Evaluation of Comparative Damaging Effects of Multiple Truck Axles for Flexible Pavements

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INTRODUCTION

The objective of this research is to evaluate the comparative damaging effects of multiple truck axles including overloaded axles for asphalt pavements in the South Central region of the United States, by investigating the response of the pavement structure to various truck loading configurations. This is needed in order to harmonize truck load limit regulations between US states as well as between the US and our NAFTA neighbors, Considerable work was recently done in revisiting truck weights and dimensions under MAP-21 funding. This was done using the state of the art AASHTOWare Pavement ME (ME) software that computes the damage caused by each axle based on the longitudinal strain at the bottom of the asphalt layer. It also assumes that each axle is acting independently.

Some previous work by the researchers indicated that there might be a cumulative effect of different axles on the transverse strain at the bottom of the asphalt layer, and that the cumulated transverse strain is bigger than the longitudinal strain. It seems that the accumulation of strain is due to the viscoelastic behavior of thick asphalt layers at high temperature during warm days, and the short distance between some axles. Therefore, this accumulation of transverse strain and thus, the increase in pavement damage, must be accurately determined. Moreover, this will be a major issue when automated trucks will use our roads and highways. Automated trucks will likely travel in platoons, with a driver needed only in the first truck and the other trucks following at very short distances.

A major limitation of current approaches to flexible pavement design is that all materials are considered linear elastic, homogeneous and isotropic. This assumption is made to simplify the response calculations. The effect of loading speed is considered only by adjusting the dynamic modulus of the asphalt concrete based on the master curve data provided. This assumption has a major consequence: when a truck passes over the pavement structure, the strains induced by an axle group are treated independently from those induce by subsequent axle groups (e.g., steering axle versus following tandems in a class 9 truck or 18-wheeler). In other words, there is no consideration of overlapping strain effects from the various axle groups of a truck. In-situ strain measurements from several instrumented pavement sections in the United States and overseas clearly proved that:

a) The transverse strain induced by the front axle of the truck does not completely recover before the strain induced by the following axles develops. Therefore, the transverse strains under the rear axles are much higher than those estimated by linear elastic models.
b) The strains under a multiple axle are much higher than those estimated by linear elastic models, even when the effect of the front axle(s) is removed.
c) The transverse horizontal strain at the bottom of the HMA layer is bigger that the longitudinal horizontal strain because of the compounding effects from multiple axles.

Most pavement structural models compute only the longitudinal strain because it is assumed to be the largest.

d) The compounding effect increases when the vehicle speed decreases and when the temperature in the HMA layers is high, as normally is in the South Central region of the United States.

Figure 1 shows an example of the signals for the longitudinal and transverse horizontal strains measured at the bottom of the asphalt layer of a thick pavement structure. The signals on the left side of the figure were recorded under the passing of a Class 5 vehicle (a truck with steering axle and dual tire single axle in the rear, like an UPS delivery truck). The signals on the right side were recorded under the passing of a Class 8 vehicle (a truck with steering axle and dual-tire tandem drive axles for the tractor and dual-tire single axle in the rear of the trailer). The trucks travelled at over 40 mph. The figure shows clearly that, for both trucks, the longitudinal strain caused by the steering axle does not recover completely before the arrival of the rear axle, causing strain signal overlap. It also shows that the transverse strains are larger than the longitudinal strains. These findings clearly indicate that the pavement response, and consequently the relative damage, caused by various truck and axle configurations need to be further studied through in-situ strain measurements on in-service pavements. Clearly, the effect of the strain signature overlap between consecutive axle groups needs to be considered, in order to establish the correct strain magnitude to be used for pavement design.

