

A CONCRETE PAVEMENT PROJECT WITH A 10-YEAR PERFORMANCE GUARANTEE IN QUEBEC

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ABSTRACT

Highway 40 in the Vaudreuil-Dorion area is a very heavily traveled concrete divided roadway. In 1994, a design-build call for proposals was made for the reconstruction of a 5,5-km section of the westbound pavement.

The contract was awarded to an unbonded concrete trapezoidal overlay project with a 10-year performance guarantee. While this proposal was innovative in several respects, the term of the performance guarantee was what made it exceptional. The concrete pavement criteria under guarantee are potholes, spalling, cracking, joint sealing, rutting, skid resistance and profilometry.

The behaviour of this pavement until now has tended to demonstrate the feasibility and relevance of a 10-year guarantee on a concrete pavement, even under very heavy truck traffic.

INTRODUCTION

The oldest law providing for some form of guarantee for construction work was the Code of Hammurabi, in effect in the 18th century B.C. [1]. It specified that if due to poor construction a house collapsed and killed the owner, the builder was to be executed; if the owner's son was killed, it was the builder's son who was executed, etc. In addition to this, no statute of limitations was prescribed.

Several centuries later, the Romans were not quite as harsh but they did require that public works contractors repair damages occurring within a fifteen-year period. In old French law, such liability was reduced to ten years and it was only in 1927 that the Civil Code of Quebec brought it down to five years for the failure of the work, i.e. any major deterioration of the work affecting its solidity or integrity and resulting from a design, construction or soil defect [2] [3].

The 10-year term of the guarantee covering this project is therefore not a completely new concept. However, its application to pavement performance can be considered as relatively bold given the multitude of factors that can cause the premature deterioration of a pavement within this period. Five years after construction this is the right time to make an interim assessment of this pavement's performance so far, in order to get a good indication of its future behaviour until the end of the guarantee term.

PROJECT DESCRIPTION

Highway 40 in the vicinity of Vaudreuil-Dorion Municipality, in the province of Quebec, Canada, is a divided concrete roadway with three lanes in each direction. The annual average daily traffic (AADT) was 59 000 vehicles in 1994, with the proportion of heavy vehicles amounting to 16 percent. Since this road segment is part of the main goods transportation route from Quebec to the United States, its main export market, the trucks are heavily loaded.

Originally built in 1966, this concrete pavement developed substantial transverse cracking and became quite rough. It had come to the end of its useful life due to a number of factors, including stress from heavy vehicle use, inadequate base drainage and joint failure problems typical of jointed reinforced concrete pavements.

By the time a major reconstruction was required on this highway, the *Ministère des transports du Québec (MTQ)* set up a program to promote and facilitate the use of innovative techniques by highway construction contractors. This program involved making a number of calls for proposals asking contractors to submit innovative solutions for various problems affecting pavements and structures. The objectives were as follows :

- To develop new road rehabilitation techniques;
- To adapt techniques and methods developed abroad to Quebec conditions;
- To increase the technological potential of Quebec engineering firms;
- To define an administrative method allowing MTQ to use these contractors' expertise;
- To diversify the knowledge and experience of MTQ's experts.

CALL FOR PROPOSALS

In 1994, a design-build call for proposals including a performance guarantee clause was made for the reconstruction of a 5,5-km section of the westbound pavement of Highway 40.

In addition to some requirements related to lane closure and traffic control during construction, the tender documents included : plans of the existing roadway, description of borings and core samples, results of concrete compressive strength tests and soil analyses, distress mapping, FWD (Falling Weight Deflectometer) deflection measurements, profilometry, SCRIM (Sideways Force Coefficient Routine Investigation Machine) skid resistance surveys, statistical data on hourly traffic variations, annual estimated rigid and flexible ESAL (Equivalent Single Axle Load), and projected rate of traffic growth.

The guarantee had to be in the form of a maintenance bond equal to 50 percent of the contract amount and bearing a term equal to the guarantee term proposed by the bidder. The concrete pavement criteria under guarantee are potholes, spalling, cracking, joint sealing, rutting, skid resistance and profilometry. The action levels and response times for each criterion are shown in Table 1 per hundred-metre section of traffic lane. Since the term of the guarantee was not specified in the call for proposals but left to the contractors' discretion, the action levels were chosen to yield values which should normally be observed only at the end of the pavement's useful life. However, the specifications required that the pavement be structurally designed for at least 20 years to ensure good long term performance, whatever the term of the guarantee.

