Pavement Response to Legal Overloads at the Nisku Test Road, Alberta

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Abstract

Road authorities in resource based economies are frequently challenged by the demands of heavy equipment operators requiring access to remote sites. The access to these sites is often 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 AASHTO test road and have become the basis not only for overload permitting but also for pavement design. A recent round-table discussion at the Pavements Standing Committee (PSC) of the Transportation Association of Canada, in April 2005, highlighted the wide range of approaches to overload permitting across Canada.

This paper first summarizes the various approaches to overload permits in Canadian provinces and then describes a test conducted at the Nisku Test Road in Alberta. The Nisku Test road is comprised of two thin membrane pavement sections that have been constructed and instrumented with the specific aim of monitoring real-time pavement response under vehicular loads. Within the Nisku Business Park, the Province of Alberta has allowed a 25% overload on tandem 17,000kg axles and this paper describes the finding of a series of tests conducted in 2005.

Introduction

Load Equivalency Factors (LEF) which were initially developed at the AASHTO test road have become the basis not only for pavement design but also for overload permitting. 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)).

A steady increase in traffic, in particular trucks, as a result of the move to just-in-time inventory control has resulted in accelerated deterioration as manifest by an increase in load related distresses. The National Highway System and major provincial skeletal networks are designed for high ESALs however; the low volume road network, comprised of secondary, tertiary and resource roads, is generally not engineered for either heavy single loads or high volumes. Yet, this network carries much of the primary resource traffic which includes large loads and unusual tire/axle configurations. A recent round-table discussion at the spring meetings of the Transportation Association of Canada highlighted the variability across the country permitting of large and/or unusual vehicles as summarized in Table 1. As can be seen in the table, there is no common approach to overload permits in the reporting agencies nor is there a common basis for cost recovery for damage to the pavement as a result of the load.

The Nisku Test Road is built in an industrial business park on the outskirts of Edmonton and is home to many oilfield servicing companies. Because of the large population of heavy oilfield cranes in the park (which service the various companies operating in the area), the County of Leduc received approval from Alberta Infrastructure and Transportation for a twenty-five percent overload for selected vehicles operating in the park. The standing permit allows for all vehicles in the park to carry a 25% overload regardless of season and construction of a test road in the business park has enabled a direct comparison of the pavement response under standard axle loads and the permitted overload vehicles. The purpose of this paper is to present results of the overload test comparisons done during two cycles of the Nisku Test Road program in the spring and fall of 2006.

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 and material properties for the HMA section are shown graphically in Figure 1. The test road instrumentation design and information is summarized in Table 1 and included in Figure 1.

Table 1. Summary of test road instrumentation design

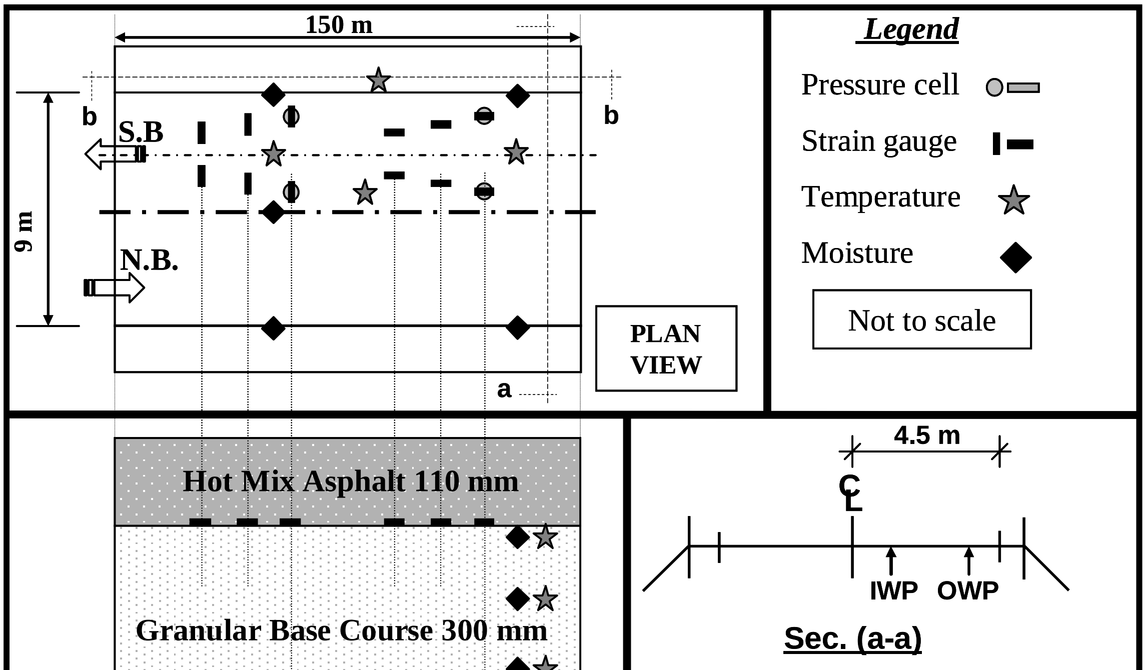
Device type	Quantity/manufacturer	Function	Location
Pressure Cells	HMA (4)/RST Instruments-strain gauge based type	Measuring vertical pressure on the subgrade	IWP & OWP paths, 300 mm below the top of the subgrade
Strain Gauges	HMA (12)/Dynatest PAST II-strain transducer	Measuring interfacial strain along 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

