Performance of a Perpetual Pavement on Highway 406 in Ontario

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ABSTRACT

The Ministry of Transportation Ontario (MTO) constructed its first perpetual pavement in 2007. Pavement monitoring was conducted to determine not only the long term performance but the potential of perpetual pavements to be classified as a sustainable pavement strategy. The use of perpetual pavements is intended to reduce major rehabilitation works and the associated greenhouse gas (GHG) emissions by reducing traffic delays associated with major construction. The first perpetual pavement trial with Rich Bottom Mix (RBM) was completed on Highway 406, near Thorold. At this location, Highway 406 is a four-lane divided freeway with annual Equivalent Single Axle Load (ESAL) of 450,000.

The Highway 406 project included widening from two to four lanes and was originally designed as a conventional deep strength flexible pavement. The perpetual pavement concept was incorporated into the project at the final design stage. As a green field project, it allowed the construction of both a trial and control section under identical conditions. The final design of the Highway 406 project was modified to accommodate the perpetual pavement concept with the addition of 80 mm RBM hot mix asphalt. Conventional deep strength pavement was constructed at the northern section as a control, and the perpetual pavement trial was constructed at the southern end.

In 2016, this first perpetual pavement trial reached its 9-year service life. Annual pavement condition data such as pavement roughness, rutting and cracking were collected and analyzed. This paper presents the pavement performance and compares the results of the perpetual pavement with conventional deep strength pavement.

1. INTRODUCTION

Highway 406 was originally constructed as a concrete pavement in 1969 with 230 mm plain concrete over 150 mm cement treated base (CTB). In 1998, it was rehabilitated and resurfaced with 90 mm Hot Mix Asphalt (HMA). Highway 406 is an important economic artery in the Niagara Region. In 2003, with an Annual Average Daily Traffic (AADT) of 25,470 and 7% commercial, the traffic on this section was fast reaching capacity and additional lanes and improvements were deemed necessary to increase capacity, address safety concerns and reduce travel times.

In late Fall 2007, Highway 406 expansion was completed as the first perpetual pavement project built in Ontario. The project included widening from two to four lanes and was originally designed as a conventional deep strength flexible pavement. The perpetual pavement concept was incorporated into the project at the final design stage. The perpetual pavement and conventional pavement sections are in the Southbound lanes of Highway 406 constructed under Contract 2005-2041. The perpetual section (Sta. 5+918 to 7+825) is located from approximately 475 m south of Niagara Regional Road 20 southerly for 1.9 km. The conventional section (Sta. 7+825 to 10+750) is located from 475 m south of Niagara Regional Road 20 northerly for 2.9 km.

