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TEMPERATURE ADJUSTMENT FACTORS FOR FALLING WEIGHT DEFLECTOMETER DEFECTIONS ON FULL DEPTH ASPHALT CONCRETE PAVEMENTS

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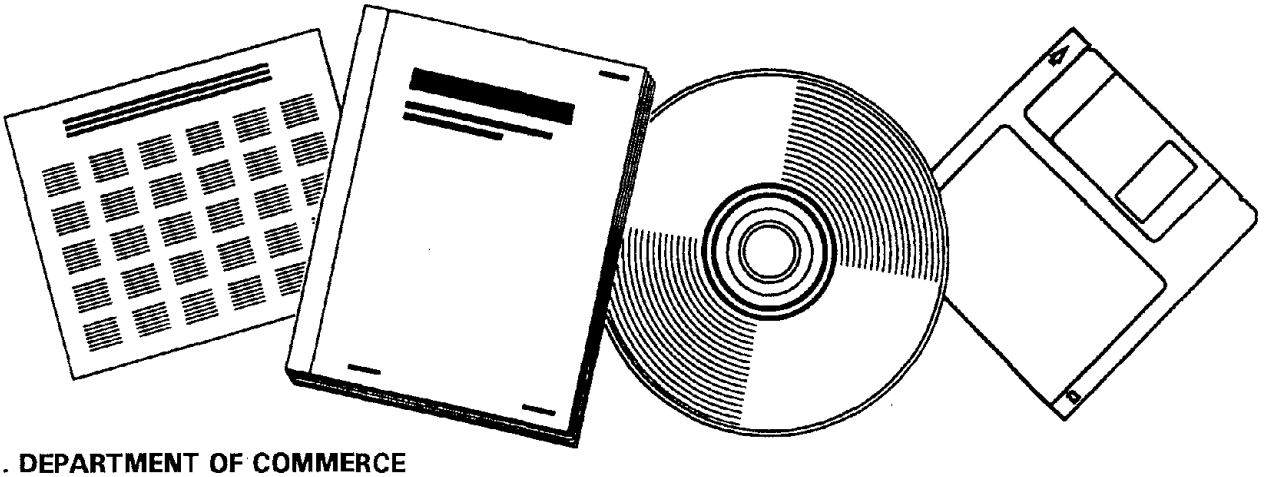

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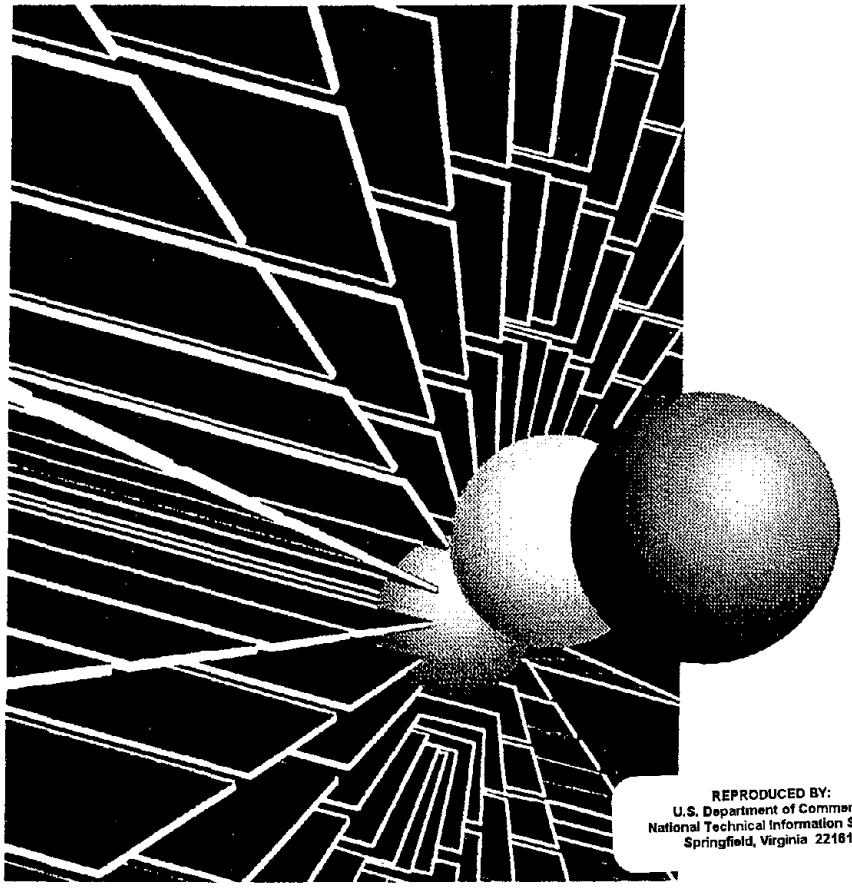
Temperature Adjustment Factors for Falling Weight Deflectometer Deflections on Full Depth Asphalt Concrete Pavements

Final Report



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16. Abstract

A convenient way to gauge the structural capacity of a pavement is to compute the structural number (SN). To make the structural capacity of various pavements comparable to each other, the structural number, and therefore the Falling Weight Deflectometer (FWD) measured deflections that the SN is based on, must be corrected to a common temperature (68° Fahrenheit).

In the following Research Investigation report, a Temperature Adjustment Factor curve (Temperature Adjustment Factor vs. Average Asphalt Concrete Mix Temperature) was developed in order to correct FWD deflections to 68°F. Also included in this report is the comparison of different methods used to determine the strength moduli of the pavement (E_p), asphalt concrete (E_{ac}), and the subgrade resilient modulus (M_r).

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RESEARCH INVESTIGATION 91-9

TEMPERATURE ADJUSTMENT FACTORS FOR FALLING WEIGHT DEFLECTOMETER DEFLECTIONS ON FULL DEPTH ASPHALT CONCRETE PAVEMENTS

PREPARED BY
MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY DIVISION

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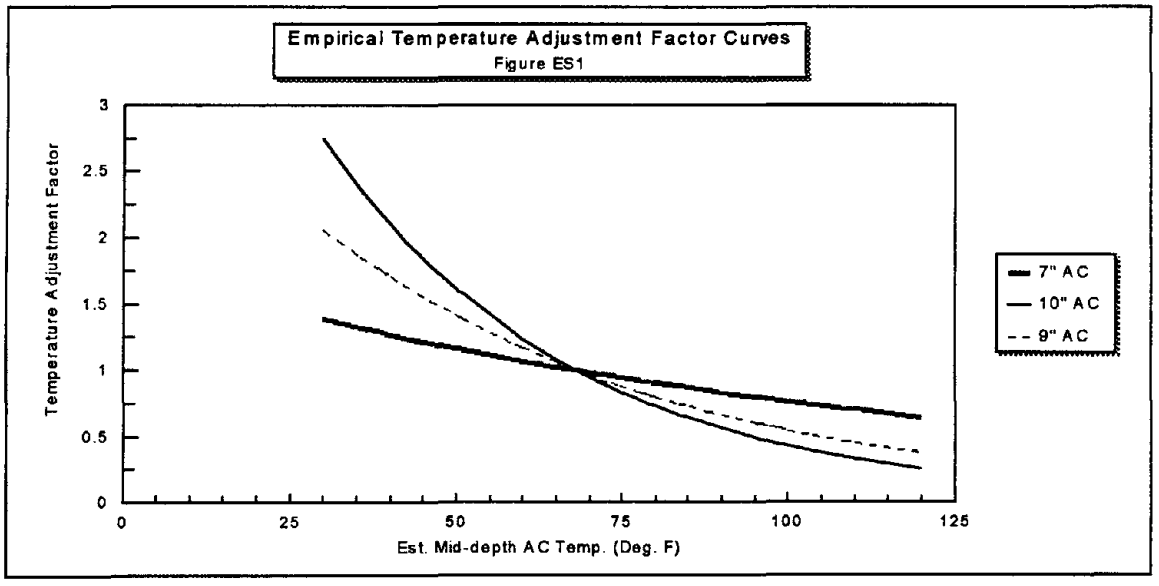
JEFFERSON CITY, MISSOURI
DATE SUBMITTED: NOVEMBER 10, 1994

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

EXECUTIVE SUMMARY

The Missouri Department of Transportation is currently considering ways to measure the structural capacity of a pavement through analyzing Falling Weight Deflectometer (FWD) deflection data. The structural capacity (or structural number) of various asphaltic concrete (AC) pavements can be compared only if the measured deflections are corrected to a standard temperature. The American Association of Highway Transportation Officials (AASHTO) recommends this temperature to be 68° F.

In Research Investigation (RI) 91-9, Temperature Adjustment Factor (TAF) curves (Temperature Adjustment Factor vs. Average Asphalt Concrete Mix Temperature) were developed based upon actual measured deflections and estimated mid-depth asphalt concrete temperatures. As a comparison, another set of Temperature Adjustment Factor curves were developed based upon theoretical deflections and assigned mid-depth AC temperatures. The empirical Temperature Adjustment Factor curves, which were developed by true deflections, are the curves recommended for MoDOT use on Falling Weight Deflectometer measurements. They can be found in Figure ES1 below.



With the above recommended TAF curve, a Falling Weight Deflectometer deflection value measured at T degrees can be multiplied by the temperature adjustment factor to get the equivalent deflection at 68° F. These equivocated deflections can then be used to calculate the structural number (SN) of a pavement which can be compared successfully to SN values of other pavements which have also been corrected to 68° F.

Also included in this Research Investigation report is a comparison of the methods used to find the strength moduli of a pavement (E_p), asphaltic concrete (E_{ac}), and the resilient modulus of the subgrade (M_r). No specific conclusions were made because laboratory data that would substantiate one method over the other was not available.

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Appendix D - Data and Graphs Relating to the Comparison of Methods Used to Find Layer Strength Moduli

LIST OF ABBREVIATIONS

a = non-destructive testing device load plate radius
a_e = effective radius of stress bulb induced in soil
AASHTO = American Association of State Highway and Transportation Officials
AC = asphalt concrete
AI = Asphalt Institute
d_0 = deflection measured at radius of 0 from applied load
D = total thickness of pavement layers above subgrade
D_r = deflection at distance r from applied load
E_{ac} = elastic modulus of asphalt concrete
E_b = strength modulus of base layer
E_p = elastic modulus of total pavement
F = loading frequency
FWD = Falling Weight Deflectometer
h_{ac} = height of asphalt concrete
h_b = height of base layer
$h_{equivalent} = h_{Ep}$ = equivalent asphalt concrete height of base and original AC layer
MoDOT = Missouri Department of Transportation
M_r = resilient modulus of subgrade layer
MTxx = monthly testing site
$n_{70\ degrees,\ 10^6}$ = absolute viscosity at 70 degrees F, in 10^6 poises
NDT = non-destructive testing
p = non-destructive testing device load plate pressure
P_{ac} = asphalt content, percent by weight of mix
P_{200} = percent aggregate passing No. 200 sieve
RI = Research Investigation
RIMS = Regional Information Management System
SHRP = Strategic Highway Research Program
SN = structural number
SPS = Special Pavement Study
t_p = asphalt concrete mix temperature
T = temperature in degrees Fahrenheit
TAF = Temperature Adjustment Factor
u = Poisson's ratio
V_v = percent air voids
z = depth below pavement surface

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ABSTRACT

A convenient way to gauge the structural capacity of a pavement is to compute the structural number (SN). To make the structural capacity of various pavements comparable to each other, the structural number, and therefore the Falling Weight Deflectometer (FWD) measured deflections that the SN is based on, must be corrected to a common temperature (68° Fahrenheit).

In this Research Investigation report, a Temperature Adjustment Factor curve (Temperature Adjustment Factor vs. Average Asphalt Concrete Mix Temperature) was developed in order to correct FWD deflections to 68° F. Also included in the report is the comparison of different methods used to determine the strength moduli of the pavement (E_p), asphalt concrete (E_{ac}), and the subgrade resilient modulus (M_r).

OBJECTIVE

The objective of Research Investigation (RI) 91-9 is to adjust the deflections measured by the Falling Weight Deflectometer (FWD) on full-depth asphalt concrete pavements to a reference temperature of 68 degrees Fahrenheit as suggested by the American Association of State Highway and Transportation Officials (AASHTO). By establishing a Temperature Adjustment Factor curve (Temperature Adjustment Factor vs. Average Asphalt Concrete (AC) Mix Temperature), the structural number (SN) can be corrected to predict the structural capacity at 68 degrees Fahrenheit. Also, the correlation between load deflection and structural capacity of pavement will be improved using both classical theory and empirical relationships based on data analysis. *(1)*

There are several justifications for conducting an investigation to produce the aforementioned Temperature Adjustment Factor (TAF) curve for measured FWD deflections.

AASHTO states, "For purposes of comparison of E_p [pavement Elastic Modulus] along the length of a project, the d_0 [FWD deflection] values used to determine E_p should be adjusted to a single reference temperature." *(2)*

In the Strategic Highway Research Program (SHRP) Procedure for Temperature Correction of Maximum Deflections, it states, "Because of the temperature-dependent nature of the asphalt concrete modulus,..., measured deflections and hence structural capacity (or SN value) of the pavement will also vary with temperature. Thus, a procedure to correct the measured maximum deflection to a standard temperature is a valid one. Also, since the AASHTO structural number or SN value is computed at a standard temperature of 68 F, maximum deflection measured in the field must be corrected to this standard temperature." *(3)*

INTRODUCTION

In analyzing a Falling Weight Deflectometer deflection data set, the most straightforward interpretation of the information is to use the mean deflection value (normalized to a constant 9 kip equivalent load drop) for a given pavement. The mean pavement temperature for a given asphalt thickness should therefore be used in establishing a Temperature Adjustment Factor curve for correcting the FWD deflection data to a reference temperature. (In the context of our usage, "mean" is defined as the average throughout all depths of the AC pavement.) Ideally, to create an empirical Temperature Adjustment Factor curve, the true mid-depth temperature at the time of deflection data collection should be the most accurate mean temperature value. However, the exact mid-depth pavement temperature was not collected at each site as a part of this investigation, so another method of mid-depth temperature estimation had to be used.

In 1968, H.F. Southgate established a relationship between pavement surface temperature plus previous 5 day average air temperature and the temperature at a designated depth within asphalt pavement. *(1)* As a part of Research Investigation 91-9, Southgate's method was employed to create regression equations of our own, using MoDOT field temperature data from Monthly Testing Sites 1-9 (MT1-MT9) and Special Pavement Study 6 (SPS-6) test sites. Because of our now established correlation between surface temperature of AC plus previous 5 day average air temperature and temperature at a pavement depth., both the mean deflection and the estimated mid-depth pavement temperature were known for different MoDOT test sites. (For our purposes, we wanted to find the mean pavement temperature which was approximated as the mid-depth pavement temperature.) Thus, the proper parameters had been defined to create a Temperature Adjustment Factor curve using FWD deflection data. Of all the test sites, MT 1-3 were the only full depth AC pavements, so they became the focus from this point on in the investigation.

In order to establish a comparison to MoDOT's Temperature Adjustment Factor curve based on empirical data discussed above, another such curve was generated based on theoretical information. The deflection equation, derived by Boussinesq andOdemark presented in the 1993 AASHTO Design of Pavement Structures *(2)* was used to generate theoretical deflection data and create another Temperature Adjustment Factor curve. It is as follows:

$$d_0 = 1.5pa\left\{\frac{1}{M_R\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_P}{M_R}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right]}{E_P}\right\}$$

The above equation will be discussed in depth in the following section, **INVESTIGATION PROCEDURE**, but some terms need some clarification at this point. Since the actual deflection data from MT1-MT3 (which was employed along with estimated mean AC mix temperatures to produce the empirical TAF curves) is a function of the subgrade resilient modulus and the pavement modulus of elasticity, these two components had to be varied in the theoretical procedure. To simulate the varying subgrade conditions due to seasonal changes and different site locations, the resilient modulus of the subgrade (M_r) required in the equation was evenly varied from 10,000 psi to 35,000 psi in 5000 psi increments to yield theoretical deflection data. However, the deflection information used in the TAF curve was averaged over all the M_r values to create the same methodology used in the empirical TAF, one with all of the various subgrades considered.

The effective pavement Modulus of Elasticity (E_p) used in the Odemark equation was a little more difficult to estimate since it depicts the material characteristics of the AC layer and the base layer combined. We calculated empirical E_{ac} (modulus of elasticity of asphalt concrete) values using the Asphalt Institute AC Elastic Modulus regression equation *(2)* using MoDOT typical mix properties and evenly varied AC mix temperature values as input variables. We did not, however, have access to a method that estimated a modulus strength value for the whole pavement structure, (E_p), versus varying temperatures. Therefore, the pavement modulus strength was approximated by using Odemark's transformed section equation to change the depth and strength of the base into an equivalent thickness of AC. This E_p is then equal to E_{ac} and the depth, D is the equivalent of h_{ac}. This procedure is discussed in depth in the following section, **INVESTIGATION PROCEDURE.**

Finally, some comparisons were made between different methods used to find E_p, E_{ac} and M_r. By using the FWD deflection data, the MODULUS software program was run three ways: 1) as a 2 layer system (AC height plus base height considered one layer of pavement, and subgrade), 2) as a 3 layer system (AC pavement, base and subgrade) and 3) as a 4 layer system (AC pavement, base, first 36" of subgrade, and remaining subgrade). (MODULUS is a pavement layer strength backcalculation program that utilizes inputted FWD deflection data to estimate an appropriate deflection bowl for the data set.) The first MODULUS run yielded values for E_p and M_r which were compared to manually backcalculated solutions using the AASHTO guide section *Determination of Subgrade Modulus for SNeff Determination (2).* The second and third runs both yielded values for E_{ac} but the third run had the least absolute error, therefore, it was compared to the Asphalt Institute AC Modulus regression equation results.

INVESTIGATION PROCEDURE

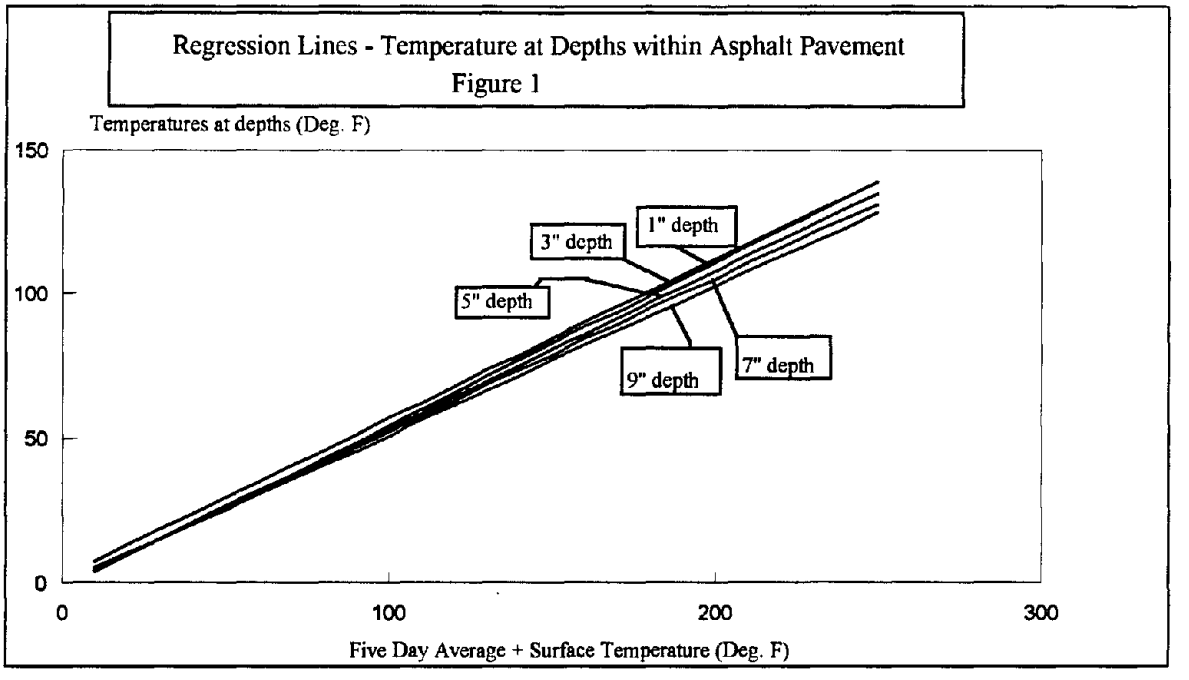
Empirical Temperature Adjustment Factor Curve

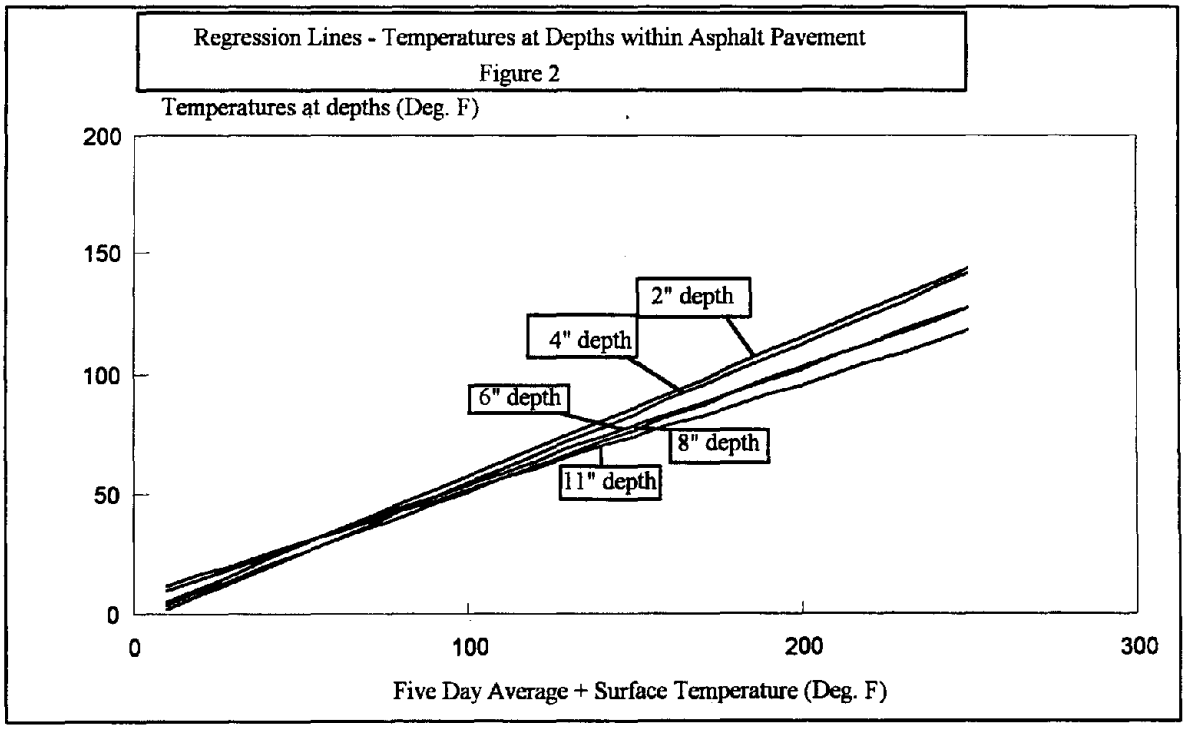
The first step in creating a Temperature Adjustment Factor curve is to establish a method to estimate the mid-depth or mean temperature of a given pavement. Field data was collected at nine monthly testing sites (MT1-MT9) as well as at SHRP site SPS-6. The data included: FWD deflection data sets, asphalt surface temperature, asphalt temperature at various (pre-determined) pavement depths, ambient air temperature at time of collection, and date of data collection (see Appendix A, pages A1-A19 for actual data). The high and low temperatures for the five days previous to data collection (for five day ambient air temperature average) were taken from National Weather Station data closest to each site.

As in Southgate's study *(1)*, MoDOT wanted to verify a relationship between Five Day Ambient Air Temperature Average + Asphalt Surface Temperature versus Temperature At a Designated Depth. This way, if the asphalt surface temperature and five day average temperature were known at a site, one could use the association determined to estimate the temperature at pavement mid-depth without drilling holes and manually measuring the temperature. With this relationship, a significant savings of time, money and manpower could be realized if the FWD is used for inventory purposes. Regression equations were found for the 1, 2, 3, 4, 5, 6, 7, 8, 9, and 11 inch depth plots and can be seen in Figures 1 and 2 on the next page (see Appendix A, pages A20-A32 for a full page view of each graph as well as the calculated regression equations).

In this study, Southgate states, "...analysis of the standard error of estimate [of pavement depth temperatures] showed that the five-day average air-temperature history sufficed for all depths greater than 2 inches. The least standard errors of estimate for the depths 0 inches through 2 inches indicated that the best estimate was obtained by the use

of the surface temperature alone. Pavement temperatures in the top 2 inches of the pave





ment are directly dependent upon the hour of the day and the amount of heat absorption whereas, temperatures at depths greater than 2 inches are assumed to be a function of the surface temperature, amount of heat absorption, and the past five days of temperature history." *(1)* This information was very useful to us in analysis of the SPS-6 data. For this site, the surface temperature readings were absent but the temperature was taken at the 1 inch depth and beyond. The SPS-6 data was essential to this portion of the investigation because it contained the majority of the various measured pavement depth temperatures, as can be seen in Appendix A. We felt that it couldn't be thrown out or disregarded in spite of the missing information. Instead, because of Southgate's conclusions previously discussed, the measured 1 inch depth temperature was used for the surface temperature reading as well as for the 1 inch depth temperature reading.

Southgate takes into consideration the different times of the day and had sufficient data to compose graphs showing pavement depth temperature relationships at certain hours of the day. This was another variance in our replication of his study because the data used in RI 91-9 was taken at different times of the day. Because of this fact, it is hard to directly compare the results of Southgate's study to the regression equations found in the relationships established by the RI 91-9 data. However, a general comparison can be made: all of the regression equations are fit to a linear relationship with a positive slope less than or very close to one.

Now, for each FWD deflection data set, the estimated mid-depth temperature of the pavement tested may be read off of the Five Day Air Temperature Average + Asphalt Surface Temperature versus Temperature at Pavement Depth graphs by using the appropriate mid-depth line. For example, if a section of pavement is 10 inches thick, the mid-depth temperature can be found on the 5 inch depth regression line. The temperature at 5 inches, or mid-depth will be read on the y-axis corresponding to the added temperature of the asphalt surface and the five day air average found on the x-axis.

In Table 1 below, the average measured FWD deflections and their estimated mid-depth temperatures can be found. The deflection measured directly underneath the Falling Weight Deflectometer load plate at a radius of zero is designated by d_0.

TABLE 1: Estimated Mid-depth AC temperature and actual FWD d_0 deflection (at the time of testing). These FWD d_0 deflections include the varying subgrade M_r conditions and values.

Site No.	Date Tested	5-day+surf. temperature (Deg. F)	Est. mid-depth temp. (Deg. F)	Measured FWD d_0 (mils)
MT1-1002	6-06-91	163	90.0	10.26
MT1-1002	7-05-91	187	103.5	13.53
MT1-1002	9-05-91	159	87.8	8.73
MT1-1002	10-03-91	136	74.8	8.01
MT1-1002	11-12-91	78	42.1	6.74
MT1-1002	2-11-92	72	38.7	6.73
MT1-1002	3-19-92	92	50.0	8
MT1-1002	5-18-92	142	78.2	8.72
MT2-1008	3-26-91	140	73.3	7.08
MT2-1008	4-24-91	137	71.9	7.8
MT2-1008	5-30-91	164	85.1	11.7
MT2-1008	6-25-91	189	97.3	15.92
MT2-1008	7-22-91	212	108.6	21.97
MT2-1008	9-04-91	152	79.2	7.84
MT2-1008	10-01-91	148	77.2	6.96
MT2-1008	1-28-92	94	50.8	4.25
MT2-1008	3-24-92	92	49.8	4.89
MT2-1008	5-20-92	161	83.6	8.39
MT3-606	6-04-91	181	95.3	23.68
MT3-606	7-02-91	187	98.4	20.81
MT3-606	7-30-91	182	95.8	19.4
MT3-606	9-10-91	151	79.4	11.35
MT3-606	10-09-91	112	58.8	7.77
MT3-606	11-05-91	68	35.6	6.54
MT3-606	1-30-92	88	46.1	7.87
MT3-606	3-31-92	96	50.4	9.49
MT3-606	5-27-92	123	64.6	11.64

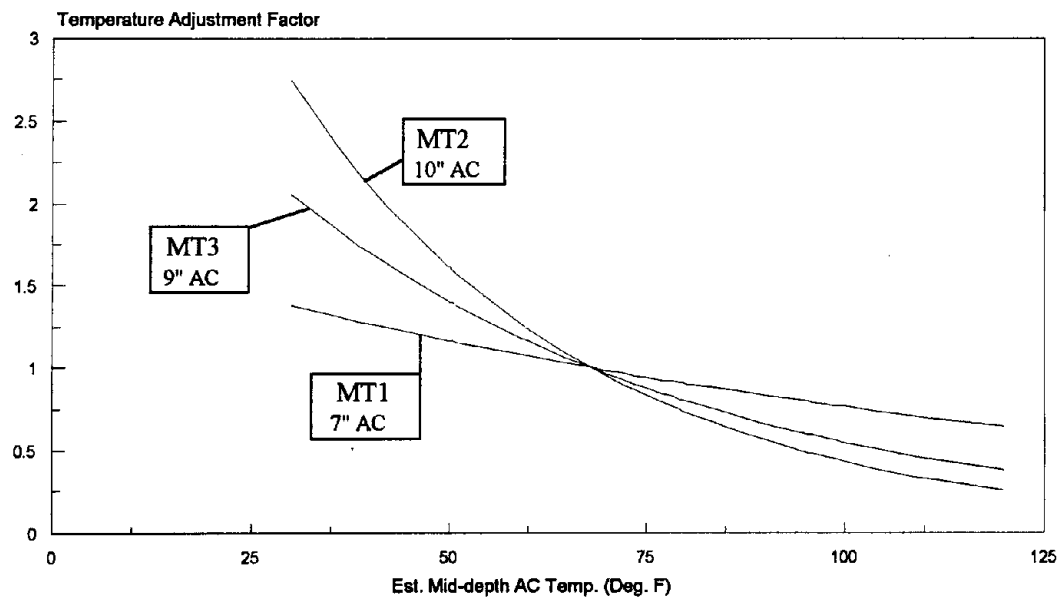
In order to find the Temperature Adjustment Factors from the above data, a best

fit exponential line was determined for each deflection versus estimated mid-depth temperature series (see Appendix B, pages B1-B4). Next, deflection values were predicted by these curve equations for temperatures at even intervals ranging from 30 degrees Fahrenheit to 120 degrees Fahrenheit (see Appendix B, page B5). Finally, the ratio of the deflection value at 68 degrees Fahrenheit to the deflection value at the varying temperatures produced the TAF curves found in Figure 3 below (for a full page view of Figure 3, see Appendix B, page B6). In summary,

$$TAF = \frac{d_{0_{68}}}{d_{0_T}}$$

where T is the temperature in degrees Fahrenheit that the deflection is being adjusted from (to 68 degrees Fahrenheit).

Empirical Temperature Adjustment Factor Curves
Figure 3



Theoretical Temperature Adjustment Factor Curve

To serve as a comparison to the empirical TAF curve above, a theoretical Temperature Adjustment Factor curve will now be developed.

As discussed earlier, deflection data was generated by using the Odemark approximate method for determining deflection in a two layer system. It is a combination of Boussinesq's one-layer equation and the concept of "equivalent thickness" described in 1940 by Barber. The deflection measured at the surface at the center of loading is assumed to be the sum of the subgrade and pavement deflections *(2)* and can be computed as follows:

$$d_0 = 1.5pa\left\{\frac{1}{M_R\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_P}{M_R}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right]}{E_P}\right\}$$

where:

d_0 = deflection measured at the center of the FWD load plate (inches)
p = NDT load plate pressure (psi)
a = NDT load plate radius (inches)
D = total thickness of the pavement layers (AC and base layers) above the subgrade, (inches)
M_r = subgrade resilient modulus (psi), and
E_p = effective Modulus of all pavement layers above the subgrade (psi).

In order to get deflection values that are representative of the empirical data and TAF curve, several of the values in the Odemark-Boussinesq equation were varied. All of the generated information was then averaged by calculating a regression equation over all the theoretical TAF data points.

The first step was to vary the resilient modulus of the subgrade (M_r) from 10 ksi to 35 ksi, which were the estimated low and high limits for the subgrades tested.

As previously mentioned, estimating values for E_p was a little more involved. Because of the Asphalt Institute Elastic Modulus Regression equation as found in the

1993 AASHTO Design of Pavement Structures *(2)*, temperature dependent values of E_{ac} were known. Average mix properties were inserted, where values were needed, yielding the equation below. Below is the Asphalt Institute Equation and a list of the mix properties that were used.

$$\log E_{ac} = 5.553833 + 0.028829\left(\frac{P_{200}}{F^{0.17033}}\right) - 0.03476V_v$$
$$+0.070377 n_{70\,\mathrm{deg}\,rees\,F,10^6} + 0.000005 t_p^{(1.3+0.49825\log F)} P_{ac}^{0.5}$$
$$+0.931757\left(\frac{1}{F^{0.02774}}\right)$$

where:
E_{ac} = elastic modulus of AC, psi (unknown)
P_{200} = percent aggregate passing the No. 200 sieve,(6%)
F = loading frequency, (18 Hz)
V_V = air voids, percent, (5%)
$n_{70degrees,10^6}$ = absolute viscosity at 70 degrees F, 10^6 poise, (2)
P_{ac} = asphalt content, percent by weight of mix, (6%)
t_p = AC mix temperature, degrees F (varied)

After inserting these mix properties, the resulting equation is as follows:

$$\log|E| = 6.486476 - 1.8038865*10^{-4} * t_p^{1.92544}$$

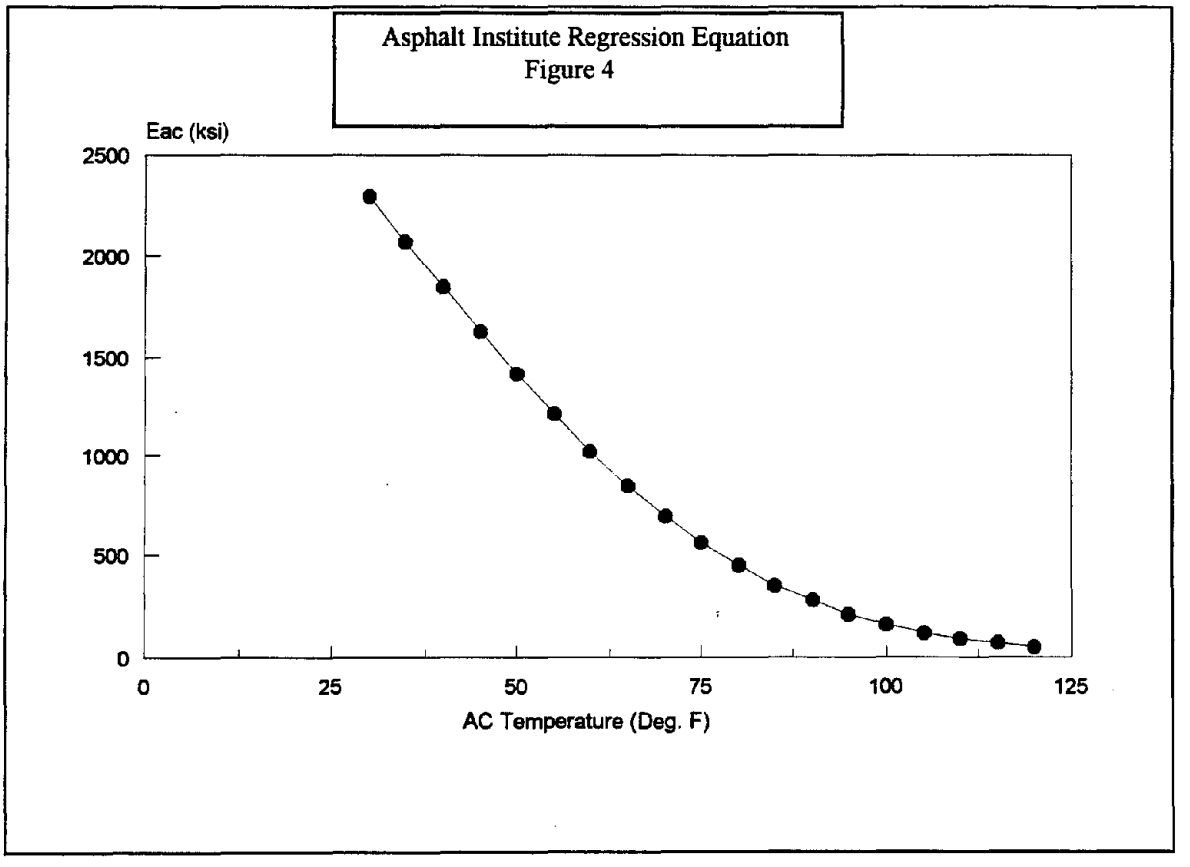
The calculated E_{ac} results from varying temperatures can be found in Table 2.
A graphical representation of the data from the resulting equation above can be found in Figure 4 on the next page. It can be easily seen from this graph that asphalt pavement strength is indeed temperature dependent.

