ESTIMATING MODULI OF PAVEMENT MATERIALS FROM FIELD DEFLECTION MEASUREMENTS

by

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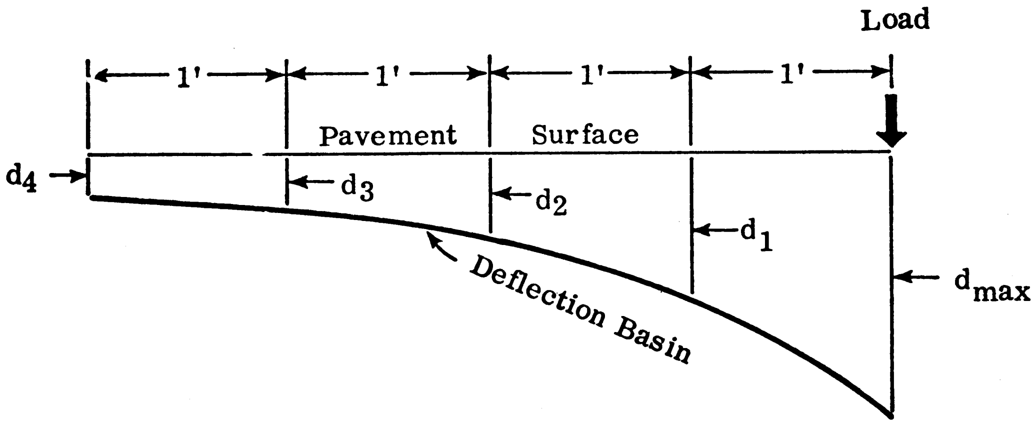

Figure 1. Deflection recording of the deflected basin by the dynaflect machine. Basic conversion unit: 1" = 25.4 mm.

S, the spreadability, is the average deflection in percent of the maximum deflection and is obtained by the following equation:

$$S = \frac{d_{max} + d_1 + d_2 + d_3 + d_4}{5\ d_{max}} \times 100 \qquad (1)$$

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

A correlation study by Hughes (2) 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. Hence, if d_{max}, d_1, d_2, d_3, and d_4 are the deflections under the dynaflect load, the estimated deflected area under the 9,000 lb. (4,080 kg) wheel load is as follows:

$$A = 28.6 \times 6\ (d_{max} + 2d_1 + 2d_2 + 2d_3 + d_4) \text{ sq. inches}$$

$$= 171.6\ (d_{max} + 2d_1 + 2d_2 + 2d_3 + d_4) \text{ sq. inches} \qquad (2)$$

DEVELOPMENT OF PAVEMENT EVALUATION CHARTS

In this study, d_{max}, S, and A were used in the development of three design charts:

1. A subgrade evaluation chart based on the maximum deflection and spreadability,

2. a subgrade evaluation chart based on the maximum deflection and the area of the deflected basin, and

3. a pavement evaluation chart based on the maximum deflection and the area of the deflected basin.

These charts are described below.

Subgrade Evaluation Chart Based on Maximum Deflection and Spreadability

Based on Terzaghi's analyses (4), the following simple relationship for vertical displacements of the top horizontal surface has been drawn for a semi-infinite single-layer system:

$$d = \frac{P}{E_s} \frac{(1 - U_s)^2}{f(r)} \tag{3}$$

where

d = Deflection in the deflected basin at a distance r from the load center.
P = Applied load.
U_s = Subgrade Poisson's ratio.
E_s = Subgrade modulus.
$f(r)$ = Function of r, the distance from the center of the applied load.

For values of $U_s = 0.47$ and $P = 9,000$ lb. (4080 kg) equation (3) reduces to the following form:

$$E_s \times d_{max} = 700 \text{ lb./in.} \tag{4}$$

In a previous publication (5) the author has shown that for given load and for any value of E_s and U_s the spreadability (defined as the ratio of the average deflection in the deflected basin to the maximum deflection) is constant. For a 9,000 lb. (4,080 kg) wheel load, S = 31.35.

In the same publication (5) the author has developed a subgrade evaluation chart giving a correlation between the maximum pavement deflection and the spreadability of the deflected basin. This chart is shown in Figure 2. Given the dynaflect deflection data — and thus the d_{max} and S values — the subgrade modulus could be determined from this chart. As shown by an example in Figure 2 for d_{max} = .02 in. (0.5 mm) and S = 50, the subgrade modulus is 15,000 psi (103 MN/m²). During the last two years this chart has been successfully used in Virginia by McGhee (6) to determine, for low primary roads, the following: (1) what needs to be strengthened — the pavement or the subgrade, and (2) the optimum overlay thicknesses within a project where an average overlay thickness has been approved.

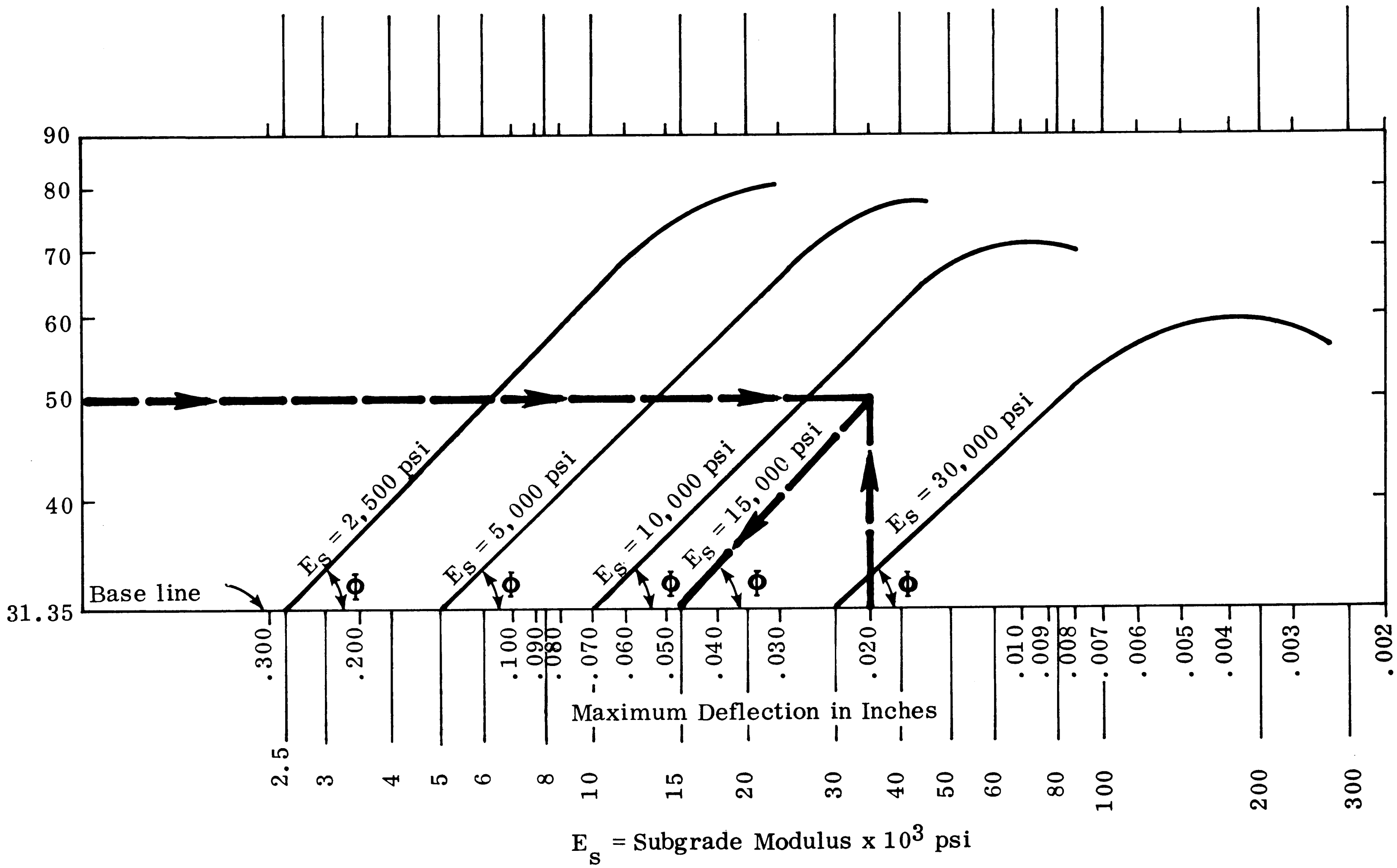

Figure 2. Subgrade evaluation chart based on spreadability. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2.

The application of this chart could lead to errors in the case of high type primary roads at the curved portions of the graph lines, i.e., where the pavement thickness is great or where the ratio of the average modulus of the pavement to that of the subgrade is low. Hence for high type pavements the subgrade modulus values determined by the spreadability method are likely to be higher than those determined by the area method.

