The Nisku Test Road: Direct Measurement of the Impact of Heavy Loads on Thin Membrane Pavements

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ABSTRACT: This paper describes the design and construction of the Nisku Test Road in Alberta which is designed to monitor the pavement response under heavy oilfield cranes (with hydraulic suspensions and super single tires) on thin membrane asphalt pavements. Three 50m test road sections (thin asphalt wearing course, bituminous surface treatment and granular surface) were built and instrumented for strain at the bottom of the asphalt layer, surface deflection, and subgrade pressures. Temperature and moisture profiles are also measured. Field testing involved controlled speed experiments of standard axle configurations and heavy (12,000kg) axle vehicles with and without hydraulic suspensions. The results presented are from the first two cycles of testing at the site where vehicles upto 95,500 kg were evaluated in an attempt to understand the impact of these large vehicles on thin membrane pavements. The tests are part of a long term study to evaluate pavement performance and to develop load equivalency factors.

Introduction and Background

Road authorities in resource based economies are frequently challenged by the demands of heavy equipment operators requiring access to remote sites during sensitive spring thaw conditions. Access to these sites is frequently along low volume, structurally under-designed pavements and consequently many of these pavements suffer premature deterioration as a result of vehicle overloads. To overcome this, agencies impose restrictions that are based upon Load Equivalency Factors (LEF) which were initially developed at the AASHO test road and have become the basis not only for overload permitting, but also for pavement design. Using LEFs, all vehicles using the road during the design period can be equated to a number of standard axles and the pavement structural thickness determined. LEFs reflect the expected damage imposed on the road by the vehicle, relative to a standard 80kN (18,000 lb) single axle (referred to as the Equivalent Single Axle Load (ESAL)).

Recently, vehicle manufacturers have begun to design the vehicle to minimize pavement design through the use of larger tires, lower tire pressures, central tire inflation, hydraulic suspension systems and new axle configurations. These changes have altered the vehicle dynamics and a lack of understanding of the impact of these new mechanical systems (referred to as super singles) on pavement structural behavior means that existing Load Equivalency Factors may not be accurate for these vehicles. Extrapolation of the current LEFs for overload permitting has resulted in increased costs to the operators as agencies require owners of these new vehicles to 'break-down' the vehicle onto multiple flatbeds and/or dollies to meet legal load limits. An indication of the costs to the operators of this break-down and reassembly was illustrated recently when a Canadian provincial highway agency allowed a heavy crane (in excess of 48,000kg on four axles) to travel between two sites during the winter months without multiple additional dollies. The operator had to move the crane approximately every two weeks for a period of four months and the cost savings were in excess of $200,000 CDN. On the basis of these cost savings an initiative was begun in Alberta to investigate the impact of the new super single vehicles on typical pavements found throughout the province. Super single tires in Canada were in question due to the fact that many Canadian roads are thin membrane structures that cannot support heavy loadings.

This study is similar to other studies that have been done in Alberta and other locations that have used instrumented test roads to evaluate pavement response (Christison et al (1978), Christison (1990), Sebaaly et al (2003)) for a range of vehicle types and pavement configurations as summarized in Table 1. These studies were selected because they reflect two factors, first because of Alberta's history with this issue and second showing studies where irregular vehicles were tested.

Table 1. Background Summary

Author/ location	Response measured	Axle configuration axle/ tire/l oad(kN)	Pavement type	Finding
Christison et al (1978)/ Alberta	**s**train @ bottom of AC, **s**tress @ top of subgrade, **t**otal surface deflection	**s**ingle/dual56-117, **s**ingle/single9-53, **t**andem/dual95-334, **s**ingle/single71-295 ,(on regular axle configuration vehicles)	**t**wo full depth flexible pavement 200 & 280 mm on a 1.2 -1.5 m of common borrow subgrade of high-ly plastic soil.	**i**nterfacial strain and surface deflection increase with the increase of pavement age and pavement temperature and decrease with the increase of vehicle velocity.
Christison (1990)/ Alberta	**s**train @ bottom of AC, **s**urface deflection	**s**ingle/single up to 98 kN/axle for two multi-axle cranes,	**t**wo flexible pavements, 135mm AC on 170 cement treated base & 135 mm AC on 250 granular base. Subgrade in both is med-high plastic till.	**LEF** for cranes varied from 5.2-26.8 depending on pavement type, crane type, vehicle speed, and basis for calculation (strain based or deflection based).
Sebaaly et al (2003)/ South Dakota	**s**tress in sub-grade, and base, **s**urface **d**eflection	**f**our agricultural vehicles on single tires and with axle load 17.9-49.5 KN.	**t**wo low volume road pavement, 100 mm & 212 mm Crushed Aggregate Base (CAB) both on silty subgrade.	**m**ost of the vehicles tested showed more damage than the standard 80 kN axle load. LEF values decreased as the season change in this order: summer (highest), fall, spring, winter (lower). LEF values decreased with the increase of the base course layer thickness.