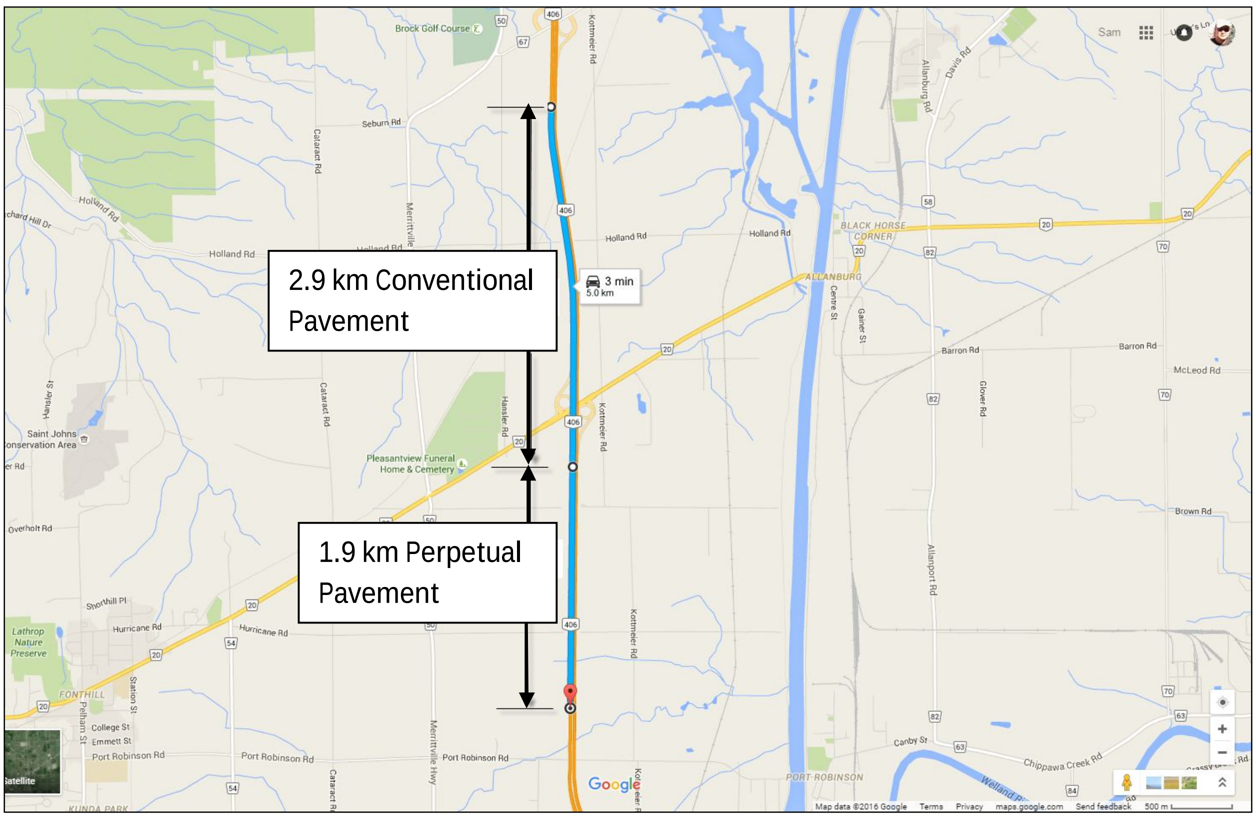


Figure 1: Location of the Conventional and Perpetual Pavement Section on Highway 406

2. PERPETUAL PAVEMENT CONCEPT

The design concept of perpetual pavement is to provide a life span of 50 years or more, with periodically scheduled renewal of the surface layer to minimize major construction delay and maintain optimum serviceability. The three layer hot mix pavement design concept to achieve the perpetual pavement objectives are described below (1):

1) Top Renewable Layer

A low permeability, rut-resistant and wear-resistant surface layer which will be periodically renewed to prevent "top-down" cracks from propagating to the lower binder layers.

2) Middle Rut Resistant Layer

Strong, rut-resistant and durable layers which remain in place during the full 50 year design life.

3) Bottom Fatigue Resistant Layer

There are two approaches to designing flexible pavements to resist fatigue cracking. One approach is to provide a sufficient thickness for minimizing the tensile strain at the bottom of the flexible pavement which contributes to fatigue crack initiation; and the other is to design a flexible bottom layer to provide increased resistance to fatigue cracking. This layer is referred to as Rich-Bottom Mix (RBM).

For this contract, RMB design was utilized as the bottom fatigue resistance layer. The rich-bottom mix was designed as a flexible layer by increasing the asphalt content of a standard Superpave 25.0 mm mix by 10% (about 0.4% additional asphalt cement), which in turn, reduces the air voids content to about 3% to optimize the flexibility of the mix. Alternately the mix could be achieved by having a lower air void requirement of 3.0% instead of directly specifying the higher asphalt cement content.

3. PAVEMENT DESIGN AND CONSTRUCTION

This Highway 406 project was originally designed as a conventional deep strength flexible pavement, and the perpetual pavement concept was incorporated into the project at its 90% design stage. As a result, many challenges were encountered to accommodate the perpetual pavement design within the existing geometric constraints and address various design and pre-construction issues.