Since the E_{ac} over the normal temperature range is now estimated, and the Odemark-Boussineq deflection equation requires E_p, a relationship between E_p and

TABLE 2: Estimated Mid-depth Temperature vs. Modulus of Elasticity for Asphalt Concrete

tp (deg. F)	Eac (psi)
30	2.293E+06
35	2.075E+06
40	1.850E+06
45	1.627E+06
50	1.411E+06
55	1.207E+06
60	1.018E+06
65	8.476E+05
70	6.959E+05

tp (deg. F)	Eac (psi)
75	5.637E+05
80	4.506E+05
85	3.554E+05
90	2.766E+05
95	2.124E+05
100	1.610E+05
105	1.204E+05
110	8.893E+04
115	6.482E+04
120	4.663E+04



E_{ac} must be established. E_p is defined as the strength modulus of the overall pavement structure while E_{ac} is the strength modulus of the asphalt only.

The E_{ac} values found by the Asphalt Institute Regression Equation may be used as an estimate of E_p if the base is transformed into an equivalent height of asphalt. The following equation is used to determine an equivalent thickness of asphalt (e.g., transforming the base height to an AC height) whose strength is equal to the strength exhibited by E_{ac} and E_b (the strength modulus of the base) combined:

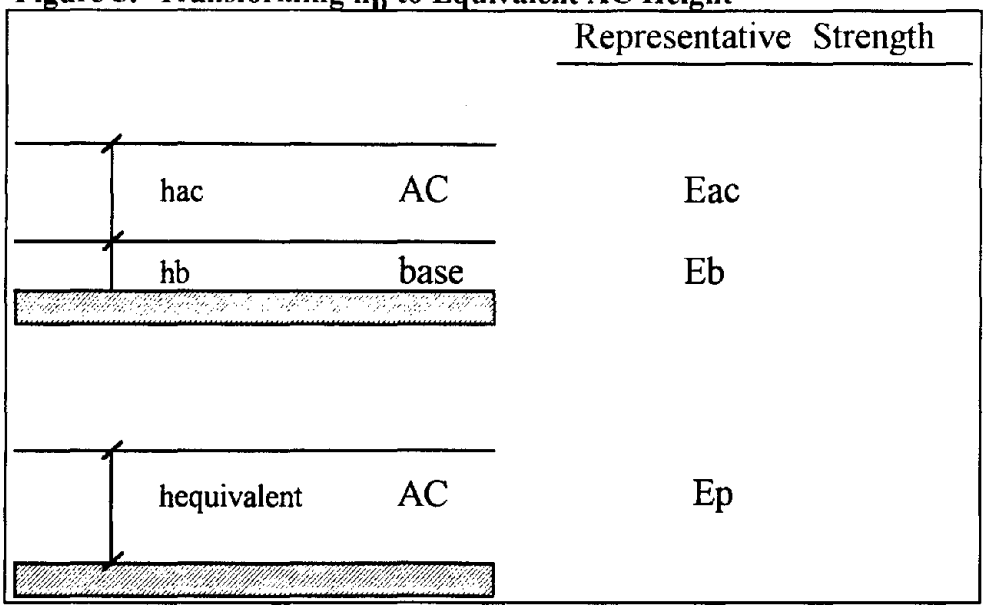
$$h_{equivalent} = h_b * \sqrt[3]{\frac{E_b}{E_{ac}}} + h_{ac}$$

The above equation is based on the concept of equivalent thickness as described in 1986 AASHTO Guide for Design of Pavement Structures *(4)*. The design guide develops the interrelationship between layer coefficients and elastic moduli. In finding an equivalent thickness, the Poisson's ratio was assumed to be equal for both layers, and therefore, cancels out. (See sample calculations in Appendix C, pages C1 and C2).

The base heights for Monthly Testing sites 1-3 were all approximately 4 inches, therefore, in the above equivalent height equation, $h_b = 4$ inches. The average E_b found by the MODULUS program for the three testing sites was 60 ksi with a standard deviation of around 30 ksi. The three values of 30 ksi, 60 ksi and 90 ksi were used for E_b because of the high deviation value. The height of the asphalt pavement, h_{ac}, was modified in increments of 2 inches from 2 inches up to 12 inches in order to represent the spectrum of possible asphalt thicknesses in pavements. (See tabulated form of results in Appendix C, pages C3-C20.) Again, the deflection information generated by these values being varied was averaged by calculating a regression equation over all TAF data points produced.

The diagram in Figure 5 on the next page is an effort to make the equivalent height procedure more clear. Because the calculated AC equivalent height is representative of the strength of E_p at a particular temperature, it can be used in the Odemark-Boussinesq equation as "D", the total depth of the pavement, while the corresponding value of E_{ac} at that temperature is used in place of E_p

Figure 5: Transforming h_b to Equivalent AC Height



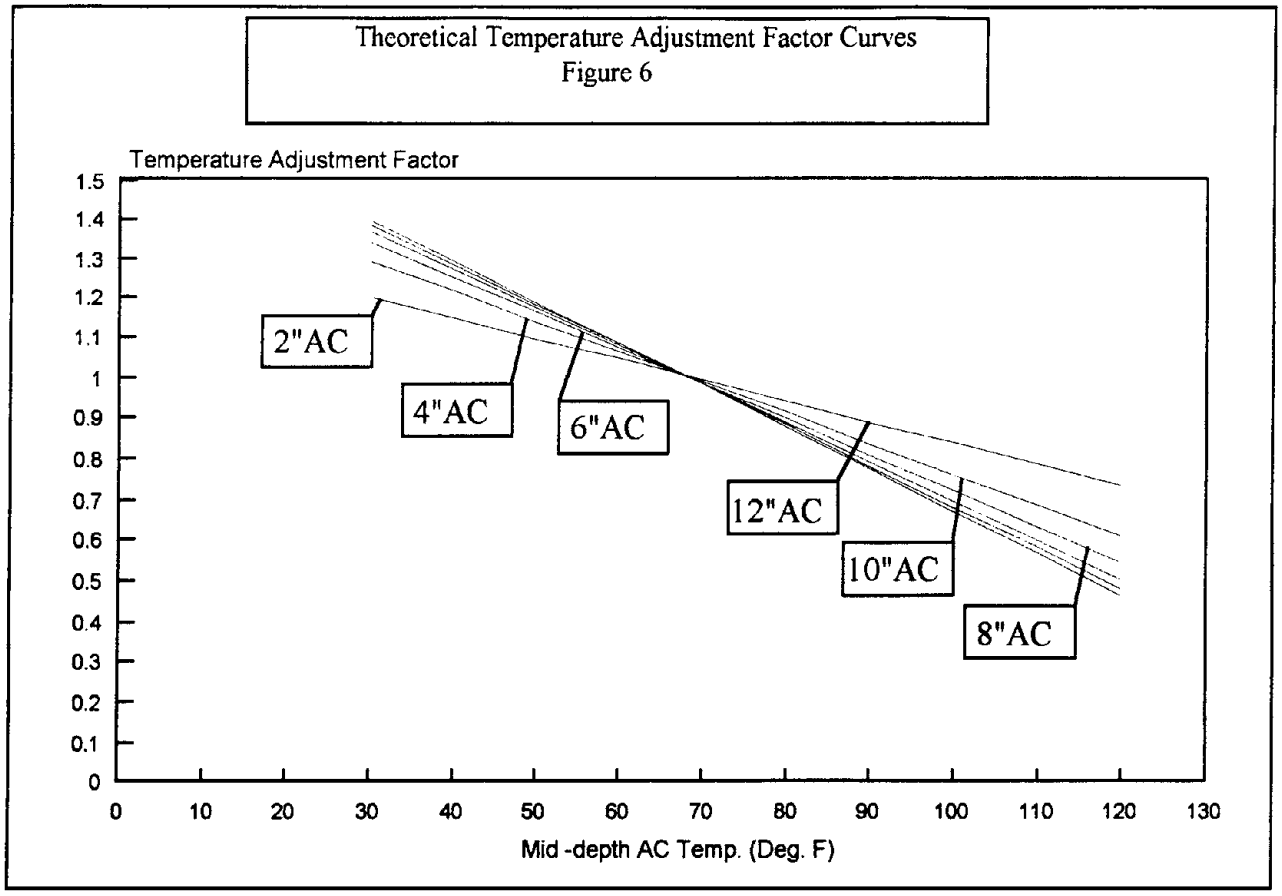
The only values left in the Odemark equation that haven't yet been defined are p, the contact pressure, and a, the circular load radius. The contact pressure, equal to 82.3 psi, is the applied equivalent load of 9000 lbs (9 kips) divided by the area of the load plate. The circular load radius, also used to find the load plate area for the contact pressure computation, is equal to 5.9 inches.

The temperature adjustment factor was calculated the same way as for the empirical TAF curve:

$$TAF = \frac{d_{0_{68}}}{d_{0_T}}$$

(See Appendix C, pages C3-C20 for all of the generated theoretical TAF data points.)

For each asphalt thickness, all the TAF data was plotted and a regression equation was computed. The regression line became the TAF curve for that asphalt thickness, just as in the empirical TAF curve procedure. (See Appendix C, page C21 for Regression Equations , pages C22-C27 for graphs of regression lines for each h_{ac} depth, and page C28 for a full page plot of Figure 6.) Below in Figure 6, a plot of all the TAF curves for the various AC thicknesses can be found.



The theoretical temperature adjustment factor curves have a different curve fit than the empirical TAF curves (linear vs. exponential), but they both have the same general slope trend and the thicker the AC thickness, the steeper the slope. In the **CONCLUSIONS** section, a much more detailed comparison of the TAF curve sets can be found.

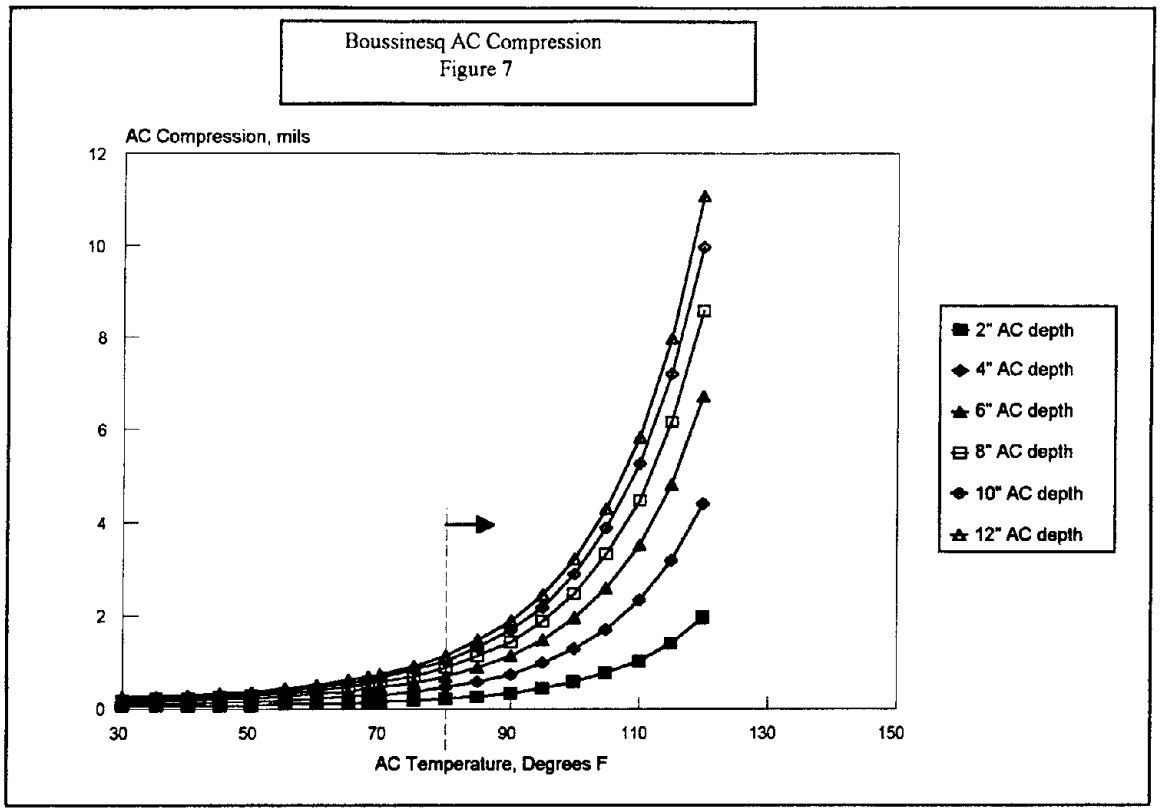
Before moving on to the comparison of methods used to find layer strengths, it should be mentioned that another method for finding theoretical deflections was examined. The method used in this investigation was based on Boussinesq's one layer system as well as on the theory of equivalent thickness presented by Odemark. Initially, Boussinesq's one layer system alone was used to find deflections. In 1885, Boussinesq developed a solution for computing stresses and deflections in a halfspace (soil) composed of homogeneous, isotropic and linearly elastic material. This solution was based on a point loading, and in

1928, Love adapted his solution for a circular load. *(5)* The equation below is for deflection at depth z:

$$d_z = \frac{(1+u)pa}{E}\left\{\frac{1}{\sqrt{1+\left(\frac{z}{a}\right)^2}} + (1-2u)\left(\sqrt{1+\left(\frac{z}{a}\right)^2} - \frac{z}{a}\right)\right\}$$

where:
p = plate pressure (ksi)
E = elastic modulus (ksi)
a = plate radius (inches)
z = depth below pavement surface (inches)
u = Poisson's ratio

The reason that this method was not used for the theoretical TAF curve procedure is that it produced inconclusive results. As can be seen from the equation above, for the same asphalt thickness, the temperature adjustment factor [TAF = d_0 at 68/d_0 at T] is only the ratio of the moduli of elasticity, everything else cancels out. For each AC depth, then, the TAF curve was identical because the modulus of elasticity values at varying temperatures are constant for each asphalt pavement thickness. From the empirical TAF curve, it can be seen that the temperature adjustment factor curve is not the same for each AC depth, thus, the results were erroneous. What this method did show is the theoretical amount of compression the AC layer is subjected to due to different AC temperatures and layer depths. As can be seen in Figure 7 on the next page, it is an exponential curve and around the 80 degrees Fahrenheit range, the amount of compression becomes greater and greater. (See Appendix C, pages C29-C30 for the generated Boussinesq compression and TAF data in tabular form and a full page plot of Figure 7.)



Comparison of Methods Used to Find Layer Strength Moduli

As the final step in RI 91-9, methods used to find pavement layer strengths will be compared. This topic will be updated in Research Investigation 91-9B which will be completed when resilient modulus laboratory data is available. The layer strengths of concern are E_p, the strength of the whole pavement structure, E_{ac}, the strength of the asphalt, and M_r, the subgrade resilient modulus.

The MODULUS program was run three different ways with the collected FWD deflection data as inputs. The first run considered the pavement as a two layer system: an AC layer height + base layer height considered as one layer of pavement, and a subgrade. The effective pavement modulus (E_p) and the subgrade resilient modulus (M_r) found by the first MODULUS run were compared to manually backcalculated values found by equations in the *Determination of Subgrade Modulus for SN_{eff} Determination* section of the 1993

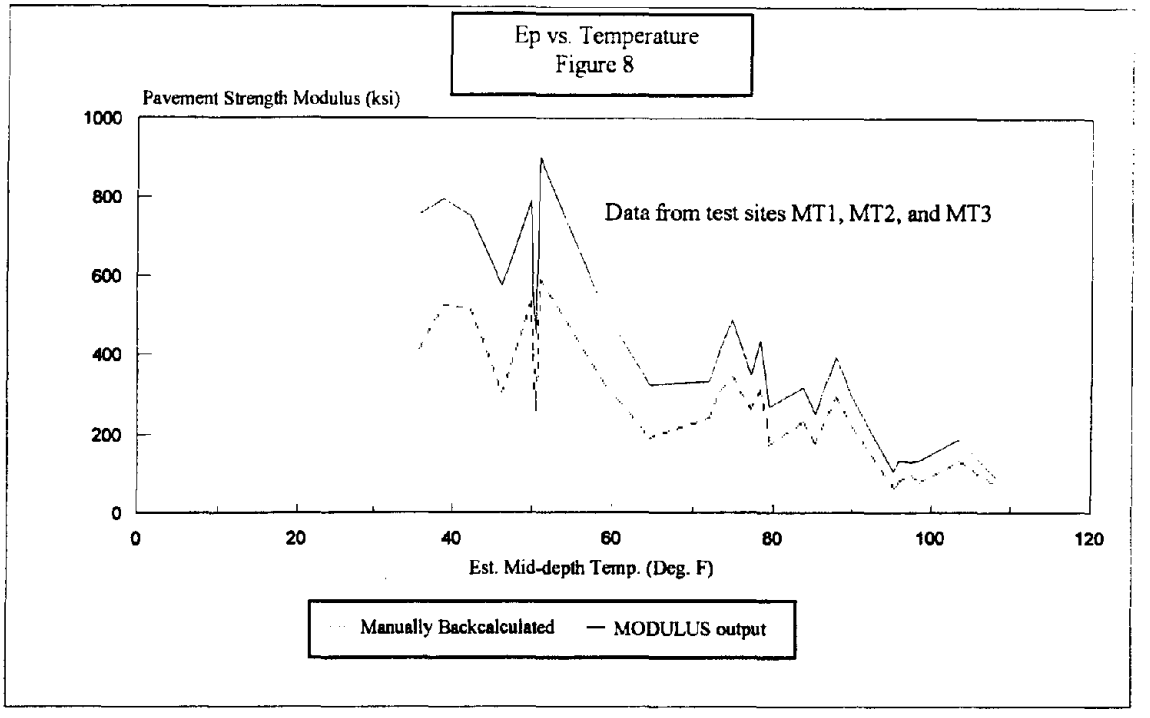
AASHTO Guide for Design of Pavement Structures. *(2)* This is a simple method proposed by Ultidtz for estimating the subgrade modulus from deflections measured at the surface of a layered pavement structure (by the FWD). It is based on the following two observations:

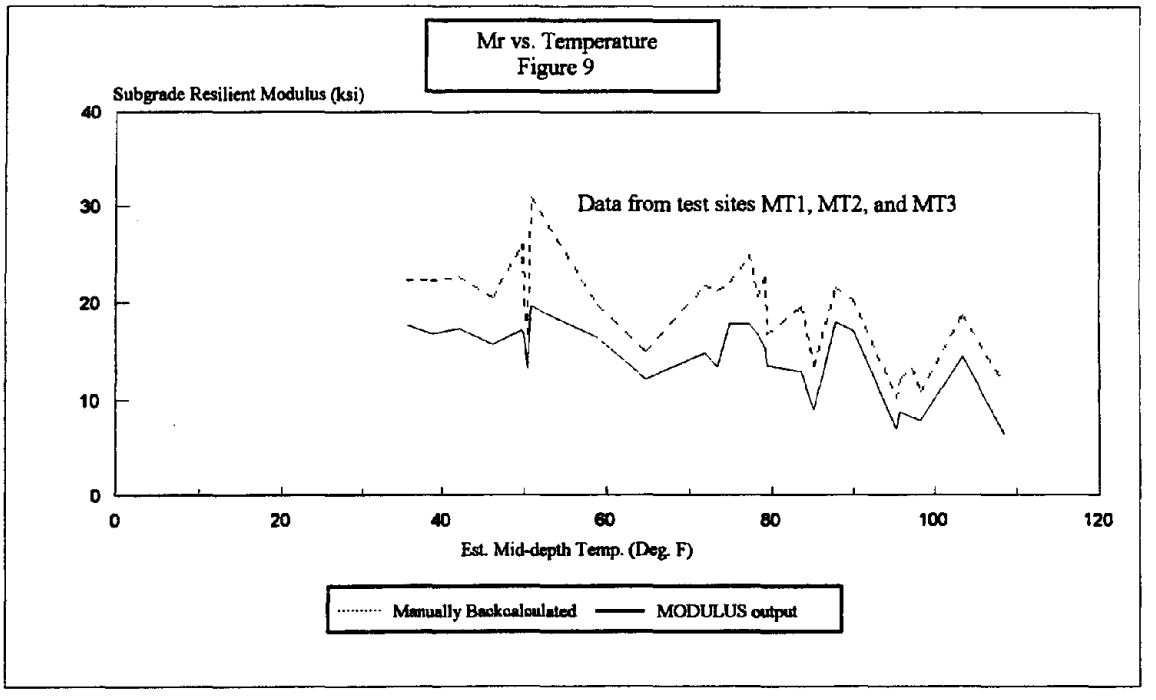
1) As distance away from the load increases, compression of the layers above the subgrade becomes less significant to the measured deflection at the pavement surface.

2) As distance away from the load increases, the approximation of a distributed load by a point load improves. *(2)*

It was assumed again that the pavement structure consisted of a two layer system, therefore, the only other strength value the procedure yielded, besides M_r, was E_p. It is logical, then, to compare its outcome to the first MODULUS run. The procedure for obtaining the backcalculated E_p and M_r values as well as a sample calculation can be found in Appendix D, pages D1-D4. Plots of E_p and M_r for both methods versus estimated mid-depth temperature can be found in Figures 8 and 9 on the next page. (See Appendix D, page D5 for the data in tabular form.)

In analyzing Figures 8 and 9, it can easily be seen that the two methods are similar in the way that they find the unknown values - they both have the same trends at each mid-depth pavement temperature. The difference between the two methods is the way that they assign strengths. For the manual backcalculation method, it assigns the subgrade more of the strength and takes away from the strength E_p assumes. The opposite is true in the MODULUS program: the pavement modulus takes on the strength that is not given to the subgrade.


Ep vs. Temperature
Figure 8
Pavement Strength Modulus (ksi)
1000
800
600
400
200
0
Data from test sites MT1, MT2, and MT3
0
20
40
60
80
100
120
Est. Mid-depth Temp. (Deg. F)
Manually Backcalculated
MODULUS output

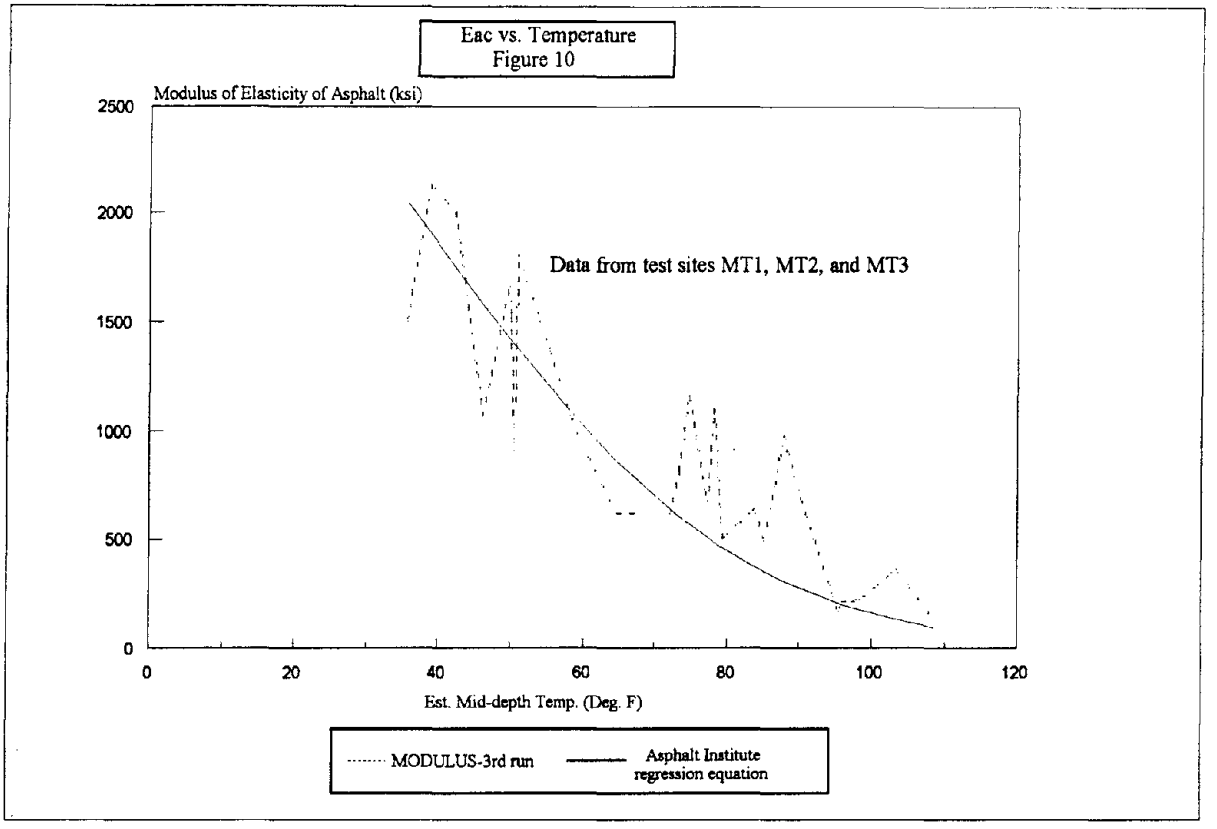

Mr vs. Temperature
Figure 9
Subgrade Resilient Modulus (ksi)
40
30
20
10
0
Data from test sites MT1, MT2, and MT3
0
20
40
60
80
100
120
Est. Mid-depth Temp. (Deg. F)
Manually Backcalculated
MODULUS output

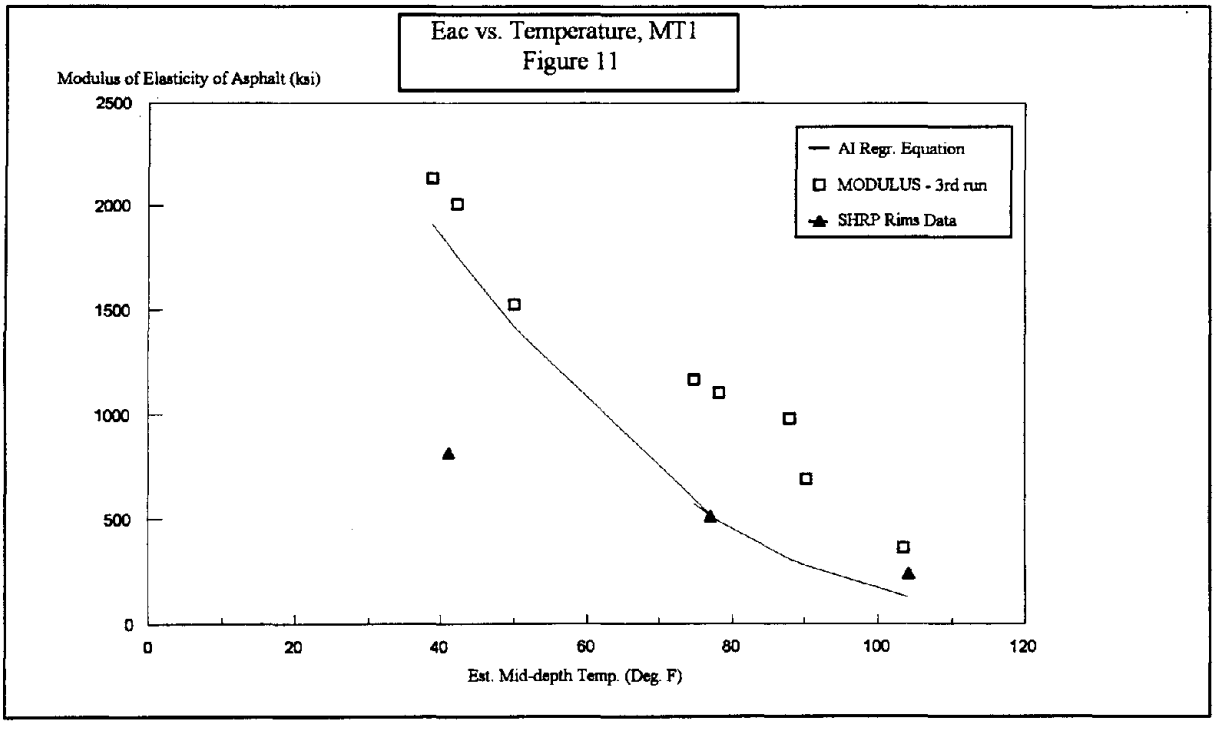
The final comparison is for E_{ac}, the asphalt concrete layer strength modulus within the pavement structure. One previously mentioned method that was used to find E_{ac} values was the Asphalt Institute Regression Equation. These values were compared to MODULUS solutions and SHRP Regional Information Management System (RIMS) laboratory data for E_{ac}.

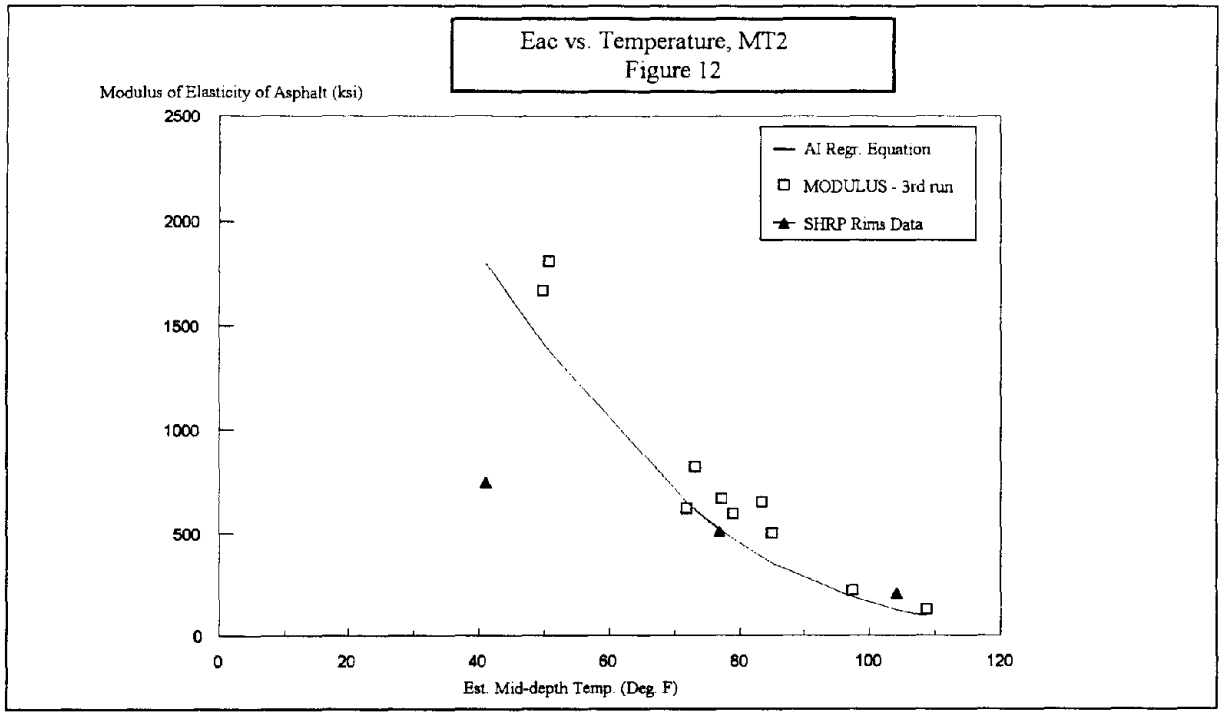
The pavement of the test sites was analyzed as a 3 layer system (asphalt layer, base and subgrade) for the second MODULUS run and as a 4-layer system (asphalt layer, base, first 36" of subgrade and remaining subgrade) as the third MODULUS run. The third run produced an overall lower absolute error than the second run and can be justified by the fact that the first 36 inches of subgrade is the most susceptible to environmental conditions, and therefore can be figured as a separate layer. Because of the lower absolute error, the third run values were used in the subsequent comparisons. The corresponding layer strengths produced by using inputted FWD deflection data were: E_{ac}, E_b, $M_{r\ @36"}$, and M_r. The researcher used the resilient modulus strength of the first 36" of subgrade layer if the stiff layer was less than 10 feet below the ground surface. If the stiff layer was greater than 10 feet below the ground surface, the first 36" of subgrade resilient modulus value and the remaining subgrade resilient modulus value should be averaged.

The MODULUS third run E_{ac} values can now be compared to the Asphalt Institute regression equation values for asphalt modulus of elasticity and to the SHRP RIMS laboratory E_{ac} data. At this point, however, we have nothing to compare the E_b values with. In Figure 10 on the following page, the MODULUS E_{ac} values for each test site and the corresponding Asphalt Institute regression Modulus of Elasticity values are plotted against the estimated mid-depth temperature of the pavement. (See Appendix D, page D6 to see the all the E_{ac} data in tabular form.)

In Figures 11 and 12, asphalt Modulus of Elasticity values as determined by the Asphalt Institute regression equation, MODULUS output, and SHRP RIMS laboratory data for test sites MT1 and MT2 are plotted against the estimated mid-depth temperature.


Eac vs. Temperature
Figure 10
Modulus of Elasticity of Asphalt (ksi)
2500
2000
1500
1000
500
0
Data from test sites MT1, MT2, and MT3
0
20
40
60
80
100
120
Est. Mid-depth Temp. (Deg. F)
MODULUS-3rd run
Asphalt Institute regression equation


Eac vs. Temperature, MT1
Figure 11
Modulus of Elasticity of Asphalt (ksi)
2500
2000
1500
1000
500
0
AI Regr. Equation
MODULUS - 3rd run
SHRP Rims Data
0
20
40
60
80
100
120
Est. Mid-depth Temp. (Deg. F)


Eac vs. Temperature, MT2
Figure 12
Modulus of Elasticity of Asphalt (ksi)
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
Est. Mid-depth Temp. (Deg. F)
AI Regr. Equation
MODULUS - 3rd run
SHRP Rims Data

CONCLUSIONS

The purpose of a temperature adjustment factor (TAF) is to be able to take a Falling Weight Deflectometer (FWD) deflection value measured at T degrees and multiply it by the TAF to get the equivalent deflection at 68 degrees Fahrenheit. This will provide structural data that is easily compared for various pavements.

The empirical temperature adjustment factor curves' (found in Figure 3) data points have a different curve fit than the data points of the theoretical temperature adjustment factor curves (found in Figure 6). The TAF values for the empirical data are generally higher for temperatures lower than 68 degrees and generally lower for temperatures higher than 68 degrees when compared to the theoretical temperature adjustment factor curve. This results in the empirical temperature adjustment factor curves being more conservative structurally when the temperature is above 68 degrees and less structurally conservative when the temperature is below 68 degrees.

The temperature adjustment factors which were based on theoretical results using Odemark-Boussinesq, which is a linear elastic equation, are basically the same as the present American Association of State Highway and Transportation Officials (AASHTO) Temperature Adjustment Factors on pages III-99 and III-100 of the 1993 AASHTO Guide for Design of Pavement Structures *(2)*. Evidently, both of these results were based on linear elastic behavior of the material, which is a false assumption since the material in actuality is not linear elastic. Therefore, the temperature adjustment factors which were based on actual FWD deflection data and empirical mid-depth asphalt concrete (AC) temperatures (referred to as the empirical Temperature Adjustment Factor curves) show that the behavior is non-linear and is perceived as a more accurate illustration of the temperature adjusment factors.

