# Highway 400 Precast Concrete Inlay Panel Project: Instrumentation Plan, Installation, and Preliminary Results

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ABSTRACT

The Ministry of Transportation of Ontario (MTO) was interested in a rehabilitation strategy that could be used to address deep-seated rutting issues encountered on its 400-series highways. A precast concrete inlay panel (PCIP) rehabilitation design was developed and constructed involving the installation of precast panels into partially-milled asphalt pavement.

Sub-surface instrumentation was installed at the PCIP-asphalt interface including earth pressure cells (EPCs) and moisture sensors installed in six instrumentation clusters. This instrumentation has been monitored to gather information regarding the PCIP trial installation.

Readings from the moisture sensors indicate that water penetrates beneath the PCIPs in precipitation events, though these moisture levels recede under dry conditions, indicating that the water can exit the sub-slab area.

Static load testing using a fully-load gravel truck was used to determine the different support reactions caused by different loading configurations. Higher loads were generally found beneath the joints in the two loading situations studied.
INTRODUCTION

Precast concrete panels (PCPs) have been used as a paving material since as early as 1931 in the Soviet Union (Rollings & Chou 1981); however, their use has only started to become a common practice in North America in the last 15 to 20 years (Tayabji & Buch 2012). During this time, various departments of transportation across the United States and Canada have used them in different ways to address different circumstances. Generally, PCPs are used in applications where scheduling or location restrictions preclude the use of conventional cast-in-place concrete. By curing concrete in off-site locations, a project schedule’s critical path can be shortened. There are also typically benefits associated with the quality control aspects of factory production in comparison with field construction.

One common practice is the use of PCPs for intermediate, full-depth repairs of concrete pavements (Buch et al. 2003; Tayabji 2016). In this practice, the damaged areas of concrete are removed and then replaced with a PCP that fits the dimensions of the concrete removal. The PCP is connected to the adjacent existing concrete using dowels and rapid-setting grout. Continuous PCP installations are another common practice, in which several PCPs are placed adjacently to form a continuous lane. These PCPs are often connected using dowels and grout, but can also use post-tensioning strands running through adjacent panels to improve performance. PCPs can also be used to address application-specific needs, including high-traffic intersections and bus bays (Tayabji & Tyson 2017).

A consistent requirement for all applications using PCPs, is uniform support beneath panels. Non-uniform support can produce point loads or un-supported spans beneath the slabs, which can result in premature cracking, loss of load transfer, and joint faulting. Constructing and maintaining proper load transfer characteristics across joints is another important characteristic of PCPs. Poor load transfer can also result in joint faulting which can cause panel degradation and ride quality issues (Tayabji & Buch 2012).

The Ministry of Transportation of Ontario (MTO) in Canada has observed rutting issues with several high-volume asphalt highways under its jurisdiction. The rutting has been observed to re-occur 3-5 years after mill-and-replace asphalt rehabilitation operations are completed, which indicates that the rutting issue stems from deep-seated issues in the pavement structure that are not addressed by milling and replacing the surface asphalt. Addressing these issues directly would require significant construction operations including excavation and reconstruction.

Ontario has some of the busiest highways in North America, which are located in the Greater Toronto Area. The average annual daily traffic (AADT) was measured in 2016 to be greater than 100,000 in many areas with the busiest sections having over 400,000 vehicles/day (Ministry of Transportation of Ontario: Highway Standards Branch 2016). Under these traffic conditions, on-road construction operations can cause significant user-costs. Therefore, the MTO will generally specify that any construction operations on these high-volume highways should take place between the hours of 10 pm and 6 am, when traffic volumes are at their lowest point in a given day. At the end of this overnight construction period (6 am) traffic flow must be fully reinstated to avoid daytime delays.
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The construction schedule restraints and deep-seated nature of the observed rutting combine to make a difficult situation for rehabilitation. It presents a situation wherein the MTO must close portions of the highway for extended periods of time in order to address the pavement issues, or use accelerated construction techniques capable of addressing the issue during the short construction periods. Of these two options, the MTO has expressed a preference for finding an accelerated construction technique to avoid incurring user costs.

