TEMPERATURE, FREQUENCY AND LOAD LEVEL CORRECTION FACTORS FOR BACKCALCULATED MODULI VALUES

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ABSTRACT

It is a well established fact that moduli values backcalculated from deflection data of one particular NDT device will be different from those of another device. Although disconcerting at first glance, this should not be surprising to the pavements engineer. NDT devices often use widely different load levels and loading frequencies. Combine this with the complex nature of pavement materials and the fact that data are often collected under different temperature and moisture conditions emphasizes the need for theoretically sound procedures for converting measured values to standard levels of load, temperature, and loading frequency. This is the subject area of this paper.

In this paper are the results of a recently completed Texas Transportation Institute study on Nondestructive Testing. One of the major recommendations of that study are standardized guidelines for applying Temperature, Frequency and Load Level corrections. These will be described in detail and typical examples will be given. Of particular interest are the load level correction factors and this is demonstrated in case studies which compare backcalculated moduli values from the Dynaflect, Dynatest Falling Weight Deflectometer, and Road Rater 2000.

Key Words: Backcalculation, deflection basins, secant modulus, initial tangent modulus, standard load level, strain level correction, confining pressure correction, temperature and frequency corrections, stress sensitivity, hyperbolic stress-strain curve, NDT devices

INTRODUCTION

The moduli that are backcalculated from layered elastic analysis must be corrected to standard temperature and frequency levels, and if the nondestructive testing device is incapable of applying a design load level, the moduli must also be corrected to this standard load level. More specifically, the modulus of the asphaltic concrete surface course varies significantly with temperature and frequency of loading. Regarding the base course and subgrade materials, associated moduli are affected by confining pressure and strain level.

Detailed descriptions of the procedures for correcting moduli to standard conditions are presented herein. For the purposes of this presentation, the standard temperature is considered to be 25°C (77°F), the standard frequency is 10 Hertz, and the standard confining pressure and strain level are those that result from a circular plate having a radius of 15 centimeters (5.91 inches) and exerting a pressure of 565 kPa (82 psi) on the pavement surface.

The procedures are applied to moduli backcalculated from deflection basins obtained using the Dynatest FWD, Road Rater 2000, and Dynaflect. Moreover, only one pavement section was used. It is part of Texas Transportation Institute's (TTI) Pavement Test Facility at Texas A&M University and consists of 2.54 cm (1 inch) of asphaltic concrete, 41 cm (16 inches) of crushed limestone base, 91 cm (36 inches) of sandy gravel subbase on a high plasticity clay (1).

TEMPERATURE AND LOADING FREQUENCY CORRECTIONS FOR ASPHALTIC CONCRETE

The temperature correction procedure follows that recommended by the Asphalt Institute (2) to determine the Mean Pavement Temperature at the time the deflection measurements are made. This requires the following data to be collected:

1. Location of test site to select a weather station from which air temperature data may be obtained.
2. Date of test to give the dates on which air temperature data must be collected.
3. Maximum and minimum air temperature for the five days prior to the date of the deflection testing.
4. Pavement surface temperature measured at the time of the deflection test.
5. Thickness of the asphaltic portion of the pavement.
6. The frequency of loading or the time duration of the load impulse.
7. The percent asphalt cement by weight of the mix.

Data items 3, 4, and 5 are used to enter the chart in Figure 1, which is Figure XII-1 in the Asphalt Institute manual on Asphalt Overlays for Highway and Street Rehabilitation (MS-17) (2) to determine the temperature in the asphalt layer at the top, middle, and bottom of the layer. The average of these three temperatures is considered to be the average temperature of the layer.

The next data item to obtain is the frequency of loading. If the loading device applies a cyclic load to the pavement, such as the Dynaflect or Road Rater, the loading frequency is the actual frequency used in the deflection