Objectives of the Study

In order to study and assess the effect of these loads, a test road was built and instrumented in the County of Leduc - Nisku Industrial Business Park – near to Edmonton International Airport in late spring 2005. The test road is funded by a consortium referred to as the Alberta Road Research Initiative, comprised of industry, academia and government. The Nisku Industrial Business Park is the home of many oilfield servicing companies, serving the Northern Alberta oil fields and consequently, is resident to many of the large vehicles of interest.

The objective of this test road is to study the impact of heavy axle loads on thin membrane, flexible pavement structures. Specifically, the study has several long-term objectives including: (1) Development of Load Equivalency Factors for non standard vehicles, (2) Evaluation of the long-term performance of standard pavement section under heavy loading, and (3) Evaluation of seasonal variation in pavement response.

Test Road Design and Instrumentation

The test road was designed to capture the Alberta provincial highway and county road standards with construction of three 150 meter sections with a road surface width of 9.0 meters. Three pavement structures: Hot Mix Asphalt Concrete (HMA), Cold Mix Asphalt Concrete (CMA) and Granular Base Course (GBC) were constructed. The subgrade soil is a heavy plastic clay and the road prism has been constructed using a silty clay borrow material. All of the pavements are constructed on a standard 150 mm prepared subgrade and the pavement structure for HMA section is shown graphically in Figure 1. The test road instrumentation design and information is summarized in Table 2 and shown graphically in Figure 1.

Table 2. Summary of test road instrumentation design

Device type	Quantity/manufacturer	Function	Location
Pressure Cells	HMA (4)/RST Instruments-strain gauge based type	Measuring vertical pressure on the subgrade	IWP & OWP paths, 300 mm below the top of the subgrade
Strain Gauges	HMA (12)/Dynatest PAST II-strain transducer	Measuring interfacial strain along and perpendicular to travel directions	IWP & OWP, at the interface between the asphalt concrete layer and the granular base course layer
Linear Strain Conversion (LSC)	HMA (4)/Apek-25 mm (LSC)	Measuring surface deflection	Centre lane (between IWP & OWP)
Data Acquisition System	HMA (1)/ National Instruments NI-SCXI (s.w. Labview- 7.3)	Captures and record data from devices	Portable unit next to the instrumentation area outside the pavement
Environmental Conditions Measurements Devices	HMA (6)/ * Thermocouples wire type-T, gauge 20 * Moisture profile-Delta-T devices	Measuring temperature and moisture across the pavement structure	Strategically distributed around the instrumentation area across pavement width to take measurements up to one meter deep in the pavement

Testing Program

The test program is designed to study the effect of the heavy loading on the pavements over a five year period. The first year testing plan includes late spring, summer, fall, winter, and early spring seasons in order to validate/evaluate seasonal adjustment factors. As of the time of writing only the late spring and fall tests have been completed. A generic testing plan for each series of tests is presented in Table 3. As seen in Table 3, each vehicle traverses the site five times with a standard 80 kN axle vehicle establishing base line results at the beginning, ending and at speed changes.

This paper discusses only two vehicles of the different vehicles that were used in both series of test. The two vehicles are: a standard 80 kN (18 kip) single axle truck, a 44,000 kg Speirings

Crane operating on eight wheels / four axles. Each vehicle was weighed on site, by County officials using a portable weigh scale system. The vehicles weights and axles details are summarized in Table 4.

