MODELING ANALYSIS OF B-TRAIN TRUCKS ON SASKATCHEWAN PAVEMENT STRUCTURES

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Paper prepared for presentation at the
Sessions: Measuring and Using Pavement Performance Data 2013 Annual Conference of the
Transportation Association of Canada
Winnipeg, MB

ABSTRACT
Saskatchewan's economy depends on bulk commodity transport including agriculture, logging, livestock, oil, and mined mineral resources. The primary mode of transport for these bulk goods is by truck. Saskatchewan's economy is dependent on interprovincial and international trucking transport and relies on over 25,000 centerline kilometers of primary and secondary highways to move these goods. The Ministry of Highways and Infrastructure policies and regulations enforce truck type and axle weight on Saskatchewan provincial highways. Recently, the Ministry decided to investigate the effect of a 9-axle B-train loading configuration on Saskatchewan's highway network.

The purpose of this study was to quantify the damage caused by a 9-axle B-train truck on Saskatchewan road structures with different axle loads and to compare it to the damage caused by a typically loaded 8-axle B-train truck configuration. This analysis was carried out using a computational mechanics road model that considers non-elastic material behaviour, Saskatchewan field state conditions, pavement structures, materials, road construction, climatic effects, and truck configurations.

For this study, damage is defined as the permanent deformation of the roadway directly beneath the truck tires after one 10 s truck cycle. This study found that when loaded past its baseline load, the 9-axle B-train truck resulted in more damage than an 8-axle B-train truck, when comparing across an asphalt concrete pavement in good and poor condition, under freeze-thaw and high temperature climatic effects.

INTRODUCTION

The Ministry of Highways and Infrastructure (MHI) has observed that commercial truck loadings can accelerate damage to its highways and have decreased the expected life performance of many of its roads. Maximum axle weights for different vehicle configurations are legislated in *The Vehicle Weight and Dimensions Regulations* (2010). Vehicles must abide by legislated axle weight and gross vehicle weight (GVW) limits. Saskatchewan has weight limits for vehicles ranging from two to eight axles. For vehicles with more axles or different combinations of axles that are not legislated, MHI may provide special permits for travel on Saskatchewan highways.

For example, permits have been developed to allow the operation of the 9-axle B-train logging truck at increased weights and dimensions in other provinces like Alberta (1). Figure 1 illustrates a 9-axle truck used for logging in Saskatchewan. In order to establish whether the 9-axle B-train was appropriate for use on Saskatchewan highways, MHI wanted to investigate how much damage a 9-axle B-train loaded at varying load configurations on different road structures caused.

Figure 1 9-axle B-train Truck in Saskatchewan

This study investigates the damage caused by a 9-axle B-train truck on Saskatchewan road structures with different axle loads and compares it to the damage caused by a typically loaded 8-axle B-train truck configuration. A computational mechanics road model was used to determine the surface deflections, and normal and shear strains for various pavement structure loadings. This analysis was carried out using an evaluation method that considers non-elastic material behaviour, Saskatchewan field state conditions, pavement structures, materials, road construction, climatic effects, and truck configurations.

BACKGROUND

Saskatchewan's Road Network

Saskatchewan's economy is dependent on bulk commodity export including agriculture, livestock, oil, and mined mineral resources. Over the years, the shift from rail transportation to road transportation has increased truck traffic on Saskatchewan highways (2,3). Saskatchewan's economy predominantly depends on interprovincial and international trucking transportation, relying on Saskatchewan highways which are vital to the movement of goods. Pavement deterioration over years of service is known to be a factor of the combined effects of traffic loading, pavement structure thickness, material quality, and environmental and climatic conditions (2,3,4).

PSIPave3D™ Road Model

PSIPave3D™ is a finite element model that is encoded into a user-friendly software package created for routine and advanced road designs. It has been used in research and development studies to assess the primary response of urban pavement structure drainage systems, recycled pavement structures, and typical road designs. The deflection as well as 3D-strain behaviour of a road structure is spatially calculated by the model incorporating road layer thicknesses, load spectra, climatic conditions and material constitutive properties into the design and analysis of any given road structure. Past studies have demonstrated validity of the model (5,6). For example, in a study comparing City of Saskatoon drainage layers, peak surface deflections measured in the field using a heavy weight deflectometer corresponded to deflections predicted using the model (5,6). The road model outputs orthogonal strains, which conventional road design methodologies typically calculate and empirically correlate to field performance, but also shear strains, which truly dictate the structural performance and failure criterion for road materials.

