

Use of Innovative Pre-Cast Concrete Slab Repair Technology in Canada

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Abstract

In 2004, the Ministry of Transportation Ontario (MTO) carried out a trial project to evaluate construction techniques for pre-cast concrete slab repairs in concrete pavement. The trial was carried out on Highway 427, a heavily trafficked freeway in Toronto, Canada. The trial project required demonstrations of three pre-cast 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 pre-cast concrete slabs to replace deteriorated concrete pavement. The methods differ in how the base is prepared and how the pre-cast slab is installed and dowelled to the existing concrete pavement. Non-destructive testing using a Falling Weight Deflectometer (FWD) was undertaken after construction to assess load transfer efficiency (LTE) and to detect loss of support underneath the pre-cast slab. Details of the methodologies, site conditions, contract specifications, construction and FWD analysis are presented. This is the first construction experience in Canada with innovative pre-cast concrete slab repairs for concrete pavements. MTO will continue to monitor the field performance of these technologies and assess the cost effectiveness of this alternative to full-depth fast-track concrete repairs.

Introduction

In November 2004, the Ministry of Transportation Ontario (MTO) carried out a trial of three pre-cast concrete pavement repair methods on Highway 427, a major urban freeway running north-south through the city of Toronto (Figure 1).

Heavy traffic volumes on Highway 427 dictate that repairs to the roadway are carried out overnight, typically with a fast-track concrete repair. Because fast-track concrete mixes are problematic and their long term durability questionable, the Ministry decided to carry out a trial to evaluate pre-cast concrete repairs.

The advantages of pre-cast repairs are thought to be better quality concrete, better curing conditions, minimal weather restrictions on placement, and reduced delay prior to opening to traffic.

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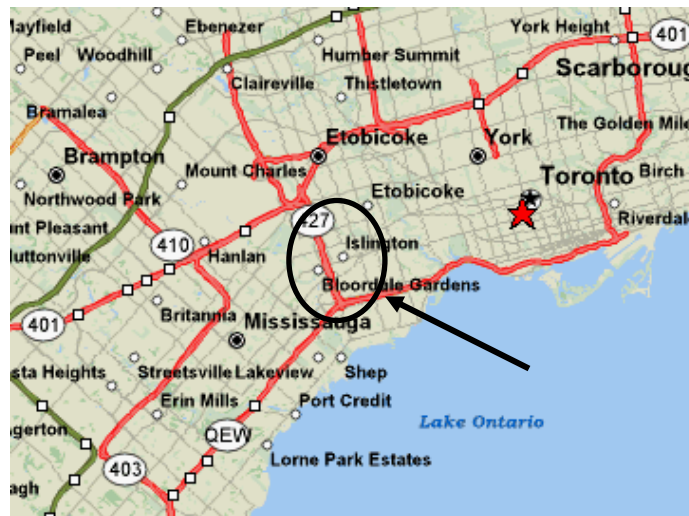


Figure 1. Location of Highway 427, west end of the city of Toronto, Ontario.

The three methods evaluated were: the Fort Miller Super-SlabTM Intermittent Method and Fort Miller Super-SlabTM Continuous Method, originating from the Fort Miller Co., Schuylerville, New York; and the Michigan Method, originating from the Michigan Department of Transportation (DOT), Lansing, Michigan. The three pre-cast methods all involve designing and fabricating pre-cast concrete slabs to replace sections of deteriorated concrete pavement. The methods differ in how the base is prepared and how the pre-cast slabs are installed and dowelled to the adjacent concrete slabs.

Construction of the three pre-cast trials was carried out in November 2004. Following construction, non-destructive testing using a Falling Weight Deflectometer (FWD) was undertaken to assess load transfer efficiency (LTE) and to detect any possible loss of support underneath the pre-cast slab.

This paper outlines the three pre-cast concrete slab design methods, the site conditions, contract specifications, construction, the results of FWD analysis, and performance to date.

Background

Pavement History. Highway 427 is a 12-lane core-collector divided freeway, originally constructed between 1968-71. The pavement has not received significant rehabilitation since its original construction. The existing pavement structure consists of approximately 230 mm of jointed plain concrete (JPC) pavement over 150 mm of cement treated base (CTB). Skewed transverse joints are spaced at intervals of 3.7 m, 4.0 m, 5.5 m and 5.8 m. The transverse joints 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 ranging in width from 2.7 m to 3.0 m. Drainage is provided through subdrains and an urban cross-section of curb and gutter.

