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EVALUATION OF INTERLOCKING CONCRETE PAVEMENT CROSSWALKS THROUGH AN INNOVATIVE FIELD EXPERIMENT

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

SUMMARY

This paper presents an innovative research project involving the design, construction and instrumentation of seven interlocking concrete pavement (ICP) crosswalks. The project is funded by the Interlocking Concrete Pavement Institute (ICPI) with research under the guidance of the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo in Waterloo, Ontario, Canada. In total, there are four different structural designs included in this research. The seven ICP crosswalks were constructed in 2007 in Waterloo, at two locations as follows: three at the Centre of Pavement and Transportation Technology Test Track (CPATT) and four at the University of Waterloo Ring Road. The purpose of the experiment is to evaluate performance and ultimately determine design guidelines for various types of loading conditions.

Each of the crosswalk test sections is instrumented with various sensors to monitor the pavement performance under heavy truck traffic and typical municipal loadings. Furthermore, sensors are included to quantify environmental effects on performance. Data is collected at four-hour intervals and includes stresses, strains, and temperature. Moisture data is collected on a weekly basis using time domain reflectometry probes. A database is being generated for all seven sections and the measured stress, strain, temperature and moisture measurements are analyzed to evaluate the expected long-term performance of the structural components of ICP crosswalks designs. Trucks loading data based on loading configuration is being collected using Weigh-In-Motion at the CPATT test track. In addition, routine portable falling weight deflectometer (PFWD) testing is performed to determine the in-situ conditions of the pavement structures.

This paper outlines the design, instrumentation, and initial pavement performance for the seven crosswalks sections. The paper also provides some initial data and in-situ performance of the seven crosswalks. It is noted that this research is a work in progress and regular monitoring will continue for a three-year period.

1. BACKGROUND SCOPE AND OBJECTIVES

Although interlocking concrete pavers have been shown to provide many benefits in municipal applications in North America, there is mounting evidence of early failures with respect to their use in crosswalk applications. Varying failure modes have been observed and there is a need to better understand the various design aspects of ICPs in crosswalk applications. It is also important that constructability and design are balanced. In short, there is a need for research, which will provide information on which pavement structural designs should be selected based on maximum loading and frequency of loads. In essence, the question of "What cross-section works best for what application?" needs to be answered.

This paper describes unique Canadian research directed at quantifying the structural performance of four different interlocking concrete pavements (ICP) Crosswalk Structural Designs under two different loading scenarios using two different field locations. The first is a waste facility site that has heavy industrial truck loading and the second is a municipal crosswalk with typical car and bus traffic loading. In addition various design options are investigated as follows:

1. Three different base designs are investigated; dense graded, asphalt and concrete base.
2. Three different header transitions are investigated; concrete header, steel header and aluminum header.
3. Bedding layer is varied; unbound concrete bedding sand and bituminous bound sand setting bed.
4. Transition border details such as sailor and soldier courses are varied.

The research study is directed at defining the mechanics of failure for the varying designs. It involves validation of current industry crosswalk design recommendations and establishing threshold values for type and/or number of equivalent single axle loads (ESAL's) for the various crosswalk assemblies. In addition, it will ultimately recommend new designs or modifications to existing designs as needed, based upon the load/traffic/environment/failure modes from the study. The goal of the research is to offer the designer/city/municipality/Department of Transportation personnel design and construction protocols, which will lead to long term successful crosswalk performance. The scope and objective of this paper is to explain the experimental design set up and monitoring of the two field locations, methodology of assessment and preliminary observations resulting from the research monitoring to date.

