Evaluation Of Seasonal Effects On Subgrade Soils

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ABSTRACT

One objective of the Federal Highway Administration Long-Term Pavement Performance (LTPP) program is to determine climatic effects on pavement performance. The LTPP instrumentation program includes Seasonal Monitoring Program (SMP) instrumentation to monitor the seasonal variations of moisture, temperature and frost penetration. Findings from the SMP instrumentation are to be incorporated into future pavement design procedures. Data from SMP instrumentation at the Ohio SHRP Test Road (U.S. 23, Delaware County, Ohio) and other reported results were analyzed in order to develop empirical equations. This paper presents general expressions for the seasonal variations of average daily air temperature and variations of temperature and moisture in the fine-grained subgrade soil at the test site. An expression for the seasonal variation of resilient modulus was derived. Average monthly weighting factors that can be used for pavement design were computed. Other factors such as frost penetration, depth of water table and drainage conditions are discussed.

INTRODUCTION

The Seasonal Monitoring Program (SMP) instrumentation of the LTPP program includes weather and pavement instrumentation (*1*). A weather station is required at each site. The pavement instrumentation measures variations of temperature, moisture and frost penetration to a depth of approximately two meters below the pavement surface. The depth to the water table is also monitored. Weather and temperature data is collected automatically and moisture and frost penetration data is collected fourteen times each year. Data from the instrumentation is available in the Federal Highway Administration (FHWA) pavement performance database DataPave Version 3 (*2*) so that researchers will be able to investigate climatic effects on pavements. A database from test pavements in Ohio is under development and will be available in 2003 (*3*). Data from the Ohio SHRP Test Road on U.S. 23 in Delaware County, Ohio from a weather station and several test pavements was analyzed order to evaluate climatic varitiations.

Resilient modulus is an important parameter for empirical or mechanistic design approaches for flexible pavements. Laboratory studies on subgrade soils and unbound materials show the dependence of resilient modulus on deviator stress, matric suction, moisture content and confining or bulk stress. Fredlund and Bergan (*4*) concluded that the resilient modulus of fine-grained soils is dependent on deviator stress and matric suction and, to a lesser extent, on confining stress. They proposed a two-parameter expression for resilient modulus. The parameters are dependent on matric suction. Resilient modulus was shown to increase with increasing matric suction. Matric suction is a primary stress state parameter affecting unsaturated soil behavior. However, matric suction is highly dependent on temperature, water content and stress history and so is very difficult to predict.

Thompson and Robnett (*5*) concluded that the resilient modulus of fine-grained soils does not depend on the confining pressure and that confining pressures in the upper soil layers under pavements are normally less than 35 kPa (5 psi). They showed that the relationship between resilient modulus and axial stress, equivalent to deviator stress for their studies, of the soils tested could be represented by a bilinear model requiring four parameters, the slopes of each line and resilient modulus and deviator stress at the intersection of the two lines (break point). They also developed linear equations for relationships between resilient modulus and saturation for soils compacted at 100% and 95% compaction (AASHTO T-99). Resilient modulus tests were conducted on the fine-grained soil at the Ohio SHRP Test Road at several moisture contents (*6,7*). The Thompson-Robnett bilinear model was used to characterize the resilient modulus of the soil similar to an earlier study on soils in Ohio (*8*).

A procedure for predicting resilient modulus as a function of moisture content and compaction effort was described by Li and Selig (*9*) for fine-grained soils. A two-parameter power model relating resilient modulus and deviator stress was recommended. Polynomial equations were derived from test results reported by other researchers for predicting the ratio of resilient modulus at any water content to the resilient modulus at the optimum water content. A procedure was described for determining resilient modulus of soils compacted with different compactive efforts but with the same dry density. A second procedure was described for determining resilient modulus for soils with the same compactive effort but with different moisture contents. An empirical equation for resilient modulus at the optimum water content as a function of percent clay and plasticity index was also presented. Procedures for predicting resilient modulus of soils at various physical states were described. Comparisons between predicted and measured values of resilient modulus were excellent.

A method for predicting the change in the resilient modulus of fined-grained soils due to increased saturation was proposed by Drumm et al. (*10*). The researchers used the resilient modulus of soil at the optimum moisture content and the maximum dry density as the reference values and considered changes in resilient modulus after the soil was compacted at optimum conditions and subsequently experienced an increase in water content. They proposed an empirical equation for the rate of change of resilient modulus with change of degree of saturation that is a function of the AASHTO classification, the resilient modulus at optimum moisture content and maximum dry density. They showed that a change in volumetric water content equal to 1.5% would result in change in degree of saturation of 4.75% and determined that the resilient modulus would decrease almost by a factor of two, 130 MPa to 70 MPa, for the same increase in saturation.

Using the results from three different fine-grained soils, Lee et al. (*11*) derived a polynomial equation relating resilient modulus corresponding to a maximum axial stress equal to 41.4 kPa (6 psi) and confining stress equal to 20.7 kPa (3 psi) to the undrained shear strength at 1% axial strain. The correlation is excellent ($R^2 = 0.97$). They further compared results from laboratory and field compacted soil from one of the sites.

Frost susceptible soils, besides being subjected to frost heave effects, experience an increase in moisture during freezing and thawing periods resulting in lower matric suction. Konrad and Roy (*12*) considered freezing effects in three soil zones: unsaturated, capillary fringe and the zone below the water table. Frost heave and consolidation effects were evaluated in terms of segregation potential. The magnitude of the reduction in strength or stiffness was shown to depend on the frost susceptibility of the soil and swell index of the soil. Soils will less than 70% saturation are not susceptible to frost. Fine-grained soils are susceptible to freeze/thaw effects. Simonsen at al. (*13*) determined that there are significant differences in resilient modulus depending upon whether the soil was undergoing freezing or thawing paths. They measured significant increases in resilient modulus in frozen soils as the temperature decreased from 0^o to -20^o C.

