



INCORPORATING FAST-TRACK PAVEMENT REPAIR METHODS INTO CURRENT INFRASTRUCTURE MANAGEMENT PRACTICES

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Abstract: Pavement infrastructure deteriorates due to environmental conditions, traffic loading, and material aging. Regular maintenance and repair is required to maintain an acceptable level of service. High-traffic volumes and heavy traffic can increase the rate of pavement deterioration, necessitating more frequent rehabilitation or maintenance on these roadways. However, construction is often limited to a short window to minimize user impacts. Another common problem in asphalt roadways is pavement cracking; it is important to repair cracking to prevent further deterioration of the roadway. Accelerated construction or “fast-track” methods provide a solution to repair and extend the service life of pavement infrastructure, quickly, easily, and with minimal construction-related delays. Throughout this paper, two examples of fast track pavement repair methods are discussed and compared to traditional repair methods. Precast concrete inlay panels are used to rapidly rehabilitate structural rutting on high traffic volume highways, and infrared heating technology is used to quickly repair cracking of asphalt pavement. The objective of this paper is to examine the innovation, benefits, and drawbacks of these fast-track pavement rehabilitation methods and to present their role in pavement management. This paper investigates the project-level decision-making process of selecting between these new fast-track repair techniques and the existing traditional repair methods by examining various decision criteria.

1 INTRODUCTION

Roadways are essential infrastructure that allow the movement of people and goods. Road quality affects the social and economic development of the community and impacts individuals in their day to day commutes. Across Canada, there are approximately 415,000 km of paved highways and roadways (“Length of Canada’s Public Road Network, 2003” 2015), so it is a large undertaking to maintain pavement quality and service.

Conventional asphalt-concrete pavements have a design life of approximately 20 to 25 years, while Portland Cement Concrete (PCC) pavements have a longer design life of 40 to 50 years. For the service life of pavement to reach its full design life, maintenance and possible rehabilitation is required. Without the proper maintenance/rehabilitation work, pavement failure or an inadequate level of service may occur before it reaches its full design life.

Today’s infrastructure is subjected to heavy traffic loading, high traffic volumes, environmental conditions, and other factors that cause pavements to deteriorate. Construction and maintenance is needed to keep the pavement in adequate condition, but the task of performing the repair work can be made difficult by time limitations and traffic constraints. The challenge of performing construction within a short time period while maintaining a certain level of service drives the development of accelerated construction or “fast-track” methods. These are methods used to perform repairs rapidly to extend the service life of pavement.

For a given pavement repair or rehabilitation project, there are often multiple feasible treatment strategies. The major benefit of fast-track methods is the speed at which they can be performed to minimize the impact to roadway users. Many different fast-track methods for performing rapid roadway repairs and rehabilitation have been developed and are continuing to be researched. Some examples of fast pavement repair methods include the use of rapid-setting concrete pavements, precast concrete pavements, or partial depth asphalt milling and replacement.

Two examples of fast-track pavement repair technologies are discussed in detail in this paper. The first is a method of rapidly repairing structural rutting issues in asphalt pavements on high-traffic volume highways by partially milling the asphalt and inlaying precast concrete panels. The traditional repair method is to mill-and-replace the asphalt with a new hot-mix asphalt layer; however, this treatment strategy does not provide an adequate service life. The precast concrete inlay panels (PCIP) can be constructed overnight to minimize lane closures, and this strategy is expected to have a longer service life than the asphalt repair. The second fast-track pavement repair technology presented is a technique to rapidly repair cracking of asphalt pavements using an innovative infrared heating technology. This technology provides longer-term crack repair than traditional repair methods such as crack sealing/filling and mill-and-replace. Using infrared heating technology provides a very fast repair solution, with less opportunities for delay than more current methods of repair. Further research in infrared heating technology has produced some specialized fast-track repair processes for longitudinal crack repairs.

Both the PCIP and infrared heating technology are new methods of rapid pavement repair that have not been used extensively. The objective of this paper is to present the benefits and drawbacks of these two fast-track repair methods and the criteria which would be used to select between fast-track methods and the traditional repair methods.

1.1 Background

Several factors contribute to the deterioration of pavement over its service life, including construction quality, material aging, traffic loading, and environmental conditions.

