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FINAL REPORT

EVALUATION OF SUBGRADE MODULI FOR FLEXIBLE PAVEMENTS IN VIRGINIA

by

K. H. McGhee
Senior Research Scientist

and

N. K. Vaswani
Former Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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SUMMARY

Advances in pavement design technology in recent years have led to more dependence on mechanistic approaches and less reliance on subjective design criteria. In Virginia, the tendency is toward a pavement design and evaluation methodology based on elastic design theories. Underlying this design approach is a need to determine the elastic properties of paving materials. These properties had been evaluated for materials other than subgrade soils in earlier research. Thus the purpose of the present research was to determine the elastic moduli of Virginia subgrade soils and to provide designers with a range of moduli values that might be used in design evaluations.

The project was only partially successful because of unidentified factors that appear to have significant effects on the elastic moduli of subgrade soils. Nevertheless, the study showed that within the statistical limitations set forth in the report, the elastic moduli of subgrade soils can be estimated from information routinely collected at the time the preliminary engineering soil survey is conducted on a proposed highway construction project.

The factors having statistically significant impacts on subgrade elastic moduli were determined to be the dry density and the gradation, particularly the percentage passing the No. 200 sieve, of the soil. Contrary to expectations, there was no significant relationship between the California bearing ratio and subgrade modulus.

Because of the possibility of large errors in estimating the elastic modulus from the prediction equations developed, the reader is cautioned to use those predicted values as guidelines only in the absence of further data.

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INTRODUCTION

Virginia's overall flexible pavement design approach, which is based on AASHTO Road Test Results,[1,2,3] does not include provision for the full evaluation of in situ flexible pavements. The basic drawback in this approach is that the strengths of the subgrade, the paving materials, and the pavement as a whole are given in non-dimensional numbers. In addition, the strength of the pavement is determined by an empirical equation that is the summation of the strengths of the layers in the pavement system. Consequently, no interaction between the layers of the pavement is accounted for and this exclusion can result in significant errors.

The interaction between layers in a flexible pavement system depends not only upon the strength modulus and the thickness of each layer but also upon the relationship of one layer to another. For example, a sandwiched layered system consisting of a weaker layer (e.g. untreated aggregate) placed between two strong layers (e.g. a cement treated aggregate underneath and an asphaltic concrete above it) would have higher maximum deflections as compared to a system consisting of a weaker layer (e.g. untreated aggregate) overlaid by a stronger layer (e.g. cement treated aggregate), which in turn is overlaid by a still stronger layer (e.g. asphaltic concrete). The sandwich layer effect is shown by an example in Figure 1 and is discussed by one of the authors in another publication.[4] The difference between the maximum deflections of the two systems would change depending on the moduli and thicknesses of the layers. In the above example, the difference between the maximum deflections of the two systems would further increase if the modulus of the cement treated aggregate layer increases beyond 100,000 psi (68.94 MN/m^2); by doubling the value of the cement treated aggregate to 200,000 psi (137.9 MN/m^2), the difference would increase by 30% to 50%.

SANDWICHED LAYER SYSTEM			NON SANDWICHED LAYER SYSTEM	
SURFACE	E_1 = 300,000 psi	d_1 = variable	SURFACE	E_1 = 300,000 psi
BASE	E_2 = 20,000 psi	d_2 = 6"	BASE	E_2 = 100,000 psi
SUBBASE	E_3 = 100,000 psi	d_3 = 6"	SUBBASE	E_3 = 20,000 psi
SUBGRADE	E_s = 5,000 psi or 20,000 psi	d_s = infinite		E_s = 5,000 psi or 20,000 psi

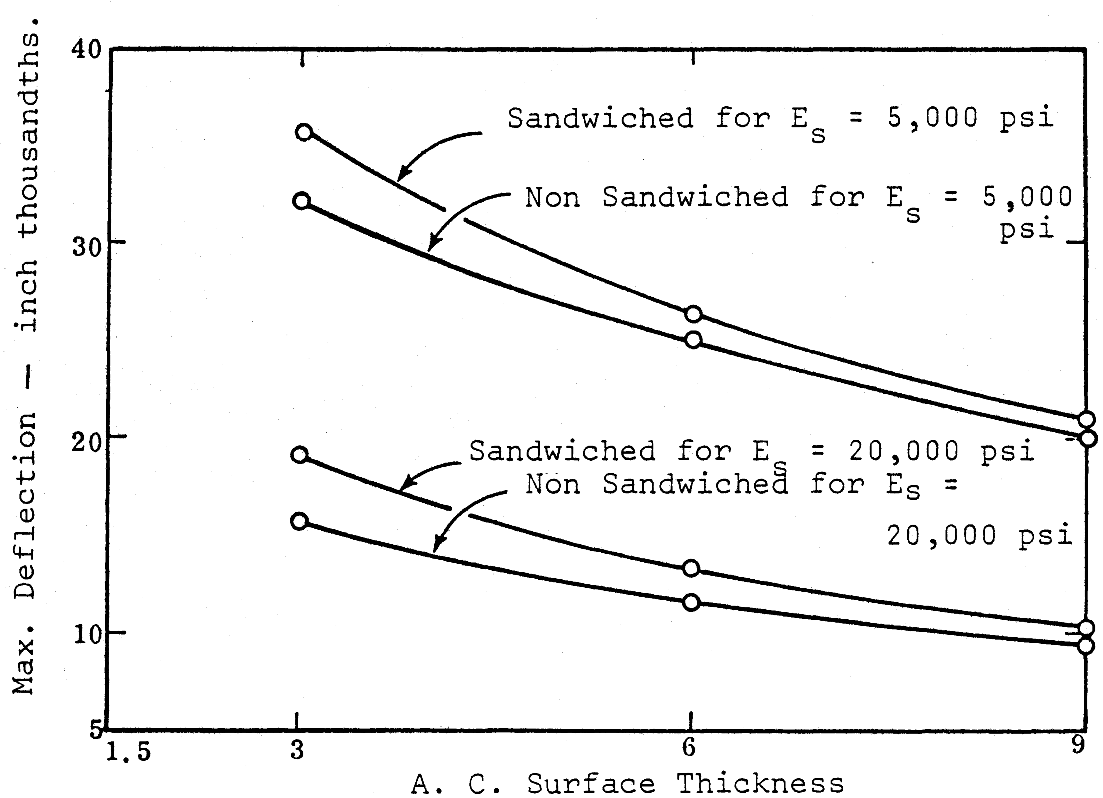

Figure 1. Example of interaction between two systems having the same material strengths and thicknesses. Note — 1 inch = 25 mm, 1,000 psi = 6.894 MN/m^2.

The elastic and viscoelastic theories account for the interaction between layers and are accepted by many designers throughout the country. In Virginia for the last few years, elastic theory has been successfully used for pavement evaluation. Designs based on elastic theory have a common basis of discussion and understanding. For that reason, analysis by the elastic theory was adopted as the approach in the present investigation.

Although an evaluation of the modulus values for all materials in the pavement system was beyond the scope of the present study, a beginning point was perceived to be an evaluation of typical subgrade moduli for various areas of the state. Furthermore, previous investigations had enabled estimates of the moduli values for other typical materials so that only subgrade moduli values were needed in order to provide a "first generation" pavement evaluation approach utilizing elastic theory.

PURPOSE

The purpose of the present study was to develop a methodology permitting the estimation of subgrade rebound moduli from the data collected during a standard preliminary engineering soil survey. Among the data available at that time are gradations, Atterburg limits, and California bearing ratio values.

APPROACH

To achieve the purpose of the study the approach outlined below was employed. A more detailed discussion of these steps will be given in the appropriate section of the report.

1. General soil areas based on subgrade soil characteristics were defined for the state. The engineering properties considered were (a) the soil classification, including Atterburg limits; (b) dry density; (c) soil resiliency factor based on experience; and (d) California bearing ratio (CBR) values. The areas were determined solely from historical soil survey data.

2. Sixteen satellite projects under construction in different physiographic provinces were selected from the historical soil survey data. Deflection data were collected for each of these projects on

the raw subgrade and on each subsequent pavement layer. From the deflection data, elastic moduli of subgrades were determined through the use of single- and two-layered elastic theory.

3. The subgrade moduli value obtained in step 2 were correlated with the subgrade soil properties determined in step 1.

4. The engineering properties of each soil area of Virginia were correlated with the subgrade moduli values of the soils as explained in Nos. 1, 2, and 3 above. Then, a physiographic map of Virginia that gives the subgrade moduli values was prepared.

VARIABLES

The dependent variables were the subgrade deflections determined for the satellite projects and the subgrade moduli calculated from the deflection data. The independent variables were:

(a) the soil classification, including Atterburg limits;

(b) the dry density;

(c) the soil resiliency factor; and

(d) the CBR by the Virginia test method.

The effects of each of the above variables on the subgrade modulus vary; hence, the most important variables were considered in more detail than the others. Some variables were ignored when their effects were not found to be of significant magnitude.

RESULTS AND DISCUSSION

General Soil Support Areas

General soil support areas for the state were examined through computer sorting and analysis of the results of over 8,900 test results from soil surveys over approximately the past 10 years. These test results are summarized in Appendix A, where all results are expressed as county averages. In some instances, former counties which have become cities are listed for identification purposes.

For analysis purposes, soils were grouped first by classification then by physiographic province. In order to pursue the analyses without unwieldy amounts of data, county average soil properties were considered as individual data points. The results of these studies are discussed below.

Soil Classification

Average soil properties for similar soil classifications are listed in Table 1. These values, while indicative of the general properties of soils in the classification, are subject to large errors due to the averaging processes used in data analysis. For this reason, the values should be used as general guidelines only where actual test results are not available. The column headed "No. of Counties" indicates the number of counties having the soil classification listed in the left column as its predominate soil type.

