

# Field Evaluation of Steel Fiber Reinforced Concrete Overlay With Various Bonding Mechanisms

G. CHANVILLARD, P.-C. AÏTCIN, AND C. LUPIEN

An experimental rehabilitation project was conducted on the Transcanadian Highway where old concrete pavement was recovered with a thin, steel fiber reinforced concrete overlay (1). In this project, 18 different construction conditions were investigated. The surface of the old pavement was either sandblasted or scarified. Three different types of steel fibers were used, and all the overlay was bonded with a thin cement grout. In addition, two lanes were repaired with some mechanical bonding provided by 37.5-mm (1½-in.) steel nails. The most significant results obtained during the construction period as well as all data recorded over the succeeding two winters are reported and analyzed in this paper.

Progressive degradation of the highway system necessitates greater attention to rehabilitation techniques. One alternative for concrete pavements is to cover the old pavement with a thin concrete overlay, although this approach is not always successful. Only well-bonded concrete overlays give satisfactory results and can increase both the surface quality and bearing capacity of the pavement, which results in thicker, monolithic pavement (2).

This rehabilitation method has been used in many projects, but not always with the expected results (3). Two major problems are faced in the field when this method is used. On the one hand, a good bond between the old and new concrete must be developed to avoid any delamination at their interface, which will cause general debonding of the overlay. The other important aspect is to use compatible concretes so they behave monolithically in spite of differential shrinkage behavior, differential thermal dilation characteristics, and cracking problems. In this context, fiber reinforced concrete, due to its improved fatigue and toughness characteristics, should be particularly suitable for the rehabilitation of old concrete pavements with thin bonded concrete overlays.

Several successful experiments with high fiber content (greater than 1 percent by volume, i.e., 80 kg/m<sup>3</sup> or 130 lb/yd<sup>3</sup>) have previously been reported (3–5), so it is possible to foresee a rational use of this technique for old concrete pavement rehabilitation. However, none of these experiments was done in climatic conditions similar to those in the Montréal area, which is characterized by temperature spreads of –40°C to +40°C (–40°F to +100°F), repeated freeze-thaw cycles, and extensive use of deicing salts.

The introduction of 1 percent or more by volume of steel fiber in the concrete presents two major disadvantages. First,

it doubles the cost of the concrete; second, it makes the concrete very difficult to place. Overcoming these drawbacks means decreasing the amount of fiber added to the overlay concrete. This approach was adopted in the experiment reported in this paper: the maximum fiber content was limited to 0.44 percent by volume (34 kg/m<sup>3</sup> or 58 lb/yd<sup>3</sup>).

## LOCATION AND FIELD CONDITIONS

The experiment took place in late October 1986 on a section of Autoroute 40 in West Montréal, where the average traffic is 30,000 vehicles per day. In that location, the actual condition of the old concrete pavement was still quite good, and a thin overlay was the only rehabilitation work required. Some damaged areas were first repaired to the full depth of the pavement, and the entire crack network was carefully recorded before the thin overlay was placed.

The originality of this experiment lies in the mechanical bonding of the old pavement and the new overlay with concrete nails partially embedded in the old pavement and in the use of less than 0.5 percent steel fiber content to enhance the mechanical properties of the overlay concrete.

The experiment took place in cold weather, with temperatures reaching freezing almost every night, in what could be considered the worst possible conditions for this kind of job.

Eighteen different field conditions were tested. They were divided into three main categories:

1. *Surface preparation.* The existing concrete slabs were either scarified with a diamond saw or sandblasted.
2. *Mechanical bonding.* Some of the experimental slabs were bonded to the old pavement with concrete nails driven on 300 or 450 mm (1 ft or 1½ ft) centers. The nails were 37.5 mm (1½ in) long and were driven halfway into the old pavement.
3. *Steel fibers.* Three different brands of steel fibers were used at volumetric contents of 0.28 percent and 0.44 percent, i.e., 22 and 34 kg/m<sup>3</sup> (37 and 58 lb/yd<sup>3</sup>). Some experimental slabs were made solely of plain concrete.

The part of the overlay with steel fiber reinforced concrete was 75 mm (3 in.) thick, while the part with plain concrete was 100 mm (4 in.) thick.

Figure 1 shows the locations of the different experimental conditions.

Department of Civil Engineering, Université de Sherbrooke, Québec J1K 2R1.

