Long Term Performance of Full Depth Reclamation with Expanded Asphalt on the Trans-Canada Highway near Wawa, Ontario

Becca Lane P.Eng.
Head, Pavements and Foundations Section
Ministry of Transportation Ontario
1201 Wilson Avenue,
Downsview, Ontario
Canada
M3M 1J8
Phone: 416 235 3732
Fax: 416 235 3919
Becca.Lane@ontario.ca

Tom Kazmierowski P.Eng.
Manager, Materials Engineering and Research Office
Ministry of Transportation Ontario
1201 Wilson Avenue,
Downsview, Ontario
Canada
M3M 1J8
Phone: 416 235 3512
Fax: 416 235 3919
Tom.Kazmierowski@ontario.ca

ABSTRACT

In 2001, the Ministry of Transportation Ontario (MTO) constructed its first full depth reclamation with expanded asphalt stabilization project on the Trans Canada Highway, between Sault Sainte Marie and Wawa, in Northern Ontario. The project incorporated three different expanded asphalt mix designs and a control section of full depth reclamation with hot mix overlay. The project has been monitored annually over the past 10 years using the Ministry's Automated Road Analyser (ARAN), which measures International Roughness Index (IRI) and rutting. Roughness data indicates a significant difference between the expanded asphalt stabilized base test sections and the control section. The expanded asphalt stabilization has delivered superior performance over the conventional full depth reclamation with hot mix overlay. Performance curves for the different treatments are compared to the ministry's average performance curve for full depth reclamation projects, and to the performance of treatments on adjacent projects. This project demonstrates the exceptional performance of the expanded asphalt mixes, with 10 years of proven superior pavement condition and ride.

1.0 INTRODUCTION

The Ministry of Transportation Ontario (MTO) constructed its first full depth reclamation with expanded (foamed) asphalt stabilization contract on the Trans Canada Highway (Highway 17) north of Sault Ste. Marie in the summer of 2001 (Figure 1). A lack of aggregate availability in the vicinity of the contract, which runs through Lake Superior Provincial Park, lead to the selection of expanded asphalt stabilization (EAS) as the rehabilitation treatment for this project.

The 22.5 km long project involved in-place full depth reclamation (FDR) of the existing hot mix asphalt (HMA) and underlying granular base to a depth of 180 mm, with the goal of obtaining a 50:50 blend of reclaimed asphalt pavement and granular base. The reclaimed material was shaped, compacted and then stabilized in place by the addition of about 3% expanded asphalt. The stabilized material was then graded to the required profile and compacted. Following a minimum two-day curing period, the stabilized base was overlaid with 80 mm of HMA.

FIGURE 1 Map of Ontario showing project location on Highway 17.

Construction of the expanded asphalt demonstration project was carried out in August through September of 2001. Extensive testing was carried out to determine the properties of the expanded asphalt mix, including compaction, thickness, gradation, per cent asphalt cement, dry tensile strength, wet tensile strength and tensile strength ratio.

In the 10 years following construction, surveys of the highway were carried out using MTO's Automated Road Analyser (ARAN), which measures International Roughness Index (IRI). Pavement distress data was also collected to determine the Pavement Condition Index (PCI) *(1)*. Performance curves were established using 10 years of ARAN data and this was compared to the ministry's performance curve for in-place full depth reclamation projects. The performance was also compared to the performance of two projects in the vicinity, a cold in place recycling with 50 mm HMA overlay and a conventional FDR project with 120 mm HMA overlay.

2.0 PAVEMENT DESIGN

2.1 Pavement Condition Prior to Reconstruction

This section of Highway 17 was originally constructed in 1959 and resurfaced in 1981. In 2001, the existing pavement structure consisted of an average of 80 mm of HMA, 100 mm of granular base and 530 mm of granular sub base. The Pavement Condition Index (PCI), a measure of pavement serviceability, was 49 out of 100, indicating a poorly performing pavement requiring major rehabilitation. Pavement performance records indicated extensive, moderate transverse cracking and extensive, moderate pavement edge break-up *(2)*. Also noted were areas of slight to moderate wheel track cracking and alligator cracking.

2.2 Traffic Conditions

The 2010 Annual Average Daily Traffic (AADT) was 2500 with 28% trucks, mostly logging trucks. During design, the estimated equivalent single axle load (ESAL) over a 20-year design period was calculated to be 2.8 million ESALs.

2.3 Design Considerations

Based on traffic volumes and a sand subgrade with 0-25% passing the 75 μm sieve, MTO design charts recommended 120 mm HMA, 150 mm granular base and 300 mm granular sub base. The adjacent project to the north was reconstructed in 1999 with FDR and 120 mm HMA overlay.
Several pavement rehabilitation options were considered including: cold in-place recycling (CIR) with a 50 mm HMA overlay; hot in-place recycling (HIR) with a 50 mm HMA overlay; full depth reclamation (FDR) with a 120 mm HMA overlay; and FDR with expanded asphalt stabilization (EAS) and an 80 mm HMA overlay.

