Performance of Precast Concrete Pavement Repairs on an Urban Freeway in Toronto

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ABSTRACT

In 2004, the Ministry of Transportation Ontario (MTO) carried out a demonstration project to evaluate use of precast concrete pavement repairs in existing concrete pavement. The trial was carried out on Highway 427, a major urban freeway in Toronto. The project included demonstrations of three precast concrete pavement full-depth repair methods: the Fort Miller Super-Slab™ Intermittent Method, the Fort Miller Super-Slab™ Continuous Method, and the Michigan Method. Each method involves designing and fabricating precast concrete pavement slabs to replace deteriorated concrete pavement. The methods differ in how the base is prepared and how the precast slab is installed and dowelled into the existing concrete. Based on MTO experiences with the trial, a specification was developed and additional precast work was carried out in 2007 - 2009. These repairs were the first construction experience in Canada with innovative precast concrete slab repairs for concrete pavements. MTO has been monitoring the field performance of the precast slabs and assessing the cost effectiveness of this alternative to full-depth fast-track concrete repairs. This paper discusses the methodologies, site conditions, contract specifications, construction, and post-construction monitoring results.

1. INTRODUCTION

Heavy traffic volumes on major urban freeways in Ontario mean that repairs must be carried out in a 6 hour, overnight lane closure. When the existing pavement is concrete, this means using fast-track concrete mixes – mixes that reach 20MPa in 4 hours through use of accelerating admixtures. Ontario experience with fast-track concrete mixes is problematic; mixes are temperamental, with questionable long term durability. As such, the Ministry of Transportation Ontario (MTO) decided to evaluate precast concrete pavement repairs. The advantages of precast slab repairs were thought to be better control over concrete quality, better curing conditions, minimal weather restrictions on placement, and reduced delay prior to opening to traffic.

In November 2004, MTO carried out a trial of three precast concrete pavement repair methods to replace deteriorating concrete pavement on Highway 427, a major urban freeway running north-south through the City of Toronto. The three methods evaluated were: the Fort Miller Intermittent and Fort Miller Continuous Super-Slab™ Methods, originating from the Fort Miller Co., Schuylerville, New York; and the Michigan Method, originating from Michigan State University, Lansing, Michigan.

Since construction of the precast trials in 2004, the Ministry has carried out periodic field reviews to assess performance of the slabs. In addition two new contracts on Highway 427 were awarded and constructed in 2007-2009 with quantities of both fast track and precast concrete repairs.

This paper outlines the precast concrete slab designs, the site conditions, contract specifications, construction, short- term performance of the 2004 precast slab repairs, and finally the results of contract placement on the two projects carried out in 2007-2009.

2. EXISTING PAVEMENT

Highway 427 is a 12-lane core-collector divided freeway, originally constructed from 1968-71. The existing pavement structure consists of approximately 230 mm of jointed plain concrete pavement (JPCP) over 150 mm of cement treated base (CTB). Skewed transverse joints, spaced at intervals of 3.7 m, 4.0 m, 5.5 m and 5.8 m, are dowelled with 32 mm dowel bars spaced every 300 mm across the joint. The pavement lanes are 3.65 m wide with hot mix asphalt shoulders. Drainage is provided through subdrains and an urban cross-section of curb and gutter. This concrete pavement had not been rehabilitated since original construction.

Pre-rehabilitation, the Pavement Condition Index (PCI) on Highway 427 ranged from 46 to 58 out of 100, indicating that the pavement was in fair to poor condition. Major distresses included severe to very severe joint-stepping (50-80%), severe joint failures (10-20%), severe joint and crack spalling (10-20%), severe to very severe cracking (20-50%), and severe to very severe joint sealant loss (20-50%). Since construction, maintenance activities have included some full depth and partial depth emergency concrete pavement repairs, asphalt pavement repairs, and diamond grinding to restore pavement friction and improve ride.

Traffic is heavy, with an Annual Average Daily Traffic (AADT) of approximately 365,000 (two directions), and 8% commercial vehicles. Due to the heavy traffic volumes, the Ministry's Traffic Section requires repairs to the freeway to be carried out during overnight lane closures, typically 11:00 pm to 5:00 am. Repairs to the highway have been typically fast-track concrete repairs or in an emergency, hot mix repairs.