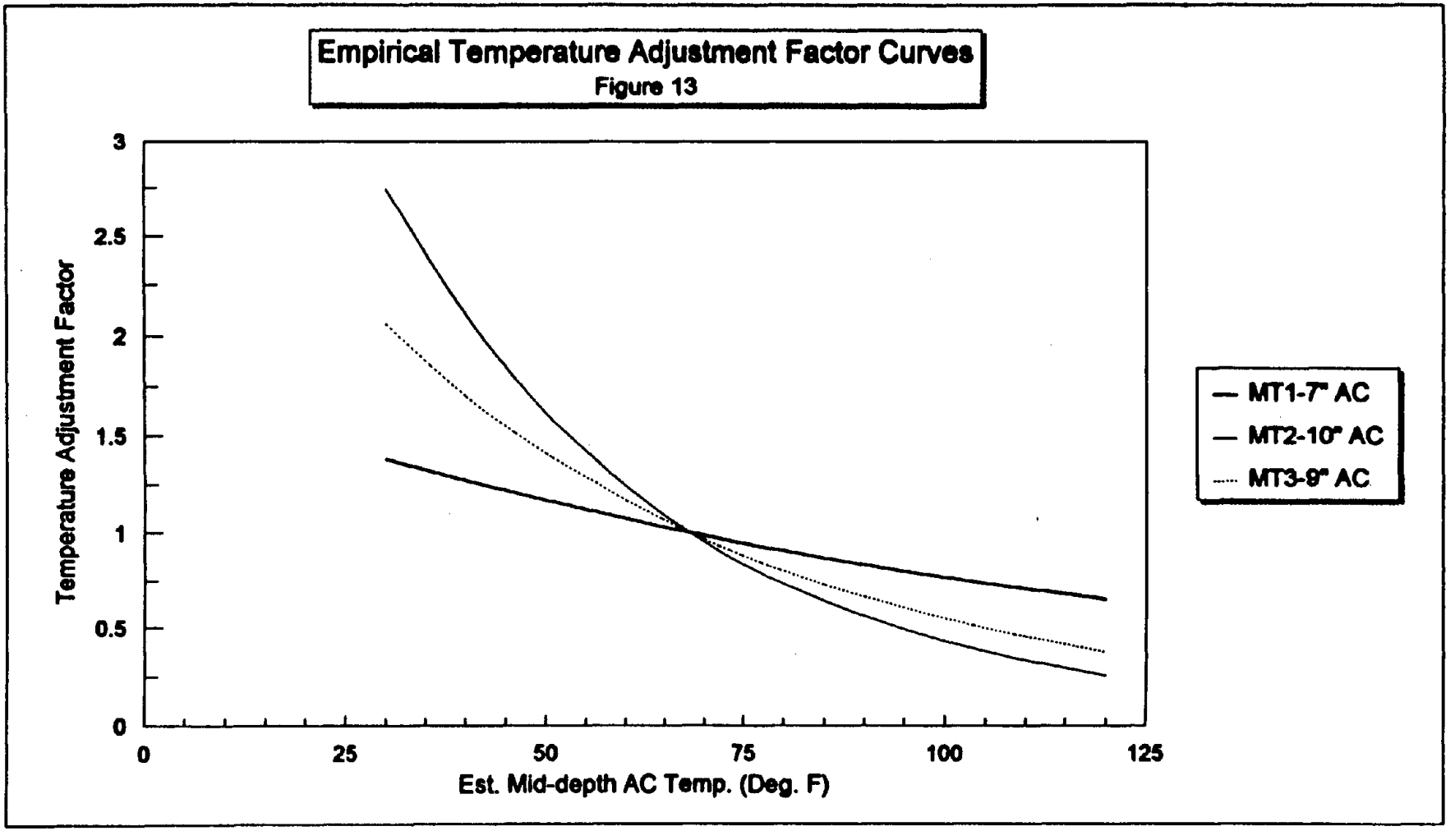
The conclusions for the comparison of methods used to find layer strengths will be brief. Overall, it appears that the manually backcalculated method and 2-layer system

MODULUS run yield parallel values for the pavement strength moduli and the subgrade resilient modulus. (see Figures 7 and 8).

The Asphalt Institute (AI) regression equation E_{ac} (strength modulus of asphalt concrete) values provide a theoretical comparison for the 4-layer system MODULUS E_{ac} results. The MODULUS values are distributed fairly close to the AI regression line. (see Figure 10). As can be seen in Figures 11 and 12, the Modulus of Elasticity values found by the Strategic Highway Research Program (SHRP) Regional Information Management System (RIMS) laboratory tests are close to the AI and MODULUS values for warm mid-depth temperatures (over 75° Fahrenheit). But for colder mid-depth temperatures, the SHRP RIMS E_{ac} values are considerably lower. It is uncertain whether it is the SHRP laboratory data or the MODULUS software and Asphalt Institute regression results that are inconsistent, considering the large difference in asphalt layer strength modulus values. The SHRP Protocol used for the testing the total resilient modulus of asphalt concrete is PO7 which closely follows ASTM D4123 specifications.

RECOMMENDATIONS

The empirical temperature adjustment factor curves, found in Figure 13 on the following page, are the recommended Temperature Adjustment Factor curves for MoDOT's use with the FWD measured deflections. These temperature adjustment factor will be used to correct the deflections to the AASHTO standard 68 degree F. (The calculated regression equations for these lines can be found on page 27.)


Empirical Temperature Adjustment Factor Curves
Figure 13
Temperature Adjustment Factor
3
2.5
2
1.5
1
0.5
0
0
25
50
75
100
125
Est. Mid-depth AC Temp. (Deg. F)
MT1-7" AC
MT2-10" AC
MT3-9" AC

Missouri Department of Transportation Recommended Temperature Adjustment Factor Curve Regression Equations.

MT1 Regression FWD Deflection Equation
Correlation Coefficient = 0.895540

$$d_0 = 4.738428e^{(0.008485*TEMP)}$$

MT2 Regression FWD Deflection Equation
Correlation Coefficient = 0.962902

$$d_0 = 1.090210e^{(0.026551*TEMP)}$$

MT3 Regression FWD Deflection Equation
Correlation Coefficient = 0.950967

$$d_0 = 3.188715e^{(0.018935*TEMP)}$$

REFERENCES

(1) "An Evaluation of Temperature Distribution within Asphalt Pavements and It's Relationship to Pavement Deflection", Thesis submitted in partial requirements for the degree of Master of Science in Civil Engineering at the University of Kentucky by Herbert Fletcher Southgate. Co-Directors: Dr. Bobby D. Hardin and Dr. John W. Hutchinson, Professors of Civil Engineering, Lexington, Kentucky, 1968.

(2) *AASHTO Guide for Design of Pavement Structures, Volume 1, 1993.* American Association of State Highway and Transportation Officials, Washington, D.C. (1993).

(3) *SHRP Procedure for Temperature Correction of Maximum Deflections.* Strategic Highway Research Program, National Research Council, Washington, D.C., 1993.

(4) *AASHTO Guide for Design of Pavement Structures, Volume 2, 1986.* Prepared for: American Association of State Highway and Transportation Officials, Under Contract with: National Cooperative Highway Reserach Program, Transportation Research Boad, National Research Council (NCHRP) Project 20-7 (Task 24 & 28)., August 1988.

(5) *National Highway Institute FWHA Backcalculation Training Course Manual.* Athens, Ohio, October 1993

APPENDIX A

Data and Graphs Relating to the Estimation of Mid-Depth AC Temperature

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC. Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth
MT1-1002	Route C, Cole County, MO Asphalt Pavement	2-27-91	40	-	-	7	64			52	49			
		5-07-91	52	-	-	7	68			64	63			
		6-06-91	77	86	163	7	92			88	87			
		7-05-91	81	106	187	7	103			105	98			
		7-29-91	72	85	157	7	82			88	88			
		9-05-91	74	85	159	7	82			77	77			
		10-03-91	68	68	136	7	68			70	72			
		11-12-91	26	52	78	7	51			47	47			
		2-11-92	31	41	72	7	40			39	39			
		3-19-92	43	49	92	7	62			54	52			
		5-18-92	65	77	142	7	74			72	72			

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth
MT2-1008	Route 171, Jasper County, MO Asphalt Pavement	2-26-91	43	45	88	10	45			42				42
		3-26-91	64	76	140	10	73			69				68
		4-24-91	50	87	137	10	93			76				68
		5-30-91	78	86	164	10	85			83				86
		6-25-91	79	110	189	10	113			100				95
		7-22-91	84	128	212	10	128			118				109
		9-04-91	77	75	152	10	75			80				84
		10-01-91	63	85	148	10	83			70				81
		10-29-91	63	54	117	10	56			63				66
		1-27-92	38	56	94	10	56			46				42
		3-24-92	42	50	92	10	50			48				52
		5-20-94	70	91	161	10	87			77				75

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth
MT3-606	Route 169, Gentry County, MO Asphalt Pavement	3-05-91	41	-	-	9	61				48			
		4-03-91	44	-	-	9	78				77			
		5-01-91	58	-	-	9	63				55			
		6-04-91	76	105	181	9	110				99			
		7-02-91	82	105	187	9	107				96			
		7-30-91	71	111	182	9	113				99			
		9-10-91	76	75	151	9	76				78			
		10-09-01	54	58	112	9	57				60			
		11-05-91	20	48	68	9	53				49			
		1-30-92	34	54	88	9	52				42			
		3-31-92	42	54	96	9	55				53			
		5-27-92	53	70	123	9	75				65			

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth
MT4-5000	I-35, Daviess County, MO Concrete Pavement	3-05-91	36	-	-	9.2	48			45				45
		4-02-91	43	-	-	9.2	60			54				57
		4-30-91	57	-	-	9.2	84			78				69
		6-04-91	76	85	161	9.2	85			80				84
		7-03-91	80	91	171	9.2	89			92				88
		7-30-91	71	69	140	9.2	69			76				83
		9-09-91	72	101	173	9.2	102			94				90
		10-08-91	51	63	114	9.2	62			61				63
		11-06-91	23	33	56	9.2	35			36				40
		1-29-92	33	60	93	9.2	59			49				42
		3-31-92	43	60	103	9.2	56			50				49
		5-28-92	53	66	119	9.2	64			60				60

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth
MT5-9005	Route 50, Cole County, MO Concrete Pavement	2-21-91	37	-	-	9	77			66			58	
		3-06-91	42	-	-	9	65			58			54	
		3-28-91	62	-	-	9	73			67			61	
		6-03-91	79	92	171	9	89			85			85	
		7-05-91	81	97	178	9	95			88			87	
		7-29-91	72	81	153	9	81			84			84	
		9-05-91	74	96	170	9	96			92			82	
		10-03-91	66	110	176	9	86			79			73	
		11-12-91	26	42	68	9	42			43			44	
		2-11-92	31	40	71	9	40			38			39	
		4-01-92	45	51	96	9	54			58			52	
		5-18-92	64	89	153	9	91			84			76	

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth
MT6-9007	Route 71, Jasper County, MO Concrete Pavement	2-25-91	43	-	-	9.3	52			55			49	
		3-25-91	59	-	-	9.3	86			84			73	
		4-29-91	63	-	-	9.3	70			74			73	
		5-30-91	77	-	-	9.3	76			81			86	
		6-25-91	79	97	176	9.3	97			92			86	
		7-23-91	86	87	173	9.3	88			88			90	
		9-04-91	78	93	171	9.3	92			84			83	
		10-30-91	62	40	102	9.3	45			48			52	
		1-28-92	37	43	80	9.3	48			47			41	
		5-20-92	62	77	139	9.3	76			74			73	

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature		
							1" depth	2" depth	4" depth
MT7-8013	I-35, Harrison County, MO Asphalt Overlay on Concrete Pavement	3-05-91	36	-	-	4		51	
		4-03-91	45	-	-	4		56	
		5-02-91	58	-	-	4		57	
		6-04-91	76	86	162	4		90	
		7-02-91	82	80	162	4		88	
		7-30-91	70	93	163	4		93	
		9-10-91	73	82	155	4		85	
		10-08-91	50	77	127	4		78	
		11-05-91	23	36	59	4		32	
		1-30-92	30	33	63	4		33	
		3-30-92	42	75	117	4		70	
		5-27-92	59	61	120	4		60	

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC Thickns. (inches)	Actual Pvmnt Temp.	
							1" depth	2" depth
MT8-5473	I-70, Cooper County, MO Asphalt Overlay on Concrete Pavement	3-04-91	41	-	-	3		26
		4-01-91	49	-	-	3		68
		5-09-91	60	-	-	3		72
		6-30-91	79	102	181	3		102
		7-01-91	82	96	178	3		96
		7-29-91	72	101	173	3		100
		9-06-91	74	81	155	3		75
		10-18-91	56	61	117	3		66
		11-13-91	28	53	81	3		46
		1-31-92	36	57	93	3		53
		3-20-92	42	43	85	3		45
		5-22-92	69	77	146	3		78

Site No.	Location	Date Tested	5-day avg. temperature	Pvt. Surface temperature	5-day+surf. temperature	AC. Thickns. (inches)	Actual Pvmnt Temp.	
							1" depth	2" depth
MT9-8014	Route 60, Greene County, MO Asphalt Overlay on Concrete Pavement	2-26-91	38	-	-	3.5		57
		3-19-91	41	-	-	3.5		71
		4-29-91	61	-	-	3.5		84
		5-31-91	75	82	157	3.5		81
		6-26-91	77	-	-	3.5		109
		7-22-91	77	115	192	3.5		113
		9-03-91	75	95	170	3.5		95
		9-30-91	59	84	143	3.5		82
		11-14-91	42	56	98	3.5		56
		1-27-92	34	54	88	3.5		50
		3-23-92	47	64	111	3.5		62
		5-19-92	67	77	144	3.5		75

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Concrete pvt. surf. temp.	5-day+surf. temperature	AC. Thickns. (inches)	Actual Pavement Temperature							
							1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6	1- Control Section	6/02/92	57.3	87	144.3	8	87			78			78	
Bethany, MO		6/02/92	57.3	87	144.3	8	87			79			79	
		6/02/92	57.3	88	145.3	8	88			81			79	
		6/02/92	57.3	88	145.3	8	88			81			79	
		6/02/92	57.3	88	145.3	8	88			81			79	
		6/02/92	57.3	90	147.3	8	90			81			79	
		6/02/92	57.3	93	150.3	8	93			83			81	
		6/02/92	57.3	90	147.3	8	90			84			80	
		10/19/92	47.3	53	100.3	8	53			54			54	
		10/19/92	47.3	52	99.3	8	52			53			54	
		10/19/92	47.3	53	100.3	8	53			54			54	
		10/19/92	47.3	51	98.3	8	51			52			53	
		10/19/92	47.3	52	99.3	8	52			51			52	
		10/19/92	47.3	49	96.3	8	49			50			51	
		10/19/92	47.3	50	97.3	8	50			51			52	
		10/28/92	60.3	55	115.3	8	55			56			57	
		10/28/92	60.3	57	117.3	8	57			56			58	
		10/28/92	60.3	57	117.3	8	57			56			58	
		10/28/92	60.3	61	121.3	8	61			58			59	
		10/28/92	60.3	63	123.3	8	63			60			59	
		10/28/92	60.3	61	121.3	8	61			60			61	
		10/28/92	60.3	63	123.3	8	63			63			67	
		11/17/92	37.9	54	91.9	8	54			52			49	
		11/17/92	37.9	54	91.9	8	54			52			51	
		11/17/92	37.9	51	88.9	8	51			51			50	
		11/17/92	37.9	47	84.9	8	47			50			50	
		11/17/92	37.9	46	83.9	8	46			47			49	
		11/17/92	37.9	39	76.9	8	39			43			43	
		4/22/93	50.1	77	127.1	8	77			73			67	
		4/22/93	50.1	79	129.1	8	79			75			69	
		4/22/93	50.1	82	132.1	8	82			78			72	
		4/22/93	50.1	84	134.1	8	84			80			74	
		4/22/93	50.1	80	130.1	8	80			78			73	
		4/22/93	50.1	79	129.1	8	79			75			71	
		4/22/93	50.1	77	127.1	8	77			73			71	
		4/22/93	50.1	73	123.1	8	73			73			71	
		5/10/93	65.6	74	139.6	8	74			73			73	
		5/10/93	65.6	72	137.6	8	72			73			73	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Concrete pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6	2 - Max. Restoration	3/12/92	46.8	40	86.8	8	40			42				46
Bethany, MO		3/12/92	46.8	33	79.8	8	33			35				37
		3/12/92	46.8	30	76.8	8	30			34				37
		3/12/92	46.8	32	78.8	8	32			34				37
		4/15/92	49.1	68	117.1	8	68			65				64
		4/15/92	49.1	71	120.1	8	71			67				67
		4/15/92	49.1	75	124.1	8	75			71				67
		4/15/92	49.1	77	126.1	8	77			72				68
		4/15/92	49.1	81	130.1	8	81			76				71
		4/15/92	49.1	87	136.1	8	87			80				75
		4/15/92	49.1	89	138.1	8	89			83				77
		4/15/92	49.1	91	140.1	8	91			84				78
		4/15/92	49.1	94	143.1	8	94			86				79
		4/15/92	49.1	95	144.1	8	95			87				80
		4/22/92	50.1	33	83.1	8	33			33				38
		4/22/92	50.1	39	89.1	8	39			36				36
		4/22/92	50.1	46	96.1	8	46			40				37
		4/22/92	50.1	50	100.1	8	50			46				39
		4/22/92	50.1	53	103.1	8	53			48				46
		10/27/92	63	46	109	8	46			48				53
		10/27/92	63	49	112	8	49			49				53
		10/27/92	63	50	113	8	50			52				53
		10/27/92	63	55	118	8	55			55				54
		10/27/92	63	62	125	8	62			57				56
		10/27/92	63	68	131	8	68			64				62
		10/27/92	63	66	129	8	66			62				56
		10/27/92	63	58	121	8	58			58				66
		10/27/92	63	65	128	8	65			57				65
		10/27/92	63	73	136	8	73			68				61
		10/27/92	63	72	135	8	72			66				61
		10/27/92	63	75	138	8	75			68				62
		10/27/92	63	71	134	8	71			67				64
		10/27/92	63	72	135	8	72			69				64
		10/27/92	63	70	133	8	70			68				68
		10/27/92	63	70	133	8	70			67				64
		10/27/92	63	67	130	8	67			67				64
		5/11/93	65.8	64	129.8	8	64			63			63	
		5/11/93	65.8	65	130.8	8	65			65			64	
		5/11/93	65.8	66	131.8	8	66			66			64	
		5/11/93	65.8	67	132.8	8	67			67			65	
		5/11/93	65.8	66	131.8	8	66			66			65	
		5/11/93	65.8	69	134.8	8	69			68			66	
		5/11/93	65.8	71	136.8	8	71			71			65	
		5/11/93	65.8	73	138.8	8	73			72			70	
		5/11/93	65.8	74	139.8	8	74			73			70	
		5/11/93	65.8	71	136.8	8	71			70			69	
		5/11/93	65.8	71	136.8	8	71			70			68	
		5/11/93	65.8	69	134.8	8	69			69			68	
		5/11/93	65.8	69	134.8	8	69			69			68	
		5/11/93	65.8	70	135.8	8	70			69			69	
		5/11/93	65.8	75	140.8	8	75			71			69	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature			
							1" depth	2" depth	3" depth	4" depth
SPS-6 Bethany, MO	3 - min. restoration	3/3/92	46.1	70	116.1	4	70			
		3/3/92	46.1	72	118.1	4	72			
		3/3/92	46.1	71	117.1	4	71			
		3/3/92	46.1	73	119.1	4	73			
		3/3/92	46.1	73	119.1	4	73			
		3/3/92	46.1	73	119.1	4	73			
		3/4/92	51.4	59	110.4	4	59			
		3/4/92	51.4	60	111.4	4	60			
		3/4/92	51.4	65	116.4	4	65			
		3/4/92	51.4	66	117.4	4	66			
		3/4/92	51.4	70	121.4	4	70			
		10/21/92	41.1	87	128.1	4	87	85		
		10/21/92	41.1	88	129.1	4	88	84		
		10/21/92	41.1	87	128.1	4	87	85		
		10/21/92	41.1	84	125.1	4	84	84		
		10/21/92	41.1	83	124.1	4	83	83		
		10/21/92	41.1	82	123.1	4	82	82		
		10/22/92	44.2	59	103.2	4	59	59		
		10/22/92	44.2	61	105.2	4	61	60		
		10/22/92	44.2	63	107.2	4	63	60		
		10/22/92	44.2	64	108.2	4	64	63		
		10/22/92	44.2	69	113.2	4	69	69		
		10/22/92	44.2	64	108.2	4	64	63		
		10/22/92	44.2	75	119.2	4	75	74		
		5/11/93	65.8	78	143.8	4	78	77		
		5/11/93	65.8	80	145.8	4	80	79		
		5/11/93	65.8	79	144.8	4	79	79		
		5/11/93	65.8	74	139.8	4	74	75		
		5/12/93	65.2	66	131.2	4	66	68		
		5/12/93	65.2	70	135.2	4	70	70		
		5/12/93	65.2	70	135.2	4	70	70		
		5/12/93	65.2	79	144.2	4	79	80		
		5/12/93	65.2	78	143.2	4	78	79		

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature			
							1" depth	2" depth	3" depth	4" depth
SPS-6	4 - min. restoration	3/02/92	39.6	99	138.6	4	99			
Bethany, MO	(saw & seal overlay)	3/02/92	39.6	86	125.6	4	86			
		3/02/92	39.6	84	123.6	4	84			
		3/03/92	46.1	58	104.1	4	58			
		3/03/92	46.1	60	106.1	4	60			
		3/03/92	46.1	64	110.1	4	64			
		3/03/92	46.1	66	112.1	4	66			
		3/03/92	46.1	66	112.1	4	66			
		3/03/92	46.1	67	113.1	4	67			
		3/03/92	46.1	70	116.1	4	70			
		3/03/92	46.1	71	117.1	4	71			
		3/03/92	46.1	72	118.1	4	72			
		3/03/92	46.1	71	117.1	4	71			
		10/21/92	41.1	51	92.1	4	51	51		
		10/21/92	41.1	54	95.1	4	54	53		
		10/21/92	41.1	57	98.1	4	57	56		
		10/21/92	41.1	60	101.1	4	60	60		
		10/21/92	41.1	65	106.1	4	65	62		
		10/21/92	41.1	70	111.1	4	70	66		
		10/21/92	41.1	74	115.1	4	74	73		
		10/21/92	41.1	75	116.1	4	75	74		
		10/21/92	41.1	78	119.1	4	78	78		
		10/21/92	41.1	83	124.1	4	83	82		
		10/21/92	41.1	85	126.1	4	85	84		
		10/21/92	41.1	85	126.1	4	85	85		
		4/20/93	45.9	56	101.9	4	56	57		
		4/20/93	45.9	57	102.9	4	57	58		
		4/20/93	45.9	59	104.9	4	59	58		
		4/20/93	45.9	60	105.9	4	60	58		
		4/20/93	45.9	60	105.9	4	60	59		
		5/11/93	65.8	82	147.8	4	82	81		
		5/11/93	65.8	84	149.8	4	84	83		

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Concrete pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6 Bethany, MO	5 - Max Restoration	3/10/92	57.5	45	102.5	8	45			44				43
		3/10/92	57.5	42	99.5	8	42			41				42
		3/10/92	57.5	42	99.5	8	42			41				42
		3/10/92	57.5	43	100.5	8	43			42				42
		3/10/92	57.5	45	102.5	8	45			46				43
		3/10/92	57.5	46	103.5	8	46			46				45
		3/10/92	57.5	48	105.5	8	48			47				47
		3/10/92	57.5	47	104.5	8	47			47				46
		3/10/92	57.5	48	105.5	8	48			47				47
		3/10/92	57.5	48	105.5	8	48			47				48
		3/11/92	53.6	29	82.6	8	29			31				35
		3/11/92	53.6	30	83.6	8	30			31				35
		3/11/92	53.6	30	83.6	8	30			32				35
		3/11/92	53.6	36	89.6	8	36			36				36
		3/11/92	53.6	41	94.6	8	41			38				37
		3/11/92	53.6	43	96.6	8	43			41				39
		3/11/92	53.6	44	97.6	8	44			42				39
		3/11/92	53.6	42	95.6	8	42			41				40
		3/11/92	53.6	41	94.6	8	41			40				40
		10/20/92	43.5	54	97.5	8	54			54				53
		10/20/92	43.5	56	99.5	8	56			55				54
		10/20/92	43.5	58	101.5	8	58			57				56
		10/20/92	43.5	61	104.5	8	61			56				55
		10/20/92	43.5	64	107.5	8	64			56				54
		10/20/92	43.5	63	106.5	8	63			57				55
		10/20/92	43.5	64	107.5	8	64			54				51
		10/20/92	43.5	64	107.5	8	64			56				52
		10/20/92	43.5	75	118.5	8	75			66				62
		10/20/92	43.5	77	120.5	8	77			64				60
		10/20/92	43.5	80	123.5	8	80			68				62
		10/20/92	43.5	81	124.5	8	81			69				62
		10/20/92	43.5	84	127.5	8	84			70				63
		10/20/92	43.5	81	124.5	8	81			74				68
		10/20/92	43.5	80	123.5	8	80			71				65
		10/20/92	43.5	74	117.5	8	74			71				65
		10/20/92	43.5	73	116.5	8	73			71				67
		10/20/92	43.5	68	111.5	8	68			66				64
		10/20/92	43.5	66	109.5	8	66			64				64
		10/26/92	62.1	72	134.1	8	72			71				67
		10/26/92	62.1	73	135.1	8	73			69				67
		10/26/92	62.1	71	133.1	8	71			70				67
		10/26/92	62.1	67	129.1	8	67			65				60
		4/21/93	48.5	73	121.5	8	73			69			60	
		4/21/93	48.5	72	120.5	8	72			70			62	
		4/21/93	48.5	70	118.5	8	70			69			62	
		4/22/93	50.1	50	100.1	8	50			47			49	
		4/22/93	50.1	54	104.1	8	54			50			50	
		4/22/93	50.1	57	107.1	8	57			53			51	
		4/22/93	50.1	64	114.1	8	64			60			56	
		4/22/93	50.1	69	119.1	8	69			61			57	
		4/22/93	50.1	72	122.1	8	72			63			58	
		4/22/93	50.1	75	125.1	8	75			67			59	
		4/22/93	50.1	78	128.1	8	78			69			61	
		4/22/93	50.1	80	130.1	8	80			70			62	
		4/22/93	50.1	81	131.1	8	81			71			63	
		4/28/93	56.4	66	122.4	8	66			62			62	
		4/28/93	56.4	67	123.4	8	67			63			63	
		4/28/93	56.4	70	126.4	8	70			66			64	
		4/28/93	56.4	72	128.4	8	72			66			64	
		4/28/93	56.4	67	123.4	8	67			66			64	
		4/28/93	56.4	65	121.4	8	65			66			64	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature			
							1" depth	2" depth	3" depth	4" depth
SPS-6 Bethany, MO	6 - Max. Restoration	3/04/92	51.4	68	119.4	4	68			
		3/04/92	51.4	51.4	102.8	4	70			
		3/04/92	51.4	51.4	102.8	4	68			
		3/04/92	51.4	51.4	102.8	4	64			
		3/04/92	51.4	51.4	102.8	4	65			
		3/04/92	51.4	51.4	102.8	4	65			
		3/04/92	51.4	51.4	102.8	4	65			
		3/09/92	57.8	46	103.8	4	46			
		3/09/92	57.8	47	104.8	4	47			
		3/09/92	57.8	45	102.8	4	45			
		3/09/92	57.8	42	99.8	4	42			
		3/09/92	57.8	42	99.8	4	42			
		12/01/92	27.5	37	64.5	4	37	38		
		12/01/92	27.5	37	64.5	4	37	38		
		12/01/92	27.5	37	64.5	4	37	38		
		12/01/92	27.5	37	64.5	4	37	38		
		12/01/92	27.5	38	65.5	4	38	38		
		12/01/92	27.5	39	66.5	4	39	38		
		12/01/92	27.5	40	67.5	4	40	39		
		12/01/92	27.5	41	68.5	4	41	39		
		12/02/92	27.5	36	63.5	4	36	35		
		12/02/92	27.5	36	63.5	4	36	35		
		5/12/93	65.2	79	144.2	4	79	77		
		5/12/93	65.2	82	147.2	4	82	79		
		5/12/93	65.2	86	151.2	4	86	82		
		5/12/93	65.2	95	160.2	4	95	86		
		5/12/93	65.2	99	164.2	4	99	91		
		5/12/93	65.2	104	169.2	4	104	94		
		5/12/93	65.2	102	167.2	4	102	98		
		5/12/93	65.2	102	167.2	4	102	99		

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature			
							1" depth	2" depth	3" depth	4" depth
SPS-6 Bethany, MO	7 - Crack/Break & Seat	4/24/92	45.8	50	95.8	4	50	55	59	
		4/24/92	45.8	52	97.8	4	52	56	59	
		4/24/92	45.8	53	98.8	4	53	56	59	
		4/27/92	41.3	79	120.3	4	79	74	65	
		4/27/92	41.3	80	121.3	4	80	75	62	
		4/27/92	41.3	82	123.3	4	82	77	64	
		4/27/92	41.3	84	125.3	4	84	78	66	
		4/27/92	41.3	84	125.3	4	84	79	65	
		4/28/92	43.6	52	95.6	4	52	52	55	
		4/28/92	43.6	52	95.6	4	52	52	55	
		4/28/92	43.6	54	97.6	4	54	54	55	
		4/28/92	43.6	55	98.6	4	55	55	56	
		4/28/92	43.6	59	102.6	4	59	56	56	
		4/28/92	43.6	64	107.6	4	64	56	50	
		11/03/92	46.5	40	86.5	4	40	40	40	
		11/03/92	46.5	41	87.5	4	41	40	40	
		11/03/92	46.5	40	86.5	4	40	40	41	
		11/03/92	46.5	40	86.5	4	40	40	41	
		11/03/92	46.5	41	87.5	4	41	41	41	
		4/06/93	36.2	48	84.2	4	48	48	48	
		4/06/93	36.2	50	86.2	4	50	49	49	
		4/06/93	36.2	51	87.2	4	51	50	49	
		4/06/93	36.2	58	94.2	4	58	55	52	
		4/06/93	36.2	57	93.2	4	57	57	55	
		4/06/93	36.2	68	104.2	4	68	64	60	
		4/08/92	39.4	50	89.4	4	50	51	50	
		4/08/92	39.4	53	92.4	4	53	54	54	
		4/08/92	39.4	53	92.4	4	53	53	53	
		9/20/92	51.6	92	143.6	4	92	90	86	
		9/20/92	51.6	95	146.6	4	95	93	88	
		9/20/92	51.6	97	148.6	4	97	96	93	
		9/20/92	51.6	92	143.6	4	92	94	91	
		9/20/92	51.6	91	142.6	4	91	90	89	
		9/20/92	51.6	88	139.6	4	88	89	89	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth	11" depth	12" depth
SPS-6	8 - Crack/Break	4/28/92	43.6	68	111.6	8	68			64				57			
Bethany, MO	& Seat	4/28/92	43.6	80	123.6	8	80			73				57			
		4/28/92	43.6	76	119.6	8	76			71				58			
		4/28/92	43.6	80	123.6	8	80			74				61			
		4/28/92	43.6	82	125.6	8	82			76				64			
		4/28/92	43.6	83	126.6	8	83			76				64			
		4/28/92	43.6	85	128.6	8	85			79				67			
		4/28/92	43.6	78	121.6	8	78			75				64			
		4/28/92	43.6	82	125.6	8	82			78				66			
		4/21/93	48.5	50	98.5	8	50			50			48				
		4/21/93	48.5	55	103.5	8	55			51			54				
		4/21/93	48.5	60	108.5	8	60			52			55				
		4/21/93	48.5	66	114.5	8	66			60			56				
		4/21/93	48.5	72	120.5	8	72			60			57				
		4/21/93	48.5	74	122.5	8	74			60			58				
		9/21/93	54.6	84	138.6	8	84			82			87				
		9/21/93	54.6	82	136.6	8	82			81			78				
		9/21/93	54.6	80	134.6	8	80			81			79				
		9/21/93	54.6	79	133.6	8	79			80			78				
		9/21/93	54.6	77	131.6	8	77			80			78				
		9/21/93	54.6	76	130.6	8	76			79			77				

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature			
							1" depth	2" depth	3" depth	4" depth
SPS-6 Bethany, MO	9 - Crack/Break & Seat	5/5/92	66.2	71	137.2	4	71			
		5/5/92	66.2	73	139.2	4	73			
		5/5/92	66.2	73	139.2	4	73			
		5/5/92	66.2	76	142.2	4	76			
		5/5/92	66.2	77	143.2	4	77			
		5/5/92	66.2	79	145.2	4	79			
		5/5/92	66.2	77	143.2	4	77			
		4/6/93	36.2	68	104.2	4	68	60	63	
		4/6/93	36.2	68	104.2	4	68	61	64	
		4/6/93	36.2	69	105.2	4	69	62	64	
		4/6/93	36.2	70	106.2	4	70	62	64	
		4/6/93	36.2	68	104.2	4	68	61	62	
		4/08/93	39.4	57	96.4	4	57	56	55	
		4/08/93	39.4	58	97.4	4	58	54	52	
		4/08/93	39.4	54	93.4	4	54	52	51	
		9/21/93	54.6	64	118.6	4	64	62	61	
		9/21/93	54.6	67	121.6	4	67	62	61	
		9/21/93	54.6	73	127.6	4	73	68	68	
		9/21/93	54.6	75	129.6	4	75	72	70	
		9/21/93	54.6	78	132.6	4	78	75	72	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature							
							1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6	10 - Crack/Break	5/05/92	66.2	83	149.2	8	83			80				76
Bethany, MO	& Seat	5/05/92	66.2	84	150.2	8	84			80				76
		5/05/92	66.2	85	151.2	8	85			80				76
		5/05/92	66.2	86	152.2	8	86			81				75
		5/05/92	66.2	84	150.2	8	84			81				75
		5/05/92	66.2	82	148.2	8	82			81				75
		4/09/93	42.2	41	83.2	8	41			42			44	
		4/09/93	42.2	44	86.2	8	44			45			45	
		4/09/93	42.2	49	91.2	8	49			47			48	
		4/09/93	42.2	53	95.2	8	53			49			47	
		4/27/93	54.3	63	117.3	8	63			63			64	
		4/27/93	54.3	63	117.3	8	63			63			64	
		4/27/93	54.3	62	116.3	8	62			63			64	
		4/27/93	54.3	65	119.3	8	65			64			65	
		4/27/93	54.3	67	121.3	8	67			65			65	
		4/27/93	54.3	68	122.3	8	68			65			65	
		4/27/93	54.3	75	129.3	8	75			68			66	
		4/27/93	54.3	72	126.3	8	72			70			67	
		9/21/93	54.6	85	139.6	8	85			84			83	
		9/21/93	54.6	90	144.6	8	90			92			90	
		9/21/93	54.6	91	145.6	8	91			90			88	
		9/21/93	54.6	88	142.6	8	88			87			87	
		9/21/93	54.6	87	141.6	8	87			86			86	
		9/21/93	54.6	84	138.6	8	84			83			83	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth	11" depth	12" depth
SPS-6 Bethany, MO	11 - Rubblized	6/04/92	63.1	105	168.1	12	105			90			87				
		6/04/92	63.1	104	167.1	12	104			92			86				
		6/04/92	63.1	109	172.1	12	109			94			89				
		6/04/92	63.1	109	172.1	12	109			94			89				
		6/04/92	63.1	112	175.1	12	112			95			94				
		6/04/92	63.1	110	173.1	12	110			96			94				
		6/04/92	63.1	107	170.1	12	107			97			93				
		6/04/92	63.1	106	169.1	12	106			96			92				
		6/04/92	63.1	104	167.1	12	104			96			92				
		11/17/92	37.9	48	85.9	12	48			47			47				
		11/17/92	37.9	48	85.9	12	48			47			47				
		11/17/92	37.9	48	85.9	12	48			47			47				
		11/17/92	37.9	48	85.9	12	48			47			47				
		11/17/92	37.9	48	85.9	12	48			47			47				
		11/17/92	37.9	48	85.9	12	48			47			46				
		4/29/93	58.3	76	134.3	12	76					65				62	
		4/29/93	58.3	76	134.3	12	76					65				62	
		5/10/93	65.6	83	148.6	12	83					77				74	
		5/10/93	65.6	83	148.6	12	83					77				73	
		5/10/93	65.6	80	145.6	12	80					77				73	
		5/10/93	65.6	75	140.6	12	75					76				73	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature							
							1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6	12 - Rubblized	4/29/92	44.9	57	101.9	8	57			60				63
Bethany, MO		4/29/92	44.9	61	105.9	8	61			62				63
		5/04/92	64	97	161	8	97			90				86
		5/04/92	64	98	162	8	98			90				88
		5/04/92	64	96	160	8	96			90				86
		5/04/92	64	95	159	8	95			90				86
		5/04/92	64	93	157	8	93			90				86
		5/04/92	64	91	155	8	91			88				85
		5/05/92	66.2	60	126.2	8	60			63				67
		5/05/92	66.2	59	125.2	8	59			62				64
		5/05/92	66.2	61	127.2	8	61			62				63
		5/05/92	66.2	64	130.2	8	64			62				63
		4/21/93	48.5	72	120.5	8	72			64			63	
		4/21/93	48.5	69	117.5	8	69			64			61	
		4/21/93	48.5	68	116.5	8	68			64			58	
		4/21/93	48.5	70	118.5	8	70			66			59	
		4/21/93	48.5	71	119.5	8	71			68			60	
		4/21/93	48.5	70	118.5	8	70			72			63	
		4/21/93	48.5	68	116.5	8	68			77			64	
		9/22/93	56.3	82	138.3	8	82			81			73	
		9/22/93	56.3	83	139.3	8	83			82			73	
		9/22/93	56.3	81	137.3	8	81			80			75	
		9/22/93	56.3	84	140.3	8	84			83			75	
		9/22/93	56.3	86	142.3	8	86			84			76	
		9/22/93	56.3	87	143.3	8	87			86			77	