It was decided that the existing thin HMA pavement was most suited to FDR. In-place FDR would mitigate reflection cracking and improve the slightly deteriorated base material. Of important consideration, however, was a lack of aggregate availability. Restrictions on aggregate extraction within the provincial park meant that aggregate would need to be produced by blasting and crushing existing rock cuts along the highway. In addition, virgin fine aggregate suitable for use in HMA was not available within the park. The advantage of a stabilization technique such as EAS is that it would reuse existing HMA and aggregate resources within the park and require less new HMA, conserving natural resources, reducing transportation distances, reducing greenhouse gas emissions and conserving energy.

The recommended pavement rehabilitation strategy was: in-place FDR to a minimum depth of 180 mm, EAS to a depth of 150 mm, and overlay with 80 mm (two lifts) HMA.

3.0 CONSTRUCTION

3.1 Expanded Asphalt Mix Design

Expanded asphalt stabilization involves injecting a small amount of expanded (foamed) asphalt into the reclaimed (in place processed) material. To expand the asphalt, a small amount of cold water is injected into the hot asphalt cement in the expansion chamber of the reclaiming/stabilizing equipment. As the cold water turns to steam, the asphalt cement expands and is dispersed through nozzles onto the reclaimed material. Expanding the asphalt cement reduces its viscosity and increases adhesion, facilitating mixing with the cold, damp, reclaimed material. The expanded asphalt mixes readily with the fine aggregate particles, forming a mortar which bonds the coarse aggregate particles together.

Prior to starting work, the contractor obtained granular and HMA samples from the roadway for mix design purposes. In the southern section of the project, the sampled material met the gradation requirements of the expanded asphalt mix (Table 1). In the northern section of the project, samples of reclaimed material contained only 6.3% passing the 75 µm sieve and corrective aggregate was added to increase the fines and bring the material into the required grading band.

The contractor was responsible for the mix designs, which were carried out according to the Wirtgen mix design method *(3)*. Three different mix designs were used including one without corrective aggregate (mix 1), and two with corrective aggregate but from different sources (mix 2 and 3). The expanded asphalt mix was required to meet the tensile strength requirements of Table 1.

The mix designs required the addition of 2.8 to 3.0% asphalt cement. Ontario performance graded asphalt cement (PGAC) guidelines *(4)* call for the use of PGAC 52-34 in this part of the province. These guidelines are for the use of PGAC in HMA and are meant predominantly to address thermal cracking of HMA pavement. With expanded asphalt, there is no requirement for the PGAC to be selected based on climatic zones, as the stabilized base is expected to have good fatigue properties and should not be prone to low temperature cracking. As a result, any PGAC can be selected as long as the asphalt cement has suitable expansion properties and the expanded asphalt mix meets the mix design requirements. The contractor opted to use PGAC 58-28, which has a stiffer consistency and good foaming properties.

TABLE 1. Requirements for Expanded Asphalt Mix Design

Gradation Requirements (LS-602) [9]		Tensile Strength Requirements (ASTM D4867/D4867M) [6]	
MTO Sieve Designation	Percent Passing by Mass	Property	Min. Requirements
37.5 mm	98-100	Dry Tensile Strength	300 kPa
26.5 mm	95-100		
4.75 mm	35-65	Wet Tensile Strength	150 kPa
600 um	15-40		
75 µm	7-15	Tensile Strength Ratio	50%

3.2 Placement

At the beginning of August, following some initial minor start-up difficulties *(5)*, the expanded asphalt operation proceeded well, with minimum interruptions. The reclaimer in-place processed an average of 1200 m of two-lane roadway per day, and the result was a uniform, well mixed and well sized material. The reclaimed material was graded and compacted to the proper cross-section and profile. Corrective aggregate, where required by mix design, was added to the roadway prior to stabilizing.

Expanded asphalt was injected into the reclaimed material through nozzles on the reclaimer/stabilizer, attached to a tanker of hot asphalt cement (Figure 2). A single steel drum 20 tonne roller was used as a breakdown roller behind the reclaimer/stabilizer. A grader followed behind, grading the mix to final grade (Figure 3). Compaction was carried out with a 21 tonne steel drum vibratory roller. Watering in combination with use of a vibratory roller brought the fines to the surface to give the mat a tight, sealed appearance. A rubber tire roller was used as the finishing roller. The freshly stabilized base resembled a damp granular base material (Figure 4).

FIGURE 2 The reclaimer/stabilizer attached to a tanker of hot asphalt cement.

FIGURE 3 The grading and compacting operation following behind the EAS.

