Modelling Pavement Response to Superheavy Load Movement

Shila Khanal, MASc., P.Eng.
Pavement Engineer
skhanal@ara.com

Chris Olidis, P.Eng.
Principal Engineer
colidis@ara.com

David K. Hein, P.Eng.
Principal Engineer
Vice-President, Transportation
dhein@ara.com

Applied Research Associates Inc.
5401 Eglinton Avenue West, Suite 105
Toronto, Ontario, Canada
Tel: 416-621-9555 Fax: 416-621-4917

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ABSTRACT

With continuous development and expansion of industrial plants in rural areas, the movement of superheavy loads has become a necessity. Over the years, researchers have attempted to develop structural response models to predict pavement damage from superheavy loads with mixed degrees of success. To date, specific structural analysis guidelines/methodologies to predict pavement damage have yet to be validated. This paper outlines the outcome of a literature survey of 'best practices' and presents the outcome of two studies of superheavy load moves each planned for the spring and winter months of 2016 and 2017.

Based on the apparent shortcomings highlighted with previous analysis methods, finite element modelling was used to determine the pavement layer stresses and strains when subjected to superheavy moves. The transport vehicle for the winter move comprised a double inter combi trailer with gross weight of vehicle of approximately 1.5 million kilograms. This vehicle had two 24 axle line trailers with 1.5m axle spacing to facilitate the move. The transport vehicle for the spring move was a 4 file – 24 line conventional trailer with gross weight of 625,000 kilograms. The paper will present the study methodology, environment factors, material properties, traffic and speed variables, and the simulation of the model replicating the pavement response.

Keywords: Superheavy load, finite element modelling, pavement impact analysis.

INTRODUCTION

In the past decade there has been a shift on development and expansion of industrial plants in rural areas. With fast-paced advancing technology, larger industrial components for variety of industry sectors can be prefabricated off-site and shipped to the destination plant. This has resulted in the movement of superheavy loads that were not previously considered in the design of the roadways.

Pavement performance is significantly influenced by the magnitude and frequency of heavy vehicle traffic loads. Many agencies in North America have placed limits on truck weight and dimensions. They are beginning to require some form of a superheavy load movement analysis in order to issue the permit for the vehicles that exceed the limit.

A review of the literature on the superheavy load movement analysis was completed. Based on the review, it appears that the analysis procedures for the superheavy load moves were based on the layered elastic theory to predict the stresses and strains associated with traffic loading. The stresses and strains were then related to pavement distress using transfer functions. The critical distress considered by many agencies include fatigue cracking and/or pavement rutting. The literature has suggested that 12.5 mm (0.5 in) of rutting with 10 to 20 percent fatigue cracking of the pavement area are common failure limiting values.

Latifi, Valbon, (Valbon 2014) evaluated the impacts of overweight permit vehicle traffic on flexible pavement performance in Wisconsin using field investigations and AASHTOWare MEPDG software. Vehicles with a gross vehicle weight of at least 270,000 pound (122,000 kilogram) are classified as superheavy loads in Wisconsin and require a detailed route analysis. For the purpose of this study, four Wisconsin State trunk highways were selected. These highways have regular Oversize/Overweight (OSOW) traffic volume. Traffic counts and visual distress survey was performed in addition to the AASHTOWare MEPDG analysis.

Wisconsin Department of Transportation's (WisDOT) pavement failure criteria were used to evaluate pavement performance in this study. A rutting failure threshold of 0.5 inches and fatigue cracking threshold of 20 percent was considered. The pavement performance was estimated using AASHTOWare MEPDG software and considered the baseline traffic, and then the baseline traffic plus a single overweight truck trip to assess the long term pavement performance and to quantify pavement deterioration. The analysis was conducted over a 20 year performance period. WisDOT statewide axle load spectra were used for the baseline analysis and segment specific oversized vehicle load spectra was added for baseline plus OSOW analysis. The results for State Trunk Highway 140 indicated that there was a predicted 0.44 percent increase in International Roughness Index (IRI), 3.16 percent increase in pavement rutting and a 4.21 percent increase in fatigue cracking over performance period due to the addition of the OSOW truck traffic. The OSOW truck movement resulted in a small increase in the amount of pavement damage and loss of ride quality when compared to the predicted deterioration levels due to only the baseline traffic.

Chen, et al (Chen 2012) presented a superheavy move case study of a 4 million pound (1.8 million kilogram) load on a flexible pavement in Louisiana. The load move was modeled with 3D Finite Element software using the Mohr-Coulomb yield criterion and the BISAR layered elastic analysis program. The model investigated whether any rapid shear forces would occur within the pavement layers. The modeled pavement section was last rehabilitated in 2002, and comprised a typical section of 13 inch (330 mm) Hot Mix Asphalt (HMA) over a 6 inch (150 mm) aggregate base on the subgrade soil. To predict pavement performance, the equations developed by the Asphalt Institute (AI) were used to estimate pavement rutting and fatigue cracking. The number of allowable load repetitions was calculated to achieve a limiting rut depth of 12.5 mm (0.5 inches) before development of 20 percent fatigue cracking over the pavement area.

Three different superheavy load configurations were considered; single-line load, multiline load, and a five-line load were selected to simulate the load of the transport vehicle. For the single-line load model, the allowable load repetitions predicted by finite element method and BISAR had similar results both for fatigue cracking and rutting. Since rutting is worse than fatigue for pavement life, rutting was the controlling factor to evaluate the accumulation of incremental damage under superheavy loads. The most conservative results were produced from the single line method with the layered elastic program. The model found that distresses were highest near the bottom of the base layer indicating that the stress could reach fully through the pavement layer. The results of the superheavy load model found that instantaneous shear failure would not occur and that pavement strength was sufficient. The single line method and layered elastic program was the preferred analysis method as it is much easier to use in practice.

