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REPAIRING HIGH VOLUME HMA HIGHWAYS WITH PRECAST CONCRETE INLAY PANELS

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ABSTRACT

The pavements which make up Canada's high volume highways are subjected to some of the most demanding conditions in the world. They must structurally be capable of supporting significant traffic loading, which can exceed an average of 30,000 trucks per day. They must be capable of supporting these loads throughout the wide variety of environmental conditions to which they are exposed, ranging from hot summers to cold winters. In order to achieve service lives which do not necessitate frequent maintenance and repair activities, these pavement structures are required to be very resilient. A complication to constructing the resilient pavement structures is that construction activities on high volume highways are generally limited to over-night construction windows that are six to eight hours long. At the end of this construction window, full traffic must typically be reinstated. Ontario's Ministry of Transportation (MTO) has a number of high volume highways which have been reaching the end of their service lives prematurely due to deep-seated pavement rutting issues. These highways have previously been rehabilitated using a mill and replace strategy. In response to this issue and the restricted construction windows for rehabilitation operations, a new rehabilitation strategy has been developed for rehabilitating high volume hot mix asphalt (HMA) highways. This strategy is the use of Precast Concrete Inlay Panels (PCIPs) which are placed within a partially milled HMA pavement structure. A trial section of the PCIP strategy has been designed and proposed to the MTO for implementation and this paper outlines the development of the rehabilitation strategy, with specific focus on details produced to address to the unique nature of this rehabilitation strategy. These details include panel support conditions, built in design details, and construction specifications that address various constructability and performance concerns.

Keywords: Precast Concrete, High Volume, Pavement Rehabilitation, Constructability, Construction Windows

1. INTRODUCTION

The Ministry of Transportation of Ontario (MTO) is responsible for several extremely high volume highways in the Province of Ontario, Canada. The largest of these is the King's Highway 401 (401), which is also part of the TransCanada Highway, which has sections which experience average annual daily traffic (AADT) levels greater than 400,000 vehicles (Ministry of Transportation Ontario: Highway Standards Branch, 2010) and average annual daily truck traffic (AADTT) levels higher than 35,000 trucks/day (Ministry of Transportation Ontario, 2014).

These high traffic levels have the following two impacts: very high loading on the pavement structure and magnified negative effects of on-highway construction operations.

In order to minimize the effects of construction on the highway traffic, the MTO specifies time windows for construction operations on the highways between the hours of 10 pm or 11 pm and 6 am. This means a 7 or 8-hour work window in which to complete construction operations. Outside of these hours, the highway must remain fully operational at full capacity. When traffic is not reinstated at the end of the work window, an initial penalty is incurred and further penalties are then accrued every minute that the highway remains unopened (Ministry of Transportation Ontario, 2012).

The substantial loading associated with the high traffic volumes has resulted in substantial HMA rutting in several locations, and particularly in the truck lane (the rightmost lane in a given direction of travel). This rutting has been observed to extend through the surface course and into the base courses of HMA. Previously, this pavement distress has been addressed by the MTO through partial-depth milling and structural resurfacing. While the service life of this rehabilitation technique depends on many factors, including layer thickness, condition of the original pavement, and traffic loading, a typical milled and structurally resurfaced pavement will last 12-15 years (Susan Tighe, Transportation Association of Canada, 2013).

When this rehabilitation technique was used in the past, the MTO observed pavement service lives of 3-4 years before the level of rutting required rehabilitation. This could be due in part to the work window restrictions discussed previously. Since the highways must be re-opened to full traffic each morning, the depth of milled HMA that must then be replaced is somewhat limited. This could result in insufficient time to fully remove and replace the deep structural rutting.

The overall scope of this research is to investigate the feasibility of using precast concrete panels for HMA repair. The objective is to assess the design considerations and to develop a strategy for usage on a high volume highway whereby night work and limited closure times are permissible due to high traffic volumes. This paper presents the development of the plans for a trial section for this novel repair technique in Ontario, Canada. The key issues being considered will be highlighted and the plan for on-going research and monitoring will be outlined.

2. BACKGROUND

Due to the previously mentioned durability issue, the MTO began to consider concrete as a pavement alternative on these highways since one of the main benefits of concrete pavements in comparison to HMA pavements is higher durability under high traffic volumes (Applied Research Associates , 2011). This benefit is specifically seen in the surface profile stability which is a result of concrete's relatively high stiffness. Furthermore, concrete overlays have seen wide success as a means to rehabilitate deteriorated HMA pavements (Harrington & Fick, 2014).

