CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS AT TRANSPORT QUÉBEC

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ABSTRACT

Historically, cement concrete pavements built in Québec have not always performed satisfactorily. This was mainly linked to the following factors: use of slabs not always suited to our climate, poor design and construction practices, an increase in traffic volume and load, as well as, a decrease in funds allocated to maintenance.

Since the early 1990s, pavement design specifications have been the object of a major turnabout at the Québec Transport Ministry (MTQ). Major strides were made in the last 10 years in terms of cement concrete pavement since jointed concrete pavements (JPCP) were adopted as standards and players from both MTQ and firms specialized in this area have become more aware of this topic. To further optimize our work methods, in keeping with the funds allocated for the maintenance and rehabilitation of cement concrete pavements, a new pavement type is being considered: the continuously reinforced concrete pavement (CRCP).

The following article shall present the advantages and features specific to CRCP, from design to construction. Two test projects were conducted since 2000 on highways under the aegis of MTQ. The characteristics of these two projects, as well as, pavement performance since opening to traffic shall be presented.

1. INTRODUCTION

Historically, cement concrete pavements built in Québec have not always performed satisfactorily (1). This was mainly linked to the following factors: use of slabs not always suited to our climate, poor design and construction practices, an increase in traffic volume and load, as well as, to a decrease in funds allocated to maintenance.

Since the early 1990s, pavement design specifications have been the object of a major turnabout at the Québec Transport Ministry (MTQ). The structural design and frost protection of all pavements type in accordance with local climatic and traffic conditions, were the targets in this change. Major strides were made in the last 10 years in terms of cement concrete pavement since jointed concrete pavements (JPCP) were adopted as standards and players from both MTQ and firms specialized in this area have become more aware of this topic.

To further optimize our work methods, in keeping with the funds allocated for the maintenance and rehabilitation of cement concrete pavements, a new pavement type is being considered: the continuously reinforced concrete pavement (CRCP). This slab is widely used by certain states in the U.S. and in some European countries. Its main advantage is the absence of a transverse contraction joint (considered as the weak point of JPCP) and main disadvantage is the heftier initial construction cost.

The following paper shall present the advantages and features specific to CRCP, from design to construction. Since 2000, two test projects were conducted on highways under the aegis of MTQ. The characteristics of these two projects, as well as, pavement performance since opening to traffic shall be presented.

2. CONTINUOUSLY REINFORCED CONCRETE PAVEMENT

CRCP is characterized by the presence of a continuous steel reinforcement set into the cement and by the omission of transverse joints other than construction and terminal joints (2). Instead of being concentrated in the contraction joints as is the case with JPCP, volumetric changes (due to temperature and moisture) result in the development of a large number of evenly distributed hairline cracks appearing at random.

The amount of longitudinal reinforcement is determined so as to control cracking and to ensure structural continuity of the pavement. The aim sought is a great number of cracks fine enough to limit the penetration of de-icing salts and to ensure proper aggregate interlock which leads to a higher load transfer efficiency.

One of the main arguments for the use of this type of slab is that it requires little or no maintenance. This represents savings in maintenance costs but also direct savings for users. Initial costs are heftier due to the reinforcement but these costs are similar to those for a conventional pavement after 10 to 15 years according to the World Road Association

(PIARC), or after 15 to 18 years according to Belgian experts. Other favourable factors are a better long-term performance and longevity of pavement smoothness.

The use of CRCP is recommended for urban and rural-area highways, especially where there is high-volume traffic and great number of trucks.

Use of CRCP is widespread in the world, especially in the United States and Europe (3) :

- The United States first used this concrete pavement in 1921. Several road tests were conducted during the 1940s and 1950s. Today, over 50 000 kilometres of highway lanes have been built in CRCP.
- Belgium built its first CRCP section in 1950. This country has made extensive use of this type of concrete pavement since 1970. Several projects were conducted since then to arrive at the current design. It is interesting to note that this country uses CRCP not only on its highways but also on its country roads and national highways. The participants of the 2001 Québec Tour in Belgium had the opportunity to witness first-hand this country's know how in the area of concrete pavement (4).
- France has used CRCP since 1983 and, to date, it has over 600 lane-kilometres, as well as, several rehabilitation projects underway.

3. DESIGN OF CRCP

The two key features in pavement design in a climate like Quebec's are structural design and frost protection (5). With regard to structural design, a distinction should be made between the design of the pavement (slab thickness) and determining the percentage of reinforcement to be place in the pavement.