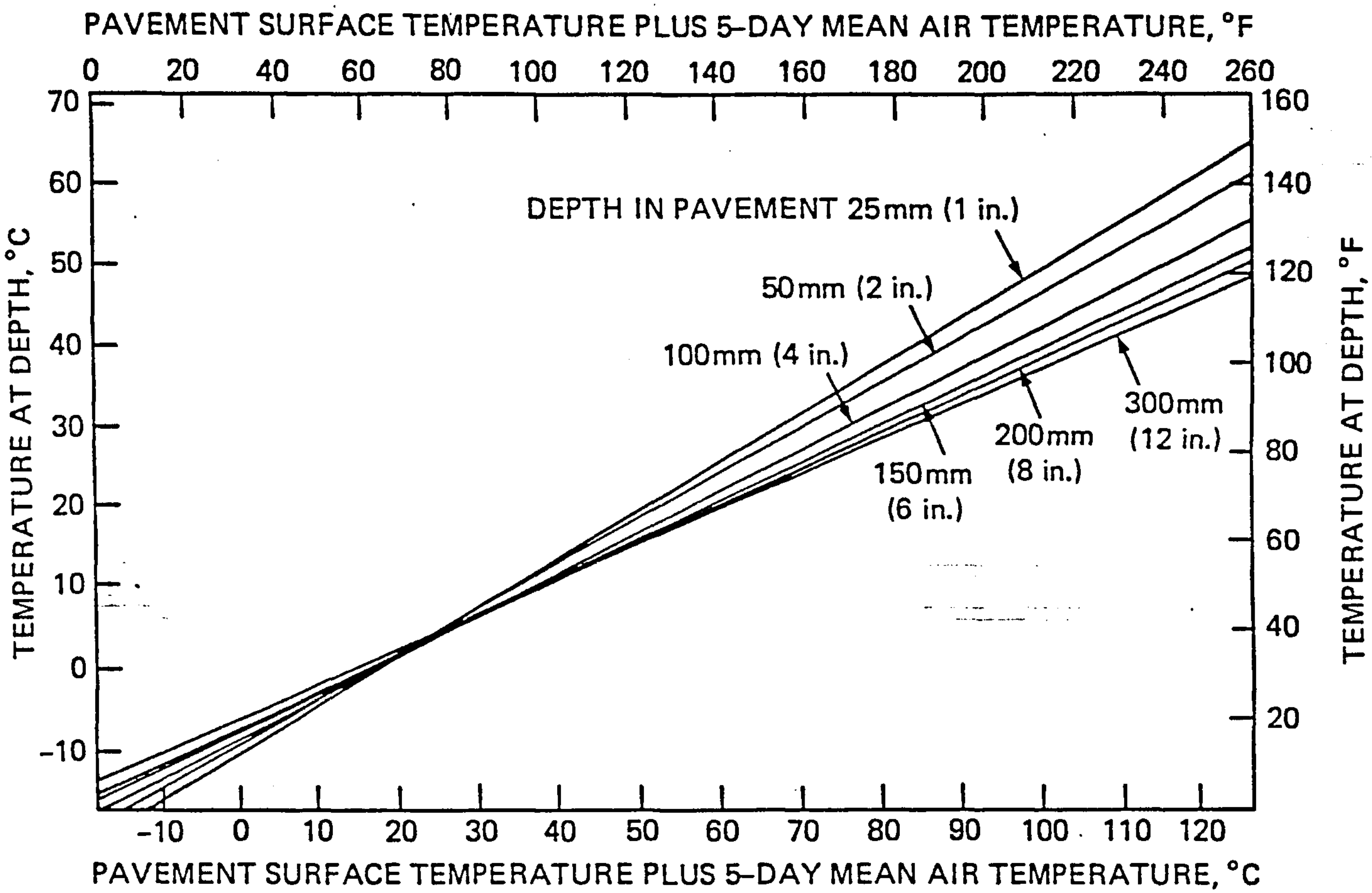

Figure 1. Predicted pavement temperatures, The Asphalt Institute (2).

test. If an impulse loading test is used, the loading frequency may be approximated by:

$$f = \frac{1}{2t}$$

where:

f = the loading frequency, in Hertz

t = the time duration of the impulse load, in seconds

The frequency and temperature correction formula (3) is taken from Asphalt Institute Research Report No. 82-2 (4):

$$\log E_o = \log E + 0.028829\ P_{200} \left[\frac{1}{(f_o)^{\ell}} \quad \frac{1}{(f_o)^{\ell}}\right] +$$

$$0.000005\sqrt{P_{ac}} \left[(t_o)^{r_o} - (t)^{r} \right] - 0.00189\sqrt{P_{ac}}\ \times$$

$$\left[\frac{(t_o)^{r_o}}{(f_o)^{1.1}} - \frac{(t)^{r}}{(f)^{1.1}} \right] + 0.931757 \left[\frac{1}{(f_o)^{n}} - \frac{1}{(f)^{n}} \right]$$

where:

ℓ = 0.17033

n = 0.02774

E = the measured or backcalculated modulus

t, f = the test temperature (°F) and loading frequency (Hertz)

t_o, f_o = the standard temperature (77°F) and loading frequency (10 Hz)

(These values were selected for the presentation.)

P_{ac} = the percent asphalt cement by weight of the mix

E_o = the corrected modulus

r_o = $1.3 + 0.49825 \log(f_o)$

r = $1.3 + 0.49825 \log(f)$

P_{200} = percent aggregate passing No. 200 sieve

Confirmation of the above frequency-temperature correction formula was attempted by two methods. One method used was to correct backcalculated asphaltic concrete moduli to the standard conditions defined in the Introduction section of this paper. The other method used was to obtain an asphaltic concrete core from TTI's Pavement Test Facility and determine its moduli at different temperatures for a given frequency. Both methods and their results are discussed in further detail below.

