TPF-5(197) The Impact of Wide-Base Tires on Pavement Damage - A National Study
Technical Advisory Committee Phase II Meeting
TFHRC, McLean, VA
May 30, 2013

Attendance

A meeting of the FHWA National study for "The Impact of Wide-Base Tires on Pavement Damage" was held at FHWA Turner-Fairbanks Highway Research Center, on May 30, 2013. Those present for the meeting were:

Stan Lew (Michelin)
Joel Neff (Michelin)
Van Teeple (Michelin)
Keith Brewer (Rubber Manufacturer Association)
Steve Butcher (Rubber Manufacturer Association)
Larry Buttler (Texas DOT)
Shongtao Dai (Minnesota DOT)
Brian Diefenderfer (Virginia DOT)
James Green (Florida DOT)
Dan Hill (Montana DOT)
Terri Holley (Oklahoma DOT)
David Lippert (Illinois DOT)
Imad Al-Qadi (University of Illinois)
Aaron Coenen (University of Illinois)
Jaime Hernandez (University of Illinois)
Angeli Gamez (University of Illinois)
Mojtaba Ziyadi (University of Illinois)
Tom Scarpas (Delft University)
Rongzong Wu (UC Davis)
Eric Weaver (FHWA-TFHRC)

Introduction

Eric Weaver gave an overview of the meeting logistics and opened the meeting with self-introductions. Imad Al-Qadi then started the presentation with a brief overview of the project and presentation topics.

Presentation and Panel Discussions

Tire Contact Stress

Jaime Hernandez discussed the three-dimensional (3D) contact stress data acquired from the Council of Scientific and Industrial Research (CSIR) in South Africa. The experimental program consisted of various combinations of tire inflation pressure (552 to 862 kPa) and tire loading (26 to 80 kN) for the two tires considered in the research study: WBT 445/50 R22.5 and DTA 275/80 R22.5. In addition, a DTA with differential tire inflation pressure was also included in the test matrix. The stress-in-motion system (SIM) at CSIR was introduced, wherein a select number of steel pins measured the applied forces as the tires traversed the pad assemblies. A detail of the measuring pin was also illustrated. Tire imprints were also obtained for the contact area.

Keith Brewer commented on the conditioning of the tire surface prior to measuring the contact stresses and Eric Weaver suggested a follow up with Morris De Beer to determine if any tire conditioning process was performed. Morris De Beer indicated that no conditioning process was performed on tires.

Jaime Hernandez continued to explain the use of the load deflection curves that would be used to calibrate the finite element modeling (FEM) of the tire and the selection of the three out of ten optimum contact stress repetitions. The three optimum repetitions were selected by comparing the applied load by the HVS to the resultant force from the measurements. The presentation then proceeded to data processing, which included filtering of the measured forces using the developed Matlab script and calculation of the contact area based on the tire imprints using AutoCAD. In addition, a Python script was developed to provide summary plots of the 3D contact stresses and tire imprint geometry. Preliminary analysis was also discussed, including the effect of the tire type, range of inflation pressures and two extreme tire loading cases (26 and 80 kN) on the 3D contact stresses and contact areas. The effect of speed was not included because it has been well documented that it has negligible effect on stresses; however, it has a large effect on loading pulse time and measured strain, which is important for visco-elastic materials like asphalt concrete.

Pavement Modeling

Tom Scarpas introduced the thick pavement model development done by Delft University in cooperation with the University of Nottingham. The thick pavement structure was defined in order to initiate the mesh sensitivity analysis. Thick structure was selected based on the assumption that with a thickness lower than 125 mm, the main load-carrying component would the base layer. Thick pavement is defined as one with two or more layers and a minimum thickness of 125 mm. The mesh size was reduced in the depth direction to provide a balance of accuracy and minimized computational time. In addition, along the tire imprint, a fine mesh was introduced in the transverse direction based on previous research at the University of Illinois. The sinusoidal contact stress distribution considered in FEM was also illustrated. Several inputs from the Smart Road data for the FEM included the 3D contact stresses and tire footprint dimensions of both the WBT and DTA, and layer material characteristics. Using the thick pavement case presented, a comparison of results using CAPA-3D by Delft University and Abaqus by University of Illinois will be performed. It was also emphasized that the surface layer needs to be realistically represented with viscoelastic properties. The analysis positions included the locations of the maximum tensile strains of the asphalt concrete at the top and bottom surfaces, maximum vertical compressive strain at the top of the subgrade, and maximum shearing strain in the asphalt layers. These responses may be considered as performance indicators and will be used in mechanistic design procedures. Preliminary outputs of the analyses due to the effect of WBT and DTA loading patterns were presented.