Tirado, et al (Tirado 2010), developed a Finite Element (FE) model to estimate the permit costs based on the actual maintenance cost of moving heavy trucks on the pavement. The representative flexible pavement selected for the model was based on a state highway in Texas, and included 3 inches (75 mm) HMA with 12 inches (300 mm) base on a 10,000psi (70 MPa) subgrade. The FE software used for the analysis was IntPave, which uses a mechanistic empirical approach to predict pavement distresses. The rutting of all layers and the fatigue cracking of the HMA layer were used for evaluating pavement damage as a function of load repetitions. Fatigue cracking was predicted using the AI MS-1 model based on a threshold of 20 percent crack area. The process of calculating permit fees was based on, “the variations in damage as a function of truck passes are developed for the standard truck and heavy truck to a predefined failure threshold of 0.5 inches of rutting or 20 percent of cracking.”

Two truck configurations were used to compare the damage done to the pavement by each. Both were AASHTO Class 9 vehicles, but one had a GVW of 80,000 lbs. (36,000 kg) and the other had a GVW of 160,000 lbs. (72,000 kg). Figure 1 below shows the rutting depth predicted by the model for the first 120 passes on the pavement by standard truck (80-kip) and heavy truck (160-kip). After 100 passes by the standard truck, the rutting depth is approximately 0.13 inches. The same rutting depth can be achieved by the second truck (GVW of 160,000 lbs.) in only five passes.

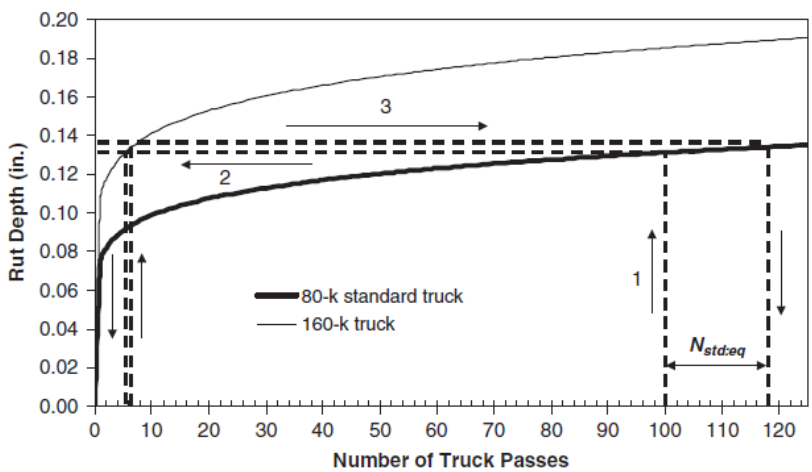

Figure 1. Rut Depth Prediction

Several other research including Jooste, F. J., and Fernando, E.G. (1994) “Victoria Superheavy Load Move: Report on Route Assessment and Pavement Modeling” and David K. Hein, Friedrich W. Jung (1998), “Assessment Techniques To Determine Pavement Damage Due to Heavy Loading” were reviewed.

METHODOLOGY

As expected, the literature review has revealed that there has been limited research into the impact of superheavy movements on specific pavement sections over long haul routes. Initially, it was anticipated that the AASHTOWare Pavement ME Design software's “special traffic loading for flexible pavement” feature could be used to analyze the special axle configuration in the transport vehicle. However, limitations in the ability to isolate the impact of the transporter's axle configuration led us to the development of a finite element model (FEM) specific to the proposed vehicle and anticipated pavement conditions at the time of the move.

A finite element modelling based methodology was chosen to analyze the impact of the movement of a heavy vehicle along the pavement infrastructure. The method considers vehicle weight and axle configuration, pavement type and thickness, subgrade type and moisture condition and environmental features. The pavement layers below the surface and subgrade were modeled as linear elastic and the asphalt layer/layers as visco-elastic using a frequency-stiffness relationship developed by Applied Research Associates, Inc. (ARA) for the AASHTOWare Pavement ME Design software. All analyses were performed with the LS-DYNA explicit FEA solver (version 7.1.1), which is well suited for modeling the load cases considered and is used widely for transportation infrastructure applications. LS-DYNA excels at modeling the nonlinear dynamic response of various materials including the visco-elastic asphalt model used in the simulations. The structured mesh preprocessor TrueGrid (version 3.0.0) was used to construct the LS-DYNA FEA models for the various load cases. The model was constructed parametrically to allow for model flexibility. The TrueGrid model outputs complete input decks, ready to run with LS-DYNA software. Completed simulations were post-processed with LS-PrePost (version 4.2), which is part of the LS-DYNA suite of tools.

The modeling application was utilized for two different case studies and is discussed in following paragraphs. It should be noted that the temperatures during the move and gross vehicle weights were significantly different in these two studies. In both the cases, the pavement loading included half of the vehicle symmetrically positioned across the pavement as shown in Figure 2.

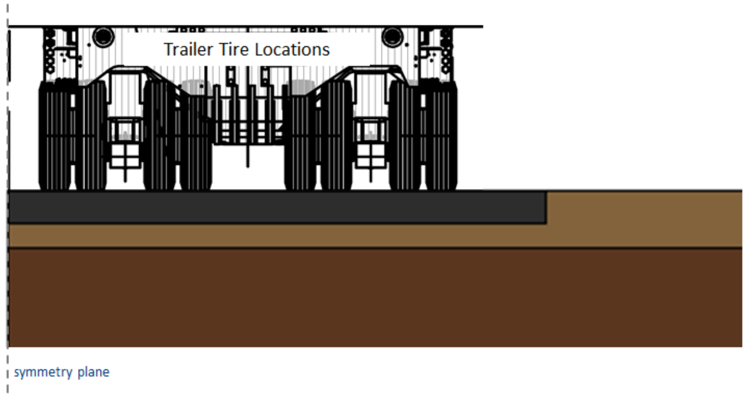

Figure 2. Transport Vehicle Axle Configuration

In consideration of the length of the move and the large variety of different pavement sections along the haul route, the pavement thickness selected for modelling was based on the lower quartile of the pavement cross section thickness. The selected cross section does not represent the worst case scenario of pavement structural capacity, but one considered to be relatively conservative, common along the route and reasonable for analysis.

Case Study – Spring Move

The move is designed to utilize a 4 file – 24 Line transport vehicle. The cargo and transport vehicle weigh 624,852 kilograms. The proposed vehicle configuration is shown in Figure 3. The platform trailer consists of 24 axle lines, with 4 axles per line and 4 tires per axle and a gross vehicle weight on the platform is 495,740 kg and weight per tire is 1,291 kg.

