ABSTRACT

Since the early 1990s, the design of every type of pavement has been impacted by a major turnaround in Québec Transport Ministry (MTQ) standards. The main focus of this turnaround has been the structural design and the frost protection of every type of pavement, taking into account local climate and traffic conditions. Jointed plain concrete pavement (JPCP) was adopted as the standard at that time.

In an effort to further optimize our work methods, and in keeping with the funds allocated for the maintenance and rehabilitation of cement concrete pavements, a new type of pavement is being considered: continuously reinforced concrete pavement (CRCP). This type of concrete pavement is widely used by several states in the USA and in some European countries. The main advantage of CRCP is the absence of transverse contraction joints (considered to be the weak point of JPCP); and the main disadvantage is the higher initial construction cost.

The first section of highway using CRCP in Canada was built in 2000 in the Province of Québec. At that time, project engineers and experts attempted to adapt the design of this type of concrete pavement from other countries to the severe wet-freeze climate in Québec. In 2002, a Technical Tour was organized to Belgium for technology transfer, with the primary purpose of developing our expertise in CRCP. Despite the fact that the performance of CRCP was unknown in a climate like ours, mainly in terms of corrosion of the steel, MTQ pavement managers were attracted by the absence of maintenance over time. Since 2000, nearly 40 kilometres of CRCP have been constructed in Québec.

This paper presents the steps that were followed in order to adapt the design and construction of this new concrete pavement, taking into account our severe wet-freeze climate. The pavement performance of various sections will be described. Finally, some unresolved issues and potential solutions will be discussed.

KEY WORDS

CONCRETE PAVEMENT/CONTINUOUSLY REINFORCED CONCRETE PAVEMENT/CRCP/QUÉBEC/CORROSION/CRACKING.

1. INTRODUCTION

Located in the northeastern part of North America, Québec is Canada’s largest province, covering 1.7 million km². That’s three times the size of France, seven times the size of the United Kingdom, and 50 times the size of Belgium. The climate in southern Québec has a temperature range of 50° to 60°C. The mercury can dip down as low as -20°C in winter, and can reach as high as 30°C in summer. In winter, the ground freezes to a depth of 1.2 to 3.0 m. The harsh, snowy winter (average snowfall of more than three metres in Québec City) is followed by an invigorating and uplifting spring, and then by a hot summer, culminating in the flamboyance of autumn. Central Québec receives approximately 900 mm of rain each year.
The first cement concrete pavements that were built in Québec date back to the 1920s. Since that time, this technology has continued to be used for road construction, but it has not always performed as expected (Thébeau, 2002). Several dominant factors have contributed to this situation: the types of slabs used were not always entirely suitable for our environmental conditions; design and construction problems; the increase in traffic volume and load; and cutbacks in the funding allocated for maintenance.

Since the early 1990s, the design of every type of pavement has been impacted by a major turnaround in MTQ standards. The main focus of this turnaround has been the structural design and the frost protection of every type of pavement, taking into account local climate and traffic conditions. The standard remains jointed plain concrete pavement (JPCP).

However, in an effort to optimize our work methods, and in keeping with the funds allocated for the maintenance and rehabilitation of cement concrete pavements, a new type of pavement is being considered: continuously reinforced concrete pavement (CRCP). One of the main arguments for selecting this type of pavement is the lack of transverse contraction joints that require regular maintenance, as in the case with JPCP. The initial cost is expected to be higher because of the steel reinforcement, but according to the World Road Association (PIARC, 1994), the cost balances after 10 to 15 years if we compare to a conventional concrete pavement. Other advantages include superior long-term performance and the longevity of surface roughness.

This article describes the process that was followed by the MTQ in order to adapt this type of pavement to conditions in Québec. It details our pavement choices in terms of design, construction, and performance assessment, and closes with a discussion of some unresolved issues and potential solutions.

2. CRCP ADAPTED TO CONDITIONS IN QUÉBEC

As mentioned, the climate in Québec is among the harshest in North America. The choice of CRCP was easy to justify in light of all of the advantages cited by other countries, but the major challenge was its long-term behaviour when subjected to Québec weather. The biggest question for the CRCP designer was the effect of corrosion of the longitudinal steel when subjected to large quantities of destructive agents such as de-icing salt and water.