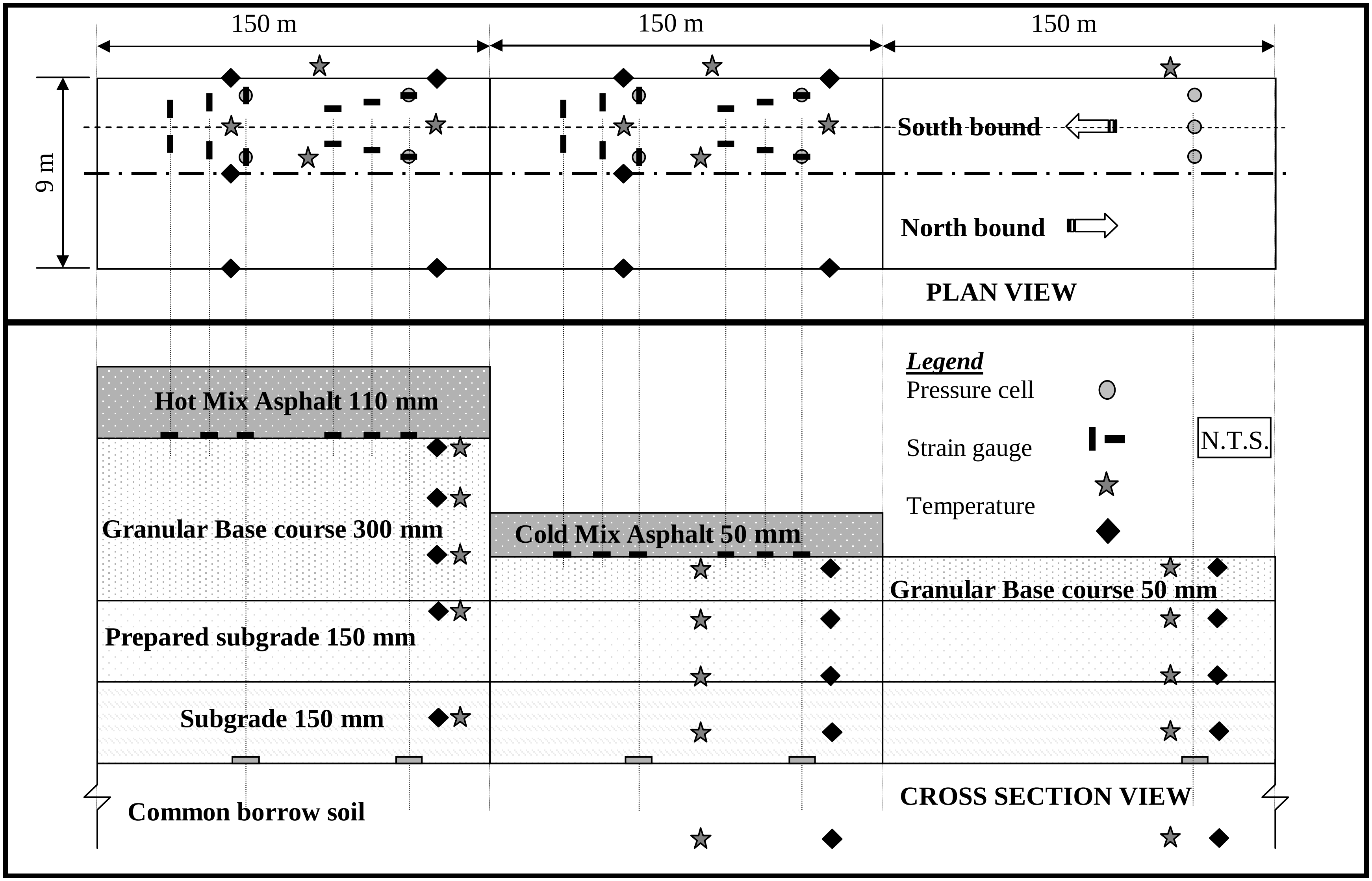


Figure 1. Test road layout and instrumentation layout

Table 3. The testing sequence

Load	Repetition No.				
	1	2	3	4	5
Standard (ST18) @ 60 km/hr	✓	✓	✓	✓	✓
Standard (ST18) @ Creep speed	✓				
Crane (CR01) @ Creep speed	✓	✓	✓	✓	✓
Standard (ST18) @ 20 km/hr	one pass				
Crane (CR01) @ 20, 40 and 60 km/hr *	✓	✓	✓	✓	✓
Standard 18kip @ 60 km/hr	✓	✓	✓	✓	✓

* Between each speed change there was one pass of the ST 18 vehicle

Table 4. Tests vehicles' weights and axle details

Vehicle (length)	Axle No.	Type	Tire Pressure (kPa)	Axle Weight (kg)	
				Spring	Fall
Standard 18	1	Single, single tires [(1)]	517	4,950	4,950
	2	Single, dual tires [(2)]	517	7,800	8,200
Crane 01 (CR01)	1	Single, super single tires [(3)]	620	11,700/8,300	13,200/9,100
	2	Single, super single tires	620	12,400/8,300	14,100/9,775
	3	Single, super single tires	620	10,650/8,300	14,000/9,800
	4	Single, super single tires	620	9,200/8,300	12,400/8,850
Crane 02 (CR01 + dolly)	5	Single, super single tires	620	n/a /6,800	n/a /8,350
	6	Single, super single tires	620	n/a /6,800	n/a /7,725
	7	Single, super single tires	620	n/a /6,800	n/a /8,400

