EVALUATION OF TEMPERATURE EFFECTS ON BITUMINOUS PAVEMENT DEFLECTIONS IN VIRGINIA

by

N. K. Vaswani
Senior Research Scientist

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

April 1976
VHTRC 76-R50

ABSTRACT

EVALUATION OF TEMPERATURE EFFECTS ON BITUMINOUS PAVEMENT DEFLECTIONS IN VIRGINIA

by

N. K. Vaswani
Senior Research Scientist

Eight satellite projects with asphaltic layer thicknesses varying from 3.5 inches (88 mm) to 13.5 inches (338 mm) were tested for dynaflect deflections during the four seasons of 1974-75. The projects were located throughout Virginia. The evaluation of the deflection data showed the maximum deflection, the area of the deflected basin, and the spreadability and modulus of elasticity of the deflected basin to be functions of the log of the temperature.

The asphaltic concrete thicknesses are divided into three groups of 2 to 4 inches (50 to 100 mm), 4 to 10 inches (100 to 250 mm), and 10 to 15 inches (250 to 375 mm) for a correlation of the mean pavement temperature with temperature adjustment factors. Correlation equations and graphs are developed.

EVALUATION OF TEMPERATURE EFFECTS ON BITUMINOUS PAVEMENT DEFLECTIONS IN VIRGINIA

by

N. K. Vaswani
Senior Research Scientist

INTRODUCTION

Flexible pavement evaluations and rehabilitative techniques in Virginia are based on pavement rebound deflections taken only during the spring season. Because of the impracticability of such a seasonal restriction, procedures are needed that would allow the pavement evaluation crew to perform their work during any season. An obstacle heretofore faced in year-round testing has been the seasonal variations in temperature and other pavement conditions that change the deflection test results.

PURPOSE

The objective of this study, therefore, was to correlate the deflection data taken in any season to the deflection data taken in the spring, and one of the most important variables that affects the deflection data is the temperature of the asphaltic concrete layers of the pavement. Consequently, this investigation sought to provide corrections for temperature such that the deflection data taken in any season could be reduced to the corresponding deflection data for spring. Corrections were developed in the form of mathematical and graphical correlations between the mean temperature of the asphaltic concrete layers of the pavement and the results of the deflection tests.

SCOPE

To achieve the above objective, this study was divided as follows:

1. Selection of the variables,
2. selection of satellite projects and collection of data,
3. evaluation and correlations between the variables, and
4. method of application for temperature corrections.

THE VARIABLES

The most important independent variables that affect pavement deflection test results are the following:

A. The temperature of the asphaltic concrete layer,
B. the thickness of the asphaltic concrete layer,
C. the hydrothermal changes in the subgrade and the pavement underlying the asphaltic concrete layer,

D. the thermal properties of the aggregate and asphalt in the asphaltic concrete mix,
E. the age of the asphaltic concrete mix,
F. the oxidation of the asphalt, and
G. the compaction of the pavement by traffic.

Variables Considered

In this study, an examination was made of the effect of two of the variables listed above; namely, the temperature and the thickness of the asphaltic concrete layer. These variables were correlated with the dependent variables obtained from the deflection data, which are classified as follows for pavement evaluations in Virginia:

1. The maximum deflection, d, in inches,
2. the spreadability of the deflected basin, S,
3. the area of the deflected basin, A, in in.^{2}, and
4. the pavement modulus, E, in psi.

A correlation study carried out by Hughes has shown that the deflection under a 9,000 lb. (4,080 kg) wheel load and 70 psi (0.48 MN/m^2) tire pressure is equal to 28.6 times the dynaflect deflection.(1) Hence d is equal to 28.6 times the maximum dynaflect deflection shown in Figure 1.

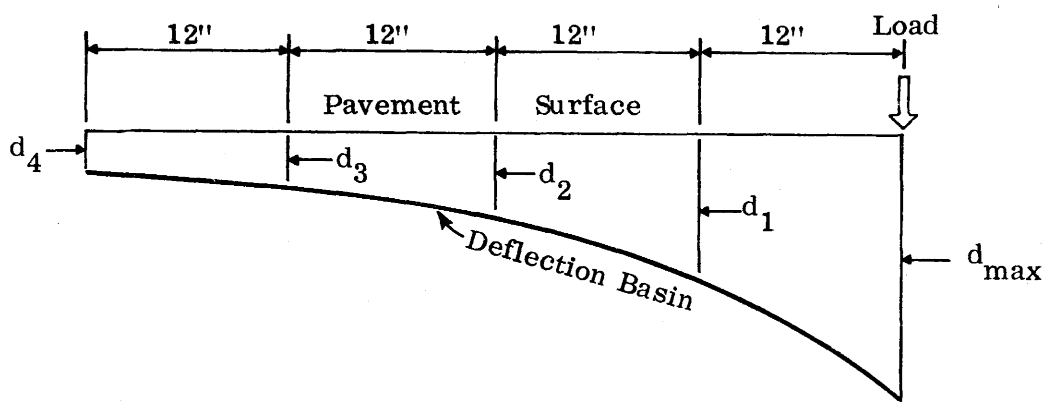

Figure 1. Deflection basin produced by the dynaflect machine.
Basic conversion unit: 1" = 25 mm.

S, the spreadability, is the average deflection expressed as a percentage of the maximum deflection, and is obtained by the equation

$$S = \frac{d_{max} + d_1 + d_2 + d_3 + d_4}{5\, d_{max}} \times 100$$

A is the area enclosed by half the deflected basin bounded by the pavement surface on top, the deflected basin curve at the bottom, and d_4 and d_{max} as shown in Figure 1. The deflected area is determined as discussed below.

Using the correlation developed by Hughes, [1] and d_{max}, d_1, d_2, d_3, and d_4 as the deflections under the dynaflect load, the estimated deflected area under the 9,000 lb. (4,080 kg) wheel load

$$A = 28.6 \times 6 \, (d_{max} + 2d_1 + 2d_2 + 2d_3 + d_4) \text{ in.}^2 \tag{1}$$
$$= 171.6 \, (d_{max} + 2d_1 + 2d_2 + 2d_3 + d_4) \text{ in.}^2$$

The pavement modulus, E, is determined from a set of charts based on d and A. The method of evaluating E is described in a separate report. [2]

The moisture change in the subgrade is another important variable affecting pavement deflections. If this variable is considered separately, the moisture content of the subgrade must be determined each time deflection data are taken. The measurement of subgrade moisture is a very difficult, time-consuming and expensive job, and cannot be recommended for each pavement evaluation. In this investigation, therefore, no separate evaluation was made of this variable; rather any changes in subgrade moisture were considered an integral part of the variation in deflections due to temperature and the thickness of the asphaltic concrete layer.

SELECTION OF SATELLITE PROJECTS AND COLLECTION OF DATA

Nine satellite projects having varying thicknesses of asphaltic concrete and distributed over Virginia were selected for study. Of these nine, eight projects were utilized for evaluation in this study. As can be seen from the listing of these eight projects in Appendix 1, projects 1 and 2 have asphaltic concrete thicknesses of 13.5 in. and 10.5 in. (338 mm and 263 mm) respectively; projects 3 through 6 have thicknesses between 10 in. and 4 in. (250 mm and 100 mm); and projects 7 and 8 have thicknesses below 4 inches (100 mm).

The data for the ninth project, which is not listed, were obtained in tests interrupted at midday by clouds and strong winds. The relationships between temperature and deflection data collected on this project were incompatible with the relationships for the other eight projects.

Pavement temperature studies by various investigators have shown that pavement temperatures vary with the duration and intensity of periods of shade and clouds. Hence any correlations between asphaltic concrete pavement temperatures and air or pavement surface temperatures cannot be correctly carried out on cloudy days or on shaded pavements. However, recommendations have been made in this report for evaluating pavements under such conditions.

Since the deflection is affected by the pavement temperature, the latter must be measured at frequent intervals during a deflection survey. In this investigation, the air and pavement surface temperatures were measured at the beginning and at the end of the forenoon tests and also at the beginning and end of the afternoon tests. The mean of the forenoon temperatures was correlated with the mean of the forenoon deflection data for each project site, and the mean of the afternoon temperatures with the mean of the afternoon deflections. Pavement surface temperatures were measured at a depth of 1 inch (25 mm) using a suitable short stem mercury thermometer. A star drill and hammer were used to make a 1-inch deep hole, which was filled with glycerine before the thermometer was inserted. A percussion type masonry drill 0.25 inch (6 mm) in diameter could be used. The air temperature was recorded in open air, under the sun but protected from wind effects, at about 4 feet (1.2 m) above ground.

Southgate and Deen[3] have shown that the average of the maximum and minimum air temperatures for the five days preceeding the day of testing will give a significantly good measure of the air temperature history which affects the temperature throughout the depth of the asphaltic concrete layer at the time of the deflection tests. The sum of this average temperature, and the pavement surface temperature shows a good relationship with the temperature at any depth of the asphaltic concrete layer. Appendix 1 lists the weather stations from which data were obtained to calculate the five day averages.

For the collection of pavement data, each site was divided into three 1,000 feet (300 m) sections spaced about 5,000 feet (1,500 m) apart. Deflection data were taken at 100 foot (30 m) intervals with the dynaflect apparatus, which records five deflections in the deflection basin as shown in Figure 1. To get a valid correlation between temperature and deflection, testing was conducted during all four seasons of the year.

Trial measurements were made of the pavement surface temperatures with the mercury thermometer as described above and three metallic thermometers. There was a variance of $5^{o}F$ to $10^{o}F$ between the two thermometers when the pavement surface was smooth. On rough pavement surfaces the variance was greater because of the wind effects on the metallic surface thermometers. The application of a coating of vaseline on the surface thermometer did not significantly reduce the error, so the use of this type thermometer was discontinued.

At the request of the FHWA, core samples were taken from two satellite projects to determine certain properties of the subgrade, untreated aggregate base, and bituminous materials. The subgrade and base materials were tested for dry density and percentage moisture, and the results are shown in Appendix 2. The 4 inch (100 mm) diameter concrete core from one project consisted of the top surface layer (S-5) and the base layer (B-3); that from another project consisted of the surface layer (S-5), the intermediate layer (I-2), and the base layer (B-3). The depth of each core tested was 8 inch (200 mm). The cores were tested for creep and dynamic modulus in MTS (Materials Testing Systems) equipment under a direct compression of 20 psi. The duration of the load was 0.1 second with a rest period of 0.9 second. The inverse values of the 1,000-second creep compliance at 0.03 second and the dynamic modulus values at 200 repititions are given in Appendix 2.