2.1 Selection of Design Criteria for a Specific CRCP Project

Since the mid-1990s, a number of proposals have been submitted to territorial project managers to consider using CRCP to rehabilitate sections of pavement. In order to determine the design and construction techniques for this type of pavement, various references were consulted from the most knowledgeable countries in this matter, namely the United States and Belgium. In addition, the AASHTO empirical formula was used to design the CRCP test section, because this is the MTQ’s standard method for designing pavement. This technique makes it possible to calculate the thickness of the concrete slab, and to determine whether the chosen percentage of steel meets the design standards.

There are currently two trends in calculating slab thickness:

- Use of the same thickness of concrete for CRCP and JPCP;
- Use of a decreased thickness for CRCP than for JPCP. Some countries consider that the effect of pavement continuity is important in this case, and the Illinois DOT has determined that the thickness can be reduced by as much as 20% (CRSI, 2001).

Accurate calculation of the longitudinal reinforcement makes it possible to prevent the occurrence of defects in the pavement surface at cracks, and to limit steel corrosion. According to the AASHTO procedure, the chosen percentage of steel must satisfy three criteria:
**Crack spacing:** On one hand, crack spacing must not be so great as to keep non-compressible materials out of the cracks and prevent spalling; and on the other hand, it must not be too small, because this can lead to the development of punch-outs (CRRB, 1997). The minimum and maximum spacings recommended by the AASHTO procedure are 3.5 feet (1.07 m) and 8 feet (2.44 m) respectively. The ideal average distance between cracks recommended in Belgium is between 1.0 m and 1.5 m (CNRST, 1992);

- Crack width has a determining effect on load transfer efficiency and the eventual corrosion of the reinforcing steel at the cracks when de-icing salts are used, and therefore, crack width must be limited. The AASHTO guide generally recommends a maximum crack width of 1.0 mm. However, 0.3 mm to 0.5 mm is preferred in Belgium;

- The maximum stress on the steel should be 75% of the ultimate tensile stress.

Regardless of the quality of the steel, the recommended percentage of reinforcement generally ranges from 0.6% to 0.7% of the cross-section of pavement. In wet-freeze climates, the percentage of steel is closer to 0.7%, or even higher. In Belgium, various designs since the 1970s have led to the use of different percentages of steel, decreasing from 0.85% in the 1970s to 0.67% in the 1980s, and settling at 0.76% since 1991.

### 2.2 First Test Section of CRCP on a Canadian Highway

Since the early 1990s, cement concrete pavements have been built using JPCP. In 1999, the MTQ’s Central Pavement Department proposed the construction of a test section of CRCP while rehabilitating northbound Highway 13 in Laval. No noteworthy problems were encountered during construction.

The characteristics of the project and the pavement were as follows:

- The CRCP test section spanned 2.0 km of a 9.1-km project. Part of the road in this area was completely reconstructed, while the remainder partially reconstructed. The granular base was a 0-20 mm material;

- The thickness of the CRCP section was the same as that of the adjacent JPCP section: 270 mm. The concrete was made using ternary cement, which was the choice of the contractor. The three 3.65-m wide lanes and the 3.25-m wide left shoulder were constructed using CRCP, while the 3.0-m right shoulder constructed using JPCP;

- The steel reinforcement characteristics were as follows: a cross-section of steel representing 0.7% of the concrete, 20M longitudinal bars, spaced 160 mm centre-to-centre with at least 700 mm overlap, and 15M bars crosswise at a 30° angle to the transverse line, spaced 700 mm centre-to-centre. Black steel was used for the reinforcement, and the specified concrete cover was 90 mm, or one-third the thickness of the slab.

### 2.3 Québec Cement Concrete Pavement Tour to Belgium

A Technical Tour (MTQ, 2003) on cement concrete pavement went to Belgium in 2002, two years after the test section was completed. This Tour included designers, project managers, and contractors, and gave us direct access to Belgian imposing knowledge and experience in this field.