[(1)] Michelin XZE M/S 275/80R22.5
[(2)] Michelin XDE M/S 275/80R225
[(3)] Goodyear Omnitrack MSS 445/75R22.5

Preliminary Test Results

The full program for this study includes conducting a series of field tests for several vehicles in different seasons over four years. The other variables in each series are related to the pavement type and vehicle speed. In this paper early findings from two series (spring 2005 and fall 2005) for two of the test vehicles: the standard 80 kN truck and the 44,000 kg Crane (referred to as ST18 and CR01 respectively in this study), for two speeds (Creep and 60 km/hr), and for two pavement sections, the hot mix and the cold mix asphalt (referred to as HMA and CMA in this study) are presented. Table 5 below shows the average temperature and moisture content recorded during the both test series.

Table 5: Average temperature and moisture content for the test road pavement structure

Layer	Spring test (June 27, 2005)		Fall test (October 16, 2005)	
	Temp. (C°)	Moisture content (%)	Temp. (C°)	Moisture content (%)

Ambient Air	16.6	N/A	5.6	N/A
Granular Base Course	18.0	51	9.6	35*
Subgrade	18.9	56	9.5	47*
Common borrow soil	13.8	88	11.3	- **

* Rained during the night before and morning of the test
** Moisture in the gauge

HORIZONTAL INTERFACIAL TENSILE STRAIN

The horizontal interfacial tensile strain measured in the field test includes both the strain along the travel direction and the strain perpendicular to the travel direction (referred to as the longitudinal and the transversal interfacial strain, respectively). The measured longitudinal strain is shown in Figure 2 below; part (a) is for the spring season and part (b) is for the fall season. This figure shows the variation in the mean longitudinal strain value in regards to the vehicle and pavement section type and for two speeds (creep and 60 km/hr). The mean value reported here is the average of the five maximum readings obtained from five trials. Following the methodology used by Priest at al. 2005, the mean value for each speed is defined as the average of five maximum readings from the instrumented array. This methodology takes into account vehicle wander over the array. In general the maximum reading for the ST18 is under the rear axle of the vehicle while the maximum reading for the CR01 is under axle #2. These results show that the mean longitudinal strain value for the CMA pavement section, in general, is greater than its value for the HMA pavement section for both vehicles in both seasons. It was also found that the mean longitudinal value for the ST18 is less than for the CR01 for both pavement sections and in both seasons. Further, the mean longitudinal strain for the creep speed is generally greater than for the 60km/hr speed. The only exception is the result for the CR01 in the CMA section in the spring season. The mean longitudinal strain value for CR01 in the CMA section is slightly less than for the HMA section and also less than for the ST18 for the same pavement section. In order to verify this finding, the box-plot results from all the strain gauges and for both pavement sections and both vehicles were graphed together and are shown in Figure 3. In that figure, the readings for the CR01 and for the ST18 were circled to identify three different groups (the CR01-CMA, CR01-HMA, and ST18-CMA section). No clear explanation for this finding is available at this time as this results need to be confirmed by more tests to see if this behavior will be repeated again. No longitudinal strain could be measured in the CMA section in the fall due to catastrophic failure of the pavement at that point. Moisture ingress to the outer wheel path as a result of rain the evening before weakened the pavement and one pass of a very large vehicle (95,000kg on 12 wheels) punched through the pavement, destroying the gauge.

Finally, an important finding is that the mean value for the longitudinal strain for the spring season is greater than for the fall season for all the vehicle-pavement combinations and this is clearly due to the change in the temperature and also to the change in the moisture content in the pavement structure under the asphalt pavement layer. The difference was greater in the case of the CR01 and for the creep speed results in general.