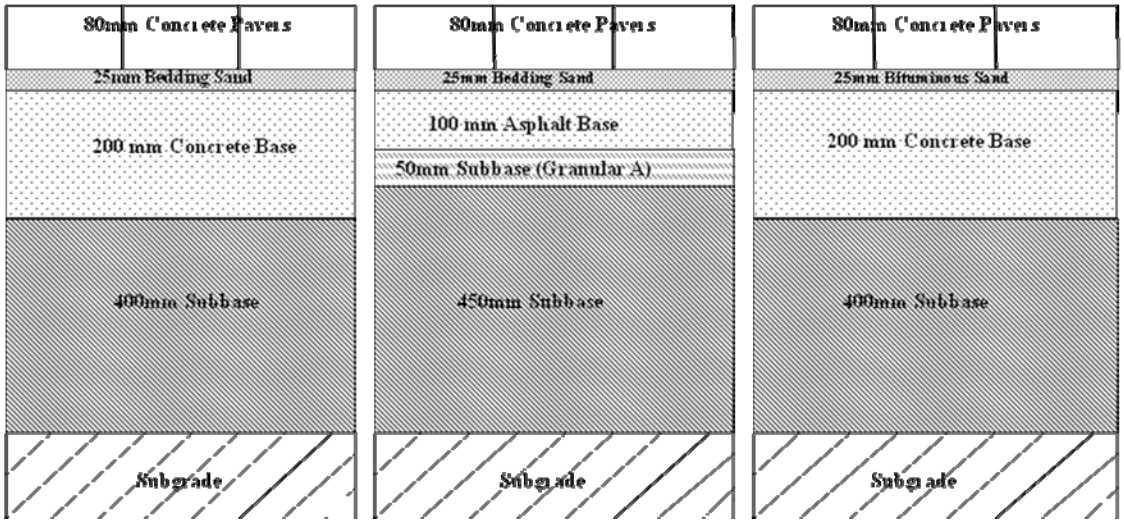
2. STRUCTURAL DESIGNS

The following four designs were selected for the study:

- Sand Set Concrete Base Concrete Header (SSCBCH)
- Bituminous Set Concrete Base Concrete Header (BSCBCH)
- Sand Set Asphalt Base Aluminum Header (SSABAH) and the same design with a steel header (SSABSH)
- Sand Set Granular Base Concrete Header (SSGBCH)

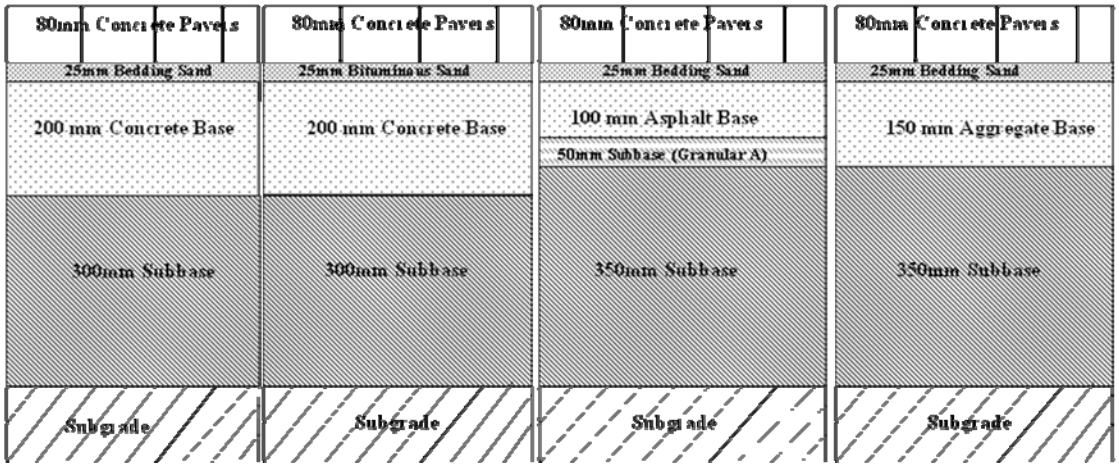
Figures 1 and 2 show the crosswalk structural thickness designs that were placed at both test site locations. At the Test Track: Crosswalk 1- Sand Set Concrete Base Concrete Header (SSCBCH), Crosswalk 2- Sand Set Asphalt Base Steel Header (SSABSH) and Crosswalk 3- Bituminous Set Concrete Base Concrete Header (BSCBCH). At the University of Waterloo Ring Road; Crosswalk 1- Sand Set Concrete Base Concrete Header (SSCBCH), Crosswalk 2- Bituminous Set Concrete

Base Concrete Header (BSCBCH), Crosswalk 3-Sand Set Asphalt Base Aluminum Header (SSABAH) and Crosswalk 4- Sand Set Granular Base Concrete Header (SSGBCH) .