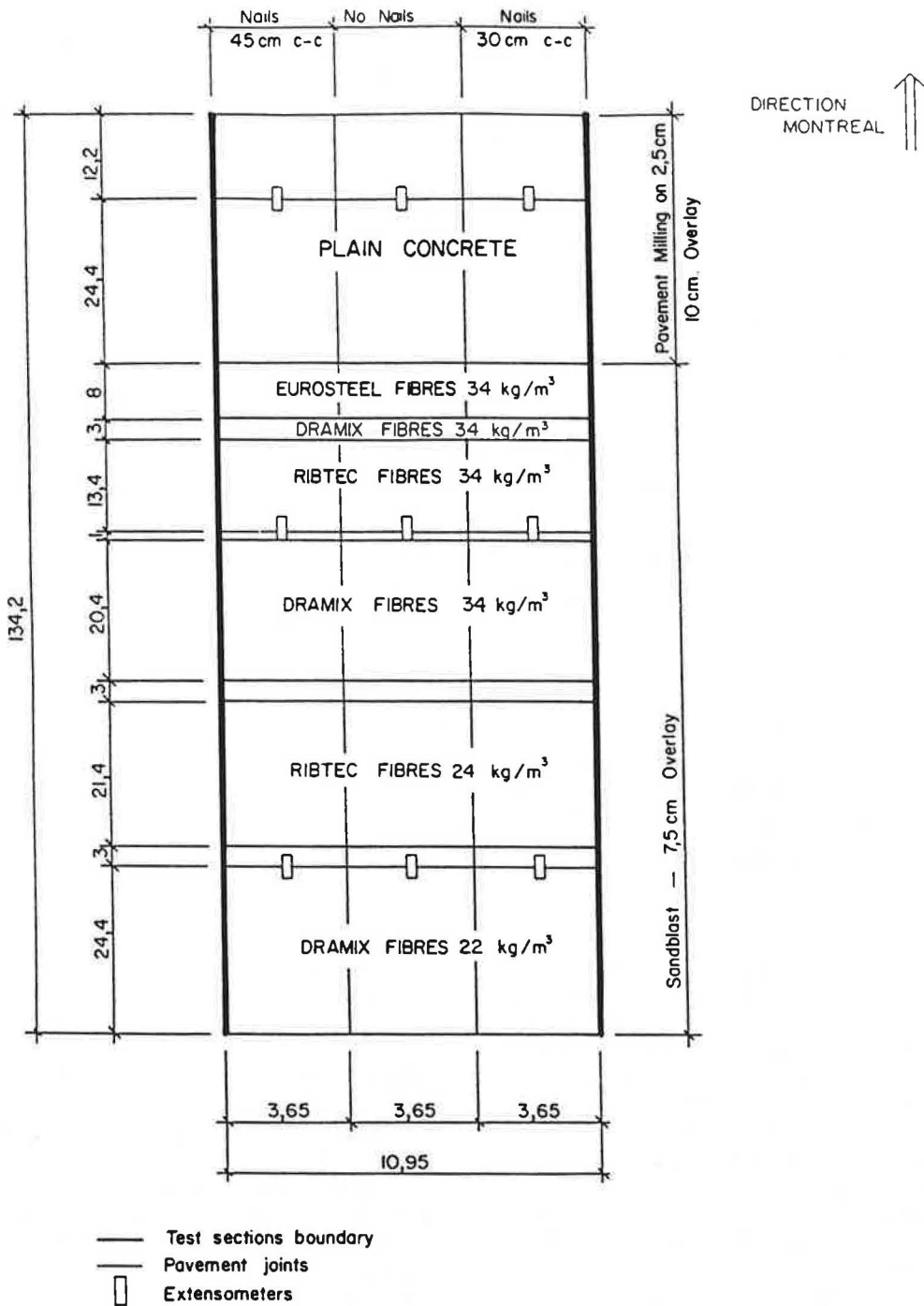


FIGURE 1 Plan view of the test sections (length in meters).

**CHARACTERISTICS OF THE FRESH CONCRETE**

To avoid the main drawbacks that can be encountered in making fiber reinforced concrete, basic design rules governing the formulation of such concretes were followed. These require that the cement content be higher than that of normal concrete, the maximum size of the coarse aggregate be reduced to no more than half the length of the fibers (in fact, 20 mm or ¾ in.), and the volume of the fine aggregate be increased to match that of the coarse aggregate. The plain and fiber

reinforced concrete compositions are given in Table 1. The fibers were introduced manually at the concrete plant, directly on top of the aggregate on the conveyor leading to the central mixer.

In this project, the three different brands of steel fibers used were Dramix, Eurosteel, and Xorex. Their main characteristics are given in Table 2.

These fibers do not perform well in matrixes with a very low water/cement ratio because the bonding that develops is too strong (6). Chanvillard (1) has shown that the critical water/cement ratio is between 0.30 and 0.40 for the type of

TABLE 1 COMPOSITION OF CONCRETE MIXES

		Concrete composition			
		kg/m <sup>3</sup>		lb./cu.yd.	
		Fibres	No fibres	Fibres	No fibres
Cement		420		706	
Water		160		269	
Sand		850	720	1430	1210
Coarse aggregate	10 mm	650	210	1100	350
	14-20 mm	216	830	360	1400
	Total	866	1040	1460	1750
Air-entraining admixture		0.5 L/m <sup>3</sup>		1.9 oz/100 lb of cement	
Unit weight		2296	2340	3865	3935
W/C ratio		0.38		0.38	

fibers used in this project. Consequently, the selected water/cement ratio was 0.38. Moreover, in spite of the fiber content used (0.28 percent and 0.44 percent), it was hoped that the post-fissuration behavior would correspond to a fiber pull-out from the matrix and not a failure of the fibers. This pull-out should be favored by the incorporation of 6 percent air entrained in the mix, reducing the anchorage of the fiber.