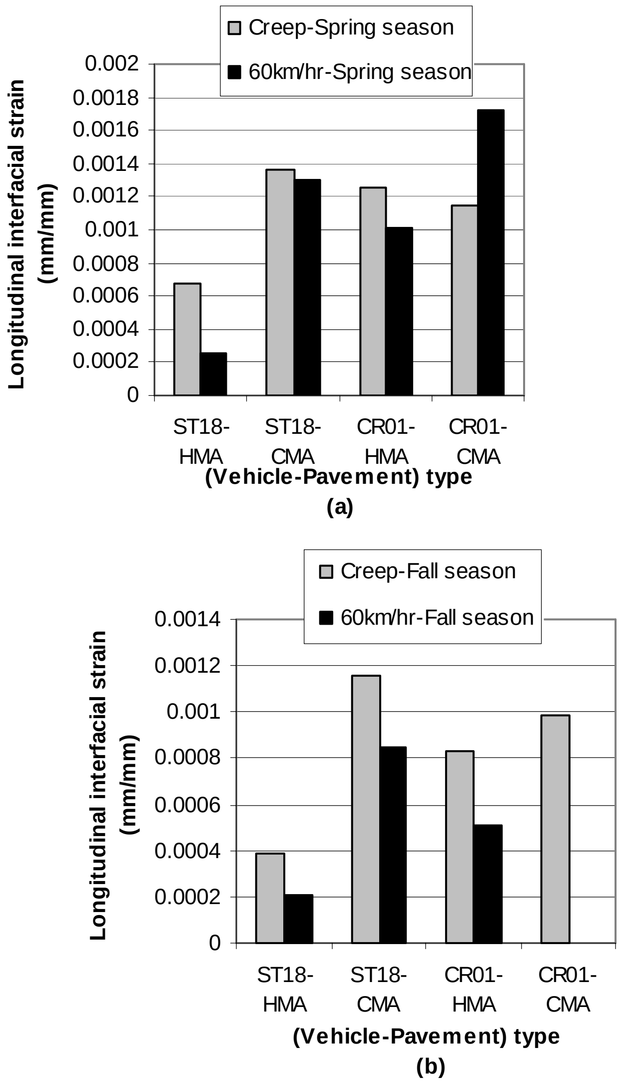


Figure 2. Mean longitudinal interfacial strain variation (a) spring season (b) fall season

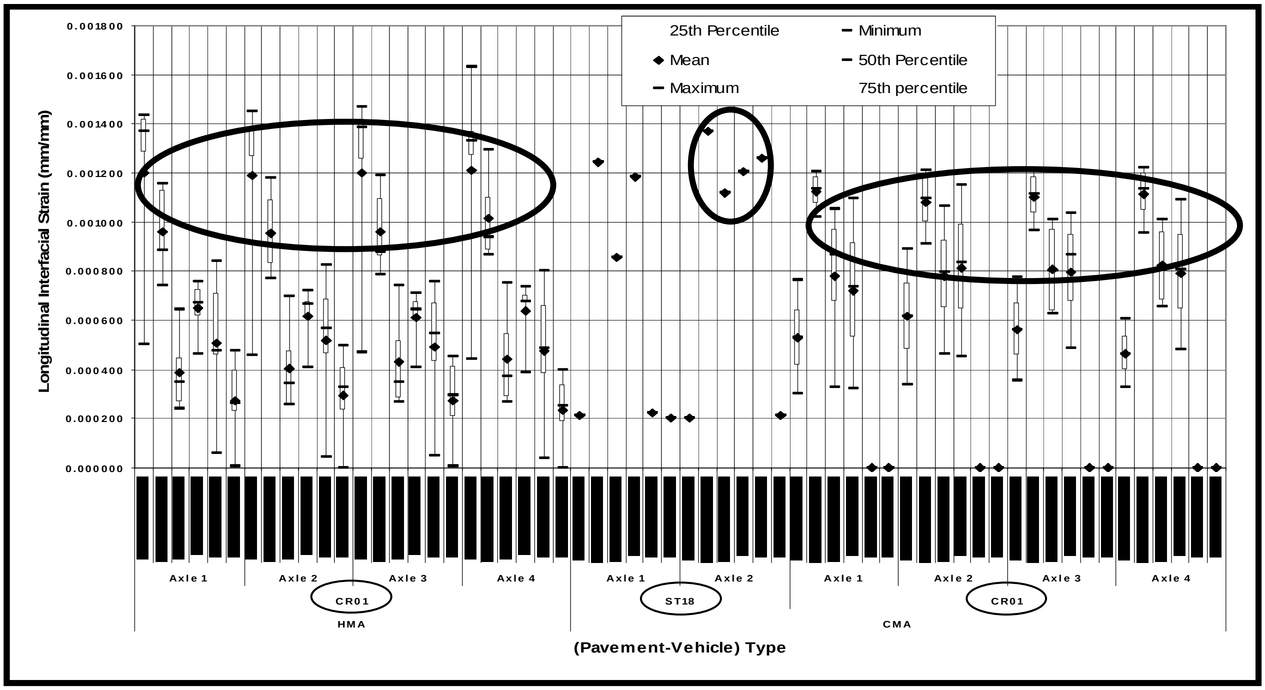
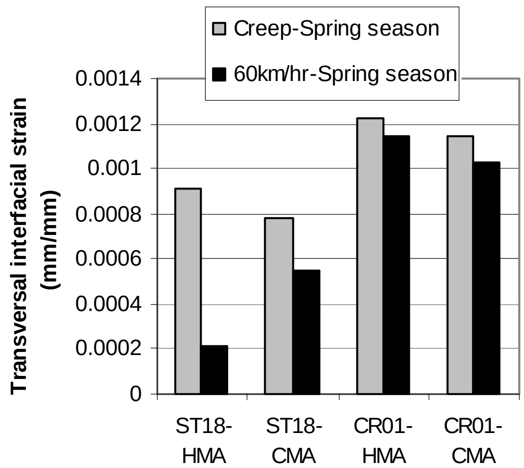
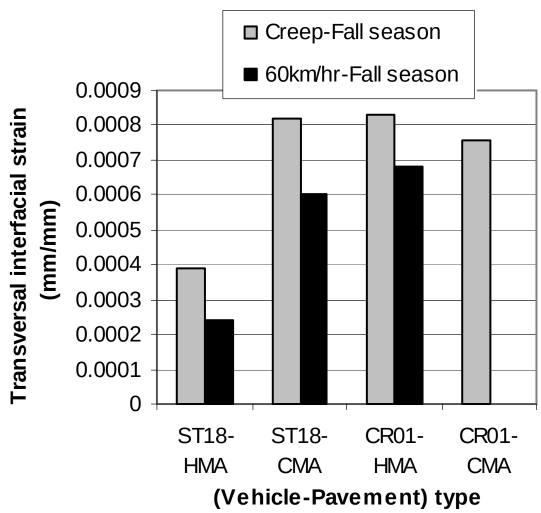