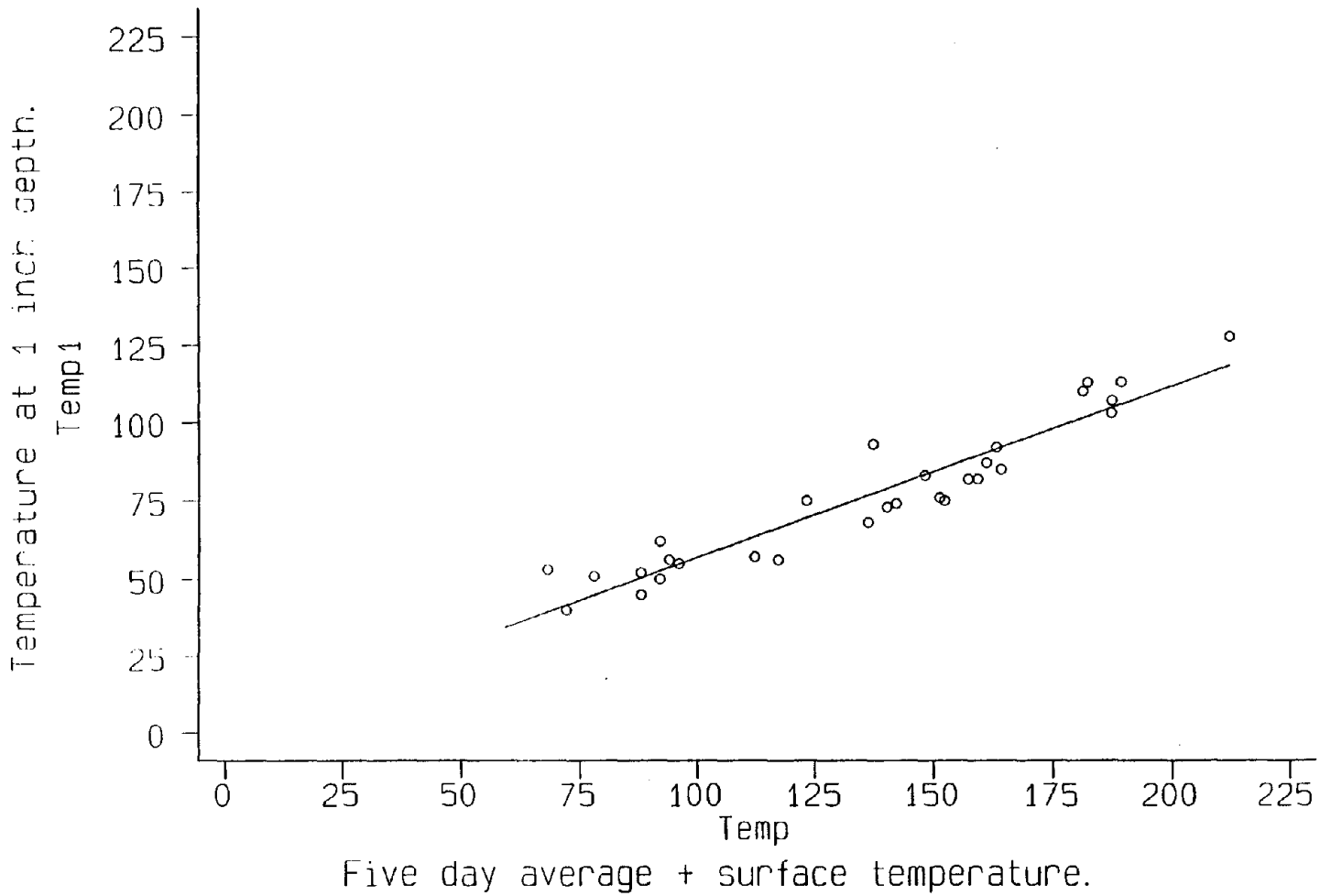
Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth	9" depth	11" depth	12" depth
SPS-6 Bethany, MO	13 - Rubblized	6/02/92	57.3	88	145.3	12	88			83			82				
		6/02/92	57.3	85	142.3	12	85			80			80				
		6/04/92	63.1	70	133.1	12	70			70			72				
		6/04/92	63.1	76	139.1	12	76			72			73				
		6/04/92	63.1	79	142.1	12	79			73			74				
		6/04/92	63.1	74	137.1	12	74			74			81				
		6/04/92	63.1	85	148.1	12	85			77			77				
		6/04/92	63.1	90	153.1	12	90			80			77				
		6/04/92	63.1	95	158.1	12	95			79			79				
		6/04/92	63.1	97	160.1	12	97			80			80				
		6/04/92	63.1	99	162.1	12	99			82			80				
		6/04/92	63.1	106	169.1	12	106			87			83				
		11/16/92	39.2	68	107.2	12	68			64			58				
		11/16/92	39.2	66	105.2	12	66			60			55				
		11/16/92	39.2	65	104.2	12	65			61			55				
		11/17/92	37.9	37	74.9	12	37			40			44				
		11/17/92	37.9	40	77.9	12	40			40			45				
		11/17/92	37.9	42	79.9	12	42			43			45				
		11/17/92	37.9	43	80.9	12	43			43			45				
		4/27/93	54.3	73	127.3	12	73					70				69	
		4/27/93	54.3	72	126.3	12	72					70				69	
		4/29/93	58.3	63	121.3	12	63					60				61	
		4/29/93	58.3	62	120.3	12	62					61				60	
		4/29/93	58.3	63	121.3	12	63					61				61	
		4/29/93	58.3	68	126.3	12	68					61				61	
		4/29/93	58.3	74	132.3	12	74					63				61	

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature 1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6	14 - Rubblized	5/06/92	65.2	51	116.2	8	51			54			59	
Bethany, MO		5/06/92	65.2	53	118.2	8	53			54			59	
		5/06/92	65.2	58	123.2	8	58			58			62	
		5/06/92	65.2	57	122.2	8	57			55			57	
		5/06/92	65.2	62	127.2	8	62			58			59	
		5/06/92	65.2	66	131.2	8	66			60			60	
		6/02/92	57.3	88	145.3	8	88			81			77	
		6/02/92	57.3	88	145.3	8	88			81			79	
		6/02/92	57.3	83	140.3	8	83			74			73	
		11/05/92	41.4	36	77.4	8	36			37			39	
		11/05/92	41.4	35	76.4	8	35			37			38	
		11/05/92	41.4	35	76.4	8	35			37			38	
		11/05/92	41.4	34	75.4	8	34			37			38	
		4/21/93	48.5	71	119.5	8	71			69			66	
		4/21/93	48.5	73	121.5	8	73			72			67	
		4/27/93	54.3	72	126.3	8	72			70			69	
		4/27/93	54.3	72	126.3	8	72			70			69	
		4/27/93	54.3	73	127.3	8	73			71			69	
		4/27/93	54.3	73	127.3	8	73			72			70	
		9/22/93	56.3	85	141.3	8	85			83			75	
		9/22/93	56.3	83	139.3	8	83			82			75	

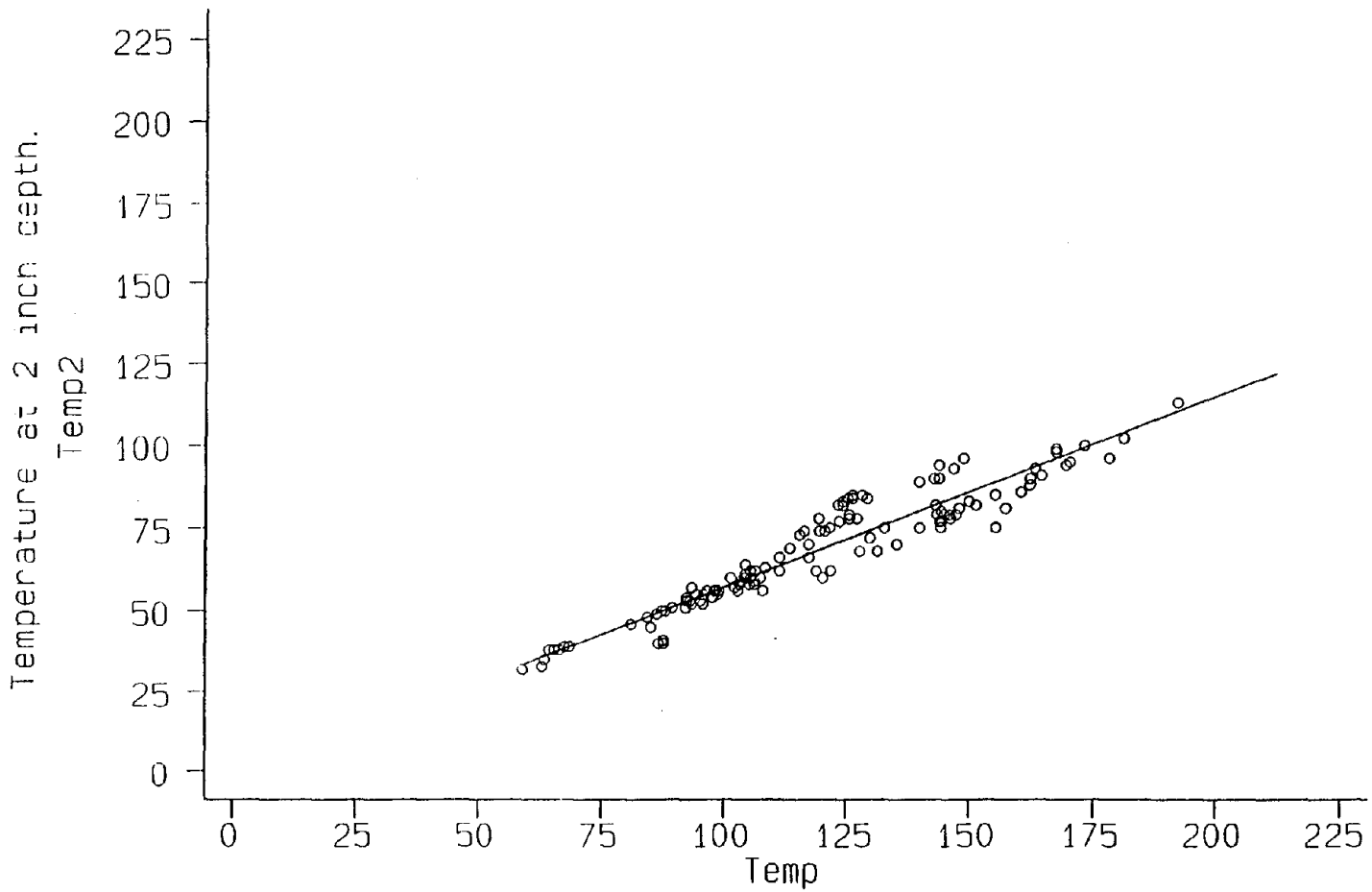
Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Asphalt pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (inches)	Actual Pavement Temperature				
							1" depth	2" depth	3" depth	4" depth	5" depth
SPS-6 Bethany, MO	15 - Typical Project	4/23/92	47.2	56	103.2	5	56				55
		4/23/92	47.2	61	108.2	5	61				57
		4/23/92	47.2	59	106.2	5	59				57
		4/23/92	47.2	57	104.2	5	57				56
		4/23/92	47.2	58	105.2	5	58				55
		4/23/92	47.2	58	105.2	5	58				56
		4/23/92	47.2	60	107.2	5	60				56
		4/23/92	47.2	62	109.2	5	62				57
		4/23/92	47.2	62	109.2	5	62				57
		4/23/92	47.2	71	118.2	5	71				62
		4/23/92	47.2	69	116.2	5	69				60
		4/23/93	50.3	59	109.3	5	59		59		
		4/23/93	50.3	63	113.3	5	63		61		
		5/13/93	64.6	58	122.6	5	58		58		
		5/13/93	64.6	59	123.6	5	59		59		
		5/13/93	64.6	60	124.6	5	60		58		
		5/13/93	64.6	62	126.6	5	62		59		
		5/13/93	64.6	70	134.6	5	70		61		
		5/13/93	64.6	73	137.6	5	73		66		
		5/13/93	64.6	78	142.6	5	78		69		

Location	Test Section No. & preparation	Date Tested	5-day avg. temperature	Concrete pvt. surf. temp.	5-day+surf. temperature	AC Thickns. (Inches)	Actual Pavement Temperature							
							1" depth	2" depth	3" depth	4" depth	5" depth	6" depth	7" depth	8" depth
SPS-6 Bethany, MO	16 - Min. Restoration	4/22/92	51.3	58	109.3	8	58			51			48	
		4/22/92	51.3	63	114.3	8	63			58			49	
		4/22/92	51.3	70	121.3	8	70			58			50	
		4/22/92	51.3	71	122.3	8	71			59			52	
		4/22/92	51.3	72	123.3	8	72			64			57	
		4/22/92	51.3	78	129.3	8	78			66			59	
		4/22/92	51.3	74	125.3	8	74			63			58	
		4/22/92	51.3	74	125.3	8	74			64			54	
		4/22/92	51.3	79	130.3	8	79			68			60	
		4/22/92	51.3	73	124.3	8	73			66			58	
		4/22/92	51.3	73	124.3	8	73			66			58	
		4/23/93	50.3	50	100.3	8	50			59			60	
		4/23/93	50.3	52	102.3	8	52			59			60	
		5/12/93	65.2	95	160.2	8	95			90			85	
		5/12/93	65.2	93	158.2	8	93			89			87	
		5/12/93	65.2	90	155.2	8	90			88			84	
		5/12/93	65.2	90	155.2	8	90			89			83	
		5/12/93	65.2	87	152.2	8	87			86			82	
		5/12/93	65.2	87	152.2	8	87			85			81	

Five day average + surface temp vs. temperature at 1 inch depth.
Regression Equation: Temp1=.549*Temp+2.152, Rsquare=.8966, n=30, S(y.x)=7.6

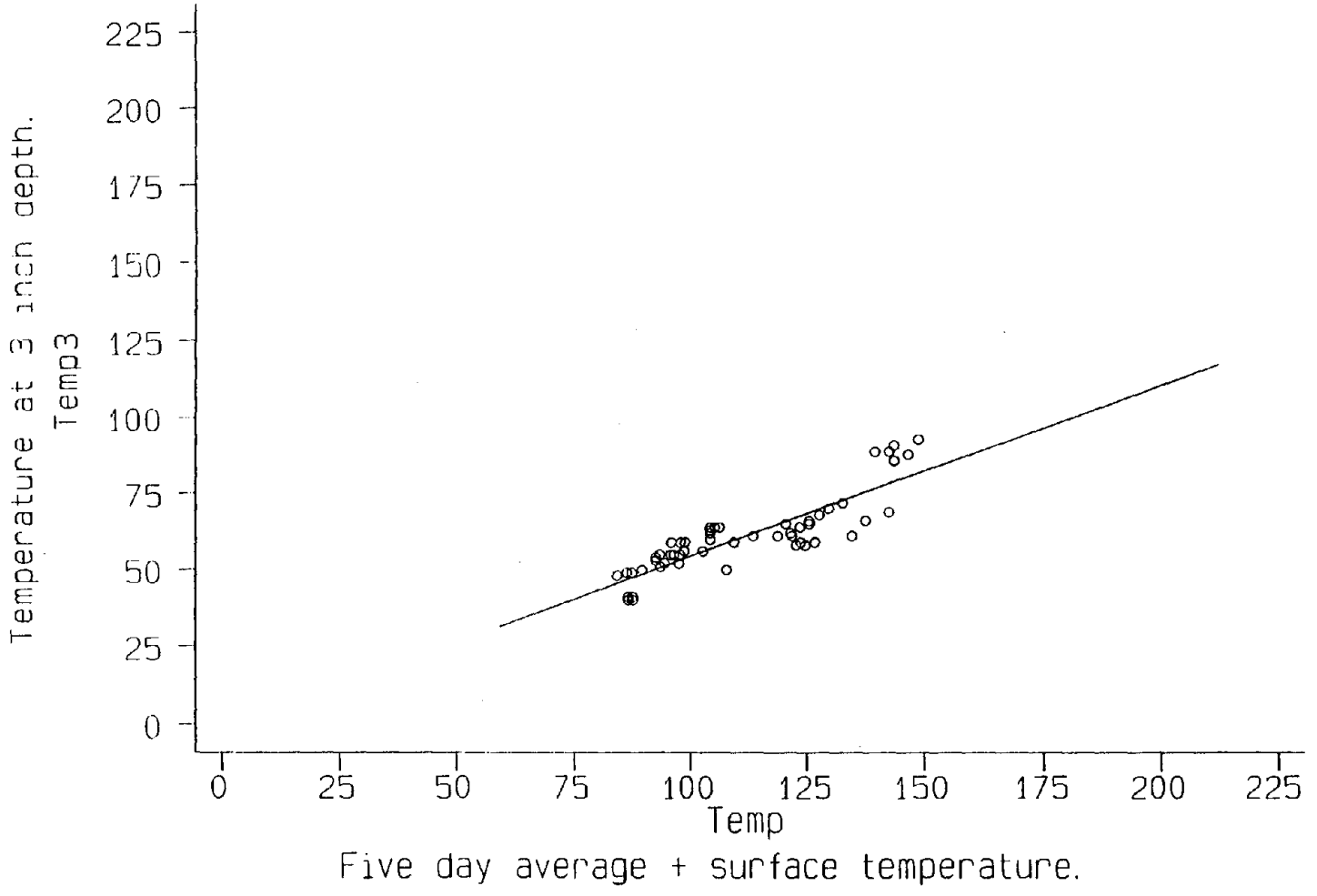


Five day average + surface temp vs. temperature at 2 inch depth.
Regression Equation: Temp2=.577*Temp-.482, Rsquare=.9070, n=132, S(y.x)=5.5

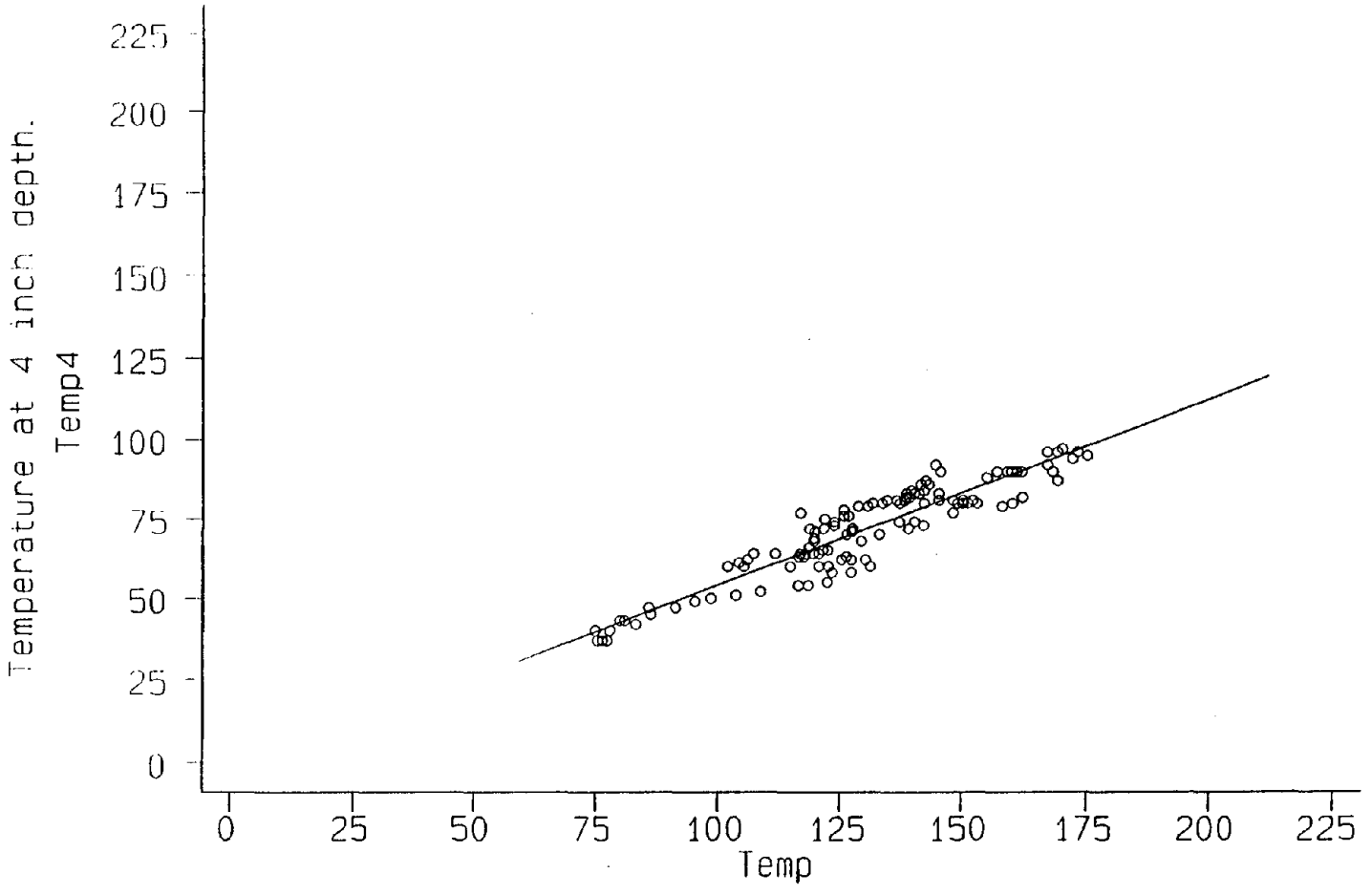


Five day average + surface temperature.

Five day average + surface temp vs. temperature at 3 inch depth.
Regression Equation: Temp3=.564*Temp-1.88, Rsquare=.7514, n=56, S(y.x)=6.3

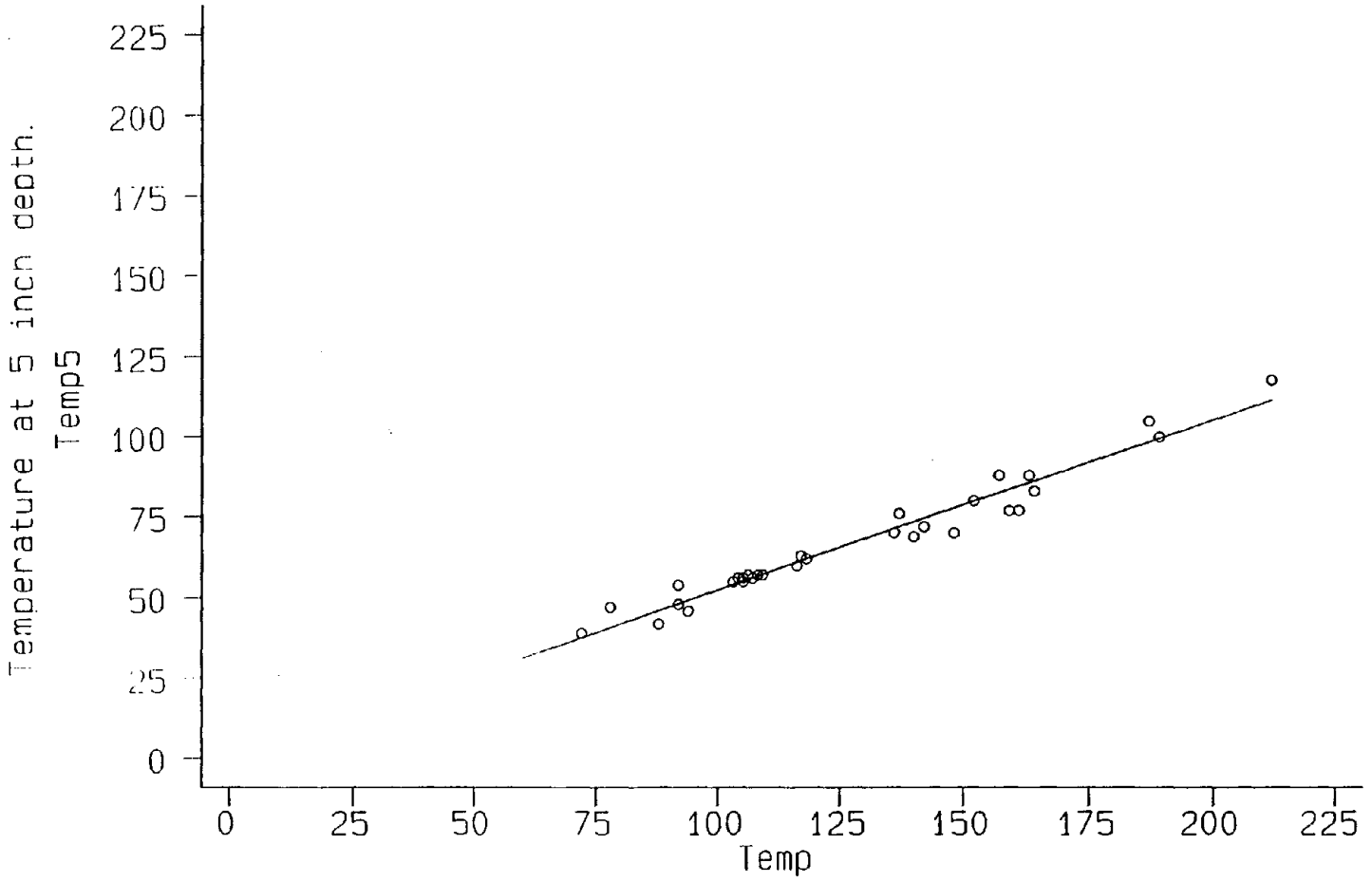


Five day average + surface temp vs. temperature at 4 inch depth.
Regression Equation: Temp4=.583*Temp-4.025, Rsquare=.8851, n=125, S(y.x)=5.3



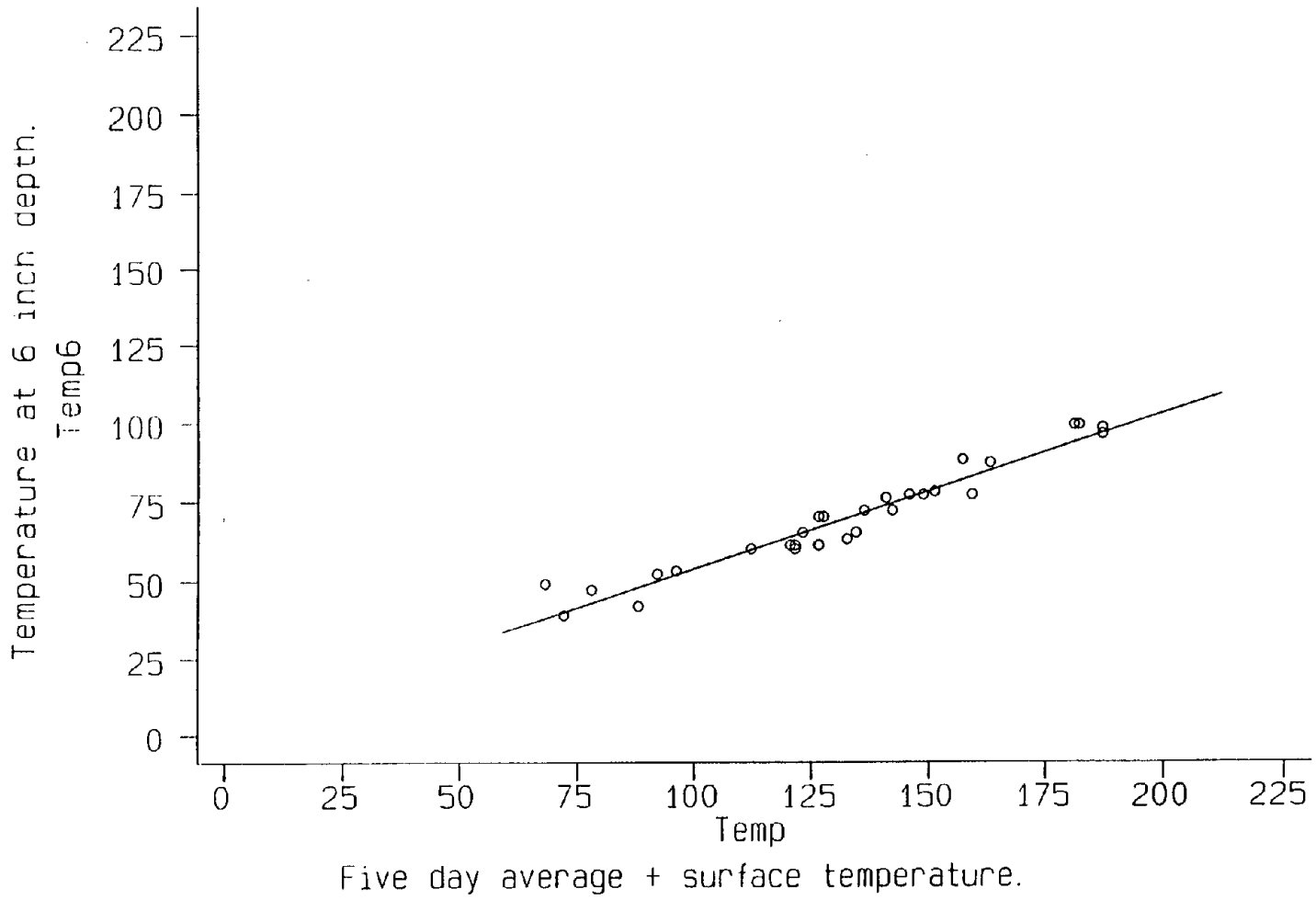
Five day average + surface temperature.

Five day average + surface temp vs. temperature at 5 inch depth.
Regression Equation: Temp5=.528*Temp-.363, Rsquare=.9580, n=32, S(y.x)=3.9

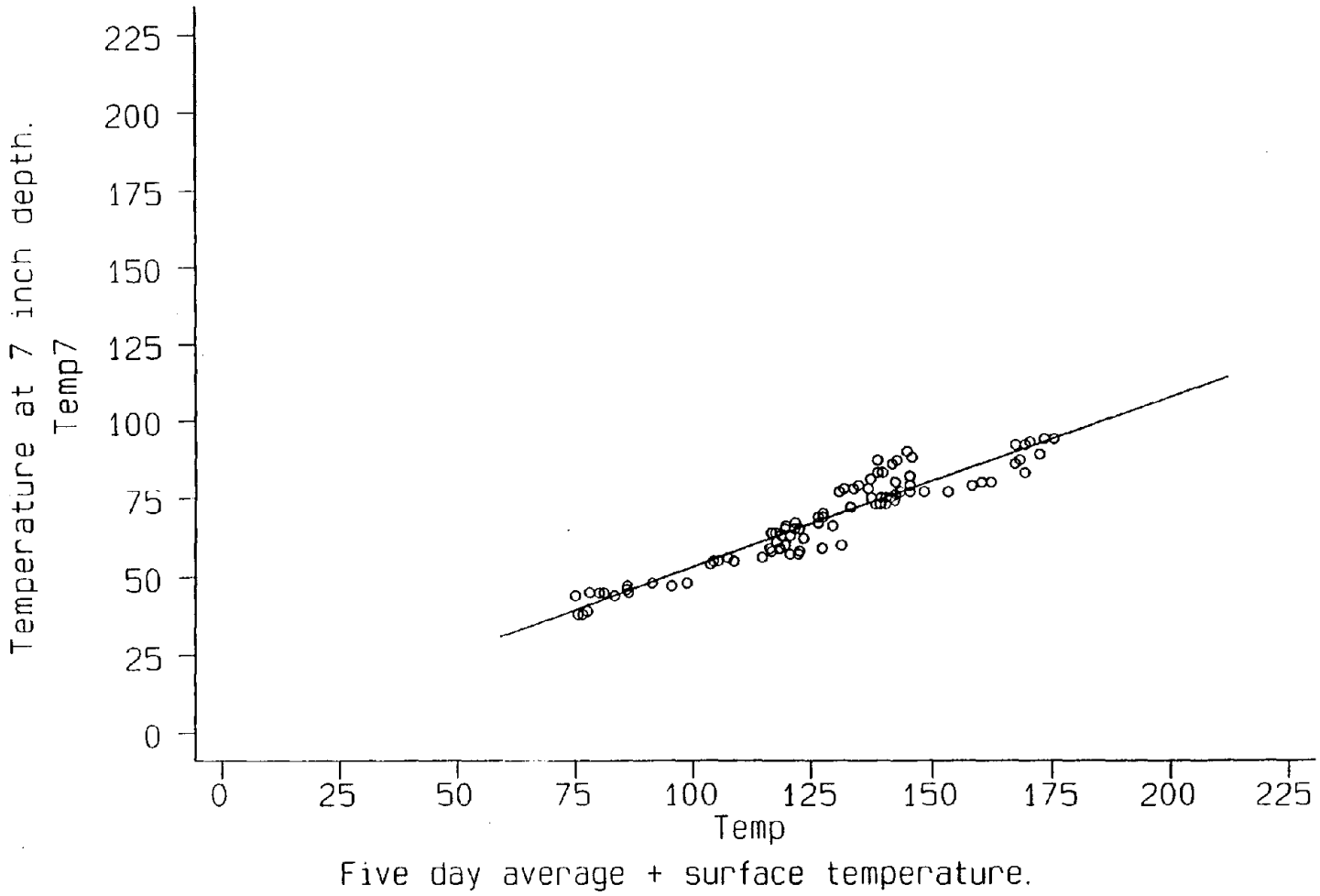


Five day average + surface temperature.