To facilitate the placing of the concrete and to have a freeze-thaw resistant overlay, the selected slump was 60 mm (2½ in.) and the air content was 5 to 7 percent. If, at the job site, the delivered concrete did not have a high enough slump or entrained-air content, superplasticizer and air-entraining admixture were added until the designated values were obtained.

The concrete was transported to the job site within 30 to 45 min in transit mixer trucks.

The overlay concrete was placed by a GOMACO C650.5 finishing machine equipped with slip forms. This machine has an auger that levels the concrete and a vibrating cylinder that oscillates laterally to consolidate the concrete and finish the overlay surface.

Initially, the overlay surface was to be burlap textured, but it rapidly became evident that the burlap was partially lifting the fibers located near the surface, requiring extensive manual correction. After the second load of concrete, the surface was no longer textured. Curing compound was spread over the overlay surface 10 to 15 min after placing to prevent drying during hydration. The concrete was completely covered with

insulating blankets at night for protection against the freezing temperatures.

### Field Controls

The fiber content homogeneity was checked carefully in each truck at the beginning, middle, and end of unloading by washing a weighed amount (about 5 kg or 10 lb) of fresh concrete in a 5-mm sieve (No. 4 ASTM) and extracting the fibers with a magnet. This demonstrated that the selected method for adding the fibers to the mix provided fairly good results (see Table 3).

To monitor slump loss, the slump was measured at four stages for each load using an ASTM C143 standard cone (see Figure 2). An average slump loss of 40 mm (1½ in.) was observed after transport to the job site.

### Field Observations

Superplasticizer was added at the job site to correct the slump. This provided unequal workability throughout the concrete load, particularly the top of the load. The more the slump deviated from the recommended level, the harder it was to correct. Increasing the slump of a full load of fiber reinforced concrete in the field presented difficulties.

When the trucks were half unloaded, concrete workability

TABLE 2 CHARACTERISTICS OF FIBERS

	unit	DRAMIX ZP 50/.50	XOREX RIBTEC 2" (50 mm)	EUROSTEEL 60/1.00
Length	mm	50	53.5	60
Diameter	mm	0.50	1.44	1.00
Section		circular	semi-circular	circular
Equiv. dia.	mm	0.50	0.96	1.00
L/d ratio		100	55.7	60
Density *	kg/m <sup>3</sup>	7850	7850	7850
Number of fibres/kg**		12800	3300	2700
Shape		hooked ends	crimped	crimped

\* 1 lb/cu.ft. = 0.624 kg/m<sup>3</sup>

\*\* No/lb = 0.45 No./kg

1 inch = 25.4 mm

TABLE 3 FIBER-CONTENT HOMOGENEITY

Truck Number	Fibre-Content at different Unloading period (%)			Theoretical Content	
	Beginning	Half period	End	%	(kg/m <sup>3</sup> )
1	0.28	0.25	0.29	0.28	22
2	0.33	0.23	0.27	0.28	22
3	0.25	0.35	0.29	0.30	24
4	0.42	0.43	0.45	0.44	34
5	0.40	0.41	0.46	0.44	34
6	0.38	0.45	0.44	0.44	34

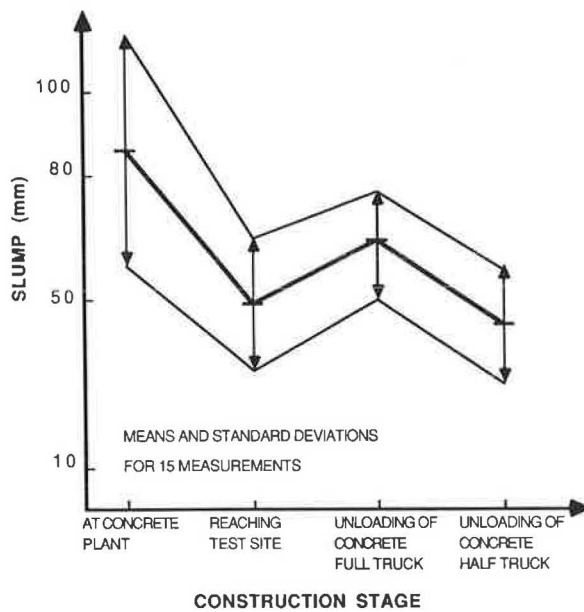


FIGURE 2 Slump versus construction stage.

was checked using the inverted cone slump test (ASTM C995). When the percentage of entrained air was increased, the measured flow time decreased. Thus, air content plays a key role in the workability of fiber reinforced concrete.