Pavement Condition. In 2003, the Pavement Condition Index (PCI) ranged from 46 to 58 out of 100. 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, reactive (unscheduled) maintenance activities have included full depth and partial depth concrete pavement repairs, asphalt pavement repairs, and diamond grinding to restore pavement friction and improve rideability.

Environmental Conditions. Based on Environment Canada data, the temperature ranges from -32°C in the winter to 41°C in the summer. Monthly precipitation ranges from 50 to 83 mm with an annual average precipitation of 793 mm.

Traffic Volumes. The 2002 Annual Average Daily Traffic (AADT) was approximately 313,060 (two directions), with 8% commercial vehicles. Since construction in 1968-71, the highway has carried approximately 58 million Equivalent Single Axle Loads (ESALs) in the express lanes and 39 million ESALs in the collector lanes (driving lane).

Design Considerations

Highway 427 is a major north-south commuter route through the City of Toronto. Due to the heavy traffic volumes, the Ministry's Traffic Office requires that repairs to the roadway be carried out overnight, the typical closure being 11:00 pm to 5:00 am. Repairs to the highway are typically fast-track concrete repairs or in an emergency, hot mix patches.

Fast-track concrete requires Type 30 Portland cement, superplasticizer and calcium chloride based accelerators. Autogenous cylinders are used for estimating compressive strength of concrete in these fast-track repair areas. The cylinders are stored in insulated curing containers in which the elevated curing temperature is obtained from heat of hydration of the cement. The cylinders are tested according to CSA A23.2-9C to verify if the concrete in the repair area has attained a minimum compressive strength of 20 MPa prior to opening to traffic.

The Ministry recognizes that fast-track repairs are not ideal; they are problematic to construct, have a restricted time frame in which they can be constructed (May 1 – October 15), they require the use of autogenous cylinders and a maturity meter to determine opening time, and they may not be giving the desired life expectancy of 15 years. It would also be useful to have an alternative method available to carry out both long term and emergency repairs, without resorting to hot mix patches.

For these reasons, the Ministry decided to investigate the possibility of using pre-cast concrete repairs. The perceived advantages to pre-cast repairs are that there would be higher quality concrete, ideal curing conditions, minimal weather restrictions on placement, and reduced waiting for the concrete to cure prior to opening to traffic. The pre-cast slabs would be manufactured off-site under controlled conditions and stored ready for use.

Pre-Cast Concrete Pavement Trials

Pre-cast concrete pavement trials were incorporated into Contract 2004-2002 on Highway 427. The Contract Documents required that three full depth pre-cast concrete slab repairs 2 m x 3.65 m x 230 mm dimension be carried out using both the Fort Miller Intermittent Method and the Michigan Method. A 25 m trial section of the Fort Miller Continuous Method was also required. The Contractor was to determine the actual dimensions of the repair areas in the field. Repair locations were all in the northbound express lane 3.

Michigan Method. In the Michigan Method, dowel bars are cast into a 2 m x 3.65 m concrete slab, three bars per wheel path, at 300 mm spacing. Following removal of the deteriorated concrete, dowel slots are cut into the existing pavement to accommodate the dowel bars. A cementitious flowable fill material is placed on the existing base prior to setting the pre-cast slab. Once the slab has been set, the exposed dowel bars are grouted in their slots to connect the pre-cast slab to the adjacent slabs.

Fort Miller Intermittent Method. In the Fort Miller Intermittent Method, block-outs are cast into a 2 m x 3.65 m concrete slab to accommodate dowel bars in the wheel paths. Following removal of the deteriorated concrete, four dowel bars per wheel path at 300 mm spacing are drilled into the adjacent slabs. Crusher screenings are placed on the existing base, precision graded and compacted, prior to setting the pre-cast slab. Once the slab has been set, the dowel bars are grouted through ports in the concrete slab to connect the pre-cast slabs to the adjacent slabs.