3. METHODOLOGY

The Ministry decided to evaluate three different precast concrete pavement repair methods: the Michigan Method, the Fort Miller Super-Slab™ Intermittent Method, and the Fort Miller Super-Slab™ Continuous Method. Repair locations were all in the northbound express, lane 3 (truck lane). The Contract specified three individual full depth precast concrete slab repairs, each 2 m x 3.65 m x 230 mm, to be carried out using the Fort Miller Intermittent Method and the Michigan Method. At a third location, a 25 m x 3.65 m x 230 mm trial section of the Fort Miller Continuous Method was also carried out.

These three precast methods all involve fabricating precast concrete pavement slabs to replace sections of deteriorated concrete pavement. The existing damaged concrete is sawcut to the correct dimensions and removed to allow replacement using a precast slab. The methods differ in how the underlying base course is prepared and how the precast slabs are installed and dowelled into the adjacent concrete.

3.1 Michigan Method

In the Michigan Method, 2 m by approximately 3.65 m (lane width) concrete slabs were fabricated off-site with three dowel bars per wheel path cast into the slabs at 300 mm spacing (Figure 1).

Figure 1. Precasting Michigan Method slabs, 3 dowel bars per wheel path

On the contract, the Contractor used a template to delineate the areas to be removed and replaced. Sawcutting was carried out the night prior to placement. The outer limits of the concrete removal area were sawcut full depth and the specification required that sawcuts not extend by more than 250 mm into the adjacent concrete. Dual cuts were made for ease of removal. Removal of the existing concrete was carried out using a backhoe. The Contractor first removed the double sawcut sections with a small hoe. The removal of this small section allowed a large grappling bucket to lift the existing concrete out. The Contractor also removed a 100 mm wedge of the adjacent hot mix shoulder to facilitate the removal. This area was later repaired with cold mix.

Dowel bar slots were also sawcut the previous night. Triple cuts were made at each dowel bar location, providing for three dowel bars in each wheel path. These were over-cut significantly (Figure 2a). Contract documents specified that hand held chipping hammers be used to excavate the slots, to reduce damage to the adjacent concrete. Unfortunately, heavier jack-hammers were used, resulting in spalling and cracking around the dowel slots (Figure 2b). The dowel bar slots were rapidly excavated using jackhammers. Since removal of the dowel slots was not a controlling operation, more time should have been taken to carefully excavate the slots with chipping hammers and more thoroughly clean out the slots. Dowel bar slots were blown out with compressed air but it was still possible to remove dried slurry from the slots, which may have had a detrimental effect on bonding.

Excavation of the dowel bar slots was not carried out with a desirable level of care. After placement, it was observed that dowel bars were not centered in the dowel slots and were sometimes resting against the walls or base of the dowel slots, meaning it would be difficult to get full encasement with grout. Some of the dowel bar slots were spalled down to the CTB and there were also cracks extending from some dowel slot removal areas into the existing concrete. It was clear that the Michigan Method requires good workmanship to ensure that the dowel bars slots are carefully excavated without damaging the existing concrete.

 

Figure 2 a) Sawcutting and b) Excavation of Dowel Bar Slots for Michigan Method

The precast design concept does not require excavation of the underlying cement treated base (CTB). Once the concrete pavement is removed, a leveling course is placed directly on the undisturbed CTB prior to placing the precast slab. This concept only works if the precast slabs are cast thinner than the existing concrete. On this trial project, the precast slabs were cast to the exact dimensions 2 m x 3.65 m x 230 mm. Coring later revealed that the existing concrete pavement, which had been diamond ground the previous year, ranged in thickness from 200 – 230 mm. It became evident that the CTB would need to be partially excavated to allow for placement of the leveling material and the precast slab. The Contractor used a large backhoe with a welded plate to scrape the CTB to the required depth (Figure 3).

Figure 3. Use of backhoe to partially excavate cement treated base.