If workability is checked by the standard cone method, it is preferable to adjust the slump at the plant to between 100 and 150 mm (depending on the travel duration) to avoid the problems posed by field adjustment. However, if workability is checked with the inverted cone flow, this research indicates that the flow time should be about 5 sec with an air content of 5 to 7 percent.

Air content, like slump, was checked at different stages. The total air content was found to decrease by 2 to 2.5 percent during transportation (see Figure 3). When the air content was low, an air-entraining admixture was directly added to the load, followed by 3 min of mixing. It was observed that the concrete unloaded immediately after this redosing had generated an increased air content. However, the air content of the middle of the load was often lower than the first air content reading.

As with slump, correcting the air content of a full load of fiber reinforced concrete in the field proved very difficult. However, it is not difficult to entrain air at a ready-mix plant. Therefore, the air-entraining admixture dosage should be adjusted in a couple of trial batches at the plant to avoid the need for correction at the job site.

#### CHARACTERISTICS OF HARDENED CONCRETE

Concrete specimens were tested for compression and flexure. While a knowledge of concrete compressive strength is not fundamentally important for pavement application, it does reflect the overall quality of the concrete.

For the selected water/cement ratio of 0.38 and an average air content of 6 percent, the tested concrete had a compressive strength of approximately 60 MPa (8,700 psi), irrespective of

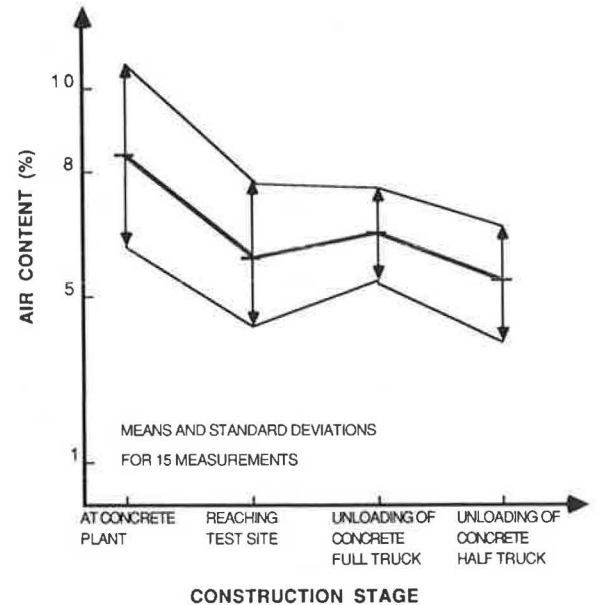


FIGURE 3 Entrained air versus construction stage.

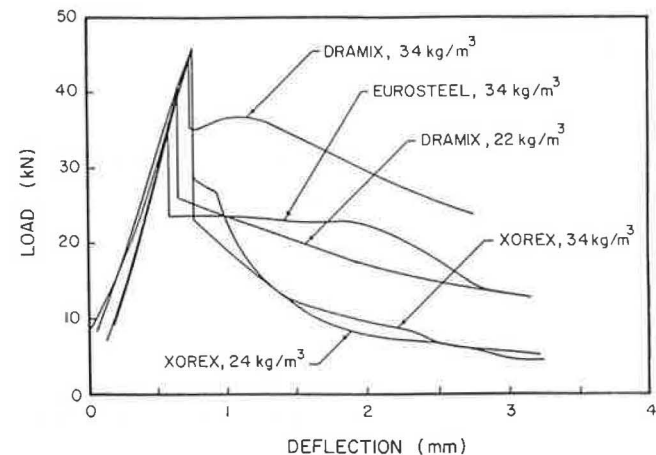


FIGURE 4 Load versus deflection for different concretes.

fiber content. These steel fibers had a more pronounced effect on the flexural strength of concrete. This effect was tested on 150 mm × 150 mm × 500 mm (6 in. × 6 in. × 20 in.) specimens submitted to flexural tests at a constant rate of strain.

As seen in Figure 4, the cracking of the matrix corresponds to the drop in the load that can be withstood by the specimen. The observed drop is mainly due to the low contents used in this field application (0.28 and 0.44 percent by volume). The cracking point corresponds to the maximum load the concrete sample can withstand (between 36 kN and 46 kN), representing its modulus of rupture. In this project, the average was 5 MPa (725 psi), with a range of about 4.6 to 5.9 MPa (674 to 862 psi).

