Instrumentation and Calibration of Virginia’s ‘Smart Road’ : A Comprehensive Literature Search

Prepared by Ken Winter, December 2006

KEY SEARCH TERMS:

Virginia’s Smart Road
Instrumentation
Calibration

Research Synthesis Bibliography No. 5

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Virginia’s Smart Road Instrumentation Calibration Literature Search

The contents of this RSB represent a comprehensive literature search on the topic of pavement instrumentation and calibrations at the Virginia Smart Road, in Blacksburg, Virginia. This search found a wealth of citations to documents (some of which may be hard to locate) on the topic, primarily by the following authors, who appear to be the preeminent experts on this topic, and who appear to have made numerous presentations and had numerous papers on the topic. Some of the information they present, no doubt, is redundant. In some cases, the best course of action may be to contact the authors directly with questions. With that in mind their contact information is listed here:

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Backcalculation Validation Through Field Instrumentation


ABSTRACT: The response of instruments embedded in pavements can be used to validate and calibrate empirical-mechanistic design and analysis approaches. This paper compares actual pavement responses measured at the Virginia Smart Road with those determined using theoretical models and backcalculated layer moduli. Falling Weight Deflectometer (FWD) tests were conducted as each layer was built, and bimonthly after the pavement was complete. The moduli of each layer were backcalculated using several approaches. The response of the instruments to the FWD loading was recorded together with the moisture content of the granular layers and the temperature of the hot-mix-asphalt (HMA) layers. Seasonal and long-term changes in structural capacity were monitored periodically to accurately assess any changes in the material properties. A detailed backcalculation procedure was defined, which included provisions to combine thin pavement layers and criteria to determine the reasonableness of the determined moduli. The procedure also considered changes in the HMA layers due to temperature fluctuations, temporal changes in the layer moduli due to strengthening of the cement treated layer, and stress-dependency of the granular layers. The backcalculated moduli were validated by conducting FWD tests directly on top of pressure cells and strain gages and comparing the measured responses with theoretical stresses and strains at the instrument locations determined using linear-elastic and nonlinear-elastic models. In general, the results show that the calculated stresses are comparable to the measured stresses. However, non-linearity may need to be considered when computing stresses in the granular layers. The strains computed in the HMA layers were also consistent between measured and computed values. Pavement instrumentation proved to be useful for the validation of theoretical material models against actual pavement performance. This practice is expected to become particularly important and possibly gain widespread acceptance as we move to full implementation of empirical-mechanistic pavement design and analysis methodologies.


Backcalculation Validation Through Field Instrumentation Response At The Virginia Smart Road


ABSTRACT: The paper presents analysis of the response of different pavement designs at the Virginia Smart Road to loading using a Falling Weight Deflectometer (FWD) over a period of time and under varying environmental conditions. It concentrates on determining the as-build structural capacity of the different pavement materials in the first 8 sections (A through H) to quantify their individual response and performance and measure their seasonal variations due to temperature and moisture changes. The structural capacity of the flexible pavement test sections was evaluated using an FWD as the pavement was constructed. Testing was performed on the surface of each finished layer shortly after placement and periodically after that. The temperature and moisture of the various pavement layers were collected using the embedded sensors. Seasonal and long-term changes in structural capacity of each section are monitored periodically (quarterly) to accurately assess any changes in the material properties. Several backcalculation approaches were evaluated for estimating the moduli of the pavement system layers. A baseline software package, which uses a layered linear elastic model, was selected after evaluating several approaches. A detailed backcalculation procedure was defined, which includes provisions to combine thin pavement layers and criteria to determine...
the reasonableness of the backcalculated moduli. The procedure also considers the strengthening of the cement treated layer and stress-dependency of the granular layers. The deflections obtained from the FWD testing were analyzed to estimate the as-built, in-situ resilient modulus of each layer. The analysis of the deflection measured over the subgrade was initially used to determine the subgrade modulus and depth to bedrock. The modulus of the granular subbase layer was then determined based on the deflections measured over that layer. The process was repeated over each subsequent layer to determine the initial moduli for all pavement layers. The measurements over the HMA base layer were repeated at different pavement temperatures to evaluate the temperature susceptibility of the HMA layers. The backcalculated moduli were validated by conducting FWD tests directly on top of embedded pressure cells. The response of the instruments was comparable with the stresses computed using a multilayer linear elastic analysis package.