Visits to pavements that had been in use for up to 30 years and a demonstration of CRCP construction gave us a better understanding of how this type of pavement works and how it should be built, which led us to align certain specifications with Belgian standards for future projects in Québec. The main standards that we adopted were as follows:

- Based on our visit to Belgium, and taking into account weather conditions in Québec, which are substantially different, the maximum crack width had to be reduced in order to limit deterioration at the surface as well as water and brine seepage. The percentage of steel could then approach the 0.76% used in Belgium;

- The Belgians use 100 mm of concrete cover, which provides more protection than the h/3 formula that is recommended by AASHTO for thicknesses under 300 mm;
In order to ensure minimum spacing between the longitudinal reinforcement bars (>150 mm) and to avoid installing two layers of steel, the possibility of using an open graded drainage layer (OGDL) base under the CRCP in order to reduce slab thickness must be assessed;

Quality must be emphasized in the construction of the transverse joints, in order to avoid air pockets under the row of reinforcement. The Belgians reported numerous punch-outs due to this construction defect.

3. TOWARD MAJOR CRCP PROJECTS

The experiment with Highway 13 has been a success in terms of construction and performance ever since the section reopened to traffic, and given the positive effect of the Tour to Belgium in 2002, the MTQ was interested to undertake one or more larger projects. In order for this to happen, both the central and the territorial divisions must be convinced that there are definite advantages in continuing to use this technology.

3.1 Why Opting for CRCP According to the Central Pavement Department?

The main purpose of the test section in 2000 was to determine whether CRCP was technically feasible, and to assess short-term winter performance. The first phase was an outright success, and therefore, the central pavement department proposed the evaluation of three factors in a second phase: the feasibility of using this type of pavement for a complete project under conditions in Québec; the proposed modifications to the structural design specification in comparison to the Highway 13 project; and determining typical costs in order to undertake a life-cycle cost analysis (LCCA).

The proposed modifications for the second project involved increased protection of the reinforcement against corrosion by specifying galvanized steel, increasing the percentage of steel to 0.76% (thereby reducing crack width), and increasing the concrete cover of the steel to 100 mm.

3.2 Why Opting for CRCP from the Perspective of Territorial Departments?

At the present time, two territorial departments in the Greater Montréal Area have used CRCP in major highway projects.

The Montréal Island territorial department took an interest in CRCP because of its numerous advantages, and also because it was well-suited to major reconstruction of the concrete pavement on Highway 40. This section of Highway 40 was built in 1963, and the construction technique that was used back then involved jointed reinforced 60-foot-long slabs (JRCP), which has produced poor results mainly near the transverse joints. It was also crucial to reduce maintenance work in this area over the long term because of the very heavy traffic, which ranges from 77,000 to 132,000 vehicles per day, with trucks accounting for approximately 12% of this figure. In addition, there is currently no budget planned for maintenance. Other potential advantages that the territorial department saw in using CRCP instead of JPCP were the slight reduction in noise from a similar surface finish due to the absence of transverse joints, and the improved performance of asphalt pavement resurfacing.

Following the first major CRCP project in 2003, a probabilistic LCCA was carried out at the request of the Montréal Island territorial department in order to compare the various options. A comparison of the net present values over the 50-year study period tipped the scales in favour of CRCP using conventional black steel by nearly 5% as compared to the standard JPCP option.

For the Highway 10 project near the Champlain Bridge on Montréal’s South Shore, the Est-de-la Montérégie territorial department opted for CRCP for essentially the same reasons cited in the Highway 40 project. The main one was that this section of highway is a strategic location, where traffic disruptions must be reduced to a minimum because the bridge to the Island of Montréal is already at its capacity.
4. FIRST EXPERIENCES WITH CRCP

Five rehabilitation projects were carried out in the Montréal area using CRCP between 2003 and 2005, and a sixth is planned for 2006. This section summarizes how the projects unfolded, the problems that were encountered, and the solutions that were adopted in order to improve the technique in light of typical conditions in Québec.

4.1 Description of CRCP Projects

Most of the CRCP projects were carried out on Highway 40 in Montréal. Given the heavy traffic in this area, the impact on road users during the work had to be minimized, and the contractor was given eight months to do the job (before the onset of winter). Multiple construction phases (up to four) were also planned for each project. When the time came for construction, the MTQ opted for complete closure in one direction in order to optimize CRCP construction in the other direction.