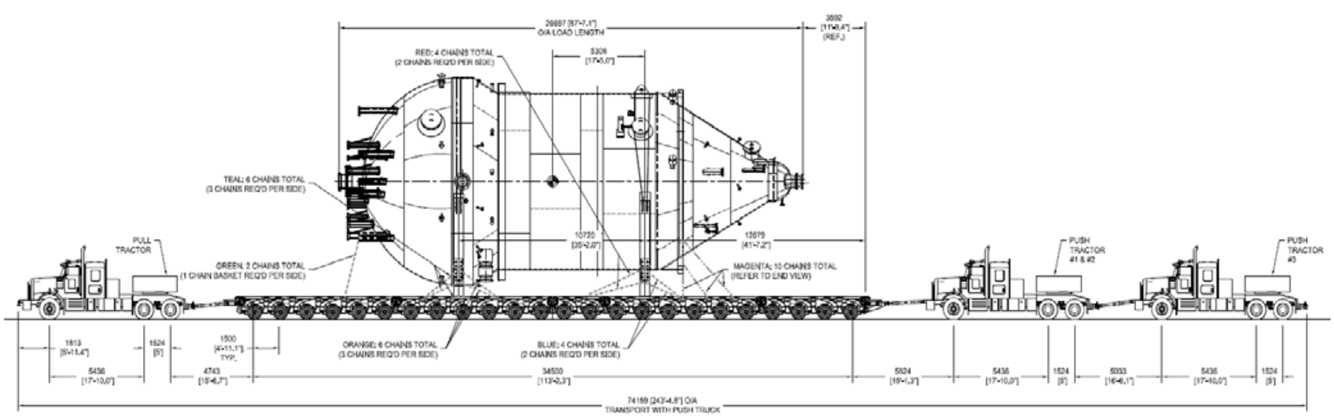

Figure 3. Proposed Transport Vehicle Configuration for Spring Move

The symmetric simulation of 8 tires for the half axle line with a tire contact length and width of 139 mm and 225 mm respectively was used. Based on the weights, dimensions, and rolling speed of the transporter (40 km/hr.), tire contact pressure of about 0.45 MPa was used. This information was obtained from the manufacturer and verified by the carrier.

The pavement section as modelled is shown in Figure 4. Falling weight Deflectometer data was used to determine representative properties for the pavement layers and subgrade. Adjustments were made to all pavement layer properties in consideration that the transport is expected to take place during spring conditions. The material properties for the pavement layers and subgrade considered are provided in Table 1.

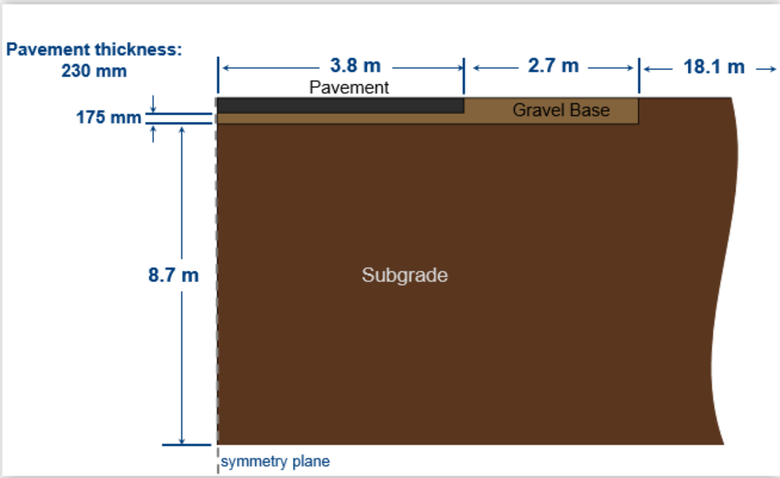

Figure 4. Road Model Section View for Spring Move

Table 1. Pavement and Subgrade Layer Properties

Property	Asphalt	Base	Subgrade
Model Type	Viscoelastic	Elastic	Elastic
Modulus (MPa)	Temperature dependent, At Temp = 3.4°C	200	15
Poisson's Ratio	0.35	0.35	0.35
Density (kg/m^3)	2,400	2,200	1,700

The asphalt concrete modulus was selected from a linear viscoelastic master curve, based on historical test data collected by ARA on other projects. A different simulation was run to check the material properties obtained from physical falling weight deflectometer (FWD) test results. Before FWD testing was common, soil moduli were typically measured in the laboratory. When FWD testing become a commonly used technique to determine soil moduli, it was found that the back-calculated FWD test values were in the order of three times larger than the laboratory values. Pavement design procedures such as the AASHTO 93 method included a "C" correction multipier to determine the equivalent laboratory value from the "dynamic" value measured from FWD testing. For this reason, a FWD "dynamic" value of 45 MPa was used for the purpose of this simulation. Figure 5 shows the simulation results using 45 MPa subgrade. In the figure, it can be seen that 45 MPa is less stiff than the physical test results.

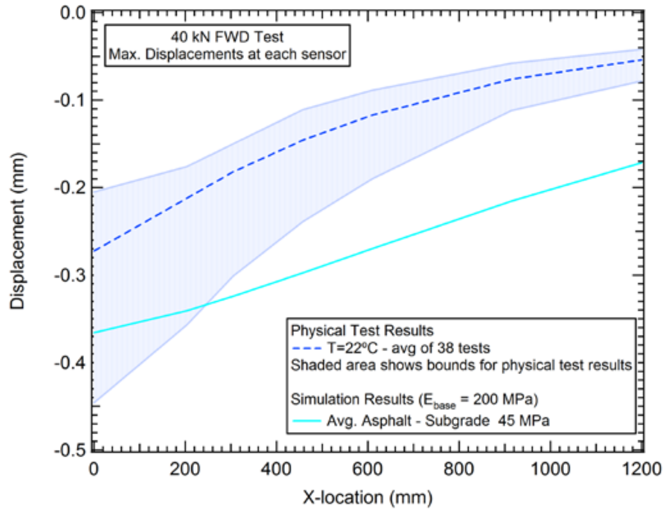

Figure 5. Falling Weight Deflectometer Simulated Physical Result

A FEM for the simulation was developed based on the geometric configuration of the transporter and pavement section, along with the pavement and subgrade material properties, outlined above. The model was of sufficient length to permit the application of the moving transport vehicle to accommodate 24 axles and width to account for the non-paved width of the roadway platform.