Imad Al-Qadi commented on the location of the measurements when comparing the DTA and WBT and the importance of considering the tire wander in the analysis. In accordance to the maximum responses, Van Teeple added that the location of the maximum responses may occur in the lateral or longitudinal direction.

Tom Scarpas commented on the contact problem between the tire and pavement surface. Moreover, Eric Weaver remarked on the result comparison using CAPA-3D and Abaqus to ensure model agreement. Tom Scarpas mentioned that the comparison would be initiated with a linear elastic analysis for an easier adjustment and development of the FEM software.

Angeli Gamez introduced the FEM development performed at the University of Illinois. Using Abaqus, a dynamic-implicit analysis is considered to represent the effect of mass inertia and damping forces on the pavement responses. Similar to the cases presented by Delft University, linear viscoelastic material properties were used for the asphalt concrete layers and non-uniform 3D contact stresses were simulated. However, in terms of the granular materials, the thin pavement cases assumed non-linear stress-dependent properties, whereas the thick pavement cases considered elastic properties. A continuous moving load was also introduced in order to simulate the rolling pattern of the tire as it traverses over the pavement structure. Other finite element model parameters discussed included the use of infinite boundary elements and various layer interactions – all alluding to a more realistic representation of the pavement analysis.

The mesh sensitivity analysis was also discussed for both the thin and thick pavement structures to optimize the distribution and location of the finite elements which controls the computational time and accuracy of the model. BISAR was used for the comparison, with a 5% difference criteria defined. Results of the comparison showed a good agreement between the responses from BISAR and Abaqus which ensures that the mesh configuration was accurately represented.

Additionally, the FEM analysis matrix was introduced. The parameters included the pavement geometry, material property and loading cases (with various combination of inflation pressure and load for WBT and DTA).

Eric Weaver commented regarding the tire model. Imad Al-Qadi mentioned that tire material properties were obtained, however modeling of the tire is beyond the scope of the research study, which should be considered in future work. Van Teeple mentioned that the contact stresses being measured to compare the WBT and DTA is one of the many important variables. However, several factors, such as tire life, design details, and operating conditions, should also be considered and are closely related to the load deflection curves. Tom Scarpas suggested that if the tire models are calibrated at low speeds, then increasing the speeds can be implemented. And that the influencing factors of the tire imprint are important. Stan Lew emphasized that it is important to keep in mind that there are many factors that changes the responses and cannot generalize. Imad Al-Qadi suggested that the outcome of the research study should be considered in a way that it should be geared to be multi-faceted and account for new tire models apart from the scope of the research. Eric Weaver mentioned that difficulty arises in obtaining an accurate tire model because the information is proprietary and that the scope of the study time and resources limits the feasibility of considering all tire types and testing.

Jaime Hernandez presented the use of the Abaqus Python Development Environment (PDE) to automate repetitive tasks on the input file generation. PDE enables the user to perform parametric studies, create and modify models, and access the output database in an efficient manner. In accordance to the FEM inputs, the 3D contact stress measurements from CSIR were transcribed onto the discretized loading imprint.

Imad Al-Qadi commented that a South Dakota study observed the difference in truck mileage impact on low and high volume roads and its importance on pavement damage and corresponding cost.