The Michigan Method uses a flowable fill as a leveling material over the existing base (Figure 4). The flowable fill consisting of a mixture of Portland cement, fine aggregate, fly ash, water, and air entraining admixture (optional). The compressive strength requirements of the flowable fill mixture were not less than 0.35 MPa at 3 days, nor less than 0.50 MPa and not exceeding 1.0 MPa at 28 days. The flowable fill was meant to be self-leveling when placed. The mix that arrived on site was fairly viscous. It was entirely a sand mix and required approximately 2 hours to set. The flowable fill was placed in the excavation, raked evenly into all areas, then screeded off to a depth of 230 mm using a full lane width leveling screed that ran along the longitudinal joint between lane 2 and 3, and the paved shoulder. A few passes of the leveling screed allowed the Contractor to achieve a smooth and even surface on the flowable fill.

Figure 4. Use of flowable fill as a levelling material.

The Michigan slabs were lowered by crane onto the flowable fill with the 12 cast-in dowel bars fitting into the sawcut slots. The first slab was placed slightly high. The contractor attempted to drive heavy equipment over the slab to settle it deeper in the flowable fill, but the slab was set. All three Michigan Method slabs were placed between 10:00 pm and 3:00 am. The second slab was the best of the three slabs, being flush with the existing concrete pavement. The other two slabs sat slightly higher than the existing concrete. These slabs should have been diamond ground to meet surface tolerances.

The grout (HD-50) was mixed on site and poured manually into the dowel slots from the small mixing unit. The grout was thin and watery, no vibration was used, and there was no curing compound, plastic or blankets. The grout required 3 hours to set, which meant that the first slab achieved the required 3 hours curing time but the next two slabs did not because of the 5:00 am opening to traffic. The Contractor was required to cast grout cubes and complete testing before opening to traffic. Strength test results were 21 MPa in 3 hours.

Figure 5. Completed Michigan Method slab repair

3.2 Fort Miller Method Intermittent Method

In the Fort Miller Intermittent Method, 3 individual 2 m x 3.65 m (lane width) concrete slabs were fabricated off-site with block-outs cast into the slabs to accommodate four dowel bars in the wheel paths (Figure 6).

Figure 6. Four block-outs per wheel path are cast into the Fort Miller intermittent slabs.

Concrete removal was carried out in the same manner as the Michigan Method. The Contractor used a template to delineate the areas to be removed and the outer limits of the concrete removal area were sawcut full depth the night before each repair, with dual cuts made for ease of removal. The Contractor first removed the double sawcut sections with a small hoe, then used a large grappling bucket to lift the existing concrete out. The CTB was then partially excavated to allow for placement of the leveling material and the precast slab.

The Fort Miller Method uses crusher screenings for leveling material beneath the precast slabs. The crusher screenings were placed, then screeded with the Contractor's full lane width leveling screed (Figure 7a). A plate-packer was used to compact the fine aggregate base (Figure 7b).

In the Fort Miller Intermittent Method, dowel bars are drilled into the existing concrete. The precast slabs have block-outs to allow the slabs to be placed over the protruding dowel bars. A gang-drill consisting of four independently powered pneumatic drills was used to drill four dowel bars per wheel path. The location of the dowel bars was accurately marked with a template. The dowel bar slots were blown out and epoxy adhesive was used to secure the bars (Figure 7c).

A crane was used to lower the precast slabs in place (Figure 7d). The first two slabs matched flush with the existing concrete pavement. The third precast slab was placed low. The slab was lifted out and screenings added, however because the dowel bars were installed, the leveling float and plate packer could not be used. The third slab was eventually levelled and met flush.

The dowel bars were grouted through ports in the precast slab. Grouting of the dowel bars was carried out with a manually operated grout pump. The grouting operation was slow. It was decided not to grout the third slab, due to problems with a clogged grout hose. The grouting was carried out the next night. Bedding grout was injected the following night through ports in the concrete slab.

a) b) c) d)

Figure 7. Construction sequence for Fort Miller Intermittent precast slab installation: a) using full lane width leveling screed to fine grade crusher screenings, b) compacting crusher screenings using plate packer, c) dowel bars installed, ready to place precast slab, d) lowering precast slab.