Two pavement design methods, AASHTO 1993 – DARWin and OPAC 2000, were used to verify the structural adequacy of this long-life pavement. The total thickness of the pavement structure was adjusted to achieve the same profile grade as the original design. The deep strength asphalt used for the control section has 200 mm of hot mix laid on top of a 450 mm Granular 'A' base. The perpetual pavement section has 250 mm of hot mix (including the 80 mm thick rich bottom mix) laid over a 400 mm thick granular base. Performance Graded Asphalt Cement (PGAC) for the surface course was PG 64-28 and PG 58-28 for the binder course.

The difference between the two designs is the rich bottom layer used in the perpetual pavement. This produced a flexible mix that is more resistant to bottom up cracking. Below are the schematics of the perpetual design and the conventional deep strength design.

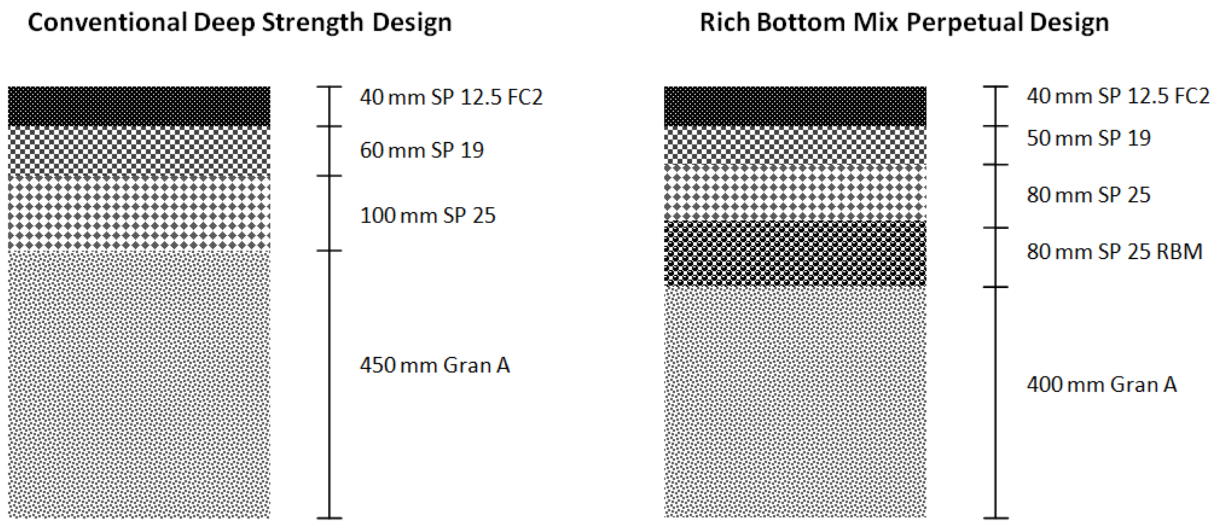


Figure 2: Highway 406 Conventional and Perpetual Pavement Design

The RBM was placed under night closures, and although there was some concern that it may be unstable, the contractor did not find this to be the case, and obtained full pay incentives for compaction.

As a side note, the section where the perpetual pavement was placed required some localized special treatments (sub-excavation and/or additional granular base material) during construction due to poor subgrade quality and very wet weather conditions.

4. NETWORK LEVEL PERFORMANCE

As pavement evaluation technology evolved, the ministry has moved from traditional manual pavement distress evaluation collection to fully automated pavement data collection using an Automated Road Analyzer (ARAN). Between 2012 and 2013, this transition caused some impact to the reported network pavement performance. This becomes apparent when the data is reviewed for this analysis.

For this network performance analysis, a few indices are being used to quantify the pavement condition. PCI is the pavement condition index used by the ministry to quantify pavement condition, it ranges from 0 to 100, where 100 represents excellent condition. DMI is the subjective distress manifestation index, theoretically ranging from 0 to 10, where 0 indicates the worst condition and 10 represents excellent condition. IRI is the international roughness index which measures the roughness through longitudinal profile and it was collected by the ARAN. An IRI of 0 represents an excellent condition.