Table 1

Average Soil Properties by Classification

Soil Class.	No. Counties	CBR	Dry Density (pcf)	Passing 200 (%)	PL	LL	PI
A-2-4, A-4	11	27.3	115.7	39.0	16	25	9
A-5, A-6	61	15.6	111.1	53.8	17	32	16
A-7-5, A-7-6	22	9.4	102.4	73.3	24	45	21

Metric Conversion: 1 pcf = 0.0625 Kg/m^3

Stepwise regression analyses were performed on each soil type for each county average. In each case the CBR was considered as the dependent variable and the given soil properties as independent variables. The results of these analyses are summarized in Table 2, where the statistically significant correlation coefficients are indicated by asterisks. In the case of the A-2-4 and A-4 soils, the dry density (DD), percentage passing the number 200 sieve (P200), plastic limit (PL), and liquid limit (LL) all had statistically significant influences on the CBR value, with the dry density being the dominate factor. For the A-5 and A-6 soils, the dry density was again the dominant factor, with all the above properties, along with the plastic index (PI), having statistically significant influences. For the

A-7-5 and A-7-6 soils, however, only the liquid limit had a statistically significant bearing on the CBR. Even in that case, the low correlation coefficient of -0.45 shows that while the relationship is significant, it is not a strong relationship, which implies that unidentified factors have strong influences on the CBR values for these soils.

Regression analyses for equations of best fit yielded the CBR prediction equations given in Table 3 for each grouping of soils. Again, the reader is cautioned that the equations should be used as guidelines only when no CBR test results are available. As mentioned earlier, the averaging process used in the regression analysis means the equations are capable of predicting population averages with a modest degree of confidence, while the prediction of individual CBR values may be subject to large errors.

Table 2

Correlation of Soil Properties with CBR by Classification

		Correlation Coefficient				
Soil Class.	No. Counties	Dry Density	Passing 200	PL	LL	PI
A-2-4, A-4	11	0.92*	-0.68*	-0.83*	-0.81*	0.26
A-5, A-6	61	0.73*	-0.69*	-0.51*	-0.68*	-0.47*
A-7-5, A-7-6	22	0.28	-0.34	-0.19	-0.45*	0.20

*Significant correlations.

Table 3

Regression Equations for CBR by Classification

Soil Type	No. Samples	Equation	Correlation Coefficient	Standard Error
A-2-4, A-4	11	CBR = 1.45DD-141	0.92	3.6
A-5, A-6	61	CBR = 0.51DD-0.25(P200) -0.45PI-20	0.77	3.7
A-7-5, A-7-6	22	CBR = 24-0.32LL	0.46	1.9

Physiographic Province

A second sorting process was used to classify soils according to physiographic province. The provinces used were in accordance with those defined by Stevens et al. and shown in Figure 2.[6] The results of this second sorting are summarized in Table 4, where county average soil properties are listed as a function of province.

As was expected, there is some similarity in the sortings according to classification and according to province, because the soils tend to be distributed generally by province in a way that most of the A-2-4 soils are in the coastal province, etc.

The results of regression analyses made in an attempt to relate the CBR values to other soil properties, sorted by province, are summarized in Table 5.

Again, statistically significant, although poor, correlations were found between the CBR values and other soils properties (Table 6). However, regression prediction equations did not correlate with actual CBR values as well as those given in Table 3 for sorting by soil classification. It is, therefore, concluded that if prediction equations are to be used, those in Table 3 are appropriate.

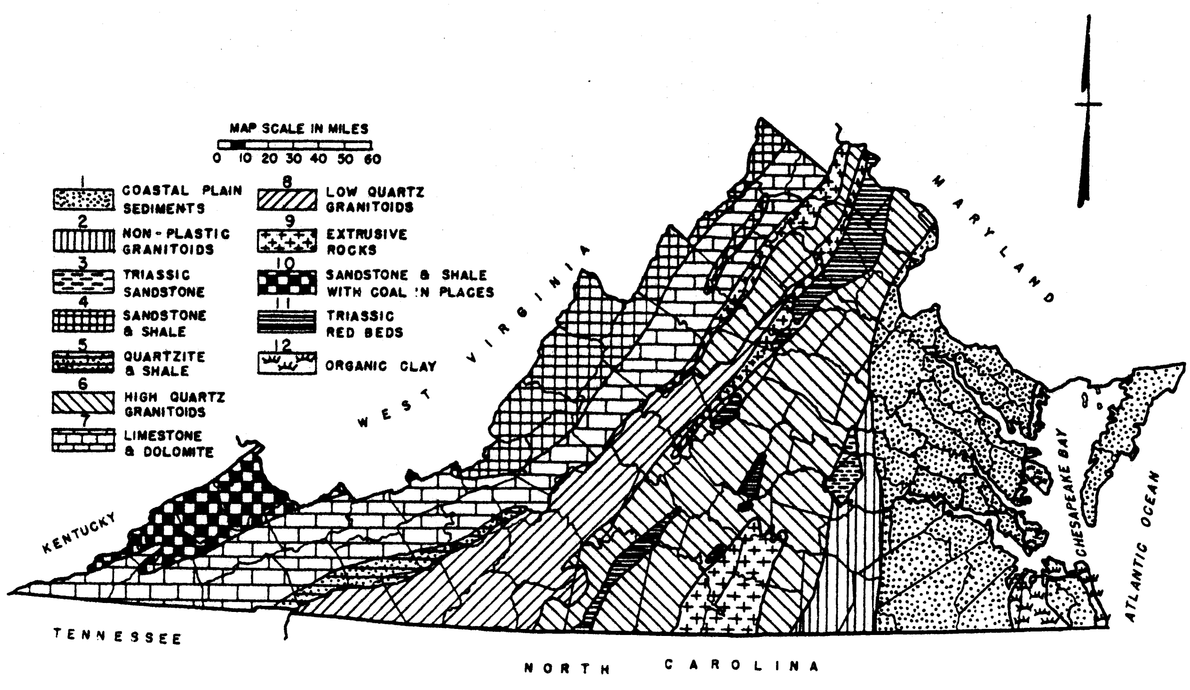

Figure 2. Map of Virginia showing general soil areas for subgrade support based on geological formations. (From reference 6.)

Table 4

Average Soil Properties
by Physiographic Province

Province	No. Counties	CBR	Dry Density (pcf)	Passing 200 (%)	PL	LL	PI
Coastal Plain	27	26.9	117.1	41.5	12	24	12
Piedmont	41	11.9	106.9	58.2	19	38	19
Ridge & Valley	27	9.9	106.5	68.1	23	39	16

Metric conversion: 1 pcf = 0.0625 Kg/m^3

Table 5

Correlation of Soil Properties
with CBR by Province

Province	No. Counties	Correlation Coefficient				
		Dry Density	Passing 200	PL	LL	PI
Coastal Plain	27	0.57*	-0.55*	0.10	-0.42*	-0.57*
Piedmont	41	0.65*	-0.34*	-0.14	-0.40*	-0.27
Ridge & Valley	27	0.47*	-0.62*	-0.48*	-0.53*	-0.57*

*Statistically significant

Table 6

CBR Prediction Equations by Province

Province	No. Samples	Equation	Correlation Coefficient	Standard Error
Coastal Plain	27	CBR = 0.60DD-0.27(P200) -0.64PI-24	0.70	3.1
Piedmont	41	CBR = 0.39DD-0.11(P200) -0.16PI-21	0.61	2.2
Ridge & Valley	27	CBR = 0.07DD-0.04(P200) -0.17PI+7.6	0.53	1.3

Studies of Satellite Projects

Data Collection

Studies of the sixteen satellite projects commenced at the time portions of the subgrade had been prepared for the succeeding operation. In some cases, the succeeding operation was cement treatment of the subgrade, in others it was the application of an aggregate base course. The sixteen projects chosen were under construction during the planned life of the study and were distributed in such a way as to incorporate some projects from each physiographic province.

Deflection data were collected on each layer utilizing the dynaflect apparatus. With this method, five deflection readings are obtained at each location, and are designated d_{max}, d_1, d_2, d_3, and d_4, as shown in Figure 3. The maximum deflection is d_{max}.

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

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

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 3. The deflected areas are determined as discussed below.

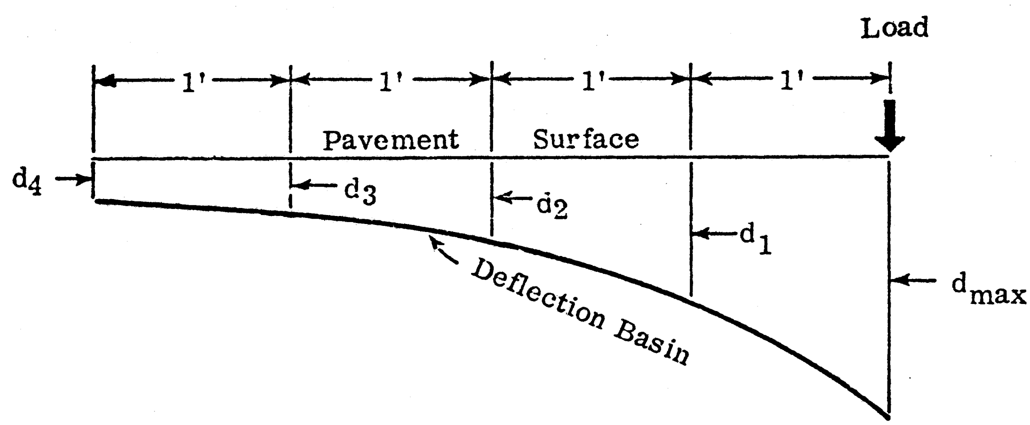

Figure 3. Deflection recording of the deflected basin by the dynaflect machine. Basic conversion unit: 1" = 25.4 mm.

A correlation study 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.[9] 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

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

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

Summaries of the project designs and the results of deflection tests on each layer of each project are given in Appendix B. Details of the studies are discussed below.

Determination of Subgrade Moduli

Subgrade moduli were determined through the use of a subgrade evaluation chart developed by Vaswani.[5] An example of such a determination is given in Figure 4, where it is seen that the subgrade modulus for a given project may be estimated from maximum deflection and deflected area data. The moduli values determined for each project are given in the project descriptions in Appendix B.