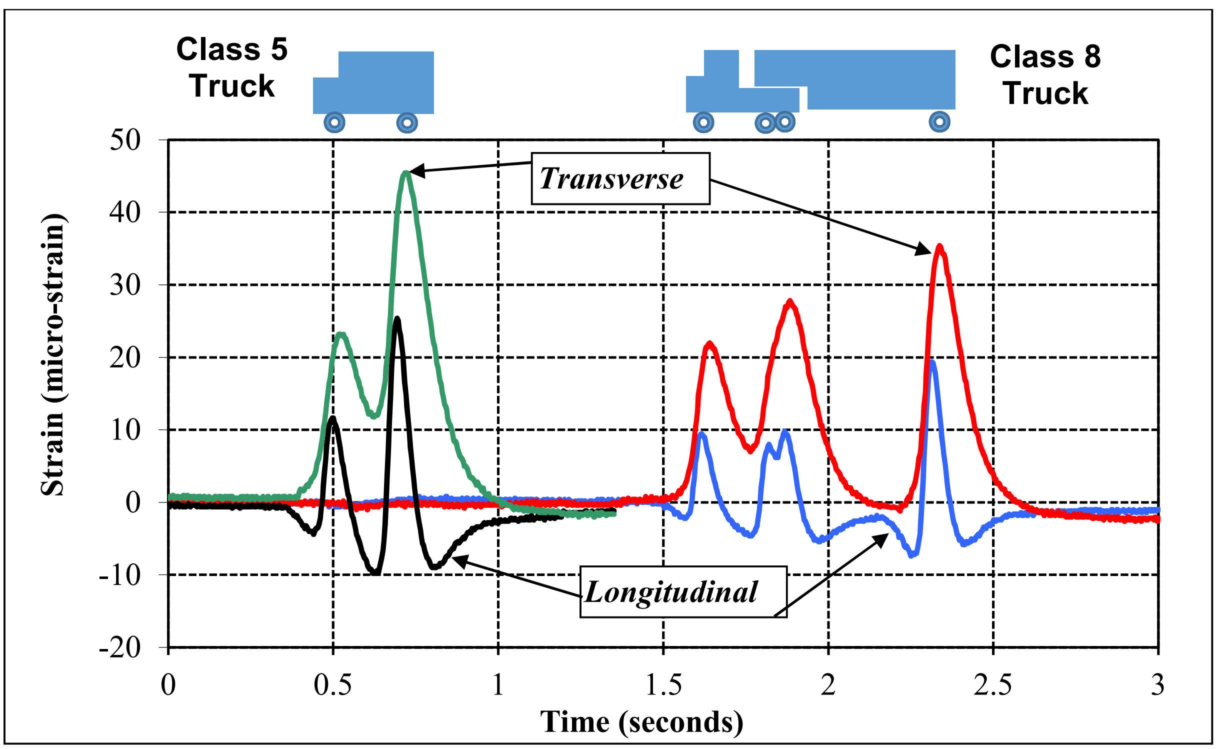

Figure 1. Transverse Strain at 60mph truck speed

Figure 1 illustrates well the importance of accurately computing the horizontal shear strain at the bottom of the asphalt concrete layer. For the class 5 vehicle, the maximum transverse under the rear axle is about 46 microstrain versus 26 microstrain for the maximum longitudinal strain. If the longitudinal strain is considered instead of the transverse strain in the computation of the fatigue damage caused by the passing of the rear axle, the fatigue damage is underestimated by $(46/26)^{3.92} = 9.36$ times. For the class 8 vehicle, the fatigue damage at the bottom of the asphalt layer caused by the passing of the rear axle is underestimated by $(28/10)^{3.92} = 56.6$ times. Clearly, the lack of considering the compounding effect of different axles on the magnitude of the transverse horizontal strain at the bottom of the asphalt layer leads to severe under-prediction of the fatigue damage and therefore, of the fatigue cracking initiation and development.

The compounding effect of the front and rear axles of the truck has not been observed before, or it has not been given a proper consideration. This is likely because most measurements of horizontal strains at the bottom of asphalt concrete layers under the passing of a truck have been done on thinner pavements, with the thickness of the asphalt concrete layers less than ten inches. For the same vehicle speed, the duration of the strain signal is considerably shorter for thinner pavements than for thicker pavements and therefore, the compounding effect is smaller.