3.3 Fort Miller Method Continuous Method

In the Fort Miller Continuous Method, dowel bars and block-outs were cast alternately into a set of six 4 m long by approximately 3.65 m (lane width) concrete slabs, which fit together like puzzle pieces (Figure 8 a & b). Following sawcut and removal of a continuous 25 m long section of deteriorated concrete pavement, the underlying CTB was partially excavated with a backhoe, then crusher screenings were placed on the existing base, precision graded and compacted (Figure 8 c & d). The first slab and last slab placed were dowelled into the existing pavement at each end of the excavation (Figure 8 e & f). All slabs in the continuous repair were tied into the adjacent lane with drilled and epoxied tie bars. Once the slabs were set, the dowel bars and tie bars were grouted through ports in the precast concrete slabs using an automatic grout pump, to connect the slabs to the existing pavement and to each other (Figure 8 g). Finally, bedding grout was injected through interconnected ports and channels in the bottom of the slabs to fill voids beneath the concrete (Figure 8h).

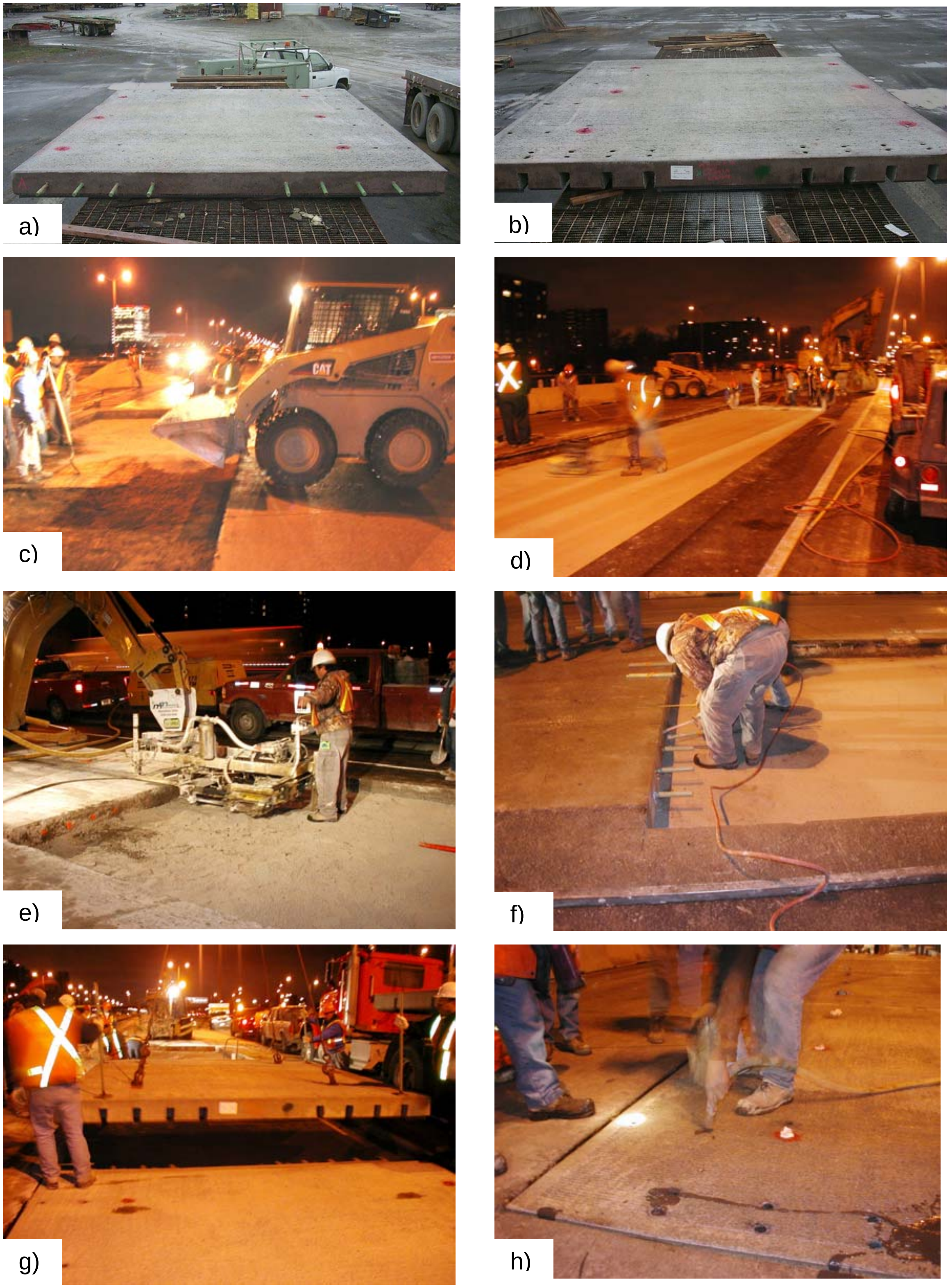

Figure 8. Construction sequence for Fort Miller Continuous precast slab installation.

4. OBSERVATIONS

The overall assessment was that the installation of the precast trials went well. The work was carried out within the required time lines and the slab placement was efficient. Surface tolerances were not met and diamond grinding would have improved the ride. However, the precast repairs were similar in ride to fast-track repairs along the same section of highway.

Workmanship issues were identified, including over-cutting, cracking and spalling of the surrounding concrete pavement. However, the work was undertaken by a Contractor carrying out precast repairs for the first time and under difficult conditions, including night work in cold, wet weather with a 6-hour work window. The following recommendations would improve construction practices:

- The specification for this work allowed over-cuts into the existing concrete of up to 250 mm for both the perimeter cuts and the dowel bars slots (Michigan Method). This over-zealous sawcutting and poor workmanship resulted in damage to the existing concrete. Over cuts should not be permitted.

- When chipping out the dowel bar slots for the Michigan Method, spalling and cracking occurred. The contract specified the use of light-weight chipping hammers, but jack-hammers were used. Since the dowel bar slots are crucial to performance of the slabs, more time should have been taken to carefully excavate the slots with chipping hammers and thoroughly clean the slots.