Cast-in-place concrete pavements require a period of curing before traffic can be allowed on them. Advances in fast-track concrete have reduced the length of this curing time to as low as 4 hours through the use of accelerating admixtures, but it is still a requirement. With a project on a major highway such as the 401, this consideration can have significant impact on the project's feasibility. The short construction windows combined with the requirement to fully open the lanes each morning make typical concrete overlay rehabilitation unfeasible for these highways. Furthermore, the MTO has experienced issues with fast-track concrete, including temperamental mixtures, shrinkage cracking, and questionable long-term durability (Lane & Kazmierowski, 2011).

A study performed by the MTO from 2004-2011 investigated the use of precast concrete panels as a repair for the concrete base of highway 427, an urban freeway in Toronto, Ontario (Lane & Kazmierowski, 2011). The study investigated the repair strategy as a potential alternative to fast-track repairs which had been problematic, as mentioned previously. The findings of the study were that each of the precast systems observed provided similar ride quality to the fast-track rehabilitation method previously used by the MTO, and were installed within the required 6-hour timeframe. Most issues which were observed were attributed to workmanship issues due to the contractor's inexperience with the repair methodology. Furthermore, the importance of precision saw-cutting of the repair areas and precision grading of the base material were identified as two key considerations in the performance of precast concrete panel repairs. Figure 1 illustrates an example of an intermittent concrete repair using the Fort Miller Super Slab™ method. Using this method, damaged concrete is saw-cut and removed then base material is adjusted to suit required elevation restrictions and a base material is placed, levelled, and compacted. Dowel holes are drilled into the exposed transverse concrete faces and smooth dowel bars are then epoxied into place. Finally, the precast panel is lowered into place such that the dovetail slots formed into the panels envelope the dowel bars. At this point, the panels will support traffic loading and lanes can be temporarily re-opened to traffic in this condition. Dowel grout, which is a non-shrink, non-expansive grout, is pumped into dowel slots at a time such that the grout can achieve a compressive strength of approximately 20 MPa prior to opening the lane to traffic. Following the dowel grout, bedding grout is pumped beneath the panel to ensure continuous support beneath the panel. The bedding grout is a thin grout that obtains a minimum strength of 5 MPa in one hour.

Subsequent projects involving spot and continuous repairs of concrete pavement were specified by the MTO using the Fort Miller Method with their trademarked Super Slab, due to this method's relative ease of installation and its trial performance.

Considering the issues associated with HMA rutting, the restrictive construction windows, and the good performance of precast repairs, a group was formed to investigate the feasibility of using precast concrete as an inlay rehabilitation technique for use on high-volume HMA highways.

3. PAVEMENT REPAIR DESIGN

In general, the repair strategy being proposed involves cold milling deteriorated surface HMA to a partial depth and replacing it with precast concrete. As these panels will be placed within the existing pavement structure, they are referred to as Precast Concrete Inlay Panels (PCIP). In order to investigate this repair strategy, a trial section on a high volume HMA highway is proposed. The plan for the trial is to implement the repair along approximately 100 m of the rightmost lane of a high volume highway which is experiencing significant HMA rutting. The cold milling will be done to a depth such that the thickness of the precast panel and the support material placed beneath it will result in final pavement surface elevation which matches the adjacent existing pavement.

Within this proposed trial section, three variations of the repair strategy will be investigated. Each variation is related to a different type of support between the existing HMA and the precast concrete panels and these include:

1. Grade Supported Panels
2. Grout Supported Panels
3. HMA Supported Panels

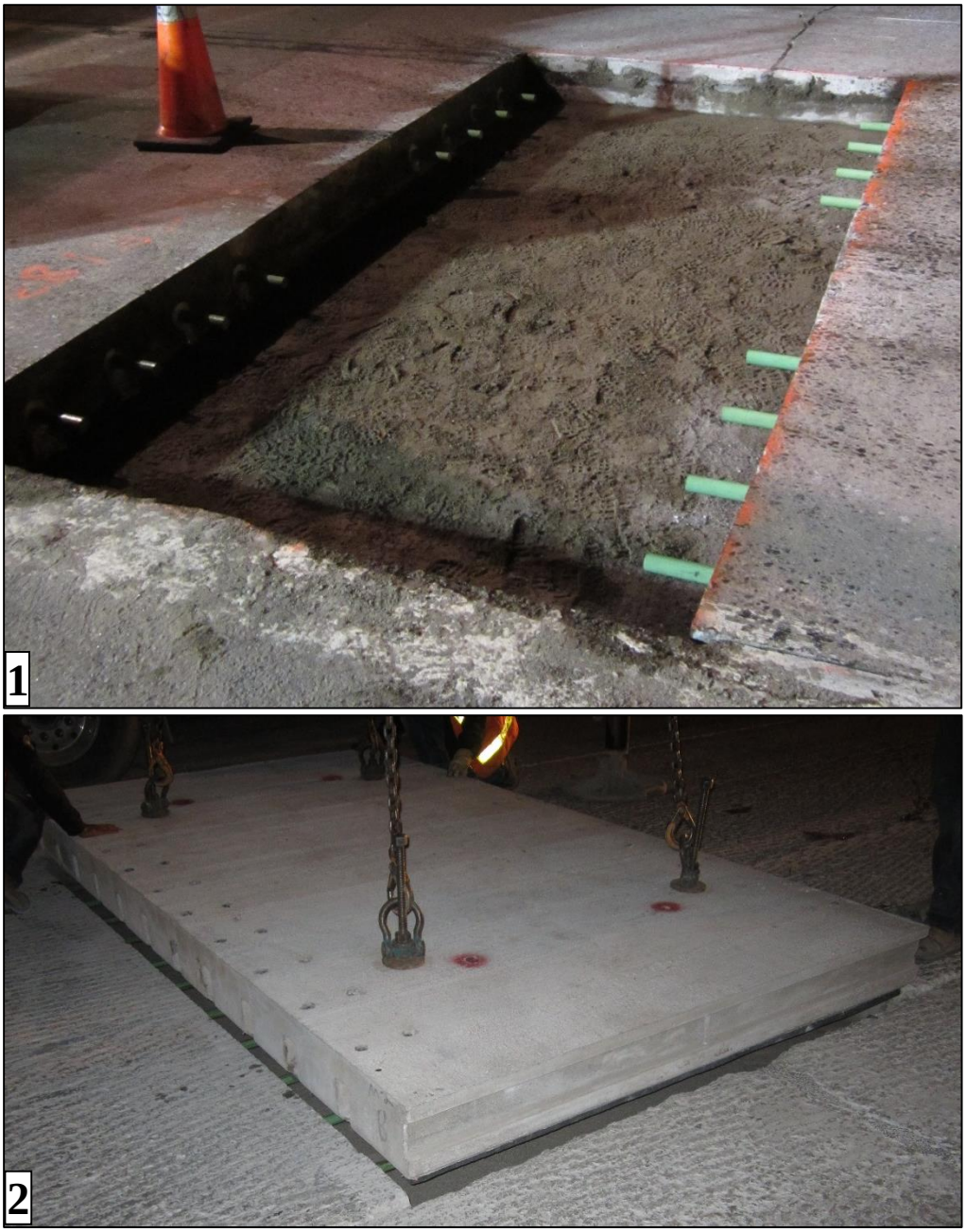


Figure 1: Repair section prepared for Super Slab™ insertion (1), Super Slab™ being placed (2).

Grade supported panels will use the support method typically used by The Fort Miller Company (Fort Miller) in the support of its Super Slabs. For this method, a cement-treated bedding material (CTBM) will be placed, levelled, and compacted on the HMA surface which is exposed after the surface HMA has been cold milled. The final surface of the CTBM will be placed with ± 3 mm accuracy. After the panels are put into place, bedding grout will be pumped beneath the panel to ensure uniform panel support.

Grout supported panels will use levelling screws to ensure that the final surface elevation of the precast panels meet the specified requirements. The screws act as feet which can be adjusted to change the elevation of the panel's surface. After the required elevation is met, edge and dowel grout will be pumped into the voids along the longitudinal and dowelled transverse edges, respectively. Following this, rapid setting bedding grout will be pumped into the void beneath the panel. This method will require that grouting occurs on the same night as panel placement. Prior to

opening the panels to traffic, edge and dowel grout should reach a strength of 20 MPa while the bedding grout should reach a strength of 5 MPa. Achieving these target strengths will require that a curing period be built into the construction plan.

HMA supported panels will rely on a micro milled HMA surface for support. The final milled surface of the HMA will be controlled to ± 3 mm accuracy, and the precast concrete panels will be placed directly on to this surface. Similar to the grade supported panels, the HMA supported panels will have bedding grout pumped beneath them to provide full uniform support and can be temporarily opened to traffic prior to grouting which makes construction scheduling more manageable.

