



Project Summary Report O-4361-S
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Project O-4361: Determine Effects of Tire Size and Inflation Pressure on Tire Contact Pressure and Primary Pavement Responses to Loading

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PROJECT SUMMARY REPORT

Summary Report: Evaluation of Effects of Tire Size and Inflation Pressure on Tire Contact Stresses and Pavement Response

Recent years have seen an increase in the number of permitted oversized and overweight loads on Texas highways. A number of tire sizes are used by the motor carrier industry in transporting oversized and overweight loads. Tire inflation pressures for these transports are often higher than those used for regular line hauling to match the higher wheel loads of the overweight truck or trailer.

In evaluating the structural adequacy of pavements to sustain the applied wheel loads, existing practice typically assumes the tire pressure to be uniform over the contact area with magnitude equal to the inflation pressure. This analysis ignores the differences in tire footprints between various tire types. Clearly, if highway agencies are to respond effectively to the increased truck use of state highways and provide pavements that will sustain higher wheel loads, they need to address existing procedures for analyzing pavement response to loads. Procedures need to be reviewed and revised as necessary to permit a more realistic modeling of tire contact stresses, which are significantly influenced by the tire construction, tire load, and inflation pressure.

To this end, the Texas Department of Transportation (TxDOT)

funded a research project with the Texas Transportation Institute to accomplish the following:

- characterize tire contact stresses for various tire types, tire loads, and tire inflation pressures;
- evaluate the effects of tire construction, tire load, and tire inflation pressure on pavement response;
- develop a methodology for estimating tire contact stresses; and
- establish how such stresses may be represented in existing layered elastic analysis programs to achieve a better approximation of the effects of non-uniform tire contact stresses on performance-related pavement response variables.

What We Did...

Previous research projects, including some conducted in Texas in the mid-1980s, have investigated the effects of tire-related factors on tire contact pressures and predicted pavement response. In this project, researchers initially conducted a literature review to establish the present state of knowledge in this area and identify what could be used from previous research and where additional work or data are necessary. Researchers used the findings from this review to assemble available data on tire contact stresses and to set up a test plan for additional measurements of tire contact stresses that were made in this project. The database of tire contact stress distributions compiled by researchers covers the tires listed in Table 1.

Table 1. Tires Included in the Database of Tire Contact Stress Measurements Collected in California Department of Transportation and TxDOT Projects.

Research Project	Tire Type	Tire Size/ Load Range	Tread Pattern
University of California at Berkeley	Bias-ply	10.00 × 20 (G)	
	Radial	11R22.5 (G)	G159A
	Radial	295/75R22.5 (G)	G159A
	Radial (wide-base)	425/65R22.5 (J)	G286
TxDOT Project O-4361	Radial	11R24.5 (G)	G159A
	Radial	215/75R17.5 (H)	G114



Tire contact measurements in this project were collected with the stress-in-motion (SIM) pad shown in Figure 1, which is instrumented with sensors and electronics to measure tire contact forces in the longitudinal (X), lateral (Y), and vertical (Z) directions under a moving tire. Figures 2 to 4 illustrate measured tire contact stresses in the X , Y , and Z directions, respectively, for the 11R24.5 radial tire loaded to 4600 lb and inflated to 100 psi. The longitudinal axis in each figure refers to the record number for a given set of measurements collected from the row of 21 triaxial load pins positioned laterally across the SIM pad. The distance between records is 0.0138 inches.

Researchers evaluated the repeatability of the measurements in developing the database of tire contact stress distributions in this project. In addition, researchers used the data to conduct a comparative evaluation of methods for representing tire contact pressure distributions in existing models to predict performance-related pavement response variables. Three different methods were investigated:

- three-dimensional (3D) finite element (FE) analysis using measured tire contact stresses in the X , Y , and Z directions;
- layered elastic analysis using the measured tire contact area to determine the equivalent uniform circular pressure distribution for the given tire type, tire load, and tire inflation pressure (BM analysis); and
- the conventional analysis procedure in which the tire load is divided by the tire inflation pressure to determine the equivalent circular area of uniform vertical stress equal to the inflation pressure (BC analysis).

Using the results from analyses of measured tire contact stresses, researchers developed a computer program called *TireView* that provides estimates of tire contact area as a function of tire type, tire load, and tire inflation pressure and predicts the stress distribution at the tire-pavement interface based on polynomial interpolations of measured tire contact stresses in the database.

What We Found...