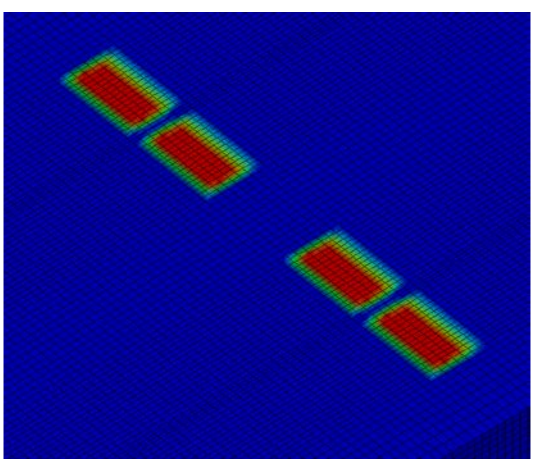

Figure 6. Vertical Stress

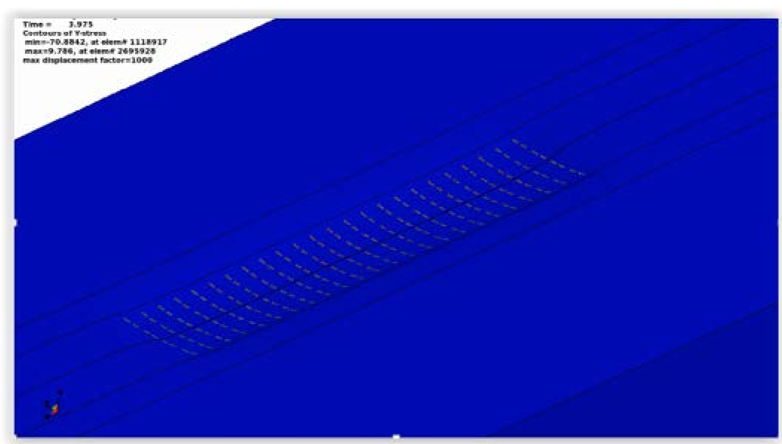

Figure 7. Simulation Results for Moving Load

The tire load was applied as a pressure on the surface of the pavement (asphalt FEM "mesh") and the load regions were moved across the mesh at the vehicle speed of 40 km/hr. (Figure 6). The tire/axle loads were gradually increased from the edge of the model (the start of fine mesh region) to 100 percent at 3.8 m from the model edge (Figure 7). This is done to minimize the dynamic effects and to achieve a steady-state stress basin shape beneath the rolling trailer.

Simulation Result

The results of the finite element modelling were analyzed to extract pavement deflections, stresses and strains for the damage impact assessment. As an initial step, the displacement of the pavement surface measured along the centreline under the load was determined. The maximum displacement of the pavement surface measured along the centreline under the load was measured to be about 1 mm as shown in Figure 8. The extent of the model was large enough that there were no unrealistic boundary effects at the ends.

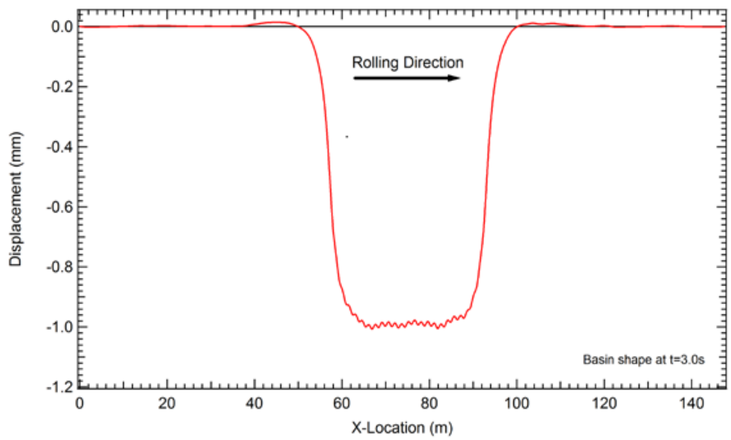

Figure 8. Roadway Centreline Displacement under Rolling Load

The compressive stresses are caused by the bending of the pavement and the tire contact pressures. Maximum compressive stress form directly underneath the tires whereas high tensile stress occurs at the bottom of the asphalt below the tires as seen in Figure 9.

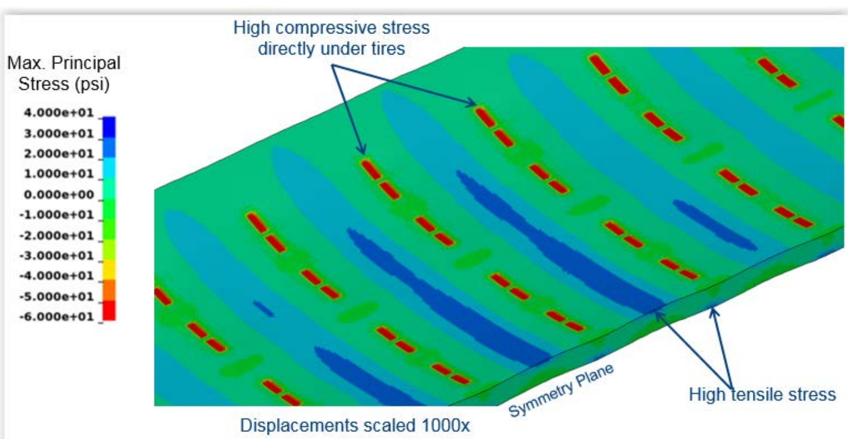

Figure 9. Stresses at the Bottom of the Asphalt Surface

The tensile stress is the highest under the front axle where the curvature is the greatest. The maximum principal stress in the asphalt is 470 MPa.

Asphalt Horizontal Tensile Strains

Horizontal tensile strains can occur either at the bottom of the asphalt layer due to the bending of the pavement in the downward direction or at the top of the asphalt layer due to the upward bending of the asphalt longitudinally between successive axles or between axles in the transverse direction of the pavement. The maximum principal strains due to the downward bending of the pavement structure are shown in Figure 10.