The resilient modulus of granular materials is dependent on stress. A two-parameter model expressing resilient modulus as a function of bulk stress is recommended for designing pavements with granular materials (*14*). Bulk stress accounts for the effects of confining stress and deviator stress. A five-parameter model for resilient modulus of granular base materials was shown to be more accurate for predicting pavement performance (*15*). The parameters were correlated using cohesion, friction angle, bulk stress and moisture content. An iterative procedure that uses a layered elastic or finite element solution for determining stress induced by the pavement was recommended for estimating the resilient modulus of unbound granular materials for use with the AASHTO two-parameter model (16).

A procedure for predicting the seasonal variation of resilient modulus of granular soils that accounts for temperature and moisture suction effects was developed by Jin et al. (*17*). The method requires first determining an empirical expression for resilient modulus as a function of bulk stress, water content, temperature and soil dry unit weight. Theoretical equations were derived to predict the change in bulk stress based on micromechanical and thermodynamics laws. The seasonal variation of resilient modulus was then computed using measured moisture contents and temperatures. The predicted values compared very well with values backcalculated from falling weight deflectometer testing.

ANALYSES OF TEST PAVEMENTS AT THE U.S. 23, DELAWARE COUNTY, OH TEST SITE

Seasonal monitoring program (SMP) instrumentation was installed in 18 test sections at a test site in Ohio (*6,18,19*). The southbound lanes of the roadway are constructed of asphalt concrete (AC) pavement and the northbound lanes are constructed of Portland cement concrete (PCC) pavements. The test includes different designs for each test section. The subgrade soil at the site is an A6 soil by the AASHTO Soil Classification System or CL by the Unified Soil Classification System. Weather data and SMP data from two sections were analyzed for this paper (see Figure 1). The pavements were constructed in 1995 so there is very little cracking to date except for AC sections that were designed to fail early. The water table for the AC pavement section (390104) is very shallow, ranging from 0.5 ft (0.15 m) below the top of the subgrade soil in the summer months to 4.0 ft (1.2 m) below in late fall and early winter. The base consists of an asphalt-treated base (ATB) with no drainage. The water table at the PCC pavement (390204) varied from 6 ft. (1.8 m) below the top of the subgrade soil during summer months to 10 ft (3.0 m) during late fall to early winter. There was no drainage provided for the dense-graded aggregate base. Properties of the subgrade soil used for calculations in this research are Gs = 2.70 and dry unit weight equal to 16.9 kN/m^3 (108.1 lb/ft^3). Gravimetric water contents that were measured during installation of the instrumentation correspond to volumetric water contents varying from 35% to 42% at the two test sections shown in Figure 1.

Analysis Of Weather Data

Weather data from the test site were analyzed for approximately a six-year period beginning in 1996. Air temperatures are measured several times each hour, and hourly and daily averages are computed and recorded. The daily air temperatures are shown in Figure 2. Daily averages were evaluated for this analysis using Fourier transform of the time series. The general expression is shown in the equation below.

$$T(t) = A_0 + B_1 \sin[\omega(t-\phi)] \tag{1}$$

Where t is time expressed as the day of the year and ω is the normalized frequency (=$2\pi/365.25$). The following constants were determined after evaluating the data.

A_0 = mean temperature = 10.70^{o}C

B_1 = the amplitude = 12.39^{o}C

ϕ = 109 days

Equation 1 is rewritten as Equation 2 to show the expression for mean daily air temperature as a function of day of the year for the Ohio SHRP Test Road.

$$T(t) = 10.70 + 12.39 \sin[2\pi/365.25\ (t - 109)] \tag{2}$$

The curve designated as computed in Figure 2 was obtained using Equation 2. It can be seen that there is considerable variation between the measured and predicted mean air temperatures, however the predicted curve fits the general seasonal trend very well.

Other weather data is available from the site. Figure 3 shows the daily precipitation at the site. Days with measurable precipitation varied randomly throughout the measurement period. No attempt was made to develop a predictive equation for precipitation. Curves of mean daily air temperature and precipitation are included in later analyses. Data obtained for relative humidity, solar radiation and wind speed were not included since these factors would not be significant for the analyses of unbound materials. These factors are important for the analysis of bound pavement materials.

Analysis of Soil Temperatures

The LTPP seasonal instrumentation at the Ohio SHRP Test Road consists of a MRC pavement temperature and thermistor probe designed to measure the pavement temperatures at three depths and unstabilized base and subgrade soil temperatures at fifteen depths. Details of the instrumentation are shown in Figure 1 for the PCC and AC pavement sections. Data from each sensor of the probes were analyzed in the same manner as the mean daily air temperature data using Equation 1 and Fourier transform analysis. The computed curves of mean daily temperature as a function of time are shown for both sections in Figure 4 for sensors near the top and at the bottom of the thermistor probes. The measured and computed mean air temperatures are also shown in the figure. The temperature variations in the base and subgrade soil behave very similarly to the air temperatures when considering the mean daily temperatures. The variations between the computed and measured soil temperatures are significantly less than for the air temperatures.

Linear regression analysis was performed on the three parameters in Equation 1 to investigate the variation of the parameters as a function of depth below the pavement surface for the AC pavement section. Values of R^2 were greater than 0.97 for all analyses. The soil temperature means varied from 14.4 to 13.8^{o}C (0.3^{o} C / m). The amplitudes of the temperature variations decrease with increasing depth from 13.3 to 5.1 (-4.4^{o}C / m). The time shifts progressively increase with increase in depth from 114 to 156 days (22.4 days / m) indicating a time lag required for the temperature changes to occur.

Analysis of Soil Moisture

Waveform data from time domain reflectometry (TDR) probes were analyzed using software MOISTER provided by the FHWA (*20*). The software uses the method of tangents as the primary method to determine the apparent lengths of the TDR probes (*21*). The probes were placed in the unstabilized base material (TDR 1) and subgrade soil (TDR 2 – TDR 10). Results from the TDR probes are shown in Figure 5 for the AC pavement section. Shown in the figure are the volumetric moisture contents of the top four (TDR 1, 2, 3 and 4) and lowest probe (TDR 10), all placed in the subgrade soil. Data from the other probes generally lie between the curves from the TDR 4 and TDR 10 probes. Freezing which reduces the apparent dielectric constant of the soil resulting in low computed water contents causes the low water contents seen in January. The upper three probes were placed in the upper 18 inches (45.7 cm) of subgrade soil, which is the subgrade soil that would have the greatest impact on pavement performance. It does not appear that there is any relationship between volumetric moisture content and precipitation for the probes in the subgrade soil and for probes placed in base layers at other test sections.

