# 16th Quarterly Progress Report to the
# FEDERAL HIGHWAY ADMINISTRATION
# (FHWA)

**On the Project**
**THE IMPACT OF WIDE-BASE TIRES ON PAVEMENT DAMAGE**
**DTFH61-11-C-00025**

**For the Period**
**January 1st to March 31st, 2015**

**Submitted by**
**Illinois Center for Transportation**
**University of Illinois at Urbana-Champaign**

**FEDERAL HIGHWAY ADMINISTRATION**
**QUARTERLY PROGRESS REPORT**

FHWA Project DTFH61-11-C-00025 FY: 2015 Quarter: 16 January-March
Research Agent Illinois Center for Transportation
Principal Investigator Imad L. Al-Qadi

| PHASE | RESEARCH TASK | 2011 | | | | | | | | | 2012 | | | | | | | | | | | | 2013 | | | | | | | | | | | | 2014 | | | | | | | | | | | | 2015 | | | | | | | | | | | | ESTIMATED % COMPLETION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | |
| 1 | 1.1. Comprehensive literature review and synthesis on past and current research | 20 | 60 | 90 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| | 1.2. Experimental plan and modeling framework | | | 50 | 60 | 80 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| | 1.3. Implementation and marketing plan | | 10 | 50 | 70 | 80 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| | 1.4. Phase I report | | | 60 | 70 | 80 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| | 1.5. Conference call with panel | 0 | 50 | | | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| | 1.6. Presentations to relevant conferences and symposiums | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| 2 | 2.1. Prepare experimental equipment, test structures, and instrumentation | | | | | 0 | 0 | 0 | 0 | 0 | 10 | 30 | 40 | 45 | 50 | 60 | 70 | 85 | 90 | 95 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 |
| | 2.2. Conduct experiments, including material characterization and accelerated loading | | | | | | 0 | 0 | 0 | 0 | 5 | 10 | 20 | 25 | 30 | 40 | 50 | 60 | 70 | 40 | 40 | 40 | 45 | 50 | 55 | 55 | 57 | 60 | 62 | 65 | 68 | 70 | 72 | 73 | 75 | 77 | 80 | 82 | 84 | 85 | 87 | 88 | 90 | 92 | 95 | 95 | 97 | 98 | 100 | | | | | | | | | | 100 |
| | 2.3. Conduct modeling | | | | | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 5 | 6 | 8 | 10 | 20 | 25 | 30 | 30 | 35 | 35 | 40 | 45 | 50 | 50 | 53 | 55 | 56 | 57 | 59 | 60 | 61 | 62 | 65 | 68 | 70 | 85 | 90 | 95 | 96 | 97 | 97 | 97 | 97 | 97 | 98 | 99 | 100 | | | | | | | | | | 100 |
| | 2.4. Development of analysis tool | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 5 | 5 | 10 | 15 | 15 | 20 | 25 | 35 | 40 | 42 | 45 | 46 | 48 | 49 | 51 | 52 | 52 | 55 | 58 | 60 | 62 | 65 | 70 | 75 | 77 | 80 | 85 | 90 | 90 | 92 | 93 | 95 | | | | | | | | | | 95 |
| | 2.5. Delivery of draft Phase II report and analysis tool | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 20 | 30 | 40 | 50 | 50 | 60 | 70 | 85 | | | | | | | | | | 85 |
| | 2.6. Present to relevant conferences and symposiums | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 60 |
| | 2.7. Prepare article, technical papers, user manuals, training, TAC meeting, and TRB webminar | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | Estimated Progress (%) | 1 | 3 | 7 | 8 | 10 | 11 | 11 | 11 | 11 | 13 | 16 | 20 | 21 | 23 | 27 | 33 | 39 | 43 | 41 | 40 | 38 | 42 | 45 | 49 | 50 | 52 | 54 | 54 | 56 | 57 | 58 | 59 | 60 | 62 | 64 | 65 | 71 | 73 | 76 | 79 | 81 | 83 | 86 | 88 | 88 | 91 | 93 | 96 | | | | | | | | | | 97 |
| | Planned Progress (%) | 1 | 3 | 7 | 10 | 13 | 17 | 21 | 25 | 29 | 33 | 36 | 40 | 44 | 47 | 51 | 55 | 59 | 61 | 63 | 64 | 66 | 68 | 70 | 71 | 73 | 75 | 77 | 81 | 85 | 89 | 93 | 97 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | | | | | | | | | | 100 |