In order to pursue this preference, a project team was put together to investigate the feasibility of using precast concrete inlay panels (PCIP) to rehabilitate Ontario’s high-volume asphalt highways. This team included members of the MTO, Cement Association of Canada, Fort Miller, Golder Associates, and the University of Waterloo. The use of a stiffer paving material in concrete was intended to provide wider dispersion of traffic loads in the lower levels of the pavement structure, thereby alleviating the concerns that have resulted in deep-seated rutting. Precast panels were considered to adhere to the typical short construction window, and due to MTO’s positive experience with the technology in the past (Lane & Kazmierowski 2010).

A design was produced for a 100 m trial section, wherein the surface layer of asphalt was removed from a lane of an asphalt highway and replaced with precast panels. The design included three different base preparation techniques which would result in three different support conditions. Briefly, the support conditions included:

**Asphalt-Supported:** Asphalt is milled to a ±3 mm surface tolerance and PCIPs are placed directly on milled surface.

**Grade-Supported:** After conventional milling, cement-treated bedding material is screeded and compacted to meet ±3 mm tolerance surface upon which the PCIPs are placed.

**Grout-Supported:** After conventional milling, cast-in lifting inserts are used to lift the PCIPs into position before rapid-setting grout is pumped beneath the slabs.

In each case, the slabs were designed to have grout pumped beneath them to fill any voids and provide uniform support (Pickel et al. 2016). Figure 1 and Figure 2 show the longitudinal and transverse cross-sections of the PCIP design as submitted to the MTO.

As shown, the precast panels are placed within the milled asphalt pavement, with asphalt remaining beneath the milled surface as supporting material.

![Figure 1: Longitudinal cross-section of PCIP design (The Fort Miller Company Inc. 2015)](https://mc06.manuscriptcentral.com/cjce-pubs)
Figure 2: Transverse cross-section of PCIP design (The Fort Miller Company Inc. 2015)

The transverse joints incorporated The Fort Miller Company’s proprietary super-slab joint details. These joints are largely defined by their inverted dovetail dowel slots which provide an uninterrupted driving surface even before dowels have been grouted into place.

Dowel bar slots at transverse joints were filled with non-expansive grout to provide load transfer and the same grout was also used to fill gaps between adjacent panels and between panels and the adjacent asphalt pavement. Transverse joints were sealed using rubberized-asphalt sealant.

The design was reviewed and accepted by the MTO and the trial section was planned for a section of Highway 400 which was under an active resurfacing contract at the planned construction date. The trial section was constructed during the week of September 19-23, 2016, on Lane #3 of the northbound portion of Highway 400. The site was located approximately 50 km north of Toronto, Ontario.

OBJECTIVES

Precast panel pavements have been used successfully in the past; however, the inlay of precast panels in an existing asphalt pavement structure is a new and novel application of the technology. For this reason, the trial section described previously represents an important opportunity to investigate this new application in order to understand how it behaves and ultimately performs. This understanding will serve to explain the performance as it is observed throughout the trial section’s lifespan. This information is important as a thorough understanding of the PCIP performance and the factors that affected it will largely determine whether this strategy is deemed to be feasible for full-scale application in the future.

Part of this broad investigation involved the placement of instrumentation at the interface between the PCIP and the milled asphalt. The objective of this paper is to present a preliminary summary of the information gathered from this instrumentation and their potential impacts to the performance of the PCIP trial. This information relates to thermal and static loading, sub-surface moisture levels, and temperature gradients throughout the PCIP.
INSTRUMENTATION

Because of the novel nature of the application, gathering information on the performance of the PCIP trial was identified as a priority. This information gathering consisted of two parts: post-construction testing, and sub-surface instrumentation.

The post-construction testing is on-going, and includes various aspects including falling-weight deflectometer testing of joints, visual surveys, roughness measurements, and coring. The results of these other testing methods will be outlined in separate papers.

The sub-surface instrumentation involved the collection of data from sensors installed beneath the slabs during the construction operation. An instrumentation plan was submitted as part of the design package which was produced for the MTO, and included the sensor types, installation plans, and positions within the project extents.