One of the factors that causes a faster rate of deterioration of pavement is high-traffic volumes and heavy traffic loads. Some of the 400-series highways in Southern Ontario are the busiest in North America with annual average daily traffic (AADT) as high as 416,000 near the city of Toronto ("Ontario Provincial Highways Traffic Volumes On Demand" 2016). High-traffic volumes cause the pavement to deteriorate more rapidly than low-volume roads, requiring more frequent rehabilitation and maintenance. Furthermore, lane closures on high-volume highways have a greater user impact because there are thousands of roadway users. The effects of construction-related closures include increased traffic congestion and delay and increased safety risks for roadway users and workers (Abdelmohsen and El-Rayes 2016; Tayabji, Ye, and Buch 2013a). To reduce these effects, some departments of transportation require that highway lane closures for construction occur during an overnight window, typically around 10 p.m. to 6 a.m., with full reinstatement following this period. In these cases, fast-track pavement repairs can be advantageous to accomplish the repair within the tight construction window.

On all roadways, no matter how well designed and constructed, cracking will occur eventually. Cracking on pavement surfaces is most often caused by fatigue, and constant expansion and contractions of the pavement during freeze and thaw cycles (Rhino Asphalt Solutions, 2015). No severe problems regarding roadway performance or safety tend to occur after minor cracking propagates, but when not treated, cracked areas can quickly expand and cause further, more severe damage to roadways. Since cracking is such a common problem on all roadways, it is hard to keep up with the large volume of crack repair projects. In addition to the new cracks propagating throughout the roadway systems, many roads which have already been repaired continue to crack due to ineffective repair methods, or poorly implemented repairs. A fast track method of repairing pavement cracking can be beneficial to keep up with repair demand, but also needs to be more effective in creating a long-term repair on the roadway to increase its service life and eliminate the need for constant re-repair on the same sections of roadway.

2 FAST-TRACK REPAIR EXAMPLES

2.1 PCIP Rapid Repair for Highways

2.1.1 PCIP Technology

Precast concrete pavement (PCP) is a relatively new technology that is advantageous for projects requiring rapid construction or repair and high strength pavement. While only a small percentage of pavements are precast concrete, in the past 15 years PCP has become a more feasible and cost-effective alternative for certain projects (Tayabji, Ye, and Buch 2013b). Precast concrete inlay panels (PCIP) are a new, innovative application of precast concrete pavement. PCIP are being investigated as a rapid repair method to address deep-seated rutting issues observed on some high-traffic volume asphalt highways near the city of Toronto in Ontario, Canada. Precast concrete inlay panels during a trial construction are shown in Figure 1.



Figure 1: Precast concrete inlay panel installation in third lane of highway (Pickel and Tighe 2017)

Previously, the sections of highway exhibiting this problem were rehabilitated by partial-depth milling and replacement of the asphalt with a new layer of hot mix asphalt. However, this strategy has an observed service life of only 3 to 5 years and did not address the underlying problem (Pickel and Tighe 2017). Structural rutting is occurring, which is caused by permanent deformations in one or more layers below the asphalt surface layer (White et al. 2002). Structural rutting can typically only be repaired by performing a full-depth reconstruction of the layers causing problems. However, the high-traffic volumes deter the use of a full-depth repair strategy that would require a longer construction shutdown and have a greater user impact than the quicker alternative of a partial-depth repair. PCIP is a fast-track construction method developed to address this problem. The precast panels can be installed rapidly to minimize construction time, and concrete is a stiffer material that will reduce the stresses in the lower pavement layers to address the deep-seated issues without requiring a full-depth reconstruction.

Repair of asphalt highways using PCIP involves partial-depth milling of the asphalt, preparing a support condition for the panels, installing the panels, and placing dowel, edge, and bedding grout. Providing a stable, uniform support condition for the panels is essential for a successful precast concrete pavement construction. Non-uniform support results in increased tensile stresses and cracking at the bottom of the panels in unsupported locations (Merritt et al. 2000). Three different support conditions were developed, designed, and constructed in the PCIP trial section; the alternatives are referred to as asphalt-supported, grade-supported, and grout-supported. The asphalt-supported condition consists of precision-milling the asphalt, placing the precast panels directly on top, and grouting. For the grade-supported alternative, the asphalt is milled, and a cement-treated base material (CTBM) is placed, levelled, and compacted before installing the panels on this base, followed by grouting. For the grout-supported alternative, the asphalt is milled, followed by placement of the panels. The panels are then raised to the correct elevation using leveling feet cast integrally with the panel, followed by grouting. Future research includes evaluating these

three alternatives for constructability and performance to determine the optimal type of support for PCIP (Pickel and Tighe 2017).