Verification of the subgrade moduli determined as above was attempted through the use of 2- and 3-layer elastic theory applied to succeeding pavement layers, also as described by Vaswani.[5] In this approach, the equation for the pavement modulus Ep is

$$Ep = \frac{E_1h_1 + E_2h_2 + - - -}{h_1 + h_2 +} \quad . \qquad (3)$$

In this equation E_1, E_2 are the moduli of the materials in different layers of the pavement, and h_1, h_2 are the corresponding layer thicknesses. Based on data in Appendix B, Ep versus hp values were determined for each layer of each pavement and plotted in a manner similar to that shown in Figure 5 for project No. 1. Then, the solution of equation 2 for each layer on which tests were conducted permitted estimations of the moduli for those layers. These layer moduli also are given in the project description in Appendix B. The subgrade moduli values, then, were verified through a comparison of actual versus theoretical deflection values for the uppermost layer tested. (In some cases it was not possible to test the completed pavement surface before the research study was terminated.)

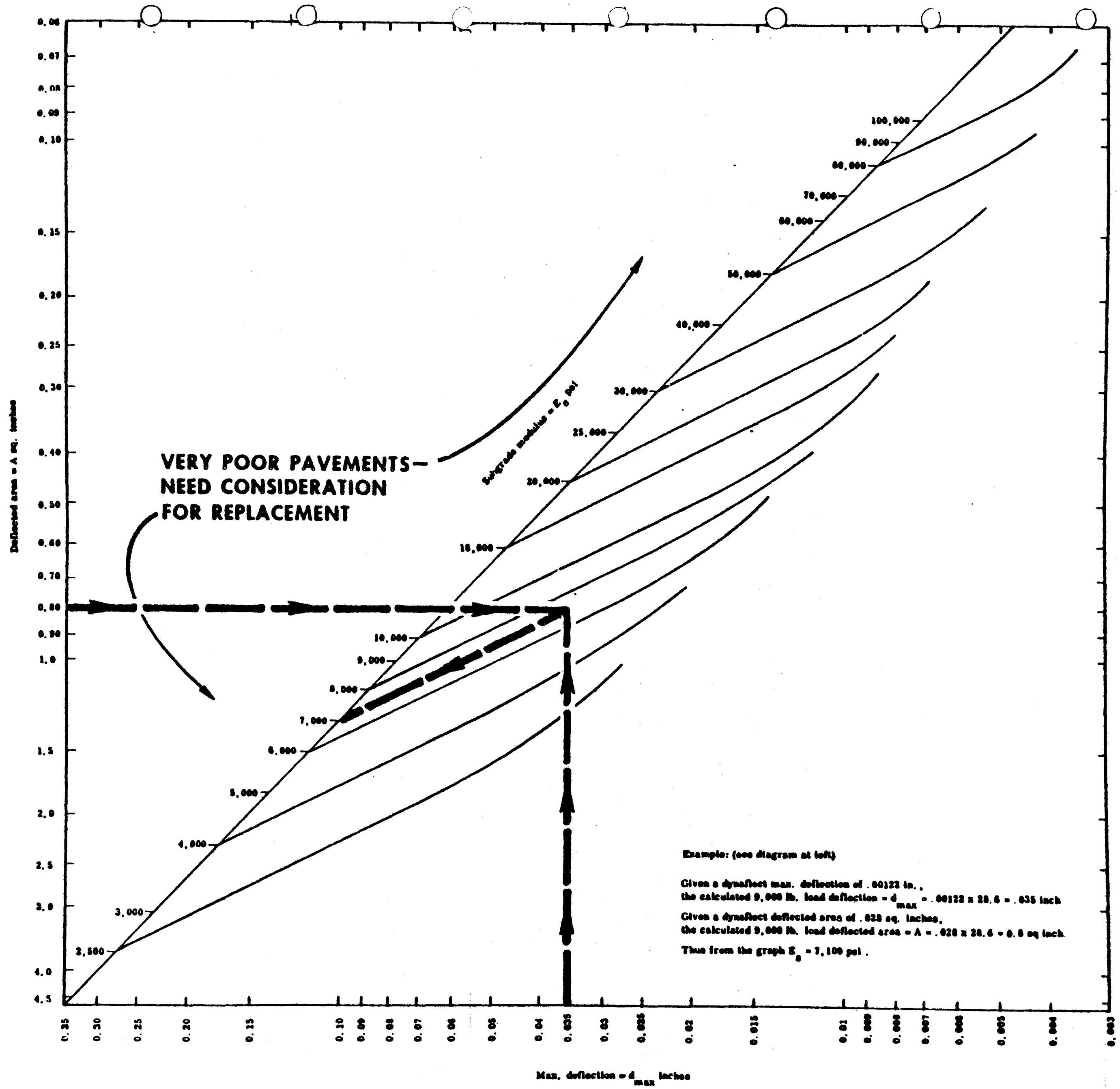

Figure 4. Subgrade evaluation chart based on area. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6.890 kN/m^2; 1 $in.^2$ = 625 mm^2.

The measured and theoretical deflections are compared in Table 7. In the development of this table, theoretical deflections were determined from 2-layer influence charts given by Burmister.[8] Note that the correlation coefficient of 0.98 shows a highly significant correlation between measured and theoretical deflections. Yet the relationship is such (standard error of estimate = 0.004) that actual deflections could not be predicted from the theoretical values with a very high degree of confidence. Nevertheless, the good correlation was taken as evidence that the estimated pavement and subgrade moduli values were interacting approximately as expected from the theory.

It is of interest to note that in some instances very low and even negative layer moduli resulted from the above analysis. This apparent anomaly occurred most frequently where the sandwich layer type of construction was employed. Examples may be seen in projects 1, 6, and 7, where low moduli for the sandwiched aggregate base material caused a relatively low net pavement modulus and effected little or no reduction in deflections as compared to the underlying layer. Of further interest is project 8, where field notes showed that the aggregate base material failed to set up, causing a net increase in the deflection. The estimated modulus for the aggregate base in that instance is a negative number. Weak and sandwiched aggregate bases are the subjects of studies recently undertaken by one of the authors.[9]

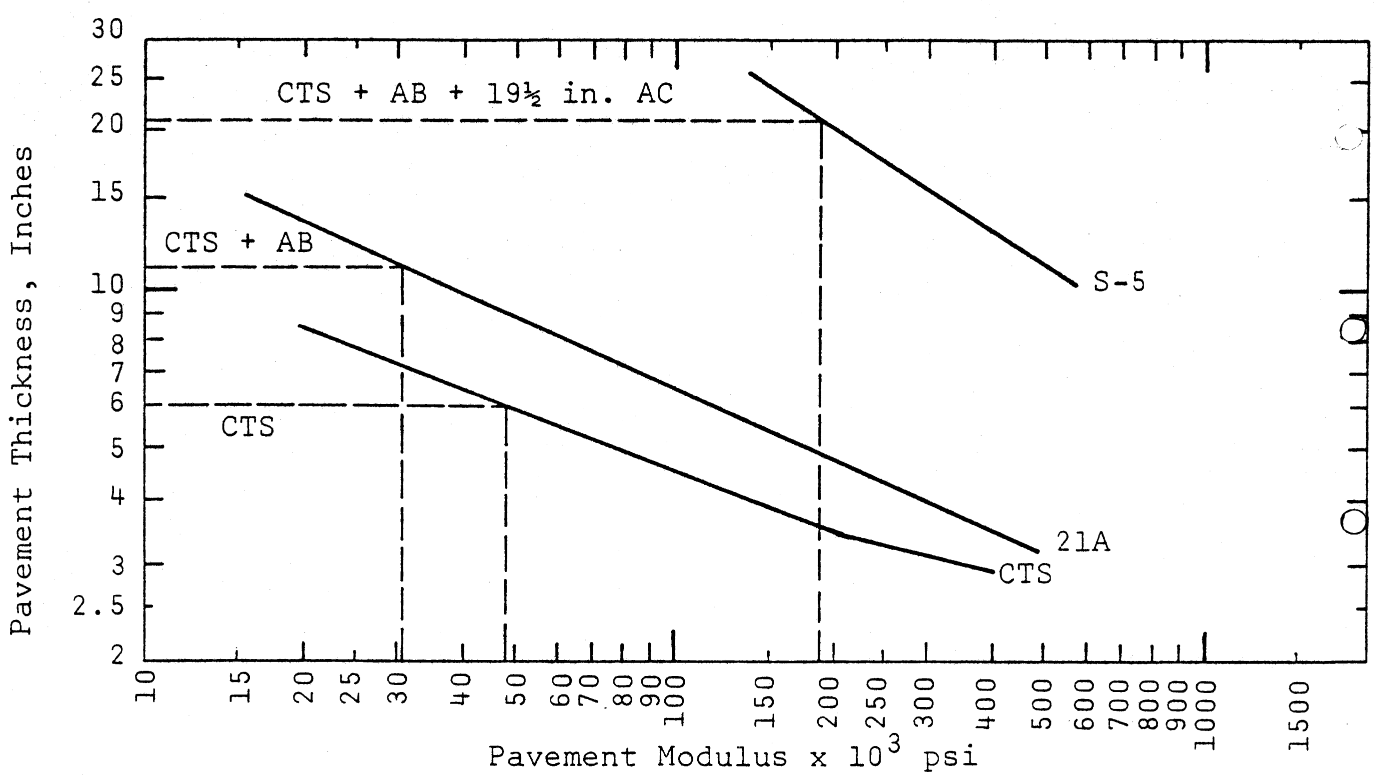

Figure 5. Determination of moduli of different materials in the layered system — Project 1. Basic conversion units: 1" = 25.4 mm; 1,000 psi = 6,890 kN/m^2.