EVALUATIONS AND CORRELATIONS OF THE VARIABLES

Temperature Evaluations and Correlations

Since pavement deflection is a function of not only the pavement surface temperature but also the temperature throughout the depth of the asphaltic concrete layer, more accurate correlations may be obtained by correlating the deflection data with the mean temperature for the layer rather than with the surface temperature. The most convenient method for determining the mean temperature of the asphaltic concrete pavement that could be applied in Virginia was believed to be the method based on research of Southgate and Deen at College Park, Maryland.[3]

The reasoning was the College Park has a longitude of 76.93°, while Chincoteague, on the eastern boundary of Virginia, has longitude of 75.23°, and Jonesville, near the western boundary of Virginia, has a longitude of 83.06°, with the mean for the two Virginia localities being 79.14°. From these values, the difference between the longitude for College Park and the average for Virginia is found to be equal to 2.22°, which is equal to the GMT (Greenwich mean time) difference of about nine minutes.

In this investigation, as during the Research Council's pavement evaluation program, temperatures are recorded at the beginning and end of the forenoon and afternoon surveys each of which takes about three hours. Considering these three hour spans between temperature determinations, a time difference of nine minutes during the forenoon or afternoon would not change the accuracy of the temperature evaluation based on the College Park methodology.

The equations given by Southgate and Deen for determining the mean pavement temperature, i.e., the temperature at the middle of the asphaltic concrete layers for mid-morning and mid-afternoon, are given in Appendix 3. Given the pavement surface temperatures taken at the beginning and end of the forenoon or afternoon deflection tests and the average of the maximum and minimum temperatures for the five preceding days, these equations could be used to determine the mean pavement temperatures.

Thus given the thickness of the asphaltic concrete as 12 in. (300 mm), forenoon pavement surface temperature readings of 45° and 52°F (7 and 11°C), and the mean of minimum and maximum temperatures the previous five days as 39°F (3.9°C). The mean temperature of the asphaltic concrete pavement, i.e., the temperature at the 6-in. (150 mm) depth is

$$
\begin{aligned}
Y &= -1.6 + 0.525X \\
&= -1.6 + 0.525\left(\frac{45+52}{2} + 39\right) \qquad (2) \\
&= 44^{\circ}F
\end{aligned}
$$

Correlation Between Air Temperature, Pavement Surface Temperature, and Mean Pavement Temperature

The air and pavement surface temperature data were collected for each of the satellite projects and are given in Appendix 4. The temperature of the middle of the asphaltic concrete layer, hereinafter termed the mean pavement temperature, was calculated from the surface temperature by means of the equations given in Appendix 3. The mean pavement temperature so determined from each surface temperature reading is given as the pavement temperature in Appendix 4.

Correlations were carried out as follows:

1. Air temperature versus pavement surface temperature for mid-forenoon and mid-afternoon;
2. forenoon mean pavement temperature versus forenoon surface temperature for asphaltic concrete layer below 4 inches (100 mm) thickness and for 4 inches (100 mm) and above 4 inches (100 mm) thickness;
3. afternoon mean pavement temperature versus afternoon surface temperature for asphaltic concrete layer below 4 inches (100 mm) thickness and for 4 inches (100 mm) and above 4 inches (100 mm) thickness.

The correlating equations along with their correlation coefficients are given in Appendix 5. The graphs for the same correlations are given in Figures 2, 3, and 4, respectively. As can be seen from Appendix 5, the six correlations have correlation coefficients varying from 0.86 to 0.996, with four of them having values of 0.97 and above. These are therefore excellent correlations, and hence could be used to obtain the pavement surface temperature from the air temperature or the mean pavement temperature from the pavement surface temperature with little sacrifice in the accuracy.

Deflection Data Evaluation and Correlations with Temperatures

As stated before, pavement deflections in Virginia are taken by means of a dynaflect which measures deflections in a basin. For many years the state's pavement and subgrade failures and serviceability and rehabilitation programs have been determined from the maximum deflection, the spreadability of the basin, the area of the deflected basin, and the subgrade and pavement moduli obtained with the dynaflect apparatus. In evaluating the effects of temperature in the present study, this same approach was utilized. The maximum deflection, spreadability, area of the deflected basin, and pavement modulus data are summarized in Appendix 4.

To adjust the deflection data determined in different seasons for changes due to temperature, which was the objective of the investigation, a reference temperature had to be determined. The Asphalt Institute has adopted a reference temperature of 70°F (21°C),[4] Southgate and Deen used 60°F (15.5°C), and Norman et al. used 68°F (20°C). Appendix 4 gives the average forenoon and afternoon pavement temperatures on the satellite projects in this investigation. The average of the spring season* forenoon pavement temperatures in this appendix is 70°F, and the average of the forenoon and afternoon

* Historically, in Virginia deflections have been taken from about the middle of March to about the first of June.

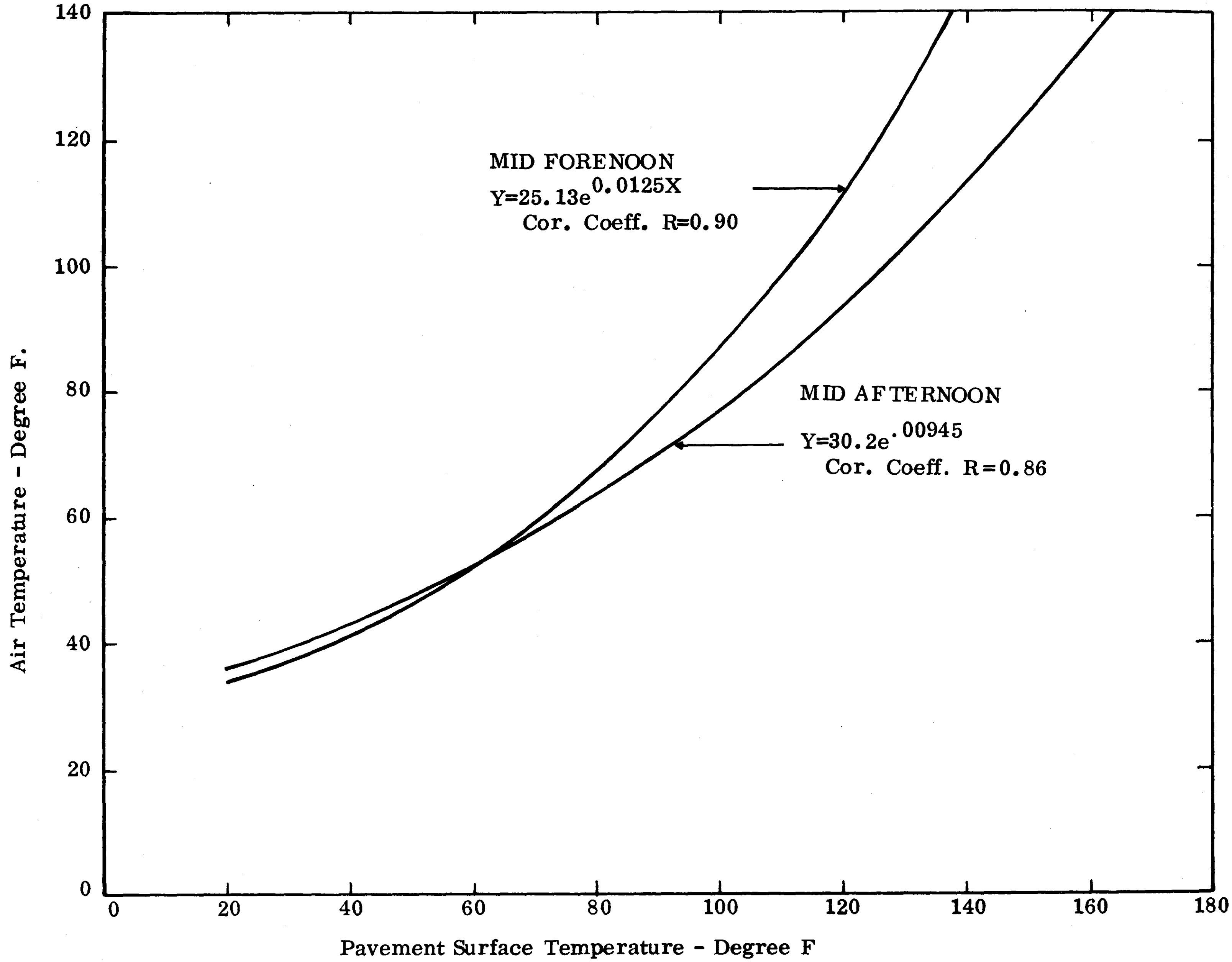

Figure 2. Correlation between air and pavement surface temperatures.
(Deg. C = (F-32) $\frac{5}{9}$)