Two types of sensors were installed as part of this project: earth-pressure cells (EPCs) and moisture sensors. The sensors were installed at the PCIP-asphalt interface in order to provide information relating to the support conditions beneath the slab.

Two clusters of sensors were installed for each support condition type. Each cluster of sensors was located beneath the right wheelpath and included two EPCs (one 300 mm from the leading edge and one beneath the centre of the slab being instrumented) and one moisture sensor. In total, twelve (12) EPCs and six (6) moisture sensors were installed. Figure 3 illustrates the layout of the site and the positions of the six instrument clusters within the project extents.

A 25 mm deep trench was cut and chipped into the milled asphalt’s surface in the sensor locations. This provided space to install the sensors, and also included a trench through the adjacent shoulder to run the instrumentation cabling. The sensors were seated and covered in packed sand with the surface of the pressure cells at the elevation of the milled surface. The

![Figure 3: Project instrumentation schematic](https://mc06.manuscriptcentral.com/cjce-pubs)
moisture sensor was located between the pressure cells, adjacent to the channel where cabling was run to the side of the road. The cabling was run through a buried conduit to data-logger housed in a cabinet located approximately 10 m from the edge of the shoulder. Figure 4 shows a typical instrumentation cluster being installed on-site and the cabinet.

![Figure 4: Instrumentation cluster installation (left), solar-powered data-logger cabinet (right)](image)

The instrumentation was planned to provide information relating to the distribution of load through the PCIP into the asphalt support layer and the presence of moisture at the PCIP-asphalt interface. Locating the EPCs adjacent to a joint and at the centre point of the panels was intended to provide any insight into the differential pressures associated with these locations.

Table 1 summarizes the two types of sensors which were employed as part of this project.

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Model</th>
<th>Sensors Installed</th>
<th>Measurements Made</th>
<th>Sampling Frequency (readings/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Pressure Cell (EPC)</td>
<td>LPTPC09-V</td>
<td>12</td>
<td>· VW Frequency (Hz)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>· Therm. Resistance (ohm)</td>
<td></td>
</tr>
<tr>
<td>Moisture Probe</td>
<td>CS-655</td>
<td>6</td>
<td>· Volumetric Water Content (m$^3$/m$^3$)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>· Temperature (°C)</td>
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Internal sensors within the PCIPs were initially considered in order to gauge strains throughout the panel depth, but ultimately these were not used due to concerns with cabling during panel casting, transportation, and placement, combined with uncertainty related to positioning on the site.

METHODOLOGY

Moisture Sensors
The moisture sensors beneath the slabs were monitored in conjunction with local precipitation information. The precipitation data was gathered from a weather station located 17.5 km north-west of the project site (44°14'02"N, 79°46'45"W) that provided daily cumulative precipitation amounts (mm/day). This weather station was the closest location which provided information relating to precipitation, and provides the best available data relating to site precipitation events. Comparing precipitation data with sub-slab moisture provides information into the permeability of the design.

Because the design includes concrete sitting in an asphalt “bath tub”, the ability of water to get and stay beneath the slab is an important consideration in the performance of the PCIP design, particularly in a climate susceptible to freeze/thaw cycling.

Earth Pressure Cells
Since shortly after construction, the EPCs have been collecting readings at 15 minute intervals. This process collects daily pressure variations that can be tracked over the course of the year.

Following the completion of construction, the MTO specified that falling-weight deflectometer (FWD) testing be undertaken on the PCIPs to gauge the load transfer efficiency across all of the inter-panel joints. During the lane closure for this testing on October 6 and 7, 2016, a fully-loaded gravel truck was brought to site in order to conduct static load testing on the slabs. On each instrumented slab, the truck was parked in two positions to gauge the load imparted from the slab to the asphalt support layer. Each position was maintained for approximately five minutes and the sampling frequency on the EPCs was increased to 33 mHz. The two positions and a photo of the truck in Position #2 are shown in Figure 5.