To determine slab thickness, these two trends have been observed:

- Slab thickness for both the CRCP and the JPCP is the same. The American Association of State Highway and Transportation Officials (AASHTO) uses the same procedure (6) to determine slab thickness for both concrete pavement types.
- Slab thickness of CRCP is smaller than that of JPCP. On this topic, some countries have emphasized the importance of the continuous effect of the CRCP in this case and, in the state of Illinois, this has resulted in a 20% reduction in slab thickness (7).

The AASHTO empirical procedure was used to design various sections of CRCP at MTQ. This procedure is used to calculate slab thickness of the concrete pavement and to verify if percentages meet design specifications.

The objectives of the reinforcement design are to limit surface defects and corrosion. To attain these objectives, the reinforcement percentage must meet three criteria set out in the AASHTO procedure:

- On one hand, crack spacing must be limited to keep incompressible materials out of the cracks and to protect against spalling, yet, on the other hand, it must be wide enough to limit the development of punch-outs (8). Punch-out is a typical deterioration of CRCP (figure 1). When transverse cracks are too close together, cracks perpendicular to the latter develop and, due to traffic stress and to entrapped voids under the slab, pieces of concrete are expelled. The minimum and maximum allowable crack widths recommended in the AASHTO procedure are, respectively, 3.5 feet (1.07 m) and 8 feet (2.44 m). The mean crack width recommended in Belgium is 1 to 1.5 m (9).
- Crack width has a definite impact on the load transfer efficiency and eventual corrosion of the reinforcing steel at the cracks when de-icing salts are used. Openings must therefore be limited. The AASHTO procedure recommends using a maximum crack width of 1 mm. The Belgians favour a maximum allowable crack width from 0.3 to 0.5 mm
- According to the AASHTO, the maximum stress in the steel must correspond to 75% of the ultimate tensile stress.

Generally, the recommended total area of longitudinal reinforcing is of 0.6 to 0.7% of that of the cross-sectional area of the pavement, regardless of steel quality. In wet-freeze climatic regions, the reinforcement percentage is closer to 0.7 or even higher. Since the 1970s, particularly in Belgium, various design practices have led to the implementation of several reinforcement percentages—from 0.85% in the '70s, to 0.67% in the '80s it has remained at 0.76% since 1991.

Transverse reinforcement is used on the entire width of CRCP lanes. Their main purpose is to support the longitudinal reinforcement during construction and to tighten potential longitudinal cracks. The recommended percentage is 0.05 to 0.1% of the concrete section.

4. CONSTRUCTION OF CRCP

Construction of CRCP is similar to that of other concrete pavement types. Planning and execution are crucial since errors made during these stages can be detrimental to the overall success of the project. It is important to pay special attention to certain details such as the selection and installation of the reinforcement, the carrying out of the construction joints, and so forth.

As with any other type of pavement, the base must be finished to ensure a uniform roadbed for the reinforcement supports and construction equipment, as well as, to provide a uniform slab thickness. The base must ensure proper drainage to the slab-base interface and be non-erodable to limit the potential of punch-outs. A permeable base fully satisfies these criteria.

First, the transverse reinforcement bars are manually placed on metal supports by teams of steel fixers. A sufficient amount of supports will prevent any collapsing under a 250-kg load (10). Their design must be in accordance with the concrete cover specifications. Figure 2 shows the laying down of the reinforcement.

Longitudinal reinforcement bars are placed on the transverse ones and then tied to the latter. Generally, it is recommended that longitudinal reinforcement be placed on the upper third section of the slab to limit crack openings. A sufficient amount of concrete cover above the reinforcement is necessary to prevent any corrosion. A minimum spacing of 150 mm between the reinforcement bars is recommended to ensure adequate steel cover. The longitudinal bars may be welded to one another or tied. If tied, the recommended overlap is 25 to 35 bar diameters. The overlaps are usually offset from one lane to the next to ensure they are not all in the same cross section.

The free ends of CRCP are exposed to movements mainly caused by temperature differentials. Systems are installed at each end to restrict the movements from the last 100 metres of the slab. Surveys conducted in certain American states concluded that a wide-flange beam provides a cost-effective method for accommodating end movements. In Belgium, anchors made of fixed beams embedded in the base are used. The use of bridge expansion joints is also acceptable. Figure 3 shows the plan of work and a picture of an anchorage beam.

Concrete placement for the CRCP is similar to that of the conventional pavement. Desirable results are dependent on the following factors: vibrator adjustment to avoid contact with the reinforcement bars and concrete workability to ensure adequate steel cover. Figure 4 shows pavement placement achieved with a slipform paver. Tie-bars should be placed in longitudinal construction joints to keep slab edges together on either side the joint.