Temperature Correction

The elastic modulus of the asphaltic concrete core was determined by the diametral resilient modulus (M_R) device. This test is basically a repetitive load test using the stress distribution principles of the indirect tensile test (5). Results of the laboratory test are provided in Table 1. Next, the laboratory-determined modulus for a give temperature was corrected to the other tested temperatures in Table 2 using the frequency and temperature correction formula for comparison to the laboratory results.

The percent differences presented in Table 2 indicate that correcting a modulus measured at a low temperature to a higher temperature (specifically 0.56°C (33°F) to 42°C (108°F)) is more reliable than vice-versa. However, similar percent differences were obtained for correcting a modulus at 42°C (108°F) to 25°C (77°F) as was for correcting a modulus at 0.56°C (33°F) to 25°C (77°F). These trends may or may not be applicable to asphaltic concrete mixes differing from the mix used at the TTI Pavement Facility.

Diametral Resilient Modulus (M_R) Results for a Frequency of 10 Hertz:

Temperature	M_R
0.56 C (33°F)	8.16×10^6kPa (1184 ksi)
25 C (77°F)	3.94×10^6kPa (572 ksi)
42 C (108°F)	1.22×10^6kPa (177 ksi)

Mechanical Gradation:

Sieve Size	Percent Passing
3/8"	100%
No. 4	98%
No. 10	78%
No. 40	26%
No. 80	14%
No. 200	7%

Penetration at 77°F = 8 dmm

Percent Asphalt by Weight = 6.25%

Table 1: Asphaltic Concrete Mix Properties
(TTI Pavement Test Facility)

Laboratory E	Test Temp t	P_{ac}	P_{200}	$f = f_0$ (Hertz)	Corrected Temp t_0	Corrected E_0	Percent Difference*
1.22x10^{6}kPa (177 ksi)	42°C (108°F)	6%	10%	10	25°C (77°F)	6.63x10^{6}kPa (961 ksi)	-68
					0.56°C (33°F)	32.18x10^{6}kPa (4667 ksi)	-294
394x10^{6}kPa (572 ksi)	25°C (77°F)	6%	10%	10	42°C (108°F)	0.724x10^{6}kPa (105 ksi)	41
					0.56°C (33°F)	19.15x10^{6}kPa (2777 ksi)	-135
8.16x10^{6}kPa (1184 ksi)	0.56°C (33°F)	6%	10%	10	25°C (77°F)	1.68x10^{6}kPa (244 ksi)	57
					42°C (108°F)	0.3x10^{6}kPa (45 ksi)	75
1.22x10^{6}kPa (177 ksi)	42°C (108°F)	5%	10%	10	25°C (77°F)	5.72x10^{6}kPa (829 ksi)	-45
					0.56°C (33°F)	24.19x10^{6}kPa (3509 ksi)	-196
3.94x10^{6}kPa (572 ksi)	25°C (77°F)	5%	10%	10	42°C (108°F)	.841x10^{6}kPa (122 ksi)	31
					0.56°C (33°F)	16.68x10^{6}kPa (2420 ksi)	-104
8.18x10^{6}kPa (1184 ksi)	0.56°C (33°F)	5%	10%	10	25°C (77°F)	1.93x10^{6}kPa (280 ksi)	51
					42°C (108°F)	.414x10^{6}kPa (60 ksi)	66

$$\text{*Percent Difference} = \frac{E - E_0}{E} \times 100\%$$

Table 2: Comparison of Laboratory and Asphalt Institute Corrected

Figure 2 illustrates a comparison made by the Asphalt Institute (4) of predicted and laboratory-determined asphaltic concrete moduli. The predicted moduli were determined from the equation referred to in Reference (4) as the "Witczak Modified |E*| Equation," or WME. It was from this equation that the frequency and temperature correction formula was derived. A consequence of this is that the percent differences given in Table 2 should not be expected to be any better than the relative errors given in Figure 2.

Approximately all of the data points in Figure 2 would be encompassed for a relative error of ±100%. Referring to Table 2, except for correcting the modulus at 42°C (108°F) to 0.56°C (33°F), the percent differences are generally within the ±100% relative error range.

Frequency Correction

Evaluation of the frequency and temperature correction formula for correcting asphaltic concrete moduli to a desired frequency was performed by backcalculating asphaltic concrete moduli and correcting them to a frequency of 10 Hertz at 25°C (77°F). These moduli were backcalculated from deflection data provided in the Appendix and were obtained from the Dynatest FWD, Road Rater 2000, and Dynaflect. Additional data pertinent to these nondestructive testing devices along with the backcalculated moduli are given in Table 3.

The corrected asphaltic concrete moduli backcalculated from the Dynatest FWD deflection data for the three different load levels in Table 3 are quite similar. However, these corrected moduli differed significantly from the laboratory test results in Table 1. This discrepancy is probably more a result of errors associated with the NDT devices and backcalculation procedure (6) than with the frequency and temperature correction formula. Incidently, MODULUS (3), which for this study utilized BISAR, was used for backcalculation of the moduli.