The asphalt concrete material properties were obtained from the LTPP Data Release # 26, in order to represent two extreme materials (weak and strong). The selection was performed using

a statistical analysis with an NMAS criterion for each asphalt concrete layer (wearing surface, intermediate layer and base layer). In addition, the thin pavement cases considered the cross-anisotropic stress-dependent material property for the granular base layer. Similar to the AC layer, the weak and strong (extreme) material properties were generated. Another important FEM parameter was the temperature distribution in the asphalt concrete layer. Based on a past research study, the temperature distributions for various asphalt concrete thickness combinations was determined. Imad Al-Qadi commented that due to the viscoelastic property of the asphalt concrete, it becomes dependent on speed of the load and the temperature. However, the granular materials are not considered to be temperature and frequency dependent.
Using the discussed input parameters, preliminary FEM runs were performed for both the thin and thick pavement cases due to the effect of the load and material property combinations. A sample of the output was also presented.

Van Teeple commented on the discontinuity of strain indicates no bonding between the layers. Jaime Hernandez mentioned that the FEM simulates field conditions wherein the asphalt concrete is not fully bonded to the granular material. Imad Al-Qadi emphasized that shearing has a major effect on distresses and should be considered.

Data Management

Mojtaba Ziyadi presented the process of data management, filtering process and its importance for the Artificial Neural Network (ANN). The field and accelerated pavement testing (APT) data would be used to train and test the ANN model. Main data sources that were used for the in-progress interface development include the test sections at the University of Illinois, Florida DOT, UC Davis, Ohio DOT, and Virginia Smart Road.

The data from Florida and Ohio is currently in the filtering stage using a Matlab script. The filtering process includes the transfer of data to origin, smoothing using the Robust Local Regression Method, and extraction of local extremes. Eric Weaver commented on the data extraction, which is a robust and labor intensive process in order to obtain the peak points for the responses. Mojtaba Ziyadi added that automating the filtering process is difficult, as the noise can be dependent on the various factors, e.g., sensor, and therefore, requires user effort in determining the appropriate filter. Imad Al-Qadi emphasized that proper grounding could also affect the data. Preliminary response data from Ohio and Florida were presented to illustrate filtering.

In order to organize all the data, a user-friendly interface was initiated. The interface consists of the response data, reports, instrumentation schematic and pictures for added documentation. The future plans of data management and organization includes the creation of ANN, which is a robust and nonlinear statistical learning technique. It trains from a given data and extracts the knowledge to interpolate cases within the provided boundary and accuracy of the data. Benefits of using ANN includes the ability to predict pavement damage caused by various loading and tire configurations with less computational time. The training stage of the ANN model will include the FEM results from the thin and thick pavements, while field and APT data will be used for the validation.

Laboratory Testing

Aaron Coenen presented the material acquisition and sample preparation performed at the Ohio test section in September 2012. Research engineers and graduate students from the Illinois Center for Transportation (ICT) created a “mobilized” lab setup at the asphalt plant in Ohio in order to acquire the appropriate amount of specimens for material characterization. An area adjacent to the satellite testing building of the plant housed the "mobilized" lab, which includes portable gyratory compactors, small ovens and various testing equipment. Alongside the interval collection of specimens, Illinois graduate students documented the paving sequence of all the layers of the test sections to ensure that the material at instrumented area is properly characterized.

The collected specimens were divided between the University of Illinois and Texas A&M University. The UIUC specimens were then divided into various laboratory tests, including dynamic modulus, semi-circular bending, indirect tension (IDT), disk-shaped compact, and push-pull. Specimen fabrication for each tests were illustrated and test specifications were briefly discussed, as performed at ICT. Another important factor was the influence of the target density, which should reflect the in-field density. By preparing the specimens at the same density as laid on the field test sections, not only would the FEM cases have a more accurate material property characterization; but also this method would monitor the consistency of the production truck-by-truck. Appropriate analysis will be provided in the final report

Adjustment for field cores from the Florida and UC Davis test sections was mentioned, as the thin pavements does not meet the required test specimen dimension of the dynamic modulus and push-pull tests. It was suggested to compensate the dynamic modulus data using the IDT creep compliance test.