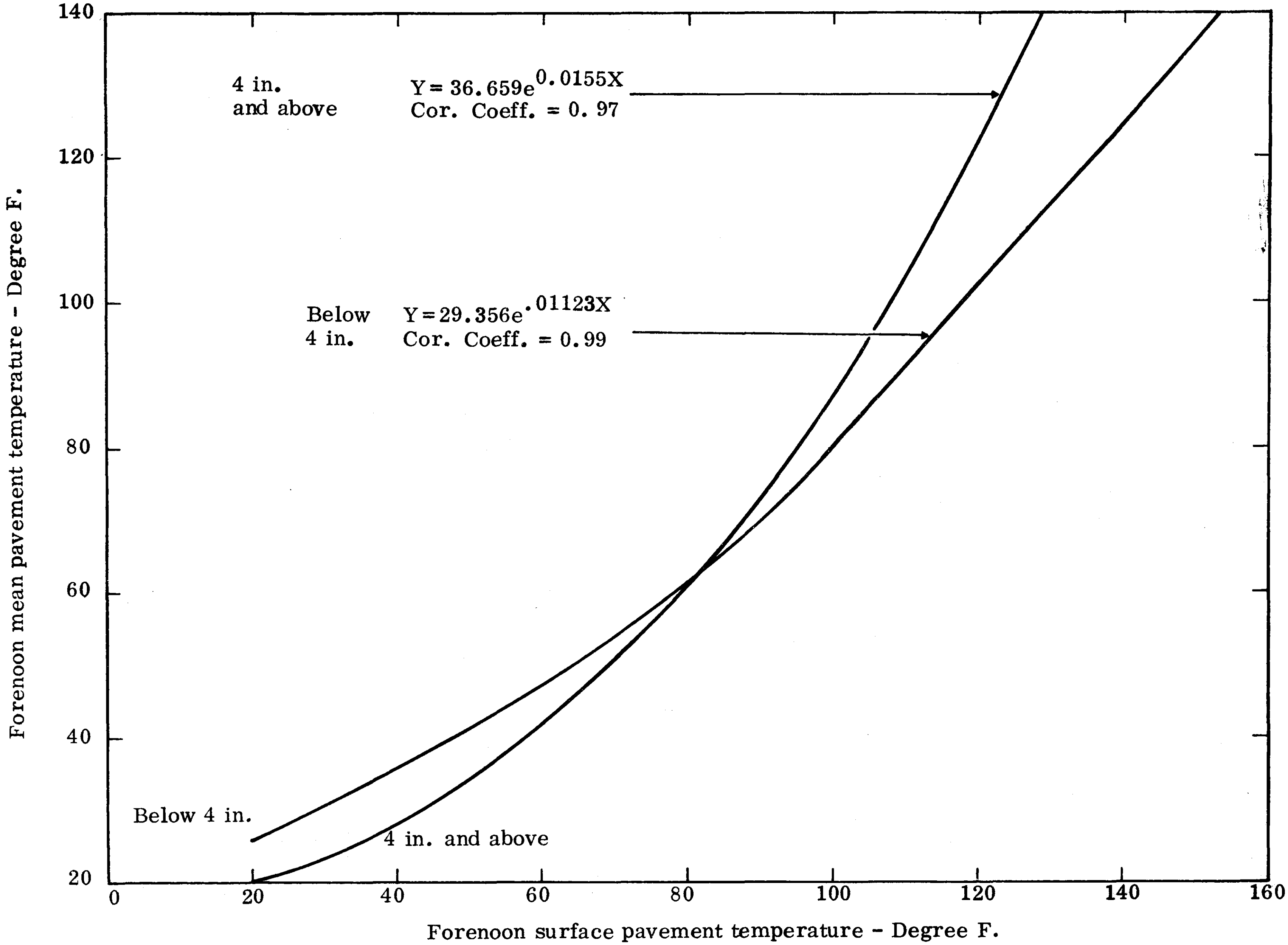

Figure 3. Correlation between forenoon surface and forenoon mean pavement temperature. (Deg. C = (F-32) $\frac{5}{9}$) (1 in. = 25 mm)

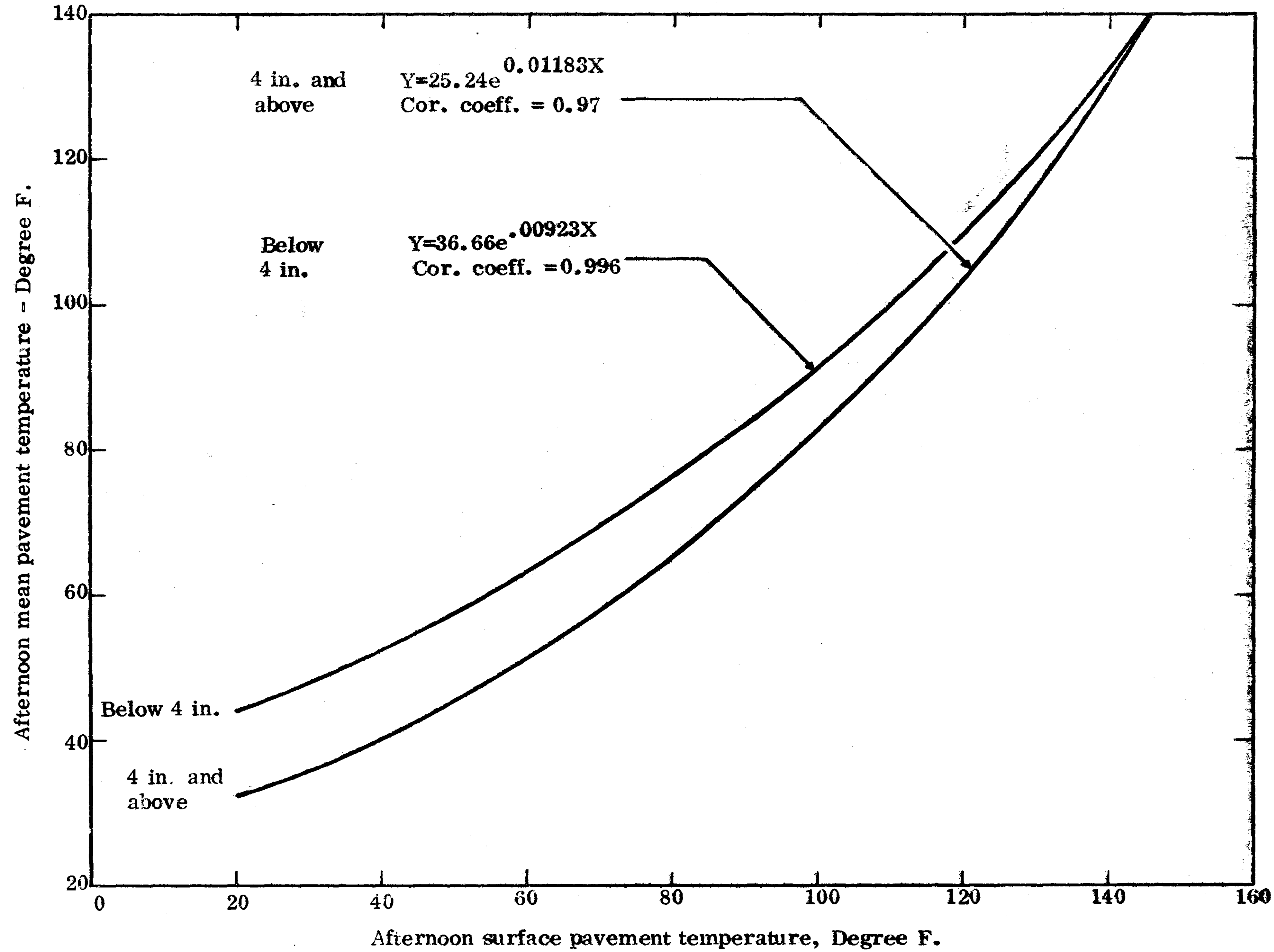

Figure 4. Correlation between afternoon surface and afternoon mean pavement temperatures. (Deg. C = (F-32) $\frac{5}{9}$) (1 in. = 25 mm)

temperatures is 80^{o}F. It was decided to assume the forenoon spring temperature of 70^{o}F (21^{o}C) as the reference temperature for adjusting the deflection data.

In correlating the pavement temperatures with the deflection data the following three model equations were tried:

$$D_T = P^{QT} \qquad (3)$$

$$D_T = P + Q \, LnT \qquad (4)$$

$$D_T = P + \frac{Q}{T} \qquad (5)$$

where

D_T = maximum deflection, or area of the deflected basin, or spreadability of the deflected basin,

T = mean pavement temperature in deg. F at the time of taking the deflection data, and

P and Q = constants.

Based on the correlation coefficient values and the values of the standard error of estimate obtained by the use of these three equations, model equation (4) was adopted for general application. Thus the following equations were used:

$$d_t = P_1 + Q_1 \, LnT \qquad (6)$$

$$A_T = P_2 + Q_2 \, LnT \qquad (7)$$

$$S_T = P_3 + Q_3 \, LnT \qquad (8)$$

$$E_T = P_4 + Q_4 \, LnT \qquad (9)$$

where

d_t = Maximum deflection in inches for 9,000 lb. (40,800 kgms) wheel load at temperature T, deg. F,

A_T = Area of the deflected basin in inches^2 at temperature T, deg. F,

S_T = Spreadability of the deflected basin at temperature T, deg. F,

E_T = Modulus of the pavement in psi at temperature T, deg. F,

P_1, P_2, P_3, P_4, Q_1, Q_2, Q_3, and Q_4 = constants, and

T = Mean pavement temperature in deg. F at the time of taking the deflection data.

For each project given in Appendix 4 the mean pavement temperature was separately correlated with (1) the maximum deflection by equation (6), (2) the area of the deflected basin by equation (7), (3) the spreadability of the deflected basin by equation (8), and (4) the modulus of the pavement by equation (9). The correlation equations for each of the projects were thus determined. As an example, the following equations were obtained for the project designated Serial No. 5 in Appendix 4.

$$d_t = -0.00123 + 0.00365 \, \text{Ln}T \qquad (10)$$

$$A_T = 0.43857 - 0.01376 \, \text{Ln}T \qquad (11)$$

$$S_T = 111.0 - 12.518 \, \text{Ln}T \qquad (12)$$

$$E_T = 592{,}000 - 108{,}680 \, \text{Ln}T \qquad (13)$$

By means of these four equations the values of d_t, A_T, S_T, and E_T for any given mean pavement temperature for this project could be determined.

The adjustment factor (AF) for d_t, A_T, S_T, and E_T can be obtained from the following equations:

$$\text{AF for } d_t = \frac{d_{70}}{d_t} \qquad (14)$$

$$\text{AF for } A_T = \frac{A_{70}}{A_T} \qquad (15)$$

$$\text{AF for } S_T = \frac{S_{70}}{A_T} \qquad (16)$$

$$\text{AF for } E_T = \frac{E_{70}}{E_T} \qquad (17)$$

Appendix 6 is an example of the determination of the adjustment factors for d_t, A_T, S_T, and E_T for mean pavement temperatures of 30°, 50°, 70°, 90°, 110°, 130°, and 150°F. The data used are those for the project designated Serial No. 5 in Appendix 4. The values of d_t, A_T, S_T, and E_T were calculated by equations (10), (11), (12), and (13); the adjustment factors by equations (14), (15), (16), and (17). The adjustment factors were similarly calculated for the other projects. Graphs of the mean pavement temperatures versus the adjustment factors were drawn and are shown in Figures 5, 6, 7, and 8.

For the purpose of temperature corrections, the data in Appendix 4 were divided into three groups as follows:

1. Two pavements with asphaltic concrete thicknesses of 2 inches (50 mm) to 4 inches (100 mm).
2. Four pavements with asphaltic concrete thicknesses of 4 inches (100 mm) to 10 inches (250 mm).
3. Two pavements with asphaltic concrete thicknesses of 10 inches (250 mm) to 15 inches (375 mm).