**QUARTERLY PROGRESS REPORT**

**QUARTER 16**

**The Impact of Wide-Base Tires on Pavement Damage – A National Study**

## 1. Work Performed

The following tasks were accomplished during this quarter:

- Finite element re-runs were completed.
- Artificial Neural Networks (ANN) models were developed based on the new FEM data. Models for each response and for each pavement structure (thin and thick) were also developed. Appendix A shows the model error for eleven responses. The figure presents the average error on all ANN models developed for each pavement structure.
- The adjustment factors were updated based on the new data. Values of adjustment factors slightly changed, but conclusions on the effect of wide-base tire and model complexities remained the same.
- Damping values were corrected for the thick pavement cases. Twenty-four cases, encompassing the scope of the simulation matrix, were run. Adjustment factors for damping are presented in Appendix B.
- A section from the Smart Road and other thin sections at University of Illinois were used to validate the finite element model. A sample of the validation is presented in Appendix C

## 2. Work to Be Accomplished in the Next Quarter

- Complete sensitivity analysis for ANN models
- Validate finite element model using section from Florida, Ohio, and UC-Davis
- Update ICT-Wide tool
- Finalize thin and thick pavement damage analyses.

## 3. Problems Encountered

- No issues this quarter. All encountered errors were corrected.

## 4. Current and Cumulative Expenditures

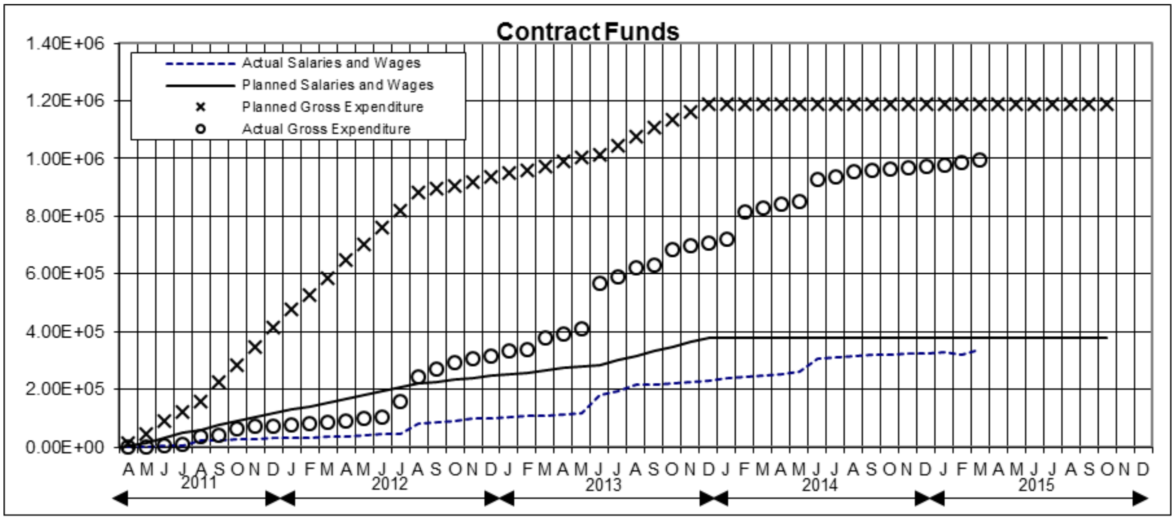