Brian Diefenderfer recommended performing the dynamic modulus test on the IDT specimen. Imad Al-Qadi mentioned that the modulus is only reflected in two different directions, which may sacrifice the accuracy of the process. Jamie Green mentioned that they gathered a limited number of data using the IDT specimen for the dynamic modulus test. Eric Weaver commented that during a study on cores extracted from Connecticut, high difficulty and variability was encountered using the IDT E* method. Eric Weaver recommended using small-specimen uniaxial fatigue in the AMPT. A draft procedure and software are available. Imad Al-Qadi mentioned that the main goal of the material characterization was to obtain the Prony series for the viscoelastic property, which could be obtained via the creep compliance test.

Instrumentation and Field Testing
Florida
James Greene presented the instrumentation and testing phases of the test sections at Florida, and a brief overview of the Florida DOT APT facility. The facility includes eight test tracks, two test pits and a heavy vehicle simulator (HVS) with an independently controlled heating system. The cross sections of the test pit and test track sections were also discussed, along with the instrumentation schematic. The types of instruments for the test sections included 24 surface strain gauges (foil), 6 asphalt strain gauges (H-type), and 4 pressure cells. A preliminary filtered strain data was also presented. The construction, paving, and material sampling processes were also illustrated.

In terms of laboratory testing, both the granular and asphalt concrete materials were characterized. Asphalt concrete cores and loose mixture were also collected. Additionally, the HVS test matrix was defined and completed, and the response data was sent to the University of Illinois. Currently, shipment of the specimens is being arranged between the Florida DOT and the University of Illinois.

James Greene commented that the layer thicknesses are typical for Florida pavement designs consisting of a thin asphalt concrete layer and stiff base. Imad Al-Qadi mentioned that the HVS data from Florida would be used for FEM validation, considering the same material property and pavement geometry. It was also emphasized that by collaborating with other agencies, such as the Florida DOT, it minimized the cost of paving a new test section and allowed access to various test sections with a limited budget.

Brian Diefenderfer referred to how the foil strain gauges were used in between layers and its constructability. Imad Al-Qadi commented that the foil gauges would be easily damaged. In Ohio, cores were removed and the foil gauges were placed on the circumference of the core at various depths. Florida, on the other hand, placed the foil strain gauges 3, 6 and 12 in away from the tire edge for surface data.

Imad Al-Qadi mentioned that the importance of considering a variety of test sections and material properties would provide a broad spectrum of analysis and affect the validation stage of the finite element models of the previously presented thin and thick pavements and ANN.

UC Davis

Rongzong Wu presented the instrumentation and testing phases of the test sections at UC Davis. The HVS response testing on two flexible pavements was recently completed and the life cycle assessment (LCA) framework was established. Similar to the case in Florida, the defined full depth recycling pavement structure was also connected to a Caltrans study.

The types of instrumentation included 8 strain gauges, 4 pressure cells, 1 multi-depth deflectometer (MDD) with three depths, and 12 thermocouples for the thick pavement section, whereas the thin pavement section included 6 strain gauges, 1 pressure cells, 1 multi-depth deflectometer (MDD) with four depths, and 12 thermocouples. A multi-depth deflectometer is constructed by stacking LVDTs on top of another to measure deflections at various depths. Unfortunately, few strain gauges malfunctioned during testing, which may be due to the construction process.

Tire imprints were also generated for both tires. Moreover the HVS testing program included a combination of pavement temperatures, various tire pressures and half axle load ranges, and lateral offsets. The testing sequence was initiated with the half axle loads below 18 kips to avoid possible damage. Each combination consisted of 100 repetitions with a constant speed of 8 kph and no wander. The thick section was tested between March 6th and April 15th, with a total of 22,100 repetitions, whereas the thin section was tested between April 26th and March 20th, with a total of 20,300 repetitions. Preliminary response data and surface rut contours were also presented.

In terms of the LCA, the selected scenarios were based on the traffic level and pavement structure. Additional analyses would also involve several factors including market penetration rates, tire types, traffic levels, and congestion levels. From the LCA, decision makers would gain an additional tool in considering the impact of WBT.