CHOICE OF PROPOSAL

The proposals were assessed on the basis of the following factors (weighted on 100 %) :

- The contractor's competence, reliability and experience (10 %);
- The quality of the proposal (20 %);
- The proposal's innovativeness (15 %);
- Ease of implementation and use constraints (10 %);
- Anticipated increase in short and long term overall pavement quality (10 %);
- Guarantee term offered (10 %);
- Total cost (25 %).

Ten proposals were submitted by seven consortiums, with the guarantee terms ranging from a minimum of 2 years to a maximum of 15 years. The six proposals involving asphalt included various techniques for fragmenting or recycling existing slabs, in place or at a fixed plant, or using an elastomeric membrane interlayer, before overlaying with special bituminous mixes (high modulus, rough texture, draining, dense, or with asbestos) built conventionally or in planned stages over the term of the guarantee. The four concrete pavement proposals consisted essentially in unbonded concrete overlays, complemented by reconstruction in the sectors where overpass clearance precluded raising the elevation of the road profile. Different types of slabs were proposed : with dowelled or undowelled joints depending on lanes, of even thickness or trapezoid shaped, 20 or 30-year design, or continuously reinforced concrete with galvanized reinforcement.

The chosen proposal was for an unbonded plain jointed concrete overlay of trapezoidal transverse section as shown on Figure 1. This proposal was designed for a 20-year life, with a 10-year guarantee for a total cost of 4,2 million Canadian dollars.

PAVEMENT DESIGN

This project essentially involved building a new slab over the existing one, which had previously been overlaid with 25 mm of asphalt concrete. Old slabs which were broken up into several pieces were replaced with plain regular concrete.

Four sections of the existing slab had to be excavated and rebuilt directly on the existing base, over a length of a few hundred meters. This was required at the project's two extremities to link up with the bridge structures and under two overpasses to maintain vertical clearance. Standard transitions were built between sections of slab on grade and unbonded concrete overlay.

The existing base consisted of a granular material 770 mm thick laid directly on the natural soil. FWD deflection tests assessed the bearing capacity of the existing base at 45 MPa/m (150 psi/in) and that of the slab's surface at 200 MPa/m (700 psi/in). The base drainage was improved by adding an edge drain under the right shoulder in order to get rid of the water trapped by the side bank.

The estimated increase in truck traffic on this major route is 4 percent per year and the estimated load factor per truck is 3,1. This yielded a rigid ESAL of 14 000 for an AADTT (Annual Average Daily Truck Traffic) of 3 000 in the busiest lane in 1994. The distribution and growth of this estimated truck traffic, expressed as rigid ESAL over the 20-year life, are shown in Figure 2.

The slabs were designed with the PCA method [4], using the heaviest loading conditions to determine the required thicknesses. A specific risk analysis was then conducted to minimize cracking probability, particularly during the term of the guarantee. To this effect, the firm ERES Consultants provided an in-service pavement behaviour model in accordance with NCHRP Project 1-30 [5]. A minimum reliability level of 97 % was chosen, which led to increase the thicknesses obtained from the PCA method by 20 mm. Figure 1 shows final design thicknesses. The pavement was also widened by 300 mm at the edge of the right lane to reduce further the risk of cracking.

To ensure that minimum thicknesses were laid in each lane, a precise levelling on a 3 meters by 5 meters grid was computer-generated. Core sampling showed that minimum thicknesses were met and that average slab thickness was 20 mm greater than the minimum required.

The characteristics of the materials used for the concrete slabs are shown in Table 2. The contractor set up a quality assurance plan to ensure that minimum concrete strengths were achieved. The results show that these requirements were exceeded at all times. Crushed trap-rock (nepheline syenite) was used as coarse aggregate to reduce surface wear and rutting.

A preformed joint sealant was selected for its long service life compared to hot-poured sealant.