Two arrays of strain gauges and pressure cells were placed in the HMA section for redundancy. In each array the pressure and strain devices were distributed symmetrically over the inner wheel path (IWP) and outer wheel path (OWP). The strain gauges are aligned to capture both the longitudinal and transversal strain at the asphalt – granular base course interface. Devices in each array were distributed over three horizontal lines that have different transversal spacing forming a trapezoidal shape. The different widths allow for a variety of vehicle axle sizes and can track multiple axles and/or dollies as they traverse the site.

Deflection is measured using a surface deflectometer beam, similar in principle to the deflectometer beam attached to a Falling Weight Deflectometer. Four Linear Strain Transducers (LST) are attached to a three meter steel beam that is placed on the centrelane of the pavement (in the middle between the two wheel paths). This design was used to avoid drilling the pavement which was felt to be inappropriate for this test road as the introduction of a corehole on a thin membrane pavement introduces a discontinuity and a site for crack propagation. Because of this design, deflection can only be measured at creep speed to avoid destruction of the LST cables which rest on the road surface (under protective hoses).

The Data Acquisition System (DAS) and dedicated computer are capable of capturing and recording the dynamic readings with 500 Hz frequency. This provides differentiation of each axle of the vehicles even at 60 km/hr.

Background environmental conditions (air and ground temperature and soil moisture) are measured at the beginning of the test cycle using thermocouples and soil moisture gauges strategically located around the instrumentation array.



Materials Properties

Hot Mix Asphalt			
Density kg/m^3	Air voids %	AC %	Max. aggregate size (mm)
2312	5.0	5.52	12.5
Granular Base Course			
Max. dry density	O.M.C.	Max. agg. size	
2189 kg/m^3	6.2 %	19.0 mm	
Prepared Subgrade			
Max. dry density	O.M.C.		
1490 kg/m^3	24.7 %		

Figure 1. Test road layout and instrumentation layout

Test Vehicles

Two test vehicles were used for the overload study as described in Table 3. A single axle picker crane (referred to as ST18) that is loaded to 8,000kg (18kips or 80kN) on the back axle is used as the reference vehicle for all test cycles. Pavement response data under this load is collected before, after and during all test runs to establish a datum for data analysis. A second reference vehicle consisting of a tandem axle flatbed truck loaded to 17,000kg on the deck was added to the experiment for the 25% overload test. This vehicle has a single front steering axle and two tandem axles under the flatbed. This vehicle was run in the spring session under normal load and in the fall session it was charged with 25% overload on the rear-tandem axle configuration. All axles are equipped with dual tires. Test vehicles are provided as a donation in kind to the experiment and because of the demands of the oil patch, not all vehicles are available for each test cycle with the exception of the ST18 picker truck. This causes some challenges in analysing the data between seasons, but in all cases, data can be compared to the performance of the road under the ST18.