2400

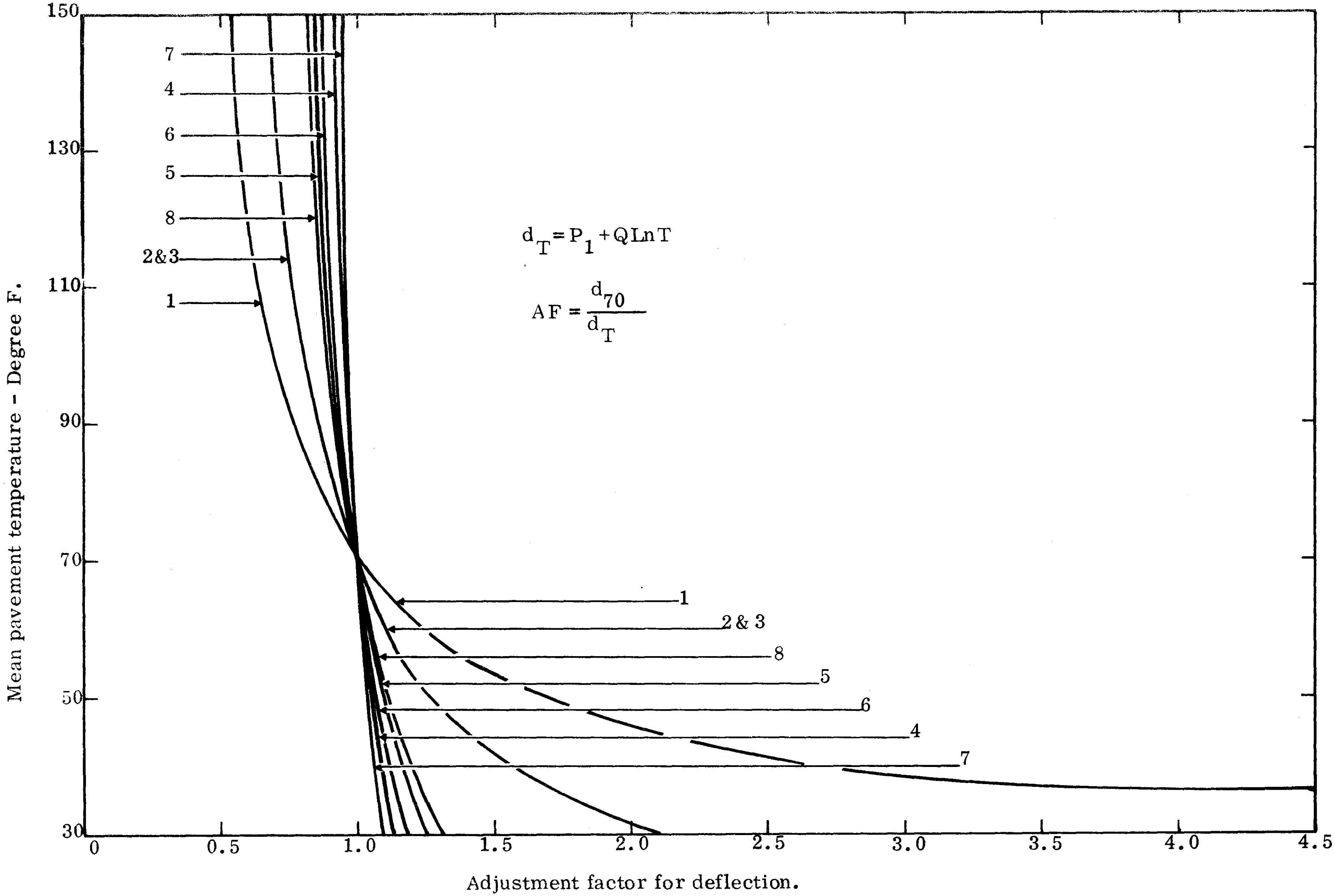

Figure 5. Adjustment factors for deflection versus mean pavement temperature in degrees F for each project.
(Deg. C = (F-32) $\frac{5}{9}$)

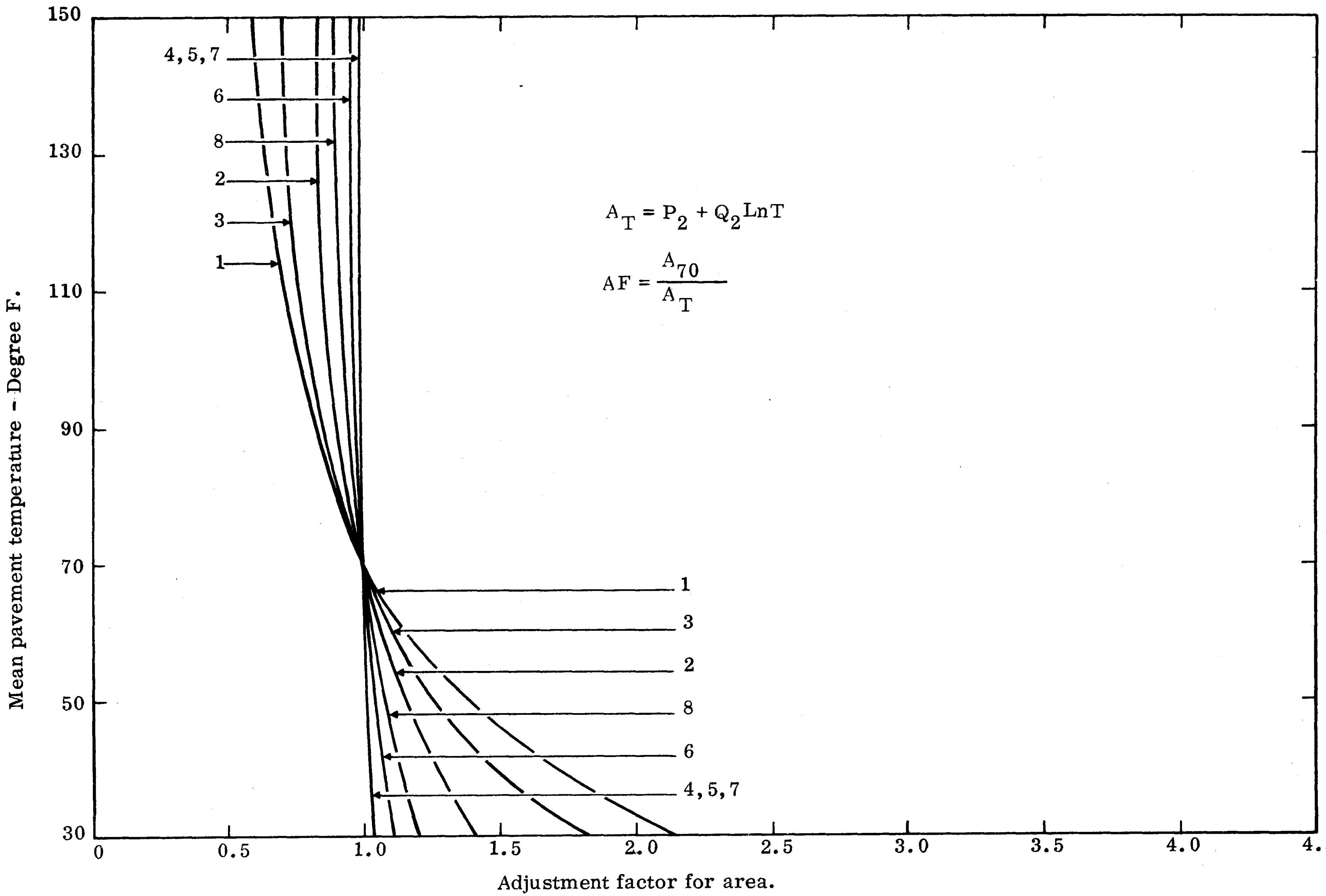

Figure 6. Adjustment factors for the deflected area A versus the mean pavement temperature. (Deg. C = (F-32) $\frac{5}{9}$)

2401

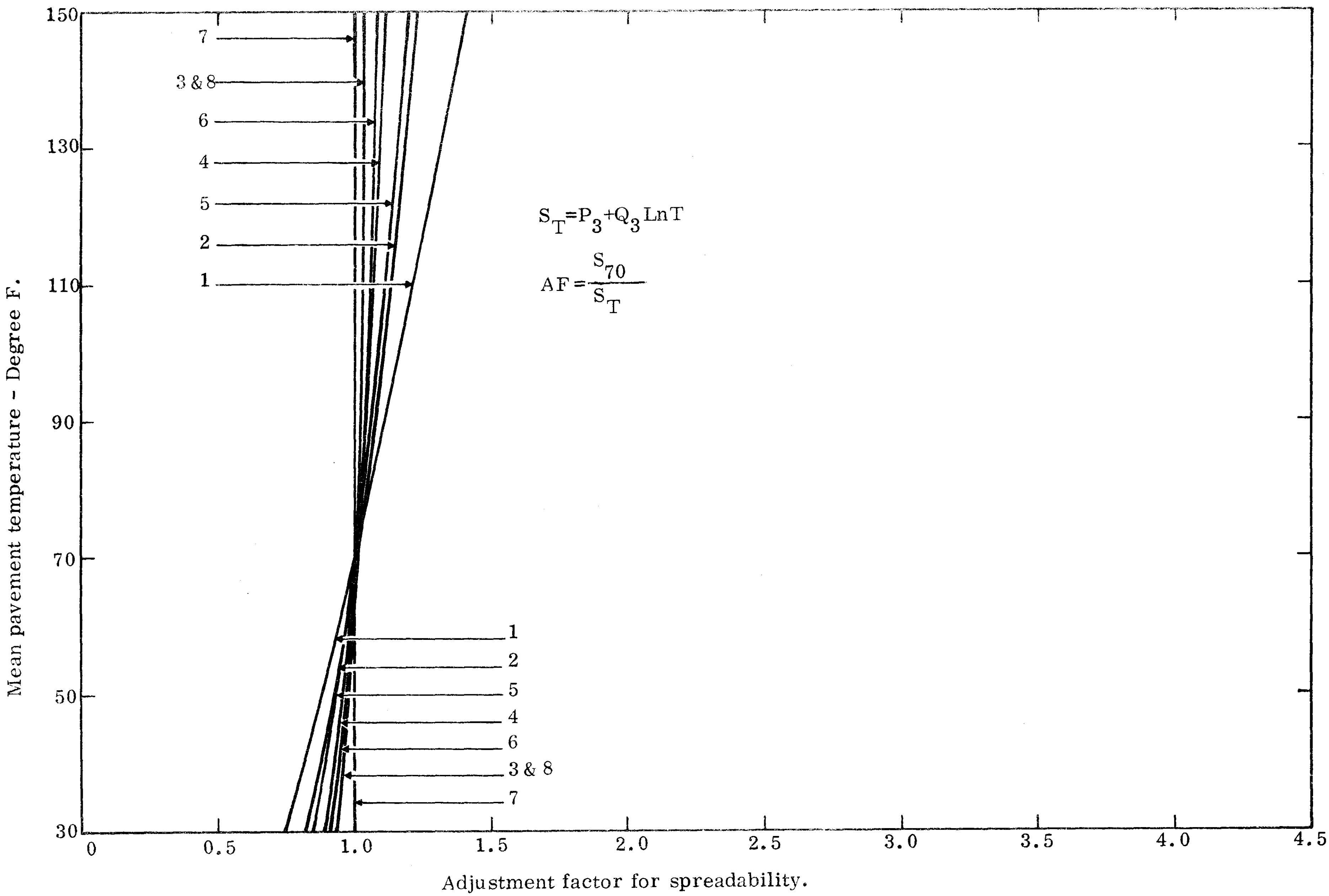

Figure 7. Adjustment factors for the spreadability versus the mean pavement temperature in degrees F for each project. (Deg. C = (F-32) $\frac{5}{9}$)