A closer examination of the volumetric water content data reveals that it varies seasonally similarly to the seasonal variation of soil temperature. Figure 6 depicts the variation of both volumetric water content and soil temperature. For this figure, volumetric water contents from the top three TDR probes in the subgrade soils were averaged and soil temperatures from near the top of the thermistor probe were averaged. Low water contents that can be attributed to freezing were excluded from the averages. The soil moisture data from the AC pavement section is well behaved so it was possible to analyze the data using the Fourier transform procedure presented previously as shown in the Equation 3.

$$\mathrm{VMC}(t) = 37.1 + 1.66 \sin[2\pi/365.25\ (t - 130)] \qquad (3)$$

The soil moisture curves are very similar in shape to the soil temperature curve indicating that the seasonal variations in moisture and temperature are similar.

The average volumetric water content obtained from above (37.1%) is significantly higher than the optimum water contents obtained from the standard (31%) or modified (22%) Proctor procedures. Volumetric moisture contents measured during the TDR probe installation varied between 35% and 42%. Thus, the moisture content of the subgrade soil at this site with a high water table increased after construction until it approached the saturated state. For the PCC pavement section it was not possible to approximate an analytical curve for the data due to the large amount of variation, however there are trends in the seasonal variations of soil moisture. Assuming that the subgrade soil approaches saturation at volumetric water content of 40% with $G_s = 2.70$, then an increase in volumetric water content from 35% to 39% corresponds to an increase in the degree of saturation from 88% to 98%. For the dense-graded aggregate (DGA) base under the PCC pavement, the volumetric moisture contents typically varied from 20% to 24% corresponding to a variation of saturation from 72% to 86%. It is concluded that the seasonal variation of subgrade soil moisture can be predicted independent of precipitation.

SEASONAL VARIATION OF SOIL RESILIENT MODULUS

As mentioned previously, the resilient modulus of unbound materials is an important factor for the design of pavements and directly affects pavement performance. Empirical evidence from the researchers cited previously shows that there is a strong dependence of soil resilient modulus on the moisture condition of the soil (*6-10,15*). It was shown that soil moisture and matric suction are important parameters affecting soil resilient modulus (*4*). Soil hysteresis due to wet/dry and freeze/thaw effects has been shown to affect resilient modulus (*12,13*). Temperature affects soil resilient modulus to some extent since it affects surface tension and consequently matric suction. This section discusses approaches for estimating the seasonal variation of resilient modulus for both fine-grained and coarse-grained soils.

Resilient Modulus of Fine-Grained Soils

A generalized method that can be used to predict the seasonal variation of resilient modulus for incorporation into mechanistic design procedures is discussed. The research summarized previously indicated that the resilient modulus of a fine-grained soil can be expressed as a function of deviator stress, and is dependent on compaction energy and moisture, changes in moisture after compaction and freeze-thaw effects. According to research, the resilient modulus of fine-grained soils does not depend on the confining stress (*5*). The Thompson-Robnett equation expresses resilient modulus as a function of deviator stress using a bilinear relationship. The intersection of the two lines is referred to as the break point. Researchers have shown that, for the upper soil layers that most significantly affect pavement performance, the level of deviator stress is low. Tests on fine-grained soils in Ohio have shown that the deviator stress at the break point is at least 41.4 kPa (6 psi) on soil compacted between 70% and 100% saturation (*6,8*). The break point from tests by Alvarez (*7*) occurred at deviator stress between 14 and 20 kPa (2 and 3 psi). The research also shows that resilient modulus does not vary significantly after the deviator stress at the break point is exceeded. It is therefore recommended that Equations 4 and 5 be used for estimating resilient modulus, M_R.

For $\sigma_d < \sigma_{di}$

$$M_R = M_{R0} + K_1 (\sigma_d) \tag{4}$$

For $\sigma_d > \sigma_{di}$

$$M_R = M_{Ri} \tag{5}$$

Where M_{R0} is the intercept value of resilient modulus, K_1 is the slope of the line (negative), M_{Ri} is the resilient modulus at the break point or a representative value of M_R after the break point. Alternatively, logarithmic plots of M_R versus σ_d may be used as shown in Equation 6 (*11*).

$$M_R = K_1 (\sigma_d)^{K_2} \tag{6}$$

Research has shown that the resilient modulus can vary by as much as a factor of two for a variation in saturation from approximately 85% to 95% which will then lead to a significant variation in required AC pavement thickness or to a significant reduction in pavement life (*6,7*). The variation between resilient modulus and degree of saturation is approximately linear. Laboratory tests were conducted on soil samples that were compacted at different water contents and on soil samples that were compacted at lower water contents with subsequent increases in moisture content after compaction. Data from test sections in Ohio shows that there is a seasonal variation of moisture content even at this site where there is a high water table and no drainage. Consequently, there will be a seasonal variation of resilient modulus.

Research on the effects of freezing has shown that resilient modulus can be significantly affected by freezing and thawing (13). The resilient modulus of fine-grained (frost susceptible) soils increases significantly as the temperature decreases to –20°C. The resilient modulus of thawed soils is significantly lower than unfrozen soils. There is a hysteresis effect or difference in resilient modulus depending on whether the soil is freezing or thawing. The data from the test site in Ohio indicates that frost penetration (or subzero temperatures) does not extend beyond about 18 inches (45.6cm) below the top of the subgrade soil, that the soil did not remain frozen for more than 1 month and that the subgrade soil remained unfrozen during some years. Frost penetration and duration will increase significantly as the severity of climate increases.