4.1 Manual Data Collection from 2008 to 2013

The contract was completed in Fall 2007, therefore the first evaluation was done in 2008. The evaluation combined the conventional and the perpetual pavement sections together, as distress evaluation did not reveal a notable difference between the two sections.

Below is the summary table showing the Pavement Condition Index (PCI), International Roughness Index (IRI), Distress Manifestation Index (DMI) and the distress descriptions (2).

Table 1: Manual Data Collection Performance from 2008 to 2013

YEAR	PCI	IRI	DMI	Distress Descriptions
2008	99.19	-	10	No distress identified
2009	91.18	1.32	9.7	A few slight distortion; some very slight centerline and pavement edge cracking
2010	90.91	1.35	9.7	A few slight distortion; some very slight centerline and pavement edge cracking
2011	88.22	1.29	9.35	A few slight distortion; some slight centerline and pavement edge cracking; a few slight centerline alligator cracking
2012	88.56	1.45	9.52	A few slight distortion; some slight centerline and pavement edge cracking; a few slight centerline alligator cracking
2013	87.86	1.55	9.52	A few slight distortion; some slight centerline and pavement edge cracking; a few slight centerline alligator cracking

The manual data collection indicated that the pavement was performing well for the first six years of life and deteriorating steadily. Minor distresses were being identified and mainly related to cracking that were subsequently rout and sealed.

4.2 Automated Data Collection from 2009 to 2015

The automated data collection was generated separately for the 2 sections since 2009, where IRI was collected at 50 m interval for comparison. Since 2012, rutting and cracking data, also collected at 50 m interval, were further gathered for comparison.

Table below shows the summary of the automated data collection for both conventional deep strength and perpetual pavement sections. In general, the data shows the two sections are very similar in performance.

Table 2: Automated Data Collection Summary from 2009 to 2015

	Years	IRI (m/km)	RUT (mm)	Combined Longitudinal Crack Length (m)	Combined Transverse Crack Length (m)	Combined Alligator Crack Area (m^2)
Conventional Section	2009	1.32	-	-	-	-
	2010	1.34	-	-	-	-
	2011	1.31	-	-	-	-
	2012	1.46	3.14	20	3	0
	2013	1.52	2.48	12	1	0
	2014	1.56	3.66	45	25	4
	2015	1.65	3.45	82	23	33
Perpetual Section	2009	1.32	-	-	-	-
	2010	1.36	-	-	-	-
	2011	1.26	-	-	-	-
	2012	1.45	2.07	21	3	0
	2013	1.61	2.08	9	1	0
	2014	1.35	2.21	32	22	8
	2015	1.38	2.74	92	32	35

For better visualization, below are the graphs showing the performance of the 2 sections with time.