FIGURE 4 The expanded asphalt mat following initial pass of the breakdown roller.

Three to five passes of the reclaimer/stabilizer, with 100 mm overlap, were required across the full width of pavement. Each tanker of hot asphalt cement contained roughly 40,000 kg of PGAC, stabilizing 4,250 m2 of roadway in four hours. The heated asphalt cement was brought in from Thunder Bay, an eight-hour drive to the job site. To address concerns that the asphalt cement may be cooling down, the expansion ratio and half-life of the expanded asphalt were checked regularly in the field.

Traffic control was carried out using a detour vehicle and flagging. The stabilization was carried out in 500-600 m sections, resulting in little inconvenience to the travelling public. Traffic ran on the pulverized grade while the expanded asphalt operation moved across the pavement width. Once the first stabilized pass was on grade and properly compacted, traffic was switched to run on the expanded asphalt surface. The finished, cured surface provided a smooth, hard, uniform surface, which held up well under Highway 17 traffic.

The expanded asphalt operation experienced delays due to inclement weather. In August and September, 15 working days were lost due to wet weather. Heavy rain resulted in slight to moderate ravelling and washboard. The damaged material was repaired by reprocessing or scarifying 25 to 40 mm, regrading and compacting. A second reclaimer was brought in to increase production. Utilizing two tanker loads of asphalt cement, production was increased to 8500 m2 per day.

In order to assess the benefits of the EAS technology, a 304 m control section of full depth reclamation with 80 mm hot mix overlay (no expanded asphalt stabilization) was established on a tangent section in the centre of the project. This control section has been instrumental in demonstrating the benefits of expanded asphalt stabilization.

A minimum two-day curing period was required prior to HMA paving. Tack coating was recommended on the expanded asphalt surface prior to HMA overlay. It was thought that bonding with the HMA layer was desirable and that tack coating would help to prevent water from being trapped at the interface. The paving operation proceeded at approximately twice the pace of the stabilizing, but because two lifts of HMA were required, the two operations were well synchronized.

4.0 QUALITY ASSURANCE

For acceptance purposes, the asphalt cement content, gradation and tensile strength of the expanded asphalt mix were determined from material sampled from the roadway. Thickness and compaction were verified in the field.

4.1 Asphalt Cement Content

To determine the amount of new asphalt cement added to the reclaimed material, samples were obtained immediately before and immediately after stabilization, from the same station and offset. The per cent by mass of new asphalt cement added to the reclaimed material was determined by subtracting the total asphalt cement content of the reclaimed material from the total asphalt cement content of the expanded asphalt mix. Extensive testing revealed that asphalt cement contents were variable throughout the contract, possibly as a result of the sampling method.

Accurately determining the amount of new asphalt cement added was important to both the Ministry and the contractor. The Ministry was concerned that the amount of asphalt cement being added did not correspond to the mix design and that in some instances the amount of asphalt cement added was less than the 2.8% minimum specified. The contractor maintained that equipment and distribution rates were carefully monitored and that asphalt cement variability was not attributable to the expanded asphalt process.

The asphalt cement content has a direct influence on the properties of the expanded asphalt mix, such as the tensile strength. Low asphalt cement contents may not bind the reclaimed material together, resulting in low strengths. High asphalt cement contents may increase the risk of instability and rutting. Rather than penalize the contractor for failing to meet minimum requirements for added asphalt cement, a payment adjustment was made based on the mean asphalt cement content of each lot. For example, if the lot met the tensile strength requirements but was found to have only 2.5% new asphalt cement added, then the contractor was paid only for 2.5% asphalt cement.

4.2 Gradation

Extensive testing revealed that the gradation of the expanded asphalt mix was slightly out of specification, mainly on the 4.75 mm sieve. The specification called for a maximum of 65% passing 4.75 mm, while many test results exceeded this maximum, ranging up to 75%. Contract administration staff noted that the FDR specification, which had also been included in the work, allowed up to 75% passing the 4.75 mm sieve. For a number of reasons, including conflict with the FDR specification, test result variability, concerns with the sampling method, and potential for aggregate breakdown in the ignition oven, it was decided not to penalize the contractor for the out of specification gradation.

4.3 Tensile Strength Determination

The indirect tensile strength test evaluates the strength of the expanded asphalt mix in the wet and dry state, and then compares the strengths to determine the moisture sensitivity. Samples of expanded asphalt mix were tested for dry tensile strength, wet tensile strength, and tensile strength ratio in accordance with ASTM D4867/D4867M-96 *(6)*. The test method was modified by moisture conditioning the samples to the field moisture content prior to manufacture of the briquettes, and by curing the briquettes at 60 ± 2°C for a period of 72 ± 4 hours before determining the strength properties.