The following recommendations are suggested for estimating the seasonal variation of resilient modulus for fine-grained soils. It is first necessary to estimate resilient modulus for the subgrade soil as it is compacted in the field (*9,11*). The research has shown that resilient modulus is dependent on moisture content and dry density during compaction and on moisture content or matric suction thereafter (*10*). Drumm, et al. proposed methods for estimating resilient modulus based on soil type and properties. Because of the difficulty in determining relationships between matric suction and moisture content, it is necessary to rely on the use of moisture content variation. The present research has shown that it may be appropriate to approximate the seasonal variation in moisture content as a function of day of the year using a sinusoidal curve. The seasonal variation of resilient modulus would then vary similarly as shown in Equation 7.

$$M_R(t) = M_{Rm} + B_1 \sin[2\pi/365.25\ (t-\phi)] \tag{7}$$

Where M_{Rm} is the mean resilient modulus, B_1 is the amplitude and ϕ is the time shift. By inspection of Equation 7, B_1 corresponding to 33% of M_{Rm} would result in a seasonal variation of resilient modulus by a factor of 2. It may be necessary to account for freeze-thaw effects for climates where freezing is significant (*12,13*). Design for pavements can then be accomplished by accounting for the seasonal variation of the subgrade soil resilient modulus using the monthly averages. A method described by Guan et al. (*22*) uses weighting factors to determine resilient modulus for design of flexible pavement.

Resilient Modulus of Aggregates and Coarse-Grained Soils

Research on aggregates and granular subgrade soils indicates that resilient modulus is a material property that depends on gradation, density and moisture content of the soil. The resilient modulus of coarse soils decreases significantly as the gradation changes from coarse to fine, as the density decreases and as the moisture content increases (*23*). The recommended expression for resilient modulus is given in Equation 8 (*14*).

$$M_R = K_1(\theta)^{K_2} \tag{8}$$

Researchers have investigated the variation in resilient modulus and the two empirical parameters given in Equation 8. Equations relating resilient modulus to soil properties have also been derived (*15*). The empirical parameters determined from the investigators vary significantly depending on the soil type. Further research is required in order to rely on the use of empirical equations for determining resilient modulus.

It is necessary to correct for seasonal effects once the parameters from Equation 8 are determined. The resilient modulus of coarse soils decreases with increases of moisture content due to changes in matric suction. A theoretical model was developed for the change in resilient modulus as a function of temperature and moisture change (*17*). Resilient modulus was predicted using measured monthly variations of moisture and temperature and the theoretical model. The relative effects of temperature and moisture were not discussed, however it can be expected that changes in moisture, since they affect soil matric suction and bulk stress, would have a much greater effect on resilient modulus than temperature effects. Laboratory samples were also tested at selected values of temperature and moisture. The comparison between predicted and values determined in the laboratory was excellent. In addition to the excellent agreement between predicted and measured values, the results show that the seasonal variation of resilient modulus can be approximated very accurately using a sinusoidal equation such as given in Equation 7. The maximum value of resilient modulus was approximately 1.4 times the minimum value for the study by Jin et al.

Frost heave effects are not normally significant for coarse-grained soils. Coarse-grained soils are not considered to be frost susceptible because the degree of saturation is typically lower. Coarse soils can be affected by freezing if they are near saturation when frozen and the density decreases due to frost heave effects.

The following recommendations are suggested for estimating the seasonal variations of resilient modulus for aggregate bases and subgrade soils. It is necessary to estimate resilient modulus using empirical equations that depend on soil type, moisture content and density for the soils at the site and Equation 8. It is then necessary to adjust the resilient modulus for seasonal effects. A sinusoidal expression for resilient modulus as a function of day of the year, Equation 7, is recommended. The use of Equation 7 requires information on the effects of moisture content on resilient modulus and the seasonal variation of moisture at the site. A representative value of resilient modulus can then be computed using weighting factors (*22*).

Example Calculation For Seasonal Variation Of Resilient Modulus

An example calculation for the seasonal variation of resilient modulus was performed for the asphalt pavement section. The seasonal variation of the volumetric moisture content was computed using the averages from the top three TDR moisture probes. The seasonal variation of moisture content obtained from the analysis of the data is given in Equation 3. The average volumetric water content was computed for each month using the equation. An expression for the variation of resilient modulus obtained from laboratory tests on soil from the site was derived by Alvarez (7). The equation is

$$M_r \text{ (psi)} = 77235.54 - 639.121\, S(\%) - 5418.33\, \sigma_d \tag{9}$$

where Mr is the resilient modulus corrected for saturation, S%, and deviator stress, σ_d. Values of degree of saturation were computed by dividing the average volumetric water contents by the porosity which was assumed to be 40%. The estimated deviator stress is 1.2 psi (8.3 kPa). After computing values of the monthly average resilient modulus, the procedure by Guan et al. (22), based on the 1993 ASSHTO Guide, was used to compute weighting factors for each month. The equation for weighting factor is

$$WF_i = \frac{12\, M_{Ri}^{-2.32}}{\sum_{i=1}^{12} M_{Ri}^{-2.32}} \tag{10}$$

where WF_i is the weighting factor for each month and M_{Ri} is the average resilient modulus for each month. An example of the calculations is given in Table 1. The weighting factors can be used to compute the weighted-mean annual resilient modulus or to determine the design season corresponding to periods when the weighting factor is equal to one. It may be necessary to adjust the values of resilient modulus during periods of freezing and thawing before computing the weighting factors. Since low values of the weighting factors indicate months with low subgrade resilient modulus, the weighting factors can be used to determine when weight restrictions would be beneficial. Alternative equations for the weighting factors would have to be derived for use with other mechanistic equations.

CONCLUSIONS

Data from SMP testing at a test site in Ohio were analyzed for seasonal variations of moisture and temperature. It was shown that Fourier transform analysis could be used to develop equations for the seasonal variations based on plots of the variations of temperature and moisture as a function time expressed as day of the year. The analyses were performed using daily averages for air and soil temperatures and monthly measurements of soil volumetric water content. The expressions can be used to predict the mean values for any day or to predict the mean monthly values. More research is required in order to verify these findings and to develop expressions for the seasonal variations of soil temperature and moisture.