Fort Miller Continuous Method. In the Fort Miller Continuous Method, dowel bars and block-outs are cast alternately into a set of 4 m x 3.65 m concrete slabs, which fit together like puzzle pieces. Following removal of the deteriorated concrete, crusher screenings are placed on the existing base, precision graded and compacted, prior to setting the pre-cast slabs. The first slab and last slab placed are dowelled into the existing pavement at each end of the excavation, in between, the slabs are connected to each other. All slabs in the continuous repair are tied into the adjacent lane with drilled and epoxied tie bars. Once the slabs have been set, the dowel bars and tie bars are grouted through ports in the concrete slabs to connect the pre-cast slabs to the existing pavement and to each other.

Specification Requirements for Pre-Cast Slabs

Concrete Mix Design. The pre-cast concrete slabs were required to meet a minimum compressive strength of 30 MPa at 28 days. The contract specified that the air void parameters of the hardened concrete be a minimum air content of 3% and have a maximum spacing factor of 0.200 mm. Aggregates used in the mix were required to meet Ministry specifications for physical properties and gradation. The nominal maximum size of the coarse aggregate was 19 mm.

Finishing. Before initial curing and protection of the concrete, the plastic surface of the pre-cast concrete slab was required to have an initial and final texturing. Initial texturing was carried out using a longitudinal burlap drag to produce a uniform textured surface. Final texturing was achieved using equipment manufactured to produce transverse tines $3\text{ mm} \pm 1\text{ mm}$ wide, on $16\text{ mm} \pm 3\text{ mm}$ centres, with a tine depth of $4\text{ mm} \pm 1\text{ mm}$. Tining was required to extend to within $75\text{ mm} \pm 15\text{ mm}$ of the edge of slab. The surface was required to be free from displaced aggregate particles and local projections.

Reinforcing Steel. Reinforcing steel within the pre-cast concrete slabs was required to be epoxy coated.

Surface Tolerance. Specifications required that the surface of the pre-cast concrete slab repair join flush with the existing concrete pavement. Surface tolerance of the repair areas was to be measured with a 3-m long straight edge placed in any location and direction. There could not be a gap greater than 3 mm between the bottom of the straightedge and the surface of the slab. Pre-cast concrete pavement slabs not meeting surface tolerance requirements were to be corrected by diamond grinding at the Contractor's expense.

Construction

Construction was carried out in mid November, beginning with the Michigan Method on Wednesday, November 16, the Fort Miller Intermittent Method on Thursday, November 17, and the Fort Miller Continuous Method on Friday, November 18, 2004.

Concrete removal was carried out in the same manner for each method. According to the specifications, the Contractor was required to use a template to precisely delineate the limits of the areas to be repaired. The outer limits of the concrete removal area were sawcut full depth and the specifications required that sawcuts not extend (overcut) by more than 250 mm into the adjacent concrete. Overcuts were to be filled with a proprietary product acceptable to the Ministry.

The Contract Documents allowed sawcutting to be carried out up to one week in advance of the expected date of repair. The Contractor was concerned that sawcutting in advance of the repair would disturb the base material and perhaps cause the damaged slab to settle or lift out. The Contractor made the decision to sawcut the night before each repair. Dual transverse cuts were made for ease of removal.

The specifications required that concrete removal be carried out without damaging the adjacent concrete slabs or disturbing the underlying base. Heavy breaking equipment such as a hoe ram was not permitted. Removal of the existing concrete was carried out using a backhoe. The Contractor first removed the double sawcut sections with a small hoe machine. The removal of this small section allowed the Contractor to place the large grappling bucket into the removal area and 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.

The pre-cast design concept set out in the Contract Documents did not require excavation of the CTB. It was presumed that once the concrete pavement had been removed, a leveling course would be placed directly on the undisturbed CTB prior to placing the pre-cast slab. In the Michigan Method, flowable fill would be used and in the Fort Miller Methods, crusher screenings would be used to set the slabs. This concept works only if the pre-cast slabs are thinner than the existing concrete. On this trial project, the Contractor pre-cast the Michigan Method slabs to the exact dimensions 2 m x 3.65 m x 230 mm. Fort Miller slabs were pre-cast 215 mm thick. 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 apparent that the CTB would need to be partially removed to allow for placement of the required leveling material and the pre-cast slab. The Contractor brought in a large backhoe with a welded plate to scrape off the CTB to the required depth.

Michigan Method

The first pre-cast concrete trial, carried out on November 16, from 10:00 pm to 3:00 am, was the Michigan Method. The trial consisted of placement of three individual pre-cast slabs, each 2 m x 3.65 m x 230 mm. The weather was cool and damp with a temperature of 8°C and intermittent light rain.