Individual test results on expanded asphalt material sampled from the field did not always meet the specification requirement of 300 kPa for dry tensile strength (Table 3). However, the standard deviation of the results was within the published within-laboratory, single-operator standard deviation for the test method (55 kPa). Rather than looking at individual test results, the mean and standard deviation of the lot were used to accept the expanded asphalt mix. It was thought that problems achieving the dry tensile strength requirements may have been the result of insufficient pass 75 μm material and the fact that the existing granular base material was a well rounded gravely sand with up to 75% passing 4.75 mm.

4.4 Thickness

The contract called for EAS to a depth of 150 mm. In order to measure thickness of the EAS, a shallow excavation was made along the edge of the stabilized pass. It was fairly easy to distinguish between the darker stabilized material and the lighter unstabilized material. The specification required at least 90% of all thickness measurements to be equal to or greater than 130 mm with no single measurement less than 120 mm. Thickness requirements were met throughout the contract.

TABLE 2. Indirect Tensile Strength Test Results

Sublot	Mix Design 1, Lot 1						Mix Design 1, Lot 2						Mix Design 1, Lot 3					
	DTS (kPa)		WTS (kPa)		TSR (%)		DTS (kPa)		WTS (kPa)		TSR (%)		DTS (kPa)		WTS (kPa)		TSR (%)	
	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC
1	233	389		280		72	242	494	222	403	92	81	397	402	289	417	73	103
2	263	341	246	251	93	73	376	300	317	275	84	91	437	380	270	404	62	106
3	233	323	198	291	85	90	294	329	220	278	75	84	361	473	319	438	88	92
4	257	247	237	242	92	98	316	318	248	286	79	90	407	439	274	450	67	102
5	238	262	128	245	54	83	367	357	248	337	68	94						
6		285		283		99	317	325	278	239	88	78						
7		301		260		86	431	328	343	298	80	90						
8		387		374		96	474	300	321	260	68	86						
9		552		391		70	297	418	205	378	69	90						
10		517		399		77	352	427	220	396	63	92						
mean	246	373	198	301	87	82	346	365	262	310	76.6	85	380	397	300	403	80	101
Stdev	14.2	118	53.7	66.1	18.4	10.6	68.8	68.9	49.5	58.8	9.6	9.3	43.7	53.0	27.0	45.0	16.9	5.4

	Mix Design 2, Lot 1						Mix Design 3, Lot 1						Mix Design 3, Lot 2					
	DTS (kPa)		WTS (kPa)		TSR (%)		DTS (kPa)		WTS (kPa)		TSR (%)		DTS (kPa)	WTS (kPa)		TSR (%)		
Sublot	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC	QA	QC
1	405	327	314	315	78	96	354	339	225	339	63	100	330	317	215	254	65	80
2	378	354	251	374	66	105	372	349	325	311	87	89	445	316	291	325	65	102
3	360	419	271	323	75	77	291	331	244	218	101	65		319		313		98
4	329	402	269	367	82	91	286	362	191	255	67	70	386	327	243	220	63	67
5	435	442	295	367	68	83	274	314	289	227	105	72	303	301	302	231	100	76
6	406	385	265	287	65	74	383	315	231	223	60	70	343	311	339	224	99	71
7	356	357	245	349	69	97	310	343	308	289	99	84						
8	426	422	310	332	73	78	353	309	233	283	66	91						
9	298	396	173	348	58	87	304	407	242	363	91	89						
10	361	516	219	439	61	85	314	373	236	358	73	96						
Mean	375	404	261	355	69	88	324	344	252	291	81	84	340	325	257	261	76	80
Stdev	43	43	42	42	7	10	36	28	41	52	16	12	63	24	40	40	17	12

4.5 Compaction

In the field, compaction checks were made using a nuclear density gauge, according to Ontario Provincial Standard Specification (OPSS) 501, the compaction specification for granular materials *(7)*. A control strip was used to determine the required roller pattern. The specification required that compaction of the expanded asphalt mix be carried out to 97% of the target dry density established by the mix design. Because the stabilized base contains asphalt cement, the nuclear gauge could not be used to determine the field moisture content. The field moisture content was determined according to MTO Laboratory Testing Manual LS-701 *(8)*, by obtaining field samples and determining the moisture in the laboratory using a microwave oven. With this method, moisture results could be determined within a few hours of sampling. Achieving compaction was not a problem on the project, and all individual compaction measurements met the requirements of the specification.

5.0 POST-CONSTRUCTION MONITORING

5.1 Pavement Condition

The 2011 Pavement Condition Index (PCI) for this project is 83, indicating a pavement still in very good condition. Existing distresses include slight ravelling and coarse aggregate loss, slight wheel track rutting, a few slight longitudinal wheel track cracks, intermittent, moderate centreline cracking, and intermittent, moderate transverse cracking. Pavement experts in the Region are recommending that microsurfacing be considered in the next two years as a preservation treatment over a pavement in good condition.