ACCESS: Also available to VDOT employees through Interlibrary Loan.

**Data Collection And Management Of The Instrumented Smart Road Flexible Pavement Sections**

CITATION: Loulizi, A; Al-Qadi, I; Lahouar, S; Freeman, T.E., Transportation Research Record No. 1769, (2001), p. 142-151.

ABSTRACT: The flexible pavement research facility at the Virginia Smart Road consists of 12 different designs. All sections are closely monitored through a complex array of sensors located beneath the roadway embedded during construction. The environmental sensors include thermocouples for temperature measurements, time domain reflectometry probes to measure moisture content in the base layers, and resistivity probes to measure frost penetration. The dynamic sensors include pressure cells and strain gauges to measure stresses and strains, respectively, induced at different layers from truck loading. Environmental data are collected daily every 15 min for temperature, every hour for moisture, and every 6 h for frost penetration. Truck testing is performed every week with different loading configurations. The loading variables include three load levels, three wheel inflation pressures, and four different speeds. Data are managed by saving environmental data from different instruments separately using date and section number. Truck loading data are saved by test type (based on loading configuration, inflation pressure, and speed), date of test, and section number. A database is being generated for all 12 sections to study the effect of all tested variables on the different flexible pavement designs. The performance of the used instruments and collected data are presented, and the techniques used to manage the overwhelming data are discussed. In addition, based on instrumentation responses, a preliminary discussion of the load distribution in a tested pavement system, the effect of speed on pavement stress and strain responses, and the effectiveness of drainage layer are discussed.

ACCESS: VDOT Research Library, Call Number TA 1001.5 .T71 no.1769

**Design and Construction of Smart Road Over Wilson Creek: Montgomery County, Virginia**


ABSTRACT: The Smart Road over Wilson Creek, located in Montgomery County, Virginia, is the primary bridge project on a future four-lane divided roadway between Blacksburg, Virginia, and Interstate 81. The road was given the name Smart because it will be used as a test bed for research in such areas as variable weather and lighting conditions, communications systems, and experimental pavements. Figg Bridge Engineers, Inc., designed the bridge for
the Virginia Department of Transportation (Virginia DOT) and provided construction engineering and inspection services on site. Aesthetics were a major concern for the Virginia DOT and the local community because of the natural beauty of the surroundings. Long spans were used to minimize the number of piers. The 605-m five-span structure has three interior spans of 144 m (472 ft) and end spans of 86.5 m (284 ft). The variable-depth concrete box girder superstructure was built by using cast-in-place balanced cantilever segmental construction with form travelers. The cast-in-place piers are conventionally reinforced voided rectangular sections with variable slopes in both directions. With pier heights varying up to 41.4 m (135 ft), the bridge deck is a maximum of approximately 53 m (175 ft) above the valley floor, making the Smart Road the tallest bridge in Virginia. Other aesthetic enhancements implemented on this project include monolithic connections between the piers and the superstructure, the use of natural stone treatments on the piers and railing terminal walls, an open bridge railing, and a concrete surface coating.