Special attention must be paid when forming the transverse construction joints when concrete placement is completed at the end of the day. The Belgians noted incidents of slab blow-ups (9) at construction joint mainly due to the poorer quality of concrete resulting from a delayed or inadequate vibratory compaction on one or both sides of the joint.

The phases subsequent to the placement of CRCP (finishing, texturing, curing, saw cutting of the longitudinal joints and sealing) resemble to that of other slab types.

5. CHARACTERISTICS OF TWO CRCP PROJETS AT MTQ

Since the beginning of the 1990s, cement concrete pavements were constructed with JPCP. In 1999, the *Direction du Laboratoire des chaussées* proposed the construction of a test section in CRCP within the framework of a pavement rehabilitation project for Highway 13 North in Laval. The construction of the pavement was carried out without a hitch.

The project and slab characteristics are as follows:

- The test section in CRCP is 2 km in length within a 9-km project. In this section, one part of the pavement was completely reconstructed and the other only partially reconstructed. The granular base was of a type MG-20 material.

- Slab thickness of CRCP was the same as that of the adjacent JPCP, that is, 270 mm. A ternary cement mixture was used to make the concrete; it was the contractor's choice. The three 3.65-m wide lanes and the 3.25 m-wide left shoulder lane were in CRCP whereas the 3-m right shoulder lane was constructed with a JPCP.
- Steel reinforcement characteristics: percentage of longitudinal reinforcement represents 0.7% of the cross-sectional area of concrete pavement, 20M longitudinal bars with a recommended distance of 160 mm from centreline to centreline with a recommended minimum lap of 700 mm and 15M transverse bars placed at a 30-degree angle in relation to the transversal and spaced 700 mm from centreline to centreline. Reinforcement was composed of black steel. The concrete cover thickness specification was of 90 mm, or, 1/3 of the depth of the slab.
- Anchorage with six reinforced wings and a 200-mm slab were specified in the design. A 1.2-m extension of the slab covering the wings was also in the specifications but only implemented on the northern end. A compression seal approximately 75 mm wide was placed between the end of the CRCP and the first jointed concrete slab.

Since the Highway 13 test project was successful in terms of its construction and performance since it has been in service, the *Direction du Laboratoire des chaussées* has recommended that the project be renewed but, this time, within the framework of a large-scale project. Therefore, this proposal is aimed at evaluating the feasibility of using this concrete pavement type for an entire project considering our climatic conditions, the design changes proposed in relation to that used for Highway 13, as well as, its cost effectiveness. The proposed changes for this second project aimed at a providing a better protection of the steel reinforcements against corrosion.

The *Direction de l'Île-de-Montréal* accepted the contract proposal for the rehabilitation of Highway 40 East between the Highway 520 Interchange and Des Sources Boulevard.

The project and the CRCP characteristics are as follows:

- The project was 9,1 km in length. Certain pavement sections were partially or fully reconstructed. Elsewhere, the old pavement was rubblized and covered with a MG-20 material. The pavement was placed over a 100-mm thick open granular drainage layer stabilized with cement.
- Slab thickness was 275 mm. A ternary cement mixture was specified in the contract. The three driving lanes were constructed in CRCP while both shoulder lanes were built using JPCP. To prevent multiple cracking in the CRCP due to contact with transversal joints of the JPCP shoulder, a saw cutting of the longitudinal joint was made through the entire slab at the joint corner. The use of a compressible insert as specified in the plans was not conclusive.
- Steel reinforcement characteristics: percentage of longitudinal reinforcement represents 0.76% of the cross-sectional area of concrete pavement, 20M longitudinal bars spaced at 145 mm intervals from centreline to centreline and 15M transverse bars placed at a 30-degree angle in relation to the transversals. The reinforcement bars were galvanized for this project. The concrete cover thickness specification of 100 mm was higher than the one used in the Highway 13 project.

- The same system to deal with end movements as the one specified in the Highway 13 project was used. The jointed concrete slab built at each end of the CRCP serve as transition slab. This slab has two layers of reinforcement. A compressive seal with a width of approximately 75-mm was installed as in the Highway 13 project.

6. PERFORMANCE OF THE CRCP

A provincial long-term performance program was implemented at MTQ in 1992. Its main objectives are to improve pavement life and performance as well as to optimize the use of the funds allocated to the construction and maintenance of the road network (11). Our will to improve our practices and the various steps taken to meet the abovementioned objectives are insufficient unless a genuine feedback process such as field visits for data collection on pavement performance is implemented. It is at this stage that our methods must be validated. A result may lead to the rejection, modification or standardization of a new technique.