Table 7

Measured and Theoretical Deflections for Topmost Layer Tested

Project	Measured Deflection (in.)	Ep (psi)	Theoretical Deflection (in.)
1	0.016	181,000	0.019
2	0.032	300,000	0.037
3	0.017	340,000	0.018
4	0.014	250,000	0.016
5	0.021	82,000	0.022
6	0.024	48,000	0.029
7	0.027	90,300	0.024
8	0.060	25,000	0.049
9	0.011	420,000	0.014
10	0.016	140,000	0.019
11	0.082	25,000	0.080
12	0.019	89,000	0.023
13	0.013	139,000	0.014
14	0.015	370,000	0.012
15	0.017	95,000	0.017
16	0.020	97,000	0.018

Measured vs Theoretical

Correlation Coefficient = 0.98
Standard Error of Estimate = 0.004 in.

Metric Conversion - 1 in. = 2.54 cm
1000 psi = 6.894 MN/m^2

Correlation of Subgrade Moduli With Soils Properties

In an effort to correlate measured subgrade moduli with subgrade soil characteristics, the project soil survey data summarized in Table 8 were used. It will be noted that no information is given for projects 1 and 13; data were not available from the project files.

Table 8

Project Soils Information
(average for each project)

Project	E_s (psi)	CBR	Dry Density (pcf)	Passing 200 (%)	PL	LL	PI
2	5,600	10.0	114.0	58.5	29	18	11
3	7,500	23.0	117.6	40.8	34	19	15
4	9,000	15.7	115.2	59.4	36	26	10
5	13,000	8.2	112.0	62.5	37	24	13
6	7,800	12.9	112.9	61.7	37	14	23
7	7,500	25.2	102.9	51.0	31	7	24
8	9,500	7.8	108.6	69.4	42	29	13
9	7,500	6.8	99.8	62.2	36	6	30
10	8,200	6.8	101.9	42.0	33	1	32
11	2,500	3.5	98.7	46.9	40	40	0
12	8,000	11.3	104.9	54.4	39	3	36
14	13,000	12.8	101.0	76.7	38	26	12
15	13,000	9.2	112.3	65.4	40	22	18
16	1,000	6.9	103.8	59.1	49	24	25

Metric Conversion - 1,000 psi = 6.894 MN/m^2
1 pcf = 0.0625 Kg/m^3

For the 14 projects analyzed, the results of regression analysis, where subgrade modulus is the dependent variable and other soil characteristics are independent, are summarized in Table 9.

Table 9

Correlation of Soil Properties with Subgrade Modulus (14 Projects)

Soil Property	Correlation Coefficient	Statistical Significance
CBR	0.02	None
Dry Density	0.31	Poor
P200	0.66	Fair
PL	0.18	None
LL	0.02	None
PI	0.12	None

A study of these regression results shows that only dry density and percentage passing the No. 200 sieve are of any statistical significance. Even these correlations are poor and suggest that other variables significantly influence the subgrade modulus. Somewhat surprising was the total absence of any statistically significant relationship between the CBR value and subgrade modulus. Thus, the often used approximation

$$E_s = 1,500 \times CBR$$

appears to have no validity in the case of the Virginia soils studied.

Of additional interest is the finding that the best correlation is between the subgrade modulus and percentage passing the No. 200 sieve (P200). This suggests that the "best" subgrade moduli will be found where soils have a high clay content. While the authors concede that this may be reasonable for dry subgrade, it is likely that subgrade saturation would result in a reduction in the modulus. Some efforts to verify this suspicion showed no significant variation in subgrade moduli within the duration of the study.

Conversely, some indication of a relationship between the subgrade modulus and dry density was not surprising, since high soil support values are expected in the relatively high-density sand and gravel soils.

Stepwise regression analyses made in an effort to predict the subgrade modulus from the dry density (DD) and P200 resulted in the equation

$$E_s = 142DD + 184(P200) - 17{,}000. \qquad (4)$$

This equation has a correlation coefficient of 0.74 and a standard error of estimate of 2,000 psi (14 MN/m^2). While this correlation coefficient suggests that the relationship given in equation (4) is significant at a 99% confidence level, it also shows that the combination of dry density and P200 only partially accounts for the subgrade modulus. Other contributing factors were not identified.

Statewide Estimate of Subgrade Moduli

Utilizing equation (4) and the information on soils properties given in Appendix A, estimated subgrade moduli were developed for all counties in the state and are listed in Appendix A as the "predicted" subgrade moduli.

Consideration of the resulting predicted subgrade moduli, in view of engineering judgment and observations of pavement performance, suggests that the predicted moduli are too high in some resilient soil areas. For this reason, the predicted moduli were adjusted by the resiliency factors given in Appendix A to yield "design" moduli, which are also given in Appendix A for most counties. The resiliency factors used are the inverse of those given by Vaswani.[1] The authors recommend use of the "design" moduli in pavement evaluation analyses until such time as further studies produce moduli values having greater reliability.

Finally, all subgrade moduli were grouped according to magnitude as given in Table 10 to develop a design subgrade moduli map for the state. This map is given in Figure 6.

It should be noted that an area of the state designated as subgrade classification A has a design subgrade modulus of 2,000 - 3,000 psi (14 - 21 MN/m^2) and that the moduli increase in 1,000 psi (6.894 MN/m^2) increments to classification G, where the design moduli is 8,100 - 9,000 psi (56 - 62 MN/m^2). The reader is cautioned that the moduli indicated are statistically derived values and that actual moduli may deviate significantly from the map values. The map values do, however, represent the average values one could expect in a given area and can serve as useful guidelines.

Table 10

Design Subgrade Moduli

Subgrade Classification	Design Subgrade Moduli (psi)
A	2,000 - 3,000
B	3,100 - 4,000
C	4,100 - 5,000
D	5,100 - 6,000
E	6,100 - 7,000
F	7,100 - 8,000
G	8,100 - 9,000

Metric Conversion: 1,000 psi = 6.894 MN/m^2

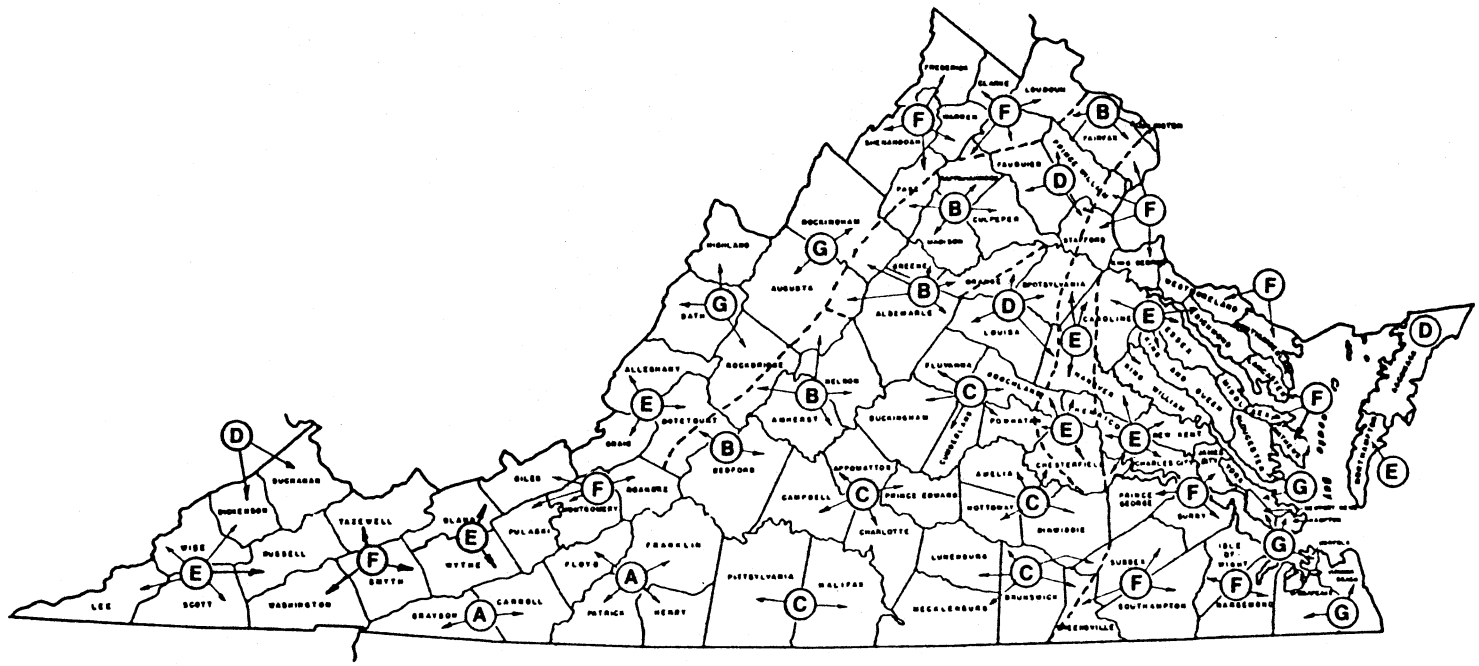

Figure 6. Design subgrade moduli.

CONCLUSIONS

The following conclusions appear warranted from the results of research discussed above.

1. The CBR values of Virginia subgrade soils sorted by either soils classification or physiographic province are statistically related to soil properties determined during a routine soil survey.

2. The CBR prediction equation developed earlier may be used to predict project average CBR values. Such predicted values should be used only as engineering guidelines in the absence of test results. Because of the possibility of large errors, predicted values should not be considered as substitutes for test results.

3. For Virginia soils, no statistically significant relationship was found between the CBR value and the elastic modulus (E_s) of subgrade soils. For this reason, the often used expression

$$E_s = 1,500 \text{ CBR}$$

appears to have no validity in Virginia.

4. Statistically significant relationships between the subgrade modulus and other soil properties were detected only in the cases of dry density and percentage passing the No. 200 sieve. When the limitations of statistically derived relationships are recognized, it is possible to predict average subgrade moduli values from the soil survey data.

5. A map, developed earlier, may be used as a guideline in determining the average design subgrade modulus for a project. The value so determined may be used in pavement evaluation studies in the absence of field test results giving more reliable values.