PAVEMENT CONSTRUCTION

The working atmosphere on site was quite different than in the case of a traditional contract. Since the contractor was responsible for practically every aspect of the project, the potential for disputes with MTQ personnel was reduced. Moreover, the 10-year guarantee was in itself enough of a financial incentive for the contractor to pay constant attention to the quality of the work.

The role of MTQ was basically limited to maintaining a daily operations log and to check the conformity of the work with the mutually agreed quality assurance and traffic management plans. A laboratory was commissioned to carry out the validation tests and audits.

Traffic management is the aspect of the contract which has been the most problematic. This is a priority concern for MTQ given its overall responsibility for ensuring smooth and safe traffic flow as well as its role as roadway owner. For the contractor, the concern for traffic management is not as much a top priority because this is an operational constraint entailing a substantial cost with no direct benefit. A number of conflicts arose on this issue, especially at the beginning of the contract, since the specifications for traffic management were rather succinct given the turnkey approach. The situation improved when the contractor realized that MTQ's recommendations were justified. This experience shows that the specifications have to explicitly stipulate standards relating to traffic control on the construction site, geometric parameters to be used and related safety equipment.

PERFORMANCE MONITORING

The specifications require that surveys and tests aimed at assessing the guarantee's criteria be conducted once a year, in May, by MTQ or an agent. The contractor participates in the inspections and in the validation of procedures and results.

Profilometry

The profilometry was measured annually in the three lanes from 1995 to 2000, except in 1999, with a Road Surveyor T6500 inertial profilometer.

Figure 3 shows the IRI (International Roughness Index) results for the centre lane. The other lanes, which are not shown here, follow similar curves : they vary relatively little over most of the project but the section between chaining 0+100 and 0+400 exhibits a higher-than-average IRI. This section on an upward slope posed some problems during construction and the IRI has now reached the action level of 3,5 m/km over a 100-metre control lot in the centre lane.

Figure 4 shows the evolution of IRI averages per lane. The two lanes built in the same pass of the slip-form paver (centre and passing lanes) have almost identical average values and behaviours. The slow lane, constructed in a subsequent pass, exhibits similar behaviour over time, but the average roughness is substantially better (lower by 0,2 m/km) since the beginning.

Rutting

Rut measurements with a high performance equipment, as stipulated in the specifications, were not carried out. No ruts have been observed visually until now.

Skid Resistance

Skid resistance has been measured annually in the three lanes from 1996 to 2000, except for 1997, with a SCRIM.

Figure 5 shows the SFC (Sideways Force Coefficient) for the centre lane, which is the lane with the lowest values. Out of a total of 54 control lots per lane (100-metre each), only a few show SFC values below or equal to the action level of 40. In the centre lane, eight control lots were deficient in 1998, six in 1999 and eight in 2000. In the slow lane, two control lots were under 40 in 1998, but none were deficient in 1999 and only one in 2000. There were no deficient control lots in the passing lane. Figure 5 also shows that the 1996 results, which were quite acceptable, are in sharp contrast with those of subsequent years.

Figure 6 shows that the average SFCs for each lane dropped sharply in the first years, then stabilized as of 1998. The average SFC values since 1998 have settled at approximately 51 for the slow lane, 44 for the centre lane and 59 for the passing lane. Under the contract, MTQ could have required that corrective action be taken in control lots where the skid resistance fell below the action level, but there are several reasons why no action has yet been taken.

Firstly, the technique used in this project to produce a non-skid texture on the concrete's surface is the same as that specified in MTQ standards [6], i.e., Astroturf drag. This technique produces a low-noise surface and SCRIM surveys conducted immediately after construction, and even up to a year afterwards, usually show good skid resistance. Ever since 1997, monitoring of experimental sections and a number of contracts with performance guarantees awarded since 1994 have shown a trend similar to this project : in the first few years SFC values dropped sharply but then levelled off close to action level.

At the same period, we learned about the results of an exhaustive study conducted in the United States on the subject [7]. This study reported that the texture obtained with Astroturf drag only did not produce sufficient skid resistance for a high-speed traffic highway.