The Highway 40 and Highway 10 projects shared the following characteristics:

- The pavement was partially or completely reconstructed in certain areas. In other areas, the old JRCP were rubblized and covered with a 0-20 mm material to insure a 1-m thick frost protection. The CRCP was laid over a cement stabilized OGDL of 100-mm thick. It has been noted that CRCP construction takes longer than JPCP construction because of the extra step of installing the OGDL when used;
- The specifications called for ternary cement in the concrete. However, the compression resistance gain of ternary cement is slower, and therefore, its use is limited to before September 30 due to the onset of the cold season and the greater risk of scaling if de-icing salts must be used immediately after reopening, or in other words, in late autumn or early winter.
- The three traffic lanes were constructed using CRCP, and both shoulders were constructed using JPCP (paved separately);
- Type 20M steel was used for the longitudinal bars, and type 15M was used for the transverse bars, which were laid at a 30° angle to the transverse line, and spaced approximately 700 mm apart;
- Anchorage with six reinforced lugs was specified for each end (except for the 2006 project where four lugs are planned). A preformed sealant of approximately 75-mm wide was installed at the end of the CRCP.

Table 1 presents the characteristics of all CRCP projects that have been completed since 2000 and is planned in 2006. It also reflects the MTQ’s approach in modifying the specifications over time, primarily with a view to protecting the steel bars from corrosion. These changes followed the construction of the test section in 2000 and the Tour to Belgium in 2002. There was a brief experiment with galvanized steel in 2003, as well as an increase in the percentage of steel from 0.70% to almost 0.76%. The concrete cover of the bars was also increased, from 90 mm (h/3) in 2000 to 110 mm in 2006.
### Actual or Anticipated Problems and Solutions Adopted

Several problems have been encountered with the projects since 2000, primarily during CRCP construction. Solutions were found or proposed based on acquired knowledge or the experiences of other countries:

- Cracking in the first JPCP slab at one end of the CRCP in 2000. A short slab reinforced with a double row of bars is built since then at each end of the CRCP in order to serve as a transition slab;
- Sympathetic cracking. In 2000, a concentration of multiple cracks was found in the CRCP at the JPCP shoulder joints. These cracks were very close to the edge of the slab. In order to minimize this effect, a compressible board was installed in the longitudinal joint between the lane and the shoulder to buffer the transfer of stress, but this solution led to new problems. At present, a saw cut is carried out down to the full thickness of the slab at the longitudinal joint (300 mm on either side of the JPCP transverse joint);
- Longitudinal cracking of the CRCP in 2004: 134 linear metres of longitudinal cracks were found in a 330 m² section of CRCP, up to 200 mm deep in the slab. Most of the cracks were in wheel paths. The cause remains unknown. For areas of large cracking concentration, the reconstruction of the slab has been carried out; in the other cases, the cracks have been sealed with epoxy. Standard specifications now prohibit the presence of longitudinal cracks;
- Insufficient concrete cover of the longitudinal steel. During core inspection of thickness in the 2005 project, the project manager found, unexpectedly, that the concrete cover of the reinforcement was insufficient: as little as 65 mm, whereas the specifications called for 100 mm. There are two possible reasons for this: the metal supports for the transverse bars were too high, or the slipform machine raised them slightly during its pass, by approximately 10 to 15 mm. A cover of 110 mm ±15 mm on the longitudinal reinforcement will be specified for the 2006 contract, along with galvanized steel. If the contractor fails to meet the specification for the cover, the CRCP section will have to be rebuilt at the contractor’s expense;
- Transverse construction joints. Until now, most of the problems encountered since reopening to traffic involve the transverse construction joints. The 2003 CRCP project has “Y” shape cracks and faulting at some of these joints. This situation has been associated with a lack of concrete vibration caused by the difficulty of access below the 20M longitudinal bars, which were doubled at the joints. Some of the concrete vibration must be carried out manually in order to