The PSIPave3D™ model assumes that the roadway materials are viscoelastic. When a material is viscoelastic, a cyclic loading produces a load-displacement curve that predicts a hysteresis loop on each loading cycle, as shown in Figure 2. This hysteresis loop correlates to the energy lost during the loading cycle (unloading or relaxation period), and the resulting permanent deformation is a measure of the damage to the roadway. Therefore, one truck cycle occurs from the time the load passes a point in the roadway, to the time the material relaxes once it is unloaded.

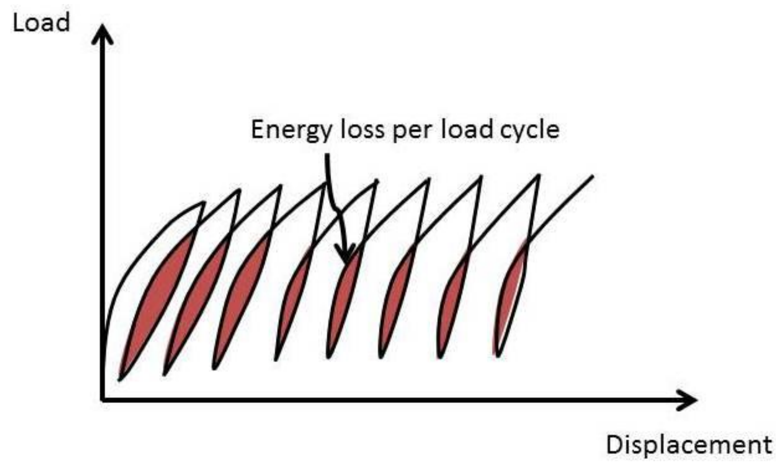


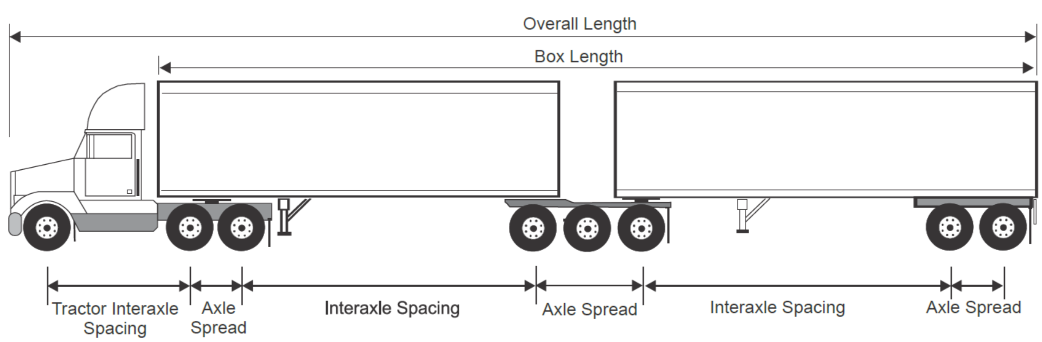
Figure 2 Cyclic Loading for a Typical Viscoelastic Roadway Showing Energy Loss per Loading Cycle

OBJECTIVE

The objective of this study was to investigate the damage caused by a 9-axle B-train truck on Saskatchewan road structures with different axle loads and compare it to the damage caused by a typically loaded 8-axle B-train truck configuration using a 3D non-linear orthotropic computational mechanics road model. The road model is capable of quantifying the road's response to loading and considers viscoelastic material behavior.