Figure 3. Box-plot for all the strain gauges reading for the CR01 and ST18-creep speed-spring season

The measured transversal interfacial strain is shown in Figure 4 below; part (a) is for the spring season and part (b) is for the fall season. Similar results were obtained for the CR01-CMA and CR01-HMA with the CMA section exhibiting less strain than the HMA.



(a)



(b)

Figure 4. Mean transversal interfacial strain variation (a) spring season (b) fall season

VERTICAL STRESS IN SUB-GRADE

The vertical stress in the sub-grade was measured by two pressure cells in each of the HMA and CMA sections. Figure 5 above, shows the variation in the measured mean vertical stress in sub-grade by vehicle type and season. Due to some technical problems in the CMA section considerable parts of the data were not retrieved and therefore only results from the HMA section are reported. As shown in Figure 5, the mean vertical stress in sub-grade for the CR01 is greater than for the ST18 for both seasons. As for the speed, the vertical stress associated with the creep speed is greater than for the 60 km/hr for both vehicles and for both seasons. Finally, for the seasonal change, the mean vertical values for the spring season is greater than for the fall seasons for both vehicles and for both speeds. This is again primarily due to the change in the moisture content in the pavement structure and due to change in temperature.

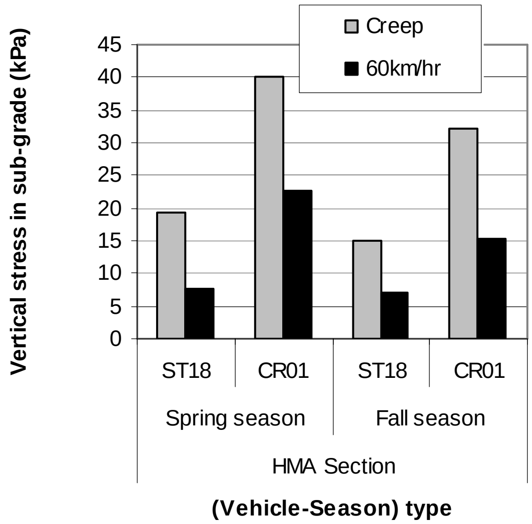


Figure 5. Mean vertical stress in sub-grade variation-HMA section

SURFACE DEFLECTION

The surface deflection results for the fall test are shown in Figure 6. These results show the maximum recorded values for both deflection at the base of the asphalt layer with a positive deflection indicative of tension and a negative deflection of compression. The results show close and even slightly higher values for the ST18 vehicles compared to CR01 (the typical deflection profiles for the Crane CR01 and the ST18 vehicles is presented with more details in section 5.4). Compression deflections for the CMA section are slightly greater than the deflections for the HMA section when comparing the results for the same vehicle. This is could be due the difference in strength between the two pavements On the other hand tension deflections are slightly higher for the HMA when compared to the CMA.