<table>
<thead>
<tr>
<th>Site</th>
<th>Year of construction</th>
<th>Slab thickness (mm)</th>
<th>Type of steel</th>
<th>Percentage and spacing (mm) of longitudinal steel</th>
<th>Concrete cover of the longitudinal bars (mm)</th>
<th>Maximum crack width (mm)</th>
<th>Crack spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound Highway 13, Laval</td>
<td>2000</td>
<td>275</td>
<td>Black</td>
<td>0.70 160</td>
<td>h/3 = 90</td>
<td>1</td>
<td>1.07 to 2.40</td>
</tr>
<tr>
<td>Eastbound Highway 40, Montréal</td>
<td>2003</td>
<td>275</td>
<td>Galvanized</td>
<td>0.76 145</td>
<td>100</td>
<td>0.5</td>
<td>1.00 to 2.01</td>
</tr>
<tr>
<td>Westbound Highway 40, Montréal</td>
<td>2004</td>
<td>270</td>
<td>Black</td>
<td>0.76 146</td>
<td>100</td>
<td>0.5</td>
<td>1.00 to 2.01</td>
</tr>
<tr>
<td>Westbound Highway 40, Montréal</td>
<td>2005</td>
<td>270</td>
<td>Black</td>
<td>0.76 146</td>
<td>100</td>
<td>0.64</td>
<td>0.98 to 2.44</td>
</tr>
<tr>
<td>Highway 10, Brossard – both directions</td>
<td>2005</td>
<td>250</td>
<td>Black</td>
<td>0.74 155</td>
<td>100</td>
<td>0.64</td>
<td>0.98 to 2.44</td>
</tr>
<tr>
<td>Eastbound Highway 40, Montréal</td>
<td>2006 (planned)</td>
<td>280</td>
<td>Galvanized</td>
<td>0.74 135</td>
<td>110 ±15</td>
<td>0.64</td>
<td>0.98 to 2.44</td>
</tr>
</tbody>
</table>
eliminate air pockets. Furthermore, the specifications call now for metal forms and for sawing the concrete atop the reinforcement, which should result in a better surface finish at the transverse construction joints;

- CRCP interruption in one of the traffic lanes. Due to budget limitations, construction of one of the four lanes of Highway 10 had to be curtailed, and an individual anchorage was built. The performance of the CRCP at this spot will be monitored;
- Number of lugs in an anchorage. In 2000, the original anchorage design called for six beams. In an effort to optimize the design, the number was reduced to four. The State of Illinois (Illinois DOT, 1977) has reported that all of the different anchorage combinations (number of lugs and spacing) have proven satisfactory, and has adopted three beams as its standard;
- Insulating leave-outs with a moist layer of sand. In order to limit the movement of the ends of the CRCP when a pour is interrupted (in order to maintain the flow of traffic), an extra layer of sand 0.5 metres thick will be used along a 50 metre stretch in the 2006 contract. This decision stems from the publication of an article (Diependaele M. et al, 2005) concerning the rehabilitation of a highway near Antwerp in Belgium. This preventive measure was taken in view of the possible wide fluctuations in temperature during the period in which the work is scheduled.

5. CRCP PERFORMANCE SINCE 2000

A pavement performance monitoring program was launched by the MTQ in 1992, similar to the American Strategic Highway Research Program (SHRP). The main goals of this program are to improve pavement performance and lifespan, and to optimize the resources allocated for road construction and maintenance (MTQ, 1995). The desire to improve our practices and the various efforts made are not sufficient to attain these goals without receiving feedback in the form of field observations of pavement behaviour, among other things. This is the stage of the process at which we validate the way we do things. These results can lead to the abandonment, modification, or standardization of a new technique.

Performance monitoring was carried out on the MTQ’s first two CRCP projects in 2000 and 2003. Two 150-metre long stretches in each project were monitored in great detail by means of the following general and detailed surveys:

- Distress mapping of the 150-m sections and general visual surveys of the entire CRCP stretch;
- Crack width and end joint measurements;
- Longitudinal profile measurements (IRI);
- Transverse profile (rut) measurements;
- Coring and sampling;
- Deflection measurements on the slab and at the end joints;
- Skid resistance and macrotexture measurements;
- Measurements of salt penetration into the concrete;
- Measurement of steel corrosion potential.

In this article, we will focus on describing some of the characteristics of the CRCP, such as crack spacing/rate, and width, as well as the typical deterioration that we have seen to date. We will look at the difference in the IRI between the CRCP and the JPCP on Highway 13. Finally, we will examine the corrosion potential of the CRCP reinforcing steel.