Removals. Perimeter sawcutting had been carried out the previous night. Removal of the existing concrete was carried out in less than 15 minutes.

Approximately 25 mm of CTB needed to be partially excavated to accommodate the flowable fill leveling material and the pre-cast slab. The CTB at the surface was fairly easy to remove and could be excavated manually with a shovel. A first pass with the large backhoe bucket removed about 15 mm of CTB easily and evenly. A second pass was made to remove the remaining 10 mm, however the CTB was found to be more competent, and would not scrape easily. This second pass left a high spot in the northwest quadrant. Removal of the CTB was completed by 11:30 pm.

Dowel Bar Slots. Dowel bar slots were marked out and sawcut the previous night. Triple cuts were made at each dowel bar location, providing for three dowel bars in each wheel path. These were all over-cut significantly. Contract documents specified that hand held chipping hammers with a maximum weight of 9.0 kg and a maximum piston stroke of 102 mm be used to excavate the slots, to reduce damage to the adjacent concrete. Unfortunately, heavier jackhammers were used, resulting in spalling and cracking around the dowel slots. At the first slab location, jackhammers over-excavated the dowel slots resulting in 350 mm long dowel slots at the north end of the slab and 275 mm dowel slots at the south end of the slab. The dowel bar slots were excavated within minutes using jackhammers. Since removal of the dowel slots was not the controlling operation (removal of the CTB was ongoing), more time could 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 a detrimental effect on bonding.

Base Preparation. The Michigan Method uses a flowable fill as a leveling material over the existing base. The specifications required a flowable fill consisting of a mixture of Portland cement (Type 10 cement conforming to CSA A 3000), ground granulated blast furnace slag (optional), granular material (fine aggregate meet the requirements of OPSS 1002 with a maximum aggregate size of 12.5 mm), fly ash (conforming to CSA A 3000), 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 Contractor had difficulty obtaining a mix design that met the contract requirements. A sample mix design was obtained from Michigan DOT (Table 1).

Table 1. Flowable Fill Mix Design used by Michigan DOT

Cement - 50# (30 kg/m ³)
Fly Ash (c) - 500 # (300 kg/m ³)
2NS (sand) - 2850 # (1960 kg/m ³)
200 mm slump
10-13% Air
Psi = 98 (0.68 MPa) at 18 days

A trial batch was required to verify that the Contractor's mix design was providing the required compressive strength. The Contractor tested two 150 x 300 mm cylinders at 3 days and two 150 x 300 mm cylinders at 28 days. The trial batch did not meet the specification, but with time running out in the construction season, the Contractor was given permission to proceed with that mix design.

The flowable fill arrived on site at approximately 1:00 am. The Michigan Method requires a flowable material that is essentially self-leveling when placed. The mix that arrived on site was fairly viscous, with the consistency of cake icing. It was entirely a sand mix, with no coarse aggregate, 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 shoulder. A few passes of the leveling float allowed the Contractor to achieve a smooth and even surface on the flowable fill, although the fill was higher at the edge of lane 2 than at the edge of pavement due to cross-fall in the shoulder.

Slab Placement. The Michigan Method pre-cast slabs were manufactured locally by the Contractor. The transversely tined slabs appeared to be well made, with no voids evident. Four lift hooks were embedded in the slabs.

The first slab was lowered by crane onto the flowable fill at approximately 1:30 am, with all 12 cast-in dowel bars fitting into the sawcut slots. The removal area was larger than the pre-cast slab, with at least 25 mm clearance around the slab.

This 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. The end result was a slightly high spot on the leave edge of the slab.

Grouting. At 1:45 am, a crew arrived on site to grout the dowel bar slots and perimeter of the slab. The grout (HD-50) was mixed on site and poured manually into the 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 would have the required 3 hours curing time but the next two slabs would not (without an extension 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.

Observations. 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, resulting in a slight bump. These slabs will require diamond grinding to meet surface tolerances.

Excavation of the dowel bar slots was not carried out with a desirable level of care. Dowel bars were not centered in the dowel slots and where the dowel bars were resting against the walls or base of the dowel slots it will be difficult to get full encasement with grout. Some of the dowel bar slots were spalled down to the base and there were also cracks extending from some dowel slot removal areas into the existing concrete. This method requires good workmanship to ensue that the removal area is precisely delineated and the dowel bars slots are carefully chipped out without damaging the existing concrete.