**Difference Between In Situ Flexible Pavement Measured and Calculated Stresses and Strains**


**ABSTRACT:** One of the 12 instrumented sections of the Virginia Smart Road was used to compare measured vertical compressive stress and measured transverse horizontal strain under the hot-mix asphalt (HMA) layer induced by a 25.8 kN (5.8 kip) single tire and a 39.5 kN (8.9 kip) set of dual tires to those calculated using layered linear elastic theory. The pavement section is composed of 38 mm (1.5 in.) HMA wearing surface, 150 mm (6 in.) of HMA base mix, 75 mm (3 in.) of asphalt stabilized open graded drainage layer, 150 mm (6 in.) of cement stabilized aggregate layer, and 175 mm (7 in.) of unbound aggregate base. The subgrade is a fill material composed mainly of rocks. Measured stresses were obtained using pressure cells embedded in the pavement during construction. Horizontal transverse strain was measured using H-type strain gauges that were also embedded during construction. Temperature in the pavement layers was measured using embedded T-type thermocouples. Theoretically calculated stresses and strains were obtained using software based on the layered-elastic theory (Kenpave, Bisar 3.0, Elsym5, and Everstress 5.0). In addition, two finite-element approaches were used. Results indicated that the layered elastic theory overestimates pavement responses at low and intermediate temperatures, but significantly underestimates the pavement responses to vehicular loading at high temperatures.

**ACCESS:** Available to VDOT employees through Interlibrary Loan.

**ONLINE:** Full text available to VTRC Research Scientists through UVA’s library catalog.

**Evaluation of Pavement Layer Response at the Virginia Smart Road**


**ABSTRACT:** The heavily instrumented Virginia Smart Road project provided the opportunity to test various hypotheses on pavement nondestructive testing using falling weight deflectometer (FWD). This was achieved by analyzing the deflections obtained on top of each layer as the road was being constructed. Two loading plate sizes were used at the subgrade and aggregate subbase surfaces. Five different loadings were used in each testing. This allows an accurate backcalculation of in situ resilient modulus of each layer. Such results may be used to calibrate future FWD measurements. The study found that using the surface modulus to characterize the subgrade might sometimes be misleading. In addition, characterization of the deflection
basin using deflections alone may not provide accurate results. The distribution of pressure resulted from FWD loading was measured successfully by embedded pressure cells in the HMA base layer. Note: SO: Conference Title: GeoDenver 2000; Proceedings of Sessions of GeoDenver 2000. Location: Denver, Colorado. Sponsored by: Pavements Committee of the Geo-Institute of the American Society of Civil Engineers.
ACCESS: Available to VDOT employees through Interlibrary Loan.

**Flexible pavement instrumentation at the virginia smart road**
ABSTRACT: N/A
ACCESS: Available to VDOT employees through Interlibrary Loan.

**Ground-Penetrating Radar Calibration at the Virginia Smart Road and Signal Analysis to Improve Prediction of Flexible Pavement Layer Thickness**
ABSTRACT: A ground-penetrating radar (GPR) system was used to collect data over the different pavement sections of the Virginia Smart Road from June 1999 until December 2002. Three antennae at different frequencies were used for this research. The collected data were successfully used to evaluate the physical GPR detection limitations, to evaluate the GPR accuracy for pavement layer thickness determination, to control the installation of three different types of reinforcing meshes installed within the pavement, and to estimate the in-situ complex dielectric constant of several types of hot-mix asphalt (HMA). The data analysis results were verified by the well-documented structure and composition of each section of the road, in addition to the embedment of 35 copper plates (perfect electromagnetic reflectors) at the different layer interfaces during construction of the pavement. It was found that GPR is a feasible nondestructive tool to estimate the layer thicknesses of bound and unbound aggregate layers, HMA layers, and concrete slabs. However, interface detection can be altered if the layers have comparable dielectric constants. A technique was developed to estimate the frequency-dependent in-situ complex dielectric constant of HMA materials. Results have shown that the effect of the variations of the dielectric properties within the GPR bandwidth is insignificant vis-a-vis the accuracy of thickness estimation. The use of GPR as a quality control tool to verify the success of steel reinforcing mesh installation was also found to be feasible. Given the success of using GPR for the aforementioned applications in the Virginia Smart Road, it is recommended that the Virginia Department of Transportation use GPR more frequently as a quality control tool during new pavement construction projects and as an assessment tool prior to project rehabilitation and as part of Virginia's pavement management system.
ONLINE: [http://www.virginiadot.org/vtrc/main/online%5Freports/pdf/05-cr7.pdf](http://www.virginiadot.org/vtrc/main/online%5Freports/pdf/05-cr7.pdf)
ACCESS: VDOT Research Library, Call Number TE 250 .A47 2005