5.1 Crack Spacing

Cracking rates were obtained by compiling crack lengths based on mapping and crack spacing surveys in the test sections. The results shown in Figure 1 are expressed in m/m². The cracking rates are shown for each 150-m section, based on the mean rate of all lanes.
The cracking rate increases sharply in all four sections between the time of construction and the first winter, rising to values between 0.43 and 0.54 m/m². The increase continues steadily after that, but at a slower rate. It appears to be levelling off as of Year 4 on Highway 13. The cracking rate on one section of Highway 13 has reached 1.22 m/m² after 4.6 years (55 months).

For example: given a regular spacing, we would obtain a value of 0.82 m between cracks, which is below the design minimum of 1.07 m (3.5 feet). In order to confirm this figure in terms of actual crack spacing on the road, the calculation was based on the crack spacing survey that was carried out in June 2005, the results of which appear in Table 2.

<table>
<thead>
<tr>
<th>Site</th>
<th>0 to 0.50 m</th>
<th>0.50 to 0.80 m</th>
<th>0.80 to 1.07 m</th>
<th>1.07 to 2.44 m</th>
<th>2.44 m or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway 13 Laval</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Section 1</td>
<td>36</td>
<td>27</td>
<td>13</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Section 2</td>
<td>30</td>
<td>27</td>
<td>12</td>
<td>27</td>
<td>4</td>
</tr>
</tbody>
</table>

The actual results confirm that a very high percentage (69 and 76%) is actually below the design threshold (1.07 m), which will entail close monitoring in the months ahead. However, it is important to point out that the surveys do not reflect pavement deterioration since the highway was reopened to traffic.

It is probably too early to comment on the behaviour of the sections of Highway 40 where the steel rate had been increased by 0.06%. For the moment, the rates of cracking are slightly lower than for Highway 13.
5.2 Crack Width

Crack width was measured on Highway 13 using what is known as a comparative method. The width values were 0.183, 0.057, and 0.055 mm between spring (17.5°C) and winter (-22.5°C), for an average of 0.098 mm. Another measurement was taken in June 2003, at a temperature of 37°C. The difference in width from winter was still approximately 0.1 mm, which is far below the design value of 1.0 mm, and practically the same as the figure reported by the Belgians for temperatures between -1°C and 19°C (MWET, 1999).

5.3 Other Distresses

Many surveys have been carried out involving all of the CRCP projects since the highways reopened to traffic, both in summer and in winter. The purpose of these surveys is to detect distresses other than transverse cracks.

There is no major deterioration in the two-kilometre section of Highway 13, apart from slight spalling (MTQ Distress Manual, 2003) in the longitudinal joints and two potholes that probably resulted from the intrusion of a clod when the concrete was made. In fact, most of the deterioration in this section is found in the JPCP next to the CRCP at one end. For example, a major transverse crack (Figure 2, left photo) is found in the first JPCP slabs beyond the north end of the CRCP, along with medium severity spalling (Figure 2, right photo) in the corners of the slabs, and two transversally cracked slabs on the right shoulder. It is also important to note that the two transverse construction joints have been found to be in perfect condition so far.

The CRCP project on Highway 40 covers 9.2 km. Some rather narrow shrinkage cracks have been found, as shown in the left photo in Figure 3. However, the main deterioration seen in the December 2005 survey is associated with the transverse construction joints. In comparison with Highway 13, the number of joints is much higher: there are 20 transverse construction joints in the right and centre lanes (which were built at the same time), and 8 in the left lane. 35% of the construction joints in the two right lanes have already been repaired with concrete since construction, or are in need of repair in the near future (worst case in the right photo in Figure 3). All of the joints in the left lane are in good condition. The poor performance of the construction joints has not been investigated, but as explained in section 4 above, it is very likely that the lack of concrete vibration at the end of one pour or at the start of the next is the cause of the problem. As with Highway 13, many small cracks were found in the JPCP slabs on the right shoulder.
5.4 Comparison of the Change in Roughness between CRCP and JPCP

The profilometer survey makes it possible to assess pavement roughness, or in other words, the irregularity of the longitudinal profile in wheel paths compared to a perfectly flat reference surface (MTQ Rehabilitation Guide, 2003). The MTQ uses the international roughness index (IRI) to qualify unevenness of the pavement. The scale for a paved surface ranges from 0 to 12, where 0 indicates perfectly smooth. By way of information, 1.2 m/km is the level of acceptance in specifications for a new pavement, and higher values are penalized.
Figure 4 shows the mean IRI values for the three lanes in the entire CRCP section of Highway 13 (2.0 km) and a directly adjacent JPCP section (1.5 km). When Highway 13 reopened to traffic, the IRI values of two of the three JPCP lanes were slightly higher than the value of the CRCP lanes. After five years, the IRI increased by a maximum of 0.1 m/km in the CRCP (right lane), compared to 0.35 m/km in the same JPCP lane, which is obviously higher.