The load curves in Figure 4 show that the presence of fibers allows a quasi-ductile failure of the concrete specimens and that additional energy is necessary to open up a crack, even at these low fiber contents. This behavior is particularly interesting for pavement applications where a dual loading mode can be observed. First, traffic along a road develops a given

load on the pavement; consequently, the modulus of rupture of concrete is an important factor in designing concrete pavements. Second, moisture and temperature variations cause volumetric changes in the concrete that create internal stresses. When a pavement is cracking, the presence of fibers produces a residual load in the concrete, which limits the crack from opening further. Volumetric changes are also less harmful.

In conclusion, concrete with a high modulus of rupture is useful because it allows high loadings but is of no use after cracking. Quasi-ductile behavior allows a continuous load transfer across the cracks and maintains the pavement integrity.

**BEHAVIOR OF SLABS IN THE FIELD**

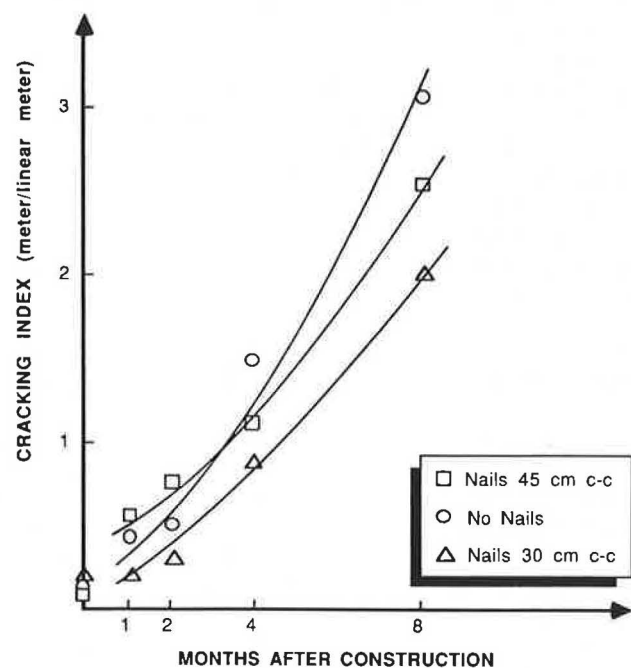
The crack network was observed periodically. Fine transversal microcracks were noticed a few weeks after the construction of the overlay, some of which propagated quite rapidly. The network of cracks at different ages is presented in Figures 5 through 7. They have been characterized in terms of length of cracks by length of overlay (both in meters) as a function of the number of months after construction.

After 13 months of service, two types of cracks were observed:

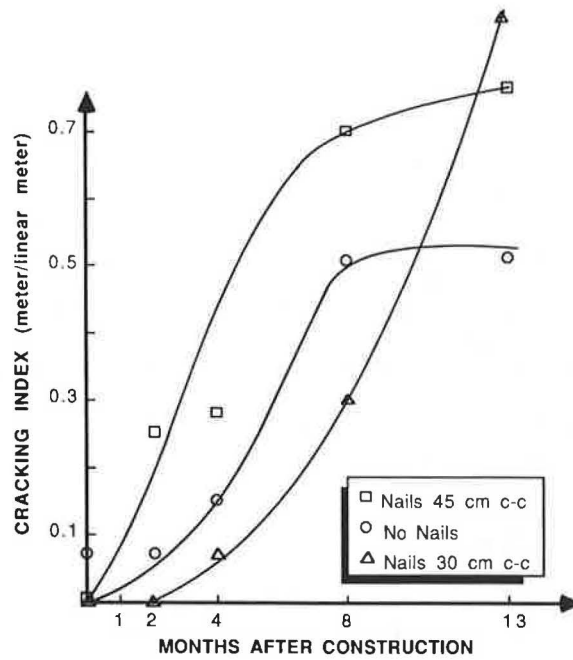
1. Very fine cracks that remained nearly closed. These cracks are difficult to see when the pavement is dry and hot but are readily visible in cold, humid weather.
2. Wider, constantly visible cracks that appeared very clear and seemed to be deeper than the first type.

**Influence of Mechanical Bonding**

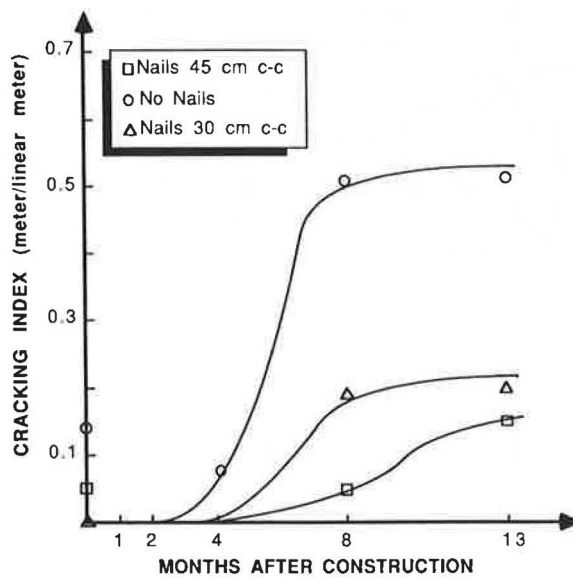
Figure 5 illustrates the cracking behavior of slabs made with plain concrete (without fibers) according to different bonding



**FIGURE 5** Development of cracking index for plain concrete.



**FIGURE 6** Cracking index versus time for steel fiber reinforced concrete (22 kg/m<sup>3</sup>).



**FIGURE 7** Cracking index versus time for steel fiber reinforced concrete (34 kg/m<sup>3</sup>).

conditions. The overall performance of these slabs was very poor.