3.1 Precast concrete inlay panel design

The PCIPs which will be used in this trial are produced using Fort Miller's trademarked Super Slab™ design. These were selected based on the favourable results of MTO's previous experience with precast panels. One of the key defining features of the Super Slab™ is how the dowels are placed. For continuous panel placement such as that which will be used on this project, the dowels on one transverse edge are cast into the panel during fabrication. On the other transverse edge, inverted dovetail slots which fit over top of the dowels of the adjacent panel are blocked out. This allows panels to be lowered directly on to the protruding dowels of the adjacent panel. This feature has several practical benefits. It leaves the pavement surface free of exposed slots for dowel bars which must be filled prior to allowing traffic on the panels. This allows the Super Slab to be temporarily opened to traffic prior to the placement of dowel grout. This design also doesn't allow for grout to be exposed to traffic wearing which can cause some cracking and spalling under certain conditions (Lane & Kazmierowski, 2011).

Figure 2 shows two drawings of the typical panels proposed for the trial. Both drawings were produced by the Fort Miller Company for the use of this project (The Fort Miller Co., Inc., 2015). Figure 2.1 is a plan view of a typical panel which shows the inverted dovetail slots and the cast-in dowels, both spaced at 300 mm O/C. The typical panel dimensions of 3.66 m x 4.57 m are also shown. The cast-in lifting inserts which are shown on the figure will be used to place the panels into position by providing a reinforced area for the on-site crane to hook on to. For the grout supported panels, the lifting inserts will also contain levelling screws to achieve the desired panel elevation.

Figure 2.2 shows a cross-section of a typical longitudinal panel edge. The gap between the precast panel and the existing HMA at either the shoulder or lane 2 will be cut to be approximately 75 mm wide and will be filled with edge grout. Edge grout will be dowel grout which is extended 60% by mass through the addition of 9.5 mm clean pea gravel. Similar to dowel grout, the edge grout will be required to achieve a compressive strength of 20 MPa prior to opening the lane to traffic. Threaded tie bars attached to the precast panel will support a longitudinal 15M reinforcing bar which will run along the edge gap. If grouting is not to occur on the same night as panel placement, the 75 mm gap between the precast panel and the existing HMA will be temporarily filled with a hollow steel section which will be bolted to the longitudinal edge of the precast panels. This steel will have a top elevation the same as the precast panel and will provide a temporary riding surface for traffic during the day. The following night of construction, the hollow steel section will be removed such that edge grouting can take place.
The specified minimum 28 Day compressive strength of the concrete to be used in the precast concrete panels is 30 MPa in accordance with typical Ontario Provincial Standards and Specifications (OPSS). The air void parameters of the hardened concrete are specified to be a minimum air content of 3% and a maximum spacing factor of 0.230 mm.