The corrected asphaltic concrete moduli associated with the road Rater and Dynaflect differ from the corrected moduli associated with the Dynatest by approximately 124% for the Road Rater and 63% for the Dynaflect. Here, again, the discrepancy is more likely attributed to NDT and backcalculation errors.

CORRECTION TO STANDARD LOAD

If the materials in each pavement layer are in their linear elastic range under the stress conditions caused by both the nondestructive test load and the design traffic load, there is no need to make any correction of the layer moduli for load level. A test of whether the materials in a pavement behave linearly is to determine whether the surface deflections vary linearly with load level, all the way up to a design load level. This test is not conclusive as will be explained later, but if the load-to-deflection ratio remains constant up to the design load level, it can be assumed that no load level correction needs to be made.

The layer moduli which must be corrected for load level are the base course and subgrade. The asphaltic concrete layer modulus is primarily dependent upon loading frequency and temperature. In the base course and subgrade materials, there are two corrections that must be made in order to arrive at a modulus that these materials would have under a moving design load: one correction for the confining pressure level and another for the strain level. Each of these will be described subsequently.

In making these corrections, it must be recognized that the only method which can approach an accurate determination of the modulus of a material under a standard load is the finite element method which adjusts the stiffness of each element in accordance with its own stress state. The finite element method recognizes that the "modulus" of a non-linear material is not something that is a characteristic of a layer but instead pertains to a material point within that layer.

Although it is technically incorrect to use a single modulus to characterize an entire layer, it is a common practice to do so with layered elastic analysis methods. The single layer modulus that is determined by these methods is a kind of an "average" modulus which produces a calculated deflection basin that is reasonably close to what was measured. It is not known whether this "average" modulus will change with load level in the same way as will a "real" modulus of the layer material. Recognizing this fact, the FHWA-ARE procedure (7) assumed that his "average" modulus of the subgrade changes with the calculated deviator stress in accordance with the same power law that the same material exhibits in a laboratory test.

The FHWA-ARE procedure makes a second assumption that the deviatoric stress corresponding to the "average" calculated modulus is the calculated deviatoric stress in the middle of the layer directly beneath the load applied by the NDT device. These two assumptions make it possible to apply a correction to the "average" layer modulus which corresponds to a calculated deviatoric stress directly beneath the design load. It would appear to be more consistent to apply a correction to the "average" layer modulus that is based upon an "average" deviatoric stress. The problem with this is that it is difficult to define, in general, at what point in each layer that the "average" deviatoric stress occurs.

It has not been demonstrated either by analysis or by field deflection tests that the "average" modulus that is corrected in accordance with these two assumptions will be the same as the "average" modulus that provides the best fit to a deflection basin under a design load. In summary, there is no question that such corrections should be made, but there are serious and unresolved questions of just how those corrections should be made.

The equation of the stress-strain curve for base, subbase, and subgrade materials is assumed to be of the form:

$$\sigma = E_p \epsilon + \frac{E_r \epsilon}{\left[1 + \left[\frac{E_r \epsilon}{\sigma_y} \right]^m \right]^{1/m}}$$

where:

σ, ϵ = the stress and strain values on the curve

E_p = the "plastic" or work-hardening modulus

E_r = $E_i - E_p$

E_i = the initial tangent modulus

σ_y = a maximum "plastic yield" stress

m = an exponent

This equation was proposed by Richard and Abbot (8). A graph of the stress-strain curve described by this equation is shown in Figure 3. If the exponent m, is equal to 1.0, and the plastic modulus E_p is equal to 0.0, the equation becomes the familiar hyperbolic stress-strain curve proposed by Kondner (9), used extensively by Duncan (10):

$$\sigma = \frac{\epsilon}{\frac{1}{E_i} + \frac{\epsilon}{\sigma_y}}$$

where:

σ, t = the stress and strain in the material

E_i = the initial tangent modulus

σ_y = the limiting stress that the material can withstand

According to those references and others, the initial tangent modulus, E_i, varies with confining pressure, as will be described below. The modulus that is of interest in the analysis of pavements is a resilient modulus, that is the modulus describing the elastic deflection and rebound under a moving load. It is assumed here that the resilient modulus is a secant modulus of the curve shown in Figure 3, and that it obeys the general hyperbolic stress-strain curve equation proposed by Richard and Abbot. The relation between the secant modulus, E, and the initial tangent modulus, E_i, in its simplest form is:

$$\left[\frac{1-a}{\left(\frac{E}{E_i} - a\right)}\right]^m - \left[\frac{(1-a)\epsilon}{b}\right]^m = 1$$

where:

$a = \frac{E_p}{E_i}$, and

$b = \frac{\sigma_y}{E_i}$

m, E_i = as defined above

The equation given above has four unknowns, a, b, m, and E_i which can be found by non-linear regression analysis of four or more points on a stress-strain curve.