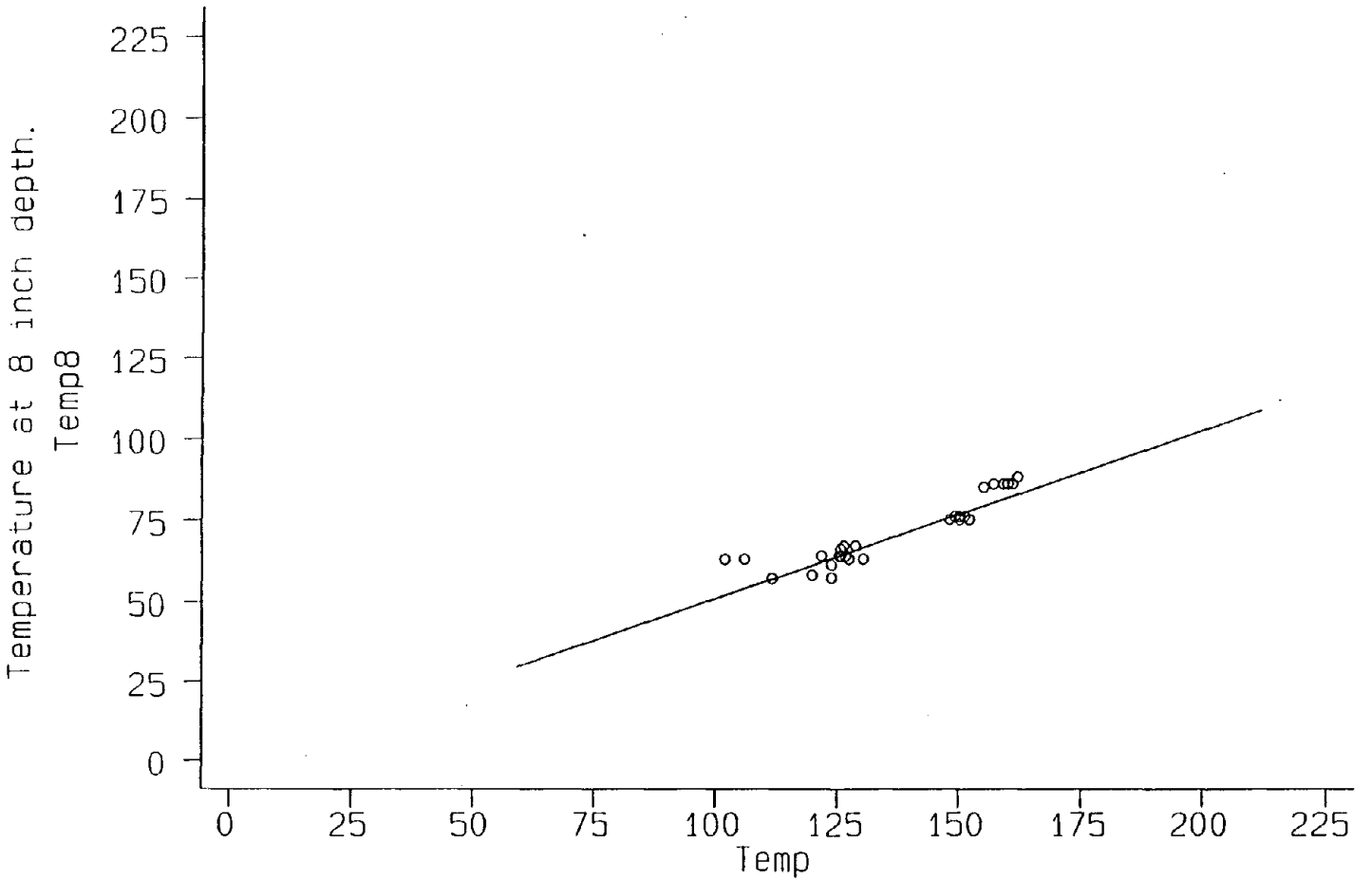
Five day average + surface temp vs. temperature at 6 inch depth.
Regression Equation: Temp6=.490*Temp+4.725, Rsquare=.9347, n=31, S(y.x)=4.2



Five day average + surface temp vs. temperature at 7 inch depth.
Regression Equation: Temp7=.545*Temp-1.228, Rsquare=.9093, n=98, S(y.x)=4.6

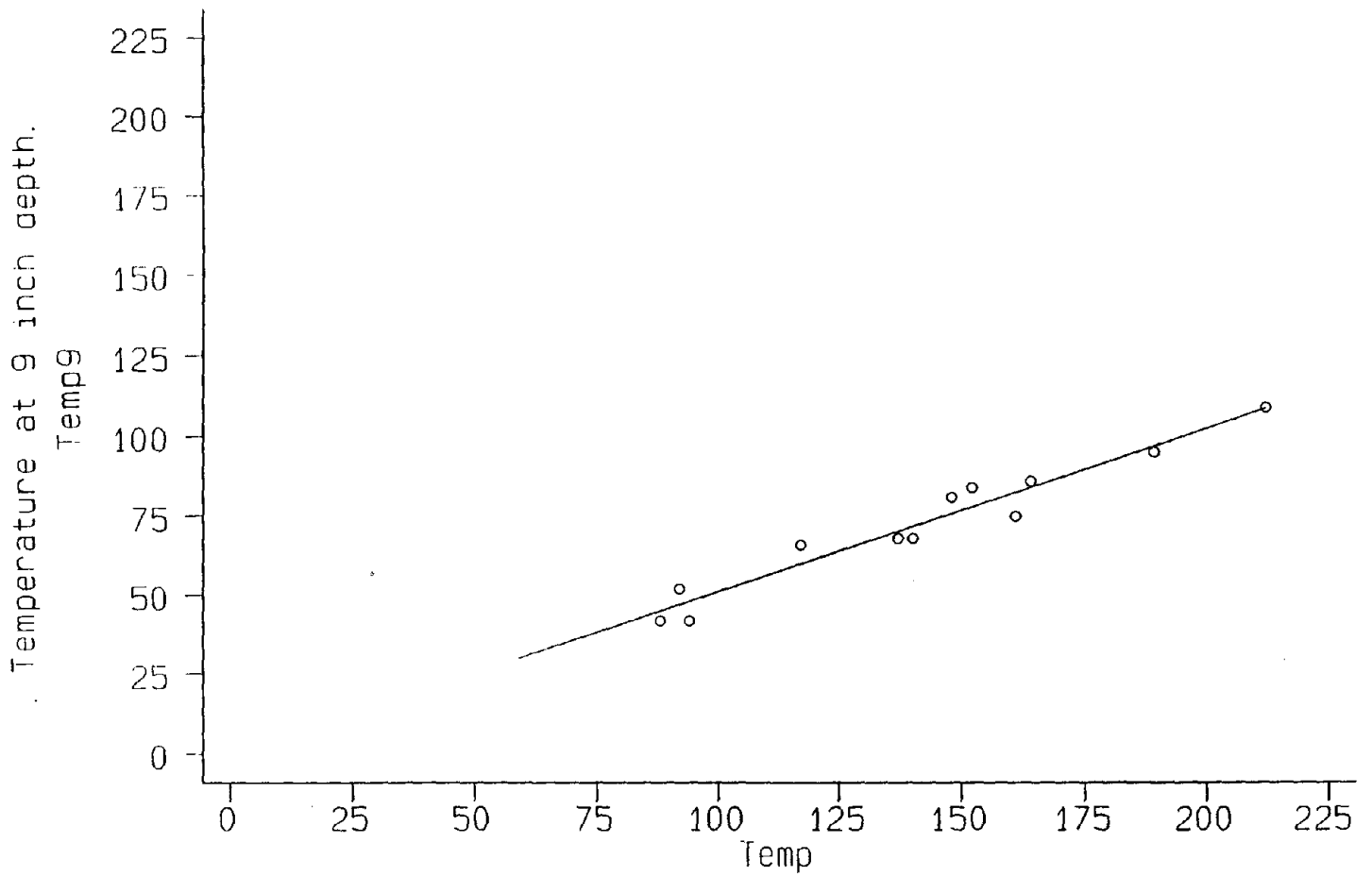


Five day average + surface temp vs. temperature at 8 inch depth.
Regression Equation: Temp8=.515*Temp-.632, Rsquare=.8476, n=27, S(y.x)=4.0



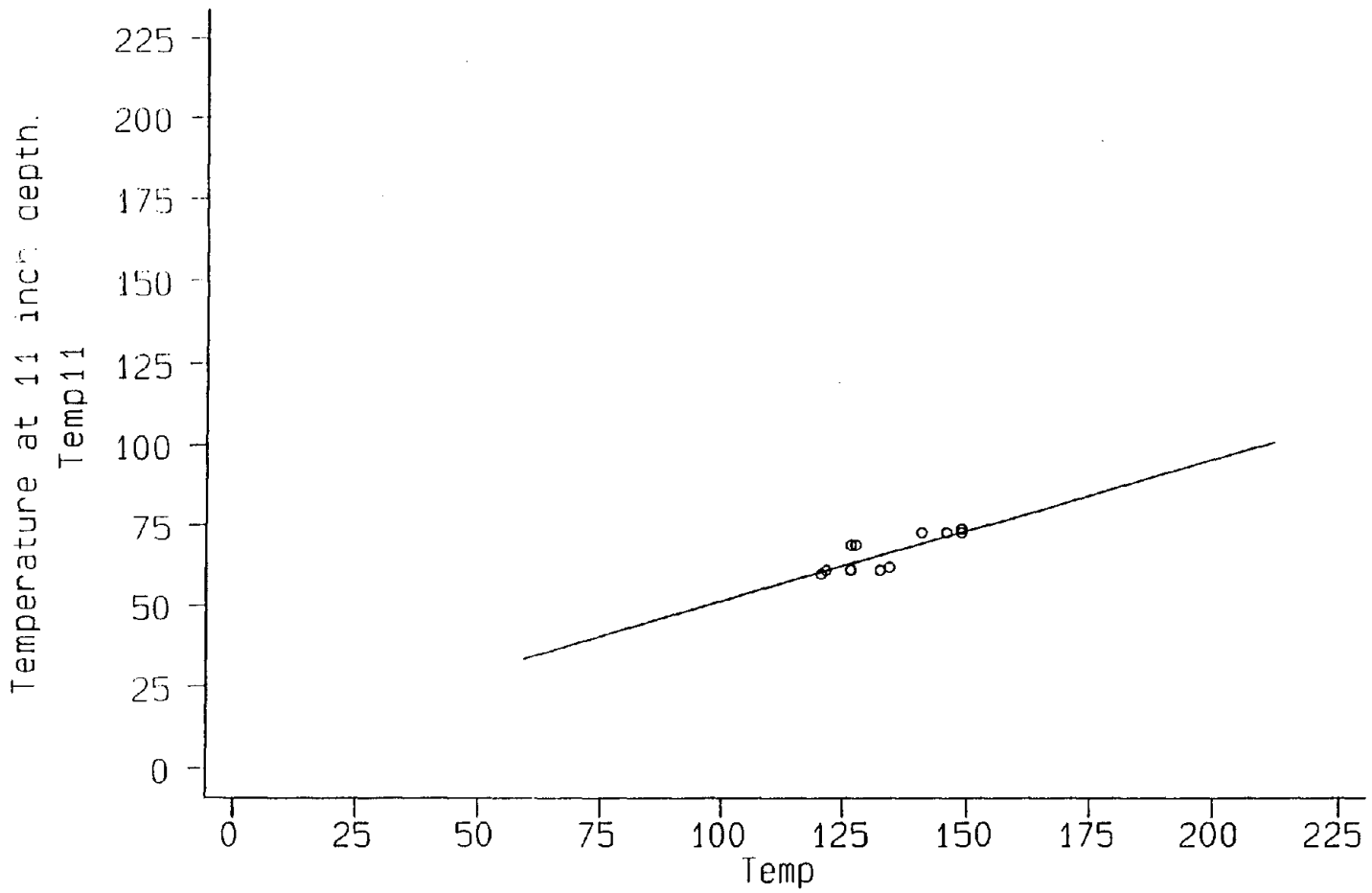
Five day average + surface temperature.

Five day average + surface temp vs. temperature at 9 inch depth.
Regression Equation: Temp9=.514*Temp-.167, Rsquare=.9447, n=12, S(y.x)=5.0



Five day average + surface temperature.

Five day average + surface temp vs. temperature at 11 inch depth.
Regression Equation: Temp11=.441*Temp+7.420, Rsquare=.6208, n=13, S(y.x)=3.7



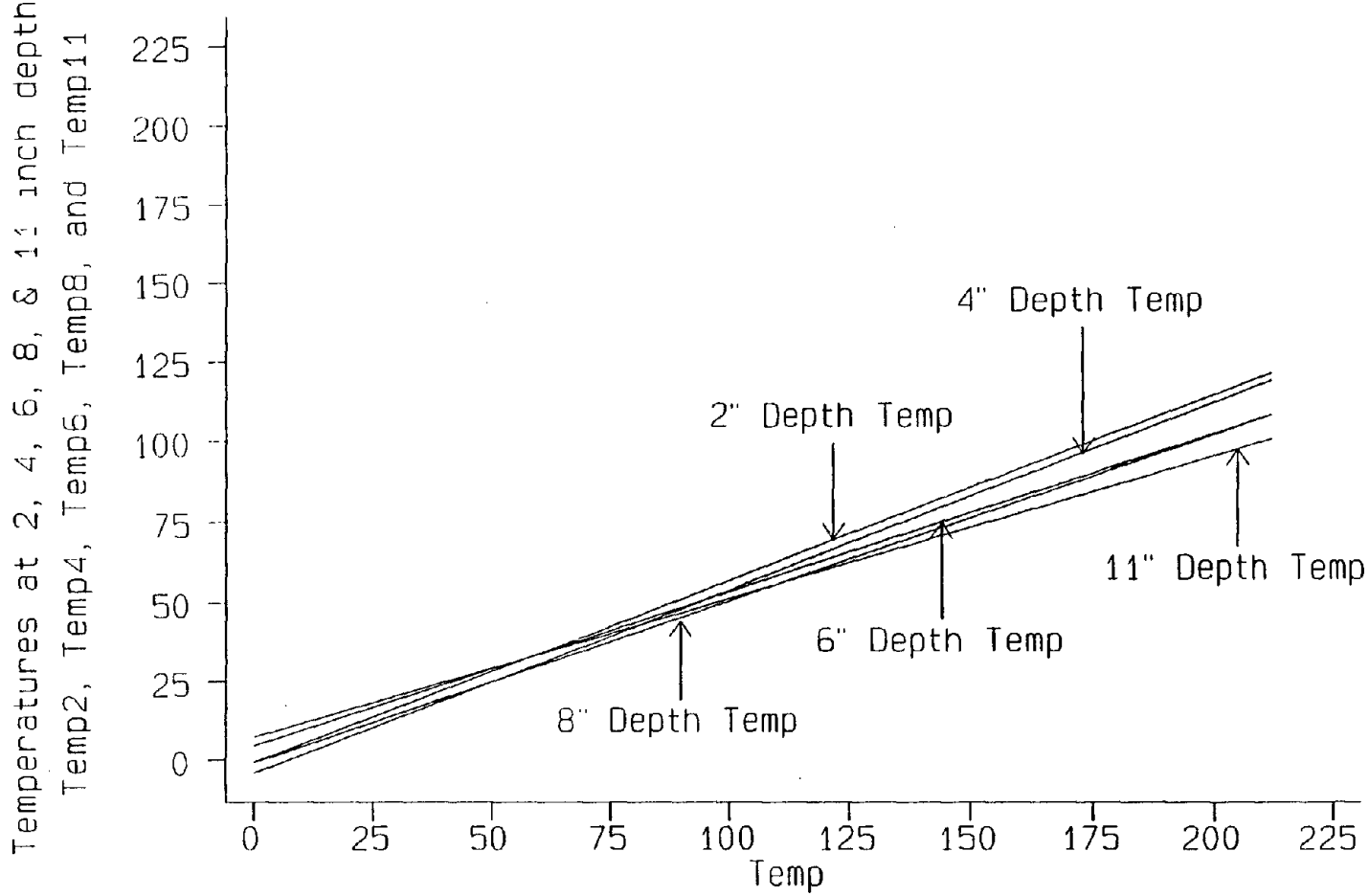
Five day average + surface temperature.

Regression values for 5 day average + surface temperature vs. depth temperature
(Asphalt pavement temperatures.)
Estimated linear regression equation: $Y^\wedge = m*X + b$
X = 5 Day average + surface temperature
Y = Depth temperature

Variable:	Sample Size n:	F–value:	Prob. > F:	Significant (Y/N):	Rsquare:	Mean Sq. Error MSE:	SqRt(MSE) S(y.x):
Temp1	30	242.68	0	Y	0.8966	57.95516	7.612829
Temp2	132	1267.5	0	Y	0.907	30.62344	5.533845
Temp3	56	163.22	0	Y	0.7514	40.06890	6.330000
Temp4	125	947.5	0	Y	0.8851	28.48441	5.337078
Temp5	32	683.99	0	Y	0.958	14.97158	3.869313
Temp6	31	414.9	0	Y	0.9347	17.90409	4.231323
Temp7	98	962.84	0	Y	0.9093	21.13139	4.596889
Temp8	27	139.09	0	Y	0.8476	16.31185	4.038794
Temp9	12	170.74	0	Y	0.9447	25.42144	5.041968
Temp11	13	18.01	0.0014	Y	0.6208	13.68139	3.698836

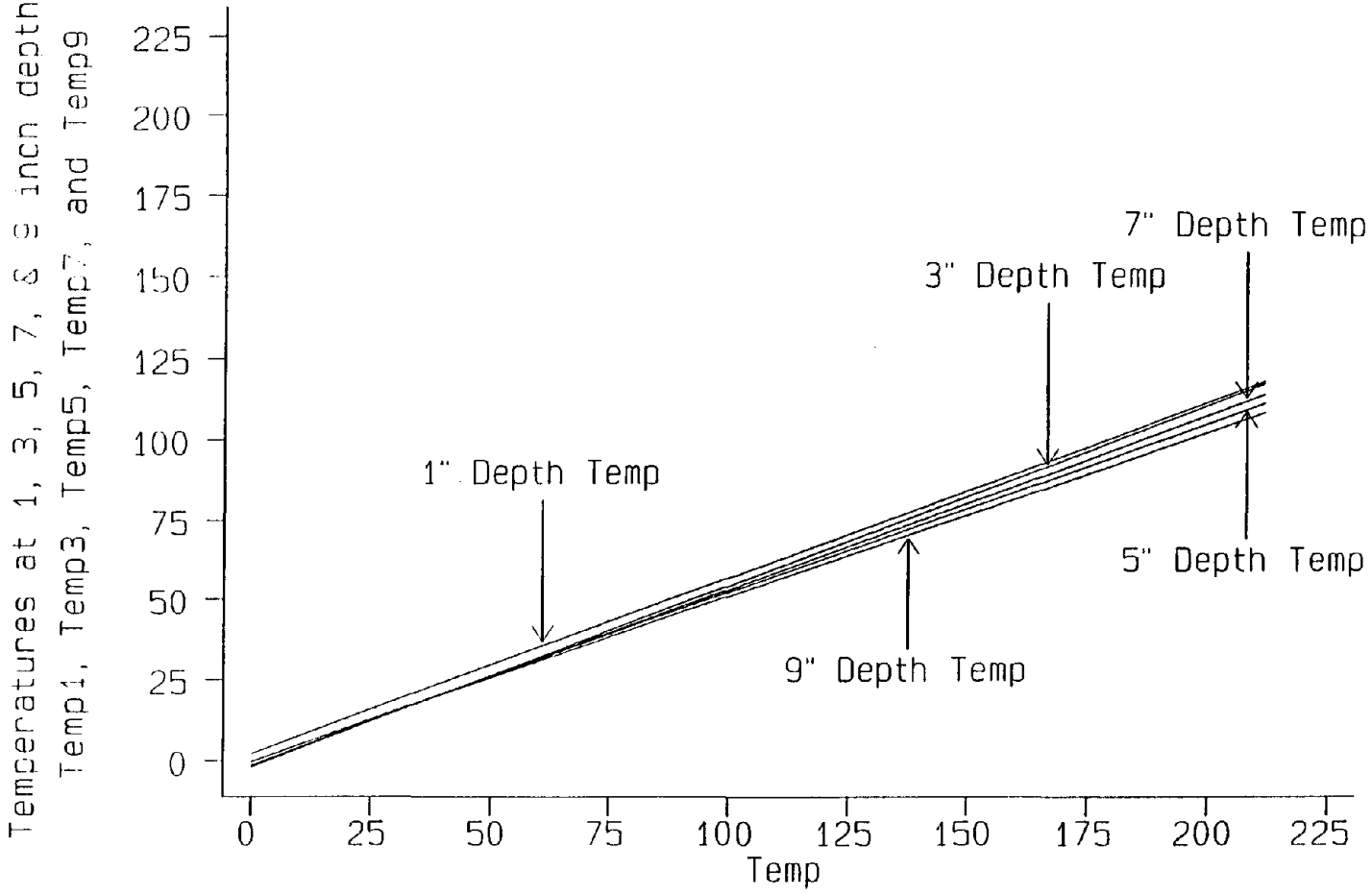
Variable:	b Y–int.:	m Slope:	Std. Err. Coeff.(m):	T–value:	Prob. > T:	Significant (Y/N):
Temp1	2.151643	0.548537	0.035211	15.57827	0	Y
Temp2	–0.48153	0.577301	0.016215	35.60181	0	Y
Temp3	–1.88034	0.563716	0.044124	12.77571	0	Y
emp4	–4.02543	0.582710	0.018930	30.78141	0	Y
Temp5	–0.36269	0.528364	0.020202	26.15316	0	Y
Temp6	4.724505	0.490000	0.024056	20.36915	0	Y
Temp7	–1.22778	0.545164	0.017569	31.02954	0	Y
Temp8	–0.63232	0.514906	0.043659	11.79378	0	Y
Temp9	–0.16731	0.513581	0.039304	13.06674	0	Y
Temp11	7.420474	0.441511	0.104030	4.244042	0.001	Y

Regression lines for five day average + surface temperature versus temperatures at 2, 4, 6, 8, & 11 inch depths.



Five day average + surface temperature.

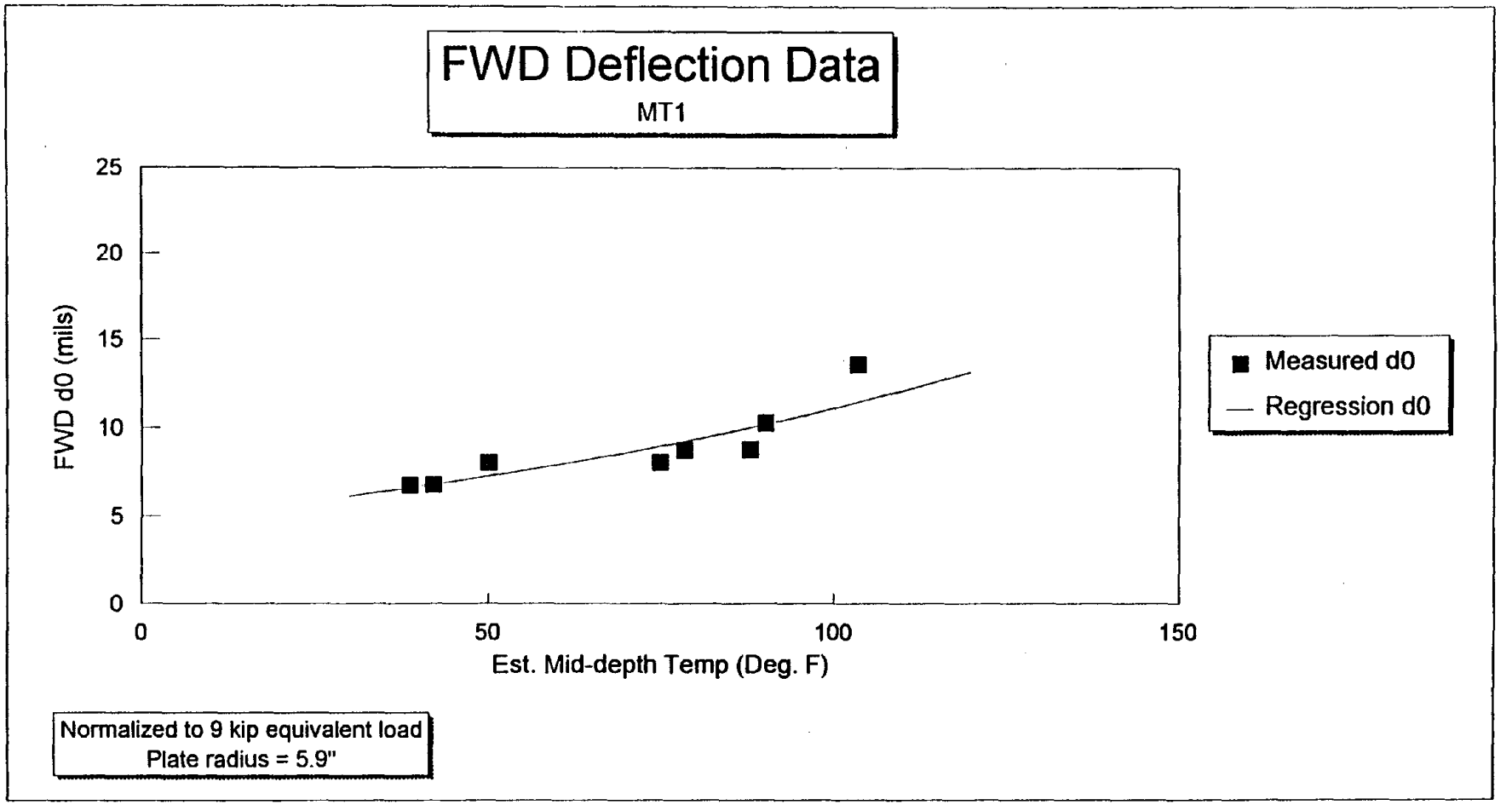
Regression lines for five day average + surface temperature versus temperatures at 1, 3, 5, 7, & 9 inch depths.

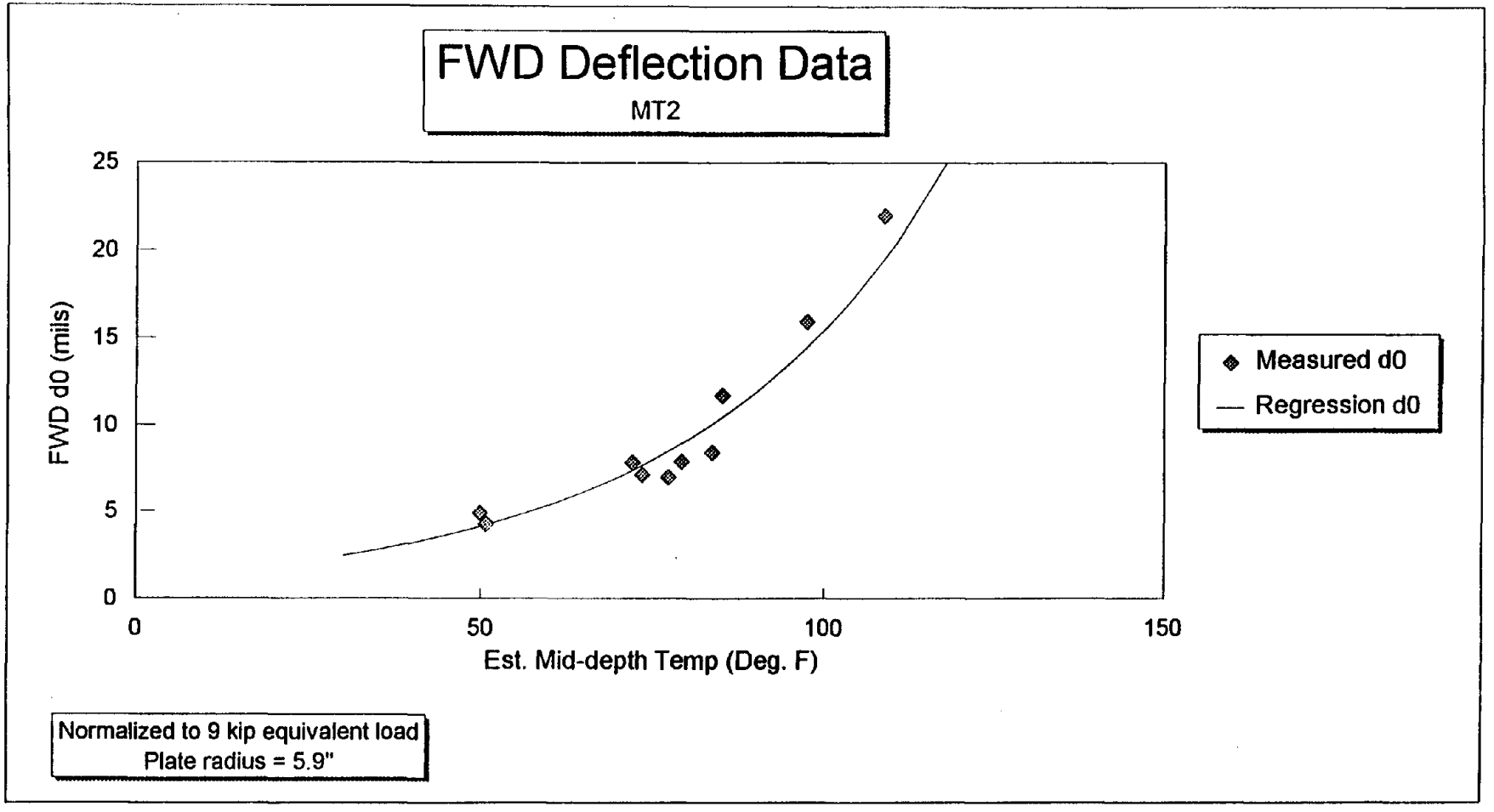


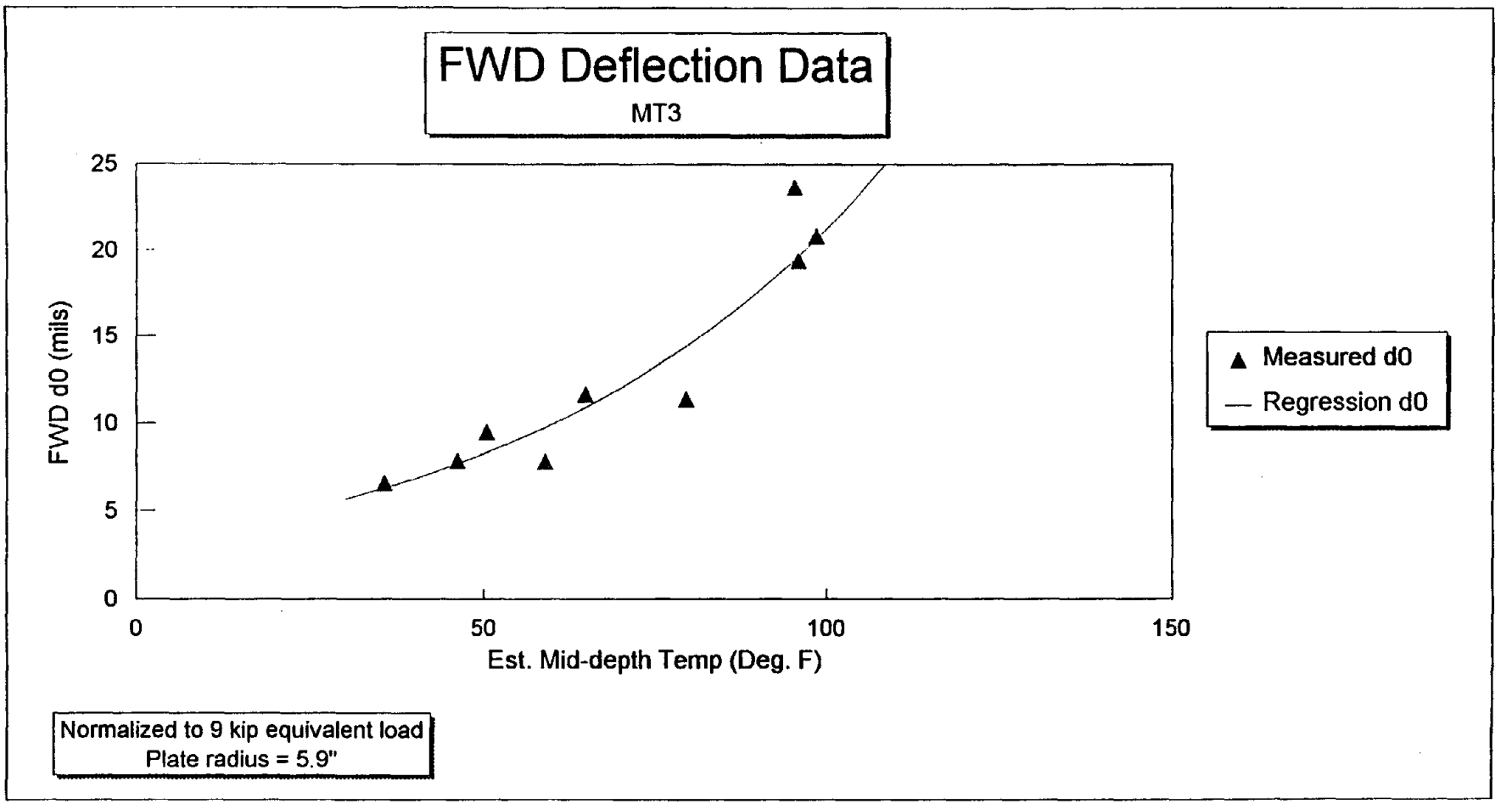
Five day average + surface temperature.

APPENDIX B

Data and Graphs Relating to the Empirical Temperature Adjustment Factor Curves


FWD Deflection Data
MT1
FWD d0 (mils)
25
20
15
10
5
0
0
50
100
150
Est. Mid-depth Temp (Deg. F)
Measured d0
Regression d0
Normalized to 9 kip equivalent load
Plate radius = 5.9"


FWD Deflection Data
MT2
FWD d0 (mils)
25
20
15
10
5
0
0
50
100
150
Est. Mid-depth Temp (Deg. F)
Measured d0
Regression d0
Normalized to 9 kip equivalent load
Plate radius = 5.9"


FWD Deflection Data
MT3
FWD d0 (mils)
25
20
15
10
5
0
0
50
100
150
Est. Mid-depth Temp (Deg. F)
Measured d0
Regression d0
Normalized to 9 kip equivalent load
Plate radius = 5.9"

MT1 Regression FWD Deflection Equation
Correlation Coefficient = 0.895540

$$d_0 = 4.738428e^{(0.008485*TEMP)}$$

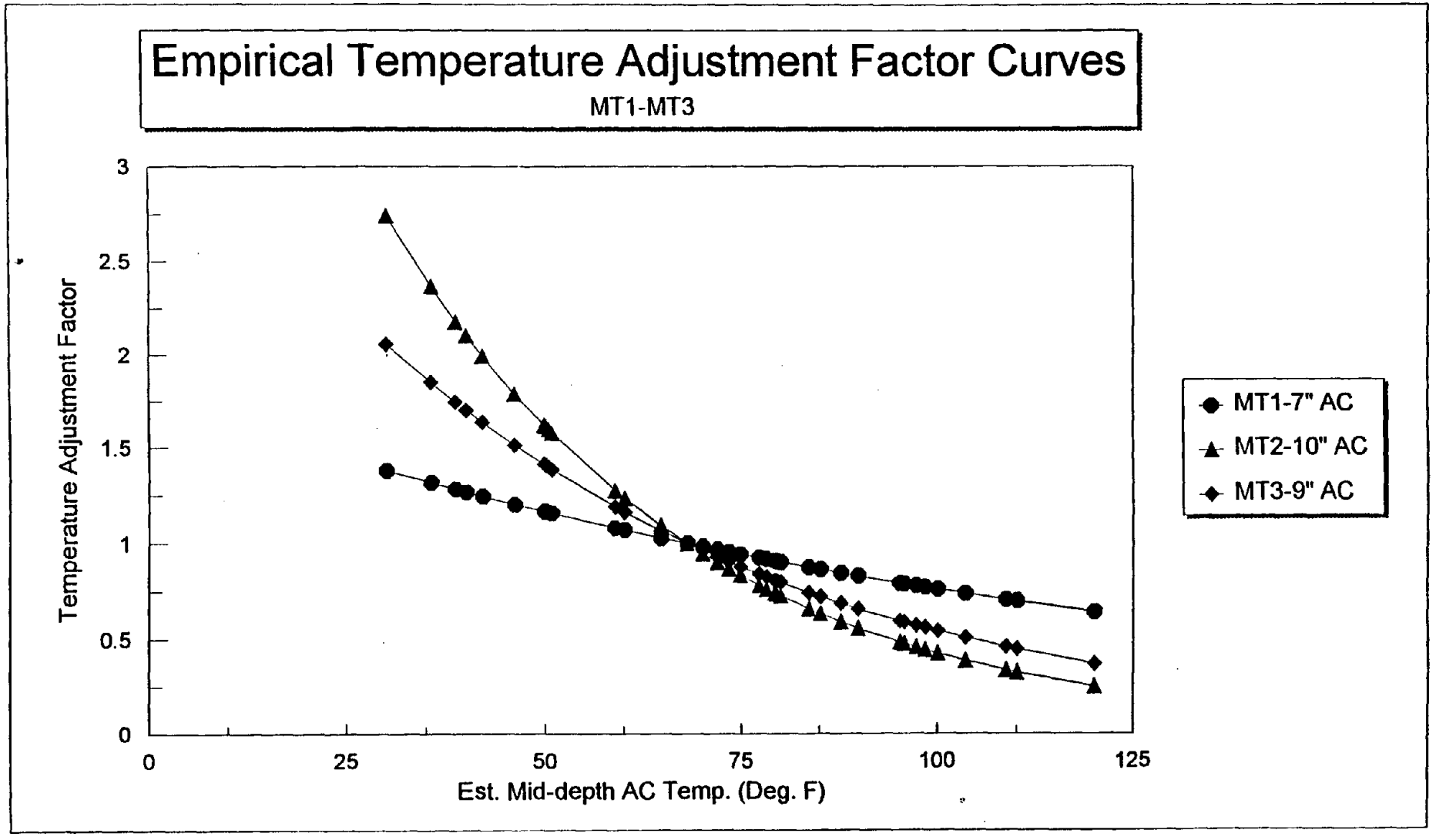
MT2 Regression FWD Deflection Equation
Correlation Coefficient = 0.962902

$$d_0 = 1.090210e^{(0.026551*TEMP)}$$

MT3 Regression FWD Deflection Equation
Correlation Coefficient = 0.950967

$$d_0 = 3.188715e^{(0.018935*TEMP)}$$

Est. mid-depth temp. (Deg. F)	FWD d0 (mils) MT1	FWD d0 (mils) MT2	FWD d0 (mils) MT3	Regr. d0 (mils) MT1	Regr. d0 (mils) MT2	Regr. d0 (mils) MT3	TAF MT1 7" AC depth	TAF MT2 10" AC depth	TAF MT3 9" AC depth
30				6.11	2.42	5.64	1.3805	2.7427	2.0574
35.6			6.54	6.41	2.80	6.26	1.3168	2.3659	1.8511
38.7	6.73			6.58	3.05	6.65	1.2822	2.1766	1.7439
40				6.65	3.15	6.81	1.2682	2.1031	1.7016
42.1	6.74			6.77	3.33	7.09	1.2459	1.9896	1.6354
46.1			7.87	7.01	3.71	7.66	1.2039	1.7871	1.5146
49.8		4.89		7.23	4.09	8.21	1.1669	1.6211	1.4126
50.0	8			7.24	4.11	8.24	1.1652	1.6135	1.4079
50.4			9.49	7.26	4.15	8.30	1.1615	1.5974	1.3978
50.8		4.25		7.29	4.20	8.36	1.1573	1.5795	1.3866
58.8			7.77	7.80	5.20	9.74	1.0811	1.2762	1.1905
60				7.88	5.36	9.96	1.0702	1.2367	1.1640
64.6			11.64	8.20	6.06	10.88	1.0290	1.0937	1.0661
68				8.44	6.63	11.60	1.0000	1.0000	1.0000
70				8.58	6.99	12.04	0.9832	0.9483	0.9627
71.9		7.8		8.72	7.35	12.48	0.9678	0.9027	0.9294
73.3		7.08		8.83	7.64	12.83	0.9558	0.8682	0.9039
74.8	8.01			8.94	7.94	13.19	0.9441	0.8351	0.8791
77.2		6.96		9.13	8.48	13.82	0.9246	0.7824	0.8390
78.2	8.72			9.20	8.69	14.06	0.9173	0.7634	0.8245
79.2		7.84		9.28	8.93	14.34	0.9093	0.7427	0.8084
79.4			11.35	9.30	8.98	14.40	0.9076	0.7384	0.8051
80				9.34	9.12	14.56	0.9032	0.7272	0.7963
83.6		8.39		9.63	10.04	15.60	0.8759	0.6606	0.7435
85.1		11.7		9.75	10.44	16.04	0.8651	0.6353	0.7230
87.8	8.73			9.98	11.20	16.87	0.8457	0.5919	0.6873
90.0	10.26			10.17	11.89	17.61	0.8297	0.5575	0.6585
95.3			23.68	10.63	13.68	19.46	0.7934	0.4848	0.5959
95.8			19.4	10.68	13.87	19.66	0.7899	0.4780	0.5899
97.3		15.92		10.82	14.45	20.24	0.7797	0.4589	0.5730
98.4			20.81	10.92	14.88	20.67	0.7724	0.4456	0.5611
100				11.07	15.51	21.29	0.7622	0.4276	0.5447
103.5	13.53			11.41	17.04	22.76	0.7397	0.3893	0.5093
108.6		21.97		11.91	19.49	25.07	0.7086	0.3402	0.4626
110				12.05	20.23	25.74	0.7002	0.3279	0.4505
120				13.12	26.38	31.12	0.6433	0.2514	0.3726