A pavement performance study started in 2000 and 2003 on the first two CRCP projects carried out by MTQ. Two 150-m long sections per project are being closely monitored. The survey includes:

- Distress mapping on the 150-m sections and general survey of the entire CRCP projects
- Measurements of crack openings and end joints
- Measurements of longitudinal profile (smoothness)
- Measurements of transversal profile (ruts)
- Coring and sampling
- Measurements of deflections on the slab and at joint edges
- Measurements of skid resistance and macrotexture
- Measurements of salt penetration levels in the concrete (Highway 13 only)
- Measurements of steel corrosion potential (Highway 13 only)

To date on Highway 13, at least two series of detailed measures have been carried out: in 2000, just before opening to traffic after reconstruction and in 2002, within a grand tour of all the road test sections in the Greater Montreal Area. On Highway 40, measurements have been conducted in November 2003, just before opening to traffic. Certain monitored parameters such as smoothness and skid resistance were the object of extensive measures on the entire section of the CRCP.

This article will focus on the parameters specific to CRCP such as cracking (rate, spacing and width) and smoothness. Levels of salt penetration in the concrete are measures that can be useful in the evaluation of the efficiency of the concrete to protect reinforcement against corrosion.

6.1 Cracking

Cracking rates were obtained by compiling the crack lengths using mapping measures from test sections. The results shown in figure 5 are expressed in m/m^2. The cracking rates are presented per 150-m section and represent the mean rate of the three lanes and the left shoulder for Highway 13 and of the three lanes for Highway 40.

During the first winter season, that is four months after opening to traffic, the rate of cracking is similar for the four test sections. Afterwards for Highway 13, the progression remains significant yet less markedly so. 30 months after reconstruction, the cracking rates are 0.83 and 0.89 m/m^2 respectively for sections 1 and 2 of Highway 13. These mean cracking rates are similar to the minimum allowable crack width criteria used for the design of the reinforcement of Highway 13 (1.07 m or 3.5 feet). To verify this result in terms of the effective crack spacing on site, calculations were made using the June 2002 mapping measurements. Approximately 9% of the spacings were in the range of 0.2 to 0.6 m, 20% in the 0.5 to 0.8 m range, 60 % in the 0.8 to 3-m range and 8% were over 3 m. A certain proportion of the crack spacing is inferior to design limit values, something that will have to be closely monitored in the months to come. However, to date, the CRCP has not revealed any damage whatsoever.

On Highway 13, three crack-width measurements were made using a so-called comparative method. The crack widths taken between spring (17.5 ^{o}C) and winter (-22.5 ^{o}C) were 0.183, 0.057 and 0.055 mm for a mean of 0.098 mm. Another measurement was taken in June 2003 at a temperature of 37 ^{o}C. There was a 0.1-mm difference with the winter opening measurement, which is far lower than the width specified in the design (1-mm). The 0.1-mm value reported is very similar to that published by the Belgians for temperatures oscillating between -1 ^{o}C and 19 ^{o}C (9).

6.2 Smoothness

A profile survey to evaluate the pavement's smoothness, that is, the irregularity of the longitudinal profile in the wheel paths compared to a perfectly smooth reference surface (12). The index used by MTQ to rate the smoothness is the IRI (International Roughness Index). For a paved surface, the scale ranges from 0 to 12, 0 being a perfectly smooth surface. Note that a surface rated 1.2 is the allowable limit indicated in the specifications, and anything beyond that may bring about a penalty. On Highway 40, grinding was forbidden for values up to 1.8 so this was not the case for Highway 13.

Figure 6 shows the mean IRI values in the three lanes for the entire sector in CRCP for Highway 13 (2 km) and for a JPCP section (1.5 km) immediately adjacent to the CRCP section. The mean values for the entire three lanes of Highway 40 are also presented on the same figure. Immediately after reconstruction of Highway 13, the IRI values of two of the three lanes with JPCP are higher than those of CRCP. Three years later, there is little change in the smoothness of the CRCP whereas there is a 0.2 increase in the values of the JPCP. For Highway 40, we observed a slight increase in the first winter.

6.3 Salt Penetration in the Concrete

The salt penetration measures are presented here, despite the fact that this parameter is normally associated with the type of materials used to make the concrete pavement and not with the type of concrete pavement itself. Using a concrete mix, which slows down steel corrosion, is beneficial to the performance of the CRCP.

From the time ternary cement were first incorporated in the concrete pavement, measures of the rate of salt penetration were taken by MTQ's *Service des Matériaux d'infrastructure* on various sections of the concrete highways, including on the CRCP of Highway 13. Figure 7 shows a table with the total chloride percentages found in the concrete for 5 tests conducted at different places and dates and at depths ranging from 0 to 100 mm. The percentage of salt was measured on Highway 13 built with CRCP containing ternary cement (at three different periods), on Highway 15 in Montréal (eight years old) and Highway 440 in Laval (eight years old), the latter two were built with conventional cement.