Different load levels will produce different secant moduli on the same curve, assuming that the confining pressure does not change. If the confining pressure does change with load level, the ratio of the moduli between the two load levels must be adjusted for the change of the initial tangent modulus that has occurred. The corrections that must be made to adjust for changes in load level may be viewed as occurring in three steps:

Step 1. Find the ratio of the secant resilient modulus to the initial tangent modulus for each load level.

Step 2. Find the ratio of the two secant moduli, assuming the two initial tangent moduli are different.

Step 3. Find the ratio of the initial tangent moduli as they depend upon confining pressure.

Each of these steps are discussed in more detail below.

Step 1:

For a load level, j, the ratio of the secant modulus, E_j, to the initial tangent modulus, E_{ij}, is:

$$\frac{E_j}{E_{ij}} = a_j + \frac{(1-a_j)}{\left[1 + \left[\frac{(1-a_j)}{b_j}\ \epsilon_j\right]^m\right]^{1/m}}$$

where:

$a_j = \frac{E_{pj}}{E_{ij}}$, the ratio of the "plastic" to the initial tangent modulus

$b_j = \frac{\sigma_y}{E_{ij}}$, the ratio of the maximum plastic yield stress to the initial tangent modulus.

Similarly, for load level, k, the ratio of the secant modulus, E_k, to the initial tangent modulus, E_{ik}, is found using the same formula with the subscript k in place of j.

Step 2:

If E_k is the secant modulus at the standard load level and E_j is the secant modulus at some other load level, the desired modulus correction term is E_k/E_j. If it is assumed that the dimensionless constants a, b, and m do not vary with stress level, the desired correction term is given by:

$$\frac{E_k}{E_j} - \frac{E_{ik}}{E_{ij}} \quad \frac{a + \dfrac{(1-a)}{\left[1 + \left[\dfrac{(1-a)\epsilon_k}{b} \right]^m \right]^{1/m}}}{a + \dfrac{(1-a)}{\left[1 + \left[\dfrac{(1-a)\epsilon_k}{b} \right]^m \right]^{1/m}}}$$

This expression is a function of the dimensionless constants a, b, and m, the two strain levels ϵ_k and ϵ_j, and the ratio between the two initial tangent moduli, which is related to the confining pressure ratio as explained under Step 3. The strain, ϵ_k, is the strain under the standard load level and the strain, ϵ_j, is the strain under some other load level.

Typical values of the dimensionless constants a, b, and m are given in Table 4. They were calculated from published repeated load stress-strain curve data from Seed and Idriss (11) and Stokoe (12).

Type of Soil	Dimensionless Constants a	b	m	Source of Stress-Strain Curve Data
Fine Grained:	0.5290	0.0435	1.002	(11)
Granular:	0.0749	0.0261	0.915	(12)

Table 4

Dimensionless Constants for the Elasto-Plastic Hyperbolic Stress-Strain Curve

The constant, a, is the ratio of the plastic modulus, E_p, to the initial tangent modulus, E_i, and represents the strain-hardening characteristic of the material. From Table 4 it is apparent that both the fine-grained and granular soils exhibit a certain degree of strain-hardening.

<u>Step 3</u>:

Depending upon the type of material, the correction term for confining pressure may be greater or less than 1. The initial tangent modulus, E_i, is known to increase with confining pressure in granular materials and decrease with the deviator stress in fine-grained soils. In particular, with granular materials the equation for the initial tangent modulus, E_i, is either

$$E_i = K_1 \ (\theta)^{K_2}$$

where:

$\theta = \sigma_1 + \sigma_2 + \sigma_3$

$\sigma_1, \sigma_2, \sigma_3$ = principal stresses

K_1, K_2 = material properties

or another form of E_i is:

$E_i = K_3 \ (\sigma 3)^{K_4}$

σ_3 = the minimum principal stress

K_3, K_4 = material properties

For fine-grained soils, the initial tangent modulus decreases with the deviator stress, σ_d, according to the following equation:

$$E_i = K_5 \ (\sigma_d)^{K_6}$$

where:

σ_d = the deviator stress, $(\sigma_1 - \sigma_3)$

σ_1, σ_3 = the maximum and minimum principal stresses

K_5, K_6 - material properties. (The constant K_6 is usually negative.) Typical values of the constants K_1 through K_6 are given in Table 5. These typical values are taken from Reference (13). Values of these constants that are intermediate between the maximum and minimum values shown in the table may be assumed to vary linearly between these limits on a log-log scale.

