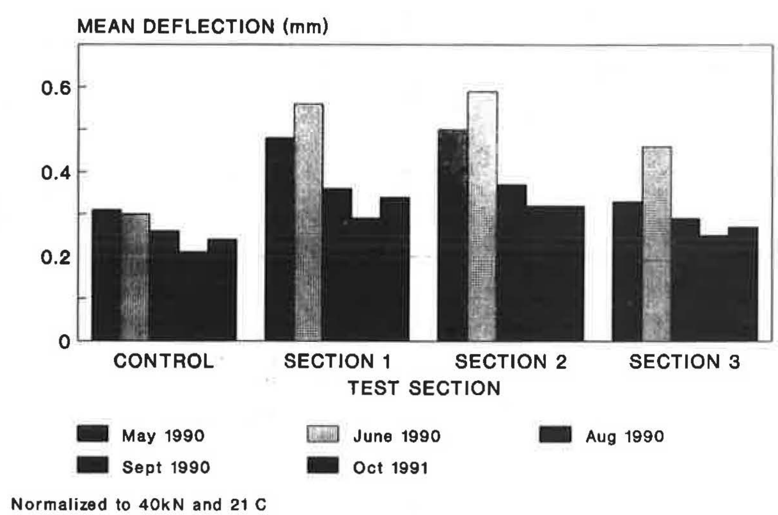


FIGURE 7 FWD testing, northbound lanes.

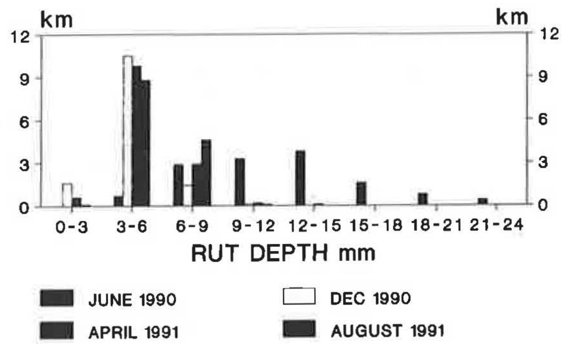


FIGURE 8 Rut classification survey, Highway 15, northbound.

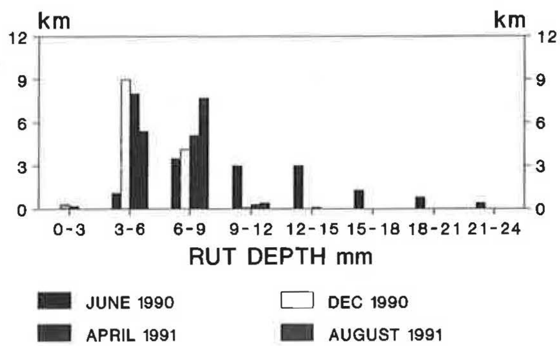


FIGURE 9 Rut classification survey, Highway 15, southbound.

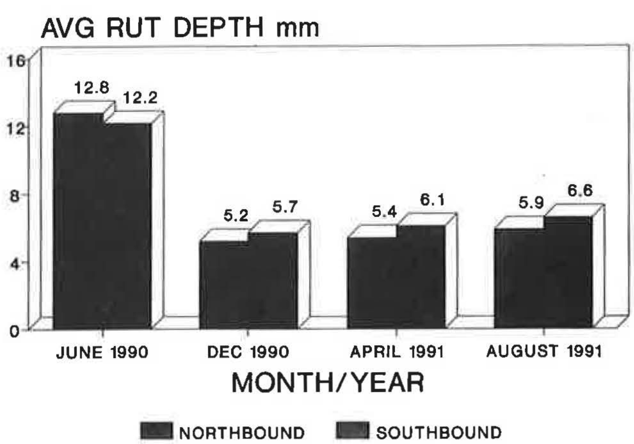
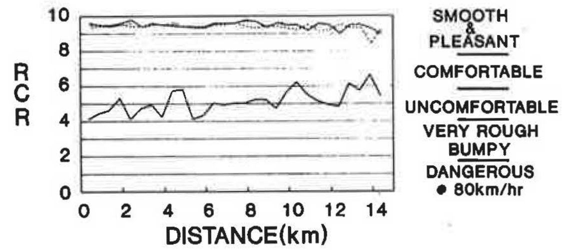


FIGURE 10 Summary of rut survey, Highway 15.