On the other hand, SCRIM surveys on some older pavements constructed with very good aggregates exhibited very high skid resistance values : at the site of the project under discussion here, average SFC values on the old slab, built with granitic aggregates, were 61 in the centre lane, 76 in the slow lane and 79 in the passing lane, even though the texture in the cement paste had disappeared for quite some time. In view of the hard aggregates used, the conclusion is that the hardened cement paste wears more quickly than the aggregate, eventually improving macrotexture. It remains to be seen over the next few years if this phenomenon will recur on the new slab.

An encouraging sign is that most SFC values have slightly increased since 1998. This phenomenon was also measured on another highway, Highway 15, which was reconstructed in 1994 and where the improvement in skid resistance is even more pronounced. As long as road user's safety is not in jeopardy it appears preferable, before taking corrective action, to wait and see if SFC values will stabilize or even increase. Action taken nearer the end of the guarantee would also have the advantage of prolonging the effect after the guarantee expires.

Distresses under guarantee

All distresses observed since 1995 have been repaired, namely :

- A few spalls;
- Three small potholes (not deficient);
- A few cracks;
- A few dozen joints with defective sealant.

These distresses are very few and as shown by Table 3, the cost of maintenance actions taken by the contractor is low and has not tended to increase until now.

Distresses not covered by the guarantee

There are no performance criteria applying to the shoulders in this contract. The shoulders were overlaid with asphalt, as was the case for the original pavement and as specified by MTQ standards [8]. There are transverse and crescent-shaped cracks near the transverse joints and a lane to shoulder drop off of about 15 mm.

The behaviour of asphalt shoulders on other concrete pavements in Quebec is rarely very satisfactory. It is no wonder that most transportation agencies and related organizations recommend that shoulders be constructed with the same material as the main traffic lanes, to simplify construction and to ensure better behaviour of the pavement and shoulders. MTQ is currently reviewing its standards for concrete pavement shoulders.

The addition of specific criteria for shoulders should be considered for future contracts including a performance guarantee.

CONCLUSIONS

The use of risk analysis in the design process, selection of durable materials, stringent quality control and attention to details in all respects made it possible for the contractor to assume a 10-year performance guarantee with reasonable confidence he could live up to it.

After five years, the general behaviour of this pavement is excellent and compares favourably with any other pavement of the same type and age. The rare distresses repaired until now and the few corrective actions to be anticipated until the guarantee expires are part of the normal contingencies of highway construction and can be done for a minimum cost. Since maintenance follow-up is being done more systematically and rigorously than is usually the case for a traditional contract, it is expected that the

condition of this pavement will be excellent at the end of the 10-year guarantee and its behaviour afterwards will also certainly be quite good.

MTQ did not face any real problem on this project. Quite to the contrary, the contractor's professionalism and thoroughness was reassuring given the fact that MTQ's role was much less involved than usual in the design and quality control phases. For future projects, it was found that specifications relating to traffic control ought to be more explicit and that some performance criteria should apply to shoulders. The guarantee period could be fixed so the performance criteria action levels can be adjusted accordingly, or the action levels could be specified as a function of the guarantee period. Also, the selection factors in the call for proposals could be changed or weighted differently so emphasis is put less on innovation but more on factors that really affect the long term performance of the pavement. Even without those contractual improvements, this project has shown that a design-build contract with a long-term performance guarantee is feasible, realistic and cost-effective for a concrete pavement.

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TABLES

Table 1. Action levels and response times for concrete pavement criteria under guarantee, by control lot (100-m length of traffic lane)

Criterion	Action	
	Response time (days)	Level
Pothole	3	4 or more with a diameter greater than 100 mm
Cracking	60	Opening greater than or equal to 3 mm or opening less than 3 mm but longer than 20 linear metres
Joint sealing	60	10 % of joints or more are defective
Spalling	60	Wider than 75 mm or between 50 and 75 mm wide but longer than 20 linear metres
Rutting	60	Deeper than 15 mm
Skid Resistance	60	SFC less than or equal to 40
Profilometry	60	IRI greater than 3,5

