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Field verification of a new asphalt compactor, AMIR

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A prototype of a new asphalt compactor termed "asphalt multi-integrated roller (AMIR)" was built as a joint venture between the National Research Council of Canada (NRC) and a Canadian manufacturer, Lovat Tunnel Equipment, Inc. The purpose of this project was to prove this new compaction concept in a full-scale environment. This paper describes one of the field trials carried out on the campus of the NRC and reports the results quantifying the quality of the AMIR compaction.

Key words: compactor, asphalt mix, field trials, laboratory testing.

Le prototype d'un nouveau compacteur d'asphalte appelé AMIR (Asphalt Multi-Integrated Roller) a été construit par le Conseil national de recherches du Canada (CNRC) et Lovat Tunnel Equipment Inc., dans le cadre d'une entreprise conjointe. Ce projet a pour but de soumettre ce nouveau concept de compactage à des essais pleine grandeur. Cet article décrit l'un des essais in situ réalisés sur le campus du CNRC et présente les résultats de l'évaluation de la qualité du compactage obtenu à l'aide de AMIR.

Mots clés : compacteur, mélange asphaltique, essais in situ, essais en laboratoire.

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Introduction

Asphalt compaction techniques have not changed in their concept for decades. There have been some modifications, such as the addition of a dynamic excitation to the steel roller, the rubber coatings on steel drums, and the use of rubber tire rollers, but the main principle of employing a single drum remains the same.

It is generally accepted that the traditional compaction techniques using static or vibratory rollers generate hairline cracks in the surface of the asphalt concrete. This is caused by the geometric and material incompatibilities between the roller and the hot asphalt mix at the time of compaction (Abd El Halim 1985; Abd El Halim *et al.* 1987). The notion that rubber tire rollers, often used behind standard compactors, can "cure" the hairline surface cracks is questionable. It has been shown (Svec and Halim 1990; Liljedahl 1990) that even after extensive use of rubber tire rollers, surface cracks remain visible to the naked eye. In addition, evidence exists that not only the surface cracks but also internal cracks remain after this treatment.

To prevent the phenomenon of "hair checking" or construction-induced cracks, a new compactor, asphalt multi-integrated roller (AMIR), has been developed based on the concept of relative rigidity (Abd El Halim 1986). Results of using small laboratory AMIR models confirmed the findings of the analytical approach. Subsequently, a large-scale AMIR prototype was built (Fig. 1) as a joint project between Industrial Research Assistance Program (IRAP) of the National Research Council of Canada (NRC) and a Canadian manufacturer, Lovat Tunnel Equipment Inc. (Svec 1989). The purpose

of this paper is to present the results of the evaluation of AMIR performance in compacting asphalt overlays under actual field conditions. It should be noted that the reliability, maneuverability, and productivity are an important part of the overall evaluation process of this new technology. However, the main objective of the research efforts presented in this paper is to evaluate the quality of the compacted asphalt concrete rather than specifications of the machine itself.

Standard compaction

The main characteristics of standard compaction by a single drum, which can be easily observed in the field, is the generation of a wave of asphalt in front of the roller. This wave is caused by a large horizontal component of the contact pressure between the roller and the fresh asphalt. The pushing action in front of the roller results in a pulling reaction behind the drum. Thus, tensile stresses are generated in the asphalt layer just behind the last contact point of the roller. Close observations of asphalt behaviour immediately behind the steel roller also reveal that there is a tendency for the asphalt to rebound due to the elastic component of deformation. The tensile stress in combination with the elastic rebounding strain result in the initiation of surface and internal cracks in the asphalt concrete. These deficiencies are caused by incompatibilities in the geometry and materials between the drum and the hot asphalt layer.

Asphalt multi-integrated roller (AMIR)

Figure 2 shows the concept of the AMIR compactor. The geometric incompatibility of a standard, single drum is solved by using two large drums and an assembly of small rollers and plates between them. In addition, a rubber belt is placed around the two large rollers, which also encompasses the small rollers' assembly. This system converts a circular contact between a single drum and the hot asphalt mix into a flat,

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¹NRC No. 32377.

FIG. 1. Prototype of AMIR I.

plate-type contact surface. Since a rubber belt is used for spreading the load, the material incompatibility is also removed.

A close observation of AMIR compaction reveals that the AMIR also generates a very slight front wave in the hot asphalt mix, but of an "order of magnitude" smaller. On the other hand, there is practically no rebound of asphalt concrete behind the AMIR. The assembly of small rollers between the two main rollers and the presence of the rubber belt does not allow any upward relaxation of deformation between the main rollers.