Crosswalk 1 **Crosswalk 2** **Crosswalk 3**

Figure 1. Three Crosswalks Sections Constructed at the CPATT Test Track.



Crosswalk 1 **Crosswalk 2** **Crosswalk 3** **Crosswalk 4**

Figure 2. Four Crosswalks Sections Constructed at the University of Waterloo Ring Road.

3. CONSTRUCTION AND MONITORING

In June 2007, at the CPATT Test Track, the three crosswalk sections were constructed at 3 m length and 8 m width, representing the full width of the asphalt road at the test track. All three of the crosswalks were retrofitted to the existing asphalt pavement, which was five years old at the time of construction (See Figure 3). There are four types of sensors installed at the CPATT location and these are shown in the cross-section detail in Figure 4; strain gauges, earth pressure cells, temperature, and moisture probe. Figure 5 shows typical installation of the earth, moisture, and temperature sensors.



Figure 3. The crosswalks at the CPATT test site were retrofitted in to the existing asphalt test track.

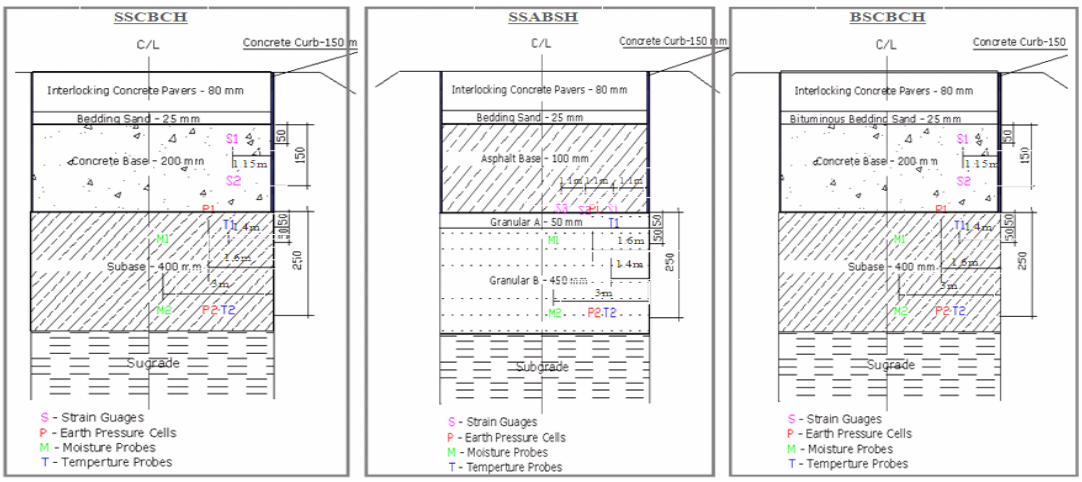


Figure 4. CPATT Test Track Sensor Locations.



Figure 5. Photograph Showing Excavation for Earth, Moisture and Temperature Sensors at the CPATT Test Site – All Sensors are in Loaded Direction.

The University of Waterloo Ring Road crosswalks were constructed in July 2007. All four sections are 2.635 m in width with two sections 12.5 m in length and two at 11.25 m length. The four crosswalks were newly constructed during reconstruction of UW ring road, offering a comparison to the retrofit construction at the CPATT test track. There are strain gauges, temperature and moisture probes installed in the SSCBCH, BSCBCH and SSABAH crosswalks and temperature and moisture probes only in the SSGBCH. Figure 6 shows the placement of the gauges in the four crosswalks at the Ring Road.