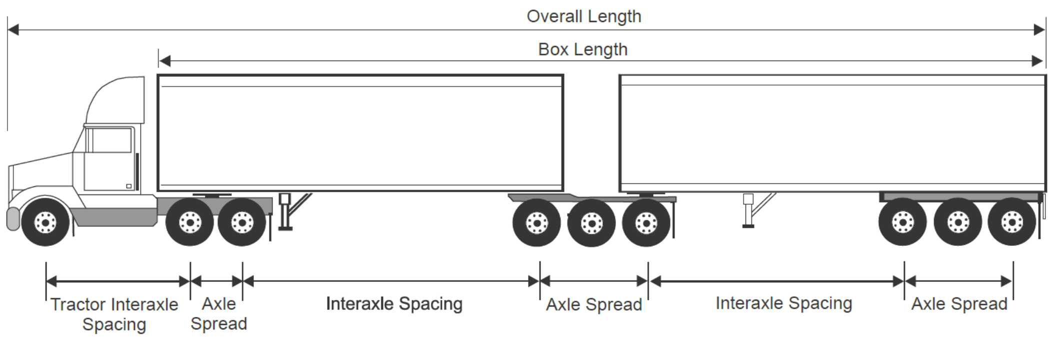
SCOPE AND METHODOLOGY

This study is limited to two types of trucks: the 8-axle B-train and the 9-axle B-train, which are illustrated in Figure 3 and Figure 4, respectively. The 9-axle B-train analysed is a tridem drive B-train (consisting of a steering axle, tandem axle, tridem axle, and tridem axle). One load was used for the 8-axle B-train (Table 1), while six (6) different loads were assigned for the 9-axle B-train (Table 2).



Overall Length	26	Tractor Interaxle Spacing	4.8	Tandem Axle Spread	1.4
Tire Width	0.305	Lead Trailer Interaxle Spacing	6	Tridem Axle Spread	3.1
Max Speed 100 km/hr		Rear Trailer Interaxle Spacing	6	Axle Width	2.6
		all dimensions in meters			

Figure 3 8-axle B-Train Configuration



Overall Length	26	Tractor Interaxle Spacing	6	Tandem Axle Spread	1.4
Tire Width	0.28	Lead Trailer Interaxle Spacing	6	Tridem Axle Spread	3.1
Max Speed 90 km/hr		Rear Trailer Interaxle Spacing	7.1	Axle Width	2.6
		all dimensions in meters			

Figure 4 9-axle B-Train Configuration

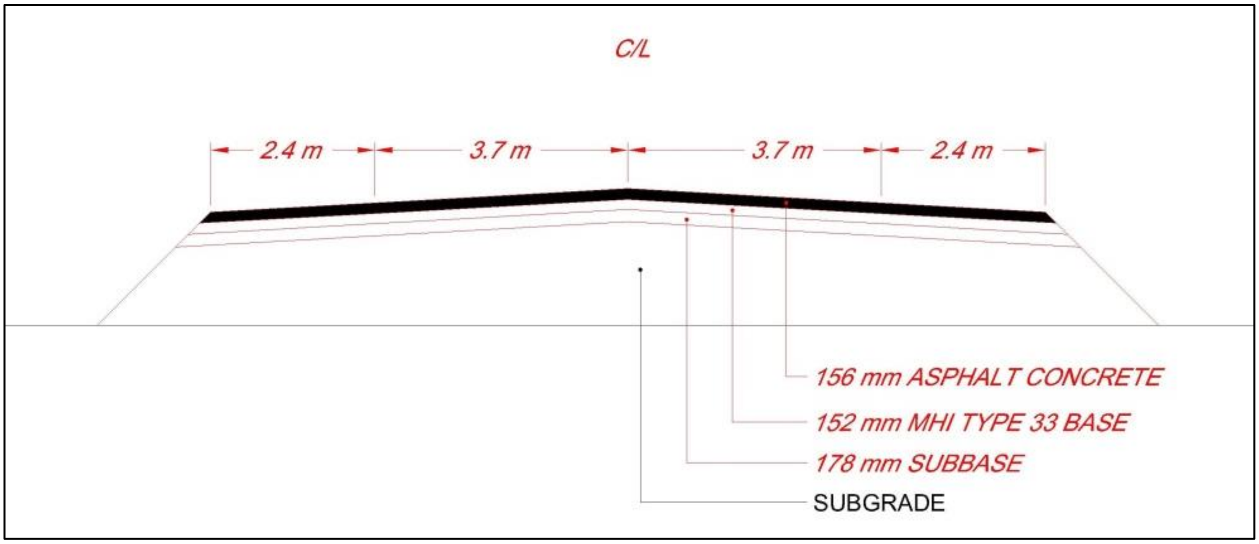
Table 1 Baseline Axle Loads for the 8-axle B-Train

Loading Case	Configuration Axle Weights (kg)				Gross Vehicle Weight (GVW) (kg)
	Steering	Tandem	Tridem	Tandem	
Baseline	5,500	20,700	29,800	19,000	75,000