**Inability Of The Elastic-Layered Theory To Predict Pavement Vertical Stresses**
CITATION: A. Loulizi, and I. L. Al-Qadi.,
ABSTRACT: Since 2000, truck testing has been conducted over the 12 flexible pavement sections of the Virginia Smart Road. The testing has utilized different axle loadings, tire inflation pressures, and speeds under different environmental conditions. Measured collected data include stresses under the pavement layers, horizontal and longitudinal strains under the
hot-mix asphalt (HMA) layers, and temperatures at different depths in the pavement system. Vertical stresses were measured in layers of four flexible pavement designs (Sections E, F, G, and H). Sections E and F were built using the same materials, but they have different HMA layer thicknesses. Section G differs from Section F by a 50-mm fine-mix placed underneath the HMA base layer. In addition, Section H has the same structure as Section G, with the exception of a 75mm asphalt treated open-graded drainage layer (OGDL) placed under the HMA base layer. The measured vertical stresses, at different temperatures, underneath the HMA of the aforementioned four sections were compared to those calculated using linear layered elastic theory to identify the conditions under which the theory can be used. Results indicated that the calculated values are higher than those measured at low and intermediate temperatures (approximately <35°C). However, at high temperatures (approximately >35°C), the layered elastic theory underestimates the vertical stresses significantly.

ONLINE: http://www.mrr.dot.state.mn.us/research/MnROAD_Project/index_files/pdfs/Loulizi_A.pdf

Laboratory Calibration And In Situ Measurements Of Moisture By Using Time-Domain Reflectometry Probes

CITATION: Diefenderfer, B K Al-Qadi,I.L.Loulizi, A. , Transportation Research Record No. 1699, p. 142-150; Figures(9); References(12); Tables(3).

ABSTRACT: Excessive moisture in pavement systems can cause considerable damage and can lead to early deterioration. One method for continually monitoring the moisture content of pavement systems nondestructively is the use of time-domain reflectometry (TDR) probes. Although originally developed to measure faults in electrical cables, TDR probes employ an electromagnetic wave that is transmitted along a set of metallic conducting rods (or waveguides). The velocity of the electromagnetic wave is influenced by the dielectric constant of the material surrounding the waveguides. The large contrast between the dielectric constants of free water and of dry soil makes this an effective nondestructive evaluation method. Soil samples with different moisture contents were prepared and the TDR output, which is a function of the dielectric properties, was compared with the measured gravimetric moisture content. Calibration equations were developed in a laboratory setting for two types of TDR probes (CS610 and CS615) embedded in the Virginia Smart Road test facility at Blacksburg, Virginia. Preliminary field data were collected for the two different probe types embedded in different pavement structures. It is shown that the two types of TDR probes yield similar data in some situations and different data in other circumstances. It appears that the composition of the pavement structure has an effect on the moisture measured in the subbase layer. Although preliminary results indicate that the use of CS615 TDR probes in pavement applications is promising, further continuous monitoring of both types of TDR probes is necessary to determine if the CS615, which can be readily connected to a data acquisition system, can be used in lieu of the CS610, which requires a time-consuming collection procedure or possible additional data collection equipment.

ACCESS: VDOT Research Library, Call Number TA 1001.5 .T71 no.1699

Measurement of Vertical Compressive Stress Pulse in Flexible Pavements:
Representation for Dynamic Loading Tests

CITATION: Loulizi A, Al Qadi IL and Lahouar S, et al. , Transportation Research Record. 2002. (1816) pp125-136 (10 Fig., 1 Tab., 14 Ref.);