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

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APPENDIX A

Soils Classification and Predicted Subgrade Modulus

Code	County	Number Samples	CBR	Dry Density	Percent Passing #200	Atterburg Limits			Resiliency Factor	Subgrade Modulus	
						PL	LL	PI		Predicted	Design
00	Arlington	20	23	114	46	21	36	15	0.67	7,700	5,200
01	Accomac	20	28	120	30	12	18	6	1.0	5,600	5,600
02	Albemarle	132	10	109	67	17	37	20	0.33	10,800	3,600
03	Alleghany	125	10	113	57	20	34	14	0.67	9,500	6,400
04	Amelia	9	7	100	63	20	48	20	0.50	8,900	4,400
05	Amherst	61	11	104	51	11	28	17	0.50	7,000	3,500
06	Appomattox	17	10	106	61	18	34	16	0.50	9,200	4,600
07	Augusta	273	11	104	75	24	43	19	0.67	11,700	7,800
08	Bath	-	-	-	-	-	-	-	0.67	-	-
09	Bedford	74	7	103	53	16	36	20	0.50	7,400	3,700
10	Bland	68	11	105	67	25	41	16	0.67	10,200	6,800
11	Botetourt	123	10	104	81	25	42	17	0.67	12,600	6,300
12	Brunswick	64	10	107	55	24	41	17	0.50	8,300	4,200
13	Buchanan	15	10	118	44	8	26	18	0.67	7,900	5,300
14	Buckingham	28	14	114	51	14	30	16	0.50	8,600	4,300
15	Campbell	146	9	102	59	12	37	25	0.50	8,300	4,200
16	Caroline	298	33	118	38	13	26	13	1.0	6,700	6,700
17	Carroll	54	6	100	48	28	37	9	0.33	6,600	2,200
18	Charles City	-	-	-	-	-	-	-	1.0	-	-
19	Charlotte	21	10	100	66	14	43	29	0.5	9,400	4,700
20	Chesterfield	306	15	114	45	12	18	6	0.83	7,400	6,100
21	Clarke	76	7	101	86	24	47	23	0.67	13,100	8,800
22	Craig	7	12	113	56	19	30	11	0.67	9,400	6,300
23	Culpeper	54	10	105	80	20	44	24	0.33	12,700	4,200
24	Cumberland	18	8	105	69	24	45	21	0.50	10,600	5,300
25	Dickenson	51	12	113	51	13	29	16	0.67	8,500	5,700
26	Dinwiddie	171	14	109	48	17	35	18	0.50	7,400	3,700
27	(Elizabeth City)	56	23	118	38	10	23	13	1.0	6,700	6,700
28	Essex	162	30	118	40	13	24	11	1.0	7,200	7,200
29	Fairfax	81	12	111	66	24	38	14	0.33	11,000	3,600
30	Fauquier	149	10	112	69	19	39	20	0.50	11,400	5,700
31	Floyd	13	10	107	46	23	32	9	0.33	6,700	2,200
32	Fluvanna	-	-	-	-	-	-	-	0.50	-	-
33	Franklin	58	8	97	58	18	41	23	0.33	7,500	2,500
34	Frederick	23	7	104	77	24	52	28	0.67	11,900	8,000
35	Giles	98	10	107	69	21	39	18	0.67	10,900	7,300
36	Gloucester	97	31	118	41	14	24	10	1.0	7,300	7,300
37	Goochland	98	11	107	46	22	38	16	0.5	6,500	3,200
38	Grayson	104	8	104	52	16	38	22	0.33	7,300	2,400
39	Greene	92	14	104	69	21	42	21	0.33	10,500	3,500
40	Greensville	8	26	114	51	20	36	16	0.67	8,600	5,800
41	Halifax	45	8	108	63	22	37	15	0.50	10,000	5,000
42	Hanover	133	19	115	44	16	29	13	0.83	7,500	6,200
43	Henrico	408	14	113	50	21	36	15	0.83	8,200	6,800
44	Henry	142	8	105	55	16	37	21	0.33	8,000	2,600
45	Highland	-	-	-	-	-	-	-	0.67	-	-
46	Isle of Wight	19	28	116	38	8	22	14	1.0	6,400	6,400
47	James City	44	21	115	49	15	29	14	1.0	8,300	8,300
48	King George	55	34	118	40	16	25	19	1.0	7,100	7,100
49	King & Queen	55	32	119	38	12	24	12	1.0	6,800	6,800
50	King William	8	38	118	37	17	26	9	1.0	6,500	6,500
51	Lancaster	61	35	119	37	12	22	10	1.0	6,700	6,700

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(Continued)

Code	County	Number Samples	CBR	Dry Density	Percent Passing #200	Atterburg Limits			Resiliency Factor	Subgrade Modulus	
						PL	LL	PI		Predicted	Design
52	Lee	107	11	104	74	26	45	19	0.67	11,400	7,600
53	Loudoun	86	12	113	71	21	39	18	0.5	12,000	6,000
54	Louisa	87	11	107	69	18	40	22	0.5	10,900	5,400
55	Lunenburg	-	-	-	-	-	-	-	0.5	-	-
56	Madison	60	16	104	64	22	44	22	0.33	9,400	3,300
57	Mathews	38	34	121	35	7	19	12	1.0	6,700	6,700
58	Mecklenburg	96	9	105	64	20	37	17	0.5	9,700	4,800
59	Middlesex	104	32	119	42	12	24	12	1.0	7,600	7,600
60	Montgomery	51	7	100	80	28	46	18	0.67	11,800	7,900
61	(Nansemond)	65	24	115	46	12	25	13	1.0	7,700	7,700
62	Nelson	33	17	103	55	13	36	23	0.5	7,700	3,800
63	New Kent	136	27	116	34	17	27	10	1.0	5,600	5,600
64	(Norfolk)	103	22	115	41	10	23	13	1.0	6,800	6,800
65	Northampton	10	19	123	35	11	20	9	1.0	7,000	7,000
66	Northumberland	139	34	120	35	10	20	10	1.0	6,500	6,500
67	Nottoway	171	11	107	54	19	38	19	0.5	8,100	4,000
68	Orange	77	6	103	82	27	50	23	0.33	12,700	4,200
69	Page	40	5	109	62	24	38	14	0.5	9,800	4,900
70	Patrick	36	11	101	64	19	39	20	0.33	9,100	3,000
71	Pittsylvania	145	11	106	54	17	37	20	0.5	8,000	4,000
72	Powhatan	25	9	104	55	12	40	28	0.67	7,800	5,200
73	Prince Edward	110	11	106	48	20	37	17	0.50	6,900	3,400
74	Prince George	26	13	109	46	12	28	16	1.0	6,900	6,900
75	(Princess Anne)	25	21	116	49	10	23	13	1.0	8,400	8,400
76	Prince William	61	9	111	65	25	40	15	0.67	10,800	7,200
77	Pulaski	36	8	94	91	30	51	21	0.67	13,100	8,800
78	Rappahannock	45	19	110	62	15	37	22	0.50	10,000	5,000
79	Richmond	102	33	120	39	12	23	11	1.0	7,200	7,200
80	Roanoke	410	8	106	70	22	35	13	0.67	10,900	7,300
81	Rockbridge	222	10	101	84	24	50	26	0.67	12,700	8,500
82	Rockingham	59	9	100	83	25	48	23	0.67	12,600	8,400
83	Russell	337	9	102	69	29	45	16	0.67	10,200	6,800
84	Scott	22	9	112	62	19	31	12	0.67	10,300	6,900
85	Shenandoah	29	7	107	72	23	43	20	0.67	11,300	7,600
86	Smyth	44	11	106	76	23	37	14	0.67	11,900	8,000
87	Southampton	28	24	113	54	20	34	14	1.0	8,900	8,900
88	Spotsylvania	272	23	114	50	21	35	14	0.67	8,300	5,600
89	Stafford	210	23	114	48	20	34	14	0.67	8,000	5,400
90	Surry	8	21	118	47	12	27	15	1.0	8,400	8,400
91	Sussex	13	25	116	42	13	27	14	1.0	7,300.	7,300
92	Tazewell	205	12	106	68	25	39	14	0.67	10,500	7,000
93	Warren	59	8	111	62	23	36	13	0.67	10,200	6,800
94	(Warwick)	41	23	113	55	13	25	12	1.0	9,200	9,200
95	Washington	139	10	104	71	25	40	15	0.67	10,700	7,200
96	Westmoreland	50	24	115	47	18	27	9	1.0	8,000	8,000
97	Wise	176	14	112	55	17	28	11	0.67	9,100	6,100
98	Wythe	301	12	102	69	28	44	16	0.67	10,100	6,000
99	York	33	18	116	48	12	28	16	1.0	8,300	8,300

APPENDIX B

Project Descriptions

and

Deflection Test Results

1644

PROJECT SUMMARY SHEET

Project: 0064-047-101, C-503
0064-099-102, C-501, C-502

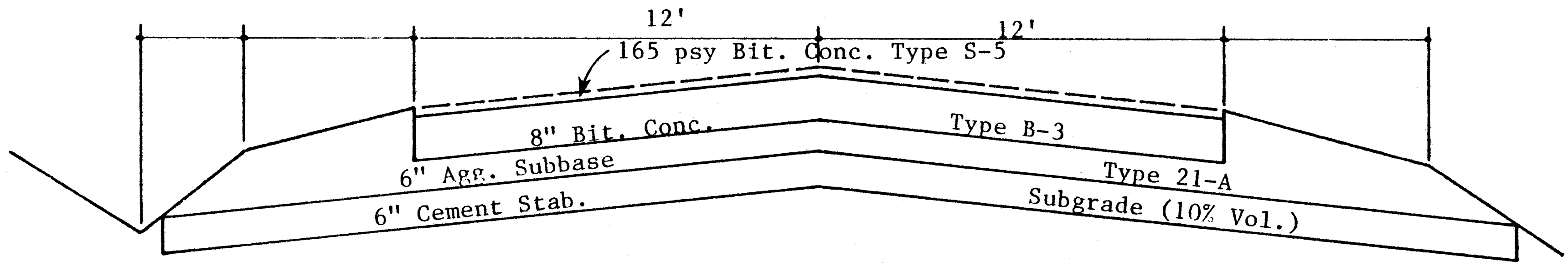
From: 0.631 Mi. E. Int. Rte. 168 & 30

To: 0.047 Mi. W. Int. Rte. 645

Study Project No.: 1

County: James City & York

Length: 9.502 mi.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	-	-	-	-	-	4,500
CTS	0.059	30	46	6	1.196	48,000
AB	0.038	20	50	6	0.837	14,000
A.C.	0.016	30	71	9.5	0.539	370,000