Van Teeple suggested a future discussion of the LCA, with regards to the needed tire-related inputs. Rongzong Wu commented that the life cycle inventory (LCI) is built from past studies of concrete and asphalt pavements, and from attendee inputs from an international workshop hosted by UC Davis. However, their LCI does not include tire materials. The lateral offset definition was clarified, wherein the zero offset was defined to be directly under the centerline of the tire. Van Teeple offered LCA data for tires from Michelin

Imad Al-Qadi mentioned that the location of the maximum responses varies, depending on the load applied and pavement thickness. Therefore, introducing the offset provides a more robust analysis of the pavement response.

Stan Lew commented that the WBT rim has a built-in 2 in offset, however the disk was modified because the American wheel does not fit with the hub, and it was checked if the 2 in offset was maintained and when mounted onto the hub the WBT would be out 2 in. This offset does not refer to the distance from the line of sensors to the center of the tires during APT testing. Rongzong Wu mentioned that the centerline of the tires were checked and ensured that it lied on the predefined line of instruments. Eric Weaver emphasized that work done this far does not draw any firm conclusions but the effect of lateral offset is significantly important.

Van Teeple mentioned a paper from the University of Laval (2012) discussing the effect of the lateral offset and would be shared with the committee for better visualization.

A collective comment by the committee was focused on the location of the strain gauge in the middle of the DTA, instead of underneath one of the two tires to locate the maximum response when the tire is directly on top of the sensor (in comparison to WBT directly over the sensor). Imad Al-Qadi mentioned that there is available data for the WBT wander from the University of Illinois but none for DTA. However, data is available in the SPS-8 section in Ohio from tests performed in 1998. One of the future plans would include a robust analysis of the current and future data. Therefore, conclusions cannot be drawn solely from the preliminary results.

Ohio

Angeli Gamez presented the instrumentation and testing phases of the test sections at Ohio. A brief description of the project purpose was discussed, by which the thick pavement structure consisted of various asphalt concrete thicknesses. In contrast to the Florida and Davis APT sections, Ohio used a controlled truck load test to compare the DTA and WBT with single and tandem axles.

The types of instruments consisted of linear variable differential transformer (LVDT), pressure cells, thermocouples, strain gauges and rosette strain gauges. The controlled truck loading test matrix was also presented. Replacement of instrumentations that malfunctioned occurred in late May and instrumentation was scheduled in June.

Eric Weaver summarized the pre-construction meeting that was organized at Ohio regarding the refinement of instrumentation and construction details of the test sections. Testing was initiated in Ohio, however, it was performed towards the end of the 2012 under cold weather conditions. This then affected the magnitude of the responses. In addition, the contractor was not satisfied with the appearance of the surface layer and decided to set a reconstruction date in June for resurfacing (this process will also remove the instruments in place). The truck load test to be performed this summer was also mentioned.

Imad Al-Qadi mentioned that Ohio may not complete the test matrix due to time constraint, and the matrix would be limited to regular loading scenarios with different speeds. In addition, the differential DTA inflation pressure case was requested to consider its significant impact, which was observed in the Smart Road project.

Eric Weaver commented on the complicated collaboration due to time constraint and instrumentation schematic change, as rosette strain gauges were not part of the initial plan of Ohio DOT. Moreover, some part of the Legacy datasets, the lateral offset was varied cautiously to observe the variation. This data is available and could be useful for this research project.

In regards to the Ohio testing plan, a lateral offset was not part of the matrix. However, at higher speeds, involuntary lateral offsets would be apparent and cannot be easily controlled, but were recorded in the field. Imad Al-Qadi added that though there is a time restriction and limitation on the test matrix, good data would be collected. Rongzong Wu commented that it is important to not only analyze the peak response but also the distribution, as wander in real traffic conditions varies highly. Van Teeple emphasized that lateral offset is highly critical and suggested that keeping track of the offset by mounting a camera onto the vehicle would track the lateral offset. Imad Al-Qadi assured that the lateral offset would be documented during the test runs. For each run, 20 passes would be completed. However, Eric Weaver clarified that pre-defined offsets were not set due to low repeatability.