Table 2. Tests vehicles weights and axle details

Axle Group Number	**Standard 18 (ST18)**				**Tandem 17 (TD17)**			
	Spring	Fall	Type	Tire Type & Pressure	Spring	Fall (25% Overload	Type	Tire Type & Pressure
1	4.95kg	4.95kg	Single, single tires	Michelin XZE M/S 275/80R22.5	4.8kg	4.8kg		
2	7.8kg	7.8kg	Single, dual tires	Michelin XDE M/S 275/80R225	6.4kg 6.7kg	6.4kg 6.7kg		
3	-	-	-	-	8.3kg 9.1kg	13.1kg 13.1kg		
Total	12.75kg	12.75kg			37.3kg	44.1kg		

Before each test all vehicles are weighed on site by either County or Provincial commercial inspection officers. Portable weigh scales are used for the large vehicles, while the legally loaded vehicles are weighed at the nearby Alberta Infrastructure and Transportation Vehicle Inspection station on Highway 2. This weigh system consists of several scales, weighing the load on each of the tires which is then summed up to give the weight of each axle configuration. Notations are made at the same time of the tire type and pressure rating. Table 1 presents the vehicles used in the spring and fall test cycles.

Testing protocol

To minimize disruption to the businesses located along the road, all tests are run on Sunday with traffic control protecting the public, test vehicles and research staff during test runs. The test sequence is presented in Table 3 with five runs per vehicle per speed completed to provide statistical variation in the readings. Prior to the test, a crack map and rutting measurements are done. After cleaning up the road a crack map was compiled of the southbound lane (in which the instruments are embedded). The northbound lane had been repaired during the year so a continuous crack map couldn't be established for this lane. This didn't present a problem because the test could be run on the right lane providing sufficient results. Rut measurements are made for both lanes at five meter intervals, using a 5m beam as described above. Environmental conditions are measured before and after the test and these are summarized for the fall test cycle in Table 4.

Table 3. The testing sequence

Load	Repetition No.				
	1	2	3	4	5
Standard (ST18) @ 60 km/hr	✓	✓	✓	✓	✓
Standard (ST18) @ Creep speed	✓				
Tandem 17 (TD17-25) @ Creep speed	✓	✓	✓	✓	✓
Standard (ST18) @ 20 km/hr	one pass				
Tandem 17 (TD17-25) @ 20, 40 & 60 km/hr *	✓	✓	✓	✓	✓
Standard 18kip @ 60 km/hr	✓	✓	✓	✓	✓

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

Table 4. Environmental Conditions for the Spring and Fall Testing

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

Unexpectedly the Cold Mix Section failed catastrophically during the fall test because of several factors. The relatively narrow road width, coupled with large vehicular traffic had resulted in tire ruts being created on the shoulder where vehicles dropped off the pavement while passing each other. The night before the test, a rain shower passed over the site and water collected in these ruts creating saturated subgrade conditions at several locations along the southbound lane. Severe failure, in the form of punchouts in the outer wheel path occurred at these locations and this had a major consequence for the fall test cycle. Because of the location of the failure zones, it was considered unsafe for the large test vehicles (cranes) to pass over the site at speeds in excess of 10 km/hr as manoeuvring the vehicles from the normal wheelpaths in the HMA section to straddling the centreline in the CMA section could be a safety risk to all concerned. Also, as the road was effectively failed, there was some concern that further destruction of the inner wheel could result in a road closure which would have a serious impact for the businesses and County as a whole. It was decided that manoeuvring the overloaded Tandem 17 and Standard 19 vehicles was still possible and the test proceeded at 20, 40 and 60 km/hr for these vehicles.

Data Extraction Methodology

Because data is collected at 500 Hz, the file sizes are quite large and some effort is required to extract data for analysis. Using a protocol developed at Virginia Tech the data is plotted and then searched for maximum values of pressure, strain and deflections. The zero, absolute and delta values are extracted as shown in Figure 2. These diagrams are always a function of time as the vehicles are passing at different speeds showing the measured deflection, strain or pressure under the different axles. It clearly can be seen that the maximum values are recorded directly under the axles.