Physiographic Province: Coastal

Pavement Modulus, Ep = 181,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km
1 ft = 0.30 m
1 in = 2.54 cm
1 psy = 0.022 kg/m^2
1000 psi = 6.894 MN/m

PROJECT SUMMARY SHEET

Project: 0105-099-101
0105-121-101, C-501

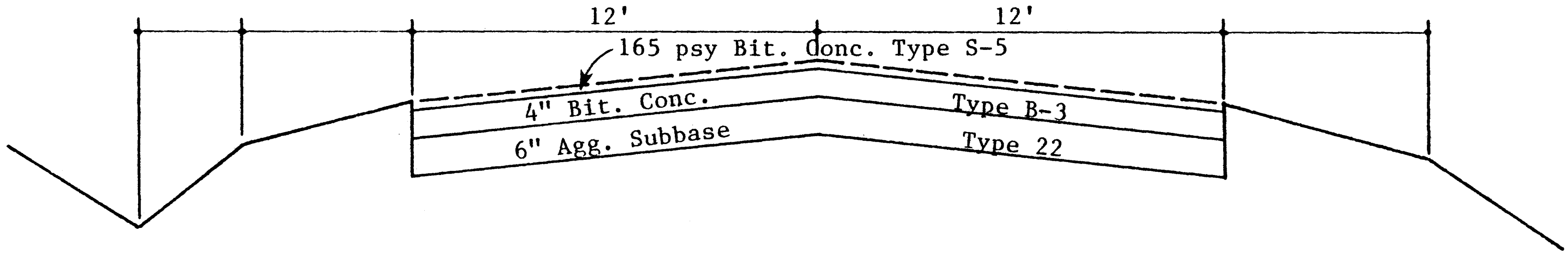
Study Project No.: 2

County: York & Newport News

Length: 3.62 mi.

From: Int. Rte. 143

To: Int. Rte. 17



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.074	15	42	-	1.374	5,600
Subbase	0.030	15	59	6	0.853	250,000
A.C.	0.032	10	47	5½	0.785	350,000

Physiographic Province: Coastal

Pavement Modulus, Ep = 300,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

PROJECT SUMMARY SHEET

Project: 0301-042-101, C-501

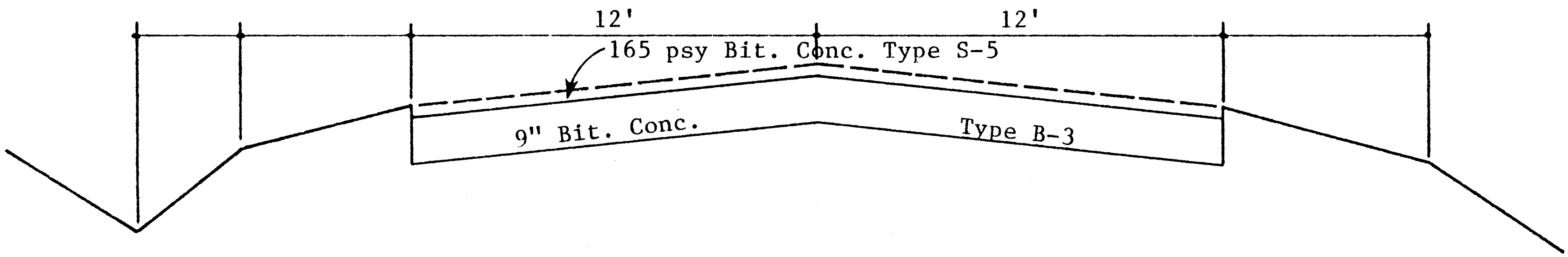
Study Project No.: 3

County: Hanover

Length: 3.547 mi.

From: 0.934 Ni. N. Henrico-Hanover C.L.

To: 4.481 Mi. N. Henrico-Hanover C.L.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.051	25	42	-	0.952	7,500
A.C.	0.017	20	70	10½	0.582	340,000

Physiographic Province: Coastal

Pavement Modulus, Ep = 340,000 psi

Remarks: Full depth asphaltic concrete.

Metric Conversions: 1 mi. = 1.61 km
1 ft. = 0.30 m
1 in. = 2.54 cm
1 psy = 0.022 kg/m^2
1000 psi = 6.894 MN/m^2

1645

PROJECT SUMMARY SHEET

Project: 0033-59-106, C-501

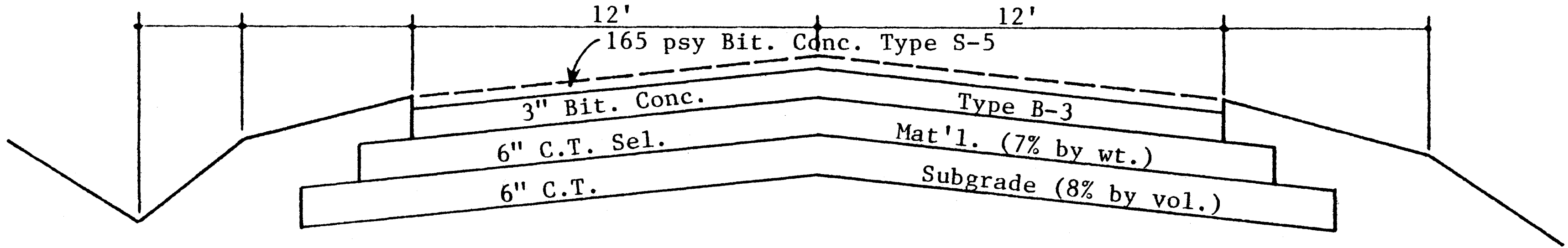
Study Project No.: 4

County: Middlesex

Length: 1.483 mi.

From: 0.131 Mi. E. Int. Rte. 227

To: 1.352 Mi. W. Int. Rte. 227



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area ($in.^2$)	Layer Modulus (psi)
Subgrade	0.033	17	46	-	0.680	8,000
C.T. Subgrade	0.048	16	46	6	0.994	92,000
C.T.S.M.	0.017	16	70	6	0.569	708,000
A.C.	0.014	17	70	4½	0.469	150,000

Physiographic Province: Coastal

Pavement Modulus, Ep = 250,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

PROJECT SUMMARY SHEET

Project: 0066-030-101, C-501

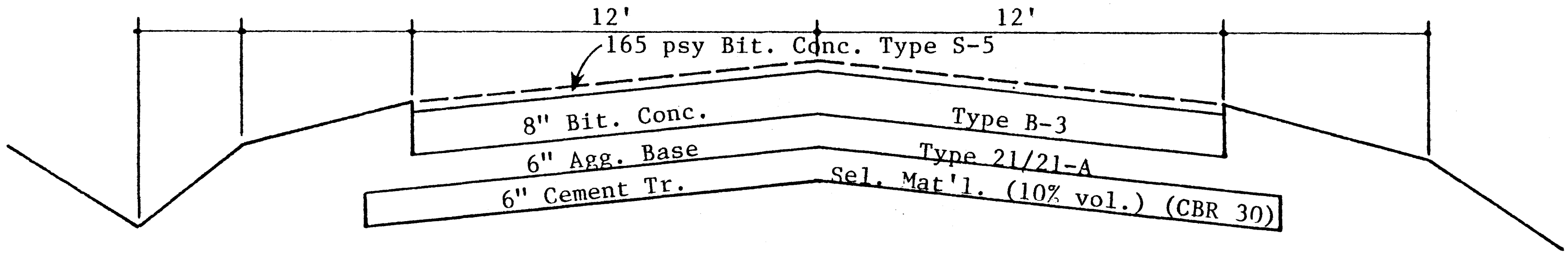
Study Project No.: 5

County: Fauquier

Length: 2.646 mi.

From: 0.304 Mi. E. Int. Rte. 17

To: 2.80 Mi E. Int. Rte. 245



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.055	15	38	-	0.903	13,000
Sel. Matl	0.036	30	43	6	0.692	68,000
C.T.S.M.	0.021	15	46	6	0.443	95,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 82,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m

PROJECT SUMMARY SHEET

Project: 0029-062-104, C-503

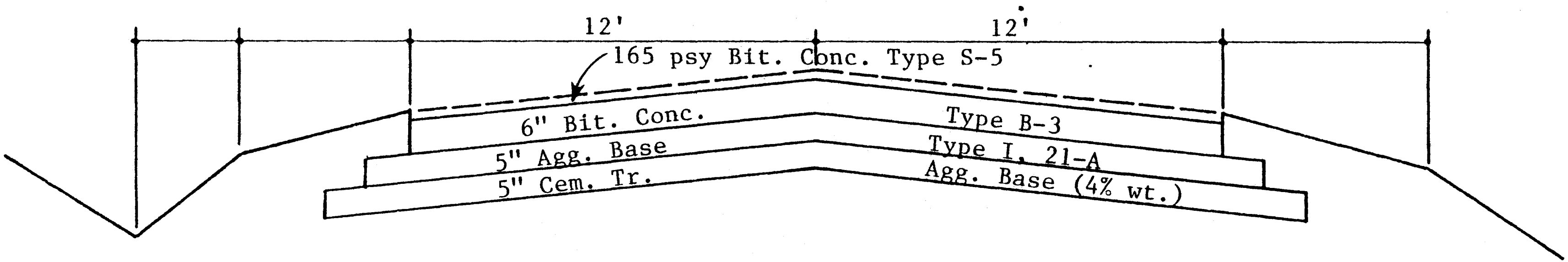
Study Project No.: 7

County: Nelson

Length: 2.155 mi.