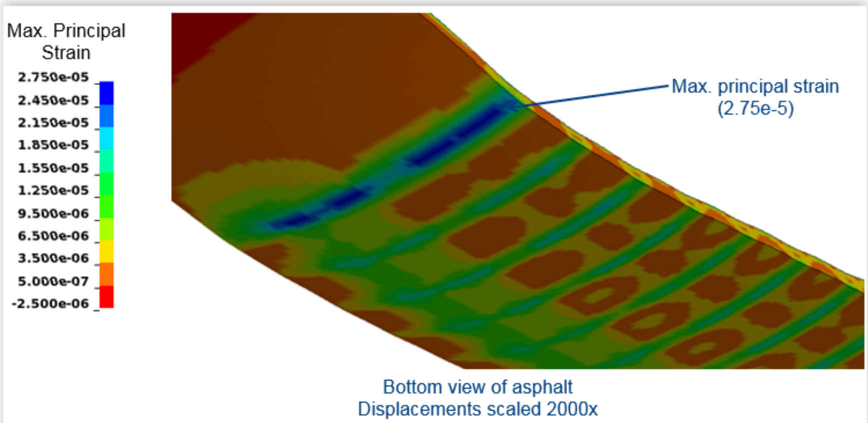

Figure 10. Horizontal Tensile Strains due to Downward Pavement Bending

The horizontal compressive strains in the asphalt concrete result in vertical tensile strains due to the Poisson effect. These tensile strains are built up as the basin grows due to the application of the transporter load. The short application of the tire contact pressure reduces the tensile strains temporarily but is a smaller effect compared to the basin shape effects.

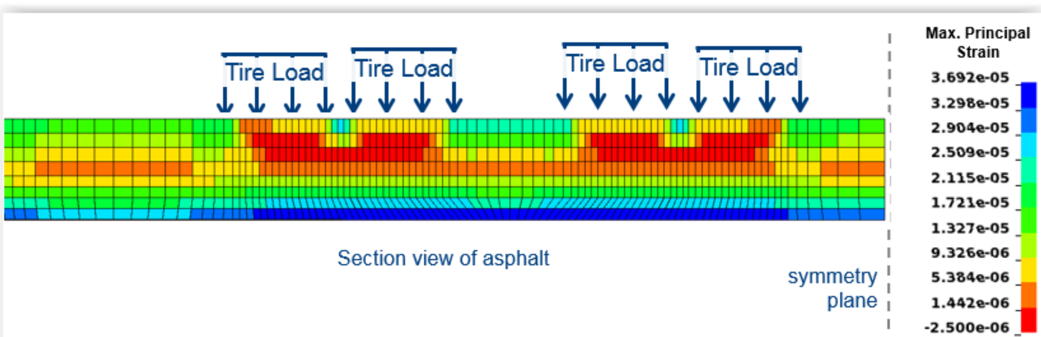

Figure 11. Horizontal Tensile Strains due to the Upward Pavement Bending

Slower moving heavy vehicles have the effect of increasing the tensile strains and are more damaging than faster moving heavy vehicles. The maximum tensile strains occur at the bottom of the asphalt, below the front axle. To refine the result, the simulation was rerun with a finer mesh in the region of peak strain to more accurately capture the strain gradient. Maximum principal strain in the asphalt after this exercise was 37 microstrain (Figure 11).

The compressive stresses below the tires lead to the lateral expansion of the asphalt concrete outwards. The asphalt between the tires is then squeezed from both sides and expands vertically upwards where it is not confined. This is the phenomenon that causes top down cracking or rutting in asphalt pavements depending on the location of maximum stress or strain.

Peak shear strains occurred between the tires of the inner tire pair and the maximum shear strain of 34 microstrain occurred at the rear axle.

Subgrade Vertical Compressive Strains

The passage of the transporter also causes the pavement to deflect vertically downwards which causes stresses and strains in the pavement layers and subgrade. As the subgrade has the lowest stiffness, the vertical compressive strains are generally the highest at the top of the subgrade. Non-recoverable vertical compressive strains cause the rutting of the pavement structure. Due to the depth of the subgrade below the pavement, the pavement surface loading is distributed over a wider area than the tire/pavement surface interaction. As such, the highest strains in the subgrade appear on the top surface below the tire locations. The result of the modelling showed the maximum compressive strain at the top of the subgrade to be 347 microstrain as shown in Figure 12.

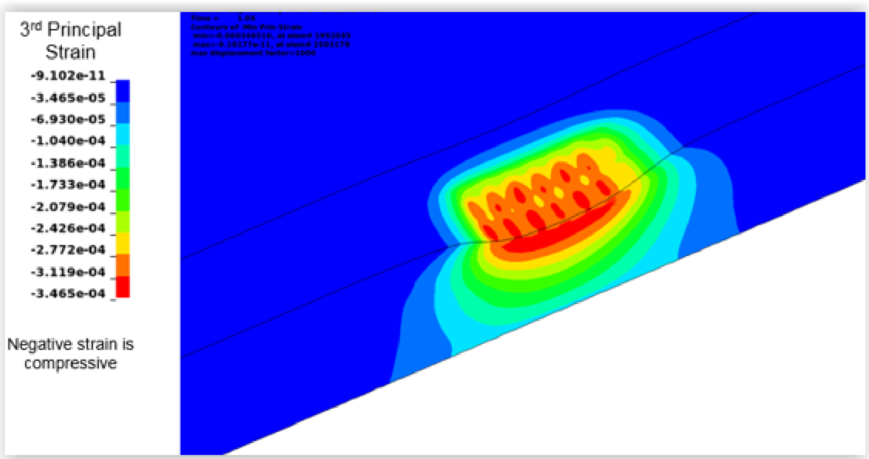

Figure 12. Subgrade Vertical Compressive Strain

Pavement Damage Analysis

Pavement damage is typically assessed in terms of the number of equivalent single axle loads that the asphalt concrete can withstand until the percentage of cracking in the wheelpath reaches a critical level. This is usually defined as 10 percent cracking along the length of the wheelpath. A similar criteria is established for subgrade rutting due to non-recoverable vertical compressive strain. The critical trigger value for subgrade rutting is usually set at 12.5 mm.