Another very important factor characterizing AMIR compaction is that of time. The unit stress applied to the hot asphalt mix is substantially less for AMIR than for a standard roller. However, the hot asphalt mix is compressed during a much longer time under the AMIR. The stress from AMIR is applied over a period of several seconds, depending on the speed of the AMIR, while the stress from a standard single drum is applied only for a fraction of a second. The time effect of AMIR compaction changes the ratio and the magnitude of the elastic and the time-dependent viscoplastic components of deformation. In other words, the asphalt mix under the AMIR has enough time to be "permanently" compressed in a viscoplastic mode. Also, the contact area provided by the AMIR, which is larger and flat, allows more confining stresses to the compacted mix. Clearly, the currently used standard roller cannot provide this advantage.

Field trials

The evaluation program consisted of (i) field trials and (ii) laboratory testing on asphalt specimens recovered from the field. The paving procedure included the AMIR compactor (Fig. 1) side-by-side with conventional rollers, so a realistic comparison between the new and the standard compaction was possible. The purpose of the field trial was to provide a detailed analysis of all the results concerning the asphalt quality, preliminary assessment of expected productivity, AMIR

FIG. 2. AMIR concept.

maneuverability, and recommendations for development of a commercial AMIR prototype. This paper contains only some of the results of asphalt quality analysis.

The overall procedure for AMIR performance included the following variables: paving over an aggregate base and over an asphalt concrete base (i.e., an overlay), different asphalt mixes, temperature at the time of compaction, layer thickness, single and double layers, compactor weight, speed, and number of passes. For the field test reported in this paper, however, the following specifications were selected: (i) overlay on top of an existing asphalt concrete road; (ii) 50 and 70 mm asphalt concrete lifts; and (iii) asphalt mix HL4 (specified by the Ministry of Transportation of Ontario).

A 150 m long test section, divided into three subsections each 50 m long, was selected on the NRC campus. The first two subsections were overlaid by 50 mm thick asphalt concrete, while the third subsection was overlaid by a 75 mm thick layer. The entire test section was 6.0 m wide. It was further divided longitudinally into two 3 m wide halves (lanes). One was designated as "A" lane to be compacted by

the AMIR, while the other was termed "S" lane to be compacted by a conventional, vibratory steel roller followed by a rubber tire roller (VIB/RTR). Each lane was further divided into three parts, the centre (i.e., adjacent to the centre line), the middle, and the edge of the pavement (Fig. 3). The section designated A was compacted by the AMIR using 6 passes per lane, while the conventional section, S, was compacted by a vibratory roller using 6 passes followed by 20 passes of a rubber tire roller.

Selection of laboratory testing methods

To evaluate objectively two different compaction techniques, four standard laboratory tests have been selected. These are density (including Marshall), tensile strength by an indirect method, tensile strength by a direct method, and flexural strength.

Specific gravity

The specific gravity or the bulk density is the simplest measure of compaction in a quantitative sense. Note that density does not reveal the true quality of compacted asphalt concrete. For example, the density alone does not reflect the effect of the presence of surface or internal cracks nor the strength of the material and its possibly anisotropic nature.

The specific gravity was tested by the ASTM standard test method ANS/ASTM D2726-73. Since this is a standard test, no description or explanation is necessary. To get an appreciation of the specific gravity related to the Marshall index test, as it is practised by transportation departments, the standard Marshall test was performed using 75 blows.

Indirect tensile strength

The indirect tensile strength test is also a standard test commonly used in pavement practice. In this test, a core taken from an asphalt concrete layer is placed horizontally in a compression testing apparatus and loaded to failure. It is based on the assumption that the maximum tensile stress is developed in the central vertical plane of the core. Furthermore, it is assumed that this tensile stress is more or less uniform. The test is carried out at a constant rate of strain of 51 mm/min at room temperature. The indirect tensile strength is calculated as follows:

$$\sigma = \frac{2P_{\max}}{\pi h d}$$

where $P_{\max}$ is the maximum load at failure, h is the height, and d is the diameter of the core.

Direct tensile strength

The direct tensile strength test was performed at room temperature on a specially designed testing table (Fig. 4). It consists of two halves: one half of the table is fixed while the other can be moved horizontally by sliding over Teflon guides. An asphalt concrete slab is fixed to the surface of the table and the movable half is then pulled under a constant rate of displacement. A data acquisition system monitors the applied load through a load cell. The corresponding deformation, i.e., the horizontal displacement of the movable half of the table, is monitored using an LVDT.