- Gang saws, like those used for dowel bar retrofit, are recommended for sawing dowel bar slots in the Michigan Method. A template is also required to mark out the dowel bar slots to ensure that dowel bars fit and are centered in dowel bar slots.

- Excavations for existing concrete removal were typically larger than the precast slabs, resulting in a 25 mm gap around the slabs. Tighter tolerances on size of the removal area are needed.

- The base preparation method used a manual screed, which was not accurate enough to place the slabs to meet surface tolerances. Precision grading is recommended.

- Existing concrete varied in thickness throughout the Contract. The actual thickness of concrete pavement at each location may need to be verified prior to precasting each repair. Alternately, the precast slabs could be cast thinner than the existing concrete pavement to accommodate fine grading material beneath the slab. It would be advantageous to avoid excavating the base to accommodate the precast slab.

5. MONITORING

Field reviews were carried out in June 2005, May 2006 and September 2007 and October 2009 to observe the performance of the three precast trials.

5.1 Michigan Method

Initially, the Michigan Method slabs were found to be in excellent condition (Figure 9), however progressive deterioration was observed in some areas of the grouted dowel bars slots, likely the result of damage to older, existing concrete during sawcutting and removal of dowel slots.

Figure 9. Michigan Method precast slab, June 2005.

a) b) c)

Figure 10. Michigan Method Slab 2 a) after construction in November 2004 b) June 2005 at one-year field review c) May 2006 in second year field review.

Dowel slots showed some cracking and spalling and in some instances the dowel bars were exposed. Figure 10 a,b,c shows a crack, which appeared during construction near a dowel bar slot in slab 2. By June 2005, the crack had progressed to block cracking in the dowel slot, with spalling of the dowel slot observed in May 2006.

It is likely that cracking and spalling at the dowel bar slots is the direct result of the removal method, which included over-cutting the slots and jack-hammering to remove concrete from the slots. The Ministry is confident that an improved method of excavating the slots, such as use of gang-saws, light-weight chipping hammers and sand-blasting to clean the slots will improve performance of the Michigan Method.

a)

b)

Figure 11 a) September 2008, some Michigan Method slabs are failing at the dowel bar slots b) October 2009, one of the Michigan slabs shows no deterioration after 5 years.