Table 2. Characteristics of materials in concrete slabs

Concrete	35 MPa in compressive strength at 28 days and 4,0 MPa in flexural strength at 10 days
Aggregate	Crushed trap-rock (nepheline syenite) 40 mm Ø
Tie bars	20 M – 750 mm x 750 mm c/c in longitudinal joints
Epoxy coated dowel bars on baskets, 300 mm c/c	Slab on grade, transverse joints at 4,5 m : • 38 mm Ø x 450 mm – centre and slow lanes • 32 mm Ø x 450 mm – passing lane Slab on slab, transverse joints at 6,0 m : • 25 mm Ø x 450 mm – center and slow lanes • none in passing lane
Preformed sealant	Phoenix type – longitudinal and transverse joints

Table 3. Repair of distresses covered by guarantee

Action	1996	1997	1998	1999	2000	Product used
Repair of spalls < 50 mm (number of tubes)	-	10	71	9	6	Sikaflex 11FC et 221 Vulkem 116
Repair of spalls > 50 mm or partial depth repair 150 mm x 200 mm (number)	23	12	25	42	19	Meadows Futura
Full depth repair 4,0 m x 3,5 m (number)	-	1	-	-	-	Fast track concrete
Repair of cracks (linear metre)	-	-	4,0	6,0	2	Sikaflex 11FC Sikadur 52 Meadows Sealtight
Joint sealing (linear metre)	180	60	145	20	7	Phoenix (preformed) for transverse joints Vulkem 116 (liquid) for longitudinal joints
Traffic control costs (C\$)	2 500	3 050	2 800	2 000	2 100	
Cost of repairs (C\$)	2 500	6 850	5 700	2 800	2 800	
Total Cost (C\$)	5 000	9 900	8 500	4 800	4 900	