**Figure 1. Project's expenditure (based on original plan without amendments).**

## 5. Planned, Actual, and Cumulative Percentage of Effort

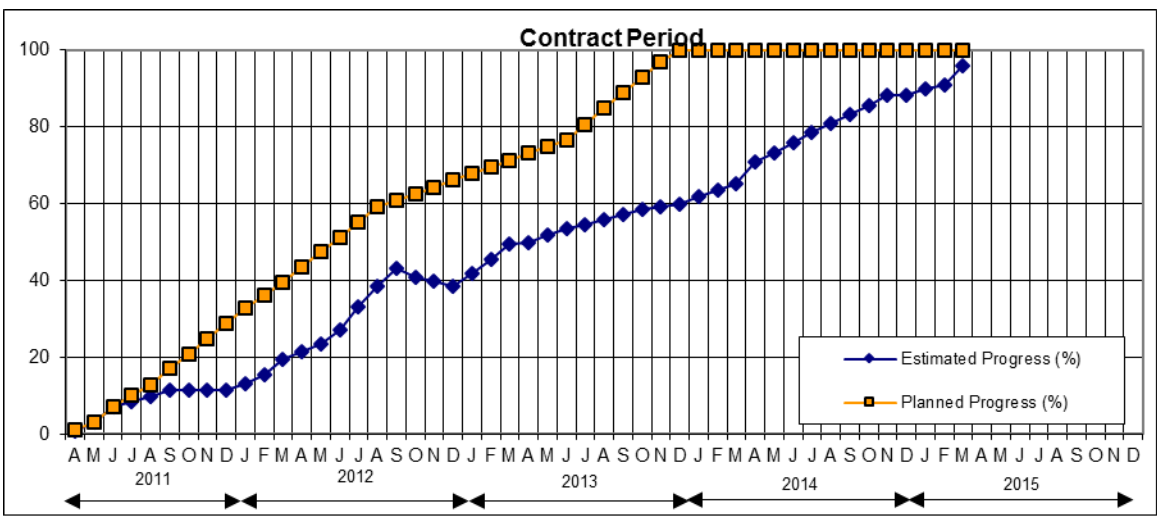


**Figure 2. Project's progress (based on original plan without amendments).**

## APPENDIX A

## ARTIFICIAL NEURAL NETWORK ERROR

Figure A-1 shows the average ANN model errors for eleven pavement responses and for thin and thick pavement structures. This is the error between ANN predicted and FEM calculated pavement responses. The error bars show one standard deviation of error higher and lower than average. According to the figure and also goodness of fit measure ($R^2$), which is higher than 0.98 for all responses, neural network models were able to accurately predict the responses. Final ANN analysis with detailed sensitivity analysis will be provided in next report as some data are being revised.

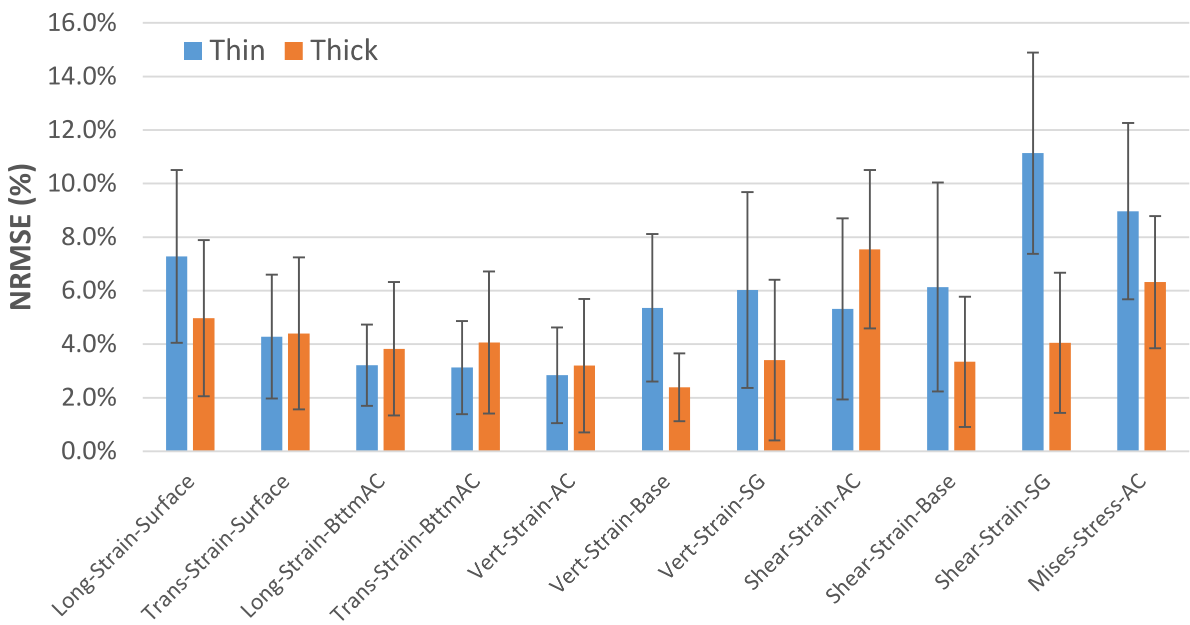


**Figure A-1. Normalized Root Mean Square Error (NRMSE) result for thin and thick cases, average on all ANN models**

## APPENDIX B
## Damping Correction

To account for damping and mass inertia effect, damping properties must be defined for all pavement layers in the finite element model. The sources of damping can be an arbitrary damping factor, friction factor, or viscoelastic material behavior. Given that the asphalt layers are characterized with viscoelasticity, the structural damping is appropriately accounted for. However, the granular layers are defined with elastic moduli values, which does not consider dissipation.