Slab samples, 25 cm wide and 50 cm long, were used in this test. These slab specimens were extracted from the pavement by cutting the asphalt concrete through the new overlay, and, as well, through the old pavement. Great care was used to lift

the samples from the road in order to avoid any damage deformation or crack propagation.

The direct tensile strength test leads to a better-defined tensile strength. It gives a good indication of absorption of the strain energy and, as well, it can describe the mechanism of failure in detail (Abd El Halim and Svec 1990a, b). The development and propagation of cracks can also be easily observed during this test. However, it is based on an assumption that the tensile stress is distributed uniformly throughout a central cross section of a slab specimen. In reality, this is not the case. On the other hand, the loading during this test is simulating that in the field under, for example, thermal stress conditions. Results of this test also allow the calculation of the incremental strain energy, which is a very important and useful information for the evaluation of mechanical properties.

Bending strength

Some of the shortcomings of the above tests can be eliminated by employing a beam flexural test. There are two major advantages of the bending test: (i) it provides the maximum tensile stress independent of stress distribution and (ii) it reflects and emphasizes the strength reduction due to any surface defects, since the maximum tensile stress develops at the surface of the sample. On the other hand, the ratio between the sample weight and the material strength of the asphalt concrete is very large, which can complicate the testing and can adversely influence the results.

For convenience and to satisfy research requirements, a two-point bending test was selected. In such a loading system, the central section of a beam is loaded by pure bending only. A special testing apparatus was manufactured to perform these tests (Selvadurai 1989).

Results

The field trial was overall quite successful and the AMIR prototype provided a crack-free surface. However, due to some difficulties experienced in the field with the steering of this prototype, the AMIR compactor crossed over the centre line of the test road, entering the lane S. Consequently, the centre part of lane S was not only compacted by the standard roller but also partly by the AMIR. The results presented below have to be considered in this context.

The evaluation of AMIR compaction described in this paper is based on the following criteria: quality of the surface, specific gravity or bulk density, and tensile strength.

Quality of the surface

Standard compaction — VIB/RTR

Numerous hairline surface cracks were observed during the compaction process. These cracks persisted immediately after the compaction, and during the following months. The majority of these cracks occurred in the middle and at the edge of the pavement, and were not "cured" (as generally assumed) by even a large number of passes by the rubber tire roller. The cracks are still present (after 8 months) and, in fact, they have somewhat worsened during the winter as expected (due to the effect of freeze-thaw cycles).

AMIR compaction

AMIR compaction has been observed in detail on several occasions. In general, no cracks were evident after the first pass and no cracks appeared after subsequent passes. The tex-

FIG. 3. Outline of test sections.

FIG. 4. Outline of the direct tensile strength testing table.

ture of the surface was always tight with no visible voids between the individual stones. No change has been observed after the first winter.

Specific gravity

Table 1 represents a summary of specific gravity measurements on 96 cores. The results for the edge and the middle parts of the AMIR lane are substantially higher than those for the S lane. This comparison for the centre part, however, is reversed. The most plausible explanation, which was also mentioned above, is that the AMIR, due to its steering problems, drove over the central portion of the test road already compacted by the vibratory roller. Thus this location, i.e., centre for lane S, was compacted twice. In analyzing Table 1, three general conclusions are evident: (i) AMIR compaction satisfies the requirements of most transportation departments (ratio Marshall

densities); (ii) densities achieved by the AMIR are higher than those by VIB/RTR; and (iii) the distribution of the density by the AMIR is more uniform than the distribution by VIB/RTR.

Indirect tensile strength

The results of indirect tensile strength tests are shown in Table 2. The improvements of the AMIR compaction method are evident both in the absolute values of tensile strength and in the uniformity of the results (note the difference in the standard deviation and variance).

Direct tensile strength

Two important results of constant strain and direct tensile strength of asphalt concrete are discussed in this section: the maximum direct tensile strength and the incremental strain energy.