Subgrade and Pavement Evaluation Charts Based on Maximum Deflection and Deflected Area

Westergaard (7) and Pickett (8) have shown theoretically the relationship between the following five variables for concrete pavements by means of certain equations: (1) The maximum deflection, (2) the volume of the deflected basin, (3) the modulus of the top layer of the pavement, (4) the subgrade modulus, and (5) the pavement thickness. Since such a relationship exists for rigid pavements it was thought that a relationship between similar variables could be graphically developed for flexible pavements. For this purpose, two charts were developed: a subgrade evaluation chart for determining the subgrade modulus and a pavement evaluation chart for determining the equivalent or average pavement modulus (9). Both the subgrade moduli (E_s) and pavement moduli (E_p) are determined at the time of measuring the deflections. The subgrade chart is shown in Figure 3 and pavement charts for E_p = 400,000; 200,000; and 50,000 psi (2757; 1379; 344 MN/m^2) are shown in Figures 4, 5, and 6, respectively.

An example illustrating the use of these charts is as follows:

A study of a given satellite project shows that the average dynaflect deflection (d_d) of the project was 0.00122 in. (.03 mm) and that half the average area of the deflected basin under the dynaflect load (A) was 0.028 sq. in. (17.5 sq. mm). Based on these data, the average pavement deflection under a 9,000 lb. (4080 kg) wheel load (d_{max}) was 0.00122 x 28.6 = 0.035 in. (0.88 mm) and A was 0.028 x 28.6 = 0.8 sq. in. (500 sq. mm).

As shown in the subgrade evaluation chart (Figure 3) the subgrade modulus for the above values is 7,100 psi (49 MN/m^2). To determine the E_p, locate the point with d_{max} = 0.035 and A = 0.8 sq. in. (500 sq. mm) on each of the charts given in Figures 4, 5, and 6 and determine thicknesses for the pavement moduli of 400,000; 200,000; and 50,000 psi (2757; 1379; 344 MN/m^2). This evaluation is shown by an example in each of the charts. The pavement thicknesses corresponding to the above moduli are 4.0, 5.25, and 11.0 in. (100, 131 and 275 mm) respectively. The pavement thicknesses so obtained are plotted against the pavement moduli as shown in Figure 7. For example this figure shows that E_p was 145,000 psi (1000 MN/m^2) if the pavement was 6 in. (150 mm) thick, and 83,000 psi (572 MN/m^2) if the pavement was 8 in. (200 mm) thick.

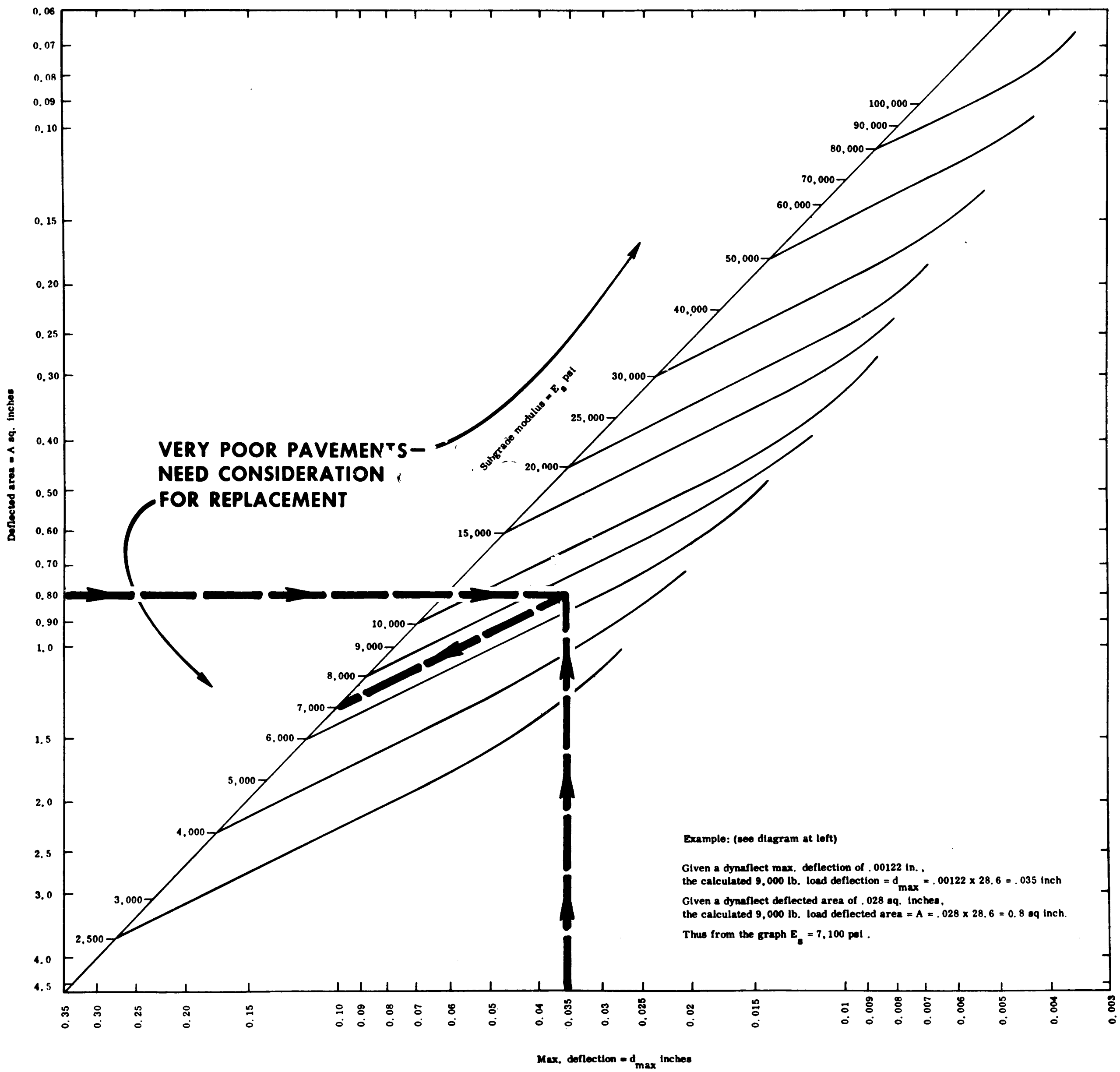

Figure 3. Subgrade evaluation chart based on area.
Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2; 1 in.^{2} = 625 mm^2.