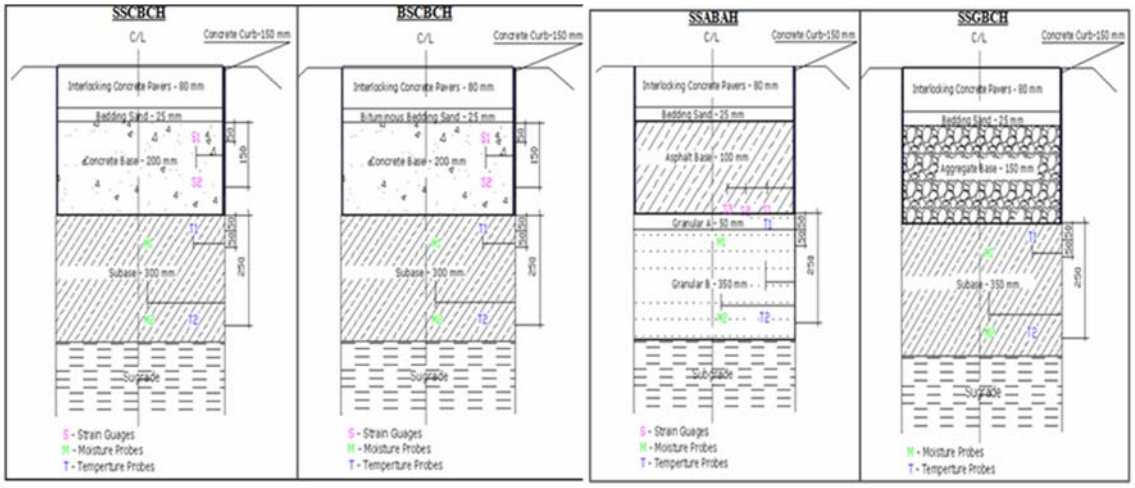


Figure 6. University of Waterloo Ring Road Sensors.

4. DATA COLLECTION

4.1 Sensor Data Collection

To date, stress, strain, and temperature data were collected at the crosswalk test sections from August 2007 to August 2008 at the CPATT test track, and strain and temperature data collected from November 2007 to November 2008 at the University of Waterloo Ring Road. All data is collected at four-hour intervals except for moisture data, which is collected on a weekly basis. The traffic data at the CPATT test track is obtained from the Region of Waterloo Waste Management automation system and the total ESAL count at the test track is calculated at 150 000/year. The traffic data at the Ring Road is obtained from previous University traffic studies and the total ESALSs are estimated to be 26 000/year. Figure 6 shows data collected to date for one section, the Sand Set Concrete Base Concrete Header (SSCBCH) section at the CPATT test track. In this example, it is notable that the moisture in the subbase fluctuates substantially while there are fewer variations in pressure at the top of the subbase and at 250 mm in the subbase. Figure 7 shows the relationship between strain and temperature. It is notable in this example that the observed strain and temperature show a direct inverse relationship.

Similar data has been collected for the other sections at the test track and the ring road and are available in the report, *Interlocking Concrete Crosswalk Research Project – Progress Report # 3* [CPATT, 2009].

4.2 Pavement Distress Evaluation

In addition to monitoring performance using the sensor data, regular pavement distress surveys are being conducted on each of the seven constructed sections. Distress condition surveys in accordance with the Interlocking Concrete Block Pavement Distress Guide developed by ICPI

[ICPI, 2008]. The guide is based on the Pavement Condition Index (PCI) methodology and was modeled on the U.S. Army of Corps of Engineers MicroPAVER distress guide as published by ASTM [ASTM, 2007]. Figure 8 shows an example of the rutting profile used in the evaluation for the SSCBCH crosswalk that was presented in Figures 6 and 7. The rut profiles are plotted in the longitudinal direction (full lane width) as well as the wheel path direction (in this case 3 m distance), and a photo of the section distress area is also provided.