ABSTRACT: Testing at Virginia Smart Road allowed determination of the vertical compressive stress pulse induced by a moving truck and by falling weight deflectometer (FWD) loading at
different locations beneath the pavement surface. Testing was performed on 12 different flexible pavement sections. Stress and temperature were measured using pressure cells and thermocouples, respectively, that had been installed during construction of the road. Target testing speeds were 8 km/h, 24 km/h, 40 km/h, and 72 km/h. The considered depths below the pavement surface were 40 mm, 190 mm, 267 mm, 419 mm, and 597 mm. A haversine or normalized bell-shape equation was found to be a good representation of the measured normalized vertical compressive stress pulse for a moving vehicle. Haversine duration times varied from 0.02 s for a vehicle speed of 70 km/h at a depth of 40 mm to 1 s for a vehicle speed of 10 km/h at a depth of 597 mm. For the FWD loading, a haversine with a duration of 0.03 s was found to approximate the induced stress pulse at any depth below the pavement surface. Currently, laboratory dynamic testing on hot-mix asphalt (HMA) specimens is performed using a haversine wave at loading duration of 0.1 s. Because HMA is a viscoelastic material, the loading time affects its properties and, therefore, it is recommended that the loading time of HMA dynamic tests be reduced to 0.03 s to better match loading times obtained from moving trucks at average speed and from FWD testing.

ACCESS: VDOT Research Library, Call Number TA 1001.5 .T71 no.1816

**Data Collection and Management of the Instrumented Smart Road Flexible Pavement Sections**


ABSTRACT: The flexible pavement research facility at the Virginia Smart Road consists of twelve different designs. All sections are closely monitored through a complex array of sensors located beneath the roadway that were embedded during construction. The environmental sensors include thermocouples for temperature measurements, time domain reflectometry (TDR) probes to measure moisture content in the base layers, and resistivity probes to measure frost penetration. The dynamic sensors include pressure cells and strain gages to measure stresses and strains, respectively, induced at different layers from truck loading. Currently, environmental data is collected daily every 15 minutes for temperature, every hour for moisture, and every six hours for frost penetration. Truck testing is performed every week with different loading configurations. The loading variables include three load levels, three wheel inflation pressures, and four different speeds. The loading is performed using the same truck and wheels to eliminate variability due to wheel configuration and tire type. Data is managed by saving environmental data from different instruments separately based on date and section number. Truck loading data is saved by test type (based on loading configuration, inflation pressure, and speed), date of test, and section number. A database is being generated for all twelve sections to study the effect of all tested variables on the different flexible pavement designs. This paper presents the performance of the used instruments and collected data, and discusses the techniques used to manage the overwhelming data.

ACCESS: VDOT Research Library, TA 1001.5 .T71a 2005 CD-ROM

**Relationship between Backcalculated and Laboratory-Measured Resilient Moduli of Unbound Materials**

CITATION: Flintsch GW, Al Qadi IL and Park Y, et al. , Transportation Research Record. 2003. (No. 1849) pp177-182 (4 Fig., 7 Tab., 11 Ref.);

ABSTRACT: The resilient moduli of an unbound granular subbase (used at the Virginia Smart Road) obtained from laboratory testing were compared with those backcalculated from in situ falling weight deflectometer deflection measurements. Testing was performed on the surface of the finished subgrade and granular subbase layer shortly after construction. The structural
capacity of the constructed subgrade and the depth to a stiff layer were computed for 12 experimental sections. The in situ resilient modulus of the granular subbase layer (21-B) was then backcalculated from the deflections measured on top of that layer. The backcalculated layer moduli were clearly stress-dependent, showing an exponential behavior with the bulk stress in the center of the layer. Resilient modulus test results of laboratory-compacted specimens confirmed the stress dependence of the subbase material modulus. Three resilient modulus models were fitted to the data. Although all three models showed good coefficients of determination (R-squared > 90%), the K-theta model was selected because of its simplicity. The correlation between field-backcalculated and laboratory-measured resilient moduli was found to be strong. However, when the stress in the middle of the layer was used in the K-theta model, a shift in the resilient modulus, theta, was observed. This finding suggests that a simple shift factor could be used for the range of stress values considered.