Fort Miller Intermittent Method

The Fort Miller Intermittent Method repairs were carried out on November 17, from 10:30 pm to 3:00 am. The trial consisted of placement of three individual pre-cast slabs, each 2 m x 3.65 m x 215 mm. The weather was cool, clear, windy and 9°C.

Removals. Perimeter sawcutting was carried out the previous night. Removal of the existing concrete began at 10:45 pm and was carried out in less than 15 minutes.

At 11:00 pm, the Contractor began excavating the CTB using a modified backhoe bucket. The Fort Miller slabs were pre-cast 215 mm thick to allow for a base course of crusher screenings beneath the slab. The Contractor excavated to 225 mm to allow for 10 mm of crusher screenings. The CTB at this location appeared to be quite competent, and as a result, the bucket removed some CTB in chunks. Removal was completed by 11:15 pm.



Figure 2. Construction sequence for Michigan Method pre-cast slab installation: a) perimeter sawcuts and sawcuts for dowel slots made the previous night, b) removal of dowel slots by jackhammer, c) scraping of CTB using a modified backhoe bucket, d) placement of flowable fill, e) lowering of pre-cast slab, and f) final product (slab 3).

Base Preparation. The Fort Miller Method uses crusher screenings for leveling material beneath the pre-cast slabs. Aggregate for base preparation was required to be 100% crushed fine aggregate, with a plasticity index of 0% according to LS-704 and a maximum micro-Deval abrasion loss of 35 according to LS-619. Fine aggregate means 100% passing the 4.75 mm sieve when tested according to LS-602.

The crusher screenings were placed, then screeded with the Contractor's full lane width leveling screed working off the longitudinal joint between lanes 2 and 3, and the shoulder. Crossfall on the shoulder meant that the crushed screenings were higher at the edge of lane 2 than at the edge of pavement due to cross-fall in the shoulder. A plate-packer arrived on site at 12:15 am to compact the fine aggregate base material.

Installation of Dowel Bars. In the Fort Miller Intermittent Method, dowel bars are drilled in the existing concrete, and block-outs are cast into the pre-cast slabs, so the slabs can be placed over the protruding dowel bars. A gang-drill consisting of four independently powered pneumatic drills was used to drill the dowel bars, which were placed with 4 bars in each wheel path. The location of the dowel bars was accurately marked with a template, which arrived on site at 11:50 pm. The gang-drilling operation began at 12:05 am, taking approximately 6 minutes per side, and resulted in some spalling at the face of the adjacent slab. At 12:25 am, the Contractor had blown out the dowel bar slots, injected epoxy adhesive into holes and was inserting dowel bars.

Slab Placement. At 12:30 am, the crane arrived on site, accompanied by the pre-cast slabs on a flat bed truck. The first slab, lowered in place at 12:50 am, matched flush with the existing concrete pavement.

Grouting. In the Fort Miller Method, the dowel bars are grouted through ports in the pre-cast slab. At 1:10 am, grouting of the dowel bars began with a manually operated grout pump. The grouting operation was slow, finishing the first slab at 1:45 am. On site staff from the Fort Miller Company indicated that grouting should only take 10 minutes per slab.

Observations. The Contractor began his removal at the second slab replacement area at 11:35 pm, excavated the CTB, placed and fine-graded the screenings by 1:10 am, and placed the pre-cast slab at 1:20 am. The slab was placed flush with the existing concrete pavement. Grouting of the second slab began at 2:00 am and was completed at 2:40 am.

The third pre-cast slab was placed at 1:45 am, but was sitting low. The slab was lifted out and it was decided that additional screenings were required. Because the dowel bars were all in place, the leveling float could not be used. At 2:10 am, more fines were brought on site to try to raise the slab. By 2:30 am, the fines had been placed and compacted, and slab 3 was lowered into place flush with the existing pavement. 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.



Figure 3. Construction sequence for Fort Miller Intermittent pre-cast 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 pre-cast slab, d) lowering pre-cast slab, e) grout pump for grouting dowel bars, and f) final product, prior to grouting.