Transfer functions have been established to relate the stresses and strains calculated in the pavement to the observed wheelpath cracking and subgrade rutting. Global calibration of these models has been completed as a part of the U.S. National Cooperative Highway Research Program (NCHRP) Project 1-37a for the development of the Mechanistic-Empirical Pavement Design Guide (MEPDG).

Asphalt Concrete Fatigue Cracking

There are two ways to determine the impact of the movement of the heavy load on cracking in the asphalt concrete. The first is to consider the absolute value of the asphalt strain. The National Center for Asphalt Technology (NCAT) in Auburn, Alabama has recommended an asphalt strain endurance limit based on asphalt temperature. This limit is 70 microstrain at the intermediate temperature.

In some cases where fatigue endurance limit data are not available, the use of 70 microstrain value is recommended to be conservative. Therefore, strains less than 70 microstrain would indicate that the asphalt concrete would still be in the elastic range and therefore the applied load would not cause any permanent damage from structural loading. Since the models show that the transporter is expected to impart a maximum tensile strain of 37 microstrain (Figure 16), it is not expected that the heavy move will cause any significant damage to the asphalt concrete layer.

The second method is to use established transfer functions to determine the number of equivalent axle loads that the pavement is capable of accommodating until the pavement "fails." For this superheavy move, 10 percent fatigue cracking in the wheelpath was used as the definition of "pavement failure".

The form of the transfer function (Finn et al 1986) to calculate the number of equivalent axle loads to 10 percent fatigue cracking in the asphalt concrete is as follows:

$$\log Nf = 15.947 - 3.291 \log\left(\frac{\varepsilon_t}{10^{-6}}\right) - 0.854 \log\left(\frac{E}{10^3}\right)$$

Where:

Nf	=	Number of load application to cause 10% cracking of the wheel tracks
ε_t	=	maximum tensile flexural strain in asphalt layer
E	=	Asphalt concrete modulus (psi)

The maximum/peak asphalt tensile strain of 3.7×10^{-5} was located at the first (front) of 24 axles. The tensile strain applied by the remaining axles would be less. To be conservative, the maximum tensile strain was considered for all axles to determine the number of load repetitions. Assuming an asphalt concrete modulus of 145,000 psi (1,000 MPa) and a strain of 8.9×10^{-4} (37 microstrain/axle * 24 axles) yields some 25,000 applied loads to failure. It should be noted that the asphalt concrete modulus value is the average modulus for the representative pavement section.

Additional pavement damage would occur when the properties of the pavement layers are different than the assumed conditions, such as, a lower subgrade modulus during the spring, a lower asphalt concrete modulus during the summer, or a lower asphalt modulus as a result of previously damaged pavement.

Subgrade Rutting

The passage of the transporter also causes the pavement to deflect vertically downwards which causes stresses and strains on the top of the subgrade layer. To avoid rutting, it is expected that the vertical compressive strains at the top of the subgrade are lower than the design thresholds. A recent publication by National Center for Asphalt Technology (NCAT) in Auburn, Alabama by Tran et al (NCAT, 2015) has listed a few studies that were performed to verify the limiting design parameter for the vertical strain or stress at the top of the subgrade. Monismith et al (NCAT, 2009) proposed a limiting vertical strain of 200 microstrain. They suggested that computed vertical strains at the top of the subgrade should be kept below this value to prevent structural rutting. Similar approach was also recommended by Walubita, 2008. In this study, for the purpose of calculating remaining life, a value of 200 microstrain has been proposed for the vertical strain limit based on the research.

Based on the results discussed in previous paragraphs, the maximum compressive strain at the top of the subgrade was 347 microstrain. This value is 73 percent higher than the vertical strain limit. An analysis was performed using the following transfer function (AI 1982) to determine the relationship between vertical compressive strain and number of axle loads to reach a rutting depth of 12.5 mm (i.e. failure due to rutting). The equation is as follows:

$$Nf = 1.05 * 10^{-9}(\varepsilon_v)^{-4.484}$$

Where

Nf	=	number of cycles to failure
ε_v	=	vertical compressive strain on top of the subgrade layer

In this move, the compressive strains on the top of the subgrade are largest directly below the trailer axles and smaller between the axles. As shown in Figure 12, the compressive strains on top of the subgrade are cyclic in nature causing a loading cycle in each axle throughout the trailer. The maximum/peak compressive strain of 3.47×10^{-4} appeared on the top surface below the tire locations in the subgrade. To be conservative, the maximum vertical compressive strain on top of the subgrade layer was considered for all the axles to determine the number of cycles to failure.

For a typical new pavement where vertical compressive strain on the top of the subgrade is 200 microstrain, the number of cycles to failure for one axle would be 50 million based on Asphalt Institute subgrade strain criteria. Substituting an expected maximum compressive strain of 3.47×10^{-4} for the settler move in spring, the number of loads of failure for one axle would be 4.2 million. This means that, with this move the pavement is losing "2 percent" of its life. The condition of pavement in the route varies from fair to excellent, and because the pavement will further deteriorate after the passage of each vehicle and since the pavement also incurs non-load damage due to environmental effects, the percentage of remaining life consumed will vary somewhat.

Case Study – Winter Move

The analysis procedure in this case study is very similar to the previously presented spring move. For the purpose of this paper, only key information is presented in this section.

This winter move will utilize a two 24 line inter combi conventional double wide trailer transport vehicle with gross weight of vehicle of approximately 1.5 million kilograms. The proposed vehicle configuration is shown in Figure 13. The platform trailer on either end of the load consists of 24 axle lines, with 4 axles per line and 4 tires per axle and a gross vehicle weight on the platform of 664,700 kg and weight per tire of 1,721 kg. The symmetric simulation of 8 tires for the half axle line with a tire contact length and width of 230 mm and 235 mm respectively was used. Based on the weights, dimensions and rolling speed of the transporter (20 km/hr.), tire contact pressure of about 0.35 MPa was used. This information was provided by the carrier.