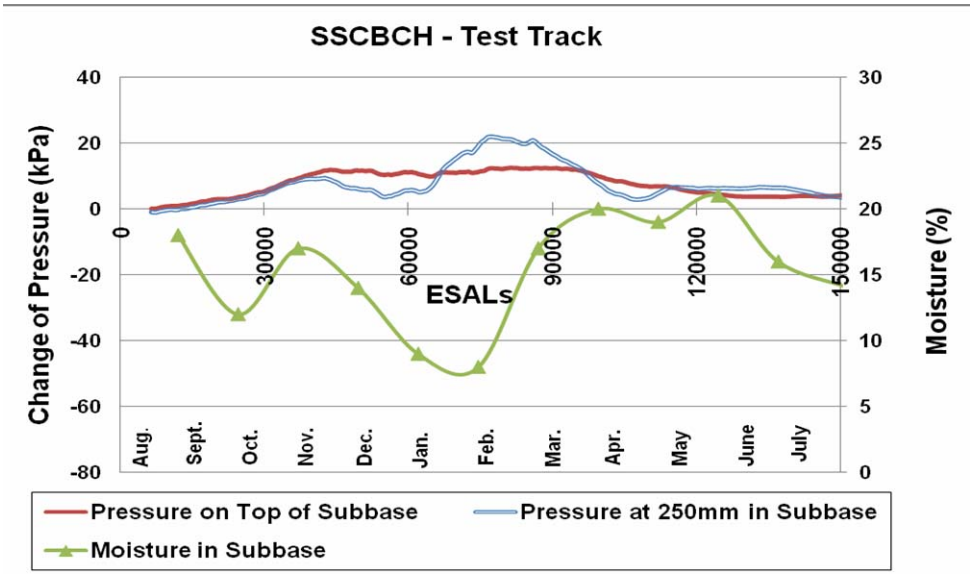


Figure 7. Example Earth Pressure Cell and Moisture Data for SSCBCH Test Track.

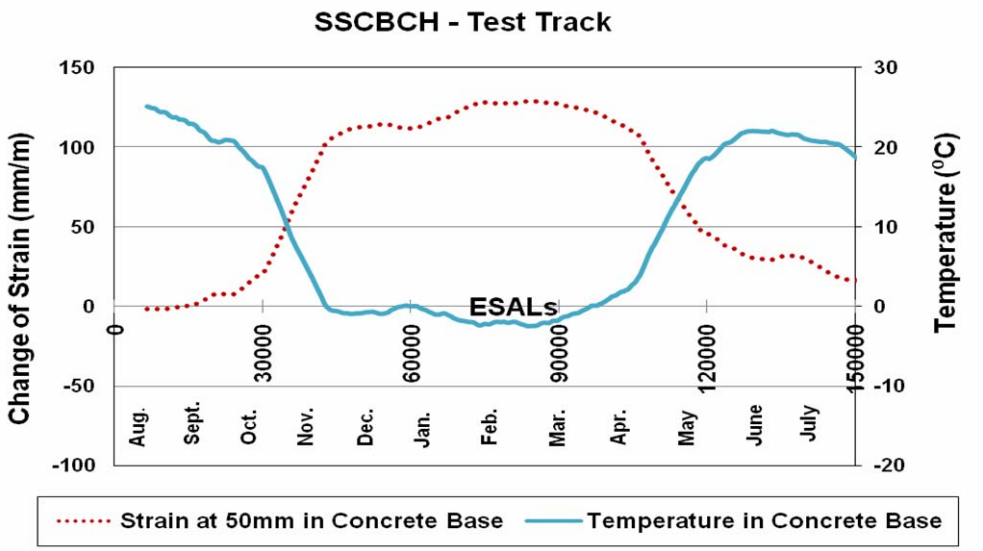


Figure 8. Example Strain Data for SSCBCH Test Track.