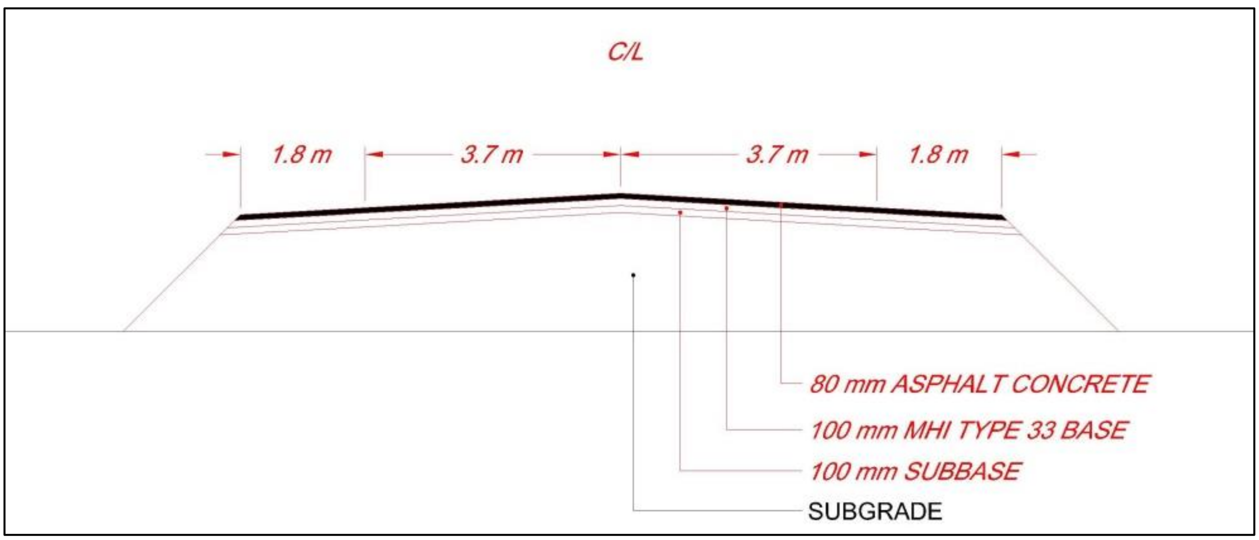
Table 2 Axle loads for the 9-axle B-Train

Loading Case #	Configuration Axle Weights (kg)				Gross Vehicle Weight (GVW) (kg)
	Steering	Tandem	Tridem	Tridem	
L1	6,000	17,000	23,000	23,000	69,000
L2	6,000	19,000	25,000	25,000	75,000
L3	6,000	21,000	27,000	27,000	81,000
L4	6,000	23,000	29,000	29,000	87,000
L5	6,000	25,000	31,000	31,000	93,000
L6	6,000	27,000	33,000	33,000	99,000

The first part of this study is limited to two asphalt concrete (AC) pavement structures: Control Section (C.S.) 3-11 and C.S. 120-02. Figure 5 illustrates cross sections of each pavement structure. C.S. 3-11 (Figure 5 a) consists of 156 mm AC, 152 mm base course, and 178 mm subbase on top of a low plastic clay/clayey sand subgrade. C.S. 120-02 (Figure 5 b) consists of 80 mm AC, 100 mm base course, and 100 mm subbase on top of a clayey sand subgrade. These structures were chosen for modeling as they represent two specific sections of Saskatchewan's road network that were identified as good and poor pavement performers by Ministry staff. Each structure was analysed under two climatic conditions: spring-thaw was considered to be a wet structure, and high temperature was considered to be a dry structure.



a) C.S. 3-11 Pavement Structure



b) C.S. 120-02 Pavement Structure

Figure 5 Pavement Structure Cross Sections

The purpose of this study was to investigate the damage caused by a 9-axle B-train truck on Saskatchewan road structures with different axle loads and compare it to the damage caused by a typically loaded 8-axle B-train truck configuration using a three dimensional non-linear orthotropic computational mechanics road model. For the purposes of this study, damage is defined as the permanent deformation of the roadway directly beneath the truck tires after one 10 second truck cycle. This study is limited in its definition of damage as the definition account for permanent deformation (rutting) following a 10 s relaxation period for the roadway. This study does not account for the effects of cracking.