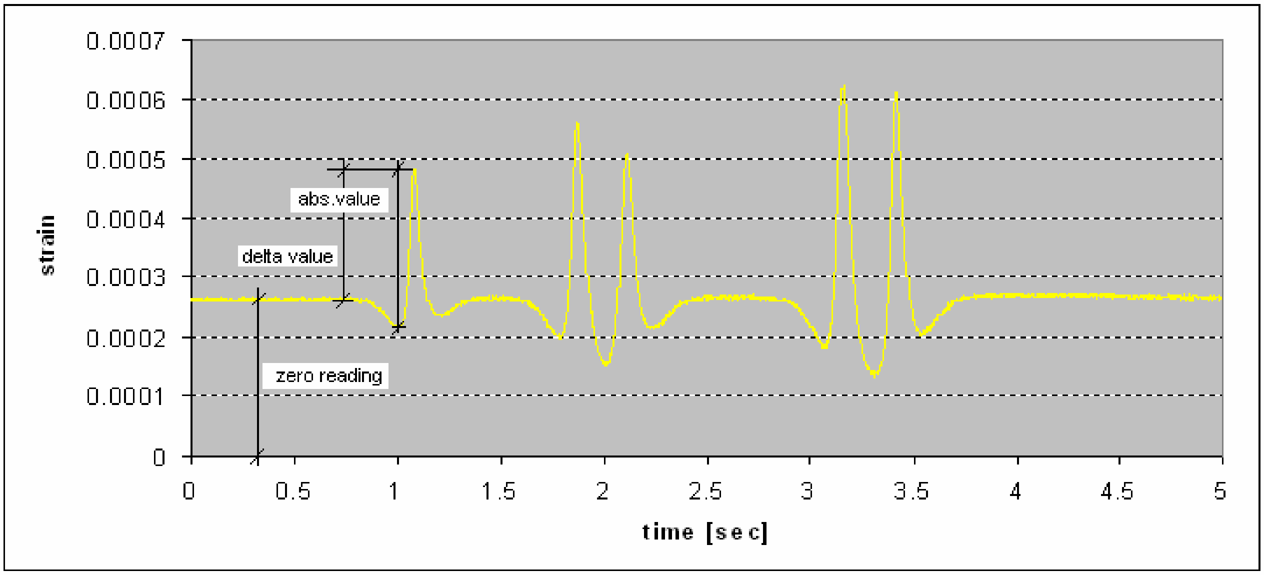


Figure 2. Absolute value, delta value and zero reading for the measured strain under the overloaded Tandem 17

For every vehicle there are results from six longitudinal strain gauges, six transversal strain gauges and four pressure cells. These measurements exist for every speed replicated five times which makes for a major data extraction process. Two methods were used as described below:

- all values

In this method, the maximum, minimum and the average out of all values recorded in the array for every speed and under every axle was used. Therefore "all values" means the values of all different gauges/cells and the five replications. As this gives a total amount of 30 values for the strain gauges and 20 for the pressure cells there is a statistically sufficient base for determining the 25% and the 75% quartiles. However these values were only evaluated for the pressure cells as the strain gauges don't give compatible values due to their trapezoidal arrangement in the structure and vehicular wander over the strain gauge array.

- maximum values

In this method, only the maximum measured value out of the different gauges/cells was extracted. The maximum, minimum and the average out of these maximum readings has been determined for every speed and every axle.

For both methods afterwards the results can be shown in diagrams separately for each axle, and the impact of the different speeds can be seen in comparison.

Results

Pressure cells

For the pressure cells the following diagram shows the typical form of the measured vertical stress under the test vehicles for the two seasons.

