TENSILE AND ELASTIC CHARACTERISTICS OF BLACK-BASE MATERIALS

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This paper summarizes the findings of a study conducted to evaluate the tensile strength, modulus of elasticity, and Poisson's ratio of black-base materials and to determine the variations in these properties for use in elastic and stochastic pavement design systems. Field cores of black-base materials from 10 recently completed highway pavement projects in Texas were tested by using the indirect tensile test. Mean values for the tensile and elastic properties were established, and the variation about these mean values was estimated. The average tensile strength, modulus of elasticity, and Poisson's ratio for all 10 projects were 105 psi (723.95 kN/m^2), 58.2 $\times$ 10^3 psi (401.28 $\times$ 10^3 kN/m^2), and 0.27 respectively; however, the mean values for the individual projects varied considerably. Tensile strengths ranged from 84 to 157 psi (579.16 to 1082.48 kN/m^2), moduli ranged from 38.6 $\times$ 10^3 to 91.5 $\times$ 10^3 psi (266.14 $\times$ 10^3 to 630.87 $\times$ 10^3 kN/m^2), and Poisson's ratios ranged from 0.16 to 0.34. Significant variation also occurred in each project, and the magnitude of this project variation differed. The average coefficients of variation for the 10 projects were 23 percent for strength, 33 percent for modulus, and 25 percent for Poisson's ratio. The ranges of project coefficients for strength, modulus, and Poisson's ratio were 14 to 27 percent, 24 to 59 percent, and 38 to 67 percent respectively. Because of the significant project differences, it was concluded that a single variation value could not be established for the state and that characteristic values were project dependent.

•MOST current pavement design procedures are empirical and deterministic; they use exact values of input and present the results as exact values. At a 1970 workshop on the structural design of asphalt pavements (1), 1 of the areas of research considered the most pressing was the application of probabilistic or stochastic concepts to pavement design. The workshop stated the problem as follows:

> So that designers can better evaluate the reliability of a particular design, it is necessary to develop a procedure that will predict variations in the pavement system response due to statistical variations in the input variables, such as load, environment, pavement geometry, and material properties including the effects of construction and testing variables. As part of this research it will be necessary to include a significance study to determine the relative effect on the system response of variations in the different input variables.

Other researchers (2) also have pointed out the need to apply probabilistic or stochastic concepts to the design parameters of design models. Current research at the Center for Highway Research has developed a design procedure for flexible pavements (3, 4, 5, 6). Trial use of this design system by the Texas Highway Department revealed a definite need to consider the random nature of many of the input variables to estimate design reliability, that is, the probability that the pavement system will perform its intended function over its design life and under the conditions encountered (2).

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In response to this need, a theory and procedures have been developed based on classic reliability theory that will allow probabilistic design concepts to be applied to flexible pavement design (2). The method makes it possible to design for a desired level of reliability through the consideration of the variabilities and uncertainties associated with pavement design. The probabilistic theory has been applied to the Texas flexible pavement system, which was originally a deterministic model.

The state of the art has advanced to the point where, in addition to considering the stochastic nature of input variables, the theory of elasticity should be applied to design (7). The first step in this direction is determining the elastic and tensile properties of pavement materials in the roadway. If at the same time an estimate is made of the variations in these properties from point to point in the pavement and for different locations in the state, then a flexible pavement design system based on elastic theory and incorporating stochastic considerations can be developed and implemented. The purpose of this paper is to summarize the findings of a study to estimate the magnitude of the tensile and elastic properties and the variation of these properties for black-base materials from actual pavements in Texas.

EXPERIMENTAL PROGRAM

The principal objectives of this investigation were

1. To characterize black-base materials by tensile and elastic properties, specifically by tensile strength, Poisson's ratio, and modulus of elasticity and
2. To estimate the variation in these properties that can be expected for an in-place pavement, but not necessarily to establish the cause of the variation.