A procedure was proposed for predicting seasonal variations of resilient modulus for unbound materials for use with flexible pavement design. Equations relating resilient modulus and deviator stress (fine-grained soils) or bulk stress (coarse-grained soils) require two empirical parameters. The parameters are obtained from tests at different levels of applied stress. Resilient modulus tests are difficult and costly to perform. Therefore, it is necessary to approximate resilient modulus or the empirical parameters based on other soil properties. Much research has been done to develop relationships between soil type, density, moisture and other properties. This research should be continued until satisfactory correlations are developed for general use. It is then necessary to correct resilient modulus for seasonal effects.

Soil moisture content should be adopted as the primary variable for predicting seasonal variations of resilient modulus. Soil matric suction is an important stress state parameter affecting soil properties. Relationships between soil matric suction and volumetric water content are used to characterize the soil moisture condition. The relationships are material dependent, difficult to measure and subject to hysteresis effects. Therefore, the recommendation is to use the seasonal variation of volumetric moisture content for estimating the variation of resilient modulus.

The subgrade resilient modulus varies seasonally due to changes in moisture content. Resilient modulus decreases with increases in moisture content. It is difficult to determine relationships between resilient modulus and moisture content because they are material and history dependent. Data from other researchers indicate that resilient modulus can vary by a factor of two or more for changes in saturation of 10% to 15%. Additional research is necessary to investigate the variation of resilient modulus with moisture content. It is shown here that seasonal changes in moisture occur at a site with a fine-grained subgrade soil with no base drainage and a high water table. A project on a test pavement with seasonal instrumentation at a site with a low water table was recently funded by the Ohio Department of Transportation. The recommendation is to approximate the seasonal variation of resilient modulus using a sinusoidal equation and to use weighting factors for determining design values.

There is a need to evaluate the large amount of data being collected for the LTPP Seasonal Monitoring Program (SMP) and being stored in the Information Management System of DataPave (currently Version 3.0) and other research. This research analyzed data from a test site in Ohio. Factors such as freeze-thaw and wet-dry effects, depth to the water table and base drainage could not be evaluated. The variables in the SMP testing include soil type, climate and drainage conditions. In addition to the LTPP testing, there has been a significant amount of research on material property characterization and pavement performance sponsored by state departments of transportation.

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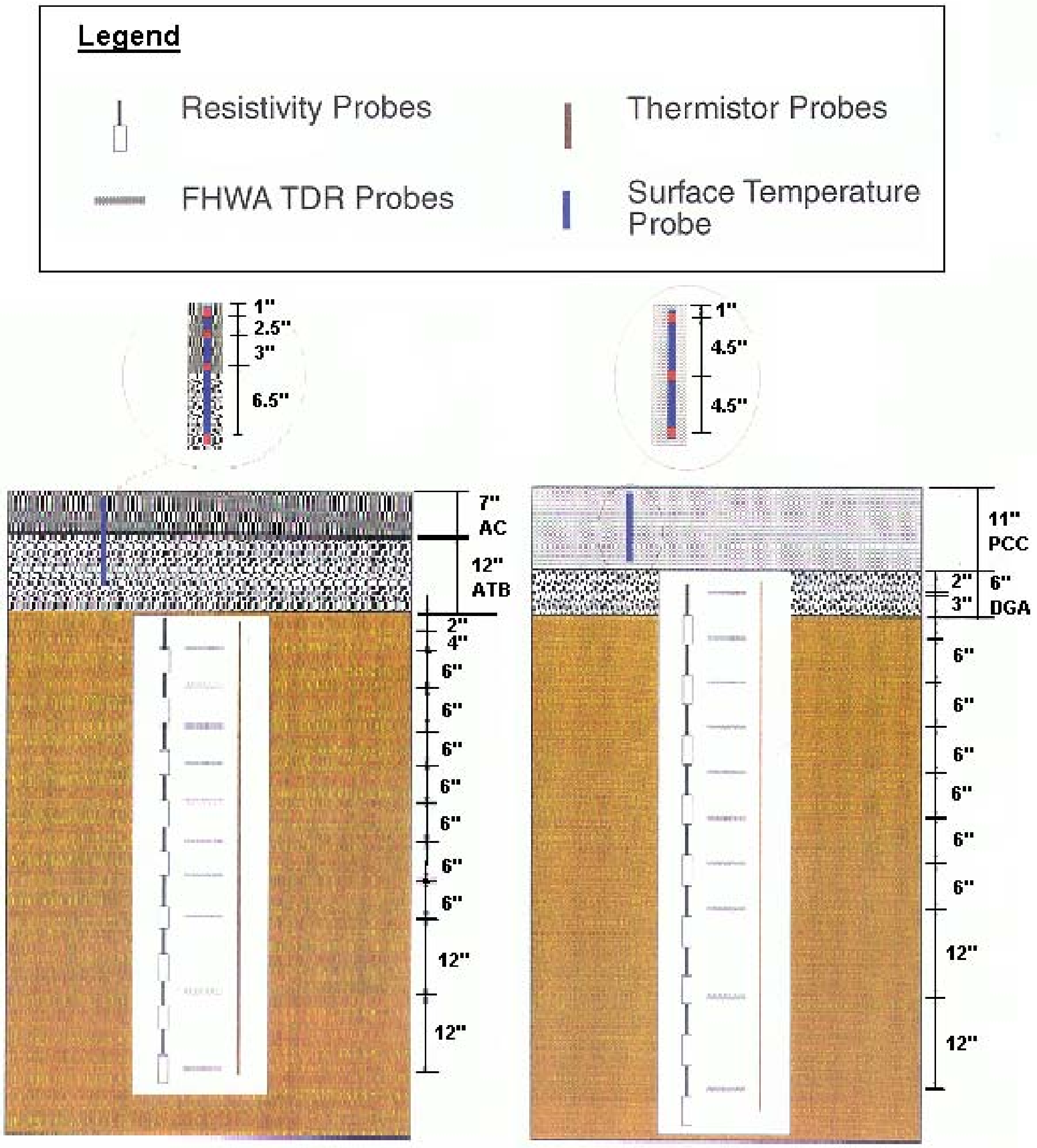