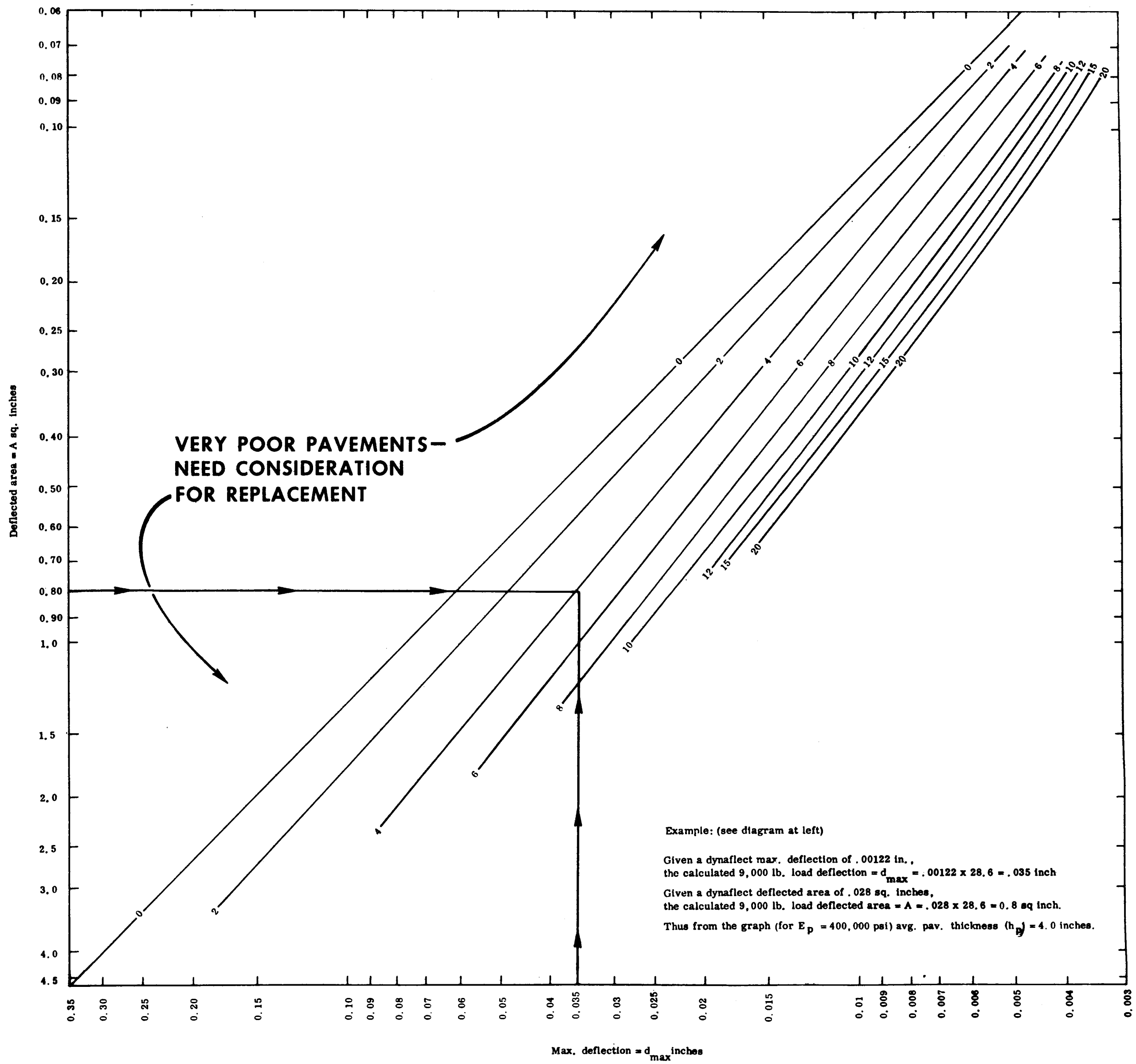

Figure 4. Pavement thickness evaluation chart for E_p of 400,000 psi. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2; 1 in.^{2} = 625 mm^2.

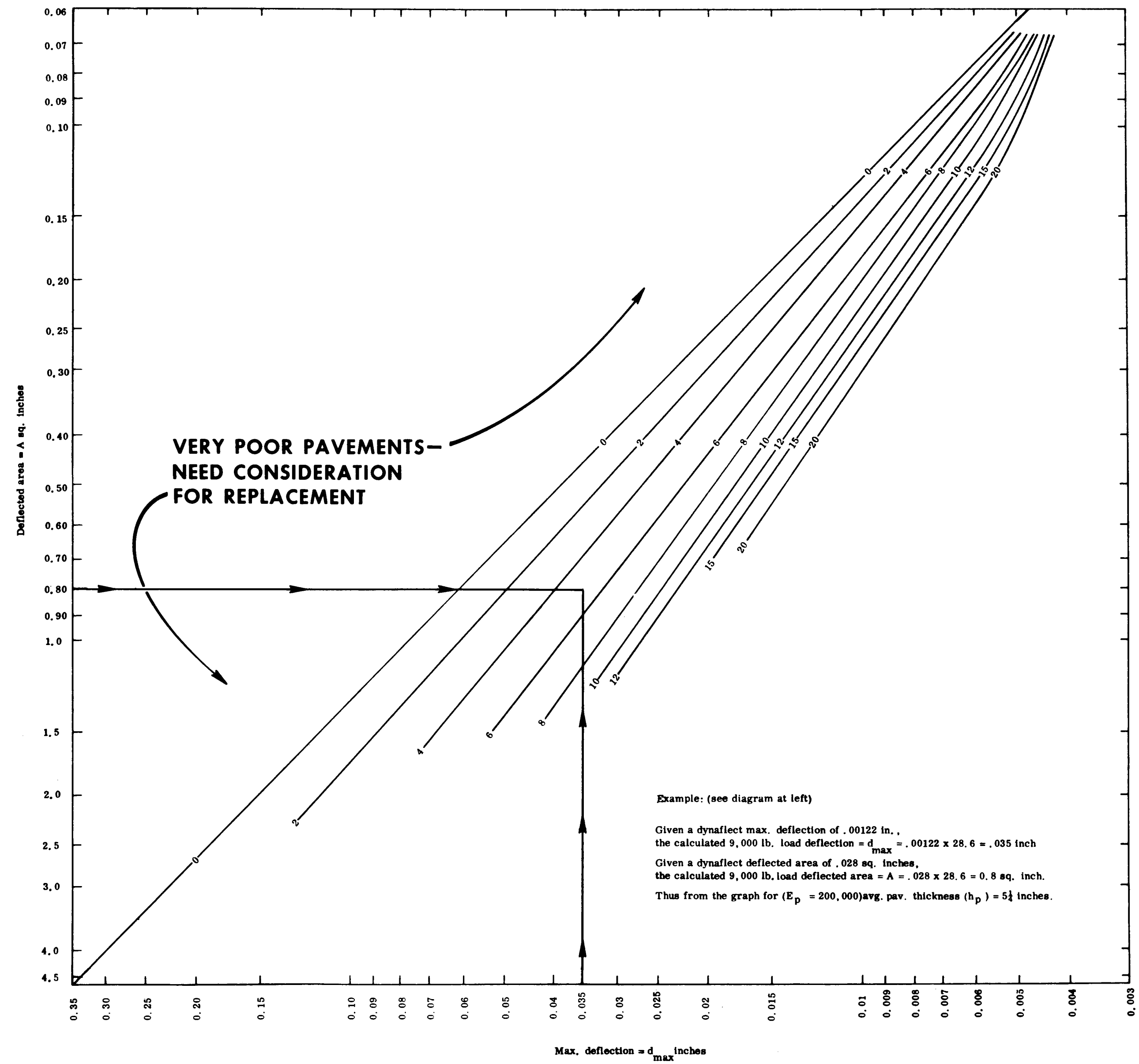

Figure 5. Pavement evaluation chart for E_p of 200,000 psi. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2; 1 in.^{2} = 625 mm^2.

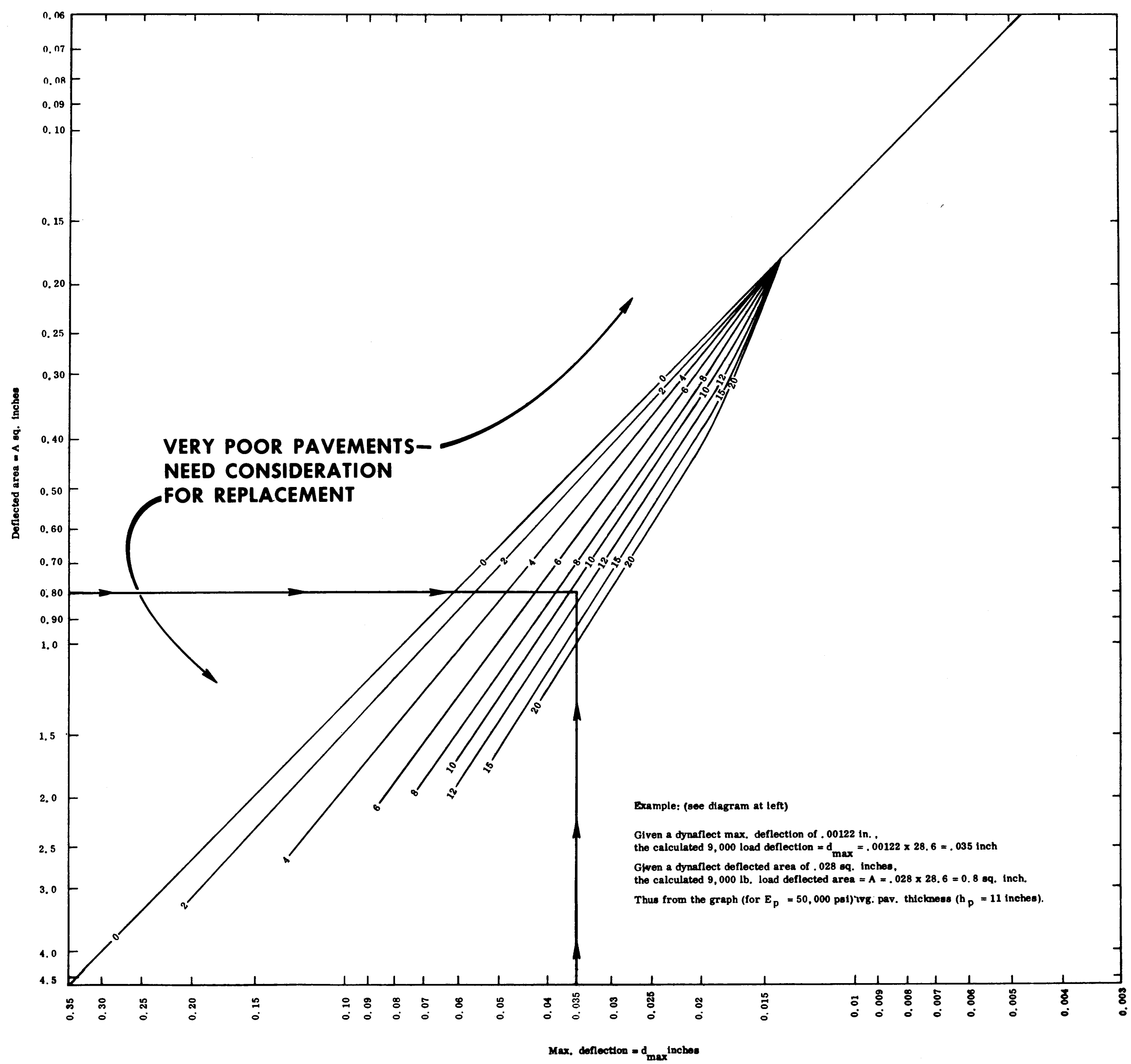

Figure 6. Pavement evaluation chart for E_p of 50,000 psi. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2; 1 in.^{2} = 625 mm^2.