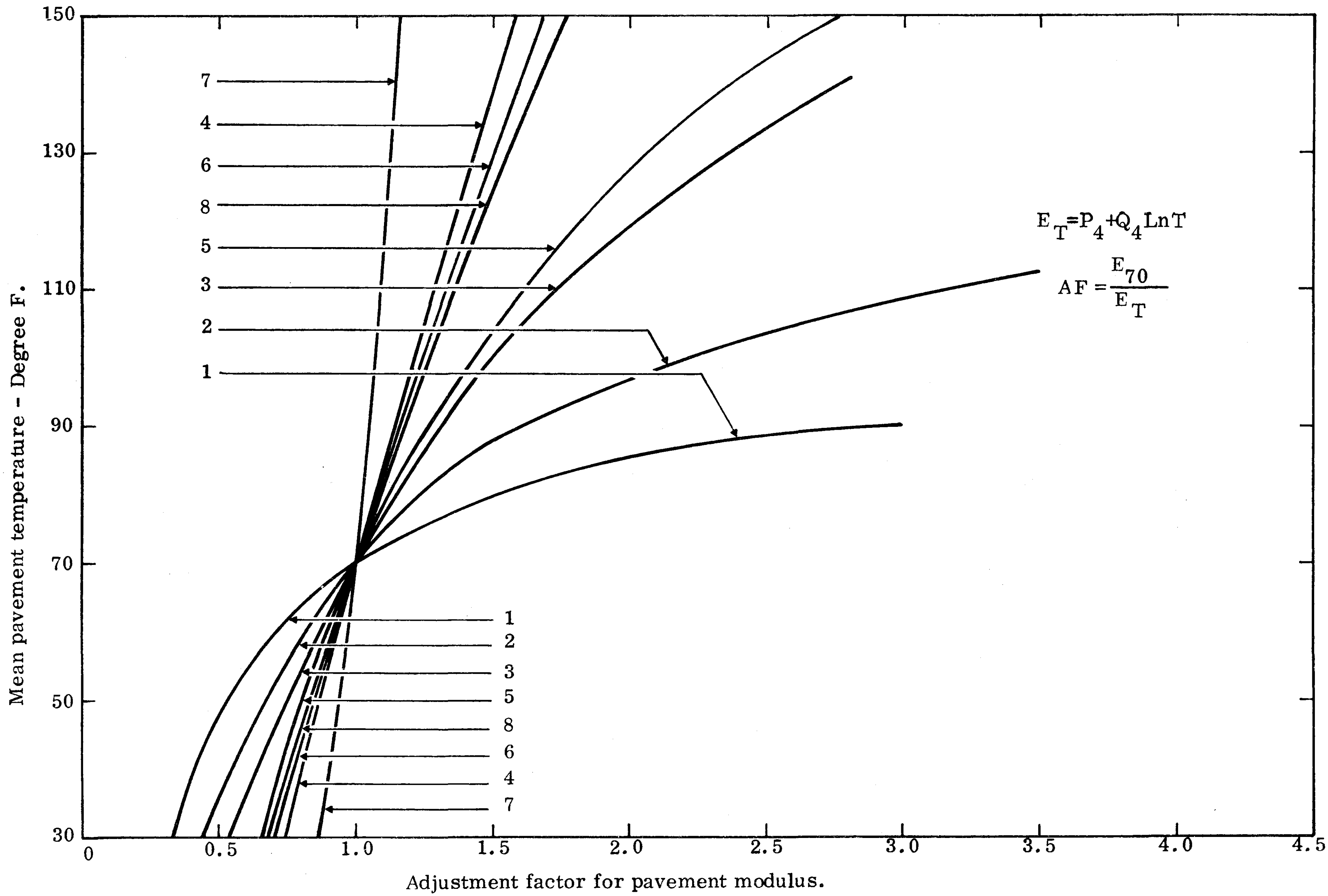

Figure 8. Adjustment factors for pavement modulus versus the mean pavement temperature in degree F for each project. (Deg. C = (F-32) $\frac{5}{9}$)

For each group the calculations illustrated in Appendix 6 were performed. Graphs of the correlation between the mean pavement temperatures and the adjustment factors for these three sets of thicknesses are shown in Figures 9. 10, 11, and 12.

PROCEDURE FOR APPLICATION

1. Selection of deflection sites — All deflection sites on each project should be so selected as to remain in direct sunlight. Selection on this basis will enable the correct application of the equation for determing the mean pavement temperature (at mid-depth) from the pavement surface temperature recorded in the field. If such selection is not possible, temperatures should be recorded at the pavement surface and at about mid-depth. The method of recording the pavement temperature is given in item 3 below.

2. Weather condition — All tests should be carried out on sunny days. If this is not possible, pavement temperatures should be recorded at the surface and at about mid-depth as explained in item 3 below.

3. Temperature recording — Determine air temperature at 4 feet (1.2 m) above the pavement under the sun, but with thermometer protected from the wind. Also determine pavement surface temperature by drilling a hole in the pavement to about a 1 inch (25 mm) depth, filling it with glycerine, and immersing a mercury thermometer in the glycerine. Both temperatures should be taken before and at the end of the forenoon and afternoon work periods. Determine the means of the morning and afternoon pavement surface temperatures. If there is shade on the pavement surface or cloud cover, drill another hole to about the mid-depth of the asphaltic concrete layer, fill it with glycerine, determine the temperature at the top and bottom of the glycerine, and assume the mean of these two temperatures to be the temperature at the mid-depth of the hole.

4. Determination of air temperature history — Determine the average of the minimum and maximum temperatures for the five previous days as recorded at the nearest weather station. These data are published monthly by U. S. Department of Commerce.

5. Evaluation of the mean pavement temperature — Add the pavement surface temperatures (item 3 above) to the average temperature of the five pervious days (item 4 above) and, by means of the equation in Appendix 2, determine the mean pavement temperature at mid-depth.

   If the field data have been collected under shade or cloud cover, then use the surface temperature and the temperature at the mid-depth of the hole to calculate the temperature at the mid-depth of the asphaltic concrete layer. For example, assume that the depth of the asphaltic concrete layer is 12 inches (300 mm), the surface temperature is 90°F (32.2°C) and the mean of the top and bottom temperatures in the 5 inch (125 mm) deep hole filled with glycerine is 85°F (29.4°C); then, assuming a straight line temperature gradient in the asphaltic concrete pavement, the temperature of 85°F (29.4°C) at mid-depth of the 5-inch hole is the temperature of the pavement at $\frac{5}{2}$ = 2.5 inch (6.25 mm) from the top of the pavement as shown in Figure 13.

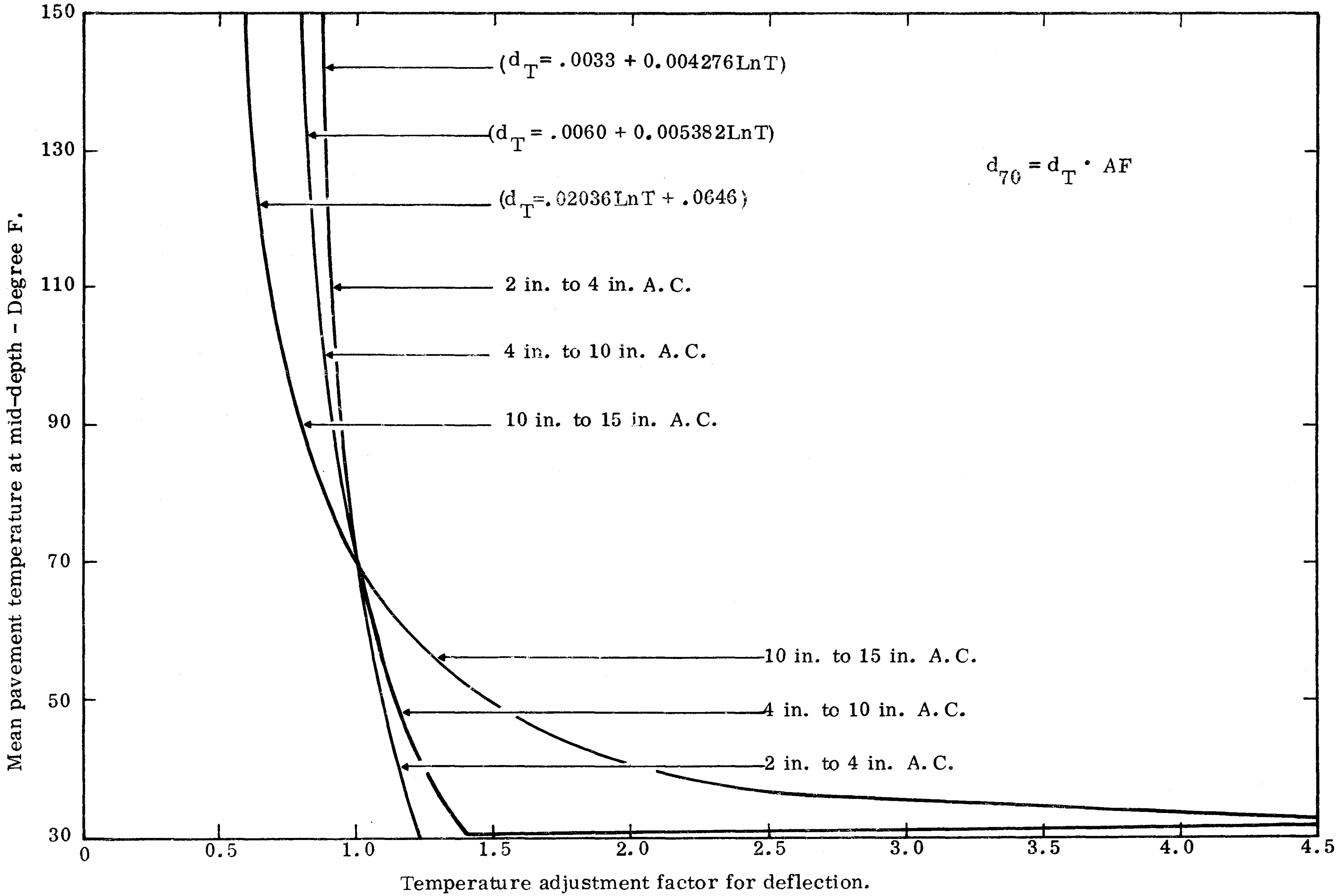

Figure 9. Recommended adjustment factors for deflection.
(Deg. C = (F-32) $\frac{5}{9}$) (1 in. = 25 mm)