One consequence of these corrections to the moduli is that if a granular material overlies a fine-grained subgrade, which is a fairly common case, an increase in load level will increase the modulus of the base course and, at the same time, decrease the modulus of the subgrade. This is illustrated in Figure 4. The net result is that the surface deflections may be nearly linear with load level. Thus, even in the load-to-deflection ratio is nearly linear with load level, that fact alone does not prove conclusively that the materials in the layers are in their linear range and their moduli need no correction for load level.

Procedure for Correction to Standard Load

The procedure to correct a modulus to a standard load level requires an iterative process in which the confining pressure (θ, σ_3, or σ_d) and strain level are calculated both for the standard load and for the other load level. Because the secant moduli under the other load level are known from the analysis of the NDT data, it is necessary only to assume a modulus for each layer under the standard loading condition in order to get the calculation process started. Then the confining pressures and strains can be calculated for both loading conditions and corrected layer moduli under the standard load can be calculated, using the material properties given in Table 5.

Table 5: Typical Values of Base Course and Subgrade Constants K_1 through K_6 (Moduli in kPa x 10^6)

Material		K_1	K_2	K_3	K_4	K_5	K_6
Crushed Stone	max			0.103	0.45		
	min			0.034	0.63		
Crushed Gravel	max	0.172	0.38				
	min	0.054	0.60				
Crushed Limestone	max	0.076	0.40				
	min	0.018	0.65				
Granitic Gneiss	max	0.234	0.19				
	min	0.010	0.73				
Basalt	max	0.061	0.47				
	min	0.032	0.65				
Sand	max			0.090	0.35		
	min			0.046	0.55		
Silty Sand	max	0.021	0.37				
	min	0.013	0.61				
Clayey Sand	max					0.172	-0.80
	min					--	--
Silty Clay	max					0.455	-0.38
	min					0.165	-0.11
Lean Clay	max					0.186	-0.50
	min					--	--
Highly Plastic Clay	max					0.172	-0.77
	min					--	--

(1 psi = 6.895 kPa)

If the new moduli are significantly different than those which were assumed, the calculation process is repeated using the new moduli until all calculated layer moduli are sufficiently close to those from which they were calculated. The most recently calculated moduli are the corrected values. Convergence of this process is fairly rapid, usually requiring no more than 3 to 5 iterations. This procedure was applied to the backcalculated moduli for the crushed limestone base as shown in Table 3.

A review of Table 3 indicates that only the crushed limestone base exhibited noticeable stress sensitivity. For this reason, application of the correction procedure was limited to the base. The formula used in correcting the moduli is a result of combining Steps 1, 2, and 3 above:

$$\frac{E_k}{E_j} = \frac{E_{ik}}{E_{ij}} = \left[\frac{(\sigma_1 + \sigma_2 + \sigma_3)_k}{(\sigma_1 + \sigma_2 + \sigma_3)_k}\right]^{k_2} \frac{a + \dfrac{(1-a)}{\left[1 + \left[\dfrac{(1-a)\epsilon_k}{b}\right]^m\right]^{1/m}}}{a + \dfrac{(1-a)}{\left[1 + \left[\dfrac{(1-a)\epsilon_k}{b}\right]^m\right]^{1/m}}}$$

with all variables the same as defined previously.

An attempt was made to use the K_2 values recommended in Table 5 for crushed limestone. Unsatisfactory results were obtained, however, and another means for obtaining K_2 was undertaken. This was accomplished by first applying Step 1. More specifically, the backcalculated moduli (secant moduli) were used in the formula presented under Step 1 for determining the initial tangent moduli. BISAR was then used in conjunction with the backcalculated moduli to calculate the bulk stresses at mid-depth of the base layer. Next, as shown in Figure 5, a log-log plot of initial tangent moduli versus bulk stress (Table 3) was made. A linear regression of the plotted data on Figure 5 permitted determination of K_2 and K_1.

The bulk stresses shown in Table 3 were calculated at mid-depth in the crushed limestone base, directly beneath the loaded area of the NDT devices