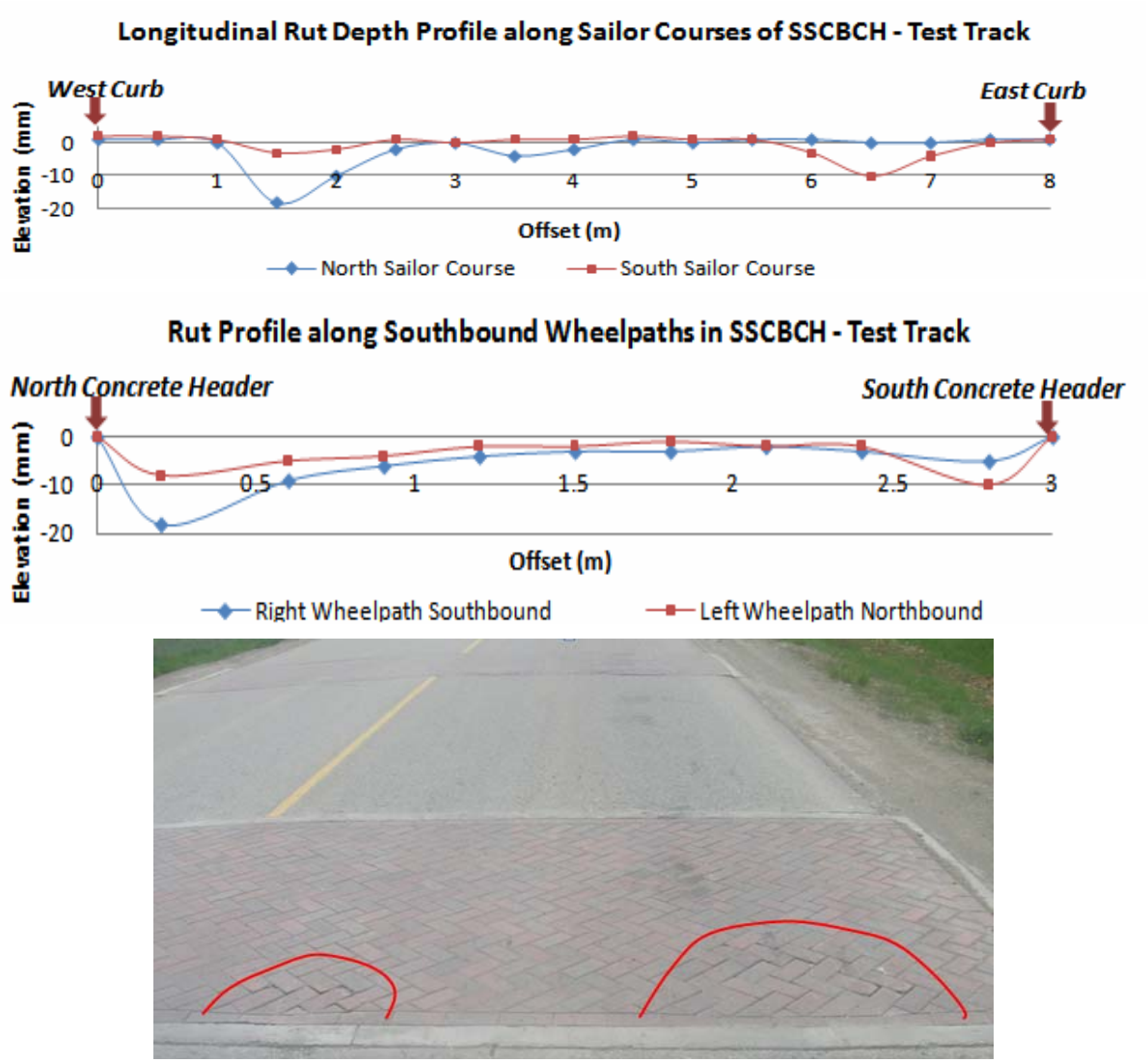


Figure 8. Example of Pavement Distress Survey measurement for the SSCBCH section at the CPATT test track and a photograph of the section in service.

Tables 1 and 2 show a comparison of the PCI for the different crosswalks at both research locations. It should be noted that the SSCBCH section shows a lower than expected PCI but this is due to a surface drainage problem at the site, not associated with the design, that was not identified during the construction phase.

4.3 Deflection Testing

Deflection measurement techniques are widely used for the structural evaluation of pavement. The testing to monitor the structural performance of the crosswalk sections is being carried out by using the CPATT Light Weight Deflectometer (LWD 3031). The LWD is a light, portable device that creates a non-destructive shock-wave through the soil as a result of the impact of a falling mass (10 kg, 15kg or 20 kg) from a variable drop height (100 mm to 850 mm).