Future Plans
Imad Al-Qadi concluded the presentation with the summary of future plans.

- Regarding the contact stresses, a detailed contact stress analysis of the DTA and WBT will be completed. Also, a future implementation of contact stress prediction would be done using FEM.
- In terms of pavement modeling, the matrix will be finished to provide a robust analysis considering the effect of the tire type, material property, loading characteristics and pavement structure.
- Material characterization in the laboratory will be completed for all the test sites.
- The field and APT collection and analyses will be finished and organized for all test sites. As data is received, it will be filtered and analyzed.
- Preliminary LCA scenarios will be established.
- Further marketing and future publications will be done.
    - There will be a WBT webinar regarding the contact stresses later this summer. Imad Al-Qadi added that there was a WBT webinar last fall.
- The data pool will be available in the future and will be easily accessible via ANN.

Eric Weaver commented that until all the data is sifted and the analysis is completed, conclusions cannot be drawn. Additionally, the committee need to think ahead regarding the technology transfer and most appropriate organization of the data and results (e.g. use of website interface). Imad Al-Qadi mentioned that the study has experienced some good delays, in terms of generating accurate pavement models, site construction and load testing. The committee is then encouraged to consider the low feasibility of completing and drawing strong conclusions on the project by December 2013. Eric Weaver stressed that the accuracy of the results weigh heavier than the planned project date completion.

After the technical discussion meeting, Eric Weaver commented on the application and implementation of the results into design guides. Additionally, the committee acknowledged the delays, however, the overall vision and expectations should be considered in a state DOT perspective. The research team is encouraged to consider and address the declined emphasis of the LCA aspect of the project. Alternative truck configuration should also be accounted and the committee members should participate in upcoming webinars to determine what other agencies, e.g. EPA, are considering. Moreover the value, implementation and practical use of the product is more important than the time it is received, the technical committee requests from the research team an answer regarding the time estimation for completing the project.

Imad Al-Qadi mentioned that the original proposal did not put a strong emphasis on LCA, but depending on the project budget, the technical panel may consider altering the proposal to allot for additional time for the LCA.

TAC Closed Session:
A closed session was held to give the TAC opportunity to speak candidly about study progress. Overall the participants were pleased with the work done so far and the approach, however they were concerned about the ability to achieve the objectives in the time available, i.e. 6 months. The TAC agreed that a no-cost time extension would likely be required. There were three specific items they would like to see addressed:

- There is a need for a clear vision to be presented by the project team on the look, feel and application of the final product. Consider the experience with the MEPDG model and address those limitations, i.e. high cost of AAHTO maintenance and hosting. This is not meant to be a criticism of this project, rather a note that past negative experiences may be avoided with proactive actions.

- Clearly define the relationship of the product to current performance and pavement design practices; how is does or does not relate and how it may be complimentary.

- There is insufficient time devoted to the LCA portion of the project. Please consider recent reports from Quebec and Ontario for reference.

After the closed session, Eric Weaver brought the research team in to summarize what was discussed. Especially looking forward to research application and implementation of the results into design guides. Additionally, the committee acknowledged the delays, however, the overall vision and expectations should be considered in a state DOT perspective. The research team is encouraged to consider and address the declined emphasis of the LCA aspect of the project. Alternative truck configuration should also be accounted and the committee members should participate in upcoming webinars to determine what other agencies, e.g. EPA, are considering. Moreover the value, implementation and practical use of the product is more important than the time it is received, the technical committee requests from the research team an answer regarding the time estimation for completing the project.

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Eric Weaver thanked the attendees and closed the meeting at 4:30 p.m.

Action Items:

- Imad Al-Qadi will send out a brief presentation overview of the Artificial Neural Network and presentation copy to committee members.
- Imad Al-Qadi will verify if De Beer conditioned the tire surfaces before testing
- Imad Al-Qadi will send the paper on “Myth and Truth of Fatigue in Asphalt Concrete.”
- Imad Al-Qadi will obtain the documentation offered by Van Teeple
- Imad Al-Qadi will to respond to the comments of the technical committee within 1 month of receiving them.