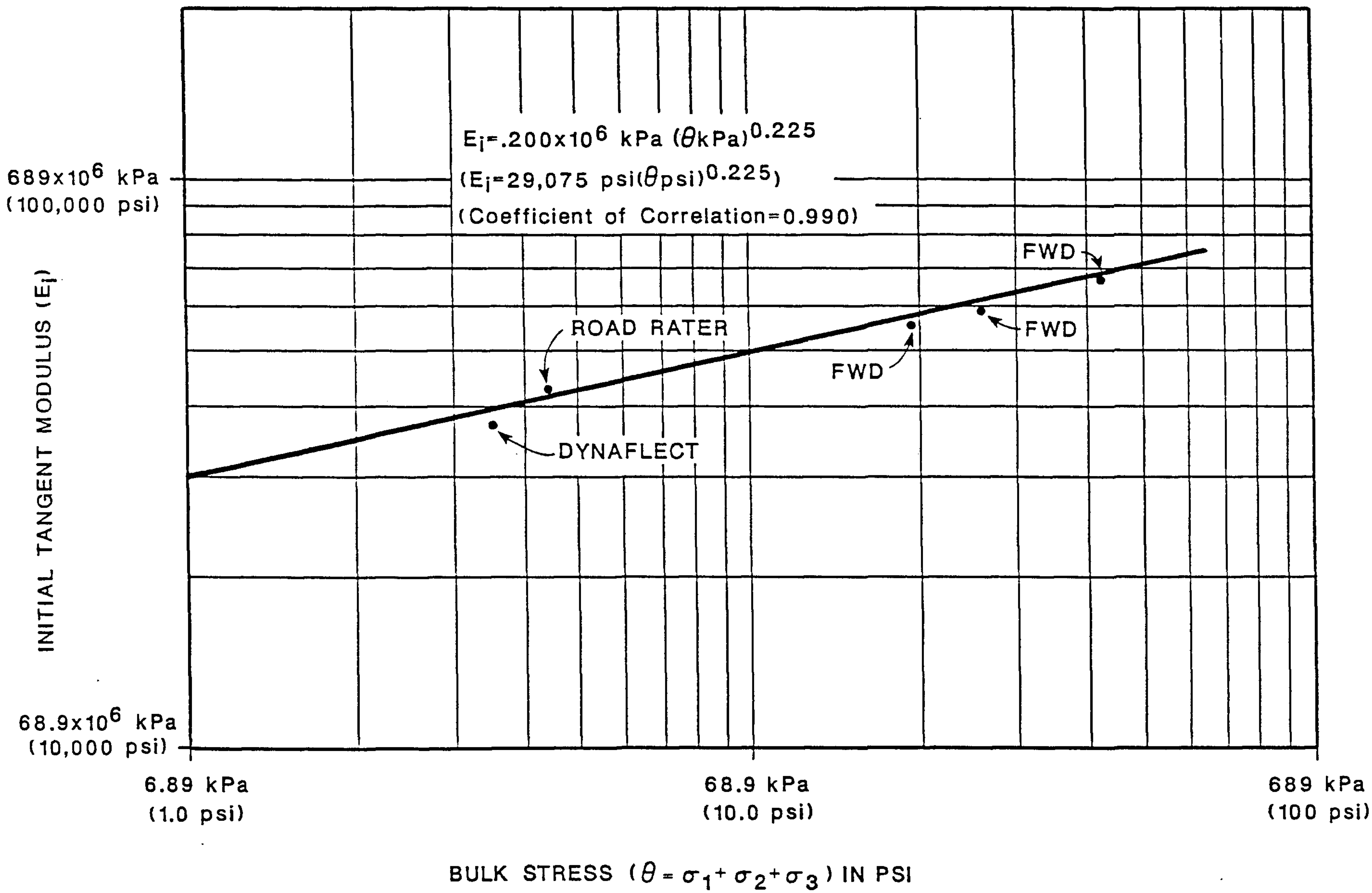

Figure 5: Resilient Modulus Backcalculated Versus Bulk Stress for Crushed Limestone.

The bulk stresses associated with the corrected moduli of the crushed limestone base are all reasonably similar as are the vertical strains (not shown) calculated at the same location as the bulk stresses. Because of this similarity of bulk stresses and vertical strains, the corrected crushed limestone base moduli are also quite similar for the various NDT devices (or loads) used.

SUMMARY AND CONCLUSIONS

The correction procedure to adjust moduli at one load level to the standard load level should be undertaken after the asphaltic concrete modulus has been corrected to standard temperature and loading frequency. The corrected value of the asphaltic concrete modulus should be used in all subsequent calculations. The load correction procedure for moduli presented in this report provides for two corrections to be made: one for strain level and one for confining pressure. Each base or subgrade material for which a corrected modulus is sought is assumed to be an elasto-plastic strain hardening material which obeys a general hyperbolic stress-strain curve.

If the material properties a, b, m, and K_1 through K_6 presented above are considered not to be representative of the actual material, or if it is essential to know precisely what these properties are for the material, cores should be taken and triaxial stress-strain tests should be made on the material to determine these material properties. The correction procedure for load level can then be used with these experimentally determined properties.

In lieu of triaxial tests, consideration could be given to utilizing different NDT devices, or NDT devices capable of applying several load levels, for obtaining material properties K_1 through K_6 as done here. As for material properties a, b, and m, these values are not as significant as the K_i (K_1 through K_6) values. In other words, the correction for confining pressure which utilizes the K_i values is more effective than the correction for strain level which utilizes a, b, and m. For example, the strain correction term is typically close to unity whereas the confining pressure correction term is not. This emphasizes that the K_i values are more crucial than the a, b, and m values.