5.2 Roughness

In the 10 years following construction of the expanded asphalt stabilization project, the Ministry carried out ARAN surveys of the highway to determine the International Roughness Index (IRI) and pavement distress surveys to determine the Pavement Condition Index (PCI). Results of 10 years of performance monitoring show that the expanded asphalt project is performing extremely well. Figure 5 shows the average IRI performance for the contract, which has remained below 1 (IRI=0.83), indicating a smooth pavement over the course of 10 years. Also illustrated is the performance of the three different mix designs, one without corrective aggregate (mix 1) and two with different sources of corrective aggregate (mixes 2 and 3). These three mixes perform in a similar fashion.

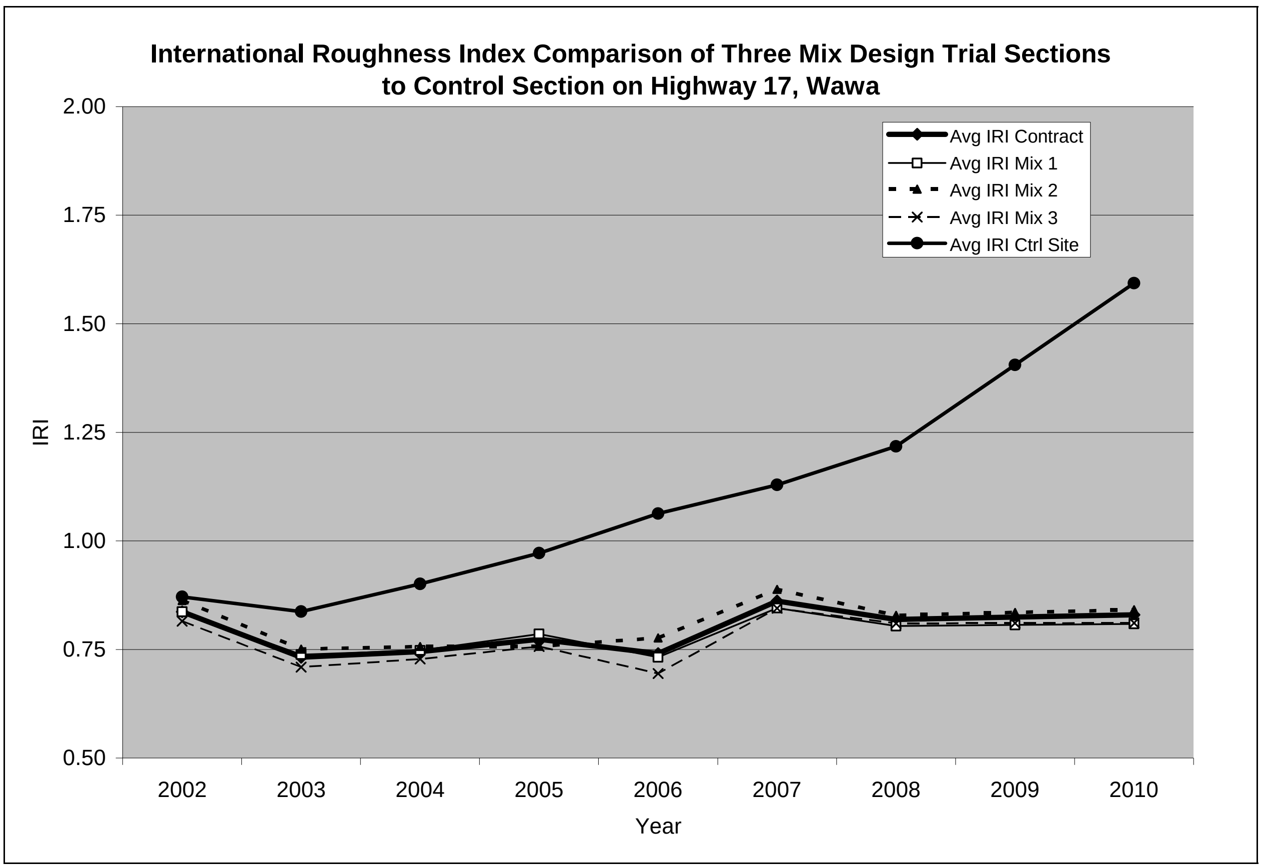

FIGURE 5 International Roughness Index comparison of the average IRI for the FDR with EA contract, to each of the three mix designs and the control section.