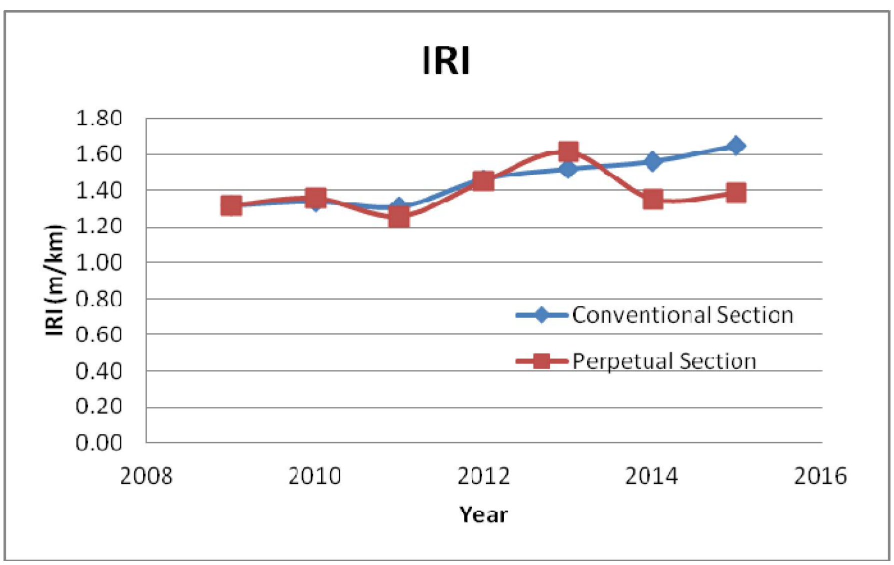


Figure 3: IRI Comparison of Conventional vs. Perpetual Pavement Section

The IRI (Figure 3) for both conventional and perpetual section are comparable for the first few years, and the perpetual pavement section seems to be performing slightly better in the last two years of data in 2014 and 2015.

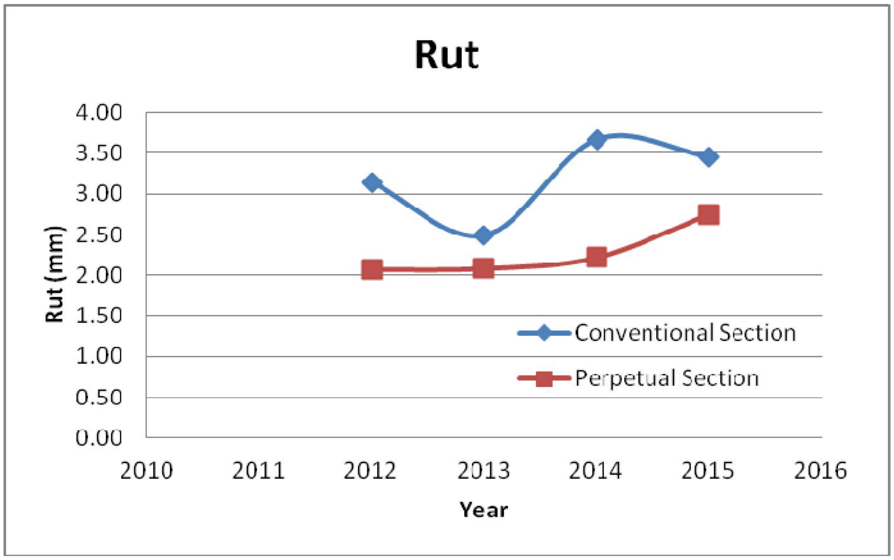


Figure 4: Rut Comparison of Conventional vs. Perpetual Pavement

Due to the limitation of ARAN data rut collection, typically any rutting below 3 mm is consider to be no rutting. Therefore, both conventional and perpetual section bascially has very minimal rutting over the years (Figure 4). However, the perpetual section consistently shows less rutting than the conventional section.