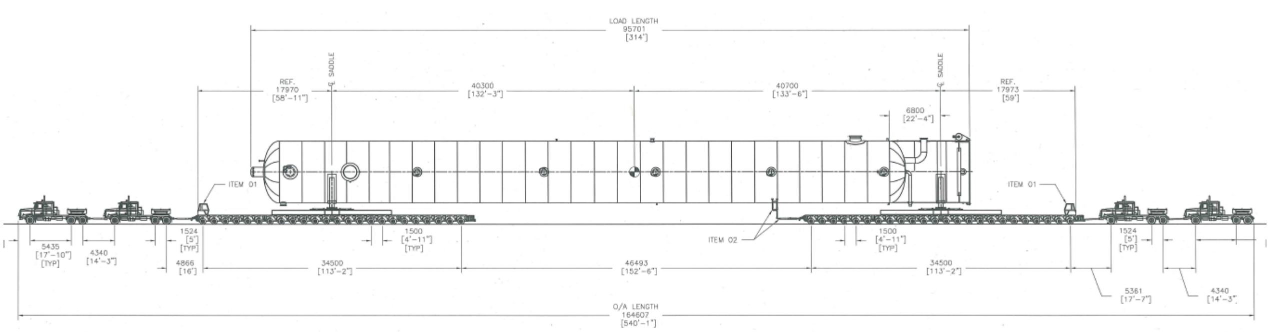

Figure 13. Proposed Transport Vehicle Configuration for Winter Move

The pavement section as modelled is shown in Figure 14. FWD data was used to determine representative properties of the pavement layers and subgrade. Adjustments were made to all pavement layer properties in consideration that the transport is expected to take place during winter conditions.

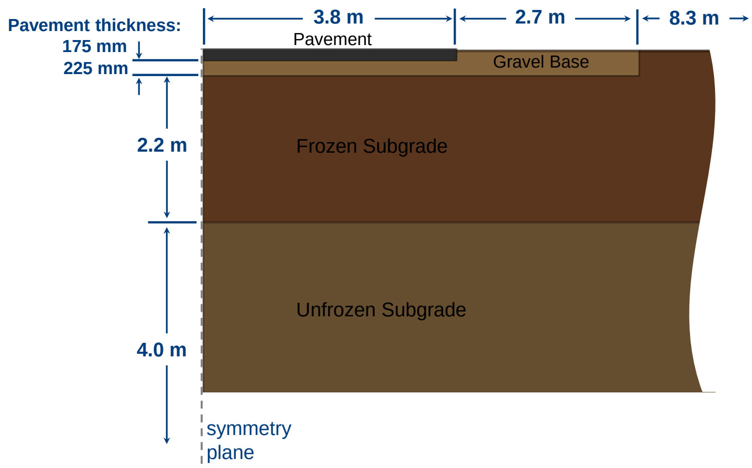

Figure 14. Road Model Section View for Winter Move

The material properties for the pavement layers and subgrade considered are provided in Table 2.

Table 2. Pavement and Subgrade Layer Properties

Property	Asphalt	Base	Frozen	Unfrozen Subgrade
Model Type	Viscoelastic	Elastic	Elastic	Elastic
Modulus (MPa)	Temperature dependent, At Temp = -7°C	6,900	6,900	23
Poisson's Ratio	0.35	0.35	0.35	0.34
Density (kg/m^3)	2,400	2,200	1,700	1,700

Simulation Result

Similar to spring move, the results from the finite element modelling were analyzed to extract pavement deflections, stresses and strains for the damage impact assessment. The maximum displacement of the pavement surface measured along the centreline under the load was measured to be about 0.95 mm. As in the case of spring move, the maximum compressive stress formed directly under the tires. However, the tensile principle stress in this case only occurred near the boundaries.

The maximum tensile strains at the top of the asphalt concrete occur between the axle pairs. The tensile strains are the lowest for the outer axles and largest near the centre. The maximum tensile strain in the asphalt concrete is 21 microstrain and is found at the 15th axle from the front of the transport vehicle as shown in Figure 15 and Figure 16.

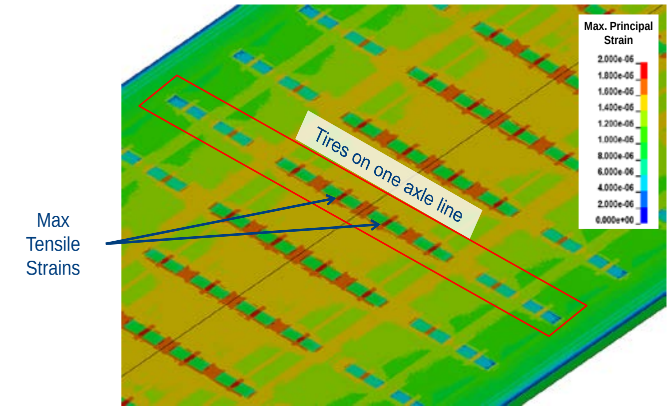

Figure 15. Horizontal Tensile Strains due to the Upward Pavement Bending

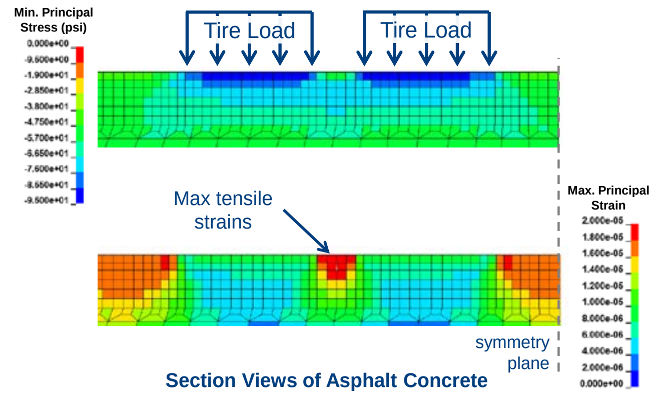

Figure 16. Horizontal Tensile Strains between the Tire Loads

The result of the modelling showed that the maximum compressive strain at the top of the frozen subgrade to be 18 microstrain and 250 microstrain at the top of the unfrozen subgrade, as shown in Figure 17 .