FIGURES

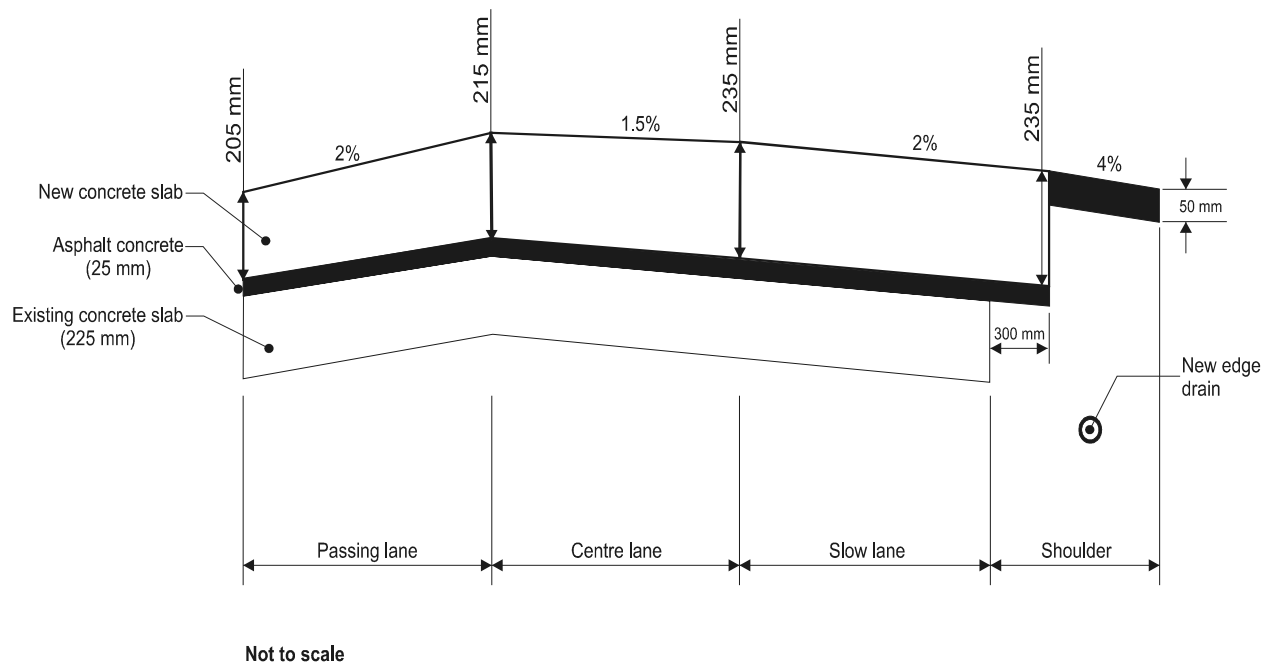


Figure 1 – Cross-section of unbonded concrete overlay trapezoidal section

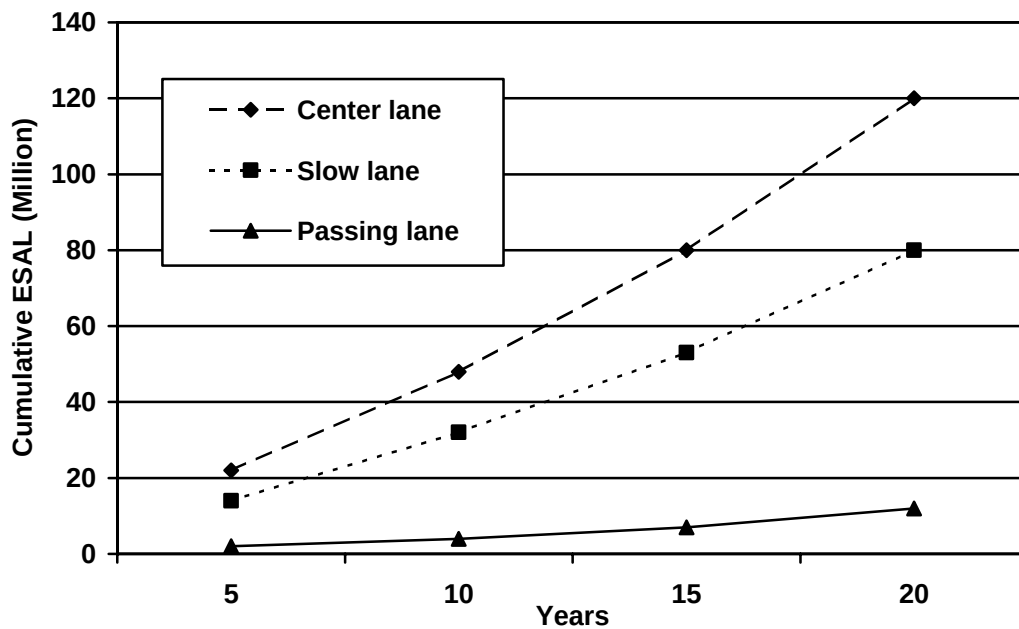