ACCESS: VDOT Research Library, Call Number TA 1001.5 .T71 no.1849

**Use of Time Domain Reflectometry for Determination of Water Content and Density of Soil**

CITATION: Siddiqui, S I Drnevich,V.P.,

ABSTRACT: A new method is developed for measuring in-place density and moisture content of soil using the technique of Time Domain Reflectometry (TDR). The method is applicable for construction control of earthworks. The method is extended for measuring moisture content of soil in the laboratory and in the field for various other geotechnical purposes. Laboratory uses include measuring moisture content of soil in compaction molds; field uses include measuring moisture content of soil in Shelby tubes and soil retrieved during drilling and sampling operations. In the course of achieving these goals, this study develops the principles of TDR probe design, test methodology, and relationships of TDR measured dielectric constant with density and moisture content of soil. TDR was originally developed to locate faults in cables and transmission lines. For the last 20 years, it has also been used (mostly in soil science) to measure the volumetric moisture content of soil by using its capability of measuring the dielectric constant of soil. Some use has been made for measuring moisture content for engineering applications but soil density had to be known before volumetric moisture content could be converted to gravimetric moisture content which is used in geotechnical engineering. This study proposes a method of using TDR technique for measuring density of soil and extends the use of TDR for measuring moisture content of soil for various geotechnical purposes. In order to achieve these goals, this work develops various transmission lines/probes and devices. It develops coaxial transmission line (CTL) probes, composed of coaxial apparatus (CA) and cylindrical cells (CC). It develops multiple rod probes (MRP) which extend the capabilities of existing MRP. Analytical and experimental investigations are made to design different parameters of the probes. Investigations are carried out to study the effect of probe rod installation on measurements and experimental methods. Experiments are conducted to develop calibration equations to relate dielectric constant with moisture content and density of soil. The work describes how the TDR method can be used to measure in-situ density and moisture content of soil. The procedure makes use of the designed probes and devices. Significant testing of the procedures on a variety of soil types, along with comparisons with other measures of density and oven dry moisture content indicates that this new method is quick, safe and sufficiently accurate for measuring in-place density and moisture content of soil.

ONLINE: [http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1690&context=jtrp](http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1690&context=jtrp)
Using field measured stresses and strains to quantify flexible pavement responses to loading

CITATION: LOULIZI A (Virginia Tech Transportation Institute, Roadway Infrastructure Group, USA), AL QADI IL (Virginia Tech Transportation Institute, Roadway Infrastructure Group, USA) and FLINTSCH GW (Virginia Tech Transportation Institute, Roadway Infrastructure Group, USA), et al. , International Society For Asphalt Pavements, Ninth International Conference On Asphalt Pavements August 17 - 22, 2002. Proceedings. 2003. Pp- (14 Refs.).

ABSTRACT: One of the 12 instrumented sections of the Virginia Smart Road was used to evaluate the effect of several loading parameters on the measured stresses at different layers and the measured horizontal transversal strain in the bottom of the hot-mix asphalt (HMA) layer. It was found that speed does not affect the measured vertical compressive stress in all layers, but does significantly affect the measured horizontal transversal strain under the HMA layer (190.5mm below the pavement surface). Strain was found to decrease by a factor of 2.7 when the speed increases from 8km/h to 72.4km/h at 25_C. Variation in tire inflation pressure from 551.6kPa to 724kPa was found not to affect the measured vertical compressive stress in all the layers and the measured horizontal transversal strain in the bottom of the HMA layer. Vertical stresses under the HMA layer were found to vary linearly with the applied tiresÆ load at 25_C.

ACCESS: Available to VDOT employees through Interlibrary Loan.