METHODOLOGY

The aim of this project is to develop a strain measurement dataset that will allow revisiting pavement response under in-service traffic for the purpose of quantifying pavement damage under various truck/axle configurations. For this, a thick flexible pavement structure will be instrumented with sensors to measure the horizontal strains at the bottom of the asphalt layer in the longitudinal and transverse direction. This dataset will include complete strain signal data, not only the maximum strain values. The dataset will be supporting further development of mechanistic models for the calculation of strains in asphalt pavement structures.

In addition, the pavement layer properties from the instrumented pavement site will allow comparing the measured versus estimated strains using conventional layer visco-elastic techniques. The mechanical properties of pavement layers will be measured in the laboratory; the for the moisture This effort will support further improvements to any ME pavement design methods because it will provide measured data supporting the concept of compounding effects for the transverse strain at the bottom of the asphalt layers.

A literature review that aims to assemble information from previous pavement response monitoring projects has been conducted. The goal of the review was not only collect information on the methodology used for measuring horizontal strains at the bottom of the HMA layer, but to identify projects in which the compounding effect of different truck axles on the longitudinal and transverse strains at the bottom of the HMA layer has been observed.

The design the instrumentation to be used for the strain measurements when trucks with various axle loads and configurations pass over the pavement structure was also done. The instrumentation plan has been prepared. The strain gauges were purchased and their wires were extended to the desired length. The pressure relays to be used for the lateral position measurements have been ordered. The programming of the data acquisition system has been completed.

The project will significantly impact the process of computing the damaging effect of various truck configurations. It will better provide data to support the inclusion of visco-elastic models for asphalt materials, the inclusion of the entire truck when computing the damage and not treat each axle independently. This will improve significantly the quantification of relative pavement damage due to the load limit increase and the search for trucks with improved configurations. The project will lead to extension of the life of flexible pavement and an improved utilization of funds for the maintenance and rehabilitation of state and local roads.

FINDINGS

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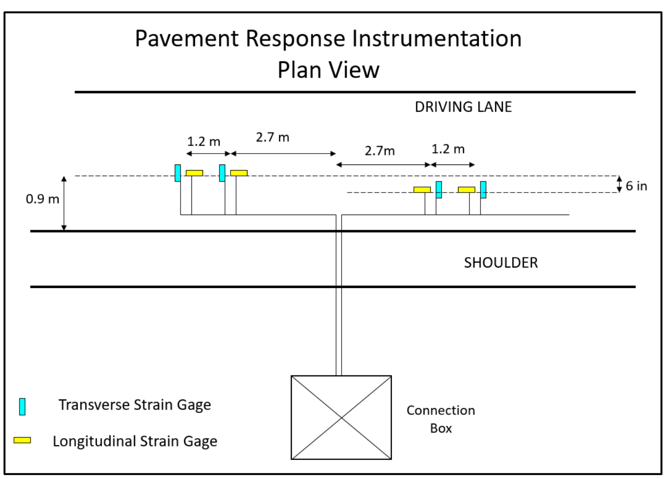
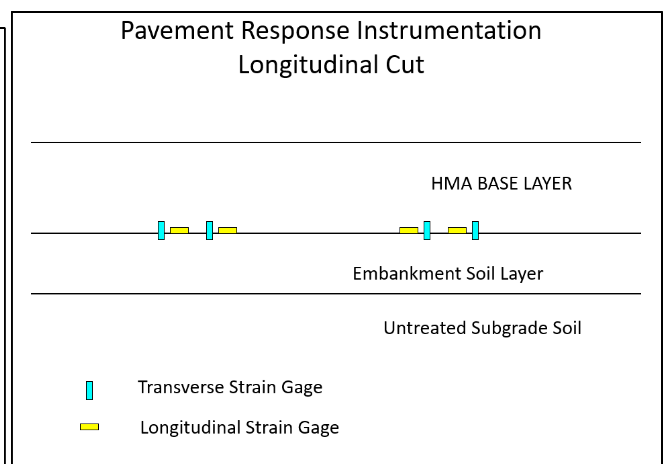
The design of the instrumentation was completed; the configuration of the in-situ instrumentation is presented in Figures 2. The strain gauges selected are model KM-100HAS manufactured by Tokyo Sokki in Japan. These are the only strain gauges specifically designed to measure strain in asphalt layers. They are robust to survive installation and can measure strains up to 5,000 macrostrains. The cable purchased for connecting the strain gauges to the acquisition system is model TX4-1000 shielded cable distributed by Omega Inc.