Table 1. Pavement Condition Index for the CPATT crosswalk sections.

	(SSCBCH)	(SSABAH)	(BSCBCH)
PCI	**70**	**64**	**100**
PCI Rating	Good	Good	Excellent
Pavement age	1 Year	1 Year	1 Year
Total ESALS	150 000	150 000	150,000

Table 2. Pavement Condition Index for the Ring Road crosswalk sections.

	(SSCBCH)	(BSCBCH)	(SSABAH)	(SSGBCH)
PCI	**51**	**100**	**78**	**83**
PCI Rating	Fair	Excellent	Very Good	Very Good
Pavement age	1 Year	1 year	1 year	1 Year
Total ESALS	6,400	6 400	6 400	6 400

Using the data from the LWD, the structural behavior of each section is compared in terms of composite elastic modulus, deflection, and Structural Adequacy Index (SAI). The deflection used in SAI calculations has been adjusted for temperature in accordance with standard practices. The values for SAI range from a perfect score of 10 to a totally inadequate score of 0, are calculated using measured deflection, and deduct curves [TAC, 1997]. Figure 9 shows the elastic modulus and deflection results for the SSCBCH section at the CPATT test track. Figures 10 and 11 show the maximum deflection measurements of all of the crosswalks at both test site locations and the SAI comparison. It should be noted that all sections are demonstrating very high SAI values after one year.

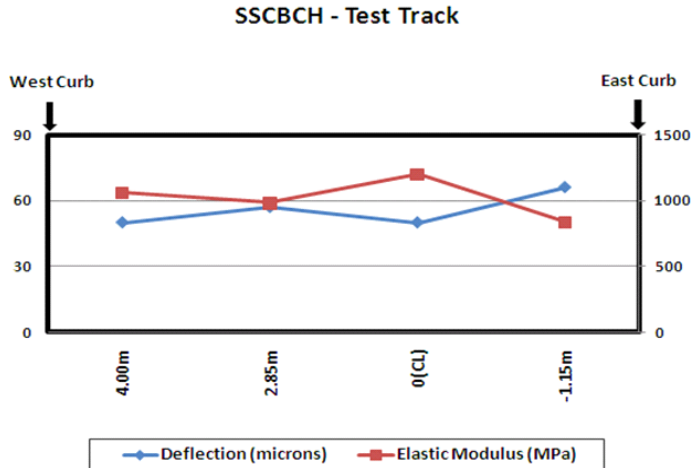


Figure 9. Elastic Modulus and Deflection in SSCBCH at the CPATT Test Track.

5. SUMMARY OF OBSERVATIONS TO DATE

At the Test Track, the stresses and strains are observed as follows:

- The maximum observed stress for all sections is measured in the asphalt base section (SSABSH) followed by sand set concrete base (SSCBCH) and bituminous set concrete base (BSCBCH) crosswalks. This observed trend is also consistent with the distress observations and measurements.
- The maximum strain is observed in the bituminous set concrete base crosswalk (BSCBCH) followed by sand set concrete base (SSCBCH) and sand set asphalt base (SSABSH)

crosswalks. Since the maximum strain value is well below the allowable strain from typical models, there is no indication at this time of unserviceable fatigue cracking in the sections. The fatigue cracking occurs when the maximum tensile strain exceeds the maximum allowable strain.