Using Field Measured Stresses and Strains to Quantify Flexible Pavement Responses to Loading


ABSTRACT: One of the 12 instrumented sections of the Virginia Smart Road was used to evaluate the effect of several loading parameters on the measured stresses at different layers and the measured horizontal transversal strain in the bottom of the hot-mix asphalt (HMA) layer. It was found that speed does not affect the measured vertical compressive stress in all layers, but does significantly affect the measured horizontal transversal strain under the HMA layer. Strain was found to decrease by a factor of 2.7 when the speed increases from 8km/h to 72.4km/h at 25 deg C. Variation in tire inflation pressure from 551.6kPa to 724kPa was found not to affect the measured vertical compressive stress in all the layers and the measured horizontal transversal strain in the bottom of the HMA layer. Vertical stresses under the HMA layer were found to vary linearly with the applied tires' load at 25 deg C. Note: SO: Conference Title: SC: ACCESS: VDOT Research Library, Call Number CD-ROM TE 275 .I5 2002

Utilization of Instrument Response of SuperPave ™ Mixes at the Virginia Smart Road to Calibrate Laboratory Developed Fatigue Equations


ABSTRACT: In the current mechanistic-empirical (M-E) design procedures for flexible pavements, the primary transfer functions are those that relate (a) maximum tensile strain in the hot-mix asphalt (HMA) surface layer to fatigue cracking and (b) compressive strain at the top of the subgrade layer to rutting at the surface. These functions, called fatigue and rutting equations, are usually derived from statistically based correlations of pavement condition with observed laboratory specimen performance, full-scale road test experiments or by both methods. Hot-mix asphalt fatigue behavior is an important component of a M-E design
procedure; unfortunately, most of the existing models do not reflect field fatigue behavior. This is manifested in the fact that HMA fatigue failure is achieved much faster under a laboratory setting than in a field environment. This difference has been typically accounted for by the use of a single shift factor based mainly on engineering experience. The flexible pavement portion of the Virginia Smart Road includes 12 different flexible pavement designs. Each section is approximately 100m long. The sections are instrumented with pressure cells, strain gages, time-domain reflectometry probes, thermocouples, and frost probes. The instruments were embedded as layers were built. Laboratory fatigue tests of field cores and field-mixed laboratory-compacted specimens along with measured response from the instrumented pavement sections at the Virginia Smart Road were used to quantify the differences between laboratory and field environments. Four shift factors were identified to correlate field and lab fatigue behavior: stress-state, material difference, traffic wander, and healing. Field-measured critical strains and strain energy exerted during truck loading were both used to determine the stress state shift factor. Strain measurements of truck loading distribution (wander) were used to determine the wander shift factor. Finally, results from laboratory fatigue tests on cores and laboratory compacted specimens were used to evaluated a shift factor to account for the difference in compaction procedures. While the derived shift factors utilize the measured stresses and strains at the Virginia Smart Road, calculated strains and stresses, based on appropriate pavement and loading modeling, may also be used.

ONLINE: http://scholar.lib.vt.edu/theses/available/etd-07242001-115642/

Validation of FWD testing results at the Virginia Smart Road: Theoretically and by Instrument Response