In Figures 6 and 7, the cracking index of the experimental slabs built with the various fiber reinforced concrete mixes (fiber contents of 22 and 34 kg/m<sup>3</sup>) is presented. In general, the degree of cracking was much smaller than with the plain concrete, so the influence of the nails used to anchor the overlay to the old pavement is less evident. In the concrete with the higher fiber content, however, there was less cracking in the slabs with nails than in those without (see Figure 7).



### Influence of Fiber Content

In Figure 8, the average level of cracking for all the experimental slabs is presented. A comparison of the three corresponding curves indicates the beneficial influence of the fibers on the control of the crack growth.

The network of cracks developed rapidly during the first few months. After 8 months, these cracks were almost stabilized in the fiber reinforced concrete but continued to develop in the conventional concrete.

The nonreinforced part of the overlay rapidly showed a number of signs of distress, which resulted in debonding. This portion had to be replaced by an asphalt patch after only 18 months of service, which confirms the difficulty in obtaining a good level of performance with a conventional concrete in severe climatic and traffic conditions.

### Overlay Bonding

To check the level of bonding between the old pavement and the overlay, full-depth core samples with a diameter of 100 mm (4 in) were taken through the overlay and the pavement at different locations, particularly where cracks were observed. It was impossible to recover a complete core where the overlay was made of conventional concrete. In all cases, the core broke at the interface between the old pavement and the overlay. This behavior demonstrates that the bond was unable to resist the shear stresses resulting from the strains induced in the overlay.

In the case of the cores drilled in the fiber-reinforced part of the overlay, the bonding between the old pavement and the new overlay was so good that the cores never exhibited interface failure when they were extracted from the pavement (see Figure 9), even when a cracked area was cored. Moreover, the different cores taken after 18 months of service

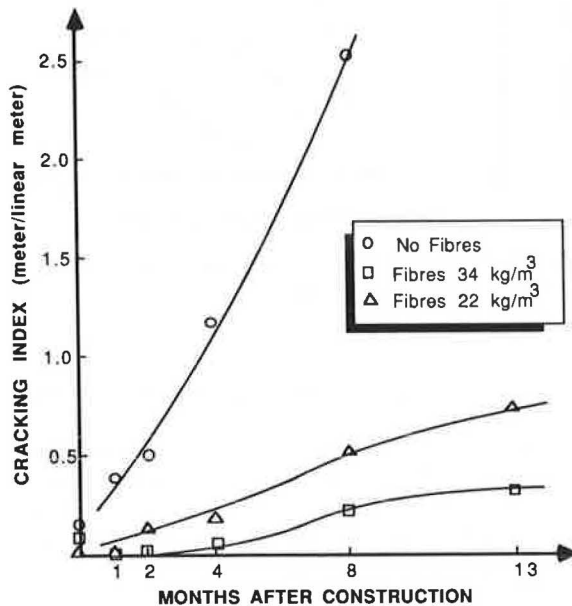


FIGURE 8 Development of cracking index versus concrete type.

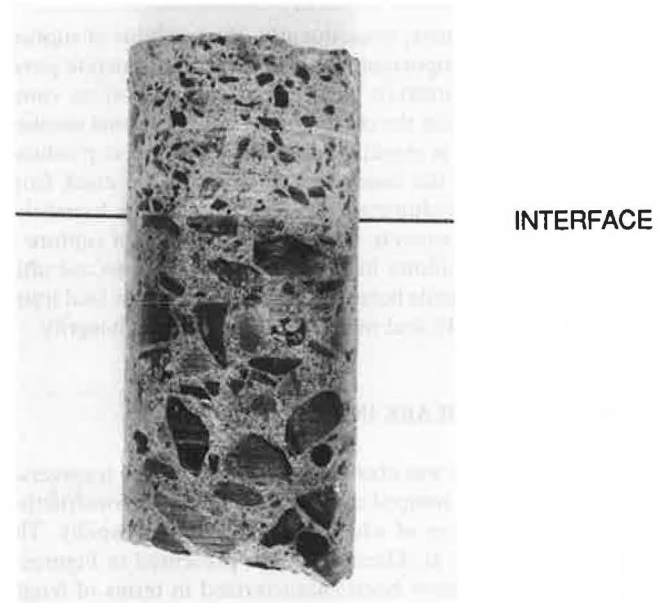


FIGURE 9 Core sample showing good bonding between concrete layers.

clearly revealed the different nature of the two types of cracks that were observed in the overlay's surface.