From: 0.407 Mi. N. S. Int. Rte. 6

To: 2.155 Mi. S. Nelson-Albemarle C.L.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.072	18	40	-	1.398	7,500
C.T.S.	-	-	-	5	-	100,000
A.B.	0.0433	10	51	5	1.015	-21,000
A.C.	0.0274	10	52	7½	0.646	175,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 90,300 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 psy = 0.022 kg/m^2
1 ft. = 0.30 m; 1000 psi = 6.894 MN/m
1 in. = 2.54 cm

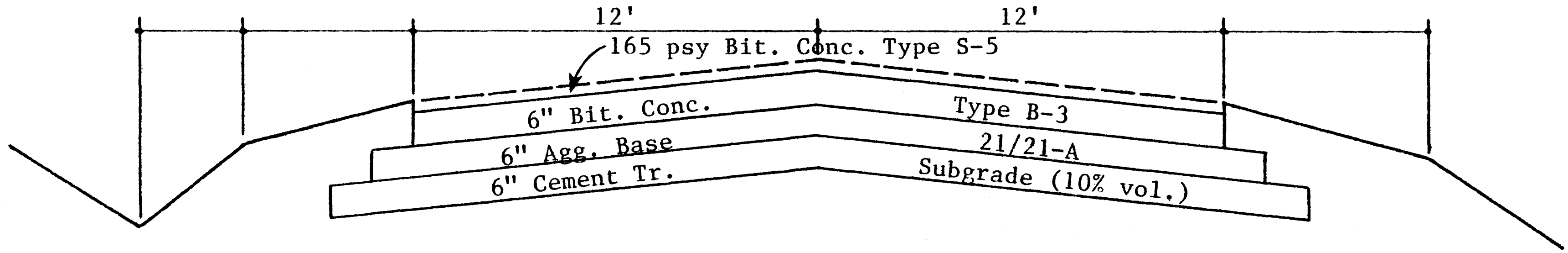
16.00

PRO CT SUMMARY SHEET

Project: 0017 J30-105, C- 1
Study Project No.: 6
County: Fa quier
Length: 4.132 mi.

From: 5.660 Mi. W. Stafford C.L.

To: 3.106 Mi. E. SRR



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area ($in.^2$)	Layer Modulus (psi)
Subgrade	0.057	30	39	-	0.952	7,800
C.T.S.	0.026	30	43	6	0.495	110,000
A.B.	0.026	30	49	6	0.586	36,000
A.C.	0.024	30	51	7½	0.575	80,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 48,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

PROJECT SUMMARY SHEET

Project: 6211-078-104, C-502

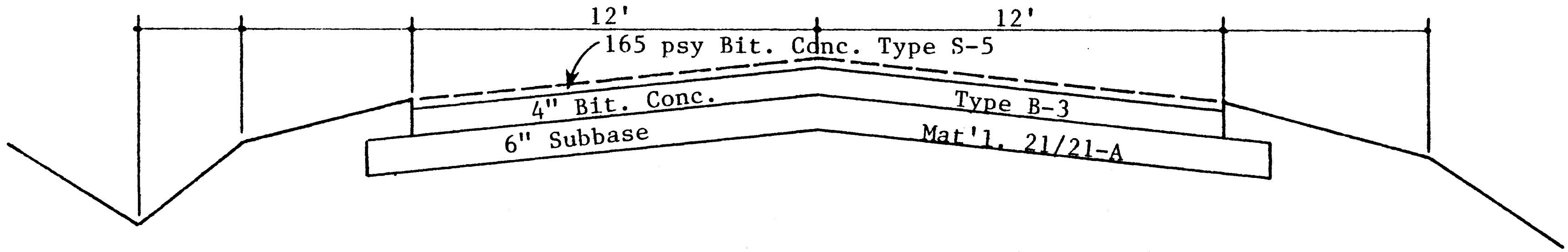
Study Project No.: 8

County: Culpeper & Rappahannock

Length: 2.394 mi.

From: 1.81 Mi. E. Culpeper-Rappahannock C.L.

To: 0.584 Mi. W. Culpeper-Rappahannock C.L.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.040	20	42	-	0.733	9,500
Subbase	-	-	-	-	-	-160,000
A.C.	0.060	20	41	4	1.087	25,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 25,000 psi

Remarks: Subbase too loose for dynaflect to test.

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

1653

PROJECT SUMMARY SHEET

Project: 0015-014-104, C-502

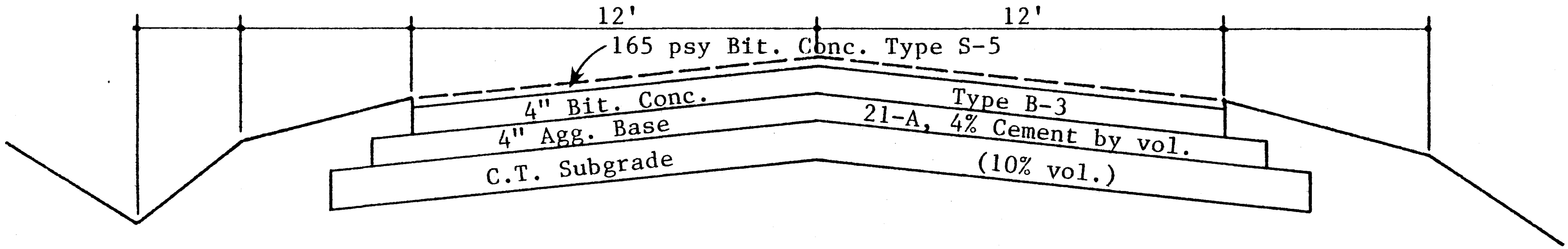
Study Project No.: 9

County: Buckingham

Length: 4.456 mi.

From: 5.566 Mi. S. Buckingham-Fluvanna C.L.

To: 0.090 Mi. S. Buckingham-Fluvanna C.L.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.059	20	43	-	1.117	7,500
CTS	0.030	20	52	6	0.720	200,000
CTA	0.026	20	56	4	0.708	50,000
A.C.	0.011	20	80	5½	0.419	1,040,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 420,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft = 0.30 m; 1 in = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

PROJECT SUMMARY SHEET

Project: 007, 017-102, P-403

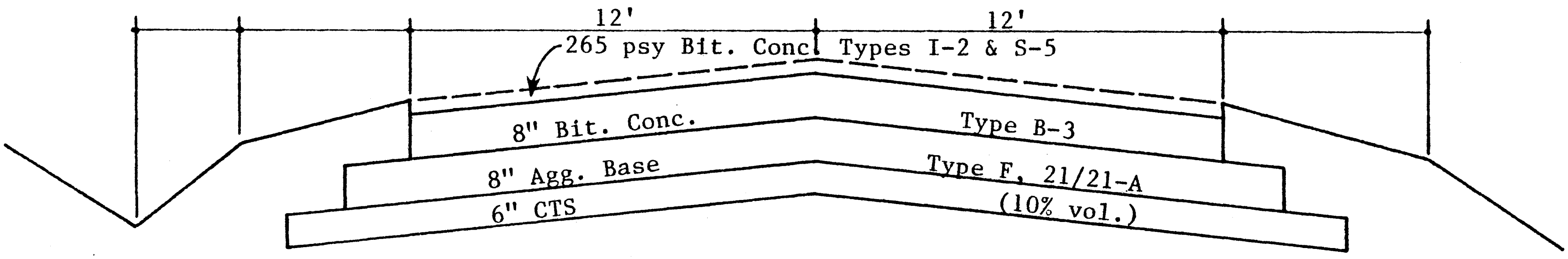
Study Project No.: 10

County: Carroll

Length: 2.881 mi.

From: 1.449 Mi. N. Int. Blue Ridge Parkway

To: 4.330 Mi. N. Int. Blue Ridge Parkway



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.062	30	41	-	0.946	8,200
CTS	0.027	30	49	6	0.612	200,000
Agg Base	-	-	-	-	-	-
A.C.	0.016	30	58	10½	0.458	106,000

Physiographic Province: Ridge & Valley

Pavement Modulus, Ep = 140,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

PROJECT SUMMARY SHEET

Project: 0058-017-103, C-501

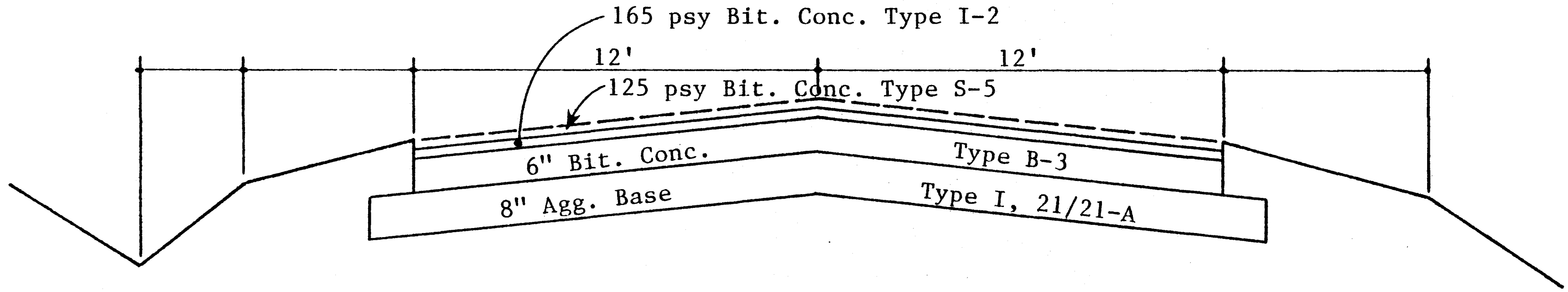
From: 0.356 Mi. E. Int. NBL Rte. 77

To: 0.377 Mi. W. WCL Hillsville

Study Project No.: 11

County: Carroll

Length: 1.178 mi.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area ($in.^2$)	Layer Modulus (psi)
Subgrade	0.163	12	39	-	1.881	2,500
Agg Base	0.202	25	52	8	4.855	10,000
A.C.	0.082	15	56	8 3/4	2.162	39,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 125,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