5.2 Fort Miller Intermittent Method

The Fort Miller Intermittent Method slabs are performing very well. In the June 2005 field review no defects were observed in any of the intermittent slabs. In the May 2006 field review, the only distress that could be detected was very slight cracking at a few locations over the dowel bars (Figure 12 a & b, below).

a)

b)

Figure 12 a & b) May 2006 observed slight cracking over dowel bars Fort Miller Intermittent slab.

It is likely that the very slight cracking at a few dowel bar locations in the Fort Miller Intermittent slab repairs was caused by non-uniform support beneath the slab. In the cracked areas, the slabs may be resting on the dowel bars due to poor base excavation and levelling practices during construction.

a) b)

Figure 13 a) September 2007 and b) November 2009, Fort Miller Intermittent slabs performing well.

5.3 Fort Miller Continuous Method

The Fort Miller Continuous Method slabs are also performing very well (Figure 14). No cracking or spalling was observed in any of the six continuous slabs during the June 2005 and May 2006 field reviews. In September 2007 hairline cracking was observed of the dowel bar locations (Figure 15) and in November 2009 very slight transverse cracking was noted in one of the slabs.

Figure 14. Performance of Fort Miller Continuous Slab repairs, May 2006.

Figure 15. Performance of Fort Miller Continuous Slab repairs, September 2007.

6.0 ADDITIONAL WORK

As a result of these trials, MTO carried out two additional precast contracts, also on Highway 427 in 2009: Contract A, with 1336 m2 of precast repairs and Contract B, with 1699 m2 of precast repairs. On these contracts, the Ministry had the opportunity to implement lessons learned from the trial projects of 2004.

These contracts elected to use the Fort Miller Intermittent and Fort Miller Continuous methods. The most significant change to construction practice was introduction of precision grading equipment rather than using a manual screed to grade the crushed screenings prior to setting the slabs (Figure 16).

Figure 16. Precision grading equipment implemented on two contracts in 2009.

Dowel bars were installed at 300 mm intervals across the full transverse joint, rather than only in the wheel path, as was the practice in 2004. This was meant to provide load transfer across the full width of joint. Continuous slabs were dowelled together, but were not tied into the adjacent lane as was done in 2004. This was meant to allow the continuous slabs to work together, but independent to the adjacent lanes, hopefully reducing the risk of cracking over the dowel bars.

Despite improvements to construction practices, some workmanship issues were still encountered. Overcutting of the slabs created gaps between the adjacent slabs. Imprecise sawcutting meant that sometimes the slabs didn't fit. Spalling to the adjacent slabs occurred during cutting and removal of the old slabs and during placement of repair slabs. An important lesson was learned when it was decided that the slabs need not be grouted immediately and up to a week passed before they were grouted – many of these slabs settled, cracked and spalled.

The contractor agreed that more care was needed in the sawcutting and removals, since the specification required that any damaged slabs be removed and replaced at no additional cost to the owner. Grouting was carried out the next night if possible to prevent the slabs from moving, rocking, cracking, spalling. These changes improved the quality of the work.

Under the latest Highway 427 contract, the concrete pavement was overlaid with hot mix asphalt, as a result it is no longer possible to monitor performance of these precast slabs.

7. CONCLUSIONS

The November 2004 trial was the first construction experience in Canada with innovative precast concrete slab technology for repairs to concrete pavements. The overall assessment of the Ministry is that installation of the precast trials went well. The work was carried out within the required timeframes. The precast slabs did not crack, spall or rock. The only issues identified were workmanship issues, understandable for a contractor carrying out the work for the first time, and ride. The precast repairs were similar in ride quality to fast-track repairs along the same section of highway.

The success of the November 2004 trial led to further work being carried out and implementation of improvements to the construction practices, including use of precision grading equipment. MTO continues to pursue the use of precast concrete pavement repairs as an alternative to fast track repairs on high volume freeways.

8. REFERENCES

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