Only grouting of the dowel bars was carried out the first night. Bedding grout is also required for the Fort Miller Method, to ensure that there are no voids beneath the slab. The following night, bedding grout was injected through ports in the concrete slab.

The ride over all three Fort Miller Intermittent slabs is good, although the third slab, which was not grouted, did sink slightly overnight.

Fort Miller Continuous Method

The Fort Miller Continuous Method was carried out on Friday, November 18, 2004, from 12:00 midnight to 6:00 am. Six interlocking pre-cast slabs 4.2 m x 3.65 m x 215 mm make up the 25 m long continuous repair. The weather was 6°C with light rain.

Removal. Sawcutting of the 25 m long removal area was done the previous night. Removal began at 12:00 midnight, and full removal of 25 m x 3.65 m of lane 3 was carried out in less than an hour.

Base Preparation. By 1:00 am, excavation of the CTB with a backhoe bucket was underway. A stringline was used to measure down for depth of the excavation. A template and the lane width leveling screed were also used to ensure the base was excavated to the correct depth. At 1:55 am, with the CTB excavation two-thirds complete, the Contractor began placing crusher screenings in the removal area using a Bobcat. At 2:25 am the backhoe had finished excavating the CTB, and placing of the crusher screenings was 75% complete. Base preparation for the entire removal area was completed by 4:10 am.

Installation of Dowel Bars and Tie Bars. The Contractor began gang-drilling dowel bar locations, and individually drilling longitudinal tie bar locations at the south (approach) end of the excavation at 1:30 am. The drill holes were blown out with compressed air. The Contractor measured the depth at each tie bar location to ensure the tie bars would fit into the block-outs in the pre-cast slabs. At 2:15 am, the Contractor began inserting dowel bars into the drill holes with epoxy adhesive. At 3:25 am the Contractor began gang-drilling dowel bar locations at the north end of the removal area. At the same time, the Contractor was inserting the tie bars for the third slab. At 3:40 am they began drilling the tie bars for the fourth slab and at 4:00 am they began drilling tie bars for the fifth slab. At 4:25 am the Contractor was inserting the dowel bars and tie bars for slab 6.

Slab Placement. The six pre-cast slabs which make up the 25 m long continuous slab replacement arrived on site by 2:30 am, and a crane began lowering the first slab in place at 2:45 am. The first slab was placed too low, with a gap of 35 mm between the slab and the existing concrete.

At 3:05 am, the crane placed the second slab with a 35 mm to 50 mm gap between slab 1 and 2. It became apparent that the Contractor was intentionally spacing the slabs 35 mm apart. After some discussion, it was agreed that the slabs needed to be placed closer together. The second slab was lifted and placed with an 8

mm gap between slabs 1 and 2. The gap between the second slab and the existing lane 2 was variable (5 mm at approach end, 35 mm at leave end), and the second slab was higher than the first slab by about 12 mm at the approach side near the shoulder.

At 3:35 am the Contractor began placing the third slab. Three attempts were made to place the slab, which would not sit flush with the longitudinal joint between lanes 2 and 3.

The fourth slab was placed at 3:55 am, and the fifth slab at 4:20 am, both looked good. The Contractor drove a Bobcat onto slab 5 to place screenings in the gap between slab 5 and the shoulder.

Slab 6 was placed at 4:35 am. The slab looked good, except for a gap of 180 mm between slab 6 and existing concrete. The Contractor had over-cut the excavation area. He proposed to mix grout with pea gravel to fill gap, since there was no fast-track concrete available to carry out a repair.

Grouting. At 4:10 am the Contractor started pumping grout at the first slab using an automatic grout pump. The HD-50 grout was flowing well and the grouting operation was very fast. The grout was pumped in through one grout port and quickly flowed out of the other. The grouting of the dowel bars and tie bars at the first slab took only 5 minutes. At 4:15 am the Contractor started grouting the dowel bars at the second slab. At 4:25 am they finished grouting slab 3 and starting grouting slab 4 dowel bars. At 5:10 am, they had finished grouting all of the slabs.

Midway through grouting the continuous slab repairs, the Contractor ran out of HD-50, and switched to CPD rapidcrete. Test results on the CPD rapidcrete gave 28.8 MPa at 3 hours (20 MPa at 2 hours).