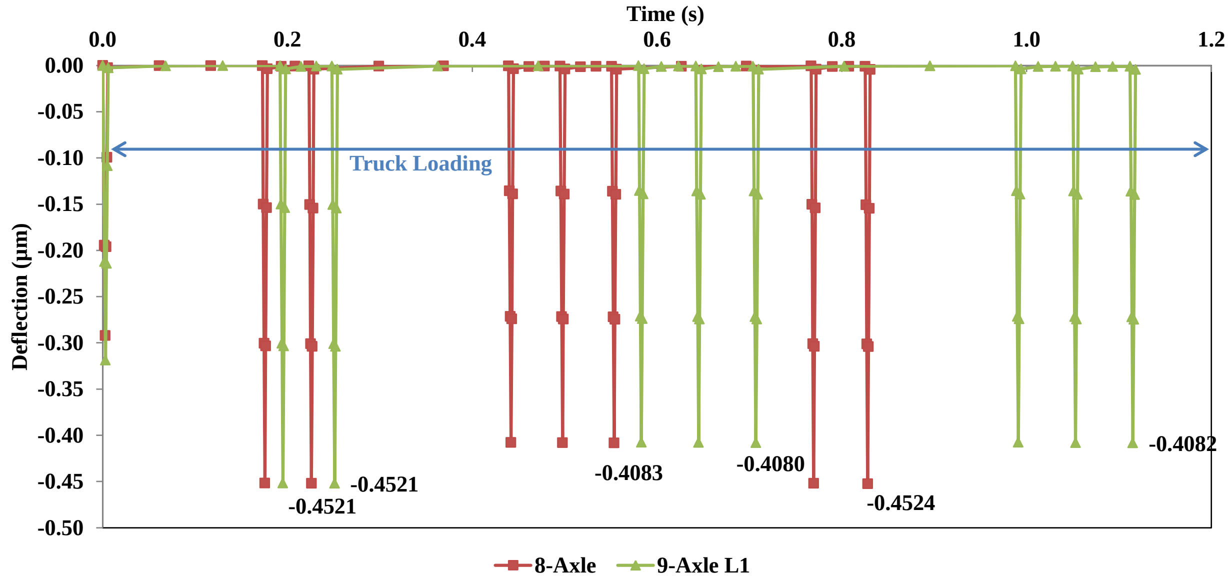
DEFINING DAMAGE FOR THE PURPOSES OF THIS STUDY

The outputs of the PSIPave3D™ simulations are peak surface deflection and permanent deflection. The peak surface deflection refers to the maximum deflection while a truck is driving by a point. The permanent deflection is the amount of damage left as a residual in the pavement after one truck passes through a point and is referred to as residual deformation (i.e. permanent deformation, rutting).

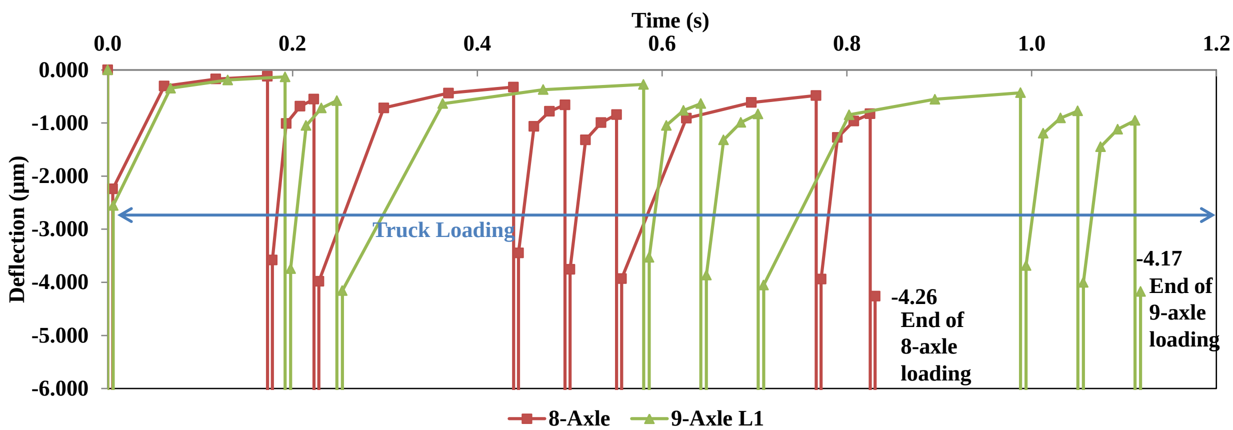
Figure 6 a) illustrates the peak surface deflections with time of both the 8-axle B-train and 9-axle B-train trucks for the good AC pavement structure in a dry (high temperature) climatic condition state during loading. Figure 6 b) illustrates a magnified view of Figure 6 a). In this plot, the deformation that exists immediately once one truck has completed loading is shown (-0.00426 mm for the 8-axle B-train and -0.00417 mm for the 9-axle B-train). In this case, immediately following loading, the 8-axle B-train has slightly greater deformation than the 9-axle B-train. However, this is not considered a fair measure of damage.