2.1.2 Treatment Alternatives and Decision criteria

There are many criteria to consider when deciding between a repair strategy using PCIP or other traditional repair methods, such as asphalt mill-and-replace or cast-in-place concrete (CIPC). The general advantages and drawbacks of precast concrete pavement also apply to precast concrete inlay panels. Some of the primary criteria to consider when selecting between PCIP and a traditional repair method are traffic conditions, strength requirements, fabrication, construction considerations, installation and production rate, and costs.

One of the main benefits of using PCP over traditional repair methods is that precast concrete can be installed and the roadway can be re-opened to traffic rapidly to minimize construction-related lane closures for construction. Impacts of lane closures include increased traffic congestion and construction-related delays, increased safety risks for workers and roadway users, greater vehicle emissions, and higher vehicle-operating costs. (Merritt et al. 2000; Abdelmohsen and El-Rayes 2016). In overnight conditions, asphalt requires approximately 1 hour ± 20 minutes, depending on wind conditions, to cool before it can be reopened to traffic (Wang et al. 2018). CIPC typically requires 2 to 4 days after construction to gain sufficient strength to support traffic (Delatte 2008). High early strength concrete pavement can be used to reduce the time required for strength gain, however these are often accompanied by durability issues. In comparison, PCP can carry traffic immediately or shortly after installation. For the PCIP design, this depends on the support condition that is used. For the grade-supported and asphalt-supported condition, the panels can support traffic loads immediately after being placed, and the dowel, edge, and bedding grouts can be installed during the next construction shift. However, for the grout-supported case, the panels raised into position by the leveling screws cannot support traffic loads without the bedding grout; the bedding grout must be installed and requires approximately one hour to cure before the roadway can be re-opened to traffic. Although extra time is required to allow the grout to cure for the grout-supported case, this is offset by the time required to mill the asphalt to a higher precision for the asphalt-supported condition and the time to place and level the base material for the grade-supported case. In all cases, the construction can be performed overnight and the required construction activities can be completed in time to reopen the lane to traffic during the day (Pickel and Tighe 2017).

If a longer construction period is feasible and not too disruptive, then some of the conventional repair alternatives may be preferable depending on other criteria. For example, the problem that is addressed by PCIP is rutting of the asphalt pavement caused by deep-seated issues in the pavement structure; if longer construction shutdowns were allowable then this problem could also be addressed by improving the quality and performance of the lower layers through a full-depth reconstruction.

An inherent benefit of PCP is the high stiffness of Portland Cement Concrete (PCC) compared to asphalt concrete. Concrete pavement deflects less and distributes the wheel loads over a greater area to sub-surface layers than asphalt pavement (APCA 2013). This reduces the stresses transferred to the lower layers of the pavement structure. PCC pavements are well-suited to address structural rutting issues because they can carry heavy traffic and imparts less loads to the layers with deep-seated issues than flexible pavements.

Fabrication requirements may be an important decision criterion when selecting between treatment alternatives. PCIP is fabricated in a controlled environment and then transported to the site rather than being constructed on site. As a result, precast concrete is typically of better quality and durability than cast-in-place. In addition, shrinkage cracking which is a concern for CIPC and can lead to cracking, can be easily controlled in the fabrication of precast concrete (Merritt et al. 2000). High-early-strength CIPC is an alternative that can reduce the time required for strength gain to as little as 6 to 8 hours. However, the reduced setting time is often at the expense of the concrete's durability, as performance problems have been frequently observed with high-early strength concrete. Rapid-setting concrete can be successful, but they are achieved with more difficulty and there is greater risk of durability issues than in concrete with a

longer setting time (Delatte 2008). The prefabrication of PCIP also makes this repair strategy less susceptible to weather conditions. The precast panels can be installed in temperature or precipitation conditions that may be prohibitive for placing CIPC or asphalt (Merritt et al. 2000). Prefabrication also eliminates other risks, such as construction delays due to the rejection of a poor-quality batch of material.