The sensor system for the determining the lateral position of the test vehicles is similar in concept to that used at NCAT (Figure 3). However, air hoses laid on the pavement surface will use as axle sensing strips. Two air hoses placed transversely to the direction of travel will help determine the speed of the vehicle and on a third air hose placed in diagonal will help determine the lateral position based on speed. Pressure switches, mounted and the ends of the three air hoses, become activated when the pressure in the respective air hose increases because of a vehicle wheel is on top of that hose.

The National Instruments data acquisition system (CompactDAQ) and I/O modules currently available at the University of Texas at Arlington (UTA) can accommodate the selected strain gauges and the number of sensors (8 strain gauges and three positioning relays) and sampling rates (1,000 Hz) required by the project.



a) Plan view;



b) Side view

Figure 2. Instrumentation Diagram.

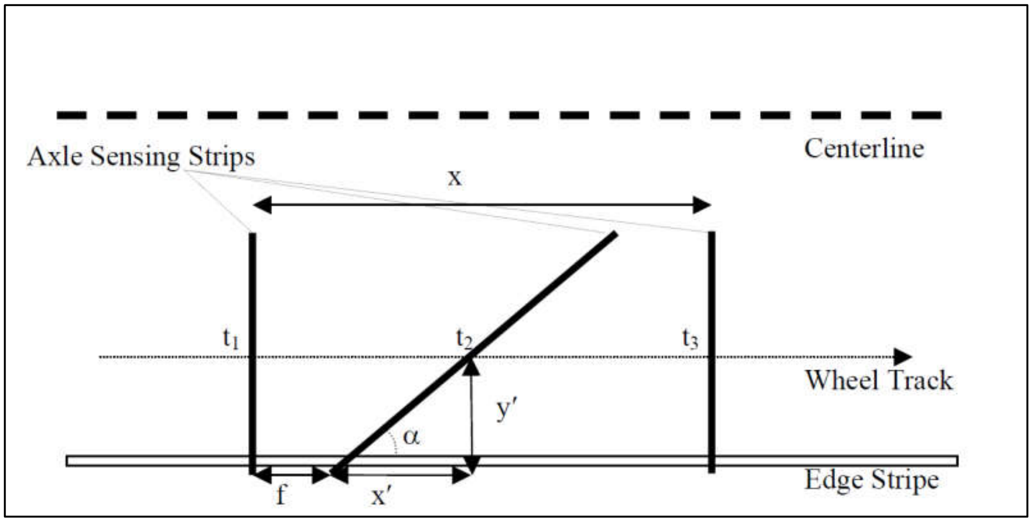


Figure 3. Plan view of the lateral positioning system used at NCAT

CONCLUSION

The project will significantly impact the process of computing the damaging effect of various truck configurations. It will better provide data to support the inclusion of visco-elastic models for asphalt materials, the inclusion of the entire truck when computing the damage and not treat each axle independently. This will optimize the quantification of relative pavement damage due to the load limit increase and the search for trucks with improved configurations. The project will lead to extension of the life of flexible pavements and an improved utilization of funds for the maintenance and rehabilitation of state and local roads.