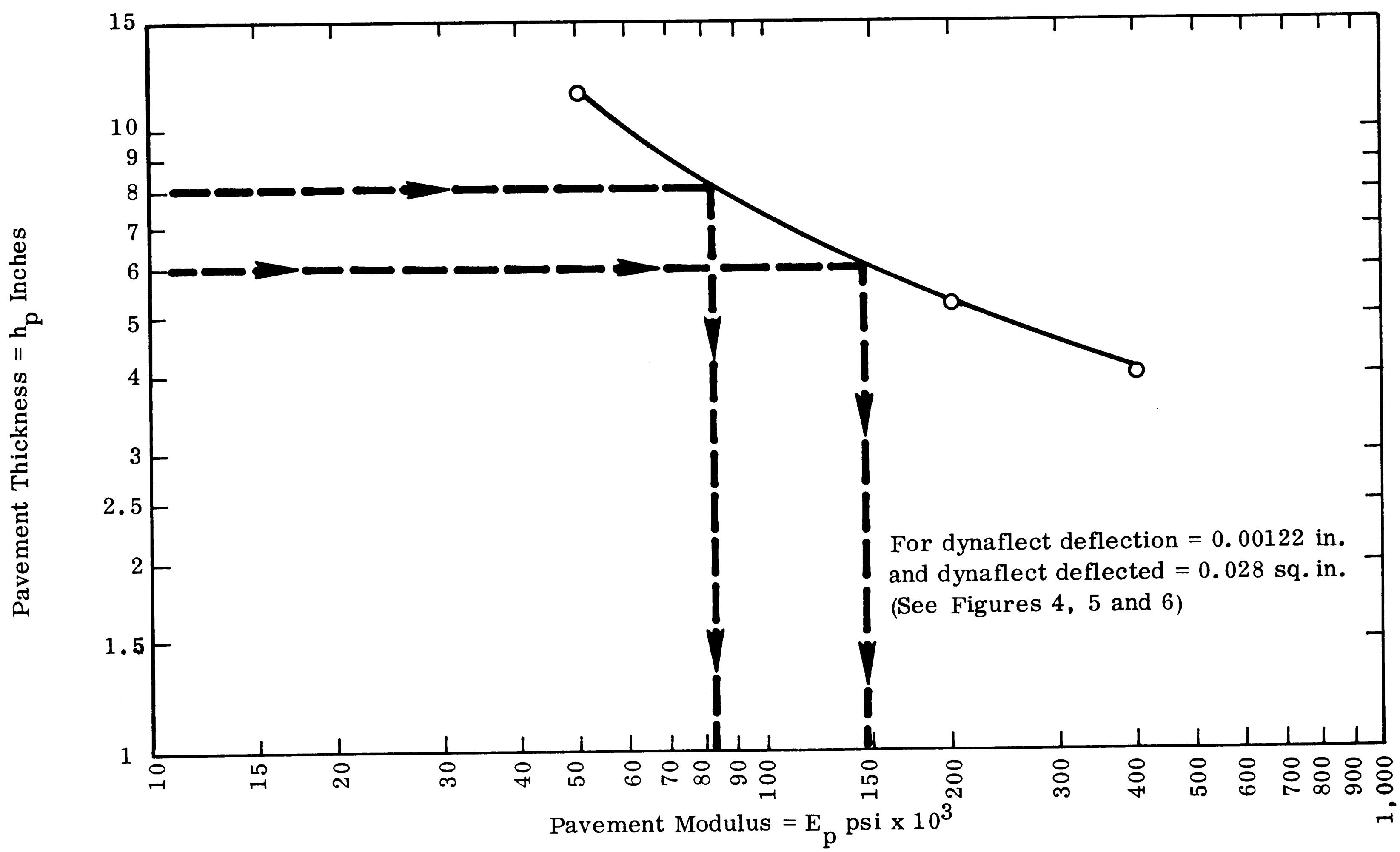

Figure 7. Determining pavement modulus for a given pavement thickness.
Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2.

SATELLITE PROJECT DESCRIPTION

Five projects were considered in this investigation: four located on the Altavista Bypass and one on the Charlottesville Bypass. Each project on the Altavista Bypass consists of two sections, one in the northbound lane and the other in the southbound lane. The Charlottesville Bypass project consists of two sections in the southbound lane, one in a cut and the other in a fill. Thus in all ten sections were evaluated, with the two on each project having the same pavement design. The details of the designs are given in Table 1.

Table 1

PAVEMENT DESIGN ON SATELLITE PROJECTS

Basic conversion unit: 1" = 25.4 mm

Project	Over Subgrade		Over Stabilized Layer		AC
	CTS	CTA	Agg.	CTA	
A (Altavista)	6"	-	6"	-	7.5"
B (Altavista)	6"	-	-	-	9.5"
C (Altavista)	-	4"	6"	-	7.5"
D (Altavista)	6"	-	-	4"	5.5"
Charlottesville	6"	-	6"	-	8"

Evaluation of the Moduli of the Materials in the Pavement System

The evaluation of the projects started after the subgrades were completed. Dynaflect deflection data were taken at 50- to 300-ft. (20 to 120 m) intervals on all the projects after each layer of the pavement was built. Sometimes it was not possible to take deflection data on some of the layers or on cement stabilized layers after 21 days of curing. A summary of the deflection data is given in Table 2. This table gives the averages of the maximum deflections, spreadability, and area for each of the sections of the four projects at Altavista and for the two sections on the Charlottesville project combined. Since deflections on the asphaltic concrete layers varied with the season, the deflection data during different times of the year are given.

The pavement evaluation was divided into two parts: (1) evaluation of the subgrade modulus, and (2) evaluation of the modulus of materials in each layer of the pavement. These are discussed below.

Table 2

AVERAGE DEFLECTION TEST RESULTS

Basic Conversion Unit: 1" = 25.4 mm

Section A (Altavista) — 1.5" A. C. (Surface) + 6" A. C. (Base) + 6" Agg. + 6" CTS

Date	NBL Top Layer	NBL Defl., 10^{-3}in.	NBL S	NBL A, in.^{2}	Date	SBL Top Layer	SBL Defl., 10^{-3}in.	SBL S	SBL A in.^{2}
June 73	Subgrade	47	50	1.094	-	-	-	-	-
July 73	CTS	39	52	0.918	Aug. 72	CTS	40	44	0.800
July 73	Agg.	29	56	0.762	Aug. 72	Agg.	29	46	0.682
July 17, 73	A. C. base	17	58	0.474	-	-	-	-	-
July 31, 73	A. C. base	20	58	0.546	Nov. 72	A. C. (base)	13	58	0.345
Aug. 14, 73	A. C. base	22	59	0.631	May 73	A. C. (base)	17	63	0.507
Oct. 19, 73	A. C. Surface	9	69	0.316	Aug. 30, 73	A. C. (Surface)	13	65	0.400

Section B (Altavista) — 1.5" A. C. (Surface) + 8.0" A. C. (Base) + 6" CTS

Date	NBL Top Layer	NBL Defl., 10^{-3}in.	NBL S	NBL A, in.^{2}	Date	SBL Top Layer	SBL Defl., 10^{-3}in.	SBL S	SBL A in.^{2}
June 73	Subgrade	82	43	1.630	Aug. 72	Subgrade	52	42	0.972
July 73	CTS	63	48	1.411	Aug. 72	CTS	39	49	0.895
Aug. 14, 73	A. C. (base)	29	60	0.842	Nov. 72	A. C. (base)	17	69	0.564
Aug. 28, 73	A. C. (base)	26	67	0.877	May 73	A. C. (base)	15	72	0.510
-	-	-	-	-	July 73	A. C. (surface)	22	68	0.726
Oct. 29, 73	A. C. (surface)	13	79	0.506	Aug. 30, 73	A. C. (surface)	15	73	0.526