Asphalt Pavement Section (390104) **PCC Pavement Section (390204)**

FIGURE 1 Seasonal Instrumentation, Ohio SHRP Test Road (From *18*)

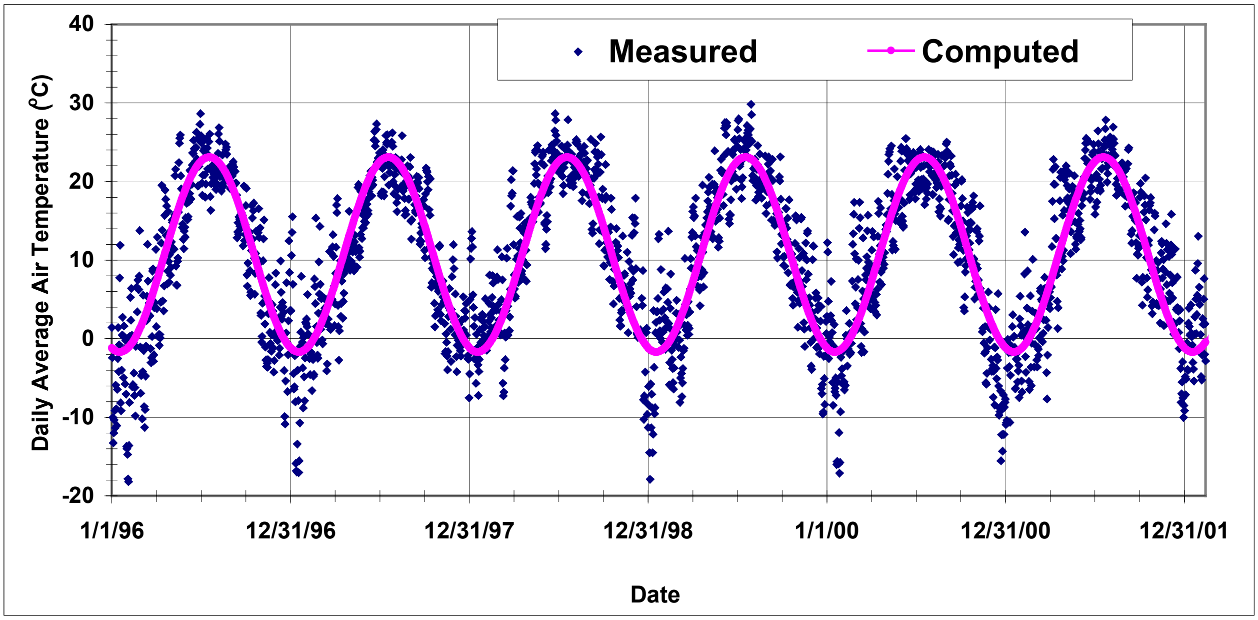


FIGURE 2 Measured and Computed Mean Daily Air Temperatures

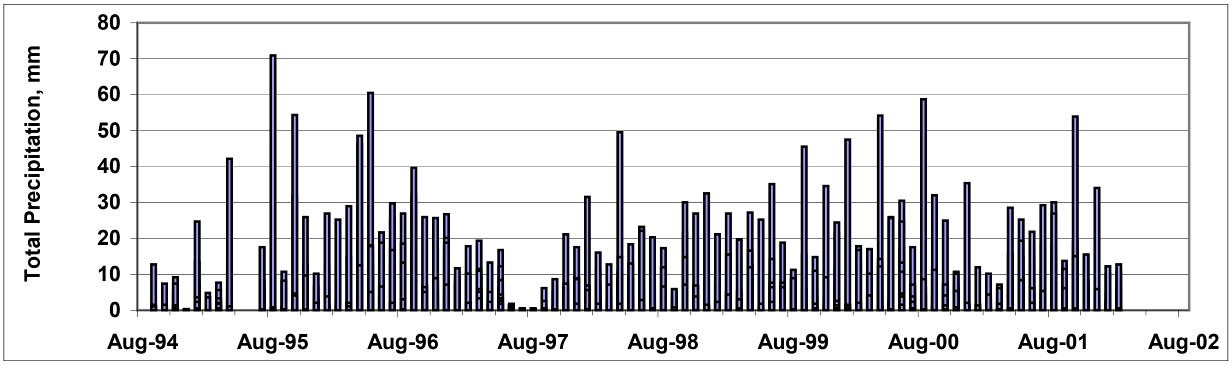
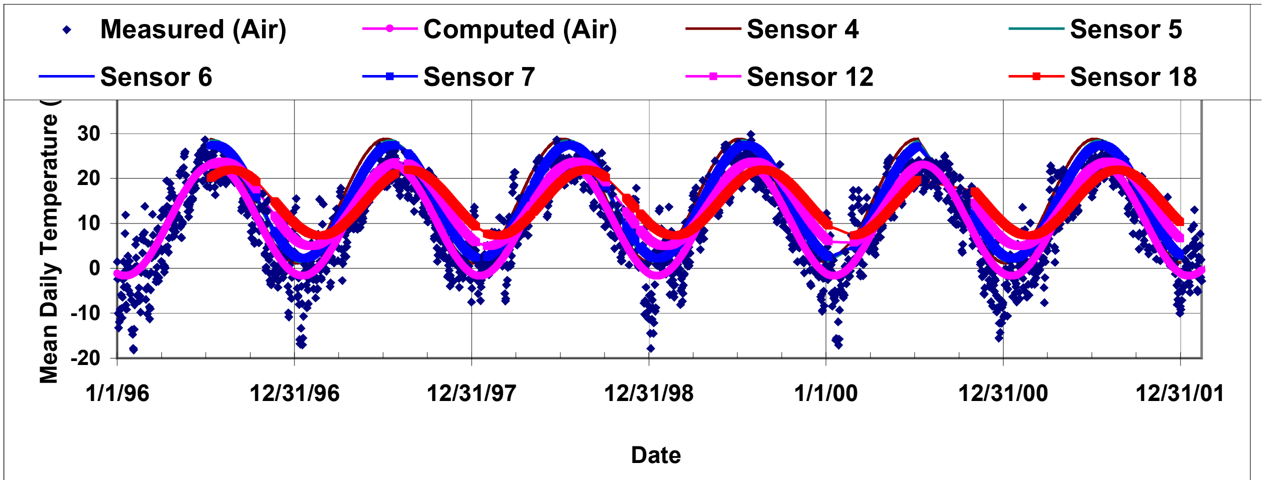
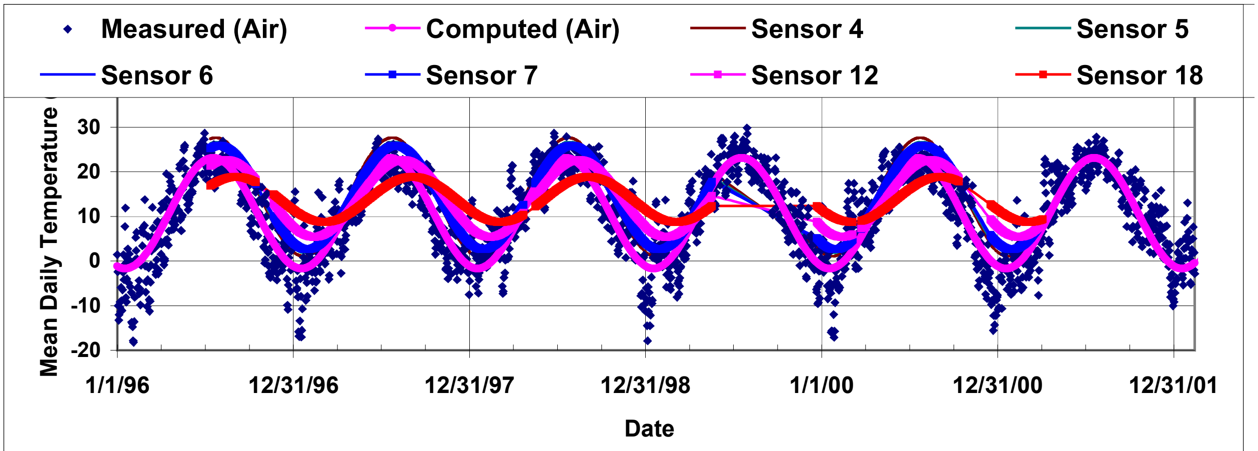