Results show that the percentage of salt in the concrete is negligible in the 50 to 75 mm depth range and this, even with older pavements built in conventional cement. Despite the young age of CRCP composed of ternary cement, small salt concentrations ranging from 0.05 to 0.17% were found at a maximum depth of 25 mm. The presence of ternary cement should have a positive impact on the long term by slowing down the salt penetration, especially if this concrete has had time to reach its strength before the first application of de-icing salts in the fall.

6.4 Summary

Generally, CRCP has performed satisfactorily in terms of the parameters mentioned above and of the other parameters used to evaluate pavement performance. Despite the fact that a certain number of cracks measured were inferior to the minimum allowable spacing design specifications, no apparent damages or signs that could lead us to believe that problems such as punch-outs will develop on the long term were noted. The tightness of the cracks and low rate of salt penetration in the concrete are reassuring signs especially since a rapid corrosion of the reinforcement had been predicted initially. The necessity of using a supplementary protection on the reinforcement such as galvanization is doubtful considering the preliminary results obtained. This is one of the reasons why (including de costs) black steel has been specified for the CRCP projects in 2004.

7. CONCLUSION

There are numerous advantages to using CRCP instead of JPCP such as a better long-term performance, little or no maintenance to be carried out over time and durability of pavement smoothness. These advantages must be considered when choosing a type of concrete pavement especially in cases where there are high-volume roadways but no money for maintenance. In addition, several road administrations have demonstrated their long-term cost effectiveness despite their heftier initial cost. Road tests conducted by several American states and Belgium have been conclusive and have shown the level of success that can be obtained by choosing this type of pavement.

Few variations were noted in the time required for the construction and execution of the works compared to that for JPCP for either test projects conducted at MTQ since 2000. Furthermore, the results of the pavement condition survey on Highway 13 for the first four years lead us to believe that pavement performance is satisfactory for the time being, that is, that no innate (linked to construction) or premature damage has resulted. The changes brought to certain design parameters for Highway 40 led to a greater confidence on the part of the personnel managing the implementation of CRCPs.

The implementation of a wide-scope project such as the one for Highway 40 was aimed at evaluating the operational and economical feasibility of the works in an urban setting. In that aspect, a preliminary analysis of the overall costs on the life cycle has been conducted to compare both options and the net present value of CRCP is about 5% lower than the one for JPCP over a 50 year analysis period. Despite that it’s not conventional in Québec, the use of the CRCP may eventually be considered when the Departmental Policy on Pavement Type Selection undertakes his revision (13).

REFERENCES:

(1) Thébeau, D. (2002) *Les chaussées en béton à Transports Québec*, Progrès dans le domaine du béton, ACI, Hull, Québec.

(2) Permanent International Association of Road Congresses PIARC (1994) *Continuously Reinforced Concrete Pavements,* no 07.06B.

(3) Federal Highway Administration, Tech (1992*) Report on the 1992 U.S. Tour of European Concrete Highways*, USA.

(4) Transports Québec (2003) Rapport : *Mission technique sur les chaussées en béton* – 9 au 13 juin 2002, Québec, Canada.

(5) Transports Québec (1994) *Normes – Ouvrages routiers – Construction routière Tome II*, Québec, Canada.

(6) American Association of States Highway Transportation Officials (1993) *AASHTO Guide for Design of Pavement Structures*, Washington, USA.

(7) Concrete Reinforcing Steel Institute CRSI (2001) *Summary of CRCP Design and Construction – Practice in the U.S.* Illinois, USA.

(8) Centre de recherches routières belge (1997) *Le problème du « punch-out »*, Bruxelles, Belgique.

(9) Centre national de recherches scientifiques et techniques pour l'industrie cimentière (1992*) Le comportement du béton armé continu*, Bruxelles, Belgique.

(10) Ministère Wallon de l'Équipement et des Transports (1999) *Cahier des charges type RW*, Belgique.

(11) Transports Québec (1995) *Guide pour évaluer la performance des chaussées*, Québec, Canada.

(12) Transports Québec (2003) *Rigid Pavement Maintenance and Rehabilitation Guide*, Québec, Canada.

(13) Transports Québec (2001) *Departmental Policy on Pavement Type Selection*, Québec, Canada.