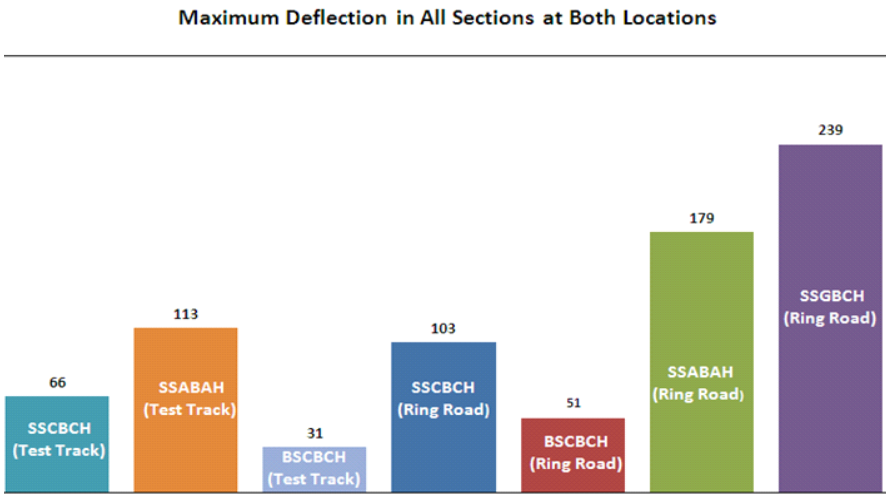


Figure 10. Comparison of Maximum Deflection at Both Locations (Microns).

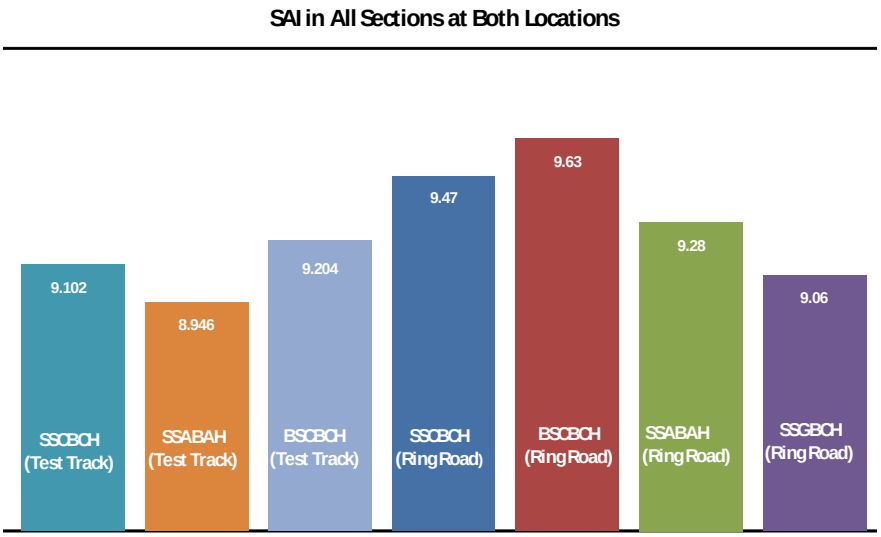


Figure 11. Comparison of SAI in All Sections at Both Locations.

At the Ring Road, the strains are observed as follows:

- Maximum observed tensile strain for all test sections is found in the bituminous set concrete base (BSCBCH) section followed by sand set concrete base (SSCBCH) and sand set asphalt base (SSABAH) crosswalks.
- The maximum tensile strain has not exceeded the maximum allowable strain. Therefore no unserviceable fatigue cracking has occurred in the sections in this period. This observed trend is not consistent with the distress observations and measurements.
- It is observed that, the lowest performance is of the concrete base sand set (SSCBCH) crosswalk and this is suspected to be due to inadequate surface drainage design which caused severe ponding of surface water runoff on this crosswalk in the spring of 2008. Horizontal

creep is also observed in this section where the half-cut paver sailor course in the loaded direction.

Other preliminary findings to date include the following observations:

- Rutting and distress is generally highest severity at header transitions and not through the entire wheel path
- At the CPATT test track maximum rutting is in the loaded truck direction
- There is some evidence that sailor course transitions are performing better than soldier course
- All crosswalks observed strains have a strong relation to temperature at both locations at both research locations

6. CONCLUSION AND NEXT STEPS

Monitoring of the test sections at both sites will continue until May, 2010. The fourth progress report will be provided in May, 2009 and will include the latest performance data. Additional modeling of the pavement performance will provide longer term trends and a database will be established within CPATT to regularly monitor the performance of the test sections. As the monitoring continues, the research team will develop and calibrate pavement prediction models using the observed strain and stresses and compare with existing empirical models. In addition, structural evaluation of the sections will continue to be carried out by PFWD.

7. REFERENCES

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