Empirical Temperature Adjustment Factor Curves
MT1-MT3
Temperature Adjustment Factor
3
2.5
2
1.5
1
0.5
0
0
25
50
75
100
125
Est. Mid-depth AC Temp. (Deg. F)
MT1-7" AC
MT2-10" AC
MT3-9" AC

APPENDIX C

Data and Graphs Relating to the Theoretical Temperature Adjustment Factor Curves

SAMPLE CALCULATIONS

Given:
h_b = 4 inches
E_b = 30 ksi
h_{ac} = 2 inches
M_r = 10 ksi
t_p = 30 deg. F
E_{ac} = 2293.46 ksi

where:
h_b = height of base
E_b = Modulus of Elasticity of base
h_{ac} = height of AC
M_r = resilient Modulus of subgrade
t_p = average AC mix temperature
E_{ac} = estimated Modulus of Elasticity at given average AC mix temperature

$$h_{equivalent} = h_b * \sqrt[3]{\frac{E_b}{E_{ac}}} + h_{ac}$$

$$h_{equivalent} = 4 * \sqrt[3]{\frac{30}{2293.46}} + 2 = h_{E_p} = 2.942$$

$$d_0 = 1.5pa\left\{\frac{1}{M_r\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_p}{M_r}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right]}{E_p}\right\}$$

$$d_0 = 1.5*82.3*5.9\left\{\frac{1}{10\sqrt{1+\left(\frac{2.942}{5.9}\sqrt[3]{\frac{2293.46}{10}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{2.942}{5.9}\right)^2}}\right]}{2293.46}\right\} = 22.6731\ mils$$

at $68°F$, $d_0 = 27.9141$ *mils found by the same method as above*

$$TAF = \frac{d_{0_{68}}}{d_{0_T}} \quad \textit{where } T = 30°F \textit{ as given above}$$

$$TAF = \frac{27.9141}{22.6731} = 1.231$$

Eb =	30 ksi
hac =	2 inches

Eac (ksi)	hEp (inches)	tp (deg. F)	Mr 10 ksi d0 (mils)	Mr 15 ksi d0 (mils)	Mr 20 ksi d0 (mils)	Mr 25 ksi d0 (mils)	Mr 30 ksi d0 (mils)	Mr 35 ksi d0 (mils)	Mr 10 ksi TAF	Mr 15 ksi TAF	Mr 20 ksi TAF	Mr 25 ksi TAF	Mr 30 ksi TAF	Mr 35 ksi TAF
2293.46	2.942	30	22.6731	17.0483	13.8932	11.8355	10.3709	9.2670	1.231	1.222	1.214	1.208	1.202	1.197
2074.71	2.974	35	23.1394	17.3884	14.1631	12.0600	10.5634	9.4356	1.206	1.198	1.191	1.185	1.180	1.176
1850.36	3.012	40	23.6743	17.7778	14.4716	12.3163	10.7828	9.6275	1.179	1.172	1.166	1.161	1.156	1.152
1627.24	3.057	45	24.2778	18.2160	14.8182	12.6037	11.0286	9.8422	1.150	1.144	1.139	1.134	1.130	1.127
1411.23	3.108	50	24.9495	18.7025	15.2020	12.9214	11.2998	10.0788	1.119	1.114	1.110	1.106	1.103	1.101
1207.09	3.167	55	25.6885	19.2362	15.6221	13.2683	11.5954	10.3361	1.087	1.083	1.080	1.077	1.075	1.073
1018.40	3.235	60	26.4936	19.8156	16.0769	13.6431	11.9139	10.6130	1.054	1.051	1.049	1.048	1.046	1.045
847.58	3.313	65	27.3627	20.4388	16.5645	14.0438	12.2538	10.9078	1.020	1.019	1.019	1.018	1.017	1.017
754.20	3.365	68	27.9141	20.8329	16.8720	14.2959	12.4672	11.0925	1.000	1.000	1.000	1.000	1.000	1.000
695.91	3.403	70	28.2932	21.1032	17.0826	14.4683	12.6130	11.2185	0.987	0.987	0.988	0.988	0.988	0.989
563.73	3.505	75	29.2811	21.8055	17.6282	14.9139	12.9889	11.5430	0.953	0.955	0.957	0.959	0.960	0.961
450.57	3.621	80	30.3215	22.5414	18.1977	15.3774	13.3788	11.8786	0.921	0.924	0.927	0.930	0.932	0.934
355.36	3.755	85	31.4086	23.3062	18.7869	15.8553	13.7794	12.2225	0.889	0.894	0.898	0.902	0.905	0.908
276.56	3.908	90	32.5350	24.0942	19.3911	16.3434	14.1873	12.5716	0.858	0.865	0.870	0.875	0.879	0.882
212.41	4.083	95	33.6925	24.8989	20.0052	16.8375	14.5988	12.9227	0.828	0.837	0.843	0.849	0.854	0.858
161.00	4.285	100	34.8717	25.7134	20.6237	17.3330	15.0099	13.2724	0.800	0.810	0.818	0.825	0.831	0.836
120.45	4.517	105	36.0624	26.5305	21.2408	17.8253	15.4169	13.6175	0.774	0.785	0.794	0.802	0.809	0.815
88.94	4.784	110	37.2540	27.3425	21.8509	18.3098	15.8160	13.9549	0.749	0.762	0.772	0.781	0.788	0.795
64.82	5.094	115	38.4358	28.1422	22.4484	18.7824	16.2039	14.2817	0.726	0.740	0.752	0.761	0.769	0.777
46.63	5.453	120	39.5969	28.9226	23.0285	19.2392	16.5776	14.5958	0.705	0.720	0.733	0.743	0.752	0.760

Eb =	30 ksi
hac =	4 inches

Eac (ksi)	hEp (inches)	tp (deg. F)	Mr 10 ksi d0 (mils)	Mr 15 ksi d0 (mils)	Mr 20 ksi d0 (mils)	Mr 25 ksi d0 (mils)	Mr 30 ksi d0 (mils)	Mr 35 ksi d0 (mils)	Mr 10 ksi TAF	Mr 15 ksi TAF	Mr 20 ksi TAF	Mr 25 ksi TAF	Mr 30 ksi TAF	Mr 35 ksi TAF
2293.46	4.942	30	13.9415	10.5794	8.6896	7.4545	6.5736	5.9082	1.316	1.311	1.306	1.302	1.298	1.294
2074.71	4.974	35	14.3079	10.8542	8.9130	7.6444	6.7396	6.0562	1.282	1.277	1.273	1.269	1.266	1.263
1850.36	5.012	40	14.7340	11.1734	9.1723	7.8646	6.9319	6.2275	1.245	1.241	1.237	1.234	1.231	1.228
1627.24	5.057	45	15.2221	11.5387	9.4687	8.1160	7.1514	6.4229	1.205	1.202	1.198	1.196	1.193	1.191
1411.23	5.108	50	15.7750	11.9519	9.8035	8.3998	7.3988	6.6429	1.163	1.160	1.157	1.155	1.153	1.151
1207.09	5.167	55	16.3954	12.4149	10.1782	8.7169	7.6750	6.8883	1.119	1.117	1.115	1.113	1.112	1.110
1018.40	5.235	60	17.0863	12.9294	10.5939	9.0683	7.9806	7.1595	1.074	1.072	1.071	1.070	1.069	1.068
847.58	5.313	65	17.8505	13.4973	11.0519	9.4547	8.3163	7.4569	1.028	1.027	1.027	1.026	1.026	1.026
754.20	5.365	68	18.3455	13.8645	11.3475	9.7038	8.5323	7.6481	1.000	1.000	1.000	1.000	1.000	1.000
695.91	5.403	70	18.6905	14.1201	11.5531	9.8768	8.6822	7.7807	0.982	0.982	0.982	0.982	0.983	0.983
563.73	5.505	75	19.6086	14.7988	12.0980	10.3347	9.0784	8.1306	0.936	0.937	0.938	0.939	0.940	0.941
450.57	5.621	80	20.6062	15.5339	12.6865	10.8281	9.5045	8.5060	0.890	0.893	0.894	0.896	0.898	0.899
355.36	5.755	85	21.6839	16.3251	13.3180	11.3561	9.9592	8.9059	0.846	0.849	0.852	0.855	0.857	0.859
276.56	5.908	90	22.8410	17.1712	13.9910	11.9170	10.4409	9.3285	0.803	0.807	0.811	0.814	0.817	0.820
212.41	6.083	95	24.0754	18.0696	14.7027	12.5082	10.9472	9.7713	0.762	0.767	0.772	0.776	0.779	0.783
161.00	6.285	100	25.3832	19.0165	15.4497	13.1263	11.4748	10.2314	0.723	0.729	0.734	0.739	0.744	0.748
120.45	6.517	105	26.7583	20.0064	16.2269	13.7669	12.0195	10.7049	0.686	0.693	0.699	0.705	0.710	0.714
88.94	6.784	110	28.1926	21.0326	17.0285	14.4247	12.5767	11.1876	0.651	0.659	0.666	0.673	0.678	0.684
64.82	7.094	115	29.6758	22.0867	17.8473	15.0934	13.1408	11.6746	0.618	0.628	0.636	0.643	0.649	0.655
46.63	7.453	120	31.1954	23.1589	18.6753	15.7664	13.7063	12.1609	0.588	0.599	0.608	0.615	0.623	0.629

Eb =	30 ksi
hac =	6 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	6.942	30	10.0162	7.6215	6.2751	5.3949	4.7669	4.2924	1.355	1.351	1.348	1.346	1.343	1.341
2074.71	6.974	35	10.3032	7.8386	6.4529	5.5470	4.9007	4.4124	1.317	1.314	1.311	1.309	1.307	1.305
1850.36	7.012	40	10.6388	8.0922	6.6605	5.7245	5.0568	4.5523	1.275	1.273	1.270	1.268	1.266	1.265
1627.24	7.057	45	11.0258	8.3845	6.8996	5.9289	5.2364	4.7131	1.231	1.228	1.226	1.225	1.223	1.221
1411.23	7.108	50	11.4673	8.7178	7.1720	6.1616	5.4407	4.8961	1.183	1.181	1.180	1.178	1.177	1.176
1207.09	7.167	55	11.9670	9.0946	7.4798	6.4242	5.6712	5.1023	1.134	1.132	1.131	1.130	1.129	1.128
1018.40	7.235	60	12.5288	9.5178	7.8251	6.7187	5.9294	5.3332	1.083	1.082	1.081	1.081	1.080	1.079
847.58	7.313	65	13.1570	9.9903	8.2102	7.0468	6.2168	5.5899	1.031	1.031	1.031	1.030	1.030	1.030
754.20	7.365	68	13.5677	10.2989	8.4615	7.2606	6.4040	5.7570	1.000	1.000	1.000	1.000	1.000	1.000
695.91	7.403	70	13.8559	10.5153	8.6376	7.4103	6.5350	5.8739	0.979	0.979	0.980	0.980	0.980	0.980
563.73	7.505	75	14.6302	11.0958	9.1094	7.8112	6.8854	6.1861	0.927	0.928	0.929	0.930	0.930	0.931
450.57	7.621	80	15.4842	11.7349	9.6278	8.2510	7.2692	6.5278	0.876	0.878	0.879	0.880	0.881	0.882
355.36	7.755	85	16.4223	12.4351	10.1947	8.7310	7.6874	6.8994	0.826	0.828	0.830	0.832	0.833	0.834
276.56	7.908	90	17.4480	13.1987	10.8114	9.2521	8.1405	7.3013	0.778	0.780	0.783	0.785	0.787	0.788
212.41	8.083	95	18.5643	14.0270	11.4786	9.8144	8.6283	7.7332	0.731	0.734	0.737	0.740	0.742	0.744
161.00	8.285	100	19.7730	14.9206	12.1961	10.4174	9.1502	8.1941	0.686	0.690	0.694	0.697	0.700	0.703
120.45	8.517	105	21.0739	15.8784	12.9623	11.0594	9.7042	8.6821	0.644	0.649	0.653	0.657	0.660	0.663
88.94	8.784	110	22.4652	16.8979	13.7747	11.7376	10.2876	9.1946	0.604	0.609	0.614	0.619	0.623	0.626
64.82	9.094	115	23.9427	17.9747	14.6289	12.4479	10.8965	9.7277	0.567	0.573	0.578	0.583	0.588	0.592
46.63	9.453	120	25.4991	19.1024	15.5190	13.1850	11.5259	10.2770	0.532	0.539	0.545	0.551	0.556	0.560

Eb =	30 ksi
hac =	8 inches

Eac (ksi)	hEp (inches)	tp (deg. F)	Mf 10 ksi d0 (mils)	Mf 15 ksi d0 (mils)	Mf 20 ksi d0 (mils)	Mf 25 ksi d0 (mils)	Mf 30 ksi d0 (mils)	Mf 35 ksi d0 (mils)	Mf 10 ksi TAF	Mf 15 ksi TAF	Mf 20 ksi TAF	Mf 25 ksi TAF	Mf 30 ksi TAF	Mf 35 ksi TAF
2293.46	8.942	30	7.8055	5.9462	4.9007	4.2172	3.7295	3.3610	1.376	1.374	1.372	1.370	1.369	1.367
2074.71	8.974	35	8.0391	6.1235	5.0464	4.3422	3.8397	3.4601	1.336	1.334	1.333	1.331	1.329	1.328
1850.36	9.012	40	8.3130	6.3313	5.2171	4.4886	3.9688	3.5761	1.292	1.290	1.289	1.288	1.286	1.285
1627.24	9.057	45	8.6300	6.5717	5.4144	4.6578	4.1179	3.7100	1.245	1.243	1.242	1.241	1.240	1.239
1411.23	9.108	50	8.9931	6.8469	5.6402	4.8513	4.2884	3.8631	1.194	1.193	1.192	1.191	1.190	1.190
1207.09	9.167	55	9.4058	7.1596	5.8966	5.0710	4.4819	4.0368	1.142	1.141	1.140	1.140	1.139	1.138
1018.40	9.235	60	9.8723	7.5127	6.1861	5.3188	4.7000	4.2324	1.088	1.088	1.087	1.087	1.086	1.086
847.58	9.313	65	10.3970	7.9096	6.5111	5.5968	4.9445	4.4517	1.033	1.033	1.033	1.033	1.032	1.032
754.20	9.365	68	10.7419	8.1702	6.7244	5.7792	5.1049	4.5954	1.000	1.000	1.000	1.000	1.000	1.000
695.91	9.403	70	10.9847	8.3536	6.8744	5.9074	5.2176	4.6963	0.978	0.978	0.978	0.978	0.978	0.979
563.73	9.505	75	11.6407	8.8487	7.2791	6.2530	5.5211	4.9681	0.923	0.923	0.924	0.924	0.925	0.925
450.57	9.621	80	12.3704	9.3987	7.7281	6.6361	5.8571	5.2686	0.868	0.869	0.870	0.871	0.872	0.872
355.36	9.755	85	13.1795	10.0075	8.2244	7.0590	6.2276	5.5997	0.815	0.816	0.818	0.819	0.820	0.821
276.56	9.908	90	14.0738	10.6791	8.7710	7.5239	6.6345	5.9627	0.763	0.765	0.767	0.768	0.769	0.771
212.41	10.083	95	15.0586	11.4170	9.3704	8.0329	7.0792	6.3589	0.713	0.716	0.718	0.719	0.721	0.723
161.00	10.285	100	16.1389	12.2243	10.0246	8.5874	7.5626	6.7888	0.666	0.668	0.671	0.673	0.675	0.677
120.45	10.517	105	17.3187	13.1033	10.7350	9.1880	8.0852	7.2527	0.620	0.624	0.626	0.629	0.631	0.634
88.94	10.784	110	18.6007	14.0550	11.5019	9.8346	8.6464	7.7496	0.577	0.581	0.585	0.588	0.590	0.593
64.82	11.094	115	19.9859	15.0791	12.3242	10.5257	9.2445	8.2780	0.537	0.542	0.546	0.549	0.552	0.555
46.63	11.453	120	21.4727	16.1732	13.1992	11.2586	9.8768	8.8349	0.500	0.505	0.509	0.513	0.517	0.520

Eb =	30 ksi
hac =	10 inches

Eac (ksi)	hEp (inches)	tp (deg. F)	Mr 10 ksi d0 (mils)	Mr 15 ksi d0 (mils)	Mr 20 ksi d0 (mils)	Mr 25 ksi d0 (mils)	Mr 30 ksi d0 (mils)	Mr 35 ksi d0 (mils)	Mr 10 ksi TAF	Mr 15 ksi TAF	Mr 20 ksi TAF	Mr 25 ksi TAF	Mr 30 ksi TAF	Mr 35 ksi TAF
2293.46	10.942	30	6.3911	4.8716	4.0172	3.4586	3.0600	2.7588	1.390	1.388	1.387	1.386	1.385	1.384
2074.71	10.974	35	6.5874	5.0208	4.1400	3.5641	3.1531	2.8426	1.348	1.347	1.346	1.345	1.344	1.343
1850.36	11.012	40	6.8181	5.1962	4.2842	3.6880	3.2625	2.9411	1.303	1.302	1.301	1.300	1.299	1.298
1627.24	11.057	45	7.0854	5.3993	4.4513	3.8315	3.3892	3.0550	1.254	1.253	1.252	1.251	1.250	1.249
1411.23	11.108	50	7.3925	5.6326	4.6431	3.9961	3.5345	3.1857	1.202	1.201	1.200	1.199	1.199	1.198
1207.09	11.167	55	7.7425	5.8984	4.8615	4.1836	3.6999	3.3344	1.147	1.147	1.146	1.146	1.145	1.145
1018.40	11.235	60	8.1394	6.1996	5.1090	4.3959	3.8872	3.5027	1.091	1.091	1.091	1.090	1.090	1.090
847.58	11.313	65	8.5874	6.5395	5.3880	4.6352	4.0981	3.6922	1.034	1.034	1.034	1.034	1.034	1.034
754.20	11.365	68	8.8829	6.7635	5.5718	4.7928	4.2369	3.8169	1.000	1.000	1.000	1.000	1.000	1.000
695.91	11.403	70	9.0914	6.9215	5.7015	4.9039	4.3348	3.9048	0.977	0.977	0.977	0.977	0.977	0.978
563.73	11.505	75	9.6565	7.3495	6.0524	5.2044	4.5994	4.1423	0.920	0.920	0.921	0.921	0.921	0.921
450.57	11.621	80	10.2886	7.8277	6.4442	5.5397	4.8944	4.4069	0.863	0.864	0.865	0.865	0.866	0.866
355.36	11.755	85	10.9937	8.3606	6.8803	5.9126	5.2222	4.7006	0.808	0.809	0.810	0.811	0.811	0.812
276.56	11.908	90	11.7784	8.9528	7.3643	6.3260	5.5852	5.0256	0.754	0.755	0.757	0.758	0.759	0.759
212.41	12.083	95	12.6491	9.6089	7.8998	6.7827	5.9858	5.3838	0.702	0.704	0.705	0.707	0.708	0.709
161.00	12.285	100	13.6126	10.3334	8.4901	7.2854	6.4261	5.7770	0.653	0.655	0.656	0.658	0.659	0.661
120.45	12.517	105	14.6750	11.1304	9.1383	7.8364	6.9079	6.2066	0.605	0.608	0.610	0.612	0.613	0.615
88.94	12.784	110	15.8420	12.0036	9.8466	8.4372	7.4322	6.6733	0.561	0.563	0.566	0.568	0.570	0.572
64.82	13.094	115	17.1180	12.9552	10.6165	9.0887	7.9995	7.1773	0.519	0.522	0.525	0.527	0.530	0.532
46.63	13.453	120	18.5057	13.9864	11.4481	9.7904	8.6090	7.7174	0.480	0.484	0.487	0.490	0.492	0.495

Eb =	30 ksi
hac =	12 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	12.942	30	5.4095	4.1248	3.4024	2.9301	2.5930	2.3384	1.399	1.398	1.397	1.396	1.395	1.395
2074.71	12.974	35	5.5786	4.2534	3.5083	3.0212	2.6736	2.4109	1.357	1.356	1.355	1.354	1.353	1.353
1850.36	13.012	40	5.7774	4.4047	3.6329	3.1283	2.7683	2.4962	1.310	1.309	1.308	1.308	1.307	1.306
1627.24	13.057	45	6.0082	4.5804	3.7775	3.2526	2.8781	2.5951	1.260	1.259	1.258	1.258	1.257	1.257
1411.23	13.108	50	6.2738	4.7824	3.9438	3.3955	3.0043	2.7087	1.207	1.206	1.205	1.205	1.204	1.204
1207.09	13.167	55	6.5771	5.0130	4.1336	3.5586	3.1483	2.8383	1.151	1.150	1.150	1.150	1.149	1.149
1018.40	13.235	60	6.9217	5.2750	4.3491	3.7437	3.3118	2.9854	1.094	1.093	1.093	1.093	1.093	1.092
847.58	13.313	65	7.3117	5.5713	4.5928	3.9530	3.4965	3.1515	1.035	1.035	1.035	1.035	1.035	1.035
754.20	13.365	68	7.5694	5.7671	4.7537	4.0911	3.6184	3.2612	1.000	1.000	1.000	1.000	1.000	1.000
695.91	13.403	70	7.7516	5.9054	4.8674	4.1887	3.7044	3.3385	0.976	0.977	0.977	0.977	0.977	0.977
563.73	13.505	75	8.2465	6.2811	5.1759	4.4534	3.9379	3.5484	0.918	0.918	0.918	0.919	0.919	0.919
450.57	13.621	80	8.8021	6.7024	5.5219	4.7500	4.1993	3.7832	0.860	0.860	0.861	0.861	0.862	0.862
355.36	13.755	85	9.4245	7.1741	5.9087	5.0815	4.4913	4.0454	0.803	0.804	0.805	0.805	0.806	0.806
276.56	13.908	90	10.1204	7.7008	6.3405	5.4511	4.8166	4.3372	0.748	0.749	0.750	0.751	0.751	0.752
212.41	14.083	95	10.8968	8.2878	6.8210	5.8621	5.1780	4.6611	0.695	0.696	0.697	0.698	0.699	0.700
161.00	14.285	100	11.7611	8.9402	7.3544	6.3178	5.5782	5.0195	0.644	0.645	0.646	0.648	0.649	0.650
120.45	14.517	105	12.7206	9.6633	7.9447	6.8213	6.0199	5.4146	0.595	0.597	0.598	0.600	0.601	0.602
88.94	14.784	110	13.7827	10.4620	8.5954	7.3755	6.5054	5.8481	0.549	0.551	0.553	0.555	0.556	0.558
64.82	15.094	115	14.9541	11.3407	9.3098	7.9827	7.0363	6.3215	0.506	0.509	0.511	0.512	0.514	0.516
46.63	15.453	120	16.2404	12.3027	10.0901	8.6444	7.6137	6.8354	0.466	0.469	0.471	0.473	0.475	0.477

Eb =	60 ksi
hac =	2 inches

			Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi	Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	3.187	30	21.0821	15.8835	12.9657	11.0616	9.7056	8.6830	1.214	1.207	1.201	1.196	1.191	1.187
2074.71	3.228	35	21.4877	16.1811	13.2031	11.2600	9.8764	8.8331	1.191	1.185	1.179	1.174	1.170	1.167
1850.36	3.276	40	21.9520	16.5213	13.4741	11.4862	10.0710	9.0040	1.166	1.160	1.155	1.151	1.148	1.144
1627.24	3.331	45	22.4745	16.9033	13.7780	11.7395	10.2886	9.1948	1.139	1.134	1.130	1.127	1.123	1.121
1411.23	3.396	50	23.0543	17.3264	14.1140	12.0191	10.5284	9.4049	1.110	1.106	1.103	1.100	1.098	1.096
1207.09	3.471	55	23.6905	17.7895	14.4809	12.3240	10.7895	9.6333	1.080	1.078	1.075	1.073	1.071	1.070
1018.40	3.556	60	24.3813	18.2911	14.8775	12.6528	11.0706	9.8789	1.050	1.048	1.046	1.045	1.044	1.043
847.58	3.655	65	25.1248	18.8293	15.3019	13.0040	11.3702	10.1401	1.019	1.018	1.017	1.017	1.017	1.016
754.20	3.720	68	25.5951	19.1689	15.5692	13.2247	11.5582	10.3038	1.000	1.000	1.000	1.000	1.000	1.000
695.91	3.767	70	25.9179	19.4016	15.7520	13.3755	11.6866	10.4155	0.988	0.988	0.988	0.989	0.989	0.989
563.73	3.896	75	26.7573	20.0050	16.2253	13.7651	12.0176	10.7030	0.957	0.958	0.960	0.961	0.962	0.963
450.57	4.043	80	27.6384	20.6361	16.7186	14.1702	12.3609	11.0005	0.926	0.929	0.931	0.933	0.935	0.937
355.36	4.211	85	28.5560	21.2905	17.2284	14.5876	12.7137	11.3056	0.896	0.900	0.904	0.907	0.909	0.911
276.56	4.404	90	29.5040	21.9637	17.7509	15.0140	13.0733	11.6157	0.868	0.873	0.877	0.881	0.884	0.887
212.41	4.625	95	30.4755	22.6502	18.2818	15.4459	13.4363	11.9282	0.840	0.846	0.852	0.856	0.860	0.864
161.00	4.879	100	31.4628	23.3445	18.8166	15.8795	13.7998	12.2401	0.814	0.821	0.827	0.833	0.838	0.842
120.45	5.171	105	32.4578	24.0407	19.3506	16.3110	14.1605	12.5489	0.789	0.797	0.805	0.811	0.816	0.821
88.94	5.508	110	33.4519	24.7327	19.8792	16.7367	14.5154	12.8519	0.765	0.775	0.783	0.790	0.796	0.802
64.82	5.898	115	34.4368	25.4147	20.3981	17.1532	14.8615	13.1468	0.743	0.754	0.763	0.771	0.778	0.784
46.63	6.351	120	35.4041	26.0812	20.9032	17.5573	15.1965	13.4316	0.723	0.735	0.745	0.753	0.761	0.767

Eb =	60 ksi
hac =	4 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	5.187	30	13.3056	10.1020	8.3011	7.1241	6.2845	5.6503	1.298	1.294	1.290	1.286	1.283	1.280
2074.71	5.228	35	13.6396	10.3528	8.5053	7.2978	6.4365	5.7860	1.266	1.262	1.259	1.256	1.253	1.250
1850.36	5.276	40	14.0270	10.6436	8.7418	7.4989	6.6124	5.9428	1.231	1.228	1.225	1.222	1.219	1.217
1627.24	5.331	45	14.4697	10.9755	9.0115	7.7281	6.8127	6.1213	1.194	1.191	1.188	1.186	1.184	1.182
1411.23	5.396	50	14.9696	11.3498	9.3154	7.9860	7.0380	6.3219	1.154	1.151	1.149	1.147	1.146	1.144
1207.09	5.471	55	15.5286	11.7679	9.6545	8.2735	7.2887	6.5451	1.112	1.111	1.109	1.108	1.106	1.105
1018.40	5.556	60	16.1489	12.2310	10.0295	8.5911	7.5655	6.7910	1.070	1.068	1.067	1.067	1.066	1.065
847.58	5.655	65	16.8322	12.7403	10.4412	8.9393	7.8685	7.0601	1.026	1.026	1.025	1.025	1.025	1.024
754.20	5.720	68	17.2733	13.0685	10.7062	9.1631	8.0631	7.2326	1.000	1.000	1.000	1.000	1.000	1.000
695.91	5.767	70	17.5801	13.2966	10.8902	9.3183	8.1979	7.3521	0.983	0.983	0.983	0.983	0.984	0.984
563.73	5.896	75	18.3937	13.9002	11.3764	9.7281	8.5534	7.6668	0.939	0.940	0.941	0.942	0.943	0.943
450.57	6.043	80	19.2734	14.5513	11.8995	10.1681	8.9344	8.0034	0.896	0.898	0.900	0.901	0.902	0.904
355.36	6.211	85	20.2188	15.2488	12.4586	10.6372	9.3398	8.3610	0.854	0.857	0.859	0.861	0.863	0.865
276.56	6.404	90	21.2285	15.9913	13.0519	11.1339	9.7680	8.7380	0.814	0.817	0.820	0.823	0.825	0.828
212.41	6.625	95	22.2998	16.7760	13.6771	11.6557	10.2168	9.1321	0.775	0.779	0.783	0.786	0.789	0.792
161.00	6.879	100	23.4284	17.5995	14.3308	12.1997	10.6834	9.5408	0.737	0.743	0.747	0.751	0.755	0.758
120.45	7.171	105	24.6087	18.4567	15.0088	12.7620	11.1643	9.9610	0.702	0.708	0.713	0.718	0.722	0.726
88.94	7.508	110	25.8333	19.3417	15.7059	13.3382	11.6555	10.3889	0.669	0.676	0.682	0.687	0.692	0.696
64.82	7.898	115	27.0933	20.2476	16.4164	13.9233	12.1526	10.8208	0.638	0.645	0.652	0.658	0.663	0.668
46.63	8.351	120	28.3783	21.1665	17.1338	14.5118	12.6511	11.2526	0.609	0.617	0.625	0.631	0.637	0.643

Eb =	60 ksi
hac =	6 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	7.187	30	9.6810	7.3678	6.0673	5.2170	4.6104	4.1521	1.339	1.336	1.334	1.331	1.329	1.327
2074.71	7.228	35	9.9490	7.5707	6.2335	5.3593	4.7356	4.2644	1.303	1.300	1.298	1.296	1.294	1.292
1850.36	7.276	40	10.2618	7.8073	6.4273	5.5251	4.8814	4.3951	1.263	1.261	1.259	1.257	1.256	1.254
1627.24	7.331	45	10.6217	8.0793	6.6499	5.7155	5.0488	4.5452	1.221	1.219	1.217	1.215	1.214	1.213
1411.23	7.396	50	11.0312	8.3887	6.9030	5.9318	5.2389	4.7154	1.175	1.174	1.172	1.171	1.170	1.169
1207.09	7.471	55	11.4934	8.7375	7.1881	6.1753	5.4528	4.9069	1.128	1.127	1.126	1.125	1.124	1.123
1018.40	7.556	60	12.0113	9.1280	7.5070	6.4475	5.6916	5.1206	1.079	1.079	1.078	1.077	1.077	1.076
847.58	7.655	65	12.5882	9.5625	7.8616	6.7498	5.9567	5.3576	1.030	1.030	1.029	1.029	1.029	1.029
754.20	7.720	68	12.9643	9.8454	8.0922	6.9463	6.1289	5.5114	1.000	1.000	1.000	1.000	1.000	1.000
695.91	7.767	70	13.2276	10.0434	8.2535	7.0836	6.2491	5.6188	0.980	0.980	0.980	0.981	0.981	0.981
563.73	7.896	75	13.9328	10.5730	8.6845	7.4503	6.5700	5.9051	0.930	0.931	0.932	0.932	0.933	0.933
450.57	8.043	80	14.7069	11.1534	9.1562	7.8510	6.9201	6.2171	0.882	0.883	0.884	0.885	0.886	0.886
355.36	8.211	85	15.5529	11.7863	9.6695	8.2864	7.3001	6.5553	0.834	0.835	0.837	0.838	0.840	0.841
276.56	8.404	90	16.4729	12.4729	10.2254	8.7570	7.7101	6.9196	0.787	0.789	0.791	0.793	0.795	0.796
212.41	8.625	95	17.4683	13.2139	10.8238	9.2626	8.1497	7.3096	0.742	0.745	0.748	0.750	0.752	0.754
161.00	8.879	100	18.5393	14.0087	11.4641	9.8023	8.6179	7.7241	0.699	0.703	0.706	0.709	0.711	0.714
120.45	9.171	105	19.6848	14.8559	12.1444	10.3743	9.1131	8.1615	0.659	0.663	0.666	0.670	0.673	0.675
88.94	9.508	110	20.9020	15.7525	12.8622	10.9759	9.6325	8.6193	0.620	0.625	0.629	0.633	0.636	0.639
64.82	9.898	115	22.1859	16.6944	13.6134	11.6036	10.1729	9.0943	0.584	0.590	0.594	0.599	0.602	0.606
46.63	10.351	120	23.5298	17.6756	14.3929	12.2528	10.7300	9.5827	0.551	0.557	0.562	0.567	0.571	0.575

Eb =	60 ksi
hac =	8 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	9.187	30	7.5997	5.7899	4.7723	4.1071	3.6324	3.2737	1.363	1.361	1.359	1.358	1.356	1.355
2074.71	9.228	35	7.8210	5.9580	4.9104	4.2256	3.7369	3.3676	1.324	1.323	1.321	1.320	1.318	1.317
1850.36	9.276	40	8.0802	6.1546	5.0720	4.3642	3.8591	3.4775	1.282	1.280	1.279	1.278	1.277	1.275
1627.24	9.331	45	8.3794	6.3817	5.2584	4.5240	4.0001	3.6041	1.236	1.235	1.234	1.233	1.232	1.231
1411.23	9.396	50	8.7214	6.6410	5.4713	4.7066	4.1609	3.7486	1.188	1.187	1.186	1.185	1.184	1.183
1207.09	9.471	55	9.1093	6.9350	5.7125	4.9132	4.3430	3.9121	1.137	1.136	1.136	1.135	1.134	1.134
1018.40	9.556	60	9.5464	7.2661	5.9839	5.1457	4.5477	4.0958	1.085	1.084	1.084	1.084	1.083	1.083
847.58	9.655	65	10.0365	7.6370	6.2879	5.4059	4.7766	4.3012	1.032	1.032	1.032	1.031	1.031	1.031
754.20	9.720	68	10.3578	7.8799	6.4868	5.5761	4.9263	4.4354	1.000	1.000	1.000	1.000	1.000	1.000
695.91	9.767	70	10.5836	8.0506	6.6265	5.6956	5.0314	4.5296	0.979	0.979	0.979	0.979	0.979	0.979
563.73	9.896	75	11.1918	8.5100	7.0023	6.0167	5.3136	4.7824	0.925	0.926	0.926	0.927	0.927	0.927
450.57	10.043	80	11.8655	9.0183	7.4176	6.3713	5.6249	5.0610	0.873	0.874	0.875	0.875	0.876	0.876
355.36	10.211	85	12.6090	9.5784	7.8747	6.7611	5.9667	5.3666	0.821	0.823	0.824	0.825	0.826	0.826
276.56	10.404	90	13.4265	10.1932	8.3757	7.1878	6.3405	5.7005	0.771	0.773	0.774	0.776	0.777	0.778
212.41	10.625	95	14.3219	10.8652	8.9224	7.6527	6.7471	6.0632	0.723	0.725	0.727	0.729	0.730	0.732
161.00	10.879	100	15.2982	11.5964	9.5160	8.1566	7.1872	6.4551	0.677	0.680	0.682	0.684	0.685	0.687
120.45	11.171	105	16.3576	12.3877	10.1571	8.6997	7.6605	6.8759	0.633	0.636	0.639	0.641	0.643	0.645
88.94	11.508	110	17.5012	13.2394	10.8452	9.2813	8.1664	7.3249	0.592	0.595	0.598	0.601	0.603	0.606
64.82	11.898	115	18.7282	14.1501	11.5788	9.8998	8.7032	7.8002	0.553	0.557	0.560	0.563	0.566	0.569
46.63	12.351	120	20.0358	15.1169	12.3553	10.5525	9.2681	8.2993	0.517	0.521	0.525	0.528	0.532	0.534