The construction or installation process weigh into the selection of a treatment strategy. For PCIP, the tasks of preparing the lane for panel placement and installing the panels may be more intensive than milling-and-replacing the asphalt or pouring cast-in-place concrete. The preparation for PCIP depends on the type of support condition being used and may include precision-milling of asphalt (asphalt-supported option), milling and placing a base material (grade-supported option), or milling, levelling and grouting (grout-supported option), before placing the panels. In addition, these procedures must be completed precisely so that the panels meet the desired crossfall and match the elevations of the adjacent panels and the existing pavement (Pickel and Tighe 2017).

The estimated production rate of precast concrete pavements, including PCIP, is 150 metres/day, assuming that construction only takes place overnight in a 10-hour window. The production rate of a conventional pavement is approximately 600 metres/day, assuming that construction takes place throughout the day (Merritt et al. 2000). This demonstrates that PCIP installation for a given length of road takes longer than rehabilitation with conventional pavements. However, the overall traffic disruption is minimized because all construction is performed during the off-peak hours. It is also expected that the production rate of precast concrete pavements could increase as contractors become more familiar with this technique.

Since PCIP is a novel technique, the life-cycle costs are currently unknown. The initial cost and maintenance/rehabilitation cost of PCIP are not yet known quantitatively. However, in relative terms the initial cost of PCIP is higher than that of conventional repair strategies. PCIP is estimated to have a lifespan similar to other precast concrete pavements that have an expected service life of 20 years for repairs (Tayabji, Ye, and Buch 2013b). In comparison, the asphalt mill-and-replace strategy has been observed to have a service life of only 3 to 5 years. It is predicted that repair using PCIP will require significantly lower maintenance and rehabilitation costs in comparison to the asphalt-mill-and replace for a comparable time period. Furthermore, a primary motivation for using this fast-track repair method is to reduce the user costs. User costs are indirect costs such as increased commute time and vehicle-operating costs, caused by construction-related delays (Merritt et al. 2000). User costs are minimized by performing PCIP construction overnight when traffic volumes are at their lowest, in comparison to alternative repair methods which require 24-hour traffic diversions.

2.2 Infrared Heating for Crack Repair

2.2.1 Infrared Heating Technology

Infrared heating is a relatively new pavement repair technology used primarily for fixing cracking and potholes in roadways. Infrared heating machinery has been used in the pavement repair field for almost 30 years, but has only recently gained some popularity (Kieswetter, 2013).

Infrared light consists of longer wavelengths than all visible light. When exposed to infrared radiation, objects absorb the rays in the form of heat (Ray-Tech Infrared Corp., 2017). Infrared heating machines use this infrared radiation to heat asphalt until it is malleable enough at a specified depth to rework. To produce infrared radiation, machines feed propane through a device which mixes the correct ratio of air to propane into a heater plenum which creates ignition. Ignition occurs inside a ceramic cloth which heats up to temperatures ranging from 800 to 1000 degrees Celsius (Kieswetter, 2013). This hot surface of the ceramic cloth is what emits the infrared radiation. This surface is placed near the pavement surface so that the infrared radiation is emitted to and absorbed by the asphalt. Figure 2 below displays an infrared heating machine.



Figure 2: Left: Infrared Heating Machine in Use; Right: Bottom of Machine in Use (Kieswetter 2013)

The process used when repairing a section of pavement with an infrared heating machine is as follows: First, the affected area is heated using the infrared heating machine to approximately 350°C, making sure the pavement is evenly heated past the depth of the cracked areas. Workers then rake the now malleable asphalt to remove damages and add new asphalt to bring the area back up to grade (mostly during pothole repairs). During this stage, a product consisting mostly of light oil contents called a rejuvenator is often added to the pavement to restore some of the old pavement's intrinsic properties. Old pavements tend to lose these chemicals over time and become more stiff, hard, and prone to cracking; adding the rejuvenators when the pavement is soft makes the pavement more flexible. Next, the area is compacted, making sure a strong thermal bond is created between the pavement surrounding the affected area and the rejuvenated asphalt (Parker, 2007).

Infrared heating machines are manufactured in many different sizes and shapes, depending on the jobs they were designed for. These can range from small, hand pushed machines for minor repairs to large, driver operated machines which can span a whole lane of traffic. One particular machine designed by Heat Design Equipment Inc. in Waterloo, Ontario, was specifically created to provide an effective, fast-tracked repair solution for longitudinal cracking. This machine has 14.6 metres (48 feet) in length of infrared heating mechanisms, which is towed at a rate which can exceed 1.5 metres/minute (5 feet/minute) (Heat Design Equipment Inc., 2017). By the time the affected pavement has been heated by the entire length of the train, it is at the perfect temperature to be scarified, reworked, and compacted by workers. This machine is very effective in treating longitudinal cracking repairs which tend to occur where joints were created during pavement construction while laying the asphalt layer. For the case of longitudinal crack repairs, this continuously moving "train" style of infrared heating machinery provides an improved performance with the benefits of a fast-tracked repair system. Figure 3 below displays this machine in action.