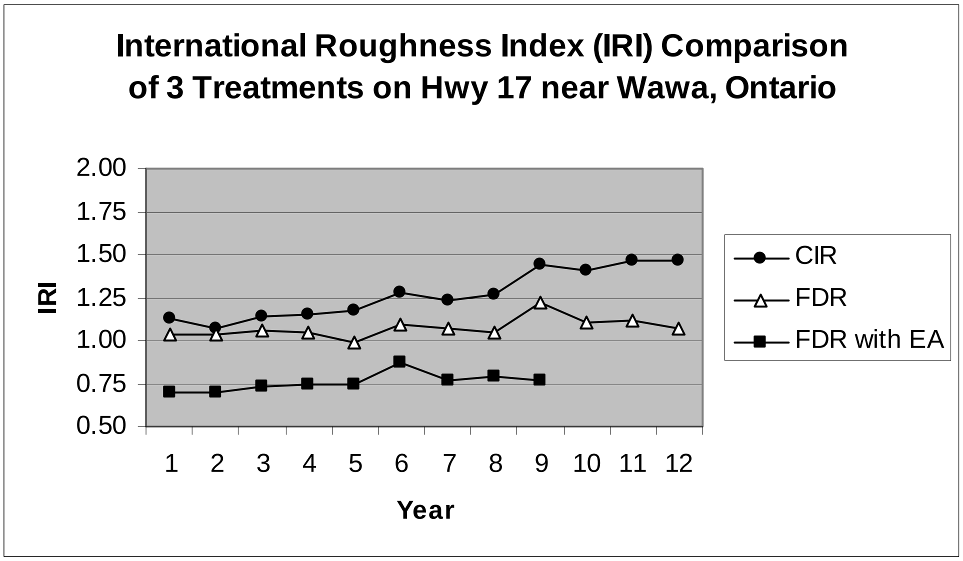

FIGURE 6 International Roughness Index comparison of FDR with EA and 80 mm HMA overlay, to adjacent projects: FDR with 120 mm HMA overlay and CIR with 50 mm HMA overlay.

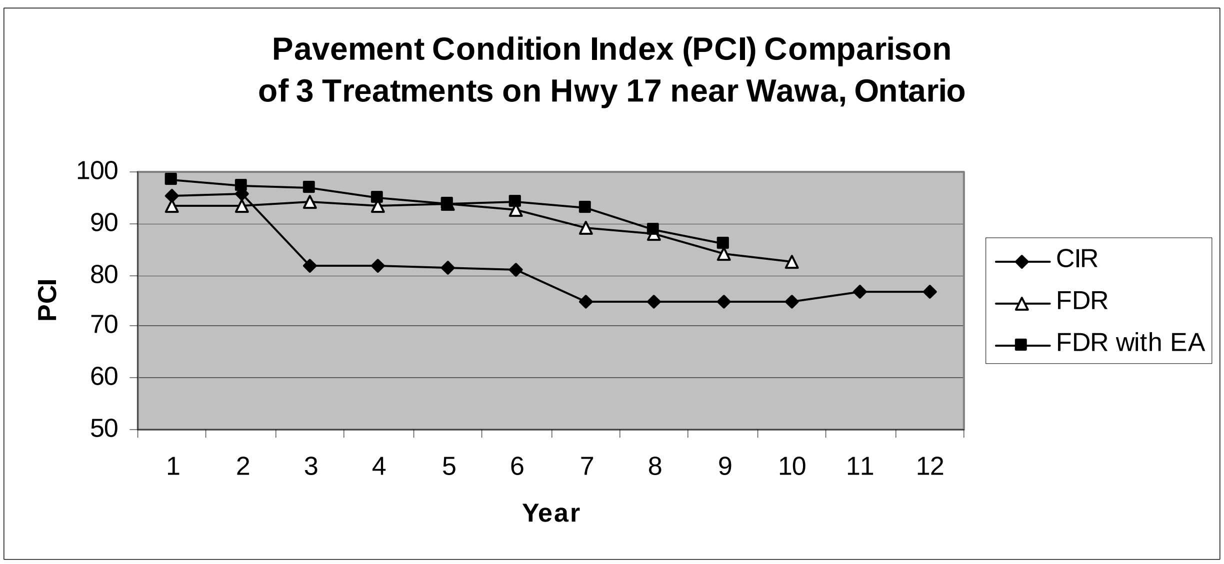

FIGURE 7 Pavement Condition Index comparison of FDR with EA and 80 mm HMA overlay, to adjacent projects: FDR with 120 mm HMA overlay and CIR with 50 mm HMA overlay.