5.5 Corrosion Potential of CRCP Reinforcing Steel

Following the problem of longitudinal steel being too close to the surface that was encountered during CRCP construction in 2005, various studies and research into the literature were carried out in an attempt to predict whether steel corrosion would have a major impact on CRCP performance. This issue is the main source of concern in terms of the performance of this type of pavement in Québec.

Given our extreme winter conditions, large quantities of de-icing salt are used on our roads. They are even higher than on flexible pavements because of the transverse tining currently used on concrete pavements. Data from a maintenance unit in Montréal indicates that we spread up to 65 tons of salt per year on a 1-km two-lane stretch in Montréal. By way of comparison, this represents about three times the amount of salt that Illinois DOT uses on its roads.

Following our visit to Belgium, we obtained a study (Verheoven, 1992) that was carried out after extracting 92 core samples from various CRCP sections that were between 10 and 25 years old. The sections of highway selected were the most heavily trafficked in Belgium, and had been exposed to considerable amounts of salt. The concrete cover of the steel ranged from 58 to 150 mm, while the reinforcement rate varied between 0.67% and 0.85%. Moderate to heavy corrosion was only found in 11% of the core samples, which is remarkable. However, the amount of salt spread on those roads is unknown so it makes it different to compare with our conditions.

Even though Belgium found almost no corrosion, even on old pavement, their winter maintenance conditions are scarcely comparable to ours. In order to determine the extent of corrosion in our climate, core samples were taken of the CRCP at the cracks in the left shoulder of Highway 13 in December 2005. The onset of corrosion was detected after only five years, as shown in Figure 5. In addition, measurements of corrosion potential in five core samples indicate active steel corrosion, but the steel that is away from the crack remains in perfect condition.

Figure 5 – Steel corrosion at a crack on Highway 13

Another question remains, whether the corrosion propagates longitudinally along the steel bar in an area where the salt has not yet reached the critical threshold.
The influence of cracking perpendicular to the steel on chloride penetration and corrosion is discussed by Maltais, 2005. In order for the salt to penetrate the crack faster than the cement matrix, the minimum crack width must be greater than 60 µm. When the width exceeds 200 µm, chloride diffusion in the cracks is as fast as in a free solution. The design standard for crack width on Highway 13 in 2000 was 1 mm (0.70% steel), compared to 0.64 mm for Highway 40 in 2006 (0.74% of steel). These values are much greater than the 0.2 mm that was mentioned earlier.

In short, the current crack width (0.64 mm) that is used to calculate the amount of steel in designing the CRCP is much greater than the minimum value for free chloride diffusion in the cracks (0.2 mm) mentioned above. In the other hand, the percentage of crack-spacing under the design threshold observed in the sections where performance was monitored is important (Table 2), resulting in short spacing between two cracks, which means that adjacent cracks should not widen as anticipated in the design.

Ever since ternary cement was first used in concrete pavements in Québec, salt penetration has been measured by the MTQ’s Central Pavement Department on various sections of road, including the CRCP on Highway 13. The findings (Thébeau, 2004) indicate that, even in the oldest pavements built using conventional cement (8 years old), the percentage of salt in the concrete is negligible at depths ranging from 50 mm to 75 mm. Despite the young age of the CRCP made using ternary cement, low concentrations of salt content were found, ranging from 0.05% to 0.17% at a maximum depth of 25 mm.

Other measures of ions chlorides content were taken on the cores sampled on Highway 13 in December 2005. First, the chloride soluble contents (CL-) measured far from the crack are lower than the threshold of 0.05% (limit adopted for the initiation of corrosion) between 50 and 75 mm of the surface of the pavement; the concrete cover currently specified for steels is thus acceptable for the moment. Secondly, other measures were taken to evaluate the transverse progression of chlorides starting from a crack and they show that CL- do not exceed 15 mm in the concrete.