Using the Rayleigh damping model in ABAQUS, energy dissipation can be considered for the elastic granular base and subgrade layers. Two damping coefficients are required for the Rayleigh model, $\alpha$ and $\beta$, which are dependent on a proper damping ratio. Based on Wang (2011), the critical damping ratio for soils range from 2% to 5%. For this study, 5% is used. In addition, the typical natural frequency of 62.8 rad/sec (10Hz) is assumed.

Given the aforementioned parameters, $\alpha$ and $\beta$ results in 3.1416 and 7.95E-4, respectively. However, the thick pavement cases were run using 0.02 and 0.06. For the same damping ratio of 5%, this corresponds to 0.695 rad/sec, a significantly low natural frequency. The difference in Rayleigh damping coefficients poses an issue of inaccurate material property representation. In addition, as these parameters are not held constant for both thin and thick pavements, a direct comparison between the two cannot be conducted appropriately.

Due to the fact that the relationship between damping influence and pavement layer thickness are inversely proportional, the simulation case selected as an initial check included the combination of lowest pavement layer thicknesses, highest applied load, tire inflation pressure, and *weak* material properties from the thick pavement matrix.

Specifically, the load case considered the applied load of 79 kN and the tire inflation pressure of 862 kPa. The selected structure has layer thicknesses of 125 mm and 150 mm, for the total asphalt concrete (AC) and granular base layers, respectively. The material characterizations were assumed *weak* for both AC and base layers.

Table B-1 shows that the difference between the baseline and corrected values ranged from 2.2% to 8.6%, wherein the maximum stemmed from the shear strain values of the granular base layers. It is also considered that 5% variation for the horizontal strain in the AC layers, connected to fatigue distresses, can have a significant impact, especially when taking the number of loading repetitions into account.

Table B-1. Difference in Responses Using Correct Damping Parameters

| L4_AC125W_B150W | | | |
|---|---|---|---|
| **Pavement Response** | **Corrected** | **Base** | **Diff (%)** |
| Long strain, surface of AC | 372.7 | 352.9 | 5.3 |
| Trans strain, surface of AC | 332.4 | 320.8 | 3.5 |
| Long strain, bottom of AC | 321.5 | 305.4 | 5.0 |
| Trans strain, bottom of AC | 318.1 | 307.8 | 3.2 |
| Vertical strain, AC | 324.2 | 311.4 | 3.9 |
| Vertical strain, Base | 795.9 | 778.4 | 2.2 |
| Vertical strain, Subgrade | 975.4 | 949.9 | 2.6 |
| Shear strain, AC | 145.9 | 142.5 | 2.3 |
| Shear strain, Base | 242.1 | 221.4 | 8.6 |
| Shear strain, Subgrade | 288.7 | 277.7 | 3.8 |
| Mises Stress, AC | 4.1 | 4.0 | 2.4 |

However, due to the fact that the impact of damping decreases as pavement thickness increases, it was deemed appropriate to perform a repetition of the extreme cases to adequately cover the scope of the thick simulation matrix. From this approach, 24 cases were rerun. The factorial included:

- Two pavement structures: AC125_B150 and AC412_B600, wherein the nomenclature "AC125_B150" denotes, AC layer thickness of 125 mm and granular base thickness of 150 mm;
- Two material properties: *weak* and *strong* for both AC and base layers; and
- Six loading conditions: L1, L5, L4, L9, L11, and L12 (specific information of these cases can be referenced from previous reports).

Figures B-1 through B-11 illustrate the relationship between the baseline and corrected cases for all critical pavement responses.

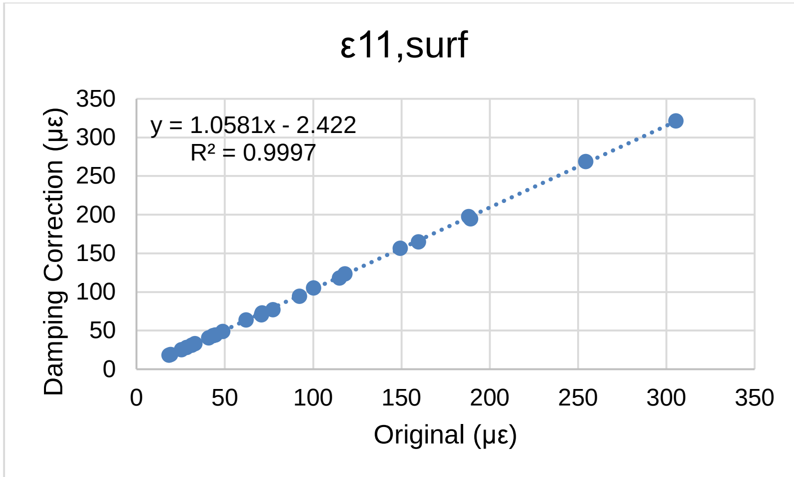


Figure B-1. Longitudinal strain at the AC surface.