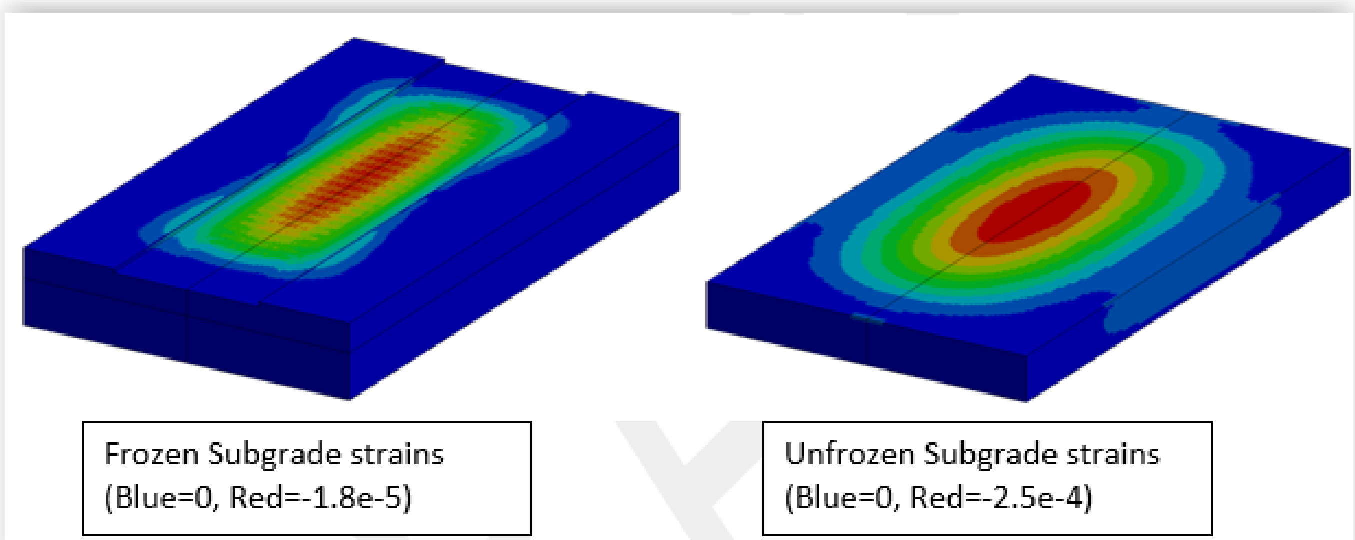

Figure 17. Subgrade Vertical Compressive Strains for Winter Move

Pavement Damage Analysis

The models show that the transporter is expected to impart a maximum tensile strain of 21 microstrain (Figure 15). As per NCAT's recommendation, fatigue endurance limit of 70 microstrain is assumed to be conservative and in this case it is not expected that the heavy vehicle move will cause any significant fatigue damage to the asphalt concrete layer.

Maximum tensile strain obtained in asphalt layer was also substituted in the transfer function (Finn et al 1986) to calculate the number of equivalent axle loads to 10 percent fatigue cracking in the asphalt concrete. The maximum asphalt tensile strain of 2.07×10^{-5}, at the bottom of asphalt layer, was located at the 15^{th} of the 24 trailer axles, measured front to back. The tensile strain applied by the remaining axles would be less. To be conservative, the maximum tensile strain was considered for all axles to determine the number of load repetitions. Assuming an asphalt concrete modulus of 1,000 MPa and a strain of 1×10^{-3} (21 microstrain/axle * 48 axles) yields some 16,474 applied loads to failure. It should be noted that the asphalt concrete modulus value is the average modulus for the representative pavement section.

For the winter move, the maximum compressive strain at the top of the frozen subgrade was 18 microstrain and at the top of the unfrozen subgrade was 250 microstrain. An analysis was performed using the transfer function (AI 1982) to determine the relationship between vertical compressive strain and number of axle loads to reach a rutting depth of 12.5 mm (i.e. failure due to rutting).

During winter, the frozen pavement layer and upper subgrade layers have very high stiffness values in the order of 6,900 MPa. This causes the load from the trailer to be dispersed over a large area. This large area supporting the load reduces the magnitude of the peak compressive strains in the unfrozen subgrade. As shown in Figure 17 there is one peak compressive strain near the centre of the trailer rather than at each axle of the trailer. On either side of this peak value, the compressive strains decrease towards zero just beyond the first and last axles. For this reason, this peak compressive strain on the subgrade can be considered as one cycle. The super heavy load mover has two of these trailers hence the subgrade will experience two peak compressive cycle.

Substituting an expected strain due to the transporter load of 2.5×10^{-4}, the number of loads of failure for one 24 axle trailer would be 18 million. With two cycle as explained above, with this move the pavement is losing “0.7 percent” of its life with every move. The condition of pavement in the route varies from fair to good, and because the pavement will further deteriorate after the passage of each vehicle and since the pavement also incurs non-load damage due to environmental effects, the percentage of remaining life consumed will vary somewhat.

CONCLUSION

A finite element model analysis was used to carry out a pavement impact study for two different scenarios of superheavy load move in spring and winter conditions. The model was used to predict the stress and strains in the pavement during 1) spring conditions, and 2) frozen conditions, when subjected to a superheavy load travelling along the route. The stresses and strains determined using the FEM were then used to calculate and predict the key types of pavement damage; fatigue cracking of the asphalt concrete and rutting of the subgrade. Spring move had about 55 percent less gross vehicle weight and the damage predicted is about three times higher when compared with winter move. Table 3 below highlights the basic difference in characteristics and results of the case studies.

Table 3. Results Overview

Details	Spring Move	Winter Move
Gross vehicle weight (kg)	624,852	1.5 million
Load per tire (kg)	1,291	1,721
Asphalt modulus	Temperature dependent	Temperature dependent
Base modulus (MPa)	200	6,900
Subgrade modulus (MPa)	15	6,900 (frozen subgrade)
Tensile strain* (microstrain)	37	21
Compressive strain**(microstrain)	347	18

* Fatigue endurance limit – 70 microstrain ** Vertical strain limit – 200 microstrain

This analysis shows the beneficial effects of a frozen subgrade horizon when compared with spring conditions.

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