![Figure 5: Loaded truck axle configurations for static testing](https://mc06.manuscriptcentral.com/cjce-pubs)
Each EPC contains a 3kΩ thermistor in order to calculate the pressure readings based off of the cell fluid’s viscosity characteristics. The temperature readings from these thermistors can also be used to determine the temperature at the bottom of the PCIPs. These data can be used with air temperature readings from local weather stations to determine a reasonable estimate of the temperature differential across the concrete panels. It is understood that pavement surface temperatures will generally be higher than air temperatures during sunny periods; however, no thermistors were installed in the concrete surface to get a more precise surface temperature value.

Temperature differences can be considered as both positive and negative temperature differentials. Positive temperature differentials indicate that the top surface of the PCIP is warmer than the bottom surface and usually occur during the daytime. This situation corresponds with downward slab curling. Negative temperature differentials indicate that the bottom of the PCIP is warmer than the top, which corresponds to upward slab curling, and typically occurs during nighttime.

Weather data was collected from the Atmospheric Environment Service located northwest of King City, Ontario. This location is located adjacent to Highway 400, 17 km south of the project site (43°57'50"N 79°34'26"W). This data source represents the closest approximation of the weather conditions on site.

RESULTS

Moisture Sensors

Figure 6 shows moisture content readings and daily precipitation amounts from October 3, 2016 until November 7, 2016. While there were 6 instrument clusters, it can be seen that initially only 5 were reading properly. It was found that environmental conditions affected the readings, and very cold temperatures occasionally resulted in unusable readings. The volumetric water content (VWC, %) for each instrument cluster is shown on Figure 6. As there were two clusters per different support condition, VWC 1 and 2, 3 and 4, and 5 and 6, were located under asphalt-supported, grade-supported, and grout-supported panels, respectively.

Because the moisture sensors were located in a trench beneath the milled asphalt surface, it is likely that these trenches collect water which infiltrates beneath the slab and the probes provide falsely high readings. For this reason, the magnitudes of volumetric water content readings do not reflect expected conditions in PCIP applications.

The early dates shown on the plot correspond to days following construction. October 3, 2016 was the date when the data logging equipment was first brought on-line following the trial section construction. Very few, and minor precipitation events had taken place between the completion of construction on September 23, 2016 and this date. The moisture contents during this period represent the approximate moisture content of the bedding material as placed during construction.

During precipitation events observed on October 8, 13, and 17, 2016 small increases in moisture content of sensors 2, 3, and 5 indicated that some water was infiltrating the material beneath the slab. On the rain event occurring between October 20 and 21, 2016, significant increases in moisture content indicate changes in the water infiltration rates throughout the site.
This change in infiltration rate could be attributed to environmental changes, such as moisture and temperature, which affect the material volume changes of concrete and asphalt. Immediately following the construction of the trial, it could be assumed that some bond was formed between joint and edge grouting materials and the adjacent existing asphalt. If the volumetric changes of these two materials were different enough, this may have instigated a loss of bond between the PCIP and the adjacent asphalt, resulting in a seam through which water could pass freely.

Beyond October 21, 2016, frequent precipitation events combined with an increased infiltration rate resulted in an average moisture content beneath the slabs between 30% and 50%. This condition was observed throughout the months of December, 2016 to March, 2017, though it should be noted that the sensors provided no data throughout significant portions of this period.

The volumetric water contents measured at VWC 4 and 5 were seen to be consistently higher than in other locations within the project. While these two sensors were located beneath different support conditions, they were in consecutive instrument clusters. This may indicate site-specific factors resulting in higher moisture levels in this area, such as a relative low spot in the site.

Following the winter period, it was found that the moisture contents beneath the slabs were generally found to drop during periods between precipitation events. Figure 7 illustrates this point in the period between April 25, 2017 and June 13, 2017.
The moisture content of sensor #3 can be observed to have increased steadily from May 8, 2017 until May 19, 2017, with some daily fluctuations. This is despite almost no observed precipitation in the area. While this may indicate a secondary moisture source beneath the slab, it probably indicates that the readings from this sensor are no longer reliable.