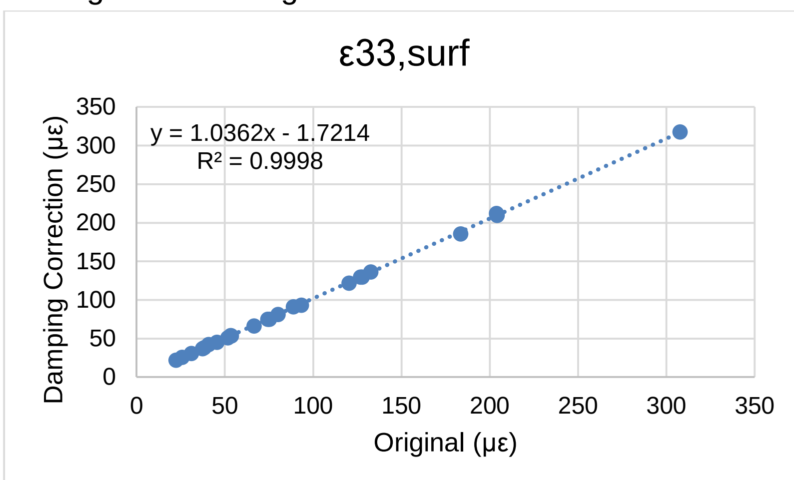


Figure B-2. Transverse strain at the AC surface.

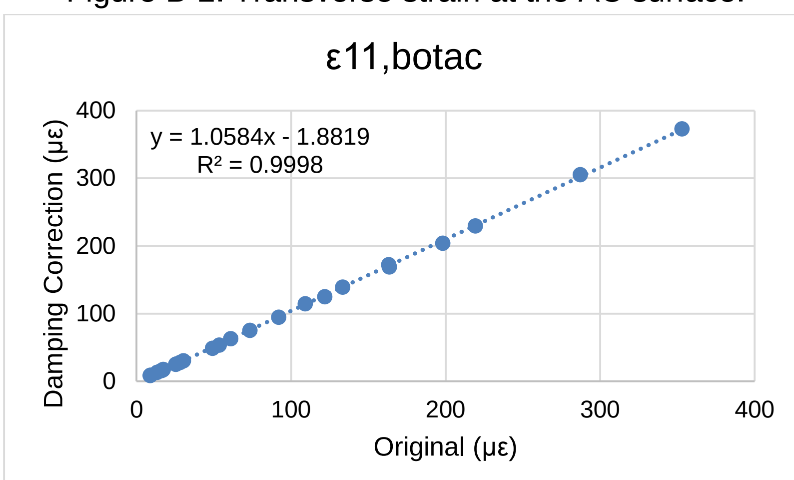


Figure B-3. Longitudinal strain at the bottom of the AC.

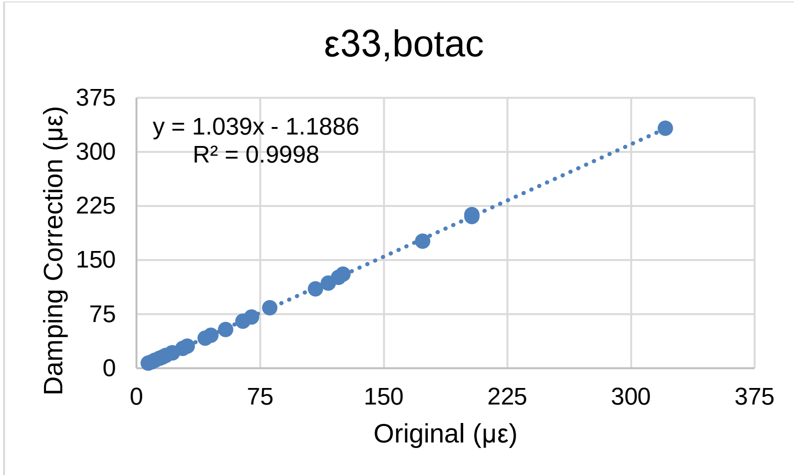

Figure B-4. Transverse strain at the bottom of the AC.