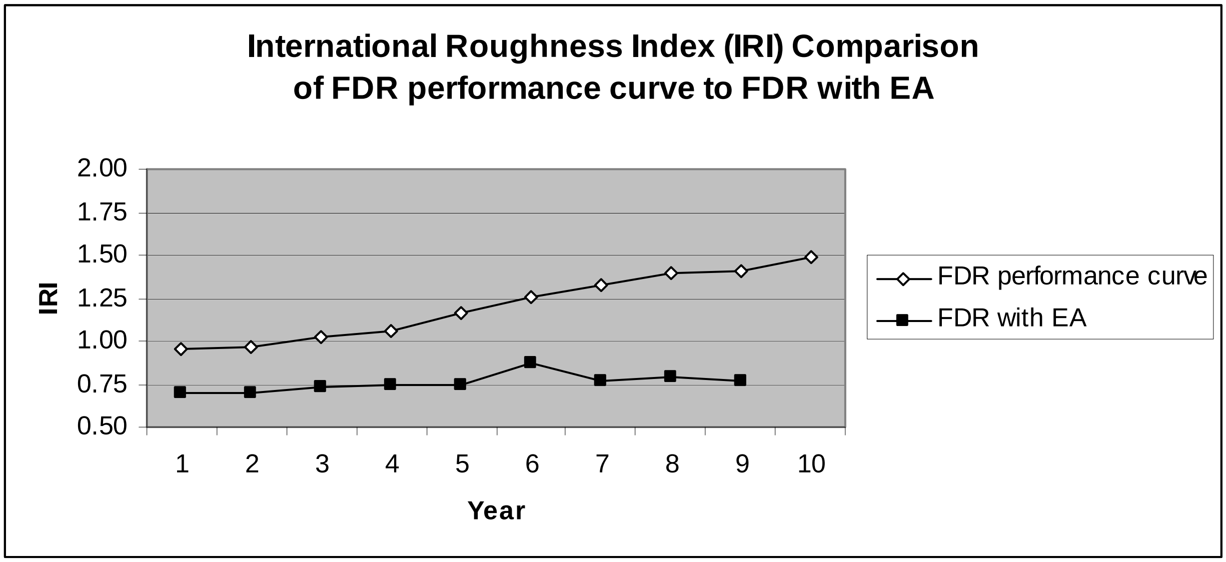

FIGURE 8 International Roughness Index comparison of FDR with EA on Hwy 17 to MTO's performance Curve for FDR with HMA overlay based on 100 contracts.

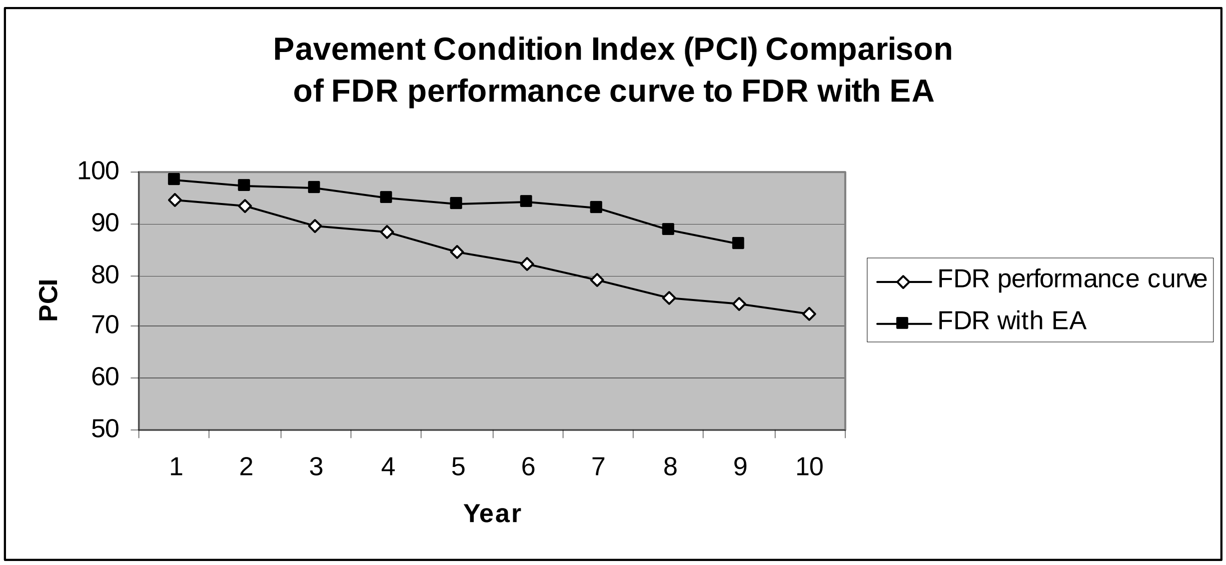

FIGURE 9 Pavement Condition Index comparison of FDR with EA on Hwy 17 to MTO's performance Curve for FDR with HMA overlay based on 100 contracts.

Of note is the 304 m control section of FDR with 80 mm HMA overlay (no expanded asphalt stabilization), placed in the centre of the project. This treatment started out with similar IRI performance but unlike the FDR with EAS, showed noticeable deterioration over the 10 years.