To accomplish these objectives, field cores of black-base materials from 10 recently completed highway pavement projects in Texas were tested by using the indirect tensile test. Mean values for the tensile and elastic properties were established, and the variation about these mean values was estimated. The density of the black-base material also was estimated, and the variations about the means were computed.

The total variation for the elastic and tensile characteristics is composed of many parts. There is inherent material variation, and some testing error, which is the variation that would occur when replicate specimens are prepared and tested under closely controlled laboratory conditions. In field construction additional variation probably would be introduced because the construction process is relatively uncontrolled. Additional variation also may be introduced during construction because of inherent material variation as well as variation caused by the environment, changes in the constituents of the mix, changes in contractor or construction technique, and other factors. Both horizontal and vertical pavement variations will occur. For example, there could be differences between the various lifts of black-base and asphalt concrete; these differences would be of interest because the lower portion of a pavement layer is subjected to the highest load-induced tensile stresses.

To estimate the variation introduced by construction, we obtained core samples from a small area in each pavement. The scatter in test results from this "clustered" sample would then provide an estimate of the variation caused by construction, the inherent variation of the material, and testing. The total variation was estimated from the variation in test results for cores taken along each roadway and for cores from different projects. To estimate the properties and variation differences that occur vertically or between layers, each core was sawed to produce specimens from each layer in the core.

Projects Tested and Core Sampling

A summary of the projects tested is given in Table 1. Figure 1 shows the geographical distribution of the Texas Highway Department districts from which the pavement cores were obtained. As given in Table 1, various black-base materials and different aggregates and asphalt were tested.

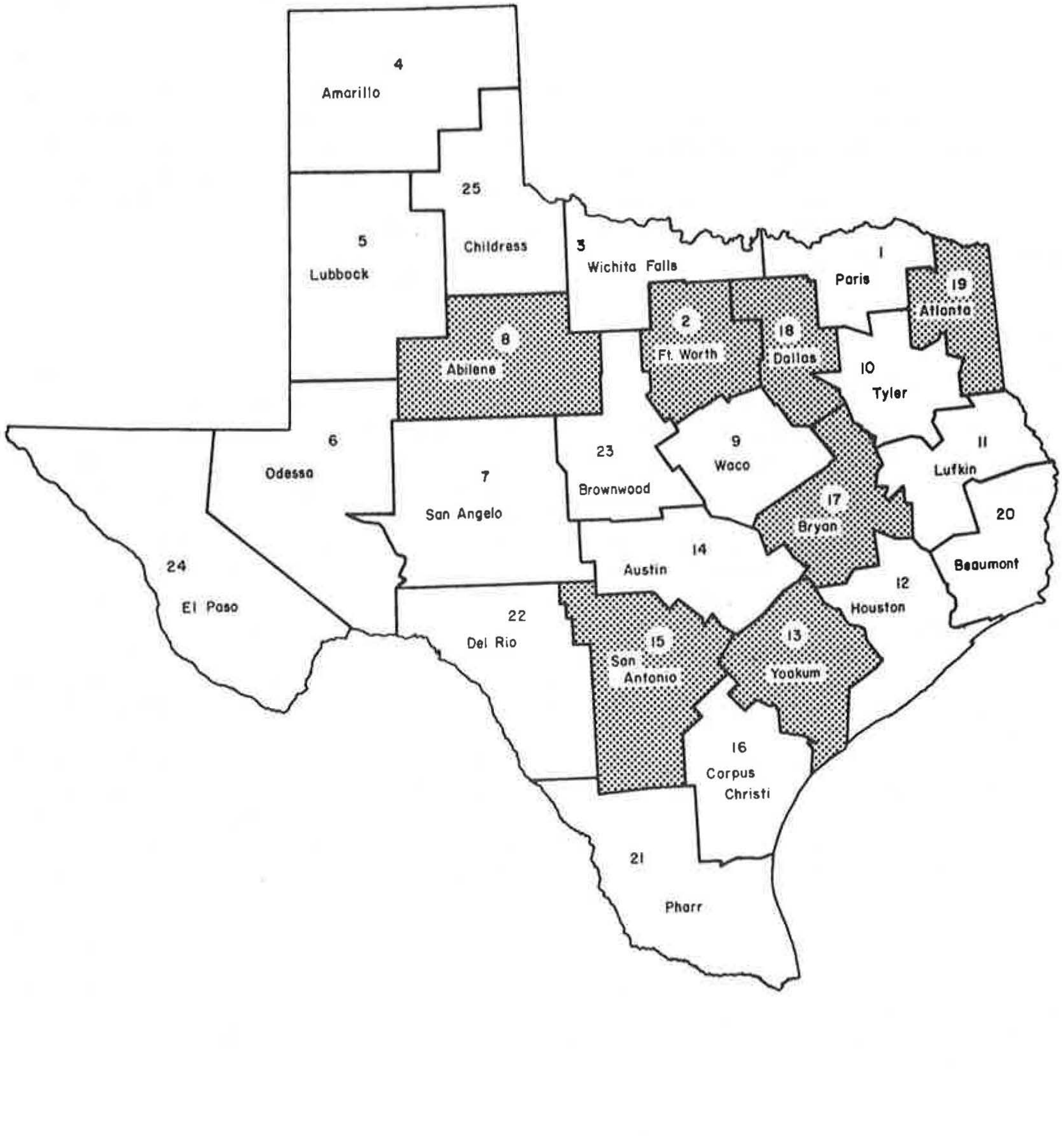
Originally, it was planned that a small number of cores would be taken from selected paving projects throughout Texas. However, the Texas Highway Department routinely