Referring now to the temperature and loading frequency correction for asphaltic concrete, it was shown that the error of this correction procedure is reasonably close to the error associated with the Witczak Modified $|E^*|$ Equation (WME). Recall that the temperature and loading frequency correction formula is based on the WME. Improvements to the correction formula would, therefore, have to occur through the WME. For example, better results may result by establishing correlations such as the WME for particular mix designs instead of grouping them all together as was done in developing the WME.

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APPENDIX

Deflection Data

Dynatest FWD: Loading Plate Radius = 15cm (5.91 inches)

Loading Plate pressure = 421 kPa (61.1 psi):

Sensor	Sensor Spacing	Measured Deflection	Calculated Deflection	Percent Difference
1	0cm (0 inches)	0.319mm (12.54 mils)	0.325mm (12.80 mils)	-2.09
2	30cm (12 inches)	0.122mm (4.79 mils)	0.113mm (4.46 mils)	6.81
3	61cm (24 inches)	0.063mm (2.48 mils	0.066mm (2.59 mils)	-4.38
4	91cm (36 inches)	0.045mm (1.79 mils)	0.046mm (1.82 mils)	-1.83
5	122cm (48 inches)	0.036mm (1.42 mils)	0.036mm (1.40 mils)	1.66
6	152cm (60 inches)	0.028mm (1.12 mils)	0.029mm (1.13 mils)	-.77
7	183cm (72 inches)	0.024mm (0.96 mils)	0.024mm (0.95 mils)	1.41

Sum of the Absolute % Differences: 19.0

Loading Plate Pressure = 586 kPa (85.1 psi):

Sensor	Sensor Spacing	Measured Deflection	Calculated Deflection	Percent Difference
1	0cm (0 inches)	0.432mm (17.00 mils)	0.443mm (17.45 mils)	-2.54
2	30cm (12 inches)	0.179mm (7.04 mils)	0.164mm (6.44 mils)	8.46
3	61cm (24 inches)	0.094mm (3.69 mils)	0.097mm (3.81 mils)	-3.36
4	91cm (36 inches)	0.065mm (2.55 mils)	0.068mm (2.67 mils)	-4.81
5	122cm (48 inches)	0.053mm (2.07 mils)	0.052mm (2.03 mils)	2.03
6	152cm (60 inches)	0.041mm (1.60 mils)	0.041mm (1.63 mils)	-1.58
7	183cm (72 inches)	0.036mm (1.40 mils)	0.034mm (1.35 mils)	3.24

Sum of the Absolute % Differences: 26.1

Loading Plate Pressure = 966 kPa (140.1 psi):

Sensor	Sensor Spacing	Measured Deflection	Calculated Deflection	Percent Difference
1	0cm (0 inches)	0.637mm (25.09 mils)	0.658mm (25.90 mils)	-3.21
2	30cm (12 inches)	0.280mm (11.04 mils)	0.252mm (9.91 mils)	10.22
3	61cm (24 inches)	0.146mm (5.75 mils)	0.151mm (5.94 mils)	-3.23
4	91cm (36 inches)	0.100mm (3.92 mils)	0.105mm (4.15 mils)	-5.75
5	122cm (48 inches)	0.080mm (3.13 mils)	0.079mm (3.12 mils)	.16
6	152cm (60 inches)	0.064mm (2.50 mils)	0.063mm (2.49 mils)	.43
7	183cm (72 inches)	0.054mm (2.13 mils)	0.053mm (2.07 mils)	3.02

Sum of the Absolute % Differences: 26

Road Rater 2000: Loading Plate Radius = 22.9cm (9.00 inches); Frequency = 10.2 Hertz

Sensor	Sensor Spacing	Measured Deflection	Calculated Deflection	Percent Difference
1	0cm (0 inches)	0.081mm (3.20 mils)	0.082mm (3.22 mils)	-0.51
2	30cm (12 inches)	0.041mm (1.63 mils)	0.041mm (1.61 mils)	1.10
3	61cm (24 inches)	0.023mm (0.89 mils)	0.023mm (0.90 mils)	-1.08
4	91cm (36 inches)	0.017mm (0.66 mils)	0.017mm (0.66 mils)	0.59

Sum of the Absolute % Differences: 3.27%

Dynaflect: Loaded Radius = 4.1cm (1.6 inches; Frequency = 8 Hertz:

Sensor	Sensor Spacing	Measured Deflection	Calculated Deflection	Percent Difference
1	25cm (10 inches)	0.208mm (.82 mils)	0.208mm (.82 mils)	-0.19
2	40cm (15.6 inches)	0.014mm (.55 mils)	0.014mm (.55 mils)	0.57
3	66cm (26 inches)	0.009mm (.35 mils)	0.009mm (.35 mils)	-0.68
4	95cm (37.4 inches)	0.007mm (.26 mils)	0.007mm (.26 mils)	0.32

Sum of the Absolute % Differences: 1.75