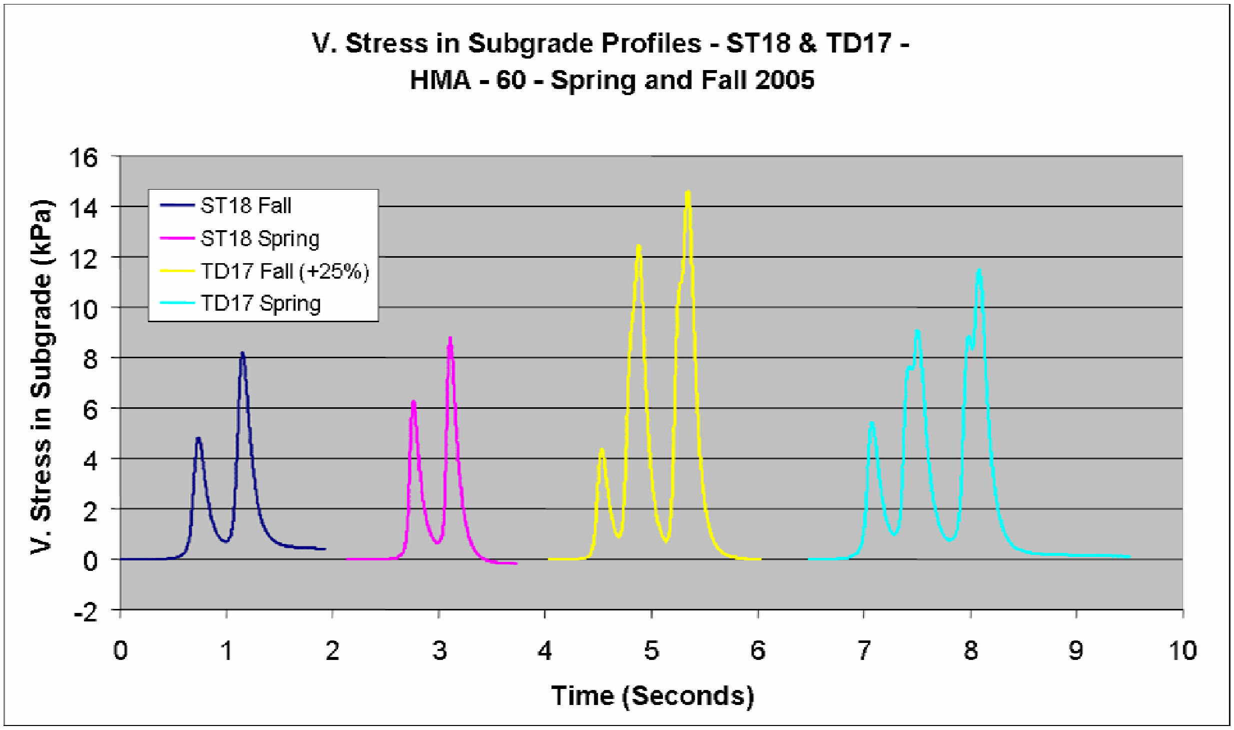


Figure 3. Comparison of Subgrade Pressure for ST18 and TD17 + 25% Overload – Spring and Fall Tests

Figure 3 presents the vertical pressure on the subgrade for the two test vehicles in the spring and fall test cycles at 60 km/hr. There is very little difference between the ST18 spring and fall response. The TD17 steering axle for spring and fall is the same weight, but weakened spring subgrad conditions produces a slightly higher pressure on the subgrade than in the fall. Of interest is the difference between the pressure imposed by the overloaded third axle group where an increase in pressure of 2kPa is seen between spring and fall.

Longitudinal strain

Similar comparative results for longitudinal strain under the asphalt surface in the spring and fall test cycles is presented in Figure 5. Of particular interest in this graph is the comparison between the overloaded TD17 in Fall and the ST18 in spring. As in spring the Tandem 17 vehicle was driven under normal load and in fall with 25% overload the direct comparison between spring and fall shows the effect of the overload quite clearly. However the different acting of the pavement at sensible thaw conditions is to be taken into account when comparing the resulting strains and pressures of the vehicle. To have a base on which to decide which amount of the stress increase is due to different weather conditions the Standard 18 vehicle is shown in the following diagrams too.