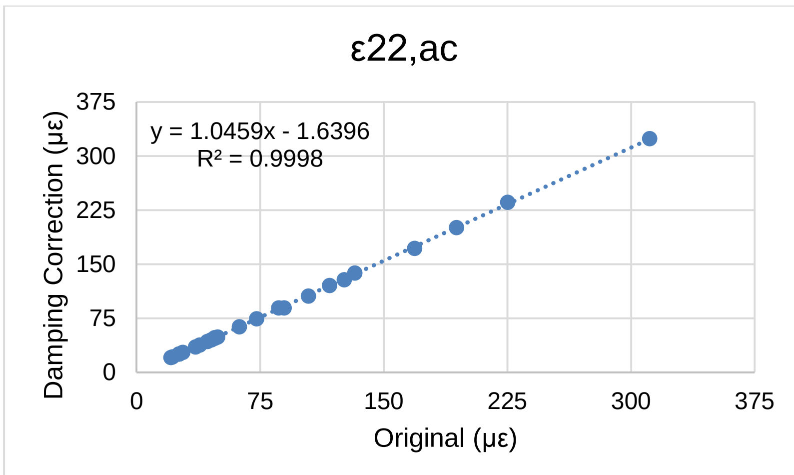

Figure B-5. Vertical compressive strain in the AC layer.

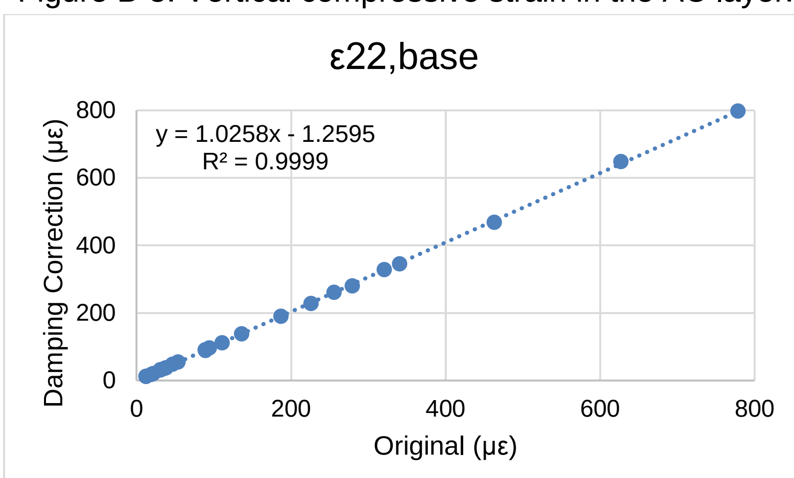

Figure B-6. Vertical compressive strain in the base layer.

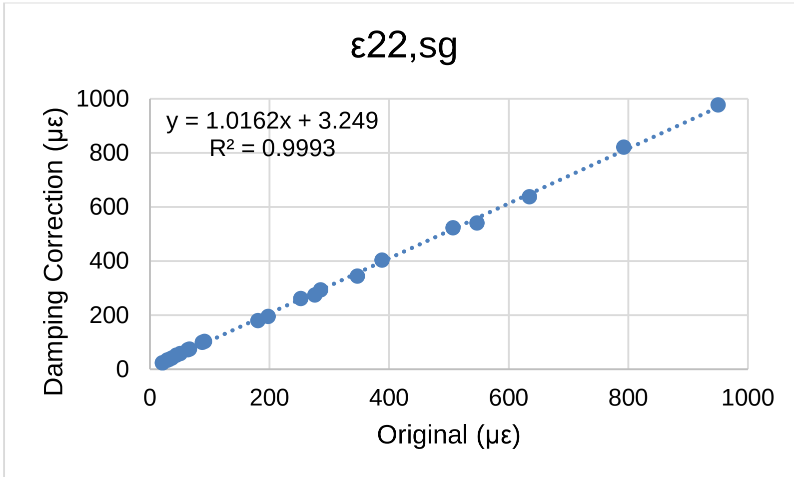


Figure B-7. Vertical compressive strain in the subgrade layer.