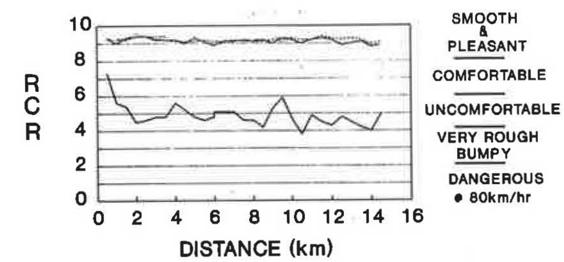
Before construction the ride was about 4.7, described as uncomfortable. Immediately after construction the average RCR reading was 9.5 and 9.2, respectively. These are excellent ratings, indicating that a high level of ride quality was achieved.

The detailed RCR readings are shown in Figures 11 and 12 for both the southbound and northbound lanes. The 10- and 16-month readings show little change in the ride quality, with RCR values consistently above 9. A summary of roughness readings is shown in Figure 13.



MONTH/YEAR	JUN 89	AUG 90	APR 91	OCT 91
AVERAGE RCR	4.8	9.5	9.5	9.2

FIGURE 11 PURD roughness, Highway 15, southbound.



MONTH/YEAR	JUN 89	AUG 90	APR 91	OCT 91
AVERAGE RCR	4.7	9.2	9.1	9.2

FIGURE 12 PURD roughness, Highway 15, northbound.

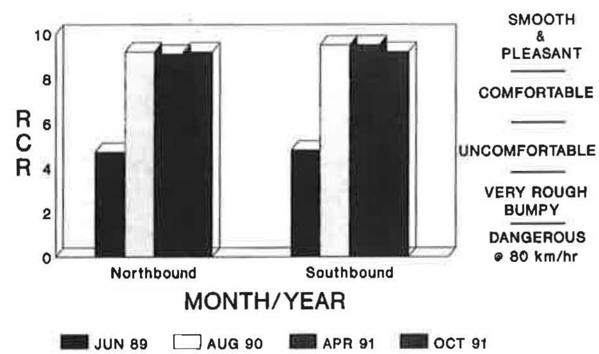


FIGURE 13 Summary of roughness, Highway 15, northbound and southbound.

CONCLUSIONS

This paper summarizes the successful design and construction of a CIR project undertaken in Ontario. An overview of the initial performance results is presented and compared with conventionally rehabilitated pavements.

Monitoring and data collection activities are continuing and future performance results will be documented.

The following general conclusions based on short-term postconstruction results are presented:

1. The drawings and specifications developed for CIR proved to be adequate, and no significant deficiencies were apparent.

2. Construction of the project went smoothly, and minimal problems were encountered with the CIR process.

3. On the basis of FWD results, the strength characteristics of the pavement have improved with time.

4. A significant improvement in ride was attained using the CIR process. Postconstruction ride measurements are better than those typically achieved using conventional rehabilitation techniques.

5. The test section using 50 mm of CIR appeared to exhibit fewer surficial defects (segregation) in the CIR mat than the 75- and 100-mm sections. Several agencies typically specify a 50-mm depth of treatment (*8*).

6. An overall conclusion is that the Highway 15 project has proven that CIR can be successfully and economically performed in Ontario.

Several aspects of CIR requiring additional developmental work include the following:

- Optimization of the depth of CIR treatment,
- Development of appropriate mix design and testing procedures for CIR mixes,
- Refinements in the methods and timing of compaction efforts on the CIR mat,
- Establishment of criteria for the binder type (normal or polymer-modified emulsions) used in CIR, and
- Investigation and monitoring of long-term deformation characteristics of CIR mixes at much higher traffic volumes.

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