Cracks almost always occurred over existing cracks in the old pavement. However, these reflected cracks never resulted in interface delamination. This was apparently due to the presence of fibers in the overlay, since the fibers allow good load transfer across the cracks (see Figure 10).

The finer cracks were only superficial—no more than 40 mm (1½ in.) deep. In this case, the presence of fibers apparently inhibited crack propagation (see Figure 11). It is believed that these cracks were either due to the differential shrinkage between the new overlay and the old concrete or were of thermal origin.

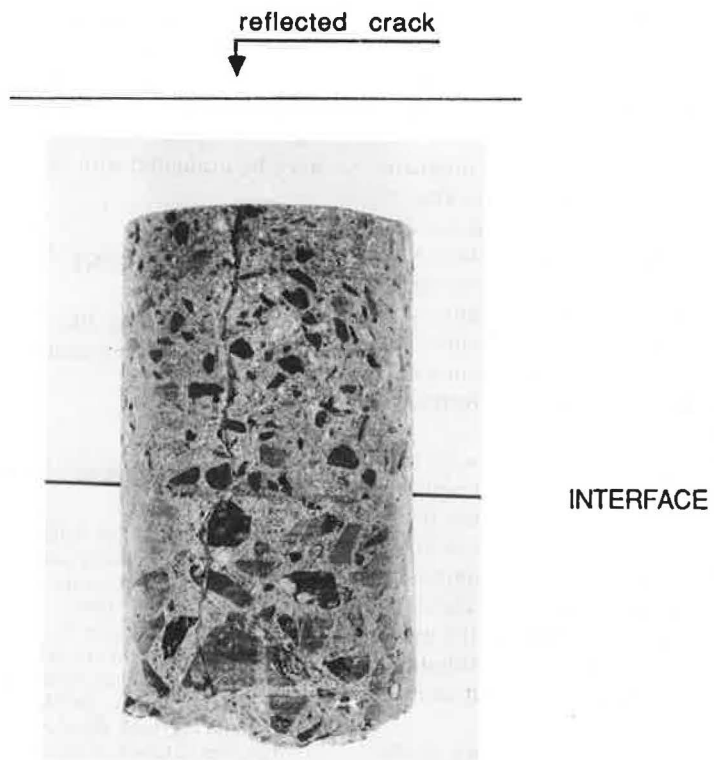
The positive impact of the fibers is clearly evidenced in all core samples. The presence of the steel fibers in these overlays inhibited crack propagation and reduced the intensity of the shear stress along the interface, thereby preventing delamination.

It can be concluded that the presence of fibers in the overlay contributed significantly to the monolithic behavior of the old pavement/overlay system.

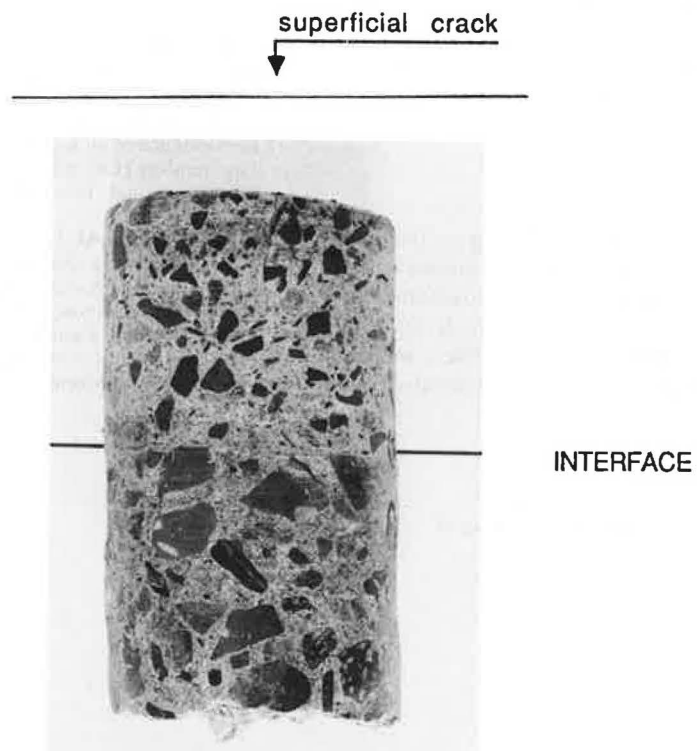
### DISCUSSION OF OVERLAY BEHAVIOR

Cracks appeared quite rapidly after the construction of the overlay but were almost stabilized after 8 months of service in the fiber reinforced sections. These cracks were transversal and very fine. The development of microcracks can be explained by thermal stresses as well as by concrete shrinkage, both of which create differential movement between the old concrete pavement and the new overlay.