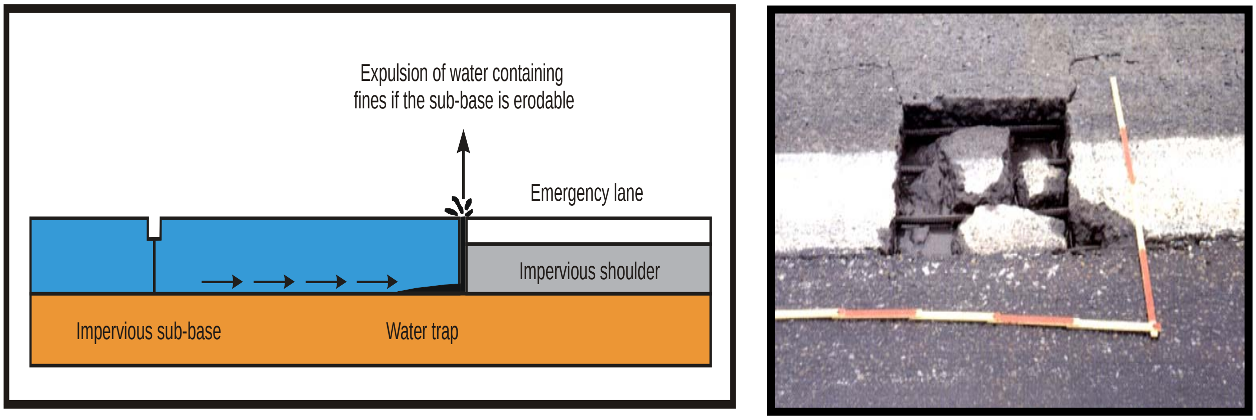

Figure 1 – Punch-out

Figure 2 – Placement of the transversal and longitudinal reinforcement

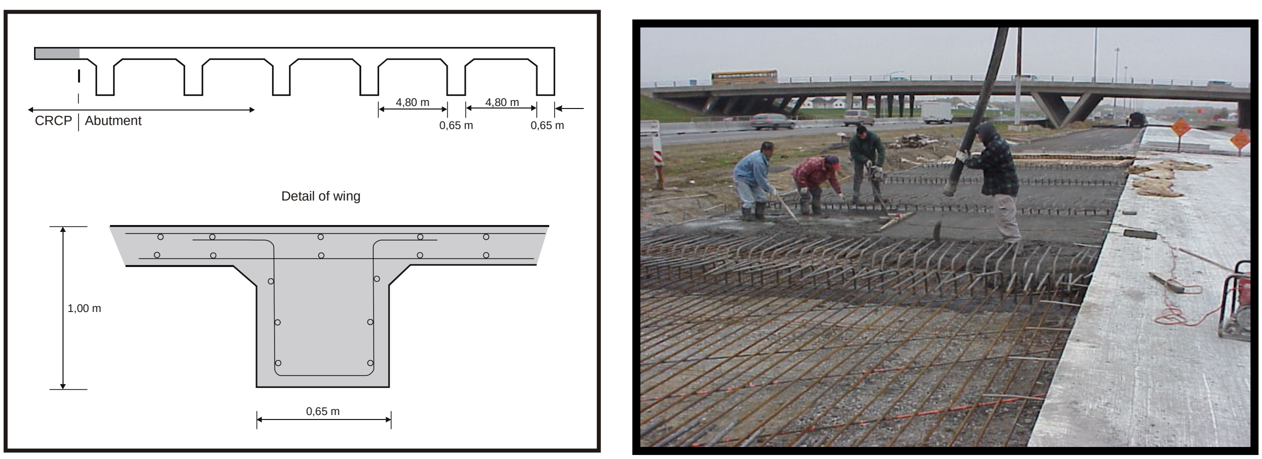

Figure 3 – Anchorage beams – Plan of work