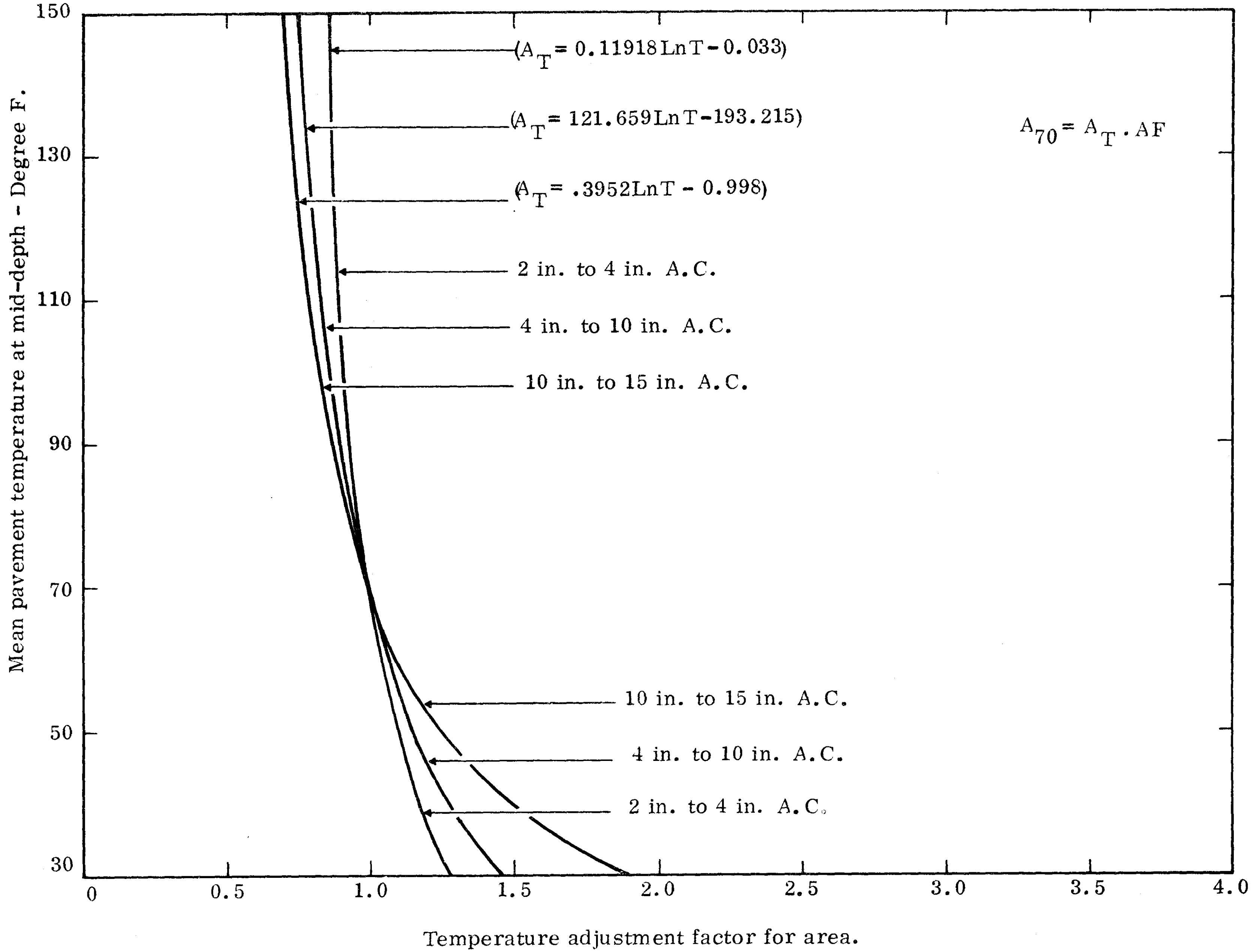

Figure 10. Recommended adjustment factors for area. (Deg. C = (F-32) $\frac{5}{9}$) (1 in. = 25 mm)

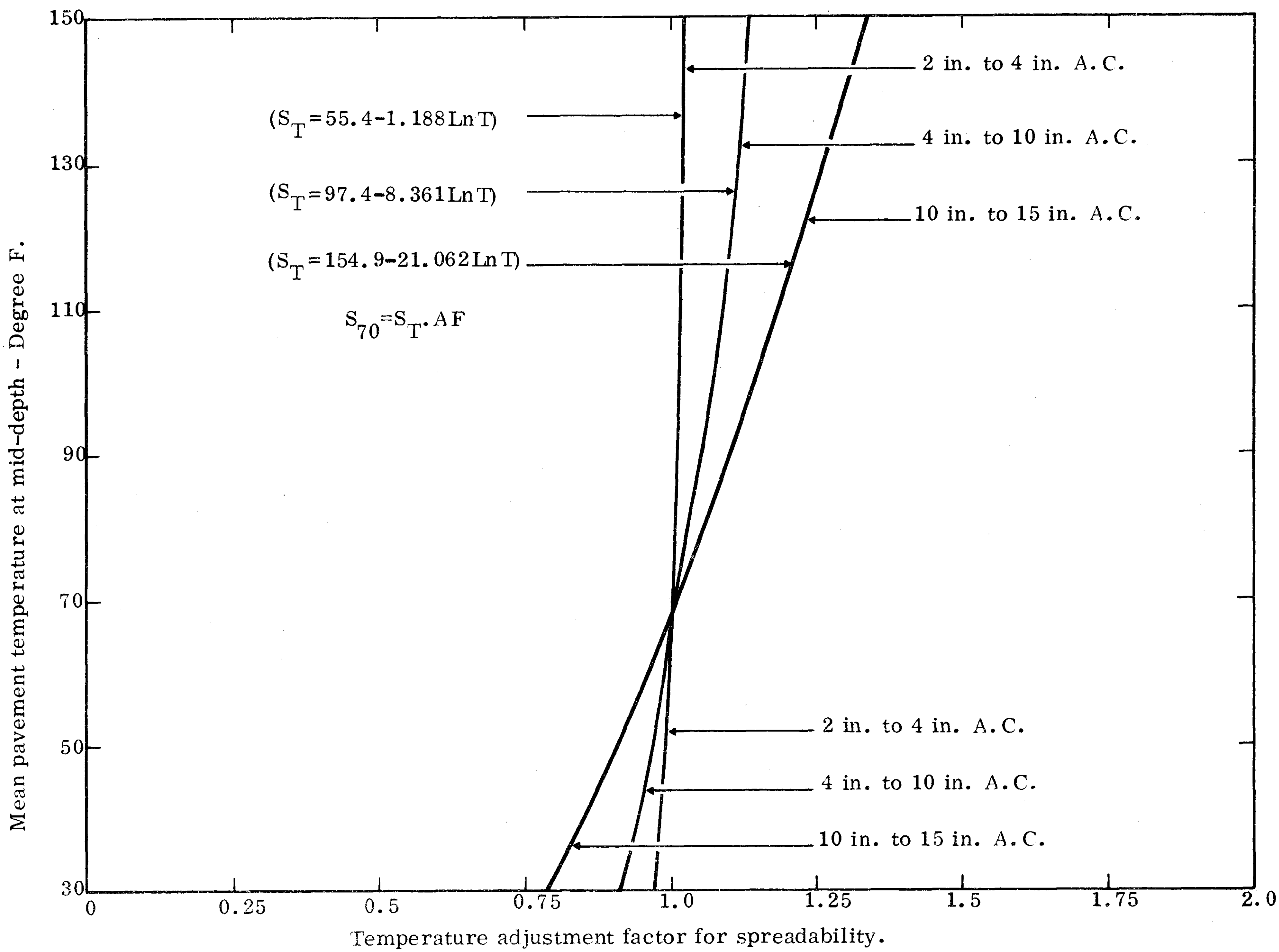

Figure 11. Recommended adjustment factors for spreadability.
(Deg. C = (F-32) $\frac{5}{9}$) (1 in. = 25 mm)