Eb =	60 ksi
hac =	10 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	11.187	30	6.2522	4.7660	3.9303	3.3839	2.9940	2.6994	1.378	1.377	1.376	1.375	1.374	1.373
2074.71	11.228	35	6.4400	4.9088	4.0478	3.4848	3.0832	2.7797	1.338	1.337	1.336	1.335	1.334	1.333
1850.36	11.276	40	6.6603	5.0762	4.1856	3.6032	3.1877	2.8738	1.294	1.293	1.292	1.291	1.290	1.289
1627.24	11.331	45	6.9153	5.2700	4.3450	3.7402	3.3086	2.9825	1.246	1.245	1.244	1.244	1.243	1.242
1411.23	11.396	50	7.2075	5.4921	4.5276	3.8970	3.4470	3.1070	1.196	1.195	1.194	1.194	1.193	1.192
1207.09	11.471	55	7.5400	5.7446	4.7352	4.0752	3.6043	3.2484	1.143	1.142	1.142	1.141	1.141	1.141
1018.40	11.556	60	7.9160	6.0301	4.9697	4.2765	3.7818	3.4081	1.089	1.088	1.088	1.088	1.087	1.087
847.58	11.655	65	8.3393	6.3513	5.2335	4.5028	3.9814	3.5874	1.033	1.033	1.033	1.033	1.033	1.033
754.20	11.720	68	8.6177	6.5625	5.4069	4.6514	4.1124	3.7051	1.000	1.000	1.000	1.000	1.000	1.000
695.91	11.767	70	8.8139	6.7112	5.5290	4.7561	4.2046	3.7879	0.978	0.978	0.978	0.978	0.978	0.978
563.73	11.896	75	9.3444	7.1132	5.8587	5.0386	4.4534	4.0113	0.922	0.923	0.923	0.923	0.923	0.924
450.57	12.043	80	9.9354	7.5607	6.2255	5.3526	4.7298	4.2593	0.867	0.868	0.869	0.869	0.869	0.870
355.36	12.211	85	10.5920	8.0572	6.6321	5.7005	5.0358	4.5336	0.814	0.814	0.815	0.816	0.817	0.817
276.56	12.404	90	11.3192	8.6065	7.0814	6.0845	5.3732	4.8359	0.761	0.763	0.764	0.764	0.765	0.766
212.41	12.625	95	12.1222	9.2121	7.5761	6.5068	5.7439	5.1676	0.711	0.712	0.714	0.715	0.716	0.717
161.00	12.879	100	13.0057	9.8773	8.1188	6.9694	6.1495	5.5301	0.663	0.664	0.666	0.667	0.669	0.670
120.45	13.171	105	13.9740	10.6050	8.7113	7.4737	6.5910	5.9243	0.617	0.619	0.621	0.622	0.624	0.625
88.94	13.508	110	15.0309	11.3973	9.3552	8.0208	7.0691	6.3504	0.573	0.576	0.578	0.580	0.582	0.583
64.82	13.898	115	16.1785	12.2554	10.0510	8.6107	7.5837	6.8083	0.533	0.535	0.538	0.540	0.542	0.544
46.63	14.351	120	17.4177	13.1792	10.7980	9.2426	8.1338	7.2967	0.495	0.498	0.501	0.503	0.506	0.508

Eb =	60 ksi
hac =	12 inches

			Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi	Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	13.187	30	5.3096	4.0487	3.3397	2.8762	2.5454	2.2955	1.389	1.388	1.387	1.386	1.386	1.385
2074.71	13.228	35	5.4724	4.1726	3.4418	2.9639	2.6230	2.3654	1.348	1.347	1.346	1.345	1.345	1.344
1850.36	13.276	40	5.6636	4.3181	3.5616	3.0670	2.7141	2.4474	1.302	1.301	1.301	1.300	1.299	1.299
1627.24	13.331	45	5.8853	4.4868	3.7005	3.1864	2.8196	2.5424	1.253	1.253	1.252	1.251	1.251	1.250
1411.23	13.396	50	6.1399	4.6805	3.8600	3.3235	2.9407	2.6514	1.201	1.201	1.200	1.200	1.199	1.199
1207.09	13.471	55	6.4301	4.9013	4.0417	3.4796	3.0786	2.7756	1.147	1.147	1.146	1.146	1.146	1.145
1018.40	13.556	60	6.7592	5.1515	4.2475	3.6565	3.2348	2.9161	1.091	1.091	1.091	1.090	1.090	1.090
847.58	13.655	65	7.1307	5.4338	4.4797	3.8559	3.4108	3.0745	1.034	1.034	1.034	1.034	1.034	1.034
754.20	13.720	68	7.3757	5.6200	4.6328	3.9873	3.5268	3.1788	1.000	1.000	1.000	1.000	1.000	1.000
695.91	13.767	70	7.5486	5.7513	4.7407	4.0800	3.6086	3.2524	0.977	0.977	0.977	0.977	0.977	0.977
563.73	13.896	75	8.0173	6.1072	5.0331	4.3309	3.8299	3.4514	0.920	0.920	0.920	0.921	0.921	0.921
450.57	14.043	80	8.5417	6.5050	5.3599	4.6112	4.0770	3.6734	0.863	0.864	0.864	0.865	0.865	0.865
355.36	14.211	85	9.1270	6.9487	5.7240	4.9233	4.3520	3.9203	0.808	0.809	0.809	0.810	0.810	0.811
276.56	14.404	90	9.7785	7.4422	6.1286	5.2698	4.6571	4.1942	0.754	0.755	0.756	0.757	0.757	0.758
212.41	14.625	95	10.5021	7.9896	6.5770	5.6535	4.9947	4.4969	0.702	0.703	0.704	0.705	0.706	0.707
161.00	14.879	100	11.3034	8.5950	7.0724	6.0770	5.3669	4.8304	0.653	0.654	0.655	0.656	0.657	0.658
120.45	15.171	105	12.1882	9.2625	7.6177	6.5426	5.7757	5.1963	0.605	0.607	0.608	0.609	0.611	0.612
88.94	15.508	110	13.1615	9.9954	8.2156	7.0524	6.2226	5.5958	0.560	0.562	0.564	0.565	0.567	0.568
64.82	15.898	115	14.2279	10.7967	8.8682	7.6078	6.7088	6.0299	0.518	0.521	0.522	0.524	0.526	0.527
46.63	16.351	120	15.3908	11.6684	9.5765	8.2095	7.2347	6.4986	0.479	0.482	0.484	0.486	0.487	0.489

Eb =	90 ksi
hac =	2 inches

			Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi	Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	3.359	30	20.0878	15.1520	12.3809	10.5720	9.2834	8.3112	1.203	1.197	1.192	1.187	1.183	1.180
2074.71	3.405	35	20.4573	15.4241	12.5987	10.7545	9.4409	8.4500	1.182	1.176	1.171	1.167	1.164	1.160
1850.36	3.460	40	20.8797	15.7348	12.8470	10.9623	9.6201	8.6077	1.158	1.153	1.149	1.145	1.142	1.139
1627.24	3.524	45	21.3542	16.0832	13.1250	11.1948	9.8203	8.7838	1.132	1.128	1.124	1.121	1.119	1.116
1411.23	3.598	50	21.8798	16.4684	13.4321	11.4511	10.0408	8.9775	1.105	1.101	1.099	1.096	1.094	1.092
1207.09	3.684	55	22.4554	16.8894	13.7669	11.7303	10.2806	9.1879	1.076	1.074	1.072	1.070	1.069	1.067
1018.40	3.782	60	23.0791	17.3445	14.1283	12.0311	10.5386	9.4139	1.047	1.046	1.045	1.043	1.042	1.042
847.58	3.894	65	23.7489	17.8320	14.5145	12.3519	10.8134	9.6542	1.018	1.017	1.017	1.016	1.016	1.016
754.20	3.969	68	24.1718	18.1392	14.7575	12.5534	10.9857	9.8047	1.000	1.000	1.000	1.000	1.000	1.000
695.91	4.023	70	24.4618	18.3495	14.9236	12.6910	11.1032	9.9074	0.988	0.989	0.989	0.989	0.989	0.990
563.73	4.170	75	25.2145	18.8942	15.3531	13.0463	11.4063	10.1716	0.959	0.960	0.961	0.962	0.963	0.964
450.57	4.338	80	26.0029	19.4628	15.8002	13.4152	11.7204	10.4449	0.930	0.932	0.934	0.936	0.937	0.939
355.36	4.531	85	26.8220	20.0515	16.2617	13.7952	12.0431	10.7252	0.901	0.905	0.907	0.910	0.912	0.914
276.56	4.751	90	27.6664	20.6562	16.7343	14.1832	12.3720	11.0101	0.874	0.878	0.882	0.885	0.888	0.891
212.41	5.004	95	28.5298	21.2720	17.2141	14.5760	12.7041	11.2973	0.847	0.853	0.857	0.861	0.865	0.868
161.00	5.295	100	29.4055	21.8941	17.6972	14.9704	13.0367	11.5843	0.822	0.828	0.834	0.839	0.843	0.846
120.45	5.630	105	30.2865	22.5173	18.1795	15.3630	13.3670	11.8687	0.798	0.806	0.812	0.817	0.822	0.826
88.94	6.016	110	31.1653	23.1363	18.6569	15.7506	13.6922	12.1482	0.776	0.784	0.791	0.797	0.802	0.807
64.82	6.462	115	32.0348	23.7462	19.1257	16.1301	14.0100	12.4206	0.755	0.764	0.772	0.778	0.784	0.789
46.63	6.980	120	32.8880	24.3422	19.5824	16.4988	14.3181	12.6843	0.735	0.745	0.754	0.761	0.767	0.773

Eb =	90 ksi
hac =	4 inches

Eac (ksi)	hEp (inches)	tp (deg. F)	Mf 10 ksi d0 (mils)	Mf 15 ksi d0 (mils)	Mf 20 ksi d0 (mils)	Mf 25 ksi d0 (mils)	Mf 30 ksi d0 (mils)	Mf 35 ksi d0 (mils)	Mf 10 ksi TAF	Mf 15 ksi TAF	Mf 20 ksi TAF	Mf 25 ksi TAF	Mf 30 ksi TAF	Mf 35 ksi TAF
2293.46	5.359	30	12.8926	9.7914	8.0481	6.9087	6.0959	5.4819	1.287	1.283	1.279	1.276	1.273	1.271
2074.71	5.405	35	13.2063	10.0273	8.2403	7.0723	6.2392	5.6098	1.256	1.253	1.249	1.247	1.244	1.242
1850.36	5.460	40	13.5696	10.3002	8.4625	7.2614	6.4047	5.7576	1.223	1.219	1.217	1.214	1.212	1.210
1627.24	5.524	45	13.9840	10.6113	8.7156	7.4766	6.5929	5.9254	1.186	1.184	1.181	1.179	1.177	1.176
1411.23	5.598	50	14.4510	10.9615	9.0002	7.7184	6.8043	6.1138	1.148	1.146	1.144	1.142	1.141	1.139
1207.09	5.684	55	14.9722	11.3518	9.3170	7.9874	7.0392	6.3230	1.108	1.106	1.105	1.104	1.103	1.102
1018.40	5.782	60	15.5490	11.7832	9.6668	8.2840	7.2979	6.5532	1.067	1.066	1.065	1.064	1.064	1.063
847.58	5.894	65	16.1829	12.2564	10.0500	8.6085	7.5806	6.8045	1.025	1.025	1.024	1.024	1.024	1.024
754.20	5.969	68	16.5911	12.5607	10.2962	8.8167	7.7618	6.9654	1.000	1.000	1.000	1.000	1.000	1.000
695.91	6.023	70	16.8746	12.7719	10.4668	8.9609	7.8873	7.0767	0.983	0.983	0.984	0.984	0.984	0.984
563.73	6.170	75	17.6249	13.3298	10.9170	9.3410	8.2176	7.3695	0.941	0.942	0.943	0.944	0.945	0.945
450.57	6.338	80	18.4335	13.9298	11.4002	9.7482	8.5708	7.6822	0.900	0.902	0.903	0.904	0.906	0.907
355.36	6.531	85	19.2996	14.5707	11.9151	10.1813	8.9458	8.0136	0.860	0.862	0.864	0.866	0.868	0.869
276.56	6.751	90	20.2214	15.2508	12.4602	10.6387	9.3411	8.3622	0.820	0.824	0.826	0.829	0.831	0.833
212.41	7.004	95	21.1958	15.9674	13.0330	11.1181	9.7545	8.7262	0.783	0.787	0.790	0.793	0.796	0.798
161.00	7.295	100	22.2187	16.7170	13.6303	11.6168	10.1835	9.1030	0.747	0.751	0.755	0.759	0.762	0.765
120.45	7.630	105	23.2846	17.4950	14.2483	12.1313	10.6250	9.4898	0.713	0.718	0.723	0.727	0.731	0.734
88.94	8.016	110	24.3865	18.2961	14.8823	12.6576	11.0753	9.8836	0.680	0.687	0.692	0.697	0.701	0.705
64.82	8.462	115	25.5163	19.1138	15.5273	13.1912	11.5307	10.2807	0.650	0.657	0.663	0.668	0.673	0.678
46.63	8.980	120	26.6650	19.9414	16.1775	13.7275	11.9871	10.6778	0.622	0.630	0.636	0.642	0.648	0.652

Eb =	90 ksi
hac =	6 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	7.359	30	9.4588	7.1996	5.9294	5.0990	4.5065	4.0589	1.329	1.326	1.324	1.322	1.320	1.318
2074.71	7.405	35	9.7146	7.3933	6.0882	5.2349	4.6262	4.1662	1.294	1.292	1.290	1.288	1.286	1.284
1850.36	7.460	40	10.0128	7.6189	6.2730	5.3931	4.7654	4.2910	1.256	1.253	1.252	1.250	1.248	1.247
1627.24	7.524	45	10.3553	7.8779	6.4851	5.5746	4.9250	4.4341	1.214	1.212	1.211	1.209	1.208	1.207
1411.23	7.598	50	10.7444	8.1720	6.7258	5.7804	5.1059	4.5962	1.170	1.169	1.167	1.166	1.165	1.164
1207.09	7.684	55	11.1826	8.5030	6.9965	6.0117	5.3091	4.7782	1.124	1.123	1.122	1.121	1.121	1.120
1018.40	7.782	60	11.6727	8.8727	7.2986	6.2697	5.5356	4.9810	1.077	1.076	1.076	1.075	1.075	1.074
847.58	7.894	65	12.2173	9.2832	7.6338	6.5556	5.7864	5.2054	1.029	1.029	1.029	1.028	1.028	1.028
754.20	7.969	68	12.5716	9.5500	7.8514	6.7411	5.9491	5.3508	1.000	1.000	1.000	1.000	1.000	1.000
695.91	8.023	70	12.8193	9.7364	8.0034	6.8706	6.0626	5.4522	0.981	0.981	0.981	0.981	0.981	0.981
563.73	8.170	75	13.4813	10.2341	8.4088	7.2158	6.3648	5.7221	0.933	0.933	0.934	0.934	0.935	0.935
450.57	8.338	80	14.2058	10.7779	8.8511	7.5919	6.6938	6.0155	0.885	0.886	0.887	0.888	0.889	0.890
355.36	8.531	85	14.9949	11.3690	9.3312	7.9996	7.0499	6.3327	0.838	0.840	0.841	0.843	0.844	0.845
276.56	8.751	90	15.8499	12.0082	9.8494	8.4388	7.4330	6.6735	0.793	0.795	0.797	0.799	0.800	0.802
212.41	9.004	95	16.7715	12.6955	10.4054	8.9093	7.8426	7.0373	0.750	0.752	0.755	0.757	0.759	0.760
161.00	9.295	100	17.7592	13.4302	10.9983	9.4100	8.2777	7.4231	0.708	0.711	0.714	0.716	0.719	0.721
120.45	9.630	105	18.8111	14.2103	11.6263	9.9390	8.7365	7.8291	0.668	0.672	0.675	0.678	0.681	0.683
88.94	10.016	110	19.9241	15.0329	12.2866	10.4938	9.2166	8.2530	0.631	0.635	0.639	0.642	0.645	0.648
64.82	10.462	115	21.0932	15.8937	12.9754	11.0710	9.7148	8.6920	0.596	0.601	0.605	0.609	0.612	0.616
46.63	10.980	120	22.3116	16.7873	13.6881	11.6665	10.2274	9.1426	0.563	0.569	0.574	0.578	0.582	0.585

Eb =	90 ksi
hac =	8 inches

			Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi	Mf 10 ksi	Mf 15 ksi	Mf 20 ksi	Mf 25 ksi	Mf 30 ksi	Mf 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	9.359	30	7.4616	5.6851	4.6862	4.0331	3.5671	3.2150	1.354	1.352	1.351	1.349	1.348	1.347
2074.71	9.405	35	7.6750	5.8471	4.8193	4.1474	3.6679	3.3056	1.317	1.315	1.313	1.312	1.311	1.310
1850.36	9.460	40	7.9244	6.0364	4.9749	4.2809	3.7857	3.4115	1.275	1.274	1.272	1.271	1.270	1.269
1627.24	9.524	45	8.2121	6.2547	5.1542	4.4347	3.9213	3.5334	1.230	1.229	1.228	1.227	1.226	1.225
1411.23	9.598	50	8.5404	6.5038	5.3587	4.6100	4.0758	3.6722	1.183	1.182	1.181	1.180	1.180	1.179
1207.09	9.684	55	8.9122	6.7856	5.5899	4.8082	4.2505	3.8291	1.134	1.133	1.132	1.132	1.131	1.131
1018.40	9.782	60	9.3303	7.1024	5.8498	5.0308	4.4466	4.0051	1.083	1.082	1.082	1.082	1.081	1.081
847.58	9.894	65	9.7981	7.4566	6.1401	5.2794	4.6654	4.2014	1.031	1.031	1.031	1.031	1.031	1.030
754.20	9.969	68	10.1042	7.6882	6.3298	5.4418	4.8082	4.3295	1.000	1.000	1.000	1.000	1.000	1.000
695.91	10.023	70	10.3191	7.8507	6.4629	5.5556	4.9083	4.4193	0.979	0.979	0.979	0.980	0.980	0.980
563.73	10.170	75	10.8968	8.2873	6.8202	5.8611	5.1769	4.6599	0.927	0.928	0.928	0.928	0.929	0.929
450.57	10.338	80	11.5349	8.7690	7.2140	6.1975	5.4724	4.9245	0.876	0.877	0.877	0.878	0.879	0.879
355.36	10.531	85	12.2370	9.2983	7.6462	6.5664	5.7960	5.2141	0.826	0.827	0.828	0.829	0.830	0.830
276.56	10.751	90	13.0063	9.8774	8.1185	6.9689	6.1488	5.5294	0.777	0.778	0.780	0.781	0.782	0.783
212.41	11.004	95	13.8458	10.5082	8.6322	7.4061	6.5315	5.8709	0.730	0.732	0.733	0.735	0.736	0.737
161.00	11.295	100	14.7577	11.1920	9.1880	7.8784	6.9444	6.2390	0.685	0.687	0.689	0.691	0.692	0.694
120.45	11.630	105	15.7432	11.9293	9.7860	8.3856	7.3870	6.6330	0.642	0.644	0.647	0.649	0.651	0.653
88.94	12.016	110	16.8023	12.7196	10.4256	8.9270	7.8586	7.0520	0.601	0.604	0.607	0.610	0.612	0.614
64.82	12.462	115	17.9335	13.5611	11.1050	9.5008	8.3574	7.4943	0.563	0.567	0.570	0.573	0.575	0.578
46.63	12.980	120	19.1334	14.4509	11.8213	10.1043	8.8808	7.9575	0.528	0.532	0.535	0.539	0.541	0.544

Eb =	90 ksi
hac =	10 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	11.359	30	6.1583	4.6945	3.8715	3.3334	2.9494	2.6592	1.371	1.369	1.368	1.367	1.366	1.365
2074.71	11.405	35	6.3405	4.8331	3.9855	3.4313	3.0359	2.7371	1.331	1.330	1.329	1.328	1.327	1.326
1850.36	11.460	40	6.5539	4.9954	4.1190	3.5461	3.1373	2.8283	1.288	1.287	1.286	1.285	1.284	1.284
1627.24	11.524	45	6.8007	5.1830	4.2734	3.6787	3.2543	2.9337	1.241	1.240	1.240	1.239	1.238	1.237
1411.23	11.598	50	7.0832	5.3976	4.4499	3.8303	3.3882	3.0541	1.192	1.191	1.190	1.190	1.189	1.189
1207.09	11.684	55	7.4041	5.6414	4.6503	4.0024	3.5400	3.1907	1.140	1.140	1.139	1.139	1.138	1.138
1018.40	11.782	60	7.7664	5.9166	4.8765	4.1965	3.7113	3.3446	1.087	1.087	1.086	1.086	1.086	1.085
847.58	11.894	65	8.1735	6.2256	5.1303	4.4142	3.9033	3.5173	1.033	1.033	1.032	1.032	1.032	1.032
754.20	11.969	68	8.4410	6.4284	5.2969	4.5571	4.0293	3.6304	1.000	1.000	1.000	1.000	1.000	1.000
695.91	12.023	70	8.6291	6.5712	5.4141	4.6576	4.1178	3.7099	0.978	0.978	0.978	0.978	0.978	0.979
563.73	12.170	75	9.1372	6.9562	5.7300	4.9283	4.3564	3.9242	0.924	0.924	0.924	0.925	0.925	0.925
450.57	12.338	80	9.7017	7.3838	6.0806	5.2286	4.6207	4.1614	0.870	0.871	0.871	0.872	0.872	0.872
355.36	12.531	85	10.3272	7.8570	6.4682	5.5603	4.9126	4.4232	0.817	0.818	0.819	0.820	0.820	0.821
276.56	12.751	90	11.0177	8.3789	6.8954	5.9255	5.2336	4.7109	0.766	0.767	0.768	0.769	0.770	0.771
212.41	13.004	95	11.7776	8.9524	7.3642	6.3259	5.5853	5.0257	0.717	0.718	0.719	0.720	0.721	0.722
161.00	13.295	100	12.6107	9.5803	7.8767	6.7631	5.9688	5.3687	0.669	0.671	0.672	0.674	0.675	0.676
120.45	13.630	105	13.5203	10.2644	8.4343	7.2381	6.3849	5.7404	0.624	0.626	0.628	0.630	0.631	0.632
88.94	14.016	110	14.5087	11.0064	9.0379	7.7515	6.8340	6.1411	0.582	0.584	0.586	0.588	0.590	0.591
64.82	14.462	115	15.5774	11.8067	9.6877	8.3031	7.3157	6.5701	0.542	0.544	0.547	0.549	0.551	0.553
46.63	14.980	120	16.7258	12.6644	10.3825	8.8917	7.8288	7.0264	0.505	0.508	0.510	0.513	0.515	0.517

Eb =	90 ksi
hac =	12 inches

			Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi	Mr 10 ksi	Mr 15 ksi	Mr 20 ksi	Mr 25 ksi	Mr 30 ksi	Mr 35 ksi
Eac (ksi)	hEp (inches)	tp (deg. F)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	d0 (mils)	TAF	TAF	TAF	TAF	TAF	TAF
2293.46	13.359	30	5.2416	3.9970	3.2971	2.8395	2.5130	2.2663	1.382	1.381	1.380	1.380	1.379	1.378
2074.71	13.405	35	5.4002	4.1177	3.3966	2.9251	2.5886	2.3344	1.342	1.341	1.340	1.339	1.339	1.338
1850.36	13.460	40	5.5864	4.2594	3.5132	3.0254	2.6773	2.4143	1.297	1.296	1.296	1.295	1.294	1.294
1627.24	13.524	45	5.8020	4.4235	3.6484	3.1416	2.7800	2.5067	1.249	1.248	1.248	1.247	1.247	1.246
1411.23	13.598	50	6.0493	4.6116	3.8033	3.2748	2.8976	2.6127	1.198	1.197	1.197	1.196	1.196	1.196
1207.09	13.684	55	6.3309	4.8258	3.9796	3.4263	3.0315	2.7332	1.144	1.144	1.144	1.143	1.143	1.143
1018.40	13.782	60	6.6497	5.0682	4.1790	3.5977	3.1828	2.8694	1.090	1.089	1.089	1.089	1.089	1.089
847.58	13.894	65	7.0090	5.3413	4.4037	3.7906	3.3532	3.0227	1.034	1.034	1.034	1.033	1.033	1.033
754.20	13.969	68	7.2456	5.5211	4.5515	3.9176	3.4653	3.1235	1.000	1.000	1.000	1.000	1.000	1.000
695.91	14.023	70	7.4124	5.6479	4.6557	4.0070	3.5442	3.1945	0.977	0.978	0.978	0.978	0.978	0.978
563.73	14.170	75	7.8640	5.9908	4.9375	4.2489	3.7576	3.3864	0.921	0.922	0.922	0.922	0.922	0.922
450.57	14.338	80	8.3680	6.3733	5.2517	4.5185	3.9953	3.6000	0.866	0.866	0.867	0.867	0.867	0.868
355.36	14.531	85	8.9291	6.7988	5.6010	4.8179	4.2592	3.8370	0.811	0.812	0.813	0.813	0.814	0.814
276.56	14.751	90	9.5520	7.2707	5.9881	5.1496	4.5513	4.0992	0.759	0.759	0.760	0.761	0.761	0.762
212.41	15.004	95	10.2417	7.7927	6.4158	5.5157	4.8735	4.3883	0.707	0.708	0.709	0.710	0.711	0.712
161.00	15.295	100	11.0029	8.3681	6.8869	5.9186	5.2277	4.7058	0.659	0.660	0.661	0.662	0.663	0.664
120.45	15.630	105	11.8401	9.0002	7.4037	6.3600	5.6155	5.0530	0.612	0.613	0.615	0.616	0.617	0.618
88.94	16.016	110	12.7576	9.6917	7.9682	6.8416	6.0380	5.4310	0.568	0.570	0.571	0.573	0.574	0.575
64.82	16.462	115	13.7585	10.4446	8.5819	7.3644	6.4961	5.8402	0.527	0.529	0.530	0.532	0.533	0.535
46.63	16.980	120	14.8450	11.2601	9.2454	7.9287	6.9897	6.2806	0.488	0.490	0.492	0.494	0.496	0.497

TEMPERATURE ADJUSTMENT FACTOR CURVE
REGRESSION EQUATIONS

2" *depth*: $TAF = 1.358192 - 0.005227T(°F)$
$CC = -0.996296$

4" *depth*: $TAF = 1.522908 - 0.007653T(°F)$
$CC = -0.997893$

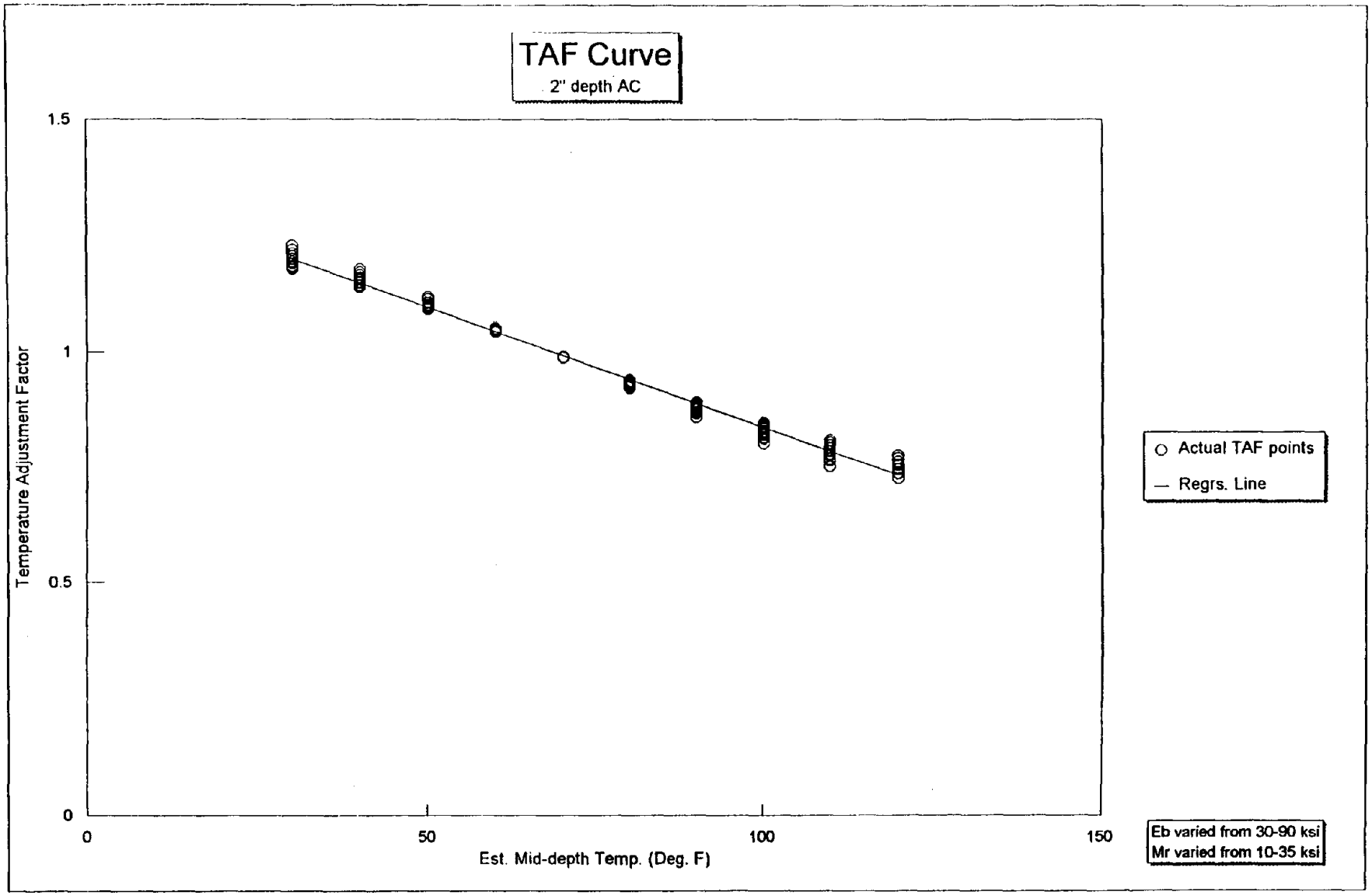
6" *depth*: $TAF = 1.605983 - 0.00888T(°F)$
$CC = -0.998475$

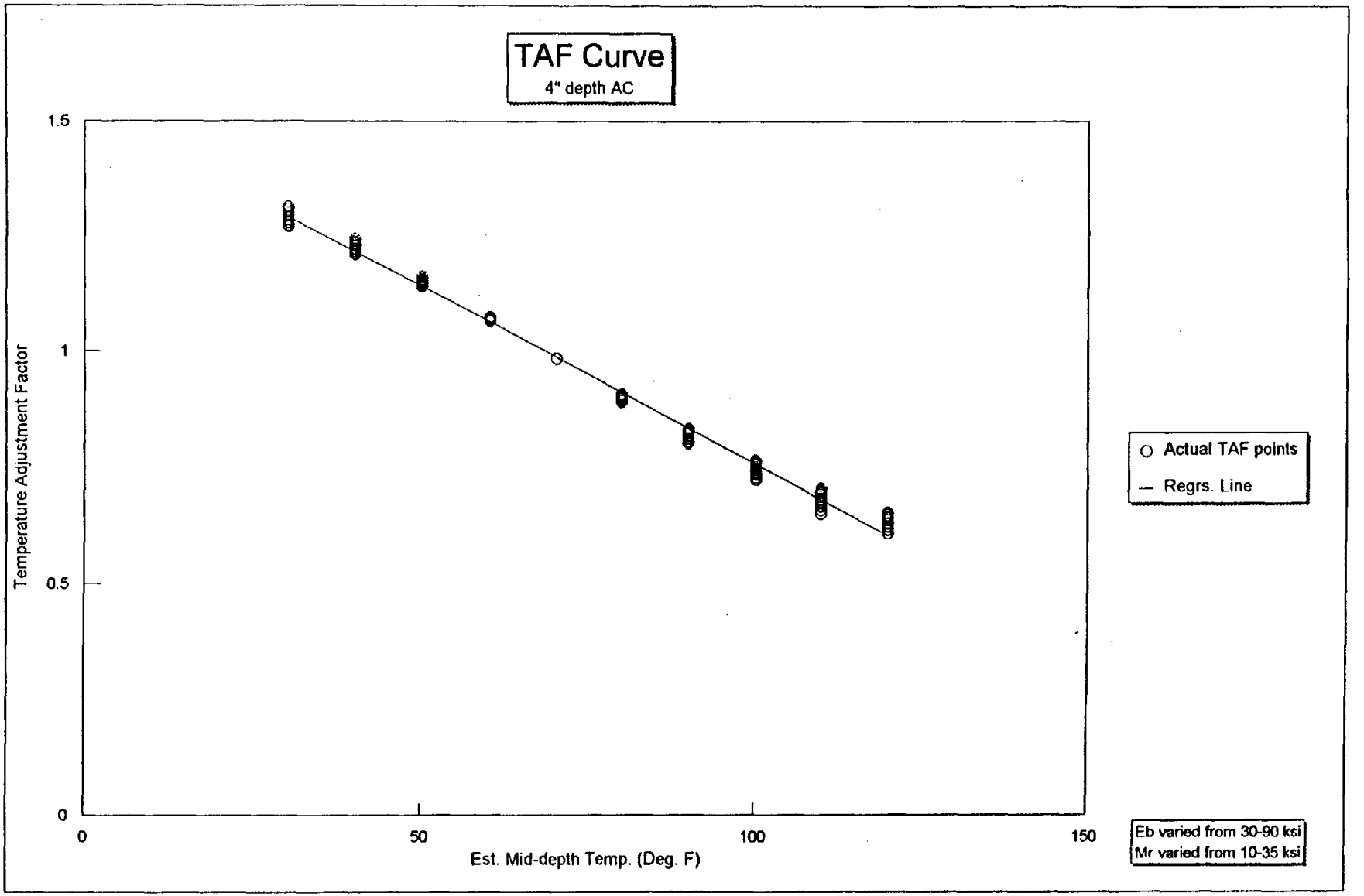
8" *depth*: $TAF = 1.654622 - 0.00961T(°F)$
$CC = -0.99875$

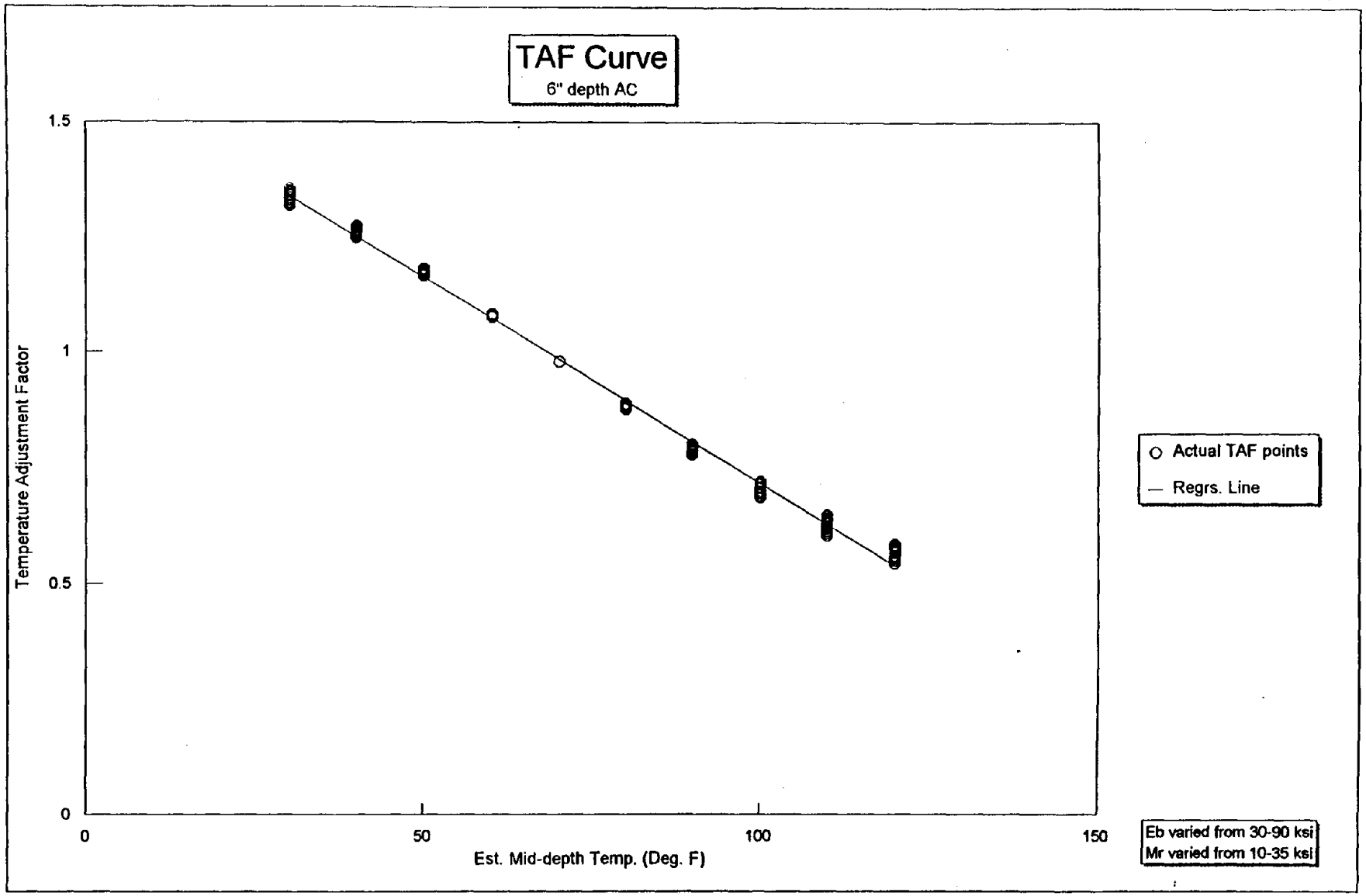
10" *depth*: $TAF = 1.686027 - 0.01007T(°F)$
$CC = -0.998884$