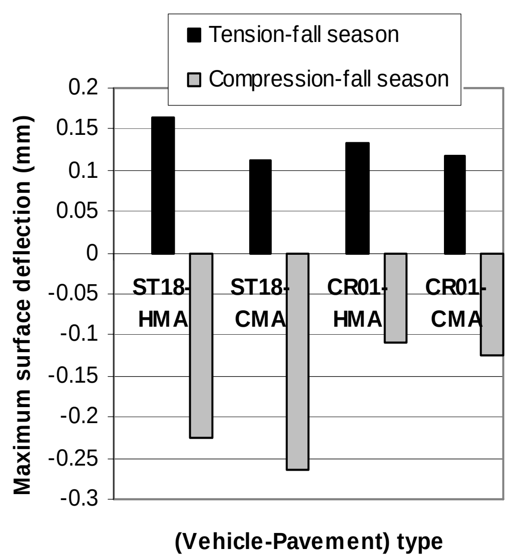


Figure 6. Maximum surface deflection in the asphalt pavement layer-fall season

THE SURFACE DEFLECTION PROFILE

The typical surface deflection profiles for the ST18 and the CR01 vehicles are shown in Figure 7 and Figure 8, respectively. These profiles are for the HMA section and for the creep speed showing axle loads and spacing as well. In both figures three curves are shown. Each curve represents the signal from one of the three devices that were aligned 12 inches apart on a straight line. In Figure 7 for the ST18 truck, the signal shows two major surface deflections from the two axle loads as the traverse the deflection beam. During the time between each axle is a time where the pavement tends to settle down with less movement due to the large spacing between the two axles. While for the crane CR01 case, shown in Figure 8, the dampening effect of the axle spacing is participating significantly in changing the direction of the surface movement and hence obtaining this oscillation type of movement that make the pavement more unstable when these types of axles move on the pavement. This could be the reason why relatively smaller maximum tension or compression surface deflections are noticed in the CR01 case compared to the ST18 case. Another thing to observe in figures 7 and 8 is the number of times through which the.

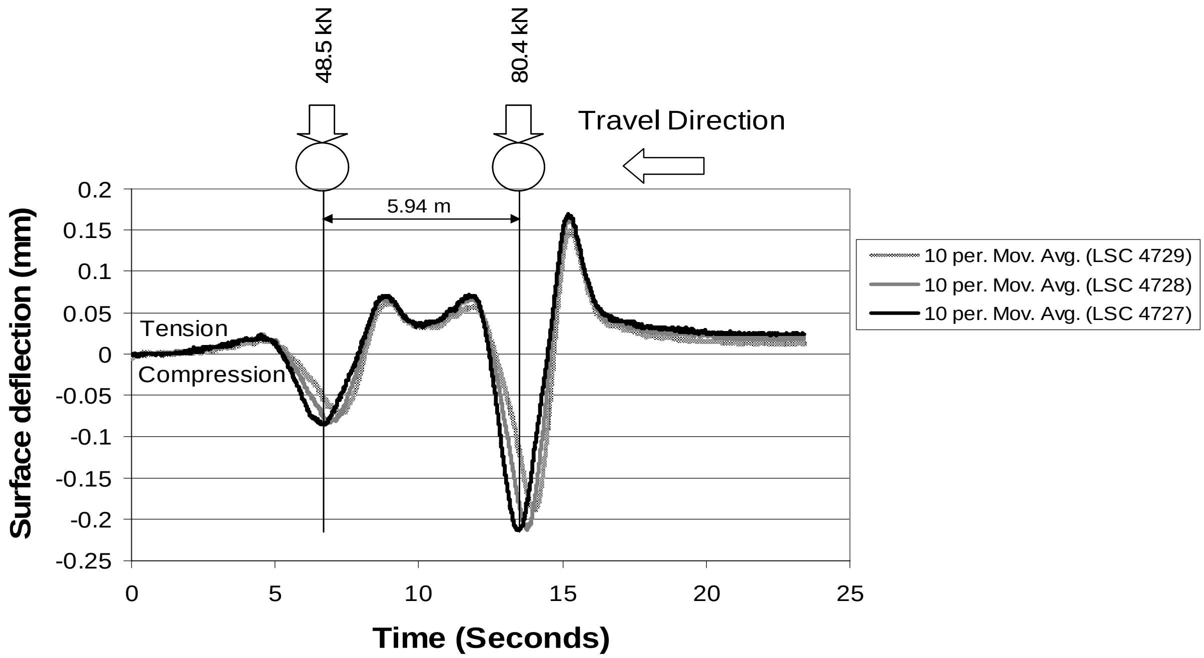


Figure 7. Typical surface deflection profile for the ST18 vehicle-HMA section, creep speed, fall season