Observations. The Contractors plan to space the slabs 35 mm apart meant that they had over-excavated the removal area. The surplus area at one end was temporarily filled with grout and pea gravel. This will need to be addressed next construction season. The continuous removal area also had a 150 mm gap between the precast slabs and the hot mix shoulder along the entire 25 m excavation. The gap was filled with crusher screenings and 75 mm of cold mix.

The ride over the six Fort Miller Continuous slabs is uneven. The slabs do not match flush with each other and do not meet surface tolerance requirements. It is recommended that diamond grinding be carried out to improve the ride.



Figure 4. Construction sequence for Fort Miller Continuous pre-cast slab installation: a) placing crusher screenings into excavation with Bobcat, b) compacting crusher screenings using plate packer, c) gang-drilling dowel bar locations, d) fixing dowel bars with epoxy adhesive, e) lowering pre-cast slab, f) 180 mm gap between slab 6 and existing concrete.

Falling Weight Deflectometer Testing

FWD testing was carried out on November 22, 2004, at each pre-cast slab to determine the load transfer efficiency across the transverse joints. Three FWD measurements were taken at the approach and leave joint of each slab, in the left wheel path and between wheel paths (12 tests per slab). Contract Documents indicated that pre-cast slabs with FWD results of less than 70% LTE should be rejected. Results of the FWD testing are presented in Table 2.

Table 2. Results of FWD Testing of Three Pre-Cast Pavement Trials

Method	Slab	Left wheel path			Between wheel paths			Average for slab	
		LTE (avg)	LTE (std)	# < 70%	LTE (avg)	LTE (Std)	# < 70%	LTE (avg)	LTE (std)
Michigan Method	slab 1	90	1.63	0	66	6.82	7	78	13.19
	slab 2	92	7.53	0	73	7.00	5	83	11.94
	slab 3	94	4.90	0	70	11.78	6	82	15.05
	avg/std	92	5.36		70	9.02		81	13.40
Fort Miller Intermittent Method	slab 1	82	3.85	0	76	4.85	2	79	5.26
	slab 2	91	2.65	0	85	6.06	0	88	5.38
	slab 3	83	8.48	2	76	6.51	2	80	8.26
	avg/std	85	6.80		79	7.27		82	7.66
Fort Miller Continuous Method	slab 1	78	13.46	3	74	1.90	0	76	9.34
	slab 2	86	7.15	0	84	3.70	0	85	5.59
	slab 3	87	1.37	0	87	1.29	0	87	1.27
	slab 4	83	3.70	0	76	6.98	1	80	6.34
	slab 5	76	7.88	2	68	3.13	3	72	6.94
	slab 6	91	11.56	0	90	6.47	0	90	8.94
	avg/std	83	9.58		80	8.71		82	9.26

Of all the slabs placed, only Fort Miller Intermittent slab 2 and Fort Miller Continuous Slabs 2, 3 and 6 fully met LTE requirements. However, if the FWD tests are averaged at each location, then all the slabs have acceptable LTE in the left wheel path and only two slabs (Michigan Method slab 1 and Fort Miller Continuous slab 5) fail in between the wheel paths. (Note that both these slabs were driven on by heavy construction equipment prior to grouting, although this may be a coincidence).

For the Michigan Method, all tests in the left wheel path passed, but between wheel paths, only half of the tests passed (18/36), but the average LTE was 70%. Of the three methods, the Michigan method had the best load transfer, in the left wheel path (92.2% and lowest standard deviation). This could be because the dowel bar slots were open and could be readily grouted to encase the dowel bars. None of the tests in the wheel path gave < 70% LTE.

Of the three methods, the Michigan method had the worst load transfer between wheel paths. This could be because the Michigan method used only three dowel bars per wheel path, whereas the Fort Miller method used 4 bars in each wheel path, giving more effective load transfer across the joint.

The Fort Miller Intermittent slabs seemed to give slightly better LTE than the Fort Miller Continuous slabs. This may be because the intermittent slabs are tied into existing concrete on either side, whereas the continuous slabs are connected to each other. In the continuous method, there was a 35 mm gap between slab 1 and the

existing concrete, this slab had the lowest FTE. At slab 6, a 180 mm gap between the slab and existing concrete was filled with a mixture of grout and pea gravel. The dowel bars were likely fully encased in the grout mixture, resulting in better LTE.