Figures 6 and 7 compare the performance of the project to two adjacent treatments along the same stretch of highway: a cold in-place recycling project with 50 mm hot mix overlay constructed in 1999 and a full depth reclamation project with 120 mm hot mix overlay constructed in 1998. In terms of pavement roughness (IRI), the expanded asphalt project is performing significantly better (smoother) than the adjacent CIR and FDR treatments. In terms of pavement condition, the expanded asphalt is performing similarly to the full depth reclamation with 120 mm of hot mix, a more expensive and less environmentally friendly treatment than FDR with EA and 80 mm hot mix overlay. These two treatments are outperforming the CIR.

MTO has also developed a performance curve for full depth reclamation projects based on a data set of 100 of these projects on 2-lane rural highways. Figures 8 and 9 compare the performance of the expanded asphalt stabilization project to the ministry's IRI and PCI performance curves for FDR with HMA overlay, considered to be one of the most effective reconstruction techniques. It can be seen from these graphs that as a reconstruction treatment, the FDR with EAS is outperforming the average FDR project both in terms of roughness (IRI) and pavement condition (PCI).

6.0 CONCLUSIONS

During construction, the expanded asphalt stabilization on Highway 17 resulted in a smooth, hard, uniform surface suitable for temporary traffic and provided an excellent platform for HMA paving operations. Once start-up issues were addressed, the EAS field operations progressed in a continuous and efficient manner, typically progressing at 1.2 km of 2-lane roadway per day. The EAS overlaid with 80 mm of HMA resulted in a smooth riding surface.

Results of ARAN surveys and pavement distress data collection carried out in the 10 years following construction found that the pavement has remained smooth (IRI<1) and in excellent condition (PCI>85) after 10 years in service, indicating that the pavement is performing very well. The three different mix designs, two with corrective aggregate and one without, performed similarly over the 10 year period. A control section of FDR with 80 mm HMA overlay started off with similar IRI performance but deteriorated at a much faster rate.

Performance of the project was compared to a cold in-place recycling project with 50 mm HMA overlay, constructed in 1999 and a full depth reclamation project with 120 mm HMA overlay constructed in 1998 along the same stretch of highway. In terms of pavement roughness (IRI), the expanded asphalt project is performing significantly better (smoother) than the adjacent CIR and FDR treatments. In terms of pavement condition, the expanded asphalt is performing similarly to the full depth reclamation with 120 mm of hot mix, a more expensive and less environmentally friendly treatment than FDR with EA and 80 mm hot mix overlay. These two treatments are outperforming the CIR.

The performance of the EAS project was also compared to the ministry's established IRI and PCI performance curves for FDR with HMA overlay. It can be seen from these graphs that as a reconstruction treatment, the FDR with EAS is outperforming the average FDR project both in terms of roughness (IRI) and pavement condition (PCI).

In conclusion, full depth reclamation with expanded asphalt stabilization provides an acceptable in-place recycling rehabilitation strategy that conserves natural resources and provides an economic alternative to conventional full depth reclamation with a HMA overlay, particularly in areas where aggregates are in short supply.

7.0 REFERENCES

(1) Ministry of Transportation Ontario. SDO-90-01, Pavement Design and Rehabilitation Manual. *Queen's Printer for Ontario*, 278 p., 1990.

(2) Ministry of Transportation Ontario. SP-024, Manual for Condition Rating of Flexible Pavements. *Queen's Printer for Ontario*, 111 p., 1989.

(3) Wirtgen GmbH. Wirtgen Cold Recycling Manual, Appendix A 2.3, Laboratory Procedure for the Mix Design of Foamed Bitumen Treated Materials. pp.114-117, 1998.

(4) Ministry of Transportation Ontario. 1998 Guide for the Use of Performance Graded Asphalt Cement in MTO Contracts. Bituminous Section, pp.1-8, 1998.

(5) Lane, B. and T. Kazmierowski. Expanded Asphalt Stabilization on the Trans-Canada Highway in Ontario. In *Canadian Technical Asphalt Association (CTAA) Proceedings*, Calgary, November 2002, 23 p.

(6) ASTM D4867/D4867M-96. Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures. *Annual Book of ASTM Standards*, Vol.0403, p. 485-489, 1996.

(7) Ontario Provincial Standards for Roads and Municipal Services. OPSS 501, Construction Specification for Compacting. 5 p., 1996.

(8) Ministry of Transportation Ontario. LS-701, Method of Test for Determination of Moisture Content of Soils. *Laboratory Testing Manual,* Ronen Publishing House, Toronto, 1996.

(9) Ministry of Transportation Ontario. LS-602, Method of Test for Sieve Analysis of Aggregates. *Laboratory Testing Manual*, Ronen Publishing House, Toronto, 2001.