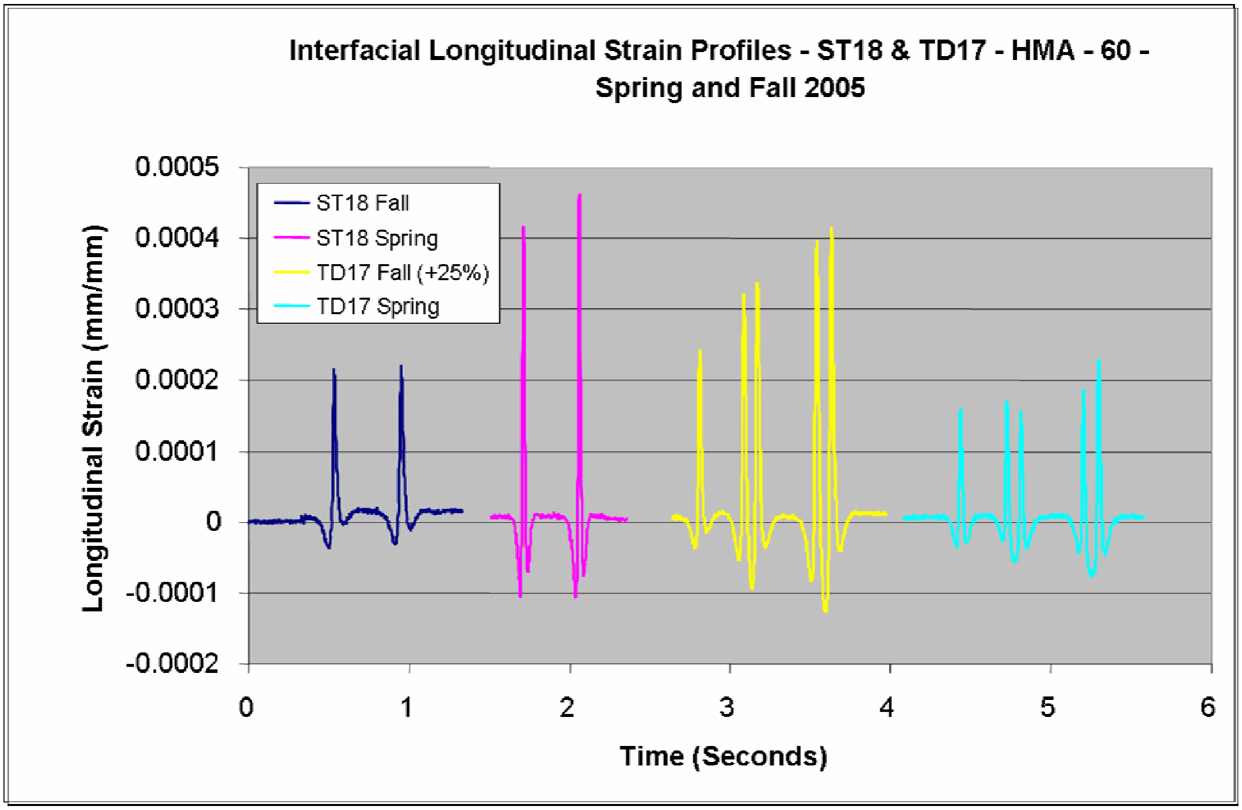


Figure 4. Comparison of Longitudinal Strain Under the Asphalt Surface Pressure for ST18 and TD17 + 25% Overload – Spring and Fall Tests

It can be seen in Figure 4, that the ST18 vehicle results at spring and fall conditions are within the same range, the values for the Tandem 17 vehicle increase considerably between the two seasons. Both pressure and longitudinal strain are higher due to the overloading.

The overload of the Tandem 17 vehicle has been put on the second tandem axle configuration. Therefore another way to show the impact of the overload on the pavement is to compare the legal loaded front tandem axle configuration (axle 2/3) with the overloaded back tandem axle configuration (axle 4/5). In this comparison it can be seen, that the higher loading on axle 4/5 leads to an increase of the strain and pressure in the pavement structure. However, this increase seems to be the same in spring, which leads to the consideration that it is not due to the overload but to the higher load on the back tandem axle configuration in general. This would have as a consequence, that the overload, even if only put on the back tandem axle configuration leads in general to a higher impact on the structure under all axles of the vehicle.

Calculation of EALFs

Equivalent Axle Load Factors (EALFs) were calculated using two methods to determine relative impact of the various axles of the Tandem 17 in overload and legal load configurations. The objective of these calculations was to compare different methods of Load equivalency calculation and to quanitify the impact on the pavement structure.

The AASHTO Equivalent factors

For calculating the Equivalency factors after the AASHTO-method, the load in kip is needed, which was derived from the in-situ weights. As failure criteria the factor pt is set 2.5 as in the AASHTO-test suggested. The Structural Number is calculated according to the AASHTO method. The layer coefficients are chosen from the AASHTO Interim Guide for Design of Pavement Structures. For the surface course in the HMA section "Plantmix, high stability" is chosen, which gives $a_1 = 0.44$. The base course is estimated with crushed stone ($a_2 = 0.14$) and the subbase course with sandy clay ($a_3 = 0.05$). The drainage factors m_2 and m_3 are set one.

EALF by theoretical method – mechanistic method

Using the methodology described in Christison (1978), EALFs are calculated using tensile strain under the pavement. Because of the amount of data, two approaches were used as described above: all values, and maximum values. The data used for each axle is presented in Table 5 for Fall and Table 6 for Spring.