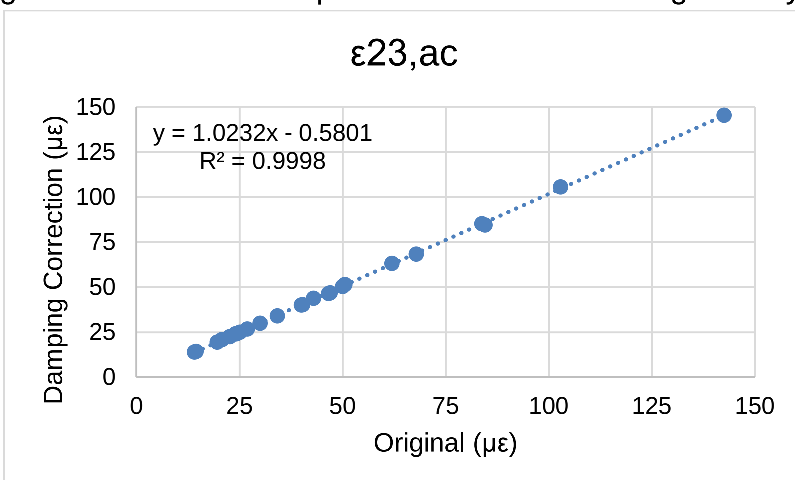


Figure B-8. Shear strain in the AC layer.

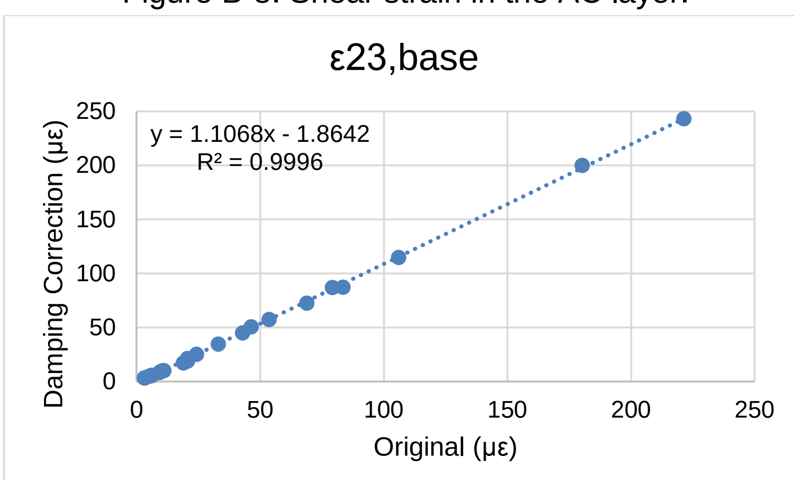


Figure B-9. Shear strain in the base layer.

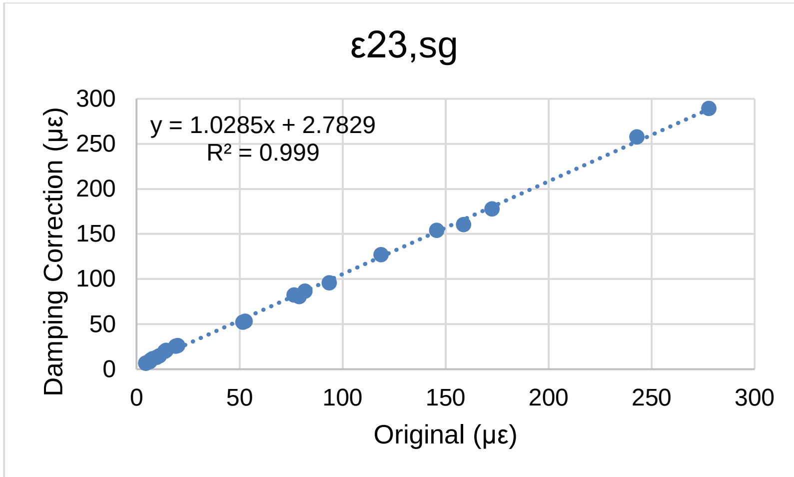


Figure B-3. Shear strain in the subgrade layer.