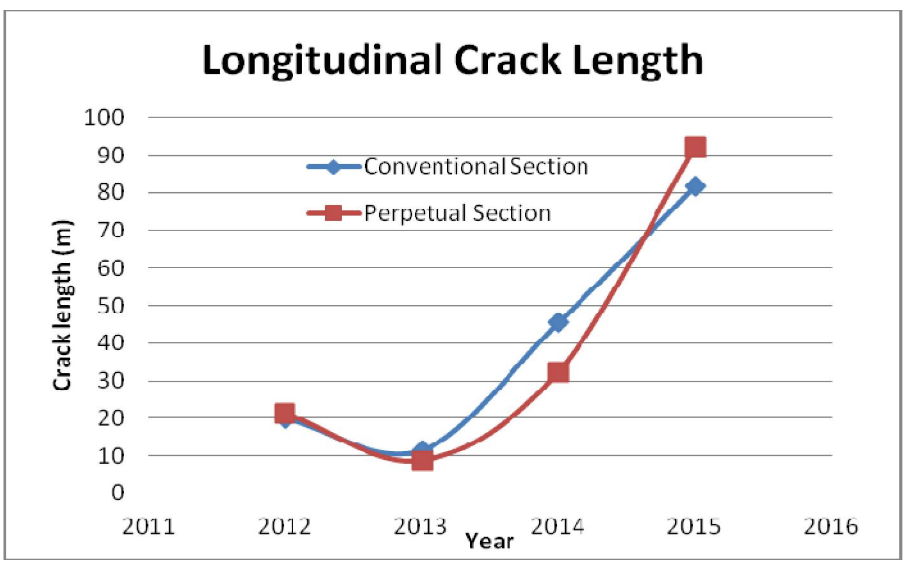


Figure 5: Total Longitudinal Crack Length of Conventional vs. Perpetual Pavement

As the automated data collection processing was not very mature at the time when the data collection began in 2012, the algorithm used to process the cracking data was upgraded from 2012 to 2013. As such, the cracking data in 2012 has shown some longitudinal cracking which is not being captured in 2013 (Figure 5). However, the crack processing algorithm stablized after 2013 and the data after that date are more representative. It shows the longitudinal cracking was comparable for the 2 sections with perpetual section exhibit slightly higher cracking in the most recent data collection in 2015.

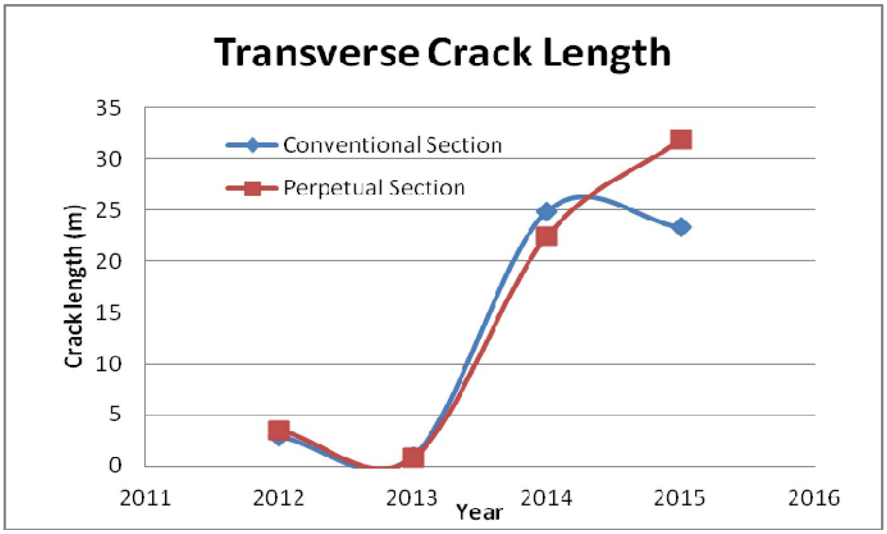


Figure 6: Total Transverse Crack Length of Conventional vs. Perpetual Pavement

Similar to the longitindal cracking, the transverse cracking for both conventional and perpetual section are similar but the most recent 2015 data reveals that the perpetual pavement section exhibits slightly higher cracking (Figure 6).