Figure 4 – Construction of CRCP

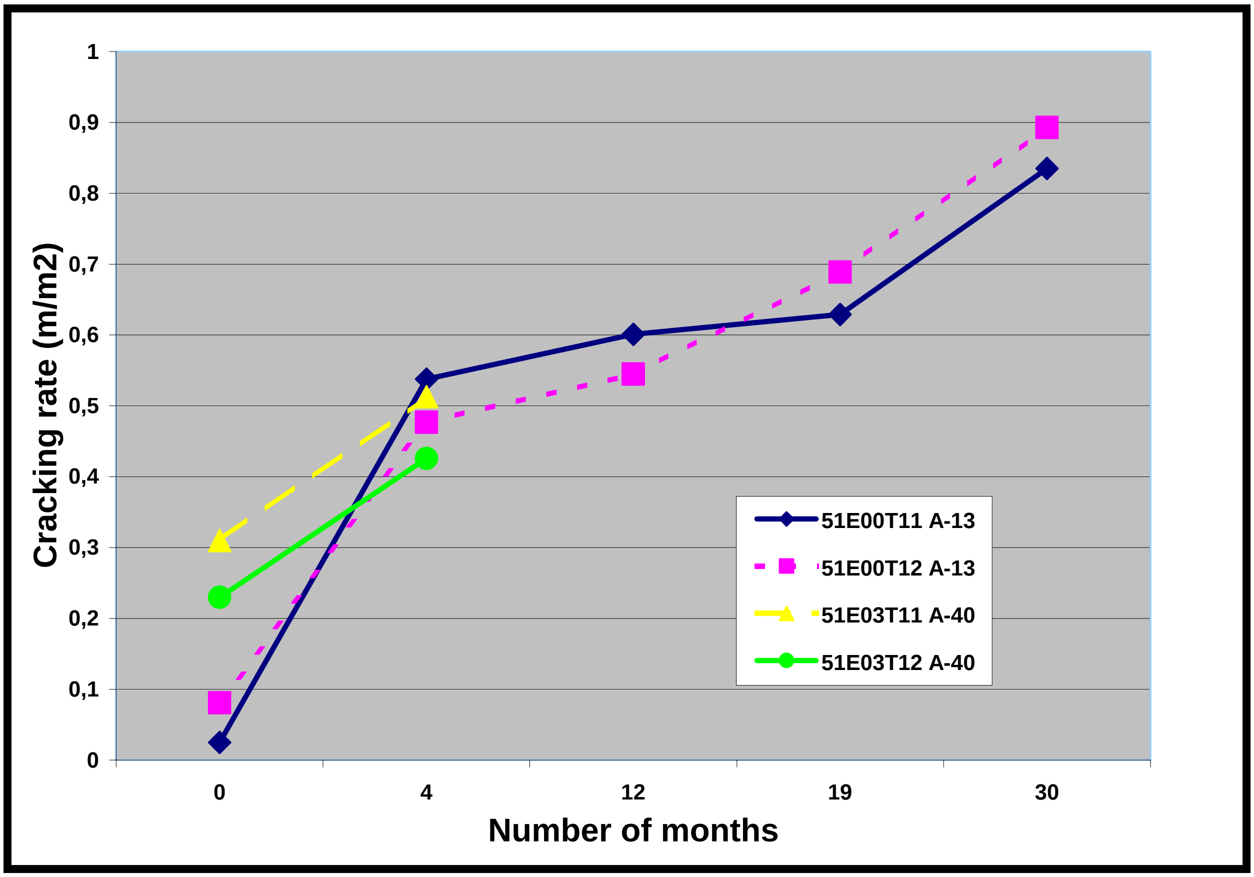

Figure 5 – Evolution of the cracking rate from 0 to 30 months

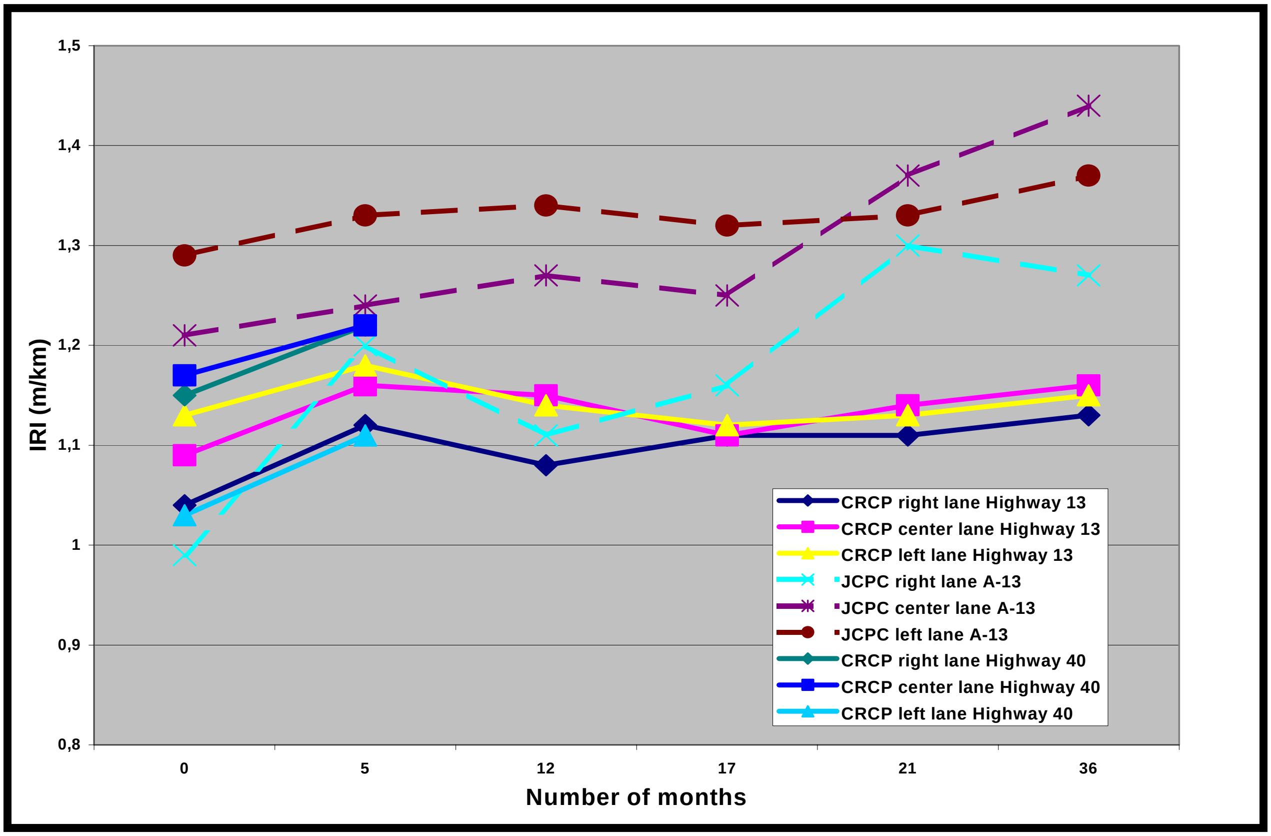