Figure 3: Infrared Heating Train (Heat Design Equipment Inc. 2017)

2.2.2 Treatment alternatives and Decision criteria

Some current, more commonly used methods for crack and pothole repairs include crack sealing, crack/pothole filling, and milling and patching. Crack sealing consists of cleaning the crack using compressed air, then filling it with a rubberized high modulus crack filling material. This method is generally used on small, lower severity cracks. For larger cracks or potholes, the affected areas are instead filled with asphalt emulsion to grade, and this is called crack or pothole filling. When crack and potholes are more severe, the affected area of asphalt is removed by milling, replaced by virgin materials and compacted (Uzarowski et al. 2011).

When compared to these more common crack and pothole repair methods, several performance benefits of the infrared heating method can be observed. Cracks repaired via infrared heating process tend to last longer without further deteriorating than these other methods mainly because of the thermal bond created between the repaired/rejuvenated area and the surrounding pavement. This thermal bond is created because both the repaired area and the pavement surrounding that area are heated when the joint between them is compacted. Compared to the cold joint created when using the more commonly used methods, the thermal bond will not allow any water or debris into the joint (Ray-Tech Infrared Corp., 2017).

When heating asphalt without using infrared heating, current methods use heat by flame. This method tends to overheat the top layer of asphalt, causing it to burn and damage the material, while also often not heating the base of the asphalt layer enough. Burnt materials will perform poorly if recycled in the future because they lose much of their innate oils and damage the aggregates. Materials which do not get heated enough fail to become properly malleable and do not mix well or properly absorb the rejuvenators (Ding et al. 2016). When using infrared heating, one does not have to worry as much about burning materials or not heating deep enough, as infrared heat penetrates the asphalt better and heats the asphalt evenly to full depth.

One main factor when selecting a repair option for any project is cost. Crack sealing is by far the cheapest repair option, costing about \$8 per linear metre (Jeong, 2015). Prices of infrared heating repair and mill and patch repairs can range from \$10-12 and \$10-15 per linear metre respectively (Uzarowski et al. 2011). When completing a job using the infrared heating method, all of the in-place material is recycled, but when mill and resurfacing is implemented, the original asphalt layer is completely replaced with virgin materials. This results in a decrease of the relative price of using infrared heating compared to mill and resurfacing as the size of a repair job increases. Also, since infrared heating provides a longer lasting repair, using this method will pay itself off over time.

Another factor when deciding what kind of repair method to choose for a specific project is the availability of that repair method. Commonly used crack repair methods are readily available in all regions of the world, while new methods like infrared heating are not. When a method is not readily available, the machinery would have to be transported a longer distance to the construction site, dramatically increasing the cost of that option.

An example in infrared heating being chosen as the optimal repair method is in the Region of Waterloo Bleams road reconstruction project. For this project, several low to medium severity cracks had propagated on the binder course of a recently reconstructed portion of road. The Region of Waterloo required a cost effective, long term repair solution with minimal time increase since construction was already being delayed due to these cracks. Infrared heating repair was chosen because it met these criteria, while not requiring replacement of any in-place materials, which were only two years old at the time (Uzarowski et al. 2011). Also, the Region of Waterloo had local infrared heating machinery available for the job, eliminating long transportation costs associated with using this new method.

When infrared heating machines are used in the constantly moving “train” formation described earlier, it provides a very fast-tracked repair method desirable for high priority longitudinal crack repair projects. Several high demand roadways in Toronto, Ontario, and Washington, D.C. have used this method for repairs. This method is also very effective when used to repair airport aprons and runways (Heat Design Equipment Inc., 2017).

3 CONCLUSIONS

Two fast-track repair technologies were presented to demonstrate the advantages and disadvantages of rapid pavement repair methods and to examine the decision criteria that play a role in choosing a pavement treatment strategy.