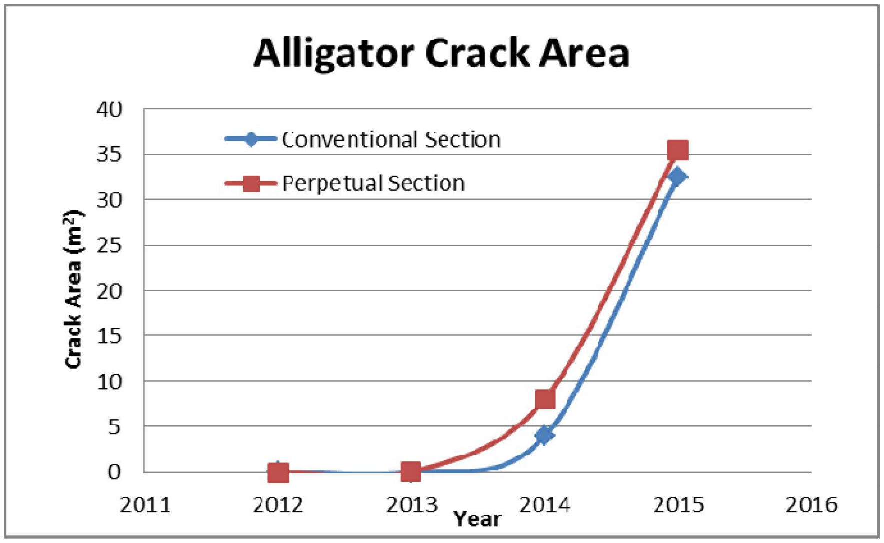
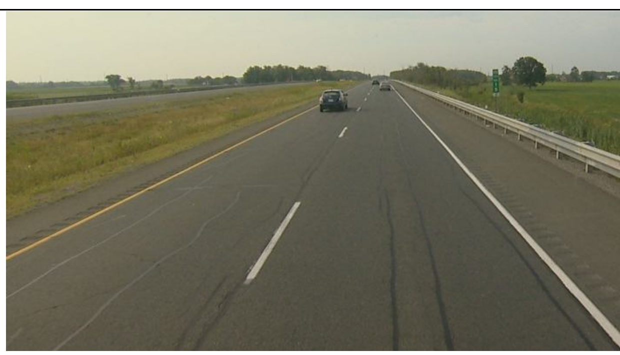


Figure 7: Total Alligator Crack Area of Conventional vs. Perpetual Pavement

The alligator cracking on both perpetual and conventional sections are comparable with the perpetual section exhibiting slightly higher cracking that is considered to be insignificant.

4.3 Visual Comparison from 2012 to 2015

Below are some of the photos taken by the ARAN. These show the typical performance on both the conventional deep strength and perpetual pavement sections. The photos are captured at the same location for comparison over time. It is notable that the pavement exhibited some longitudinal cracks, but was subsequently rout and sealed. The visual analysis shows the two sections are very similar in performance.

Conventional Deep Strength Section	**Perpetual Pavement Section**
 2012	 2012
 2013	 2013
 2014	 2014

2015

2015

Figure 8: Photo Comparison of Conventional and Perpetual Sections Over Time

4.4 Summary

In summary, the peformance data collected from 2008 to 2015 including the manual data, automated data and visual photo comparison show no signifant difference between the conventional and perpetual pavement sections. The IRI and rut analysis shows slightly better performance for the perpetual pavement section, and the cracking data has insignificant differences. The visual photos also appear to be very similar for both sections.

5. CONCLUSIONS AND RECOMMENDATIONS

Highway 406 was selected as the first perpetual pavement trial section in an attempt to verify the long-term benefit of perpetual pavement as a sustainable pavement strategy. This perpetual pavement utilized the rich bottom mix design as the flexible bottom layer that should mitigate bottom up cracking, and therefore only require periodic renewal of the top surface layer.

The performance analysis revealed both the conventional deep strength and the perpetual pavement sections are comparable in terms of performance, with the exception that IRI and rutting are slightly better for the perpetual pavement section. The analysis shows that longitudinal cracking has developed and some has even migrated into alligator cracking. Although it was expected that the perpetual pavement section would have less cracking due to the flexible bottom layer, these surface cracks are top down instead of bottom up, which explains why both sections are performing similarly in terms of cracking.

As perpetual pavement design is meant to be long-term, a nine years old performance comparison of the two sections may not be representative. It is recommended that another performance analysis be carried out at year 15, with the inclusion of falling weight deflectometer (FWD) testing to estimate pavement remaining life for an enhanced comparison.

6. REFERENCES

1. *Ontario's Experience in the Construction of Perpetual Pavement Trials.* **Ponniah, J., Lane, B., Marks, P., Chan, S.** Vancouver, British Columbia : s.n., 2009. Transportation Association of Canada.

2. *SP-024 Manual for Condition Rating of Flexible Pavements - Distress Manifestations.* Downsview, Ontario : Materials Engineering and Research Office, March 2016.