Figure 2 – Estimated truck traffic growth and distribution

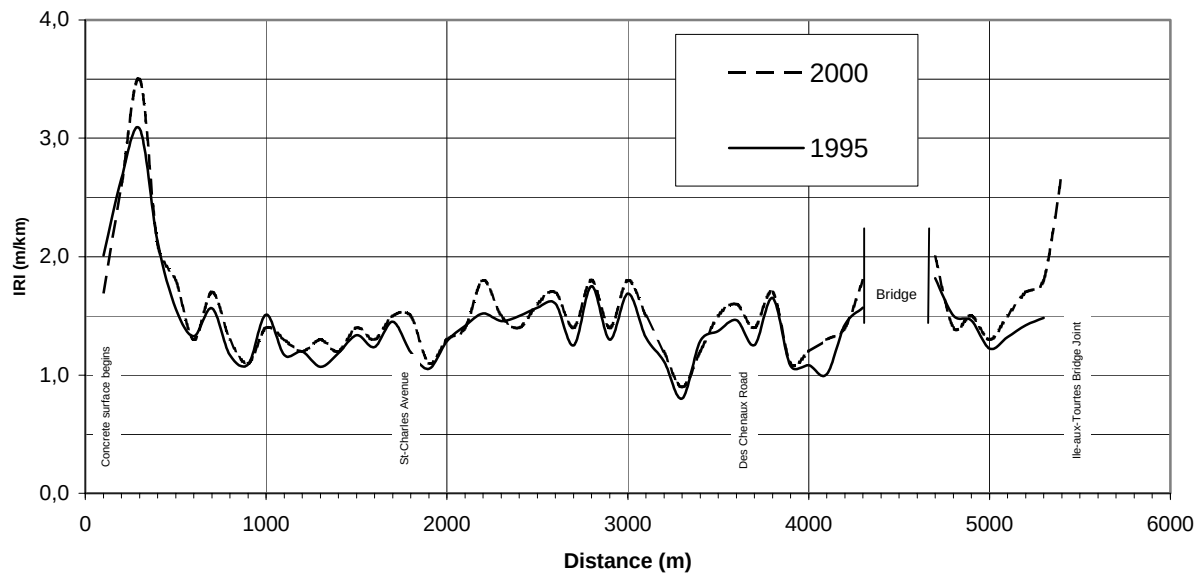


Figure 3 – Profilometry of centre lane

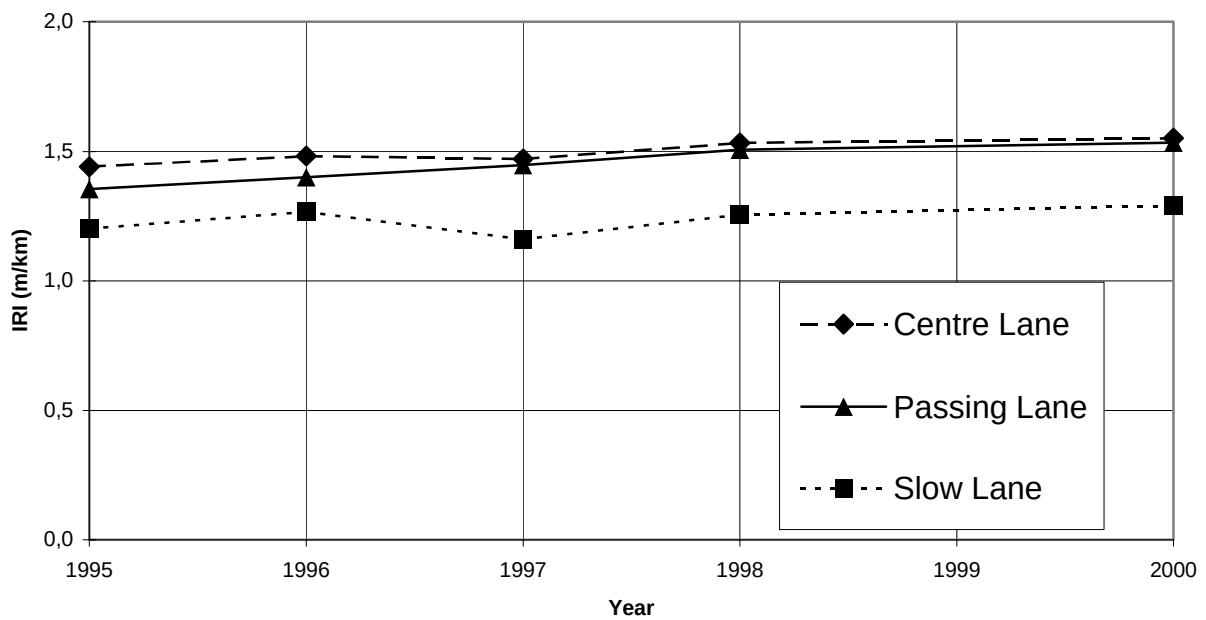


Figure 4 – Evolution of average IRI per lane