None of the three support conditions studied performed substantially differently with respect to sub-panel moisture penetration. This condition may change over time, but at this time no moisture conclusions can be drawn regarding the relative performance of the different support conditions.

Generally, all support condition types exhibited sharp increases in volumetric water content following precipitation events followed by slow decreases. This seems to indicate that water is draining from sub-slab area or evaporating from the original infiltration points, instead of remaining pooled beneath the slabs; the exit point for this water is not clear. Therefore, water located beneath the panels is a design consideration. This is especially relevant considering the PCIP is placed within a largely impermeable asphalt structure. Based on these findings it is recommended that a drainage detail be considered for any future applications of this rehabilitation technique.

**Earth Pressure Cells**

The static load testing on October 6 and 7, 2016 provided insight into the relative pressures imparted by the PCIP onto the supporting asphalt. The twelve total EPC sensors were paired within their instrument cluster: pairs 1/2 and 3/4, 5/6 and 7/8, 9/10 and 11/12, were located beneath asphalt-supported, grade-supported, and grout-supported panels, respectively. Following the static testing, it was found that sensor pairings 1/2, 3/4, 7/8, and 9/10 were producing...
readings based on significant slab loading. From these findings it was determined that sensor pairings 5/6 and 11/12 were not producing reliable results. One sensor in each of these pairings, was displaying pressure data while the second was not. For this reason, these sensor pairs were disregarded for other comparisons.

Figure 8 illustrates the typical response under the testing conditions described previously. The pressure readings were set to zero before the loads were applied to better show the effects of loading.

Under load Position #1 (rear axle group spanning joint) approximately 13 kPa pressure was observed in the EPC 9 located adjacent to the joint, with very little pressure observed in the EPC 10 at the centre. When the rear axle group was positioned centrally on the instrumented slab (Position #2), the centre EPC 10 read approximately two times the joint EPC 9, but well less than the joint EPC 9 had read under Position #1.

Comparing the measured pressures under the two loading configurations may provide insight into the slab behaviour. In each case, one EPC is between the axles and one is outside of the axles. When the joint is loaded (Position #1), high pressures are measured between the axles but almost none are seen at the mid-slab, indicating that loads are largely supported by the materials directly beneath the joints. However, when the centre of the slab is loaded (Position #2), increased pressures are measured at both sensors, indicating a distribution of the load across the full slab.
The pressure readings in each case are a function of the panel’s downward deflection under load. As the slab deflects downward, the pressure cell is engaged. Therefore, the relative pressure readings under load Position #1 and Position #2 indicate that larger slab deflections are occurring at joints than at mid-panel under the same load. This larger deflection is also localized around the joint as the mid-panel pressure cell is not engaged under the Position #1 load. The differences between the deflection results are illustrated in Figure 9. The deflected and original shape is shown for each load position. The deflections shown in the figure are exaggerated for illustration and are not to scale, but the relative magnitude of the deflections at the centre and joint locations are to scale.

Figure 9: Displacement shape under static load positions (not to scale)

In typical concrete pavements, high deflections beneath joints could eventually result in pumping of base material in that area; however, the asphalt support layer should not generally be susceptible to this.

Falling weight deflectometer testing was undertaken following construction to gauge the performance of the joints. A falling weight was dropped adjacent to each joint in strategic locations and the deflection on either side of the joint was measured. The detailed results of this testing will be included in a separate paper, but some general results provide insight into the joints following construction. The load transfer efficiency (LTE) is one of the values which is obtained using this data. This measure represents the ratio of the deflections on either side of a joint or crack when only one side is loaded. The ratio is the measured deflection of the unloaded side divided by the measured deflection of the loaded side. The MTO specifies a minimum LTE value of 70% to indicate an acceptable joint. The average LTE for the site was 81.3%, indicating that most joints were transferring load across joints acceptably. The relative deflection of the two sides of the joint can provide more meaningful insight into the behaviour of a joint than a ratio of deflections. To determine this value, the difference between the deflections on either side of the joint was found and divided by the magnitude of the applied load. On average, the joints were found to have a relative deflection of 0.42 μm/kN, which is a very small relative deflection.