ABSTRACT: Falling weight deflectometer (FWD) is currently used by most highway agencies to determine the structural condition of the highway network. Utilizing the deflections measured by the FWD, the resilient moduli of layers in the flexible pavement is determined using backcalculation software packages. The moduli can be input into semi-empirical mechanistic equations to estimate the remaining life of the pavement system and aid in informing pavement engineers about timing of maintenance and rehabilitation needs. There have been concerns among practitioners and the research community about the adequacy of the resilient moduli determined by the backcalculation software. Some of the backcalculation models have been simplified and field verification may be needed. Field-measured stresses and strains may be used to quantify the reliability of the backcalculated moduli. The Virginia Smart Road, which has 12 different flexible pavement designs and was built and instrumented with pressure cells, strain gages, thermocouples, frost probes and moisture sensors. To validate the backcalculated moduli theoretically and through instrument response, this research was conducted with following objectives: 1) to determine the resilient moduli of the unbound granular materials on the Virginia Smart Road using small and large plates of the FWD; 2) to investigate the extent of spatial and temporal variability of the FWD deflections among pavement sections; 3) to develop a temperature correction model for the backcalculated HMA resilient moduli; 4) to define an appropriate backcalculation approach and compare the four widely used software approaches; and 5) to correlate backcalculated and laboratory measured moduli. In addition, the FWD measurements were used to establish a comparison between in-situ measured and computed stresses and strains in the pavement. The analytical approaches used are linear elastic, viscoelastic, and viscoelastic combined with nonlinearity. Results show that estimation of unbound granular materials moduli using surface deflections is more reliable when 457-mm-diameter loading plate is used. Analysis of deflections from different sensors
showed evidence of spatial and temporal variability. The lowest coefficient of variation of deflections (7%) within sections occurred at low temperatures (2 to 6 °C), while the highest coefficient of variation (42%) occurred at temperatures between 35 to 40 °C. This resulted in the development of a deflection temperature correction model. The model was validated at different temperature ranges. A backcalculation procedure was defined to achieve good root mean square error using four selected software packages. This resulted in the selection of the most reliable software to perform moduli backcalculation. A correlation was established between the nonlinear models produced by backcalculation and laboratory testing of the granular 21-B material. However, for the HMA materials, difference in loading period between laboratory testing and FWD loading pulse could affect the results. The study found that when utilizing the backcalculated moduli, computed strains using viscoelastic modeling were comparable to in-situ measured values. Similarly, calculated stresses compared well with the field-measured stresses; especially at high temperatures. Mix properties, temperature of testing and loading were found to have an effect on the agreement between the measured and computed strains in the wearing surface. The study also recommended further validation of FWD measurements using embedded instruments to calibrate analytical models and further analysis of deflection data so that optimum number of testing points can be determined to limit amount of testing performed for determination of deflection variability.

ONLINE: http://scholar.lib.vt.edu/theses/available/etd-04092003-162026/

**The Virginia Smart Road: The Impact Of Pavement Instrumentation On Understanding Pavement Performance (With Discussion)**

CITATION: I. Al-Qadi, L. Loulizi and A. Elseifi, et al. , Journal of the Association of Asphalt Paving Technologists Vol. 73; Description: p. 427-465; Figures(25); References(9); Tables(1).

ABSTRACT: This paper presents the description, calibration procedures, installation, and performance of the instrumentation used at the Virginia Smart Road to measure flexible pavement response to loading. Also presented are the measured horizontal transverse and longitudinal strains induced in the hot-mix asphalt (HMA) during compaction with a steel drum compactor both with and without vibrations. In addition, this paper presents the data collected and used to determine the vertical compressive stress pulse induced by a moving truck at different locations beneath the pavement surface. These data were also used to determine the effects of temperature, speed, and tire inflation pressure on the measured vertical compressive stress and measured horizontal transverse strain, induced by a steering-axle tire of 25.8kN, under the HMA layer. The data were used to make a comparison between measured pavement responses to truck loading with those calculated using linear elastic theory. It was found that HMA is subjected to very high horizontal strains during compaction--especially when vibration is used. It was also found that a haversine equation well represents the measured normalized vertical compressive stress pulse for a moving vehicle. Haversine duration times varied from 0.02s for a vehicle speed of 70 km/h at a depth of 40 mm to 1.0s for a vehicle speed of 10 km/h at a depth of 597 mm. As expected, temperature was found to significantly affect the measured vertical compressive stress and measured horizontal transverse strain under the HMA layer. Although speed was found not to affect the magnitude of the measured vertical compressive stress, it was found to affect the loading time. On the other hand, speed was found to significantly affect the measured horizontal transverse strain under the HMA layer. Variation in tire inflation pressure from 552 kPa to 724 kPa was found not to affect the measured vertical compressive stress and the measured horizontal transverse strain at the bottom of the HMA layer. A comparison between the measured responses and those calculated using a finite element model that uses linear elastic theory indicated that the elastic theory overestimates pavement responses at low temperatures but significantly
underestimates these responses at high temperatures. An improved prediction of pavement responses was achieved by modifying the bonding conditions at the interfaces, and by modeling HMA as a viscoelastic material.

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