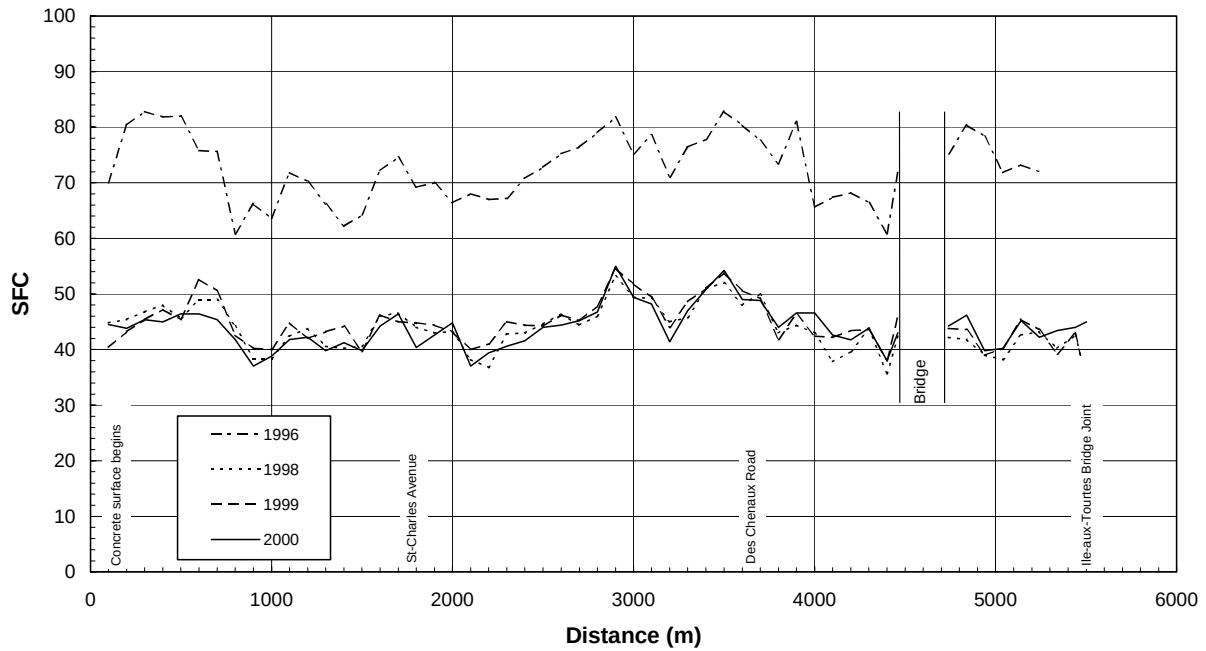


Figure 5 – Skid resistance of centre lane

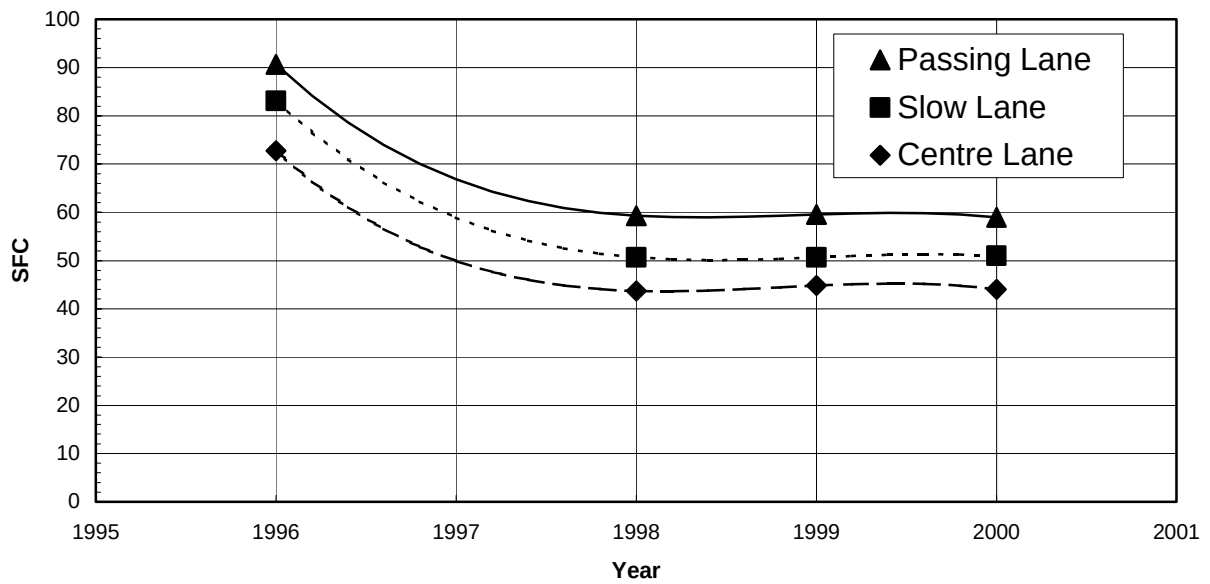


Figure 6 – Evolution of average SFC per lane