Results of the tests are presented in Table 3. It is clear that the asphalt compacted by the AMIR has considerably higher strength in the edge and the middle parts of the test lane than the asphalt compacted by the standard equipment. The comparison of results from the centre of the road, however, shows a reversed situation as seen in Table 3. The large difference in the results between the edge and middle locations and the centre location in lane S, at a 51% difference, supports the fact that the centre section was also compacted by AMIR. It should be noted that similar results have been obtained from the density measurements and indirect tensile strength testing. A graphical description of typical constant strain tests is shown in Figs. 5 and 6. Figure 5 shows the relationship of strength versus displacement, while Fig. 6 shows the function of strain

TABLE 1. Specific gravity

Location	AMIR			VIB/RTR		
	Mean	Std. dev.	Ratio to Marshall (%)	Mean	Std. dev.	Ratio to Marshall (%)
Edge	2.412	0.012	96.0	2.392	0.012	95.1
Middle	2.427	0.013	96.6	2.411	0.015	95.9
Centre	2.437	0.017	96.9	2.422	0.008	96.3
All cores	2.425	0.017	96.5	2.408	0.017	95.8

TABLE 2. Indirect tensile strength (MPa)

Location	AMIR				VIB/RTR			
	Mean	Std. dev.	Variance	Comparison (%)	Mean	Std. dev.	Variance	Comparison (%)
Edge	0.667	0.051	0.38	100.0	0.587	0.045	0.30	88.0
Middle	0.708	0.060	0.53	100.0	0.636	0.068	0.67	94.9
Centre	0.702	0.057	0.43	100.0	0.713	0.066	0.64	101.5
All cores	0.692	0.059	0.50	100.0	0.645	0.079	0.92	93.2

TABLE 3. Direct tensile strengths, S_{max} (MPa)

Location	AMIR				Steel			
	S_{max}	S_{max}	Average	Comparison (%)	S_{max}	S_{max}	Average	Comparison (%)
Edge	0.408	0.396	0.402	100.0	0.324	0.308	0.316	78.7
Middle	0.377	0.393	0.385	100.0	0.324	0.334	0.329	85.5
Centre	0.406	0.445	0.426	100.0	0.467	0.495	0.481	112.0
			0.404*				0.375*	

*Overall average.

FIG. 5. Direct tensile strength — middle of pavement (1 psi = 6.89 kPa, 1 in. = 2.54 cm).

energy versus displacement for AMIR and standard compaction techniques. The strain energy function is of particular interest, since it reveals a significant difference between these two compaction methods. The authors have shown (Abd El Halim and Svec 1990a) that the strain energy relationship can indicate the presence of internal cracks in the asphalt concrete.

Flexural strength

Pure bending tests were performed at the following range of selected temperatures: 18°C, 0°C, -20°C, and -40°C. It was evident, as shown in Table 4, at room temperature tests that large deflections occurred beyond the maximum load levels. Approaching the peak load levels, visible cracking

FIG. 6. Test results of strain energy — middle of pavement (1 psi = 6.89 kPa, 1 in. = 2.54 cm).

TABLE 4. Flexural strength

Temperature (°C)	Stress (MPa)	
	AMIR	VIB/RTR
18	1.34	0.87
0	5.09	4.58
-20	4.99	4.75
-40	4.09	3.34

occurred at arbitrary locations within the midsection of the beams (Selvadurai 1989). Asphalt concrete compacted by the AMIR showed significantly higher bending strength than the asphalt concrete compacted by VIB/RTR at all levels of temperature.

At low temperatures, the strength for both types of compaction increased dramatically, almost four times for AMIR and six times for VIB/RTR. The failures occurred abruptly, even splitting the aggregates. The results obtained from these tests suggest that the AMIR-compacted pavements are less sensitive to large changes in temperatures as compared with pavements compacted with current rollers. This observation has a significant impact on the long-term performance of asphalt pavements subjected to severe climatic conditions.

Discussion and conclusions

Summarizing the results, the following can be stated about asphalt concrete overlays compacted by the AMIR, as compared with that compacted by a conventional vibratory roller followed by a rubber tire roller (VIB/RTR):

- The AMIR compactor provides a crack-free surface.
- AMIR-compacted overlay pavements showed more consistent and uniform density distributions.
- With the elimination of the surface cracks, the new compaction method provides pavement with higher strength.

In addition, it was also found that the bond between the new asphalt concrete overlay and the old asphalt surface is considerably better in the case of AMIR compaction than in the case of standard compaction. This is a very important finding, since a well-bonded layer will act as an integral part of a composite pavement structure. Furthermore, the stripping and

cracking potential is much lower for a well-bonded overlay.

In conclusion, there are two main advantages to the AMIR method: (i) the overall quality and strength of the AMIR-compacted asphalt concrete is better than that of asphalts compacted by a standard method, and (ii) the expected productivity is considerably higher than the productivity of today's technology.

The first conclusion is based on a large amount of test data while the second conclusion stems from the fact that AMIR compaction technique required only one machine. Moreover, the results of four field trials indicate that the AMIR will need about the same number of passes as a standard static or vibratory roller.

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