The results of measuring chloride penetration into the concrete are described here even though this value is a function of the type of materials used to make the slab rather than of the type of slab itself. We expect the concrete made with ternary cement to have a positive long-term effect in slowing salt penetration, especially if the concrete has had the time to attain the acceptable resistance before the first de-icing salt is spread in the fall.

5. FUTURE OUTLOOK

The future experiments and research are obviously directed towards finding a solution for the anticipated problems of the first Canadian CRCP projects mainly the effects of corrosion of steel bars on the long term pavement performance. It is foreseen to continue the monitoring of CRCP sections and to try to explain behaviour of CRCP in harsh climate like that of Quebec.

In the mean time, MTQ is in the process of drafting standard specifications for CRCP that will include design criteria. These specifications will be made available to MTQ project managers, and will make it possible to standardize the design criteria. They will also include drawings of the anchorage and the approach slab, methods of repairing CRCP slabs, transverse construction joints, expansion joints, and transitions between the CRCP and existing slab.

Given the current uncertainty surrounding the development of corrosion in CRCP slabs, and in light of the problems that were encountered with Highway 40 in 2005, the use of galvanized steel in CRCP slabs is recommended until we have a clearer understanding of this matter. Considering that measure undertaken to protect steels against corrosion, the CRCP must nevertheless remained cost effective and profitable economically in the long run. The last LCCA carried out for the construction of a new concrete pavement in the south of Montréal shows that the net present value of CRCP with galvanized steel is approximately 11% higher than that of a JPCP over the 50-
year study period. However, LCCA must be regarded as a decision-making aid for the pavement projects, thus a criterion among so much of others.

In an effort to find the most durable solution without incurring a sharp rise in costs, it has been suggested the use of glass fibre reinforced polymer (GFRP) composite reinforcement bars in the CRCP, and eventually replace all the steel bars with GFRP bars. This material is produced in Québec and the supplier estimated that the cost of the bars in GFRP is similar with the galvanized steel bars. Also, the MTQ has a great knowledge for this material since it has been used in the bridges for several years.

As a first step, a research project has been proposed to MTQ’s Research Department in December 2005. The main objective of this study is to determine the effect of reinforcement ratio, bar diameter, thickness of the pavement, induced cracks, and number of reinforced mats on the performance of CRCP reinforced with GFRP reinforcing bars and to characterize the crack development in CRCP through a combined experimental and numerical simulation approach. This research project involves building a section that is approximately 300-metre-long and the width of one lane in order to study various aspects of designing a CRCP with GFRP bars. It is probable that it will be included in the 2006 CRCP project on Highway 40, which would also make it possible to compare the performance of the conventional slab with the GFRP-reinforced slab. Monitoring of pavement performance will be done also.

6. CONCLUSION

It is obvious that Quebec is distinguished for the harshness of its winter which implies a special freezing design of the roadways, a particular winter maintenance which requires large quantities of salts and a restricted period favourable for road work less than 8 months. Also, MTQ is a relatively new comer in the design and construction of CRCP. Since few of other countries whose environmental conditions are as extreme as those of Canada do not use this kind of concrete pavement, MTQ had to follow a process to adapt the design of CRCP to the environment. This process was described in this article.

For the territorial departments, CRCP has several advantages over JPCP, including superior long-term performance, the virtually complete absence of maintenance over time, and the longevity of surface roughness. These advantages warrant consideration when choosing the type of slab to use, especially for sections of road that bear extremely heavy traffic and for which no funding is allocated for maintenance.

In the oldest projects that were carried out by the MTQ since 2000, the results of monitoring indicate that the pavement performance is living up to expectations at present, which means that no major inherent (construction-related) or premature distress has occurred. However, the five years of Highway 13 represent a short period in the lifespan anticipated for the CRCP and the long-term behaviour especially remains unknown relating to the effect of the corrosion of steels. Certain measures were already taken to improve protection of steels like the increase in the concrete cover and the galvanization of steels. MTQ will also launch a unique research project in 2006 by replacing steel bars by GRFP bars in a trafficked concrete test sections. This is another step forward to find a solution to our main concern about CRCP.

Despite every technical criterion, it is essential before all that the type of pavement is economic in long-term and that it answers the various criteria suitable for each territorial direction with an ultimate aim to ensure the best service the roadway users.

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