Table 5. Tensile strains used for the LEF calculation - Fall

	Delta			Absolute		
	max	mean out of all	mean out of max	max	mean out of all	mean out of max
axle 5	0.00044330	0.00029048	0.00038623	0.00057600	0.00039142	0.00051320
axle 4	0.00040161	0.00030004	0.00039561	0.00052300	0.00037335	0.00049340
axle 3	0.00036230	0.00023300	0.00032206	0.00047400	0.00031569	0.00042460
axle 2	0.00035430	0.00024676	0.00031686	0.00041000	0.00029834	0.00037500
ST 18	0.00026868	0.00013574	0.00020312	0.00031500	0.00016693	0.0002416

Table 6. Tensile strains used for the LEF calculation - Spring

	delta			absolute		
	max	mean out of all	mean out of max	max	mean out of all	mean out of max
axle 5	0.0002549	0.0001059	0.0002236	0.00034900	0.00016252	0.00030880
axle 4	0.0002309	0.0000929	0.0001982	0.00030100	0.0001253	0.0002514
axle 3	0.0001699	0.0000679	0.0001428	0.0002530	0.00011404	0.000211
axle 2	0.0001959	0.0000781	0.00014338	0.000245	0.00010156	0.0001806
ST 18	0.0002871	0.0001301	0.0001857	0.000372	0.0001854	0.0002932

The results are presented in Tables 7 (Fall) and 8 (Spring)

Table 7: Summary of calculated EALFs - Fall

	Delta values			**Absolute values**		
Method	**Maximum**	**Mean out of all values**	**Mean out of max values**	**Maximum**	**Mean out of all values**	**Mean out of max values**
EALF – AASHTO	1.641 (axle 4/5)					
EALF - Mechanistic method (Christison) Tensile strain	6.705(axle5) 4.607(axle4) 3.114(axle3) 2.861(axle2)	18.013 20.371 7.793 9.691	11.496 12.593 5.764 5.418	9.909 6.866 4.725 2.723	25.296 21.305 11.262 9.085	17.511 15.08 8.522 5.316

Table 8. Summary of calculated EALFs

	Delta values			Absolute values		
Method	**Maximum**	**Mean out of all values**	**Mean out of max values**	**Maximum**	**Mean out of all values**	**Mean out of max values**
EALF – AASHTO	1.641 (axle 4/5)					
EALF - Mechanistic method (Christison) Tensile strain	0.636 0.437 0.136 0.234	0.457 0.278 0.085 0.143	2.025 1.28 0.368 0.374	0.785 0.447 0.231 0.205	0.618 0.23 0.161 0.103	1.218 0.557 0.286 0.159

As can be seen, the calculated EALFs vary in quite large ranges depending on the method chosen. Even within the mechanistic method they vary a lot depending on the value chosen for the calculation. The load factors suggest, that one application of the rear tandem axle configuration is approximately equivalent in potential damaging effect to 1.6 to 25 applications of the 80 kN standard load depending on the method and the values chosen. The highest value is obtained when using the average out of all values, the lowest when using the maximum values. Furthermore the LEFs derived of the absolute values are higher than those out of all values. With decreasing axle number the LEF decreases due to the decreasing load, but also the difference between the LEFs from absolute and delta values becomes less. The LEF obtained when comparing the load instead of the strains is close to the one using the maximum delta value for the calculation.

Conclusion

A comparison of a legally loaded and twenty-five percent overloaded Tandem 17,000 kg vehicle has been conducted to estimate the effect of that overload on pavement response on a thin membrane hot mix asphalt pavement. Under the overload, vertical pressure on the subgrade and the longitudinal strain are found to increase considerably. Comparing the axle configurations the overloaded rear tandem axle configuration is clearly higher than the legal loaded front tandem axle, but looking into the spring results the same increase can be found, which leads to the conclusion, that the impact of the higher load is distributed over the whole vehicle.

Load Equivalency Factors were calculated using two methods and it was found that they are highly and dependent on the values chosen for the calculation and on the method chosen. They vary between 1.64 after the AASHTO-method and between 9.909 and 25.3 after the mechanistic method. Calculating the LEFs with the spring values for the standard 18 kip vehicle and the legal loaded tandem 17 vehicle totally different values are derived. Using the average of the maximum values in the calculation a factor higher than one is calculated which means, that in the mechanistic method the impact on the pavement structure of the Tandem17 vehicle is less damaging than the Standard 18.

References

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