The 8-axle B-train truck is loaded at its baseline load (Table 1) and the 9-axle B-train truck is loaded with L1, which may be considered its baseline load (Table 2). There are a total of eight peak surface deflections measured for the 8-axle, each one representing a single axle loading on the pavement. There are nine peak surface deflections for the 9-axle B-train.

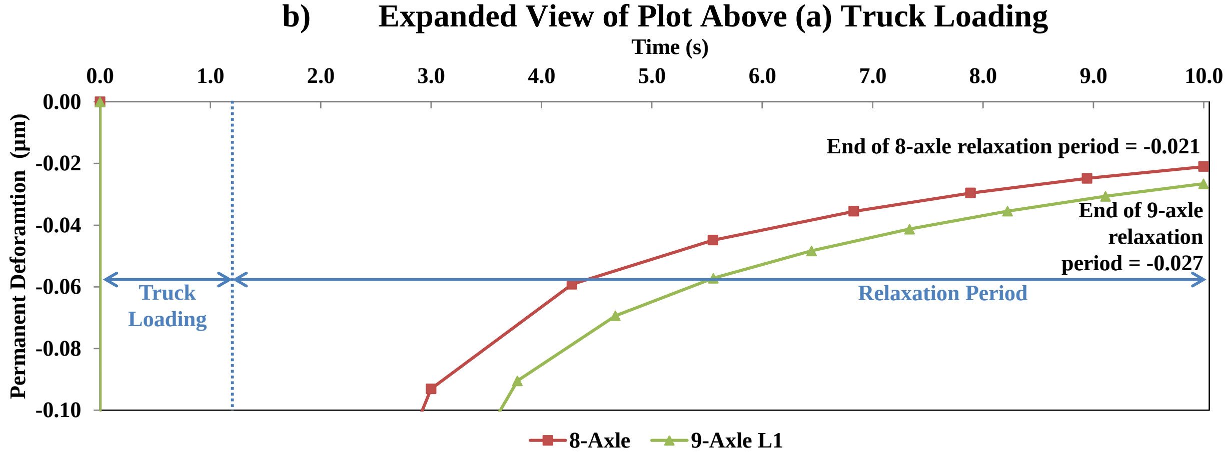
Figure 6 c) illustrates the relaxation period of the loadings, for both the 8-axle B-train baseline case and the 9-axle B-train L1 case. The relaxation period takes 10 s to allow for a fair, baseline comparison of both the 8-axle and 9-axle B-train trucks. The relaxation period shows the viscoelasticity of the material; the end result is a measure of damage where damage is defined as: the permanent deformation of the roadway directly beneath the truck tire after one 10 s truck cycle.



a) Truck Loading



b) Expanded View of Plot Above (a) Truck Loading



c) Truck Loading and Relaxation Period

Figure 6 8-Axle and 9-Axle (L1) B-Train Loading and Unloading on a C.S. 3-11 AC, High Temperature Climatic Condition

DISCUSSION OF RESULTS

Figure 7 illustrates the residual deformation caused by each 9-axle B-train loading (L1 to L6) and compares it to the damage caused by the baseline case, the 8-axle B-train truck, for both high temperature (high) and freeze-thaw (F-T) climatic conditions, for the two case study road structures, C.S. 3-11 and C.S. 120-02. The 8-axle B-train truck loaded at its typical loading configuration is used as the baseline case for comparison. However, no past precedence exists to set limiting damage values for this study.