FIGURE 3 Daily Precipitation, Ohio SHRP Test Road



b) Section 390204 (PCC Pavement)



a) Section 390104 (AC Pavement)

FIGURE 4 Mean Daily Temperatures

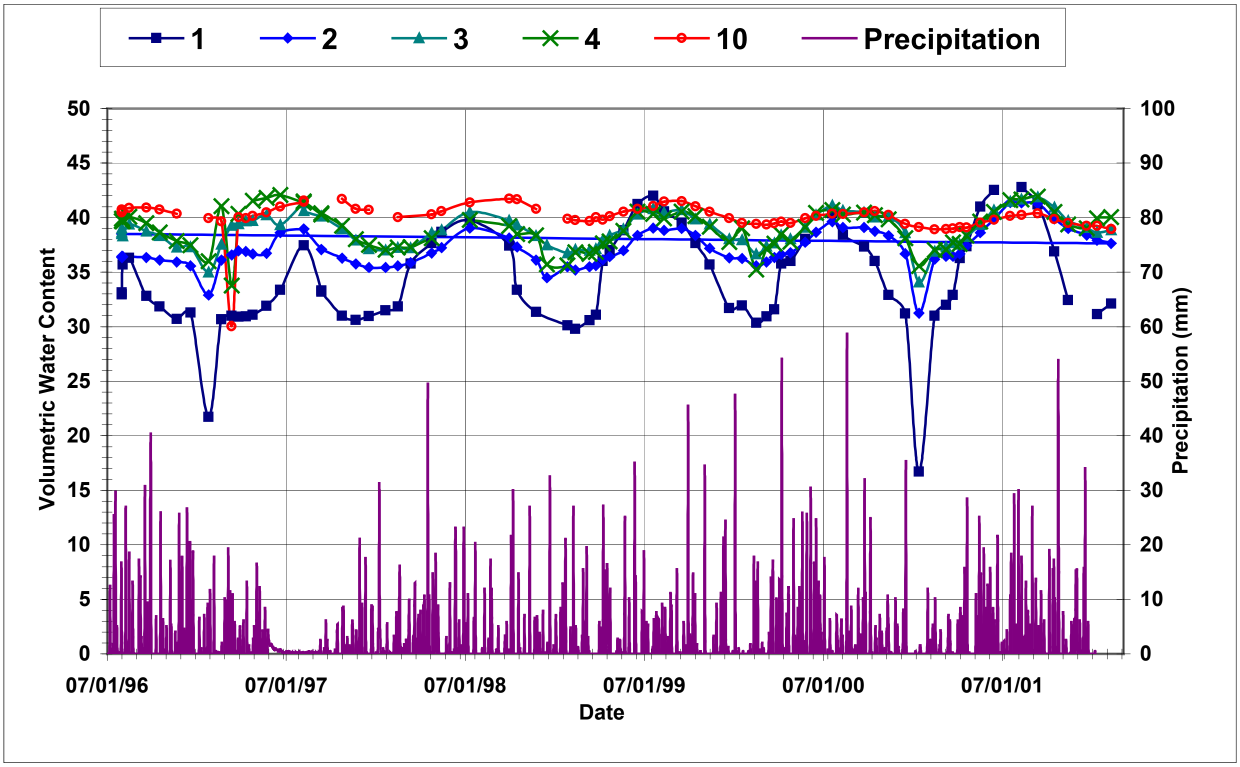
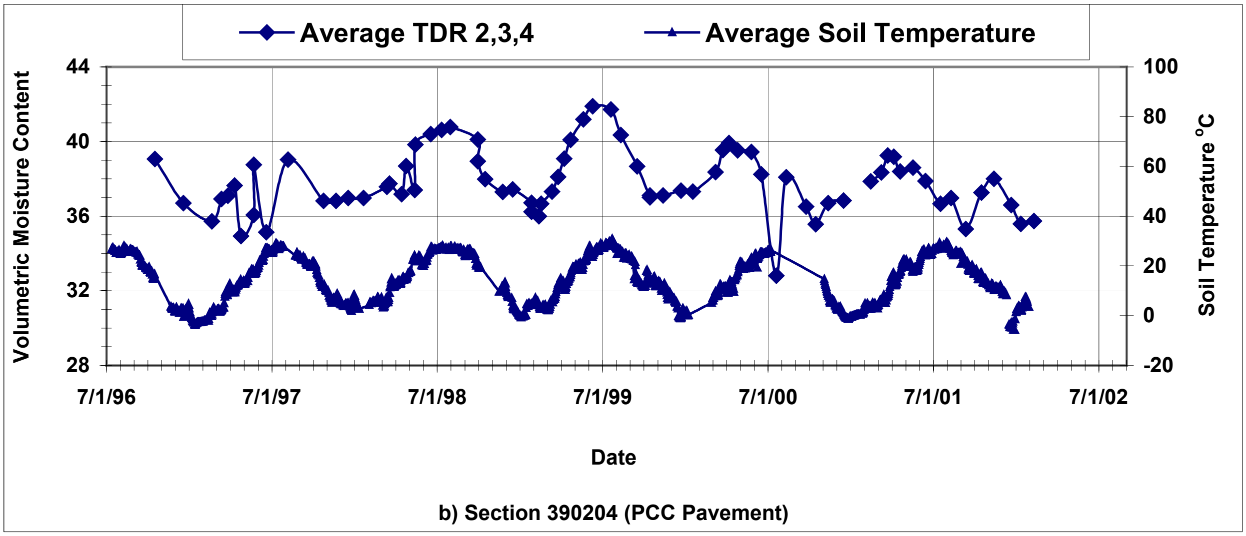