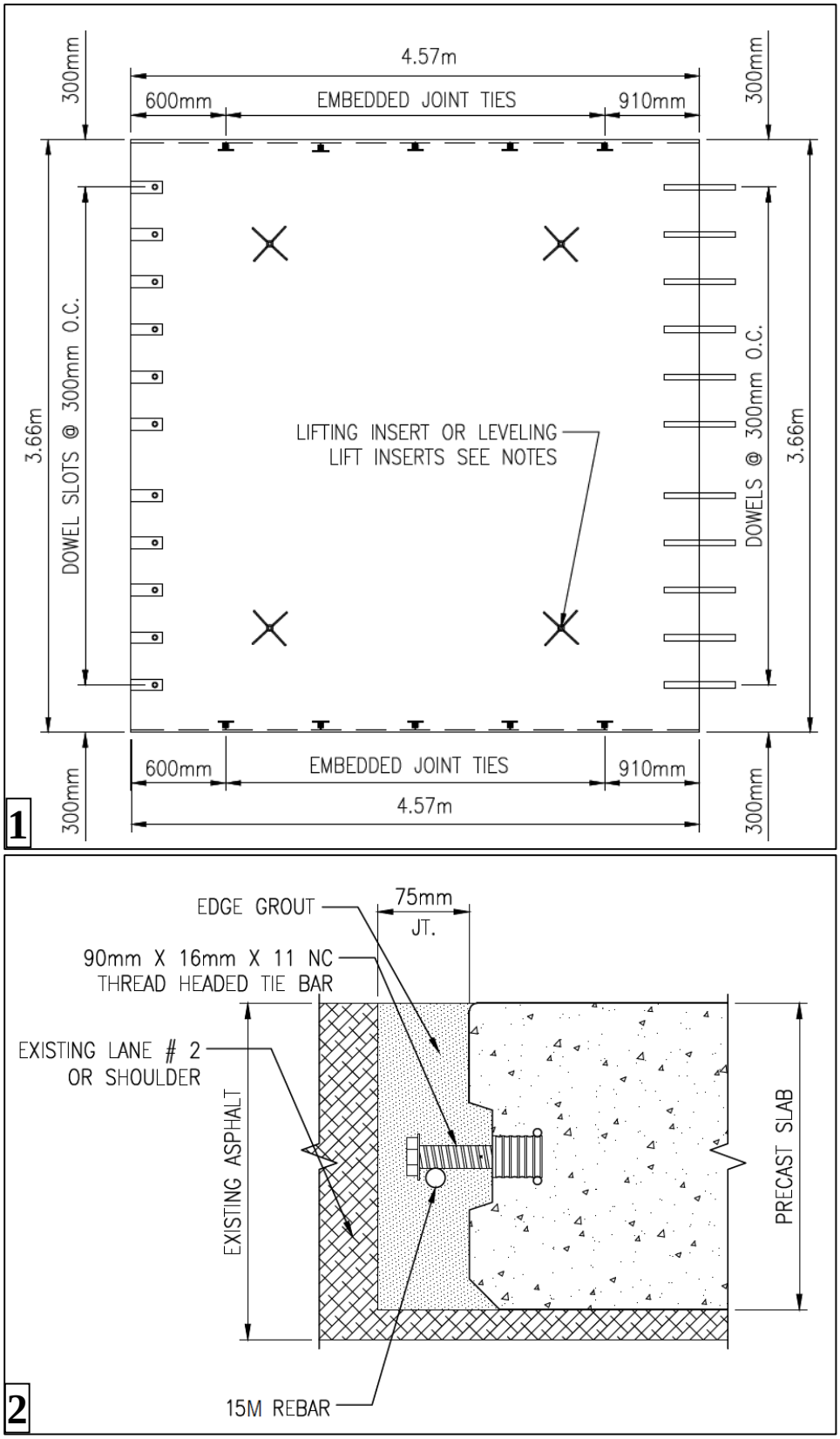


Figure 2: Plan view of typical precast inlay panel (1), Section view of typical longitudinal edge detail (2). (The Fort Miller Co., Inc., 2015)

The surface of each panel will be finished with a burlap drag and then longitudinally tined, relative to the direction of traffic flow. Following the completion of the trial section, surface grinding will be undertaken to provide a consistent surface across all panels and the transitions to and from the HMA surface. During this surface grinding, the MTO has indicated an interest in applying a next generation concrete surface to minimize the noise associated with traffic travelling over the section.

3.2 Implementation Plan

The general implementation plan for a given section is outlined below. This plan will be subjected to contractor review prior to the beginning of construction and may be changed in order to achieve better efficiency or constructability where opportunities are identified. Individual steps may change based on the individual support condition, but generally the following steps will be taken:

1. **Surveying-** Detailed surveying will take place prior to construction in order to accurately delineate the extents of the project in both the longitudinal and transverse directions. The surface elevations at each edge of the lane being repaired will be surveyed to ensure that the correct pavement cross-slope is maintained.
2. **Saw Cutting**- The prior to the night of construction, the extents of HMA removal will be saw cut. The purpose of the saw cut will be to accurately define the extents of HMA milling for a given night and also to facilitate removal of HMA at the ends of a given section which cannot be removed by the milling head of the milling machine. The depth of the saw cut will be to the specified depth of milling. This depth will change based on the support condition specified for a given section.
3. **HMA Removal-** At the beginning of each night of construction, the extent of the HMA to be repaired that night will be removed using cold milling equipment. The distance between the final milled surface of the HMA and a 3 m long straightedge placed anywhere upon the milled surface will not exceed 6mm under the grade supported and grout supported panels and will not exceed 3 mm under the HMA supported panels. The HMA at each end of the nightly extents which cannot be removed by the cold milling machine will be removed using a small chipping hammer such that the adjacent HMA is not damaged.
4. **Surface Preparation-** Following the partial removal of the HMA, the surface of the remaining HMA will be prepared for panel placement. This will include micro milling (if applicable), removing water and detritus left from the cold milling operation, and placing, levelling and compacting the cement treated base material (if applicable). During this step, instrumentation which is to be placed at the interface between the precast panels and the HMA sublayer will be installed.
5. **Panel Placement-** The panels will next be lowered into place using a crane and guide bars inserted into bedding grout port holes. If an elevation differential between consecutive panels exceeds 3 mm, the panel will be removed and the base will be modified to correct the issue. A 1 m long temporary panel will be placed at the final extent of the panels placed each night. This temporary panel will allow for traffic to be reinstated the following morning while protecting the dowels which will be protruding from the transverse edge of the final permanent panel of the night. Prior to the beginning of the following night's activities, the temporary panel can be removed.
6. **Grouting**- The grouting of the panels can be begun the same night for all support conditions or the following night for grade supported and HMA supported panels. For a given panel, the dowel grout should be placed first, followed by the edge grout, and then finally the bedding grout. This order of placement ensures that the dowels, which are the highest priority grout application, and the edges are completely surrounded by the appropriate grout and not by bedding grout, which will have a much lower 28 day strength. Nightly grouting should cease with enough time for the last installed grout to achieve its minimum specified strength.