Relatively large deflections of adjacent slabs under load Position #1 can result in high flexural stresses in the dowels and grout in the joint. Each slab will have opposite slopes at the joint under that condition, placing the dowel between the slab under a significant moment couple. This can result in high bearing stresses between the dowel and the surrounding grout.
The pressure difference between the two EPCs in each working instrument cluster was tracked throughout the course of the study period. The difference in temperature between the air and the average EPC was also tracked during this time. Both sets of data are displayed in Figure 10, which shows these data types between the dates of October 15, 2016 and October 21, 2016. Each pairing shows the relative change in sub-panel pressure between a given panel’s front joint and mid-slab locations.

This plot shows that during the period between October 18, 2016 and October 20, 2016, the system underwent rapid temperature changes. Throughout the course of those two days, the air temperature above the surface of the PCIP system went from approximately 6°C warmer to 8°C cooler twice, indicating two reversals from positive temperature gradient to negative temperature gradient and back again. During this period, the differences between the joint EPC readings minus the centre EPC readings were seen to fluctuate. Since changes in these readings are largely due to small slab deflections, changes in the difference between joint pressure and mid-panel pressure indicate the occurrence of minor slab curling. The joint and edge stresses related to curling could result in cracking of the joint and edge grouts. This may be the factor which resulted in higher sub-slab moisture contents after October 20, 2016 noted previously.

If this is the case, it indicates that a flexible sealant may be required at all edges and joints. Flexible sealant was only applied at transverse joints to account for temperature-induced changes in joint width. This material should be able to maintain its bond to both concrete and asphalt to reduce the amount of water which can penetrate beneath the PCIP. A drainage detail into the adjacent shoulder may also be a beneficial consideration where the situation allows for it.

Curling can be exacerbated by the presence of water beneath the concrete slab, particularly in the case of a negative temperature differential between the top and bottom of the slab (Delatte, 2014). When this is considered in relation to the moisture sensor data presented previously, it indicates that the conditions of the PCIP slab may be conducive to slab curling, further reinforcing the need for sub-slab moisture control.
Figure 10: Instrument cluster pressure differences and temperature differential (Oct 2016)

Figure 11 and Figure 12 show the pressure and temperature differences for a period of warm weather (daily highs approximately 25°C) and a period of cold weather (daily highs approximately -6°C), respectively.

During the warm period, the temperature differential fluctuates from positive to negative on a daily basis. Each functioning pair of sensors can be observed to fluctuate similarly as a result of this temperature change. With average daily temperature difference fluctuations of 12.7°C, the average magnitude of these daily pressure fluctuations were 1.8, 0.9, 3.5, and 0.8 kPa, respectively.

During the cold period, a similar daily pattern in the temperature differential is observed; however, it remains generally negative, meaning that the surface temperature is generally colder than the temperature beneath the panels. The average daily temperature difference fluctuation of 8.1°C, resulting in daily pressure fluctuations of 1.3, 1.0, 3.8, and 0.5 kPa, for each of the EPC pairs, respectively.

The pressure difference ranges seen in both cases are very similar, indicating that the curling pressures in both situations are similar. Because of asphalt’s viscoelastic behaviour, the supporting layer beneath the PCIP will be stiffer in cold temperatures. When a concrete pavement is supported by a stiffer material, curling and warping stresses within the concrete are magnified. Therefore, despite similar curling pressures between seasons, the curling stresses may be magnified in colder months.
Figure 11: Instrument cluster pressure differences and temperature differential (June 2017)
Figure 13 shows the distributions of the daily maximum daytime and nighttime temperature differentials between the top and bottom of slabs, as considered based on EPC thermistor readings and local air temperature readings. This distribution considers the period between October 3, 2016 and October 3, 2017. It should be noted that in some instances, the maximum daytime differential is a negative value. This indicates that during that 24 hour period, the surface of the PCIP was not warmer than the base. Similarly, the maximum nighttime temperature differential was often positive.