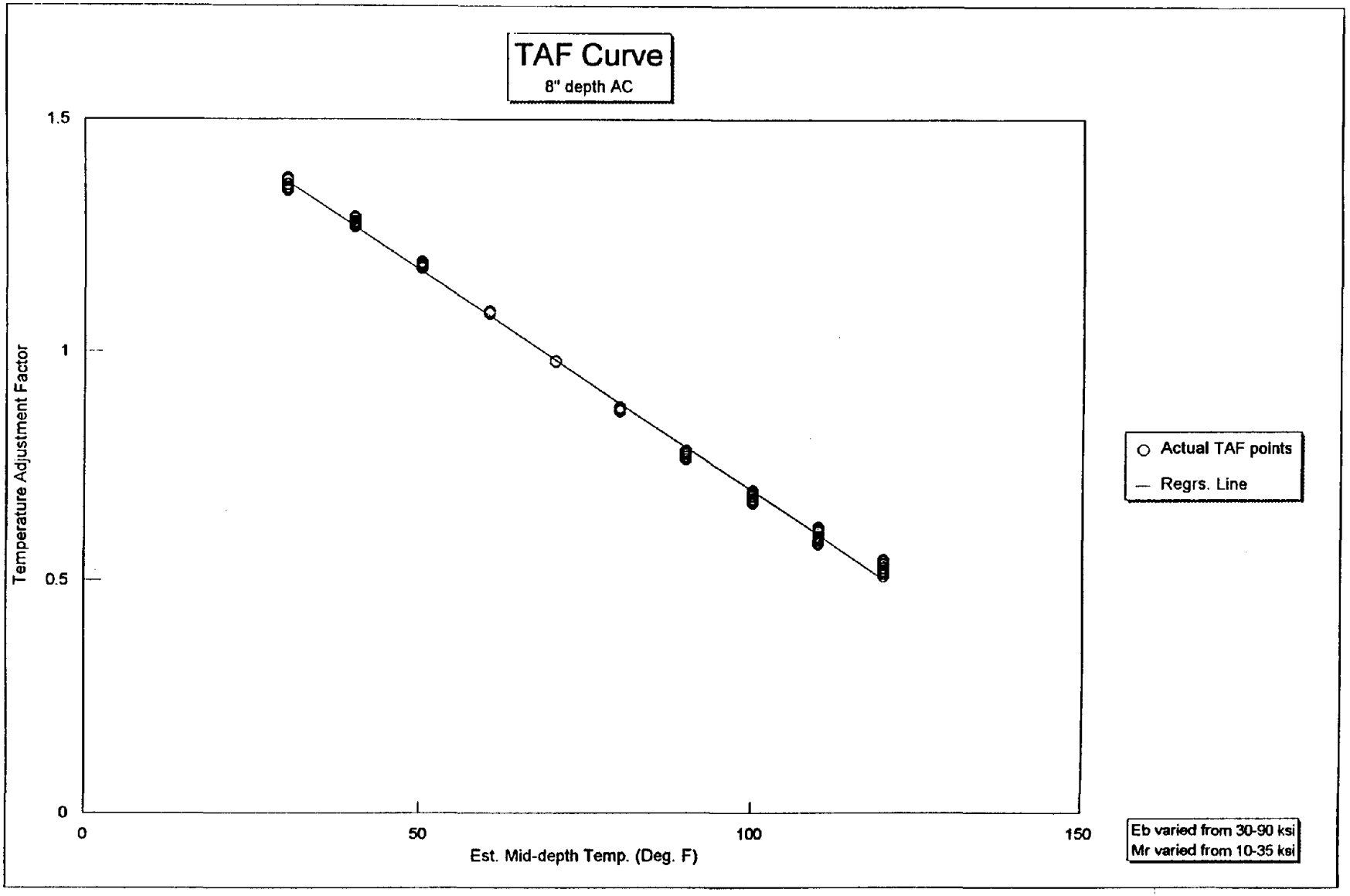
12" *depth*: $TAF = 1.707725 - 0.0104T(°F)$
$CC = -0.998995$

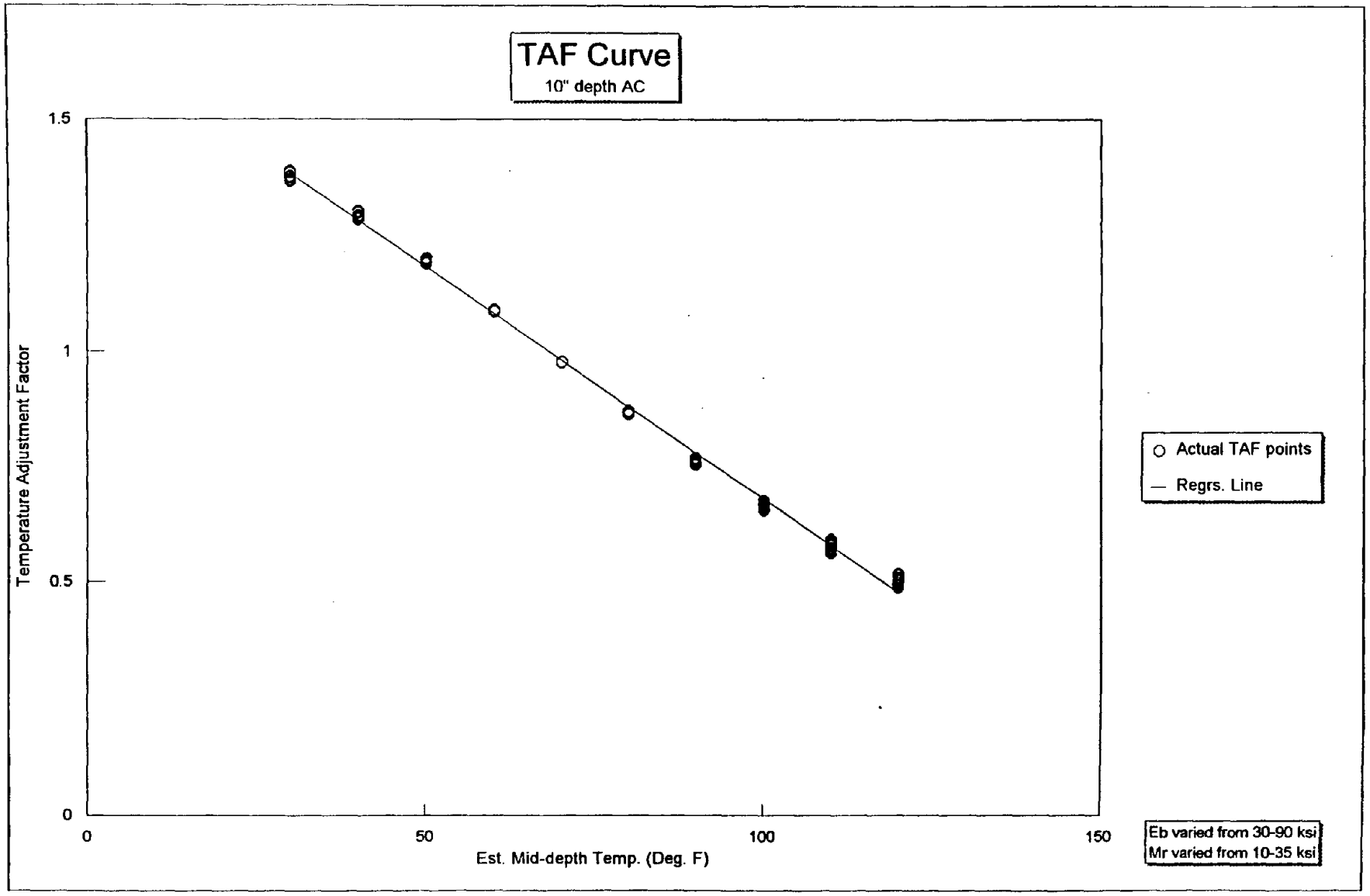
where CC is the correlation coefficient

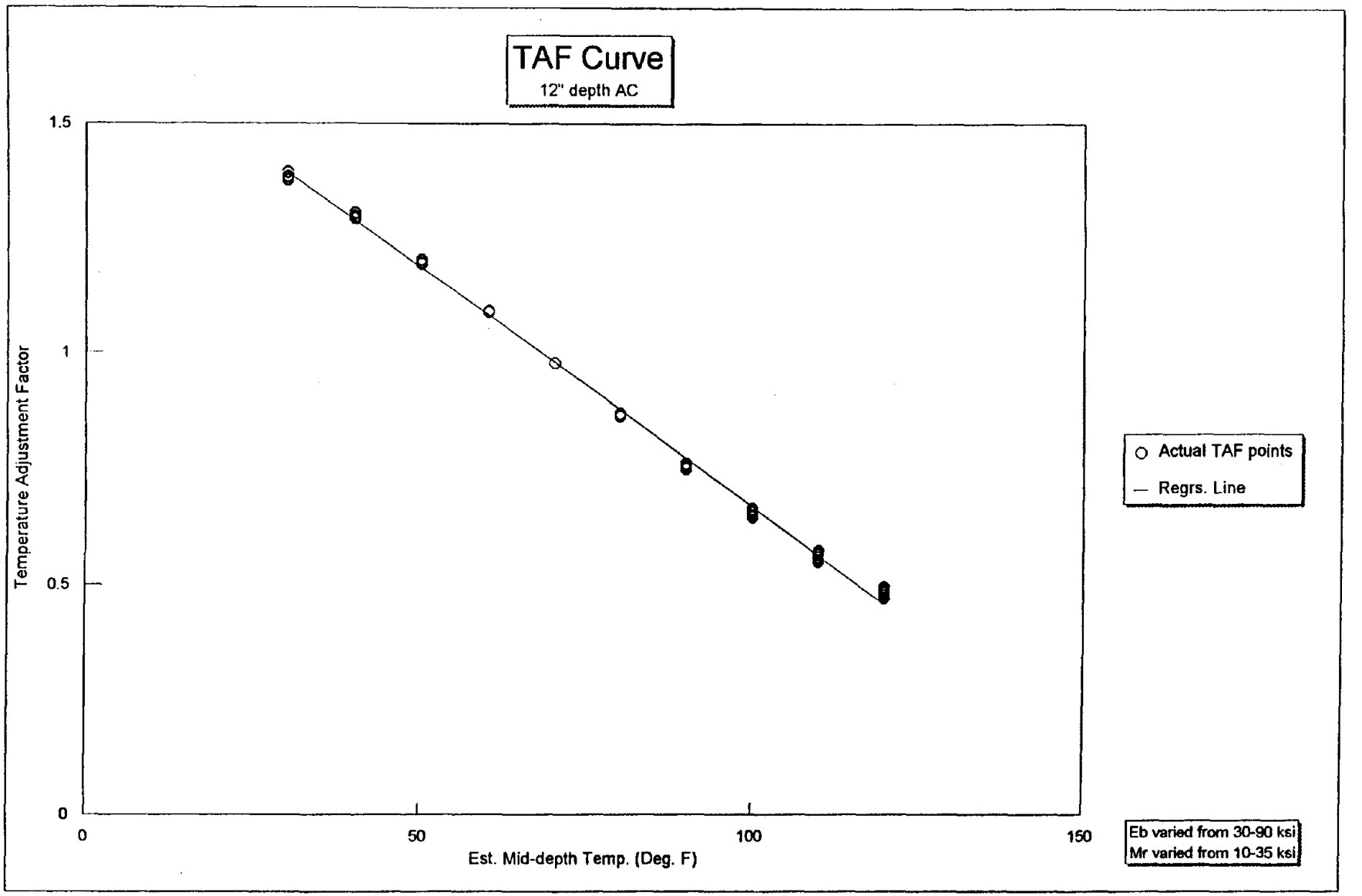

TAF Curve
2" depth AC
1.5
1
0.5
0
Temperature Adjustment Factor
0
50
100
150
Est. Mid-depth Temp. (Deg. F)
Actual TAF points
Regrs. Line
Eb varied from 30-90 ksi
Mr varied from 10-35 ksi

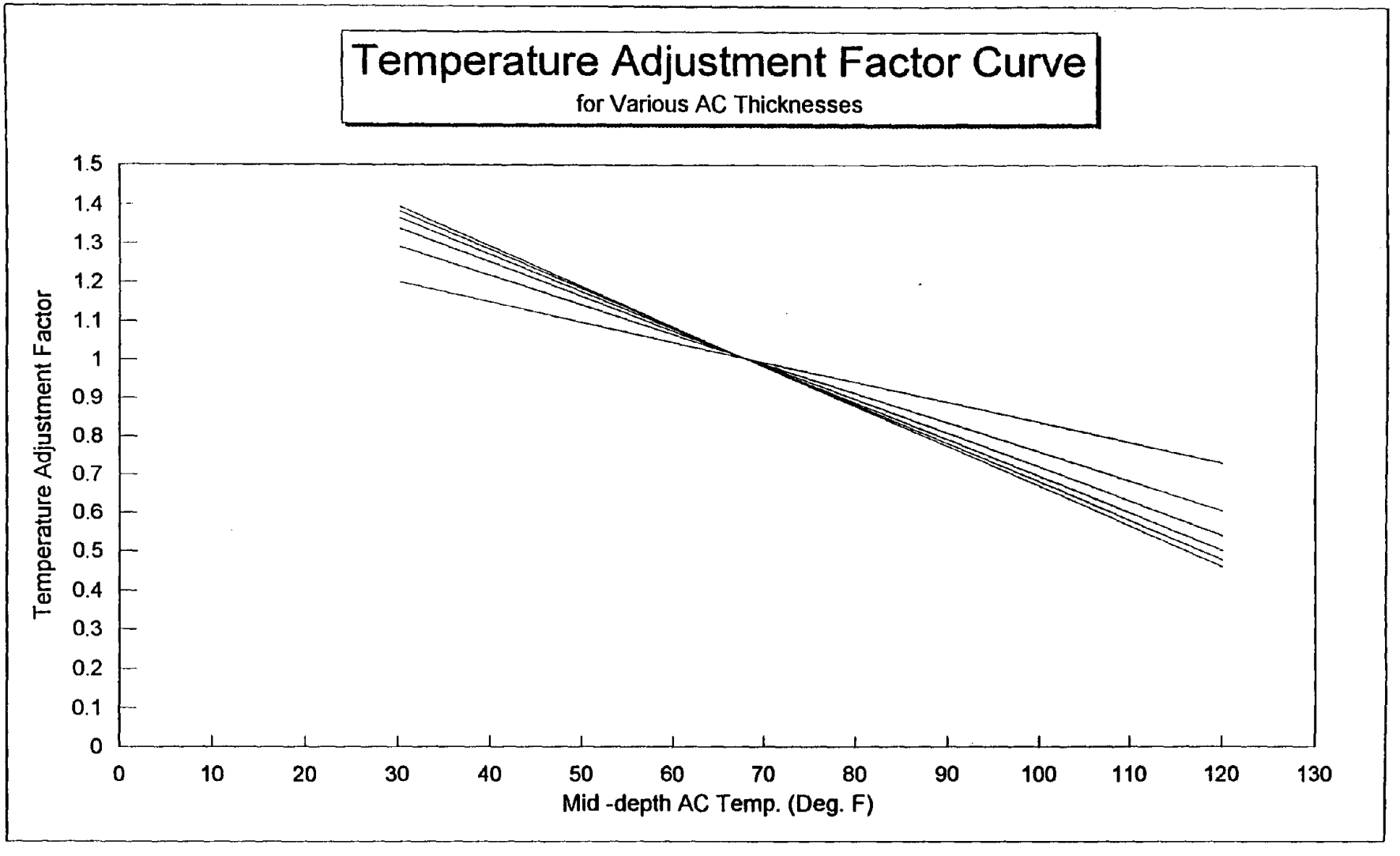

TAF Curve
4" depth AC
Temperature Adjustment Factor
1.5
1
0.5
0
0
50
100
150
Est. Mid-depth Temp. (Deg. F)
Actual TAF points
Regrs. Line
Eb varied from 30-90 ksi
Mr varied from 10-35 ksi


TAF Curve
6" depth AC
Temperature Adjustment Factor
1.5
1
0.5
0
0
50
100
150
Est. Mid-depth Temp. (Deg. F)
Actual TAF points
Regrs. Line
Eb varied from 30-90 ksi
Mr varied from 10-35 ksi


TAF Curve
8" depth AC
Temperature Adjustment Factor
1.5
1
0.5
0
0
50
100
150
Est. Mid-depth Temp. (Deg. F)
Actual TAF points
Regrs. Line
Eb varied from 30-90 ksi
Mr varied from 10-35 ksi

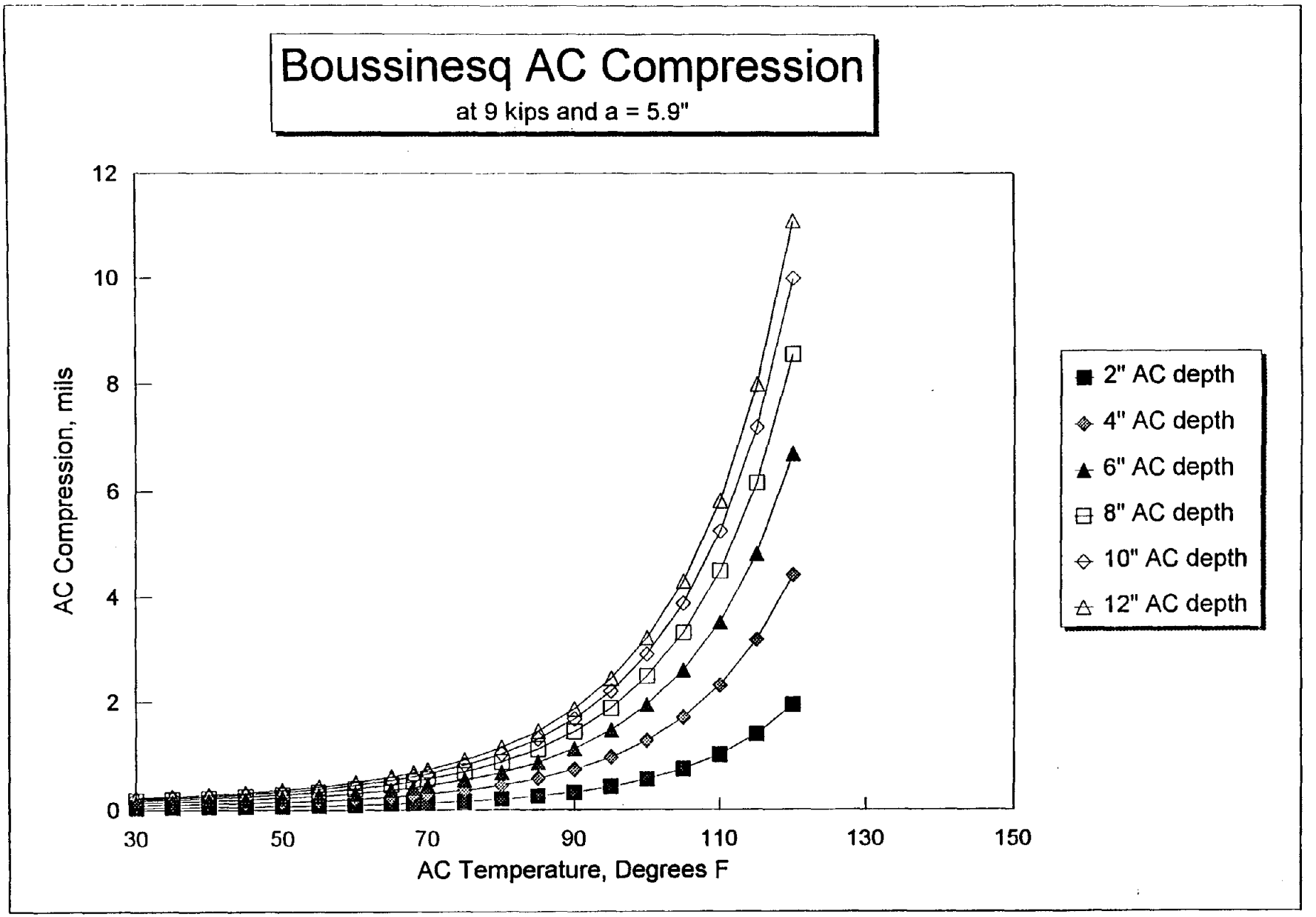

TAF Curve
10" depth AC
Temperature Adjustment Factor
1.5
1
0.5
0
0
50
100
150
Est. Mid-depth Temp. (Deg. F)
Actual TAF points
Regrs. Line
Eb varied from 30-90 ksi
Mr varied from 10-35 ksi


TAF Curve
12" depth AC
Temperature Adjustment Factor
1.5
1
0.5
0
0
50
100
150
Est. Mid-depth Temp. (Deg. F)
Actual TAF points
Regrs. Line
Eb varied from 30-90 ksi
Mr varied from 10-35 ksi


Temperature Adjustment Factor Curve
for Various AC Thicknesses
Temperature Adjustment Factor
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Mid -depth AC Temp. (Deg. F)

Bousinessq Method
for Center of Plate AC Compression

		AC Compression at Depth						TAF at Depth					
t(p) (deg. F)	E(ac) (psi)	2 inches (mils)	4 inches (mils)	6 inches (mils)	8 inches (mils)	10 inches (mils)	12 inches (mils)	2 inches	4 inches	6 inches	8 inches	10 inches	12 inches
0	3.065E+06	0.0295	0.0670	0.1018	0.1300	0.1518	0.1687	4.064143	4.064143	4.064143	4.064143	4.064143	4.064143
5	3.037E+06	0.0298	0.0676	0.1027	0.1312	0.1532	0.1703	4.026885	4.026885	4.026885	4.026885	4.026885	4.026885
10	2.960E+06	0.0305	0.0694	0.1054	0.1346	0.1572	0.1747	3.924423	3.924423	3.924423	3.924423	3.924423	3.924423
15	2.840E+06	0.0318	0.0723	0.1099	0.1403	0.1639	0.1821	3.765323	3.765323	3.765323	3.765323	3.765323	3.765323
20	2.684E+06	0.0337	0.0765	0.1163	0.1485	0.1734	0.1927	3.55842	3.55842	3.55842	3.55842	3.55842	3.55842
25	2.499E+06	0.0362	0.0822	0.1249	0.1594	0.1862	0.2070	3.313464	3.313464	3.313464	3.313464	3.313464	3.313464
30	2.293E+06	0.0394	0.0895	0.1361	0.1737	0.2029	0.2255	3.040775	3.040775	3.040775	3.040775	3.040775	3.040775
35	2.075E+06	0.0436	0.0990	0.1504	0.1920	0.2243	0.2493	2.75074	2.75074	2.75074	2.75074	2.75074	2.75074
40	1.850E+06	0.0488	0.1110	0.1687	0.2153	0.2515	0.2795	2.453292	2.453292	2.453292	2.453292	2.453292	2.453292
45	1.627E+06	0.0555	0.1262	0.1918	0.2448	0.2860	0.3178	2.157471	2.157471	2.157471	2.157471	2.157471	2.157471
50	1.411E+06	0.0640	0.1455	0.2211	0.2823	0.3298	0.3665	1.87107	1.87107	1.87107	1.87107	1.87107	1.87107
55	1.207E+06	0.0749	0.1701	0.2585	0.3301	0.3855	0.4285	1.600412	1.600412	1.600412	1.600412	1.600412	1.600412
60	1.018E+06	0.0887	0.2016	0.3064	0.3912	0.4570	0.5079	1.350246	1.350246	1.350246	1.350246	1.350246	1.350246
65	8.476E+05	0.1066	0.2423	0.3682	0.4701	0.5491	0.6102	1.123757	1.123757	1.123757	1.123757	1.123757	1.123757
68	7.542E+05	0.1198	0.2722	0.4138	0.5282	0.6170	0.6858	1	1	1	1	1	1
70	6.959E+05	0.1299	0.2951	0.4484	0.5725	0.6687	0.7432	0.922666	0.922666	0.922666	0.922666	0.922666	0.922666
75	5.637E+05	0.1603	0.3642	0.5536	0.7068	0.8255	0.9175	0.747417	0.747417	0.747417	0.747417	0.747417	0.747417
80	4.506E+05	0.2006	0.4557	0.6926	0.8843	1.0329	1.1479	0.597389	0.597389	0.597389	0.597389	0.597389	0.597389
85	3.554E+05	0.2543	0.5778	0.8782	1.1212	1.3096	1.4555	0.471145	0.471145	0.471145	0.471145	0.471145	0.471145
90	2.766E+05	0.3268	0.7424	1.1284	1.4406	1.6828	1.8702	0.366676	0.366676	0.366676	0.366676	0.366676	0.366676
95	2.124E+05	0.4255	0.9667	1.4692	1.8757	2.1910	2.4350	0.281621	0.281621	0.281621	0.281621	0.281621	0.281621
100	1.610E+05	0.5613	1.2753	1.9383	2.4746	2.8906	3.2125	0.213464	0.213464	0.213464	0.213464	0.213464	0.213464
105	1.204E+05	0.7503	1.7048	2.5910	3.3079	3.8639	4.2942	0.159692	0.159692	0.159692	0.159692	0.159692	0.159692
110	8.893E+04	1.0162	2.3088	3.5090	4.4800	5.2329	5.8157	0.117914	0.117914	0.117914	0.117914	0.117914	0.117914
115	6.482E+04	1.3942	3.1679	4.8147	6.1469	7.1800	7.9796	0.085938	0.085938	0.085938	0.085938	0.085938	0.085938
120	4.663E+04	1.9380	4.4034	6.6925	8.5443	9.9803	11.0919	0.061825	0.061825	0.061825	0.061825	0.061825	0.061825
125	3.311E+04	2.7290	6.2006	9.4240	12.0316	14.0537	15.6189	0.043905	0.043905	0.043905	0.043905	0.043905	0.043905
130	2.322E+04	3.8928	8.8447	13.4427	17.1623	20.0466	22.2793	0.03078	0.03078	0.03078	0.03078	0.03078	0.03078
135	1.607E+04	5.6247	12.7799	19.4236	24.7980	28.9657	32.1917	0.021302	0.021302	0.021302	0.021302	0.021302	0.021302


Boussinesq AC Compression
at 9 kips and a = 5.9"
AC Compression, mils
0
2
4
6
8
10
12
30
50
70
90
110
130
150
AC Temperature, Degrees F
2" AC depth
4" AC depth
6" AC depth
8" AC depth
10" AC depth
12" AC depth

APPENDIX D

Data and Graphs Relating to
the Comparison of Methods Used to Find Layer Strength Moduli

MANUALLY BACKCALCULATED PROCEDURE FOR FINDING E_p AND M_r

Determination of Subgrade Modulus for SN_{eff} Determination

1993 AASHTO Design Guide of Pavement Structures

Choose the radial distance from the load in inches, r. The first value can be approximated as 1.5 times the total depth of the pavement.

Find the deflection value, D_r, corresponding to the chosen radial distance. The value is interpolated from the FWD deflection data gathered.

Find the subgrade resilient modulus:

$$M_r = \frac{P(1-u^2)}{pi*r*D_r}$$

where P = load in lbs. (9000 lbs)
u = Poisson's ratio (0.5)
D_r = deflection at distance r from the applied load in inches (vaires with r)
r = radial distance from load in inches (varied)

Find E_p by trial and error from the following equation:

$$d_0 = 1.5pa\left[\frac{1}{M_r\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_p}{M_r}}\right)^2}} + \frac{\left[1-\frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right]}{E_p}\right]$$

where D = total depth of pavement in inches (varied for different pavements)
a = plate radius in inches (5.9 inches)
E_p = strength modulus of the pavement in psi
M_r = resilient modulus of subgrade in psi (as found above)
p = contact pressure in psi (9000 lbs./plate area = 82.3 psi)
d_0 = deflection value at r=0 in inches (varies)

The radius value used (r) should be greater than or equal to seventy percent of the effective radius a_e of the stress bulb at the subgrade/pavement interface. With the subgrade Poisson's raito equal to 0.5, the equation for effective radius is:

$$a_e = \sqrt{a^2 + \left(D\sqrt[3]{\frac{E_p}{M_r}}\right)^2}$$

$$r >= 0.7a_e$$

If the r value used is less than $0.7a_e$ or a value of r that is closer to the calculated $0.7a_e$ can be used, then another value for r is chosen and the procedure is started all over again until r is greater than or equal to $0.7a_e$. The final trial yields the values for E_p and M_r for that particular FWD deflection reading..

SAMPLE CALCULATION

Test Site: *MT*1

Date of FWD deflection data collection: 2/11/92

$D = 11"$

$a = 5.9"$

$P = 9000$ *lbs.*

estimated mid - depth temperature $= 38.7°$

FWD Deflection Data:

Mean Measured Deflection: (*mils*)

$R_0 = 0"$	$R_1 = 8"$	$R_2 = 12"$	$R_3 = 24"$	$R_4 = 36"$	$R_5 = 48"$	$R_6 = 72"$
6.75	6.13	5.61	4.11	2.86	2.03	1.16

E_p, M_r CALCULATION

inital estimate of $r = 1.5D$ *or* $1.5*11 = 16.5"$

$r = 16.5"$

D_r *found by* int *erpolation* $\frac{24-16.5}{24-12} = \frac{4.11-D_r}{4.11-5.61}$ $\quad D_r = 5.05$ *mils*

$$M_r = \frac{P(1-u^2)}{pi*r*D_r} = \frac{9000(1-0.5^2)}{3.14*16.5*5.05*10^{-3}} = 25,785.68 \text{ psi}$$

$$6.75*10^{-3} = 1.5*82.3*5.9\left[\frac{1}{25,785.68\sqrt{1+\left(\frac{11}{5.9}\sqrt[3]{\frac{E_p}{25,785.68}}\right)^2}} + \frac{\left(1-\frac{1}{\sqrt{1+\left(\frac{11}{5.9}\right)^2}}\right)}{E_p}\right]$$

E_p solved for by inputted solver programon HP42S Scientific Calculator

$E_p = 421,796.79$ *psi*

$$a_e = \sqrt{5.9^2 + \left(11 * \sqrt[3]{\frac{421.796.79}{25,785.68}}\right)^2} = 28.54"$$

$$0.7a_e = 19.98"$$

$$0.7a_e > r \quad \textit{therefore, no good}$$

$$\textit{new } r = 21"$$

$$\frac{24-21}{24-12} = \frac{4.11-D_r}{4.11-5.61} \qquad D_r = 4.49 \textit{ mils}$$

$$M_r = \frac{9000(1-0.5^2)}{3.14*21*4.49*10^{-3}} = 22,787.06 \textit{ psi}$$

$$6.75*10^{-3} = 1.5*82.3*5.9\left[\frac{1}{22,787.06\sqrt{1+\left(\frac{11}{5.9}\sqrt[3]{\frac{E_p}{22,787.06}}\right)^2}} + \frac{\left(1-\frac{1}{\sqrt{1+\left(\frac{11}{5.9}\right)^2}}\right)}{E_p}\right]$$

E_p *solved by HP solver program*= 506,094.29 *psi*

$$a_e = \sqrt{5.9^2 + \left(11 * \sqrt[3]{\frac{506,094.79}{22,787.06}}\right)^2} = 31.48"$$

$$0.7a_e = 22.03"$$

$$0.7a_e > r \quad \textit{therefore, no good}$$

$$\textit{new } r = 22.5"$$

$$\frac{24-22.5}{24-12} = \frac{4.11-D_r}{4.11-5.61} \qquad D_r = 4.30 \textit{ mils}$$

$$M_r = \frac{9000(1-0.5^2)}{3.14*22.5*4.30*10^{-3}} = 22,207.67 \textit{ psi}$$

$$6.75*10^{-3} = 1.5*82.3*5.9\left[\frac{1}{22{,}207.67\sqrt{1+\left(\frac{11}{5.9}\sqrt[3]{\frac{E_p}{22{,}207.67}}\right)^2}}+\frac{\left(1-\frac{1}{\sqrt{1+\left(\frac{11}{5.9}\right)^2}}\right)}{E_p}\right]$$

E_p *solved by HP solver program*$= 526{,}316.31$ *psi*

$$a_e = \sqrt{5.9^2+\left(11*\sqrt[3]{\frac{526{,}316.31}{22{,}207.67}}\right)^2} = 32.14"$$

$0.7a_e = 22.50$

$0.7a_e =< r \quad OK$

Therefore, for $MT1$ *on* $2/11/92$: $M_r = 22{,}207.67$ *psi*

$E_p = 526{,}316.31$ *psi*

Two layer system - AC and subgrade

Est. mid-depth tem. (deg. F)	Man. Bkcd. Ep (ksi)	MODULUS Ep (ksi)	Man. Bkcd. Mr (ksi)	MODULUS Mr (ksi)
35.6	415.6	757	22.29	17.70
38.7	524.5	797	22.26	16.80
42.1	512.44	754	22.66	17.30
46.1	303.02	574	20.50	15.70
49.8	533.54	792	26.17	17.10
50	397.12	566	20.18	16.50
50.4	254.87	449	16.81	13.10
50.8	591.62	899	31.03	19.60
58.8	324.13	511	19.89	16.30
64.6	187.3	319	14.91	12.00
71.9	240.87	327	21.84	14.80
73.3	304.71	411	21.20	13.40
74.8	343.81	487	22.24	17.90
77.2	262.95	346	25.10	17.80
78.2	311.17	432	20.65	16.80
79.2	229.26	308	22.67	15.30
79.4	173.42	265	16.69	13.50
83.6	231.47	314	19.68	12.80
85.1	174.56	246	13.47	8.80
87.8	290.9	393	21.63	18.00
90	216.36	290	20.34	17.20
95.3	65.21	104	10.06	6.80
95.8	80.74	130	12.10	8.60
97.3	95.86	128	13.23	8.10
98.4	78.78	129	10.78	7.70
103.5	129.33	183	18.69	14.40
108.6	61.45	82	11.50	6.30

Comparison of Modulus E_{ac} vs. Asphalt Institute (AI) Regression Values for E_{ac}

tp (deg. F)	AI Eac (ksi)	Mod. Eac (ksi)
35.6	2047.94	1497
38.7	1908.83	2130
42.1	1756.14	2011
46.1	1578.92	1069
49.8	1419.67	1676
50.0	1411.23	1526
50.4	1394.40	883
50.8	1377.66	1808
58.8	1062.13	997
64.6	860.55	615
71.9	643.39	613
73.3	606.50	815
74.8	568.64	1157
77.2	511.65	657
78.2	489.17	1097
79.2	467.44	589
79.4	463.18	504
83.6	380.29	642
85.1	353.62	495
87.8	309.32	974
90.0	276.56	691
95.3	208.98	167
95.8	203.38	215
97.3	187.29	219
98.4	176.18	224
103.5	131.58	364
108.6	96.94	127

SHRP Regional Information Management System Laboratory Data

Temperature (° F)	MT1 E_{ac} average (ksi)	MT2 E_{ac} average (ksi)
41	813.3	739.0
77	509.6	501.6
104	237.0	203.9

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