This early appearance of cracks has been observed in similar projects. Bagate et al. (7) and Betterton et al. (8) reported similar behavior with thin fiber reinforced concrete overlays. Domenichini (9) demonstrated that a temperature difference



**FIGURE 10** Core sample showing reflection cracking but good bonding between concrete layers.



**FIGURE 11** Core sample showing good bonding and a small thermal or shrinkage cracking at surface.



of 6°C (11°F) through the thickness of a 75-mm (3-in.) overlay, combined with shrinkage stress, can result in major shear stresses at the old pavement/new overlay interface. This is why a reduction in the overlay thickness can quite rapidly result in the formation of some cracks.

The cracks observed in the overlay surface can originate from the reflection of existing cracks in the old pavement. This phenomenon cannot be avoided with monolithic overlay when dealing with transversal cracks (2, 3). This explains why the use of thin overlays is not easy. These weaknesses appear soon after overlay construction and propagate so rapidly, due to fatigue, that the overlay is often ruined by delamination at the interface. The experiment reported by Betterton et al. (8) in Iowa, however, shows that satisfactory performance after 10 years of service is possible.

In the research described in this paper, the cracks that appeared during the first 6 months stayed almost closed and did not grow. Therefore, the beneficial action of the fibers cannot be contested in this experiment. The presence of fibers that bridge the two edges of the cracks results in a continuity of the overlay, permitting some load transfer across the crack and, above all, limiting its growth. While reducing the width of the cracks, fibers provide better shear-stress distribution, resulting in a better bond between the old pavement and the new overlay.

As discussed earlier, it is believed that satisfactory results can be obtained at a fiber content of 0.5 percent by volume (40 kg/m<sup>3</sup>).

Finally, very harsh climatic conditions such as those in Québec, where the temperature of the overlay can vary from -40°C to +40°C, the durability of the fibers needs to be established due to frequent deicing salt applications. Since the cracks are widest in winter, the bridging fibers are more extensively exposed to corrosive attack.

## CONCLUSION

The use of a thin, bonded fiber reinforced concrete overlay to rehabilitate old concrete pavements yielded encouraging results. Due to the various field conditions encountered, it was possible to establish the main influence of the fibers and their content in the overlay. The presence of fibers in the overlay stabilized the development of the transversal crack

network, resulting in more monolithic behavior between the old pavement and the overlay. The use of concrete nails to achieve a mechanical bond between the overlay and the old pavement did not produce conclusive results. The possible corrosion of the steel fibers bridging the crack by deicing salt must be evaluated with time.

## ACKNOWLEDGMENT

The authors would like to thank the Québec Provincial Department of Transportation for financial support in this field experiment.

## REFERENCES

1. G. Chanvillard. Les bétons renforcés par de faibles dosages de fibre d'acier: propriétés mécaniques, utilisation comme matériaux de resurfaçage. *Mémoire de maîtrise*. Université de Sherbrooke, Québec, Canada, 1988.
2. G. F. Voigt, M. I. Darter, and S. H. Carpenter. Field Performance of Bonded Concrete Overlays. In *Transportation Research Record 1110*, TRB, National Research Council, Washington, D.C., 1987.
3. R. L. Hutchinson. *NCHRP Synthesis of Highway Practice 99: Resurfacing with Portland Cement Concrete*. TRB, National Research Council, Washington, D.C., Dec. 1982.
4. G. C. Hoff. Steel Fibre-Reinforced Concrete Pavements and Overlays. In *Report SCM-10(85): Design With Fibre-Reinforced Concrete*, American Concrete Institute, 1985.
5. C. D. Johnston. Steel Fibre-Reinforced Concrete—Present and Future in Engineering Construction. *Composites*, April 1982, pp. 113–121.
6. R. J. Gray and D. Johnston. The Effect of Matrix Composition on Fibre/Matrix Interfacial Bond Shear Strength in Fibre-Reinforced Mortar. *Cement and Concrete Research*, Vol. 14, No. 2, March 1984, pp. 285–296.
7. M. Bagate, B. F. McCullough and D. Fowler. Construction and Performance of an Experimental Thin-Bonded Concrete Overlay Pavement in Houston. In *Transportation Research Record 1040*, TRB, National Research Council, Washington, D.C., 1985, pp. 25–33.
8. R. M. Betterton, M. J. Knutson and V. J. Marks. Fibrous Portland Cement Concrete Overlay Research in Green County, Iowa. In *Transportation Research Record 1040*, TRB, National Research Council, Washington, D.C., 1985, pp. 1–7.
9. L. Domenichini. Factors Affecting Adhesion of Bonded Concrete Overlays. *Record 1, Workshop on Theoretical Design of Concrete Pavements* (Abridgement), Epen, The Netherlands, June 1986.