FIGURE 5 Volumetric Water Content and Total Precipitation, AC Section



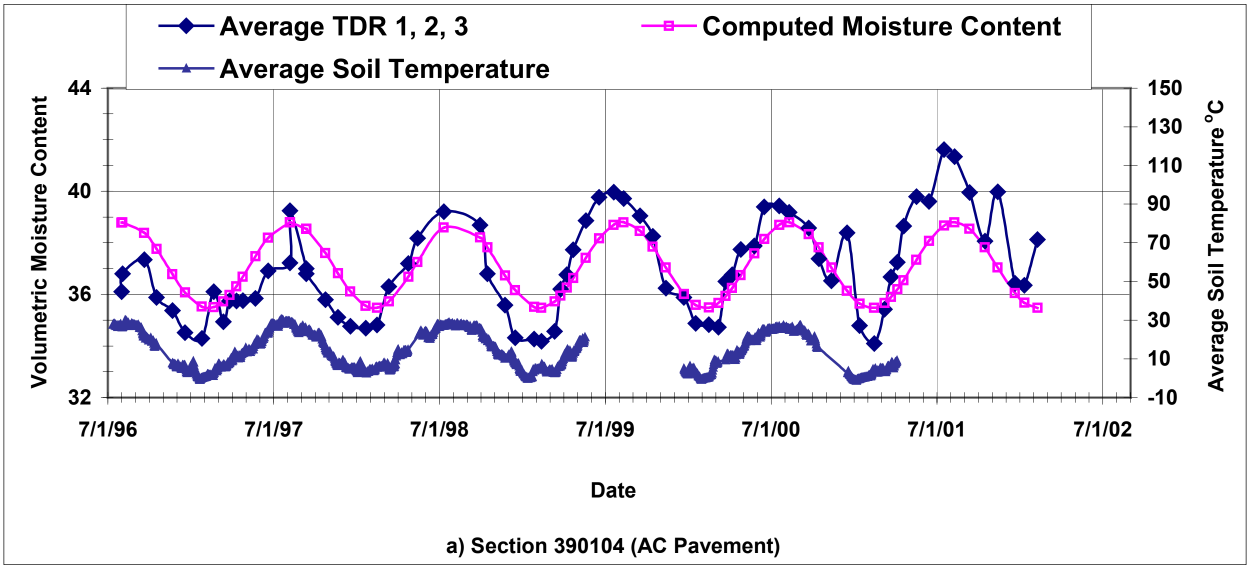


FIGURE 6 Volume Water Content and Average Soil Temperature

TABLE 1 Example Calculation for Resilient Modulus Weighting Factors, AC Section

Month	Ave VWC (%)	S (%)	Ave M_{ri} (psi)	Ave M_{ri} (MPa)	$M_{ri}^{-2.32}$ (psi)	$M_{ri}^{-2.32}$ (MPa)	WF_i
Jan	35.61	89.0	13834	95.4	2.47E-10	2.56E-05	0.577
Feb	35.50	88.7	14019	96.7	2.40E-10	2.48E-05	0.560
Mar	35.80	89.5	13536	93.3	2.60E-10	2.69E-05	0.607
Apr	36.46	91.1	12481	86.1	3.14E-10	3.25E-05	0.733
May	37.30	93.2	11137	76.8	4.09E-10	4.23E-05	0.955
Jun	38.10	95.2	9865	68.0	5.42E-10	5.6E-05	1.265
Jul	38.63	96.6	9009	62.1	6.69E-10	6.91E-05	1.561
Aug	38.76	96.9	8800	60.7	7.06E-10	7.3E-05	1.648
Sep	38.45	96.1	9300	64.1	6.21E-10	6.42E-05	1.450
Oct	37.78	94.4	10369	71.5	4.83E-10	4.99E-05	1.127
Nov	36.94	92.3	11716	80.8	3.63E-10	3.76E-05	0.849
Dec	36.15	90.4	12979	89.5	2.87E-10	2.96E-05	0.669
				Sum=	5.14E-09	5.31E-04	12.000