The distribution is considered in terms of 1°C increment. The distributions of both daily maximum daytime and nighttime differentials are approximately normally distributed. During the time period the average daily maximum daytime and nighttime temperature differentials were 1.2°C and -6.6°C. Assuming a normal distribution, only approximately 7% of the days will have a maximum nighttime differential below -12.3°C or a maximum daytime temperature differential greater than 8.1°C.

The largest observed daytime differential during this period was 15.5°C while the largest nighttime differential was -16.7°C. Based on an assumption of a spring constant of 135 MPa/m (Delatte 2014) and the PCIP design characteristics, these differentials could result in slab edge temperature stresses of approximately 2.3 MPa. This can represent a significant stress, particularly when combined with the effects of traffic loading, and should be considered in future designs of the PCIP.
Reviewing the environmental and sub-surface data, it was found that during the analysis period, the air temperature underwent 67 cycles between above and below the freezing point (0°C), or freeze-thaw cycles. Because of the insulating effects of the PCIP, only 23 freeze-thaw cycles were observed below the PCIP.

The presence of moisture beneath the slabs combined with freeze-thaw conditions indicates that any support or grout material beneath the PCIP should be designed for these aggressive conditions.

**CONCLUSIONS AND RECOMMENDATIONS**

The Ministry of Transportation of Ontario (MTO) is interested in developing a fast rehabilitation technique for the repair of high-volume asphalt highways. For this reason, the precast concrete inlay panel (PCIP) rehabilitation strategy was designed and a trial section was constructed on Highway 400, north of Toronto, Ontario. Since the purpose of the trial section was to gather information to determine the feasibility of this rehabilitation design, instrumentation was installed beneath the PCIP during the construction phase.

The instrumentation included six clusters, each of which consisted of two earth pressure cells (EPCs) and one moisture sensor. The sensors have been monitored since October 3, 2016, and this process is on-going.

Preliminary results indicate that as environmental temperatures began to drop at the end of October, a change may have occurred that resulted in increased moisture infiltration rates beneath the slabs. Beyond this point, significant amounts of moisture were observed beneath the slabs for most of the winter season. Since the end of April 2017, sub-slab moisture contents have consistently dropped to relatively low levels following the increases associated with precipitation events. This indicates that moisture is exiting the area beneath the PCIPs effectively, despite the impermeable nature of the asphalt support layer. The presence of moisture beneath the slabs
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indicates that the bond between edge grouts and existing asphalt is allowing for the passage of water. A flexible sealant material should be considered at all joints and edges of the PCIP design.

Under static load testing using a fully loaded gravel truck, the functionality of the sensors was tested. All but two EPCs were found to be functioning, resulting in four functioning EPC pairs. Two load positions were observed for each instrumented slab: one with the tandem axle spanning the joint and one with the axle tandem axle centred on the slab. Under these conditions, it was found that the supporting material beneath the joint experiences loads from traffic as much as twice those experienced under the centre of the slab. This confirms the joint load transfer efficiency measured through FWD testing. Higher deflections at joints can place the dowels and their surrounding grout under stress due to the moment caused by opposite slopes of adjacent slabs.

The temperature differentials across the PCIPs were approximated using air temperature as a surface temperature. The maximum daily daytime and nighttime temperature differentials were found to be approximately normally distributed, with average values of 1.2°C and -6.6°C, respectively. The largest negative temperature differential was found to be -16.7°C while the largest positive temperature differential was found to be 17.2°C. These values can contribute to significant curling stresses at the slab edges, and should be considered in conjunction with traffic loads in PCIP designs.

During the period of study, 67 freeze-thaw cycles were observed in the air temperature on site, while only 23 cycles were observed beneath the PCIP. Considering that moisture was found to be present beneath the slabs, freeze-thaw resistant grouts and bedding materials are a necessary design feature of PCIP rehabilitation design.

The preliminary results do not differentiate any of the support conditions considered in terms of early-age performance. Each support condition provides similar load transfer, moisture-penetration susceptibility, and relative joint vs mid-panel pressures. These values will be tracked throughout the trial section’s service life to determine the relative performance of the support conditions which could inform agencies when selecting the best PCIP strategy.

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