Table 1. Description of black-base projects.

District and Project	Cores	Specimens	Distance (miles)	Asphalt Type	Asphalt Weight Percent	Aggregate
2-A	38	76	15.0	AC-20	5.5	Crushed limestone, field sand
8-A	11	16	3.3	AC-20	5.5 to 6.2	Crushed limestone, sand, gravel
13-A	11	14	8.0	AC-20	4.2	Pit-run gravel
13-B	19	28	4.3	AC-20	4.0 to 4.9	Pit-run gravel
13-C	13	16	3.0	AC-20	4.0 to 4.4	Pit-run gravel
15-A	27	49	10.9	AC-10	5.1	Pit-run gravel
17-B	50	100	19.1	AC-10	4	Brazos River gravel
				AC-20	4	Brazos River gravel
18-B	6	12	0.9	AC-20	5.5 to 6.5	Pea gravel, field sand
19-A	22	54	19.3	AC-20	4.8 to 5.6	Gravel, crushed slag, sand
19-B	18	36	15.2	AC-20	4.3 to 6.4	Gravel, crushed slag, sand

Note: 1 mile = 1.6 km.

Figure 1. Texas highway districts from which black-base cores were obtained.



takes a large number of cores from newly completed pavements to determine pavement thickness. Because more information could be obtained by testing these cores than by testing a smaller number of cores taken solely for this study, arrangements were made with the Texas Highway Department to obtain cores from recently constructed pavements that had not been subjected to traffic.

As shown in Figure 2, the Texas Highway Department normally cores black-base pavement layers at regular intervals. But, when a section of pavement is encountered in which the thickness is less than design thickness, cores are taken at smaller regular intervals until the thickness reaches design thickness. Then, cores are taken at the larger intervals. These samples obtained in a systematic fashion can be considered random because the sampling does not coincide with any variation distribution that may exist in the pavement.

One method of estimating the additional variation that results from construction would be to test cores clustered in the pavement. Considering the total length of a project, a group of cores obtained at very small intervals approximates a cluster and is the most economical approach for obtaining cores for most projects. Along-the-road variation (variation during construction that results from changes in pit source, weather, and the like) may be estimated from the cores obtained at large intervals.

Specimen Preparation

Both 4-in. (101.6-mm) and 6-in. (152