Section C (Altavista) — 1.5" A. C. (Surface) + 6" A. C. (Base) + 6" Agg. + 4" CTA

Date	NBL Top Layer	NBL Defl., 10^{-3}in.	NBL S	NBL A, in.^{2}	Date	SBL Top Layer	SBL Defl., 10^{-3}in.	SBL S	SBL A in.^{2}
-	-	-	-	-	June 73	Subgrade	77	41	1.319
-	-	-	-	-	Aug. 73	CTA	76	36	1.235
Aug. 72	Agg.	27	52	0.645	Jul. & Aug. 73	Agg.	53	51	1.367
July 19, 72	A. C. (base)	33	52	0.808	Aug. 29, 73	A. C. (base)	30	62	0.921
May 17, 73	A. C. (base)	20	59	0.571	-	-	-	-	-
July 11, 73	A. C. (surface)	27	53	0.826	-	-	-	-	-
Aug. 28, 73	A. C. (surface)	15	65	0.471	Nov. 8, 73	A. C. (surface)	15	67	0.502

Section D (Altavista) — 1.5" A. C. (Surface) + 4" A. C. (Base) + 4" CTA + 6" CTS

Date	NBL Top Layer	NBL Defl., 10^{-3}in.	NBL S	NBL A, in.^{2}	Date	SBL Top Layer	SBL Defl., 10^{-3}in.	SBL S	SBL A in.^{2}
-	-	-	-	-	June 73	Subgrade	48	47	0.999
Aug. 72	CTS	28	46	0.594	June 73	CTS	38	51	0.923
Aug. 72	CTA	32	47	0.758	Aug. 73	CTA	23	63	0.672
Nov. 15, 72	A. C. (base)	10	67	0.324	Aug. 1, 16, 73	A. C. (base)	21	60	0.617
May 30, 73	A. C. (base)	14	65	0.441	Nov. 13, 72	A. C. (base)	16	68	0.531
Aug. 28, 73	A. C. (surface)	11	72	0.374	Nov. 8, 73	A. C. (surface)	11	72	0.391

Charlottesville — 1.5" A. C. (Surface) + 6.5" A. C. (Base) + 6" Agg. + 6" CTS

Date	Section	Top Layer	Defl., 10^{-3} in.	S	A, in.^{2}
May 69	Whole	Subgrade	53	38	0.917
May 69	Whole	CTS	36	36	0.747
June 69	Whole	Agg.	27	49	0.606
Sept. 23, 71	Fill	A. C. (surface)	14	57	0.406
Sept. 23, 71	Cut	A. C. (surface)	18	65	0.323
March 10, 72	Fill	A. C. (surface)	14	62	0.386
March 10, 72	Cut	A. C. (surface)	19	64	0.565
Jan. 14, 74	Fill	A. C. (surface)	12	57	0.305

Evaluation of the Subgrade Modulus

The subgrade modulus of each project was estimated by (1) the spreadability method as given in Figure 2, and (2) the area method as given in Figure 3. An example of the estimations by both of these methods for section D (SBL) is shown in Figures 8 and 9, respectively. The six data points for this project were taken from Table 2.

The subgrade modulus values are 7,200 psi (42 MN/m^2) for the spreadability method, and 6,000 psi (41 MN/m^2) for the area method. As explained before, the spreadability method is likely to give higher values. Hence, in this case an E_s of 6,000 psi (41 MN/m^2) was assumed as being more conservative and was adopted for further evaluation.

Evaluation of the Modulus of Materials in Each Layer of the Pavement

The estimation of the modulus of the material in each layer of the pavement was carried out by means of the model equation given below.

$$E_p = \frac{E_1 h_1 + E_2 h_2 + ----}{h_1 + h_2 + ----} \qquad (5)$$

where E_1, E_2, are the moduli of the materials in different layers of the pavement, and h_1, h_2 are the corresponding thicknesses of the layers. The development of equation (5) is given in reference (5).

Based on the data given in Table 2, E_p versus h_p values were determined for each layer on each section and were plotted as explained in the development of Figure 7. An example of the deflection data for section D (SBL) is given in Figure 10. By means of this figure, moduli of the materials in each layer of section D (SBL) were estimated as shown below.

The elastic modulus of the cement treated subgrade (CTS) is directly obtainable from Figure 10 and is found to be 150,000 psi (1,034 MN/m^2). The elastic modulus of the 6 in. (150 mm) CTS plus 4 in. (100 mm) of CTA — from Figure 10 — is found to be 146,000 psi (1006 MN/m^2). Thus the elastic modulus of the CTA layer is obtained by equation (5) as follows:

$$E_p = 146,000 = \frac{6\ (150,000) + 4\ E_{CTA}}{6 + 4}$$

$$\text{or } E_{CTA} = 140,000 \text{ psi} = (965\ MN/m^2)$$

where E_{CTA} = elastic modulus of the CTA layer.

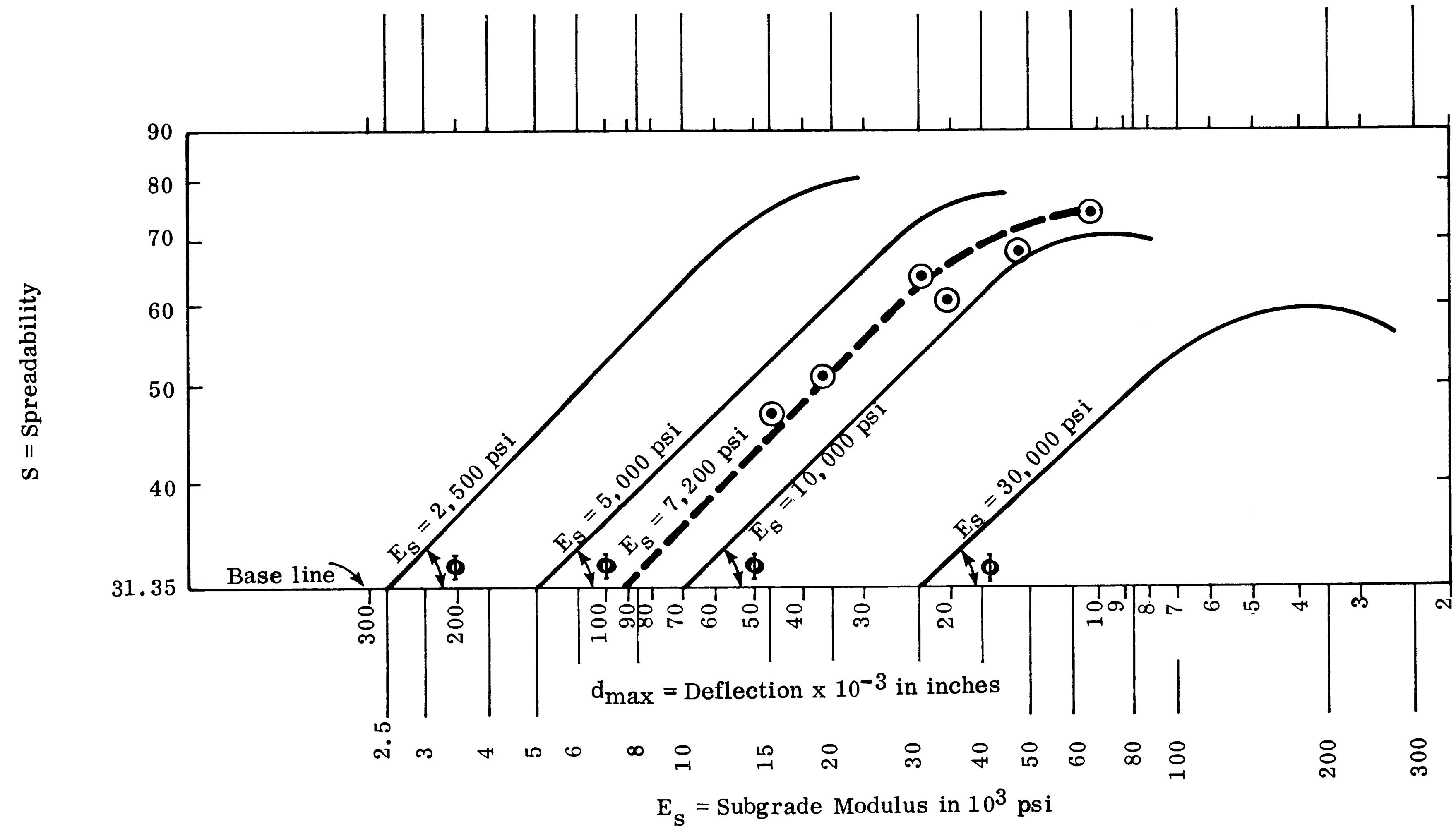

Figure 8. Example of evaluation of subgrade modulus by spreadability method — Project D (SBL). Basic conversion units: 1" = 25.4 mm; 1,000 psi - 6,890 kN/m^2.

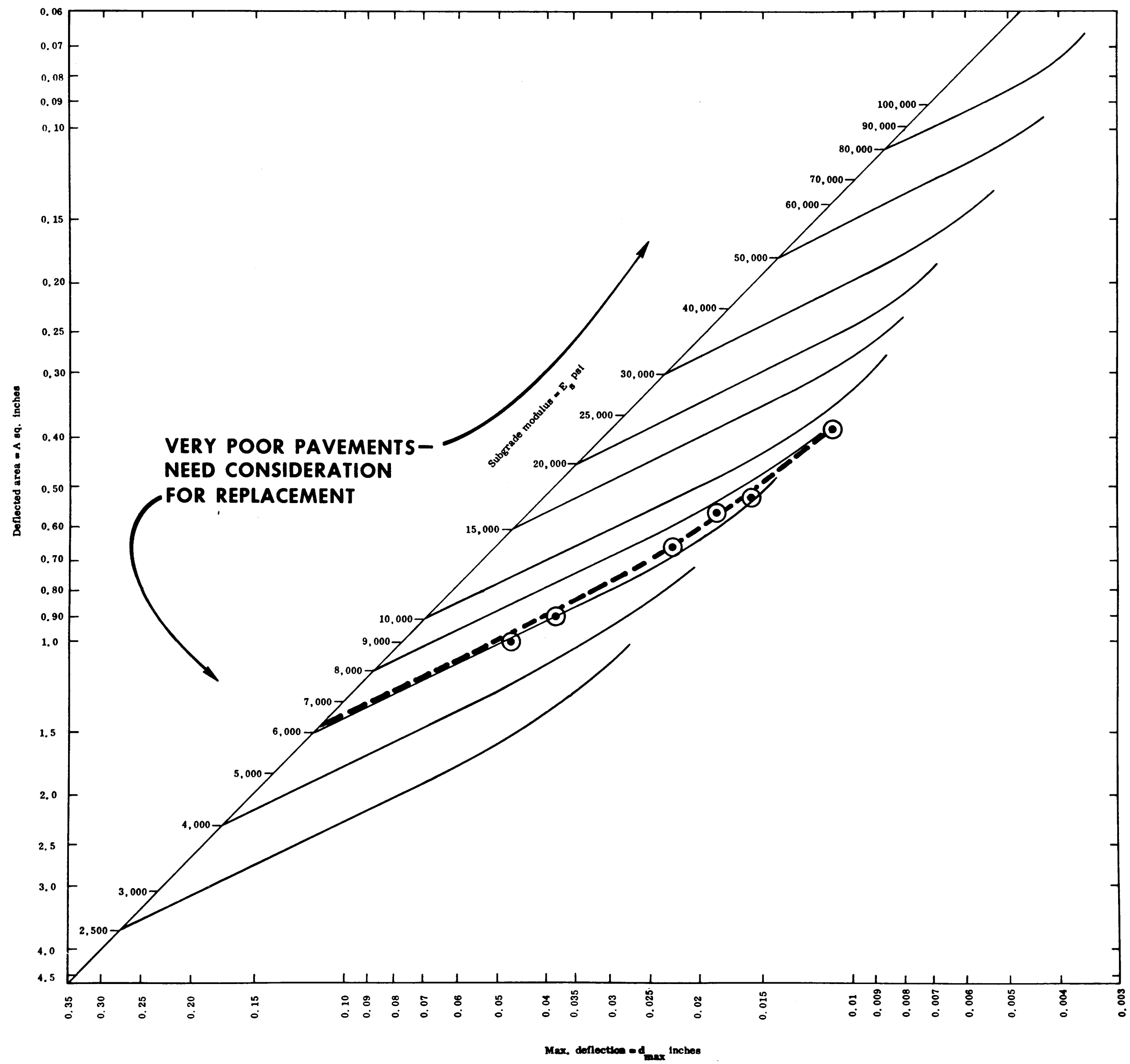

Figure 9. Example of evaluation of subgrade modulus by area method — Project D (SBL) E_s equals 6,000 psi. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2; 1 in.^{2} = 625 mm^2.

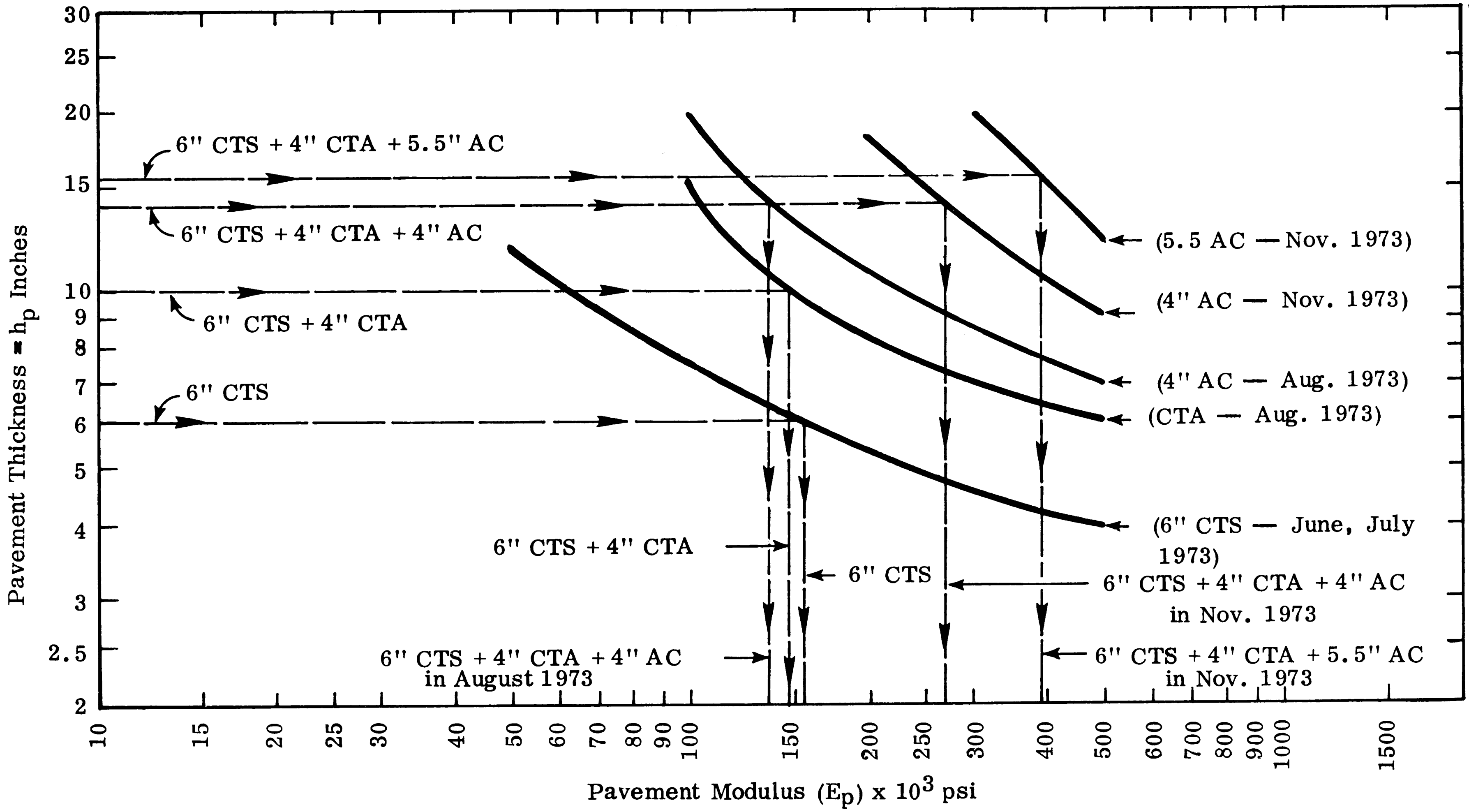

Figure 10. Determination of moduli of different materials in the layered system — Project D (SBL). Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2.

Similarly, from Figure 10 the elastic modulus of the 6 in. (150 mm) of CTS plus the 4 in. (100 mm) of CTA plus the 4 in. (100 mm) of AC base during November 1973 is found to be 266,000 psi (1,834 MN/m^2). Thus the elastic modulus of the AC base is obtained by equation (5) as follows:

$$E_p = 266,000 = \frac{6\ (150,000) + 4\ (140,000) + 4\ E_{AC}}{6 + 4 + 4}$$

or E_{AC} in Nov. 1973 = 566,000 psi = (3,900 MN/m^2)

In this manner the moduli of the materials in each layer were estimated for all the projects, and are given in Table 3 and discussed below.

Modulus of Cement Treated Subgrade

Cement treated subgrade was provided on four of the five projects. As seen from Table 3 the average cement treated subgrade modulus on all these projects was 120,000 psi (827 MN/m^2), with a minimum value of 65,000 psi (4482 MN/m^2) and a maximum of 160,000 psi (1034 MN/m^2). The low value of 65,000 psi probably resulted from some early deflection measurements when the cement treated subgrade had not sufficiently cured. It is very likely that this value would have been higher if a longer curing time had been observed. The next lowest value of the modulus of the CTS was 100,000 psi (689 MN/m^2).

For the purpose of design it is therefore safe to use the design value of 100,000 psi (689 MN/m^2) to 120,000 psi (827 MN/m^2) for cement treated subgrades. A low value of 100,000 psi (689 MN/m^2) is recommended for cases in which the subgrade soil cannot be stabilized very well with cement.

Modulus of Cement Treated Aggregate

Cement treated aggregate with 4% cement by weight was provided on two of the projects. On one project it was laid directly over the subgrade and on the other it was laid over the cement treated subgrade. Except for one section, no deflection data were recorded for the top layer of the cement treated aggregate. For the section on which the deflection readings were taken over the top of the cement treated aggregate layer the modulus was estimated to be 140,000 psi (965 MN/m^2), as shown in Table 3. This value is not very much higher than that for the cement treated subgrade, and hence could be safely assumed for the design or evaluation of pavements.

Table 3

ESTIMATED MODULI OF EACH MATERIAL IN
THE LAYERED SYSTEMS OF SATELLITE PAVEMENTS

Basic Conversion Unit: 1 psi = 6894 N/m^2

Project	Subgrade	E Value in 1000 psi				A. C.
		Over Subgrade		Over Stabl. Layer		
		CTS	CTA	Agg.	CTA	
Sec. A (NBL)	7	145	-	15	-	July 17, 73 — 134 July 31, 73 — 155 Aug. 14, 73 — 68 Oct. 29, 73 — 1,146
Sec. A (SBL)	8	160	-	12	-	Nov. 6, 72 and Nov. 15, 72 — 135 May 17, 73 — 226 Aug. 30, 73 — 304
Sec. B (NBL)	4	65	-	-	-	Aug. 14, 73 — 95 Aug. 28, 73 — 214 Oct. 29, 73 — 677
Sec. B (SBL)	6.7	100	-	-	-	Nov. 6, 72 — 245 May 17, 73 — 380 July 17, 73 — 165 Aug. 30, 73 — 450
Sec. C (NBL)	8	-	150 (assumed)	23	-	May 17, 73 — 165 July 11, 73 — 84 Aug. 28, 73 — 261
Sec. C (SBL)	6	-	130 (assumed)	16	-	Aug. 28, and 30, 73 — 115 Nov. 8, 73 — 361
Section D (NBL)	8,000	120	-	-	140 (assumed)	Nov. 15, 72 — 1,000 approx. May 30, 73 — 570 approx. Aug. 28, 73 — 1,000 approx.
Section D (SBL)	6,000	150	-	-	140	Nov. 8, 72 — 834 Aug. 1 and 16, 73 — 111 Nov. 13, 73 — 566
Charlottesville	8	100	-	24	-	Jan. 72 — 244 Mar. 72 — 157
Average		120	140	18	140	Variable with season.

Modulus of Untreated Aggregate

Untreated aggregate was provided on three of the projects. In all cases it was laid over a cement stabilized layer of either soil or aggregate. This is the usual practice in Virginia for heavy duty pavements on resilient or poor subgrade soils to prevent reflection cracks from the cement stabilized layers.

The average modulus value of the untreated aggregate overlying the rigid subbase as shown in Table 3 was 18,000 psi (124 MN/m^2) with a minimum of 12,000 psi (83 MN/m^2) and a maximum of 24,000 psi (165 MN/m^2). This value is too low for an untreated aggregate because many soils alone will have that much value. The reason for this low value seems to be that the aggregate acts as a weaker layer over the rigid cement stabilized layer. The weakening effect of the weak layer over the strong layer (9) and the weak sandwich layer system has been discussed by the author (9, 10). After this weak layer is covered with a stronger layer of asphaltic concrete, a sandwiched system with the untreated aggregate sandwiched between two stronger layers of soil,cement,and asphaltic concrete is formed. Under the circumstances, the strength of the untreated aggregate layer will increase. An average value of 50,000 psi (345 MN/m^2) is therefore recommended for an untreated aggregate sandwiched layer system.

Modulus of Asphaltic Concrete Layer

All the projects in the investigation have an asphaltic concrete layer consisting of two parts: the base, and the surface. The total thicknesses of the asphaltic concrete layers vary from 5.5 to 9.5 in. (137.5 to 237.5 mm). This layer was found to have a variable modulus that was dependent upon the time of year. Asphaltic concrete modulus values are therefore given in Table 3 for the data collected on different days of the year. A graph of the variation in the modulus of the asphaltic concrete layer for each section of the four projects on the Altavista Bypass over the first two years after construction is shown in Figure 11. Since no data were collected from the beginning of December to the end of April, the graphs are dotted for this period.

From the data given in Table 3 and Figure 11 it is evident that the moduli of the asphaltic concrete layer could have a minimum value of 100,000 psi (689 MN/m^2) in the summer and a value higher than 1,000,000 psi (6,894 MN/m^2) in the winter. The recommendation of Heukelom and Klomb (11) for the design of asphaltic concrete pavements with an E_{AC} above 700,000 psi (4825 MN/m^2) against cracking and with an E_{AC} below 300,000 psi (2,068 MN/m^2) against permanent deformation seems justifiable. Temperature stresses need to be considered when designing for failure due to fatigue and cracking.

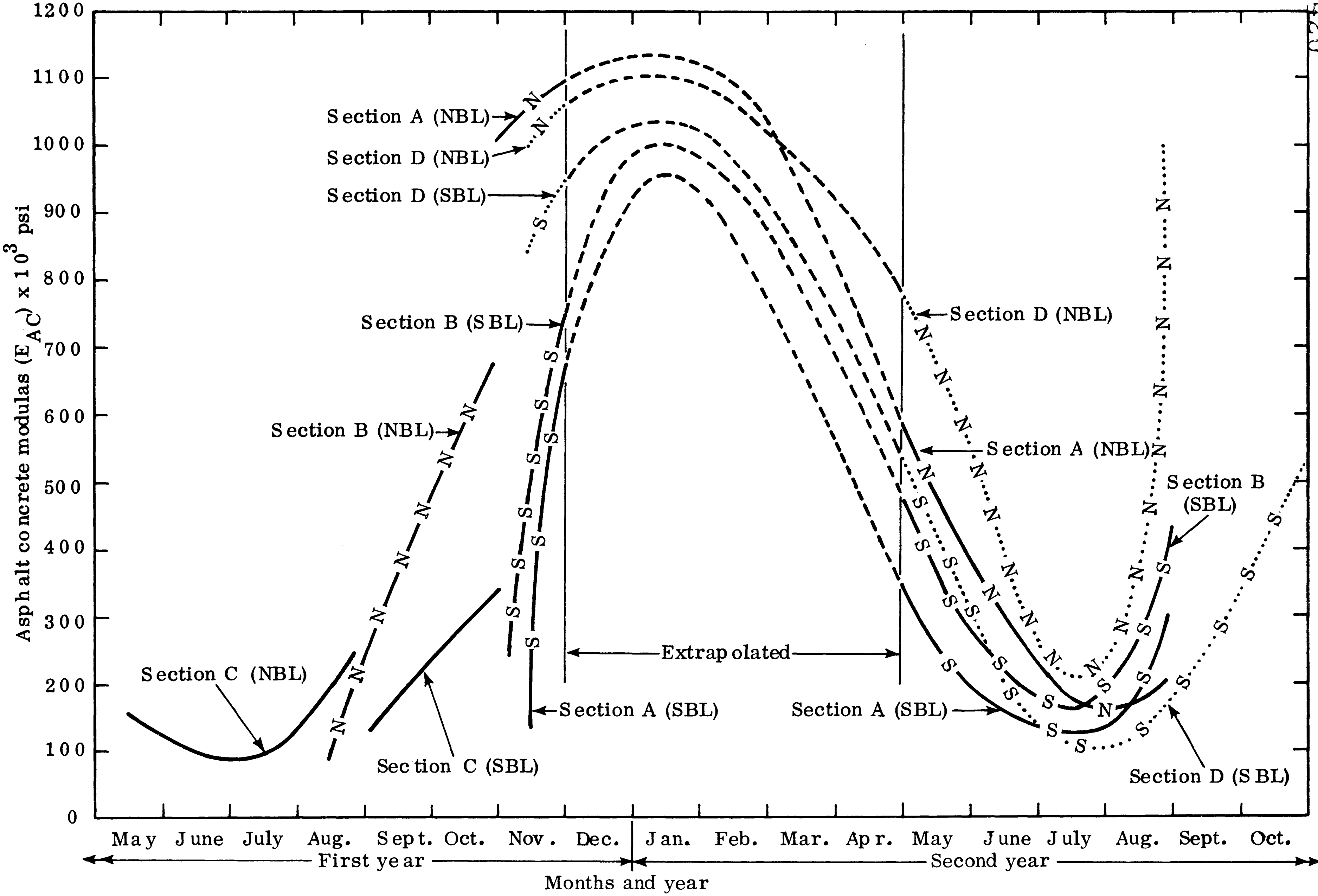

Figure 11. Variation in asphaltic concrete moduli during the first two years.
Basic converstion unit: 1,000 psi = 6,890 kN/m^2.

In Virginia pavement design has been based on spring deflections. If spring deflections are still to be considered for pavement design, the estimated design value for asphaltic concrete for this season, as shown in Figure 11, is about 300,000 psi (2068 MN/m^2). This value could therefore be used for the design of pavements or for evaluating pavements for isolated abnormally heavy loads. If evaluation is done in seasons other than spring the seasonal variation in the modulus of the asphaltic concrete should be considered.

VERIFICATION OF THE ESTIMATED VALUES

The estimated modulus values of the materials in each layer of the project — as discussed above — were used with the Chevron program to determine the d_{max}, S, and A values for each completed section of the project. The values so obtained were correlated with the values obtained from the field deflection data. The correlations between the actual and estimated values are shown in Table 4. The correlation for spreadability is shown in Figure 12. The correlation is very good, which indicates that the estimated values do represent the actual values. The correlation between actual and averaged values of d_{max}, S, and A are also shown in Table 4. This correlation is very good and hence it is recommended that the averaged modulus values of the materials determined in this investigation be adopted for pavement design or evaluation.

The estimated values give slightly higher deflections, lower spreadability, and higher deflected areas than the field values. For spreadability this fact is evident from Figure 12. Higher deflections, lower spreadability, and higher deflected area values would give lower estimated moduli values of the material, and thereby provide a factor of safety in the use of estimated values.

Table 4

STATISTICAL ANALYSES OF d_{max}, S, AND A VALUES

Basic Conversion Units: 1" = 25.4 mm
1 sq. in. = 625 sq. mm

Variable	Slope in Y = Ax		Standard Error of Estimate	
	For Estimated Values	For Averaged Recommended Values	For Estimated Values	For Averaged Recommended Values
d_{max}	1.08	1.11	0.0037 in.	.0038
S	1.01	1.02	2.49	2.59
A	1.08	1.10	0.149 sq. in.	0.142 sq. in.

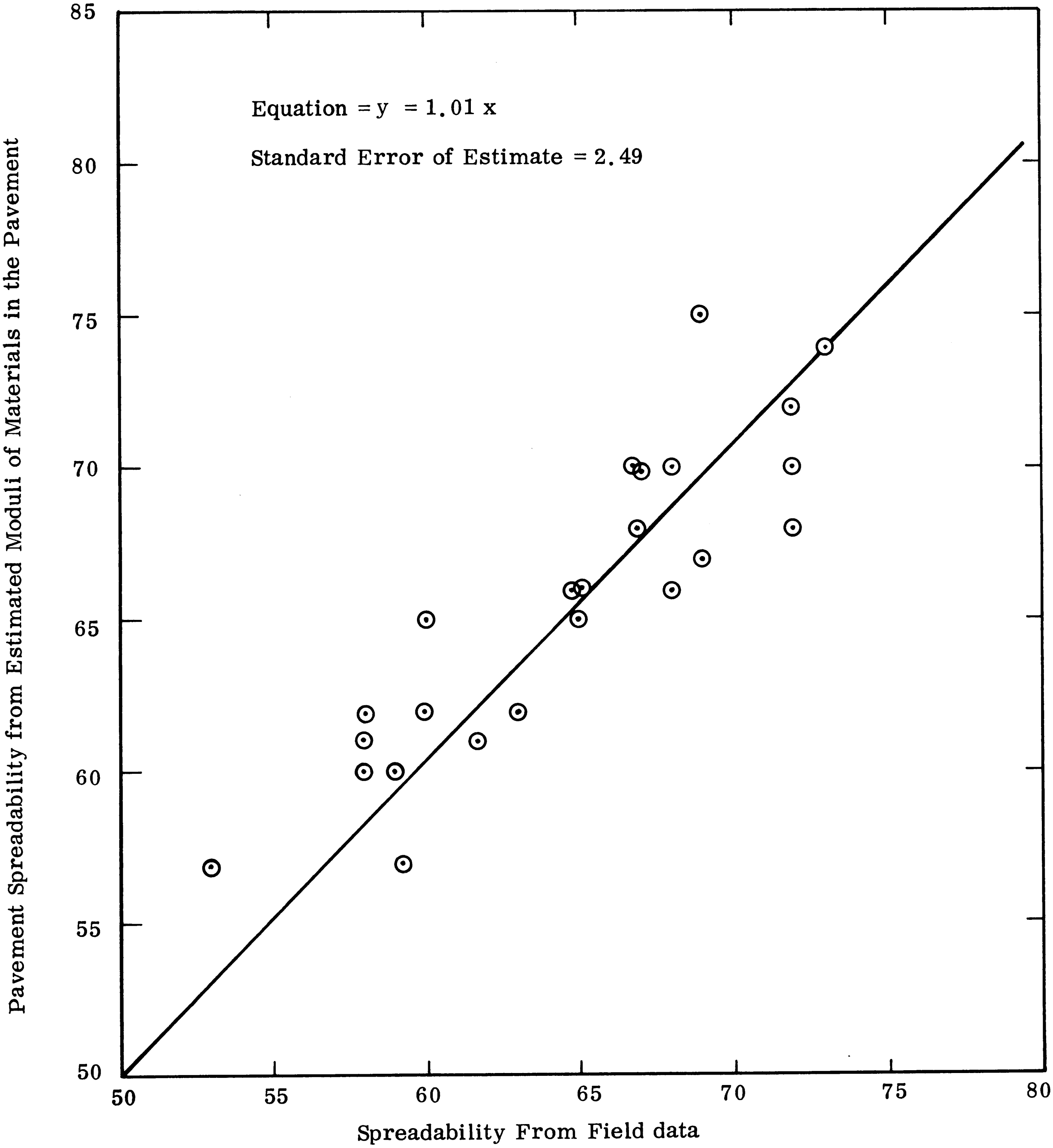

Figure 12. Correlation between estimated and actual spreadability values

CONCLUSIONS

1. The design charts developed in this investigation could be used for determining subgrade and pavement moduli for given dynaflect data.

2. The recommended averaged values of the moduli of materials for pavement design and evaluation are as follows:

   A. Cement treated subgrade — 100,000 psi (689 MN/m^2)
   B. Cement treated aggregate — 150,000 psi (1033 MN/m^2)
   C. Untreated aggregate sandwich between asphaltic concrete and cement treated layer — 50,000 psi (103 MN/m^2)
   D. Asphaltic concrete — 100,000 to 1,000,000 psi (689 to 6,890 MN/m^2), depending upon the season. However, for pavement design a value 300,000 psi (2068 MN/m^2) is recommended.

RECOMMENDATIONS FOR RESEARCH

1. Since flexible pavement evaluations and other problems connected with flexible pavements are solved by moduli of pavements and of the materials in the pavement system, the pavement design in Virginia should be modified to include material strengths in terms of moduli instead of, or in addition to, thickness equivalencies.

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NOTATIONS

A = Area of 1/2 the deflected basin under 9,000 lb. (4,080 kg) wheel load.

AC = Asphaltic concrete.

Agg. = Untreated aggregate.

CTA = Cement treated aggregate.

CTS = Cement treated subgrade.

d_{max}, d_1, d_2, d_3, d_4 = Deflections at 0, 1', 2', 3', and 4' from the center of two applied loads.

d_d = Dynaflect deflection in inches.

d_{max} = Maximum deflection under 9,000 (4,080 kg) wheel load.

E_p, E_s, E_{AC}, $E_{agg.}$, E_{CTA}, E_{CTS} = Modulus of the pavement, subgrade, asphaltic concrete, untreated aggregate, cement treated aggregate, and cement treated subgrade.

h_p = Thickness of the pavement.

NBL = Northbound lane.

S = Spreadability.

SBL = Southbound lane.

U_s = Poisson's ratio of the subgrade soil.