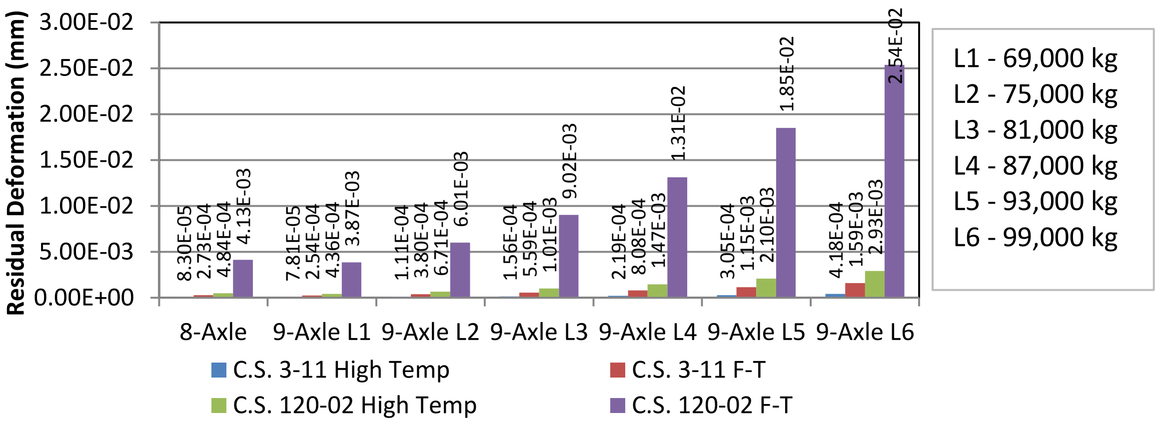


Figure 7 Residual Deformation – AC Pavement Structure

As seen in Figure 7, the damage caused by an 8-axle B-train truck is comparable to the damage caused by a 9-axle B-train truck, across both AC pavement structures and climatic conditions. The 8-axle B-train truck has a slightly higher residual deformation compared to the 9-axle B-train truck (L1). This is due to the load distribution of the 9-axle B-train truck. The residual deformation represents the viscoelasticity of the pavement structure. The damage caused by the 9-axle B-train truck increased at a non-linear rate with each loading configuration. This trend is the same for both AC pavement structures, across both climatic conditions.

The residual deformation for the AC pavement structures exhibited increased sensitivity to substructure moisture compared to the high temperature climatic condition – especially in the case of C.S. 120-02 F-T. For example, the 9-axle B-train with a 93,000 kg load (L5) exhibited a 378% increase in residual deformation compared to the 9-axle B-train with 69,000 kg (L1).

CONCLUSIONS AND RECOMMENDATIONS

It is well known that commercial truck loadings can accelerate damage and decrease the expected life performance of roadways. In order to establish whether the 9-axle B-train was appropriate for use on Saskatchewan highways, the Ministry of Highways and Infrastructure (MHI) wanted to investigate how much damage a 9-axle B-train loaded at varying load configurations on different road structures caused. The 8-axle B-train loaded to a typical loading configuration for Saskatchewan was used as the baseline for this comparison study.

A road model that considered viscoelastic material behavior was used to quantify two asphalt concrete pavement structures' response to loading. Each structure was analysed under two climatic conditions: freeze-thaw was considered to be a freeze-thaw structure and high temperature was considered to be a dry structure.

For the purposes of this study, damage was defined as the residual deformation following a 10 s relaxation period for the roadway. The effect of repeat loading was analysed over 100 s, for ten trucks. Further analysis is required to validate the damage limits for good and poor AC pavement structure, which may be set from the baseline 8-axle results.

The modeling results were determined based on the viscoelastic loading and unloading (relaxation period) of the 8-axle and 9-axle B-train trucks, under different loading configurations. The model also demonstrated its ability to model different pavement structures and material types.

Based on this study, when loaded at each of their baselines, the 9-axle B-train truck had a reduced residual deformation compared to the 8-axle B-train loaded. When loaded with more than its baseline load, the 9-axle B-train had a significantly higher residual deformation. For example, when loaded at L5 (93,000 kg), the 9-axle B-train had a residual deformation that was 267% more than the 8-axle B-train truck, for C.S. 3-11 in a high temperature climatic condition.

This study did not account for the effects of cracking. Further analysis of the effect of different trucks and loading configurations, on varying pavement structures and climatic conditions is recommended. PSIPave3D™ is capable of conducting a shear strain/failure analysis as well determining fatigue cracking on a multiscale analysis.

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