Based on the research conducted, the following findings are noted:

- The statistics determined from test data indicate that the repeatability of the measurements may be ranked from best to worst according to the following order: (215/75R17.5, 11R24.5) \rightarrow (295/75R22.5, 11R22.5) \rightarrow (10 \times 20, 425/65R22.5). For the tires tested in this project, researchers found the data from all replicate runs to be highly repeatable for each combination of tire load and tire inflation pressure included in the test matrices for both tires. The data from tests conducted on the 295/75R22.5 and 11R22.5 radials generally show excellent to good repeatability except for a few cases where only two out of the three replicates were found to be repeatable. Replicate runs from the bias-ply and wide-base radial tires showed the least repeatability among the tires tested. Based on the literature review, these tires are not used widely by truck carriers in Texas, accounting for about 2 percent (bias-ply) and 0.1 percent (wide-base) of truck tires sampled in a truck survey conducted in 2000 by the Center for Transportation Research at The University of Texas at Austin.
- From the evaluation of relationships between tire contact area, tire load, and tire inflation pressure based on the tire imprints taken during testing, researchers observed that the contact area decreases with increasing inflation pressure and increases with increasing tire load based on trend lines fitted to the data. In addition, the measured contact areas for various inflation pressures plot almost parallel for different levels of tire load, indicating a negligible interaction effect between tire load and inflation pressure. Thus, researchers used a simple additive model to evaluate the relationships between tire contact area, tire load, and tire inflation pressure. From this analysis, the effects of tire load and tire inflation pressure were found to be statistically significant.

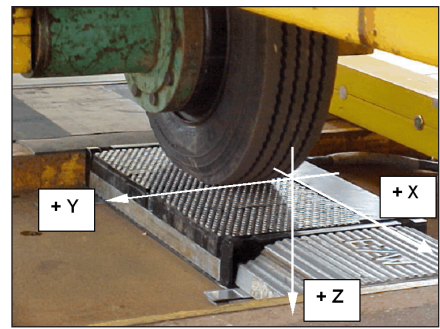


Figure 1. SIM Mk IV Pad Used for Tire Contact Stress Measurements.

- Researchers constructed and used a 3D FE model of asphalt concrete pavements to compare predictions of pavement response based on measured tire contact stresses with corresponding results obtained using layered linear elastic analyses. The suitability of the 3D FE model used in the analyses was verified by comparing the predicted pavement response with corresponding predictions from the layered linear elastic program, BISAR. For a uniform circular pressure distribution, researchers found that the predicted strains with depth from the 3D FE analysis using the ABAQUS computer program are quite comparable with the corresponding predictions from BISAR.
- In terms of the predicted service life based on subgrade compressive strain, the results show no significant differences between the 3D finite element and layered elastic analyses. This finding indicates that the effects of differences in tire contact pressure distributions are mainly seen near the surface and diminish with depth. Thus, in terms of the effect of tire contact stresses on pavement rutting, the permanent deformation properties of the surface material would be critical.
- Researchers conducted a statistical test of the differences in the predicted logarithms of the fatigue lives from the 3D FE and layered elastic analyses. At a 95 percent confidence level, it was found that the differences between the predicted fatigue lives from the 3D FE and BM analyses are



not statistically significant. However, the differences in the fatigue predictions between the 3D FE and BC analyses were found to be significant.

- Differences in the fatigue predictions between the BM and BC methods showed the effect of tire contact area in the predicted tensile strains at the bottom of the asphalt concrete material. For a given tire load and tire inflation pressure, the conventional (BC) method of analysis ignores the differences in the tire footprints between various tire types.
- Researchers calculated the Mohr-Coulomb (MC) yield function values at the center and edge of the loaded area at different depths using the 3D FE, BM, and BC methods. It was observed that differences in the MC values between the 3D FE and layered elastic analyses

are greatest near the surface and diminish quite rapidly with depth. In general, researchers observed that for the cases investigated, the differences were largest within the top 2 inches of the surface layer. Within the base and subgrade, the differences are not considered significant.

- The critical MC yield function values occurred near the top and bottom of the asphalt concrete layer for the cases considered. At these depths, researchers examined the differences between the 3D FE and layered elastic analysis methods. At a confidence level of 95 percent, it was found that the differences between the predicted MC values from the 3D FE and BM analyses are not statistically significant. However, the differences in the predicted MC values between the 3D FE and BC analyses are significant.

The Researchers Recommend...