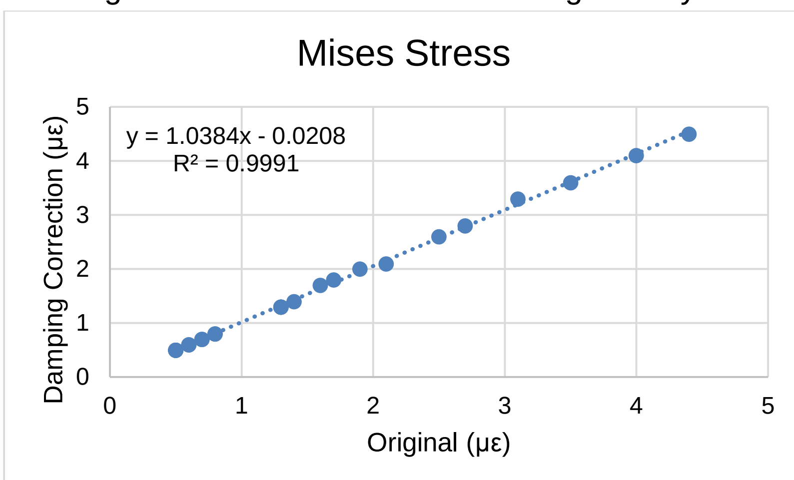


Figure B-11. Mises stress in the AC layer.

Based on the plots that compares the baseline values (with inaccurate damping parameters) to the same cases with the corrected damping parameters, one can observe a linear relationship. For all the rerun cases, all pavement responses were underestimated ranging from 1.6% to 10.7%, as indicated in Table B-2.Therefore, the slopes can be treated as damping adjustment factors for all the critical responses. By applying these factors on the remainder of the database, the finite element model represents the granular materials more accurately, and a direct comparison between the thin and thick case can be done appropriately.

Table B-2. Difference in Responses Using Correct Damping Parameters

| Response | Damping Adjustment Factor | |
|---|---|---|
| | Slope | RMSE |
| Long strain, surface of AC | 1.058 | 2.737 |

| | | |
|---|---|---|
| Trans strain, surface of AC | 1.036 | 2.038 |
| Long strain, bottom of AC | 1.058 | 2.378 |
| Trans strain, bottom of AC | 1.039 | 1.620 |
| Vertical strain, AC | 1.046 | 1.950 |
| Vertical strain, Base | 1.026 | 2.473 |
| Vertical strain, Subgrade | 1.016 | 7.874 |
| Shear strain, AC | 1.023 | 0.726 |
| Shear strain, Base | 1.107 | 2.251 |
| Shear strain, Subgrade | 1.028 | 3.784 |
| Mises Stress, AC | 1.038 | 0.042 |

Reference:

Wang, H. *Analysis of Tire-Pavement Interaction and Pavement Responses Using a Decoupled Modeling Approach*. Dissertation. University of Illinois at Urbana-Champaign. Retriever from http://hdl.handle.net/2142/24326, 2011.

## APPENDIX C
## FEM VALIDATION USING THIN PAVEMENT SECTION

### Pressure at the bottom of base

FEM was validated for a thin section that was built at the Illinois Center for Transportation, It has 5 in of HMA layer and 12 in of base layer. Loading conditions were 8 kips tire load and 100 psi tire inflation pressure for dual tire assembly. Two pressure cells were installed at the bottom of the base. Data were collected for four runs. The eight pressure measurements are given in Table C-1.

**Table C-1. Field Pressure Measurements at the Bottom of Base**

| Vertical St. (kPa) | |
|---|---|
| 10.589 | 14.456 |
| 13.784 | 16.104 |
| 15.934 | 14.906 |
| 19.500 | 17.321 |

The mean of the eight field vertical pressure measurements is 15.32 kPa with a standard deviation of 2.62 kPa. On the other hand, the FEM model predicts the vertical pressure as 16.8 kPa at the bottom of the base. FEM provides quite accurate approximation for vertical pressure at the bottom of the base

The transverse strain at the bottom of AC was used for the validation. There were four strain measurements for this section because one strain gauge was installed (1x4 pass). Table C-2 shows the strain measurements from the strain gauge.

**Table C-2. Field Strain Measurements at the Bottom of AC**

| Transverse Str. (με) |
|---|
| 68.581 |
| 59.406 |
| 76.288 |
| 79.323 |

The mean of these four field transverse strains measurements were calculated as 70.9 μ with 8.9 μ standard deviation. FEM resulted in 53.3 μ. FEM's approximation for transverse strain is not as good as for vertical pressure. Higher strain would be expected from the field for thin pavements due to potential bending of the gauge when supported by weak subgrade/base (this is the case for the studied section: subgrade has 45 MPa resilient modulus). In that case, the value coming from field for transverse strain is actually summation of principal transverse strain and strain caused by bending effect which FEM does not consider.