The first technology is precast concrete inlay panels (PCIP), use for the rehabilitation of structural rutting problems on high-traffic volume asphalt highways. The structural rutting problem has been observed to occur on some of the 400-series highways in Ontario, and in the past, milling and replacing the asphalt has been performed to try to rehabilitate the pavement. However, the observed service life of this treatment strategy is only 3 to 5 years. Concrete pavement is a stiffer material that is well suited to carry heavy traffic loads and would be more resistant to structural rutting than asphalt pavement. Therefore, conventional cast-in-place concrete pavement is another potential treatment alternative. However, longer lane closures are required to allow concrete hardening before it can support traffic loads. Therefore, precast concrete pavement is proposed to minimize the construction-related lane closures, thereby reducing user costs. Table 1 summarizes the advantages and disadvantages that were previously described for the three pavement treatment strategies.

Table 1: Comparison of treatment alternatives for structural rutting on highways

Criteria	Precast Concrete Inlay Panels (PCIP)	Cast-in-place Concrete (CIPC)	Asphalt Milling and replacement
Time before re-opening to traffic	Immediately after installation	2-4 days (typical) or 6-8 hours (rapid-setting)	40 – 80 minutes
Supporting heavy traffic loads	Higher strength	Higher strength	Lower strength
Fabrication	Prefabricated; higher concrete quality and durability	On site construction; lower concrete quality and durability	On site construction; less controlled environment
Sensitivity to weather conditions during construction	Less susceptible to weather conditions	More susceptible to weather conditions	More susceptible to weather conditions
Installation Process	More intensive process	Simpler process	Simpler process
Production Rate	150 metres/day	600 metres/day	600 metres/day
Initial Cost	Higher	Lower	Lower
Maintenance & Rehabilitation Costs	Expected to be lower than asphalt replacement	Comparable to PCIP	Higher

Based on these decision criteria and the priorities of the specific project, the most appropriate treatment strategy can be selected. If longer lane closures do not have significant adverse impact on traffic, then a conventional cast-in-place concrete or full-depth reconstruction of the pavement may be suitable options. PCIP's main advantage is for rapid construction or rehabilitation applications, when reducing construction time and user impact is a priority.

The second technology is a new method for repairing asphalt cracking utilizing infrared heating to evenly heat asphalt to the required depth to resurface the affected area. This method provides a very fast and effective repair due to the thermal bond created when the repaired asphalt is bonded to the in-place

asphalt while they are both heated. A very efficient fast-tracked repair method can be created by lining together a “train” of infrared heaters to constantly move over the affected areas. Table 2 summarizes the comparison of infrared heating to existing crack repair methods including crack sealing, crack filling, and asphalt milling and replacement.

Table 2: Comparison of treatment alternatives for crack repair on asphalt pavements

Criteria	Crack Sealing	Crack Filling	Asphalt Milling and Replacement	Infrared Heating
Typical Crack/pothole Size to Repair	Very small	Small	Large	Small-Large
Repair Time	Very low	Very low	Higher	Low
Availability	High	High	High	Low
Initial Cost	Lowest	Lower	Moderate	Moderate
Maintenance & Rehabilitation Frequency	High	High	Low	Expected to be Lower

Based on the above table, one can select the most appropriate crack sealing method for their project. For smaller projects, one may not want to invest in infrared heating due to its increased cost, however, if this technology is available in the area required, selecting this pavement repair strategy will provide a fast, effective method that will not require as much future maintenance causing increased delay for road users.

These are two examples of fast-track techniques, however, there are many other existing fast-track pavement repair methods. Due to high-traffic volumes experienced on many highways and the ongoing need to maintain and rehabilitate roadways, fast-track techniques are becoming necessary for certain projects because they offer faster construction times and a reduced user impact. The use of fast-track repair methods should be evaluated on a project-by-project basis using the decision criteria presented and other relevant criteria to select the optimal treatment strategy.

Acknowledgements

The authors of this paper gratefully acknowledge the Ministry of Transportation of Ontario, Cement Association of Canada, and the Natural Sciences and Engineering Research Council of Canada (NSERC) for providing funding for the PCIP project. We would also like to thank Heat Design Equipment Inc. for their continued support and assistance with infrared heating crack repair research, and Daniel Pickel for his support and expertise on the precast project. For their guidance and instruction in the Infrastructure Management course at the University of Waterloo, we thank Professors Chris Raymond and Vimy Henderson.

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