Researchers recommend the application of the BM method in the layered elastic analysis of pavement response. For this purpose, the equations developed in this project to estimate tire contact area for a given tire type, tire load, and tire inflation pressure may be used in practice to determine an equivalent uniform circular contact pressure and footprint size for layered elastic analysis. In this way, differences in tire footprints between tires can be considered. The calculation of the equivalent uniform circular contact pressure and footprint size may be done using the *TireView* program developed in this project.

In addition, *TireView* provides estimates of tire contact stress distributions for a given tire type, tire load, and tire inflation pressure based on polynomial interpolations of the measured values stored in its database. Researchers recommend that pavement engineers use these estimates in a 3D finite element program to predict pavement response for applications where a rigorous analysis is warranted or desired. The predictions are specific to the tires included in the database of tire contact stress distributions. Since differences in tire construction will affect tire contact pressures, the predicted tire contact stress distributions are tied to the database on which the interpolations were made. In addition, the predictions are limited to the range of the available data. For cases outside this range, researchers recommend that tests be conducted to measure tire contact stresses for the variables of interest. Future program updates should then be made as additional data become available.

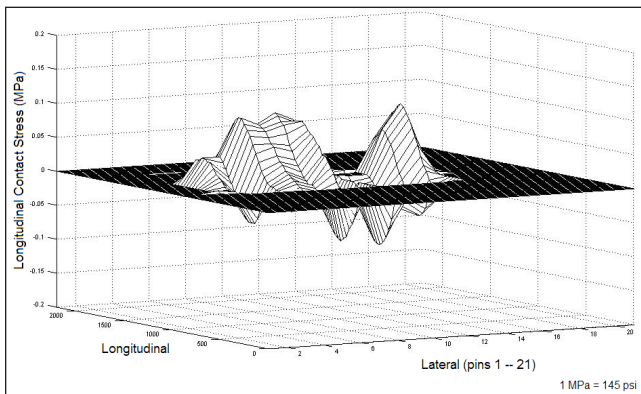


Figure 2. Measured Longitudinal Contact Stress Distribution for 11R24.5 Radial Tire Tested at a Tire Load of 4600 lb and an Inflation Pressure of 100 psi.

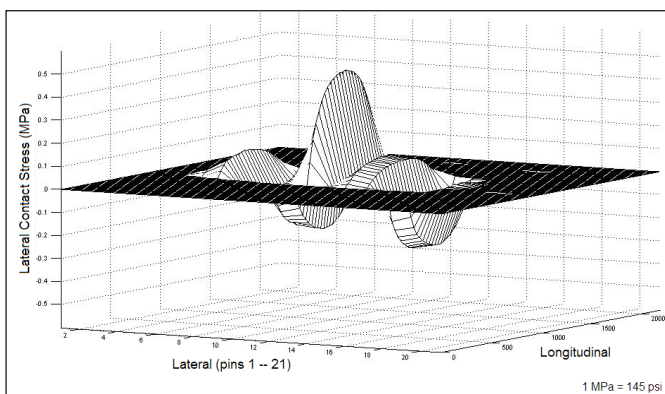


Figure 3. Measured Lateral Contact Stress Distribution for 11R24.5 Radial Tire Tested at a Tire Load of 4600 lb and an Inflation Pressure of 100 psi.

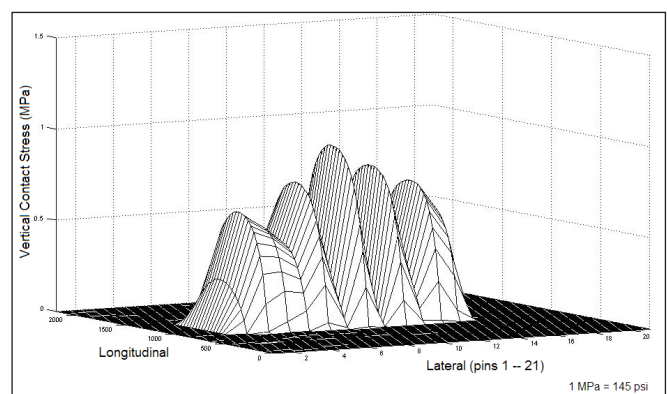


Figure 4. Measured Vertical Contact Stress Distribution for 11R24.5 Radial Tire Tested at a Tire Load of 4600 lb and an Inflation Pressure of 100 psi.



For More Details...

This research is documented in Report 0-4361-1, *Evaluation of Effects of Tire Size and Inflation Pressure on Tire Contact Stresses and Pavement Response*. The set-up file for the computer program *TireView* developed in this research project is available on compact disc as Product 0-4361-P1.

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