Based on the average FWD results meeting the minimum requirement of 70% LTE, the pre-cast slabs were not rejected. FWD testing will be carried out annually at the pre-cast trial locations to monitor their performance over time.

Discussion

According to the Contract Documents, the Contract Administrator could reject the pre-cast concrete pavement slab repairs based on the presence of one or more of the defects identified below:

- cracking or spalling
- rocking of pre-cast slab
- concrete not meeting surface tolerance or texture.
- FWD test results indicate a load transfer efficiency of less than 70%.

The overall assessment of the Ministry is that the pre-cast trials went well. The pre-cast slabs did not crack, spall or rock. The FWD results met the minimum requirement of 70% LTE. Other than workmanship issues, the work was carried out within the required timeframes, and seems to be performing well. The pre-cast repairs are similar in both ride and appearance to fast-track repairs along the same section of highway. Surface tolerances were not met and diamond grinding will improve the ride.

Workmanship was a concern, however this work was undertaken by a Contractor carrying out pre-cast repairs for the first time and under difficult conditions: night work in cold wet weather with a 6-hour work window. Some of the workmanship issues are listed below:

- Ministry standard practice does not allow the Contractor to over-cut when sawcutting for removal. The specification for this work allowed over-cuts up to 250 mm for both the perimeter cuts and the dowel bars slots. The relaxed specification resulted in over-zealous sawcutting and poor workmanship.
- When chipping out the dowel bar slots, chipping should be clean and accurate, avoiding spalling and over-chipped areas in the dowel bar slots. The contract specified the use of light-weight chipping hammers, but jackhammers were used, possibly to speed up the removal. The dowel bar slots are crucial to performance of the Michigan Method. Since removal of the dowel slots was not the controlling operation (removal of the CTB was ongoing), more time could have been taken to carefully excavate the slots with chipping hammers and more thoroughly clean out the slots.
- The excavation for the continuous method was 180 mm longer than required, leaving a large gap between the pre-cast slab and existing concrete.
- The gang-drill spalled the edges of the existing concrete pavement.
- The base preparation method was not accurate enough to place the slabs to meet surface tolerances.

- The Contractor removed 100 mm of hot mix shoulder to accommodate the removals. This was later filled haphazardly with screenings and/or cold mix.

Recommendations

1. Existing concrete will vary in thickness throughout the Contract. The actual thickness of concrete pavement will need to be verified accurately prior to pre-casting each repair.
2. The pre-cast slabs need to be cast thinner than the existing concrete pavement to accommodate fine grading material on which to set the slab.
3. A template is required carefully mark out the removal areas. For the Michigan Method, this will ensure that dowel bars are properly placed inside the dowel bar slots.
4. Light-weight chipping hammers should be used to excavate the dowel bars slots for the Michigan Method.
5. The Ministry typically specifies 32 mm dowel bars across the transverse joints at 300 mm spacings. FWD testing supported the need to dowel all the way across the joint rather than just in the wheel path.
6. Chipping hammers or a small milling machine may be useful for removing high spots in CTB.
7. Preparing the base material is key to both methods. This needs to be the controlling operation, with the most time and care taken. Once the slab is placed and found to sit high or low, it is too late to properly correct the problem.
8. A mix design is needed for the flowable fill to ensure the material is self-leveling.
9. The crusher screenings used for the Fort Miller Method should be pre-wet prior to grouting to prevent water absorption from the grout into the bedding material.
10. An automatic pump for grouting should be specified.

Conclusions

This is the first construction experience in Canada with this innovative pre-cast concrete slab technology for repairs to concrete pavements. The overall assessment of the Ministry is that the pre-cast trials went well. The pre-cast slabs did not crack, spall or rock. The FWD results met the minimum requirement of 70% LTE. Other than workmanship issues, the work was carried out within the required timeframes, and seems to be showing acceptable performance to date. The pre-cast repairs are similar in both ride and appearance to fast-track repairs along the same section of highway. The surface tolerances were not met, and diamond grinding will improve the ride.

Workmanship was a concern, however this work was undertaken by a Contractor carrying out pre-cast repairs for the first time and under difficult conditions, including night work, in cold wet weather, with a 6-hour work window.

MTO will continue to monitor the field performance of these innovative pre-cast technologies and assess the cost effectiveness of this alternative to full-depth fast-track concrete repairs.

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