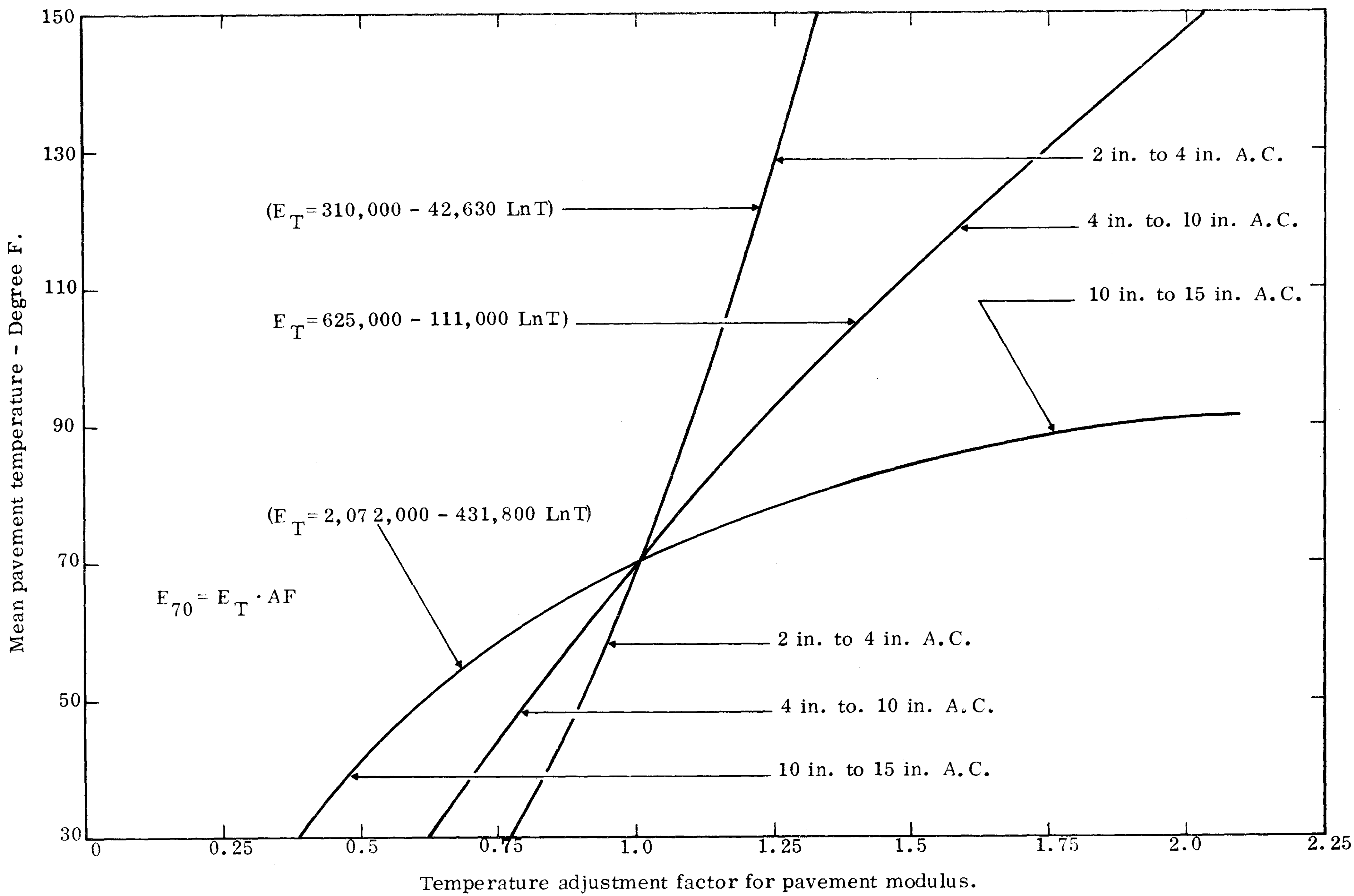

Figure 12. Recommended adjustment factors for pavement modulus.
(Deg. C = (F-32) $\frac{5}{9}$) (1 in. = 25 mm)

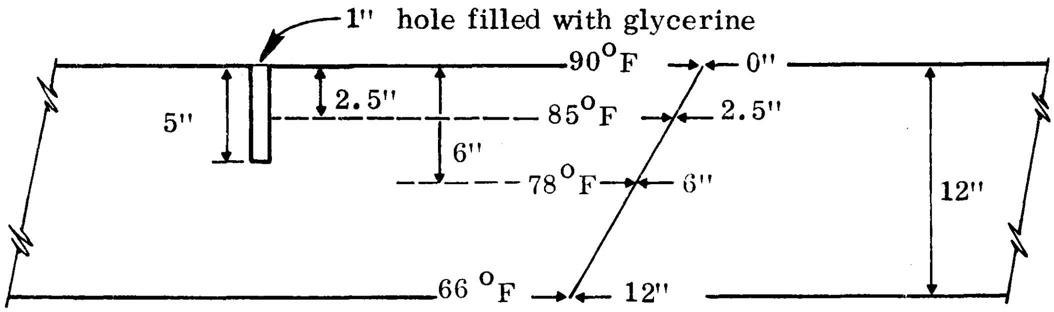

Figure 13. Evaluation of mean pavement temperatures.
(1 " = 25 mm; Deg. C = (F-32) · $\frac{5}{9}$)

This calculation gives a temperature gradient of $\left(\frac{90^{\circ} - 85^{\circ}}{2.5}\right) = 2^{\circ}F(-16.7^{\circ}C)$ for every 1 inch (25 mm) depth of the pavement. Hence, the temperature at the mid-depth of the pavement = 90 - (6 x 2) = 78°F (25.6°C).

In case the previous 5 days' temperature data are not available or pavement surface temperatures have not been recorded, the graphs in Figures 2, 3, and 4 could be used to determine the mean pavement temperature.

6. Evaluation of the adjustment factor and determination of the deflection at the mean pavement temperature of 70°F (21°C) — with the mean pavement temperature obtained from item 5 above, determine the adjustment factor for the deflection data needed from Figures 9, 10, 11, and 12. Multiply the adjustment factor by the deflection data obtained from the field. The resulting value is the value that would be obtained if the mean temperature at mid-depth of the pavement was 70°F.

CONCLUSION AND RECOMMENDATION

A method has been developed for estimating the deflection data for a standard pavement temperature of 70°F (21°C). This method is based on the deflection data obtained during any season of the year, irrespective of the pavement temperature at the time of test. The method is, therefore, recommended for use by the Virginia Department of Highways and Transportation.

ACKNOWLEDGEMENT

The author acknowledges the assistance of Gene V. Leake, who collected the field satellite data; and the counsel of K. H. McGhee in general discussions during the preparation of this report. The research was conducted under the general supervision of Jack H. Dillard, Head, Virginia Highway and Transportation Research Council, and was financed with HPR funds administered through the Federal Highway Administration.

REFERENCES

1. Hughes, C. S., "Regression Equation to Estimate Benkelman Beam Values from Dynaflect Results", Virginia Highway and Transportation Research Council, Charlottesville, Virginia, 1966.

2. Vaswani, N. K., "Estimating Moduli of Pavement Materials from Field Deflection Measurements". Conference of ASCE on "Pavement Design for Practicing Engineers", June 1-3, 1975, pp. 1-87 to 1-109. Georgia Institute of Technology, Atlanta, Georgia, or Virginia Highway and Transportation Research Council, Charlottesville, Va., VHTRC 75-R20, November 1974.

3. Southgate, H. F., and R. C. Deen, "Temperature Distribution within Asphalt Pavements and its Relationship to Pavement Deflections", Highway Research Record 291, pp. 116-130, Highway Research Board, 1969.

4. The Asphalt Institute, Asphalt Overlays and Pavement Rehabilitation, 1st Edition, November 1969, MS-17.

5. Norman, P. J., R. A. Snowdon, and J. C. Jacobs, "Pavement Deflection Measurements and their Application to Structural Maintenance and Overlay Design". Transport and Road Research Laboratory, U. K. TRRL Report LR571, 1973.

APPENDIX 1

DETAILS OF THE PROJECTS

Project Serial Number	Project Number	Test Site	Pavement Layers, in.						Weather Stations Supplying Data for 5-Day Average Temperature	Date of construction
			A. C.	Agg.	Subbase		S. C.	Total		
					Sel. Mtl.	Sel. Tr. Mt.				
1	0460-144-102-C501	Farmville	13.5	-	-	-	-	13.5	Farmville	1974
2	0031-137-102, C501	Williamsburg	10.5	-	-	-	-	10.5	Williamsburg	1970
3	7029-071-111-C501	Altavista	9.5	-	-	-	6	15.5	Lynchburg, Bedford, and Chatham	1973
4	6029-002-031-C503	Charlottesville	8.0	6	-	-	6	20.0	Charlottesville — 2	1971
5	6029-002-106-C501	Charlottesville	7.5	6	-	-	6	19.5	Charlottesville — 2	1970
6	0003-048-010-C02	Office Hall	7.25	-	6	-	-	13.25	Fredericksburg and Colonial Beach	1960
7	0522-054	Mineral	3.5	-	-	±6	-	±9.5	Louisa	1956
8	0006-032	Columbia	3.0	-	-	±6	-	±9.0	Columbia	1956

APPENDIX 2

PROPERTIES OF SUBGRADE, BASE AND BITUMINOUS MATERIALS REQUESTED BY FHWA

Project Serial Number	Project Number	Subgrade		Aggregate Base		Bituminous Layer			Test Temp., °F	Inverse Creep Compli. (psi)x10^3	Dynamic Modulus at 200 Cycles, psi
						Layer Thickness - in.					
		Dry Density	% Moisture	Density	% Moisture	Surface	Int.	Base			
3	7029-071-111-C501	184.9	11.5	—	—	2	—	6	70	725	667
3	7029-071-111 C501	182.8	11.4	—	—	1.25	—	6.75	70	667	889
5	6029-002-106-C501	129.5	38.7	281.5	4.3	1	1.25	5.25	70	—	615
5	6029-002-106-C501	161.6	25.1	325.3	4.3	1	1.25	5.25	55	1,300	1,300

APPENDIX 3

TEMPERATURE DISTRIBUTION IN ASPHALTIC CONCRETE PAVEMENT AS A FUNCTION OF DAYTIME EXPOSURE TO SOLAR RADIATION
(From Reference 3)

$$Y = A + BX$$

where: Y = temperature at depth

X = surface temperature plus 5 day average air temperature history

A & B = constants as given below in the equation column

Time	Depth below surface, in.	Equation	Corr. Coeff.	Std. Error of Estimate
Mid-forenoon	2	$Y = -2.0 + 0.521\ X$	0.985	3.1
	4	$Y = -1.6 + 0.518\ X$	0.983	3.3
	6	$Y = -1.6 + 0.525\ X$	0.982	3.5
	8	$Y = -0.9 + 0.531\ X$	0.984	3.4
Mid-afternoon	2	$Y = -3.4 + 0.595\ X$	0.784	4.7
	4	$Y = -1.4 + 0.540\ X$	0.986	4.1
	6	$Y = 0.4 + 0.497\ X$	0.982	4.2
	8	$Y = 2.6 - 0.460\ X$	0.975	4.6