Figure 6 – Evolution of the smoothness of CRCP and JPCP from 0 to 36 months

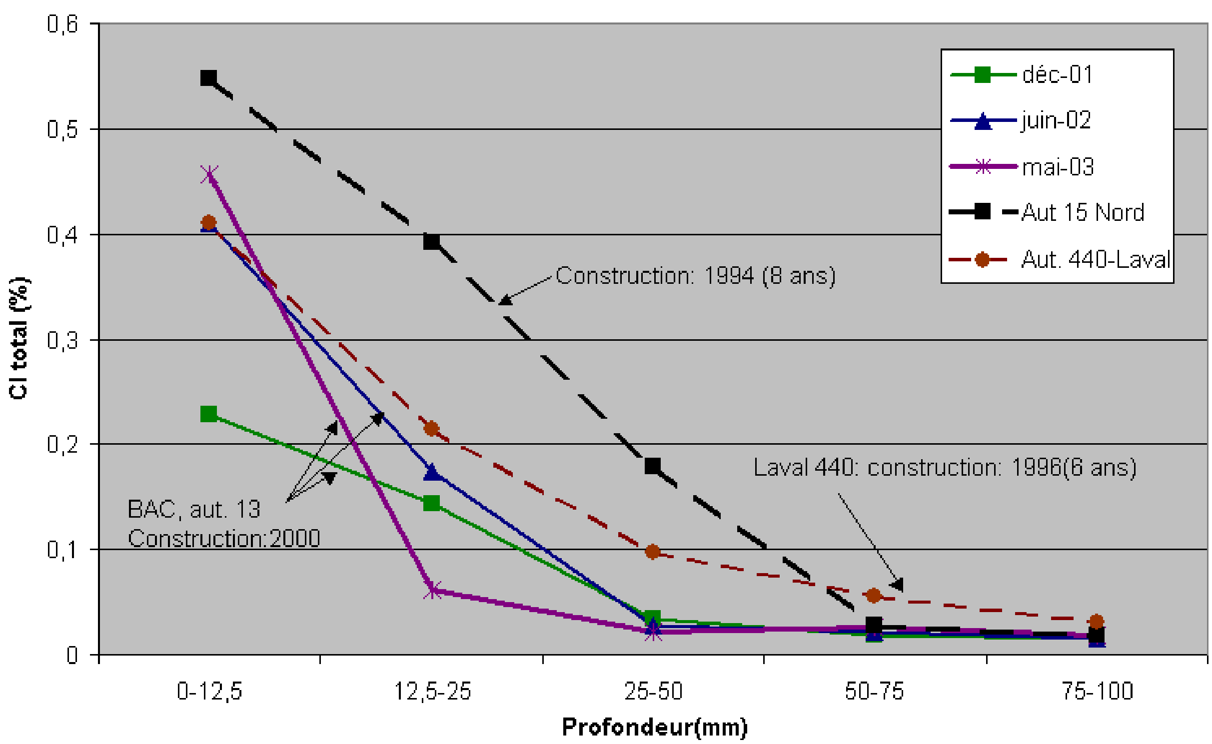

Figure 7 – Salt penetration rates for Highway 13 concrete (ternary cement), Highway 15 and Highway 440