4. RESEARCH METHODOLOGY

The research evaluates performance with respect to three main considerations: constructability, repair performance, and cost. Three different variations of this repair strategy will be assessed for feasibility. These variations involve different panel support techniques that include: grade support, grout support, and HMA support.

The repair strategy is novel and the contractor's ability to implement the plan will be monitored throughout the construction procedure. The individual components of this rehabilitation strategy will not be new to an experienced contractor, but the combination of these components under a time restriction has the potential to pose difficulties. The

research plan was developed based on contributions from members of industry with significant construction experience, however issues are likely to be identified prior to and during construction. These issues will be identified and solutions will be recommended for future projects using this repair strategy.

Once the repair is implemented, it will be monitored continuously for performance. Monitoring will include visual surveys, falling weight deflectometer testing, and the data collection discussed in the instrumentation section of this paper.

The cost of the repair strategy will be initially estimated prior to and confirmed following the construction of the trial section. The overall cost of each technique being considered will depend greatly on the constructability and performance discussed above. Furthermore, a precise cost estimate will be difficult to obtain due to the nature of trial sections. No economies of scale will be realized for the small test section and therefore the cost of the repair strategy will appear largely inflated. The potential for cost savings in this project lie in the implementation of large repairs over significant lengths of urban highway as well as the life cycle cost savings potentially realized by the increased durability of the repair strategy. Increasing the life cycle of the repair strategy and thereby the time between repair activities on the highway could also reduce the user costs associated with construction activities on high-volume highways.

The constructability, performance, and cost of each support technique will help to determine the best option for future projects involving this repair strategy.

5. INSTRUMENTATION AND FUTURE WORK

One of the most significant design considerations for precast concrete panels is the support conditions. Therefore, monitoring initial and long-term performance of the interface between the panels and the supporting HMA could provide invaluable insight into the feasibility of this repair strategy.

The instrumentation plan considers load transfer between materials, temperature gradients which can contribute to differential thermal strains, and moisture conditions at the interface layer. To examine the interface of the design, earth pressure cells (to give an indication of the stress imparted by the panel onto the concrete) and moisture probes (to measure the presence of moisture beneath the panel over time) will be installed. The pressure cells have built-in thermistors which will provide a reading of the interface temperature. Several of these sensors will be installed under panels with each support condition to assess any differences between designs. These sensors will be connected to a data logging system which will be housed in an enclosure located at the fence line of the property adjacent to the test section of highway.

A long term monitoring program for collecting and assessing the performance of the precast inlay will be instituted after the completion of construction. A major part of this task will be to review the data that comes out of the instrumentation and to work with MTO to evaluate any performance data. In conjunction with data collection and analysis from the installed instrumentation, on-site condition surveys and falling weight deflectometer (FWD) testing will also be performed to correlate measured data with observed performance. FWD testing will take place immediately after construction and will be conducted at the approach and leave joints of each precast panel and across the transverse end joints to determine the load transfer efficiency. This testing will provide an indication of the as-built performance of the joints. This FWD testing will be repeated throughout the course of the pavement's design life to provide insight into the durability of the load transfer design as well as to determine if maintenance on the panels is required.

It is anticipated that this monitoring program will continue throughout the whole life of the trial section while the readings from the installed sensors will be collected as long as the sensors remain in working condition.

Traffic noise level testing is also planned for when the section is completed. The specific plans for this testing will depend on the surface grinding regimen specified by the MTO, but measurement of the effects of implementing a next generation concrete surface on precast concrete panels could provide insight into the noise effects that this repair strategy could have if it is implemented in an urban environment.

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