2418

APPENDIX 4

TEMPERATURES AND DEFLECTION DATA OF THE SATELLITE PROJECTS

Serial No.	Project	Date	Period	Temperature °F			Pav. Mod.	Deflection Data		
				Air	Surface	Pav.		Max. Defl.	Area	Spreadability
1	0460-144-102-C501	6-4-74	A. M.	75	85	81	160,000	0.0264	0.887	69
			P. M.	83	112	88	80,000	0.0344	0.949	59
		6-5-74	A. M.	63	72	73	160,000	0.0217	0.696	67
			P. M.	82	109	87	80,000	0.0335	0.924	59
		9-11-74	A. M.	80	91	81	120,000	0.0258	0.822	67
			P. M.	95	114	88	100,000	0.0336	1.026	64
		9-12-74	A. M.	78	83	79	175,000	0.0234	0.761	68
			P. M.	95	122	94	125,000	0.0355	1.017	61
		11-13-74	A. M.	45	53	52	520,000	0.0151	0.621	87
			P. M.	54	63	55	330,000	0.0193	0.714	76
		11-14-74	A. M.	55	60	56	330,000	0.0180	0.645	73
			P. M.	65	78	62	120,000	0.0246	0.747	64
		2-14-75	A. M.	43	49	45	360,000	0.0160	0.568	75
			P. M.	54	64	51	360,000	0.0185	0.687	75
		2-19-75	A. M.	60	55	50	600,000	0.0111	0.436	81
			P. M.	72	72	56	300,000	0.0171	0.584	71
2	0031-137-102-C501	3-28-74	A. M.	62	63	56	315,000	0.0179	0.575	66
			P. M.	79	90	71	175,000	0.0217	0.618	60
		4-30-74	A. M.	77	89	77	315,000	0.0180	0.566	66
			P. M.	94	119	93	150,000	0.0242	0.665	58
		9-17-74	A. M.	72	78	78	200,000	0.0189	0.542	61
			P. M.	79	90	84	170,000	0.0215	0.610	59
		9-18-74	A. M.	73	79	72	195,000	0.0179	0.517	61
			P. M.	82	99	88	95,000	0.0243	0.646	57
3	7029-071-111-C501	5-29-74	A. M.	70	90	78	290,000	0.0155	0.558	75
			P. M.	86	102	85	190,000	0.023	0.84	70
		5-30-74	A. M.	73	76	71	265,000	0.0168	0.588	73
			P. M.	82	99	84	170,000	0.0207	0.681	69
		7-24-74	A. M.	72	75	75	250,000	0.017	0.605	74
			P. M.	88	102	90	190,000	0.0195	0.667	71
		8-21-74	A. M.	75	81	78	195,000	0.0198	0.707	74
			P. M.	84	101	90	130,000	0.0216	0.659	69
		1-28-75	A. M.	53	56	50	320,000	0.0141	0.516	76
			P. M.	76	75	61	230,000	0.0167	0.570	67
		1-29-75	A. M.	64	59	53	285,000	0.0151	0.526	72
			P. M.	74	77	63	240,000	0.0156	0.537	69

APPENDIX 4 continued

Serial No.	Project	Date	Period	Temperature °F Air	Surface	Pav.	Pav. Mod.	Deflection Data Max. Defl.	Area	Spreadability
4	6029-002-031	4-25-74	A. M.	56	74	68	150,000	0.0124	0.349	60
			P. M.	68	94	82	85,000	0.0194	0.511	57
		4-26-74	A. M.	66	81	71	170,000	0.0143	0.430	66
			P. M.	76	104	87	85,000	0.0191	0.501	57
		7-17-74	A. M.	82	100	90	95,000	0.0162	0.417	56
			P. M.	90	118	104	85,000	0.0184	0.465	55
		7-18-74	A. M.	81	92	86	95,000	0.0163	0.417	56
			P. M.	92	119	104	85,000	0.0191	0.495	56
		10-20-74	A. M.	80	84	66	140,000	0.0136	0.413	65
			P. M.	83	99	77	110,000	0.0156	0.459	62
		10-23-74	A. M.	71	74	60	160,000	0.0123	0.380	65
			P. M.	75	82	67	135,000	0.0129	0.391	64
		2-10-75	A. M.	30	46	40	170,000	0.0154	0.487	65
			P. M.	35	51	45	100,000	0.0191	0.547	59
		2-13-75	A. M.	44	53	44	110,000	0.0163	0.461	60
			P. M.	48	62	51	110,000	0.0181	0.545	63
5	6029-002-106-C501	7-17-74	A. M.	76	91	86	100,000	0.0139	0.342	54
			P. M.	91	118	105	70,000	0.0170	0.384	50
		7-18-74	A. M.	80	87	83	85,000	0.0145	0.346	52
			P. M.	99	118	105	80,000	0.0174	0.410	52
		10-22-74	A. M.	64	65	56	200,000	0.0105	0.312	63
			P. M.	83	97	77	160,000	0.0142	0.383	58
		10-23-74	A. M.	66	56	51	210,000	0.0102	0.314	64
			P. M.	78	88	71	150,000	0.0114	0.335	62
		2-10-75	A. M.	27	31	32	220,000	0.0118	0.387	66
			P. M.	34	52	45	120,000	0.0170	0.496	61
		2-13-75	A. M.	42	43	39	145,000	0.0137	0.393	60
			P. M.	49	64	52	130,000	0.0161	0.485	62
		4-25-75	A. M.	50	61	61	190,000	0.0105	0.305	62
			P. M.	62	92	82	70,000	0.0170	0.428	54
		4-26-75	A. M.	58	68	64	200,000	0.0112	0.345	
			P. M.	76	104	88	80,000	0.0176	0.433	53
6	003-048-010-C02	5-13-74	A. M.	63	74	69	215,000	0.0171	0.469	58
			P. M.	74	102	89	90,000	0.0231	0.579	53
		5-14-74	A. M.	69	77	71	140,000	0.0203	0.558	58
			P. M.	61	110	92	90,000	0.0224	0.550	53
		10-8-74	A. M.	56	70	62	290,000	0.0161	0.476	61
			P. M.	65	87	75	105,000	0.0189	0.475	54
		10-9-74	A. M.	65	67	62	130,000	0.0184	0.482	56
			P. M.	69	90	78	95,000	0.0212	0.542	54
		3-6-75	A. M.	50	46	40	140,000	0.0161	0.405	54
			P. M.	64	67	54	90,000	0.0227	0.558	53
		3-7-75	A. M.	47	45	40	170,000	0.0201	0.628	64

APPENDIX 4 continued

Serial No.	Project	Date	Period	Temperature °F			Pav. Mod.	Deflection Data		
				Air	Surface	Pav.		Max. Defl.	Area	Spreadability
7	0522-054	4-18-74	A. M.	66	85	76	115,000	0.0150	0.312	46
			P. M.	73	100	94	65,000	0.0221	0.406	42
		5-28-74	A. M.	69	95	84	90,000	0.0176	0.338	43
			P. M.	81	118	109	60,000	0.0203	0.375	42
		7-10-74	A. M.	90	110	98	170,000	0.0158	0.36	50
			P. M.	102	138	127	90,000	0.0185	0.39	49
		7-15-74	A. M.	88	102	92	155,000	0.0148	0.32	48
			P. M.	100	132	121	110,000	0.0169	0.358	47
		10-31-74	A. M.	74	79	71	250,000	0.0116	0.282	52
			P. M.	83	100	93	310,000	0.0117	0.306	55
		11-1-74	A. M.	73	81	73	220,000	0.0121	0.291	52
			P. M.	87	102	95	160,000	0.0142	0.321	49
		2-27-75	A. M.	39	41	46	115,000	0.0163	0.337	46
			P. M.	53	59	62	90,000	0.0187	0.385	45
		2-28-75	A. M.	38	35	43	175,000	0.0166	0.375	49
			P. M.	55	60	63	95,000	0.0171	0.368	45
8	0006-32	4-17-74	A. M.	48	60	61	110,000	0.0256	0.607	52
			P. M.	70	94	91	80,000	0.0265	0.591	49
		6-13-74	A. M.	70	94	88	100,000	0.0272	0.638	54
		7-8-74	A. M.	91	109	101	110,000	0.0266	0.667	54
			P. M.	100	133	126	70,000	0.0332	0.773	52
		7-9-74	A. M.	90	112	102	80,000	0.0299	0.686	53
			P. M.	99	134	127	55,000	0.0358	0.79	49
		10-29-74	A. M.	61	67	64	180,000	0.020	0.529	57
			P. M.	77	83	81	170,000	0.022	0.614	59
		10-30-74	A. M.	62	62	61	170,000	0.021	0.570	57
			P. M.	82	80	79	150,000	0.024	0.619	56
		2-25-75	A. M.	46	52	50	100,000	0.0271	0.650	52
			P. M.	58	72	69	75,000	0.0320	0.717	49
		2-26-75	A. M.	50	63	58	80,000	0.0324	0.786	53
			P. M.	60	76	72	60,000	0.0338	0.727	48

APPENDIX 5

RELATIONSHIPS BETWEEN AIR TEMPERATURES, PAVEMENT SURFACE TEMPERATURES AND PAVEMENT TEMPERATURES AT MID-DEPTH FOR VARYING PAVEMENT THICKNESSES.

Project Serial Number	Relationship	Time	Equation	Corr. Coeff.
1	All thicknesses of asphaltic concrete			
	Y= Air temp., and	Mid F.N.	$Y=25.13\ e^{0.0125X}$	0.90
	X= Pav. Surf. Temp.	Mid A.N.	$Y=30.2 + e^{0.00945X}$	0.86
2	Below 4-inch thickness of asphaltic concrete			
	Y=Pav. temp. mid-depth	Mid F.N.	$Y=29.356e^{0.1123X}$	0.99
	X=Pav. Sur. Temp.	Mid A.N.	$Y=36.66e^{0.00923X}$	0.996
3	4-inch and above thicknesses of asphaltic concrete			
	Y=Pav. Temp. at mid-depth	Mid F.N.	$Y=36.659e^{0.0155X}$	0.97
	X=Pav. Sur. Temp.	Mid A.N.	$Y=25.24e^{0.01183X}$	0.97

APPENDIX 6

AN EXAMPLE FOR DETERMINING THE ADJUSTMENT FACTOR FOR d_T, A_T, S_T, AND E_T FOR PROJECT NO. 5

Equation	Mean Pavement Temperatures °F						
	30	50	70	90	110	130	150
$d_T = -0.00123 + 0.00365 \text{ LnT}$							
d_T	0.0112	0.0130	0.0143	0.0152	0.0159	0.0165	0.0170
AF for d_T	1.28	1.10	1.00	0.94	0.90	0.087	0.84
$A_T = 0.43857 - 0.01376 \text{ LnT}$							
A_T	0.3918	0.3847	0.3801	0.3767	0.3739	0.3716	0.3696
A_F for A_T	0.97	0.99	1.00	1.01	1.02	1.02	1.03
$S_T = 111.0 - 12.518 \text{ LnT}$							
S_T	68.4	62.0	57.8	54.7	52.2	50.1	48.3
A_F for S_T	0.85	0.93	1.00	1.06	1.11	1.15	1.20
$E_T = 592,000 - 108,680 \text{ LnT}$							
E_T	222,000	167,000	130,000	103,000	81,000	63,000	47,000
A_F for E_T	0.59	0.78	1.00	1.26	1.60	2.06	2.77