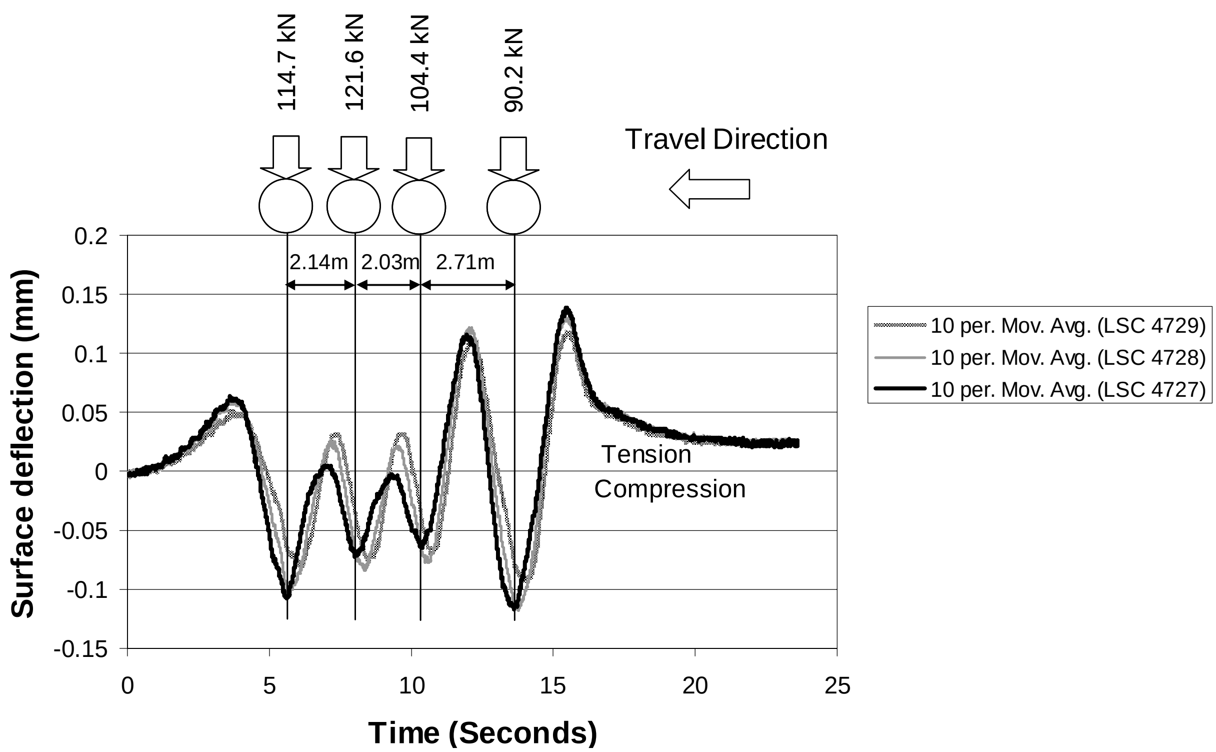


Figure 8. Typical surface deflection profile for the CR01 vehicle-HMA section, creep speed, fall season

deflection curve passes through the neutral axis is same (four each). On the other hand, the order and magnitude of the compression deflection peaks (that result in tension stresses at the bottom of the asphalt layer) is different. This will be one of the areas for future study over time and multiple seasons.

Conclusions

This paper has presented some early findings from direct measurement of pavement response at the Nisku Test Road. The testing program will continue until 2009 however, some preliminary results indicate:

1. The heavy axle vehicle (CR01) has generated higher pavement response in terms of the horizontal interfacial strain and vertical stress in sub-grade compared to the standard 80 kN truck.
2. As expected, the HMA section is more capable of handling these higher axle loads. This is clearly shown in the lower values for most of the pavement responses that were measured in this study so far.
3. The seasonal change has a considerable effect on the pavement response. This was seen in the reduction in most of the pavement responses for the fall season compared to the spring.
4. Further tests for the other seasons will continue to confirm the early findings and to work towards an improved understanding of the response of thin-membrane pavements under heavy vehicle loads.

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