1654

PROJECT SUMMARY SHEET

Project: 005(038-102, P 03

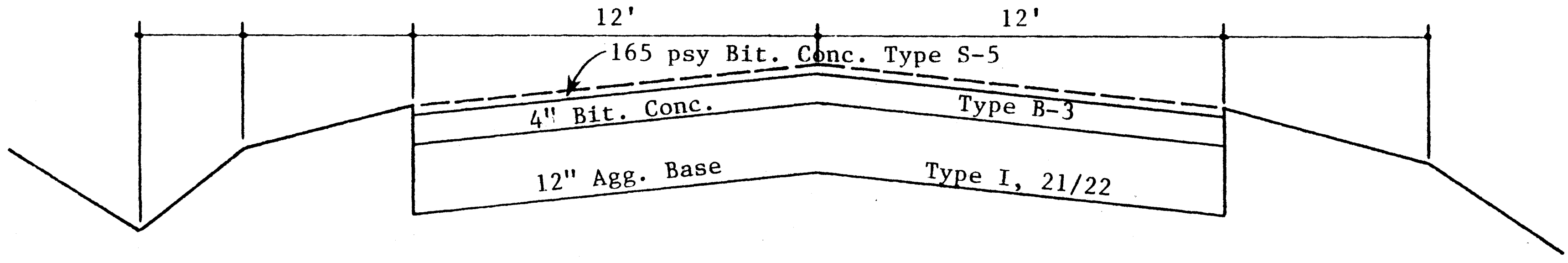
County: G ayson

Study Project No.: 12

Length: 5.532 mi.

From: 1.928 Mi. E. ECL Independence

To: 4.438 Mi. W. WCL Galax



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.057	15	45	-	1.161	8,000
A.B.	0.031	30	54	12	0.777	65,000
A.C.	0.019	30	63	5½	0.565	161,000

Physiographic Province: Piedmont

Pavement Modulus, Ep = 89,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

1656

PROJECT SUMMARY SHEET

Project: 6037-034-101, P-401

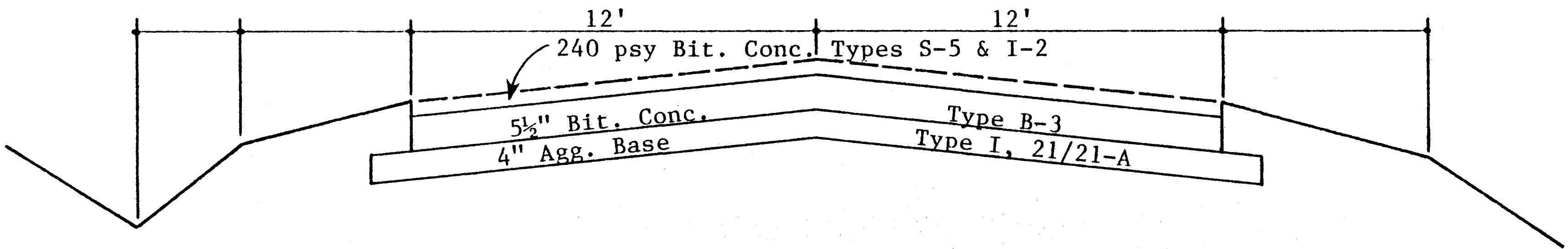
Study Project No.: 13

County: Frederick

Length: 5.165 mi.

From: 0.067 Mi. N. Int. Rte. 81

To: 0.133 Mi. N. Int. Rte. 50



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.031	10	40	-	0.538	14,000
A.B.	0.018	30	50	4	0.407	50,000
A.C.	0.013	30	49	8	0.312	186,000

Physiographic Province: Ridge & Valley

Pavement Modulus, Ep = 139,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m

PROJECT SUMMARY SHEET

Project: 0019-[illegible]3-107, C-5[illegible]

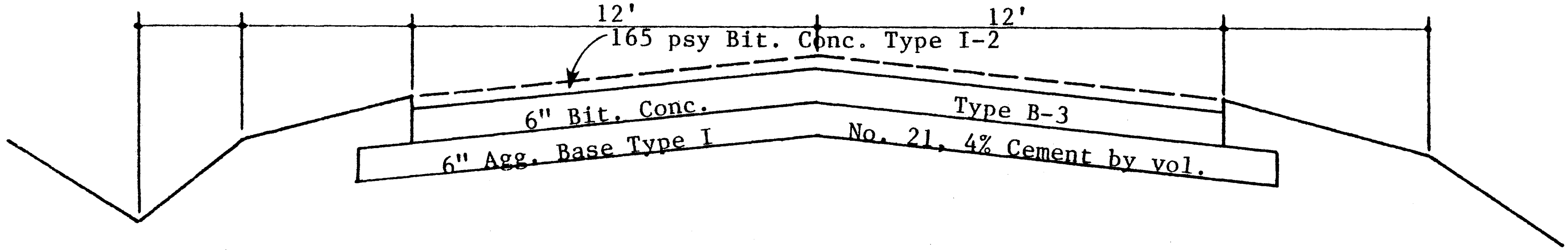
Study Project No.: 14

County: Russell

Length: 1.806 mi.

From: 0.764 Mi. E. Int. Rte. 80

To: 2.570 Mi. E. Int. Rte. 80



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.022	15	45	-	0.442	13,000
CTB	0.038	30	48	6	0.819	130,000
A.C.	0.015	30	59	7½	0.535	610,000

Physiographic Province: Ridge & Valley

Pavement Modulus, Ep = 370,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

PROJECT SUMMARY SHEET

Project: 0064-003-104, P-303

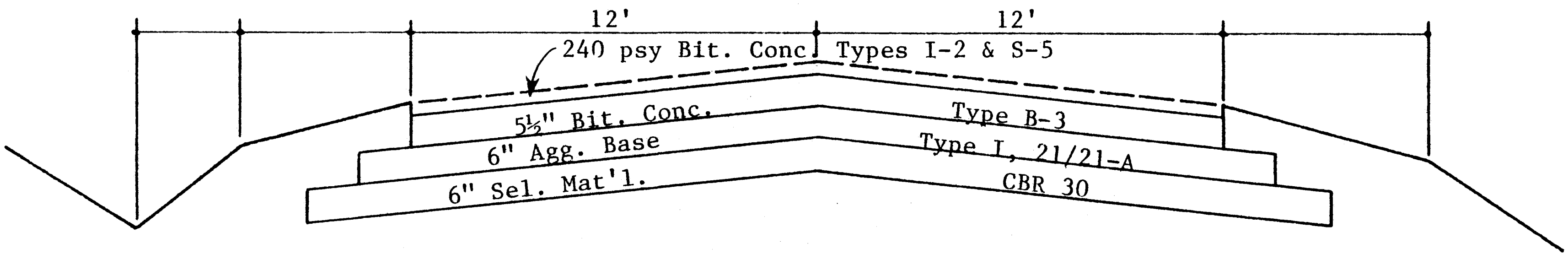
Study Project No.: 15

County: Alleghany

Length: 7.00 mi.

From: 0.49 Mi. W. Rte. 60

To: Alleghany-Rockbridge C.L.



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.020	30	44	-	0.423	13,000
CBR-30	0.034	30	38	6	0.586	50,000
A.B.	0.015	30	48	6	0.343	210,000
A.C.	0.014	30	51	8	0.332	39,000

Physiographic Province: Ridge & Valley

Pavement Modulus, Ep = 95,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m

PROJECT SUMMARY SHEET

Project: 0460-035-113, P-[illegible]04

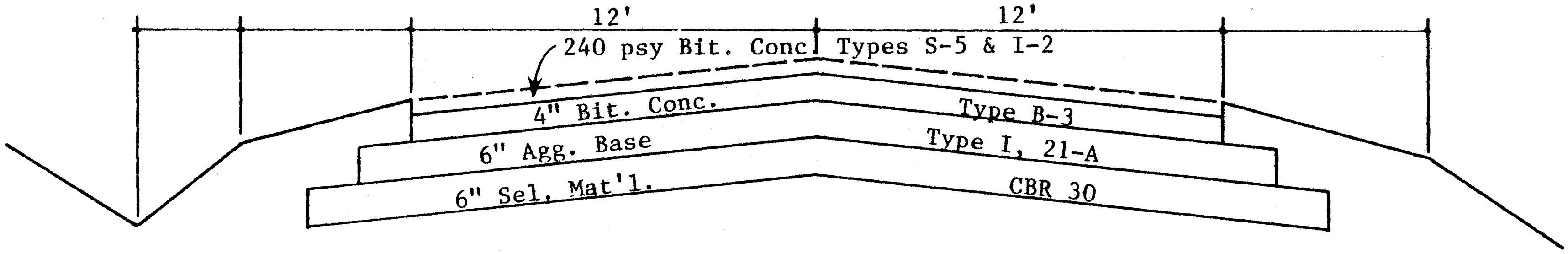
County: Giles

Study Project No.: 16

Length: 1.890 mi.

From: 2.247 Mi. E. ECL Pembroke

To: 4.137 Mi. E. ECL Pembroke



Layer	Deflection (1/1000 in.)	No. Tests	Spreadability	Thickness (in.)	Deflected Area (in.^{2})	Layer Modulus (psi)
Subgrade	0.028	17	44	-	0.559	10,000
CBR-30	0.018	10	37	6	0.283	65,000
A.B.	-	-	-	-	-	50,000
A.C.	0.020	30	57	6½	0.526	170,000

Physiographic Province: Ridge & Valley

Pavement Modulus, Ep = 97,000 psi

Remarks:

Metric Conversions: 1 mi. = 1.61 km; 1 ft. = 0.30 m; 1 in. = 2.54 cm; 1 psy = 0.022 kg/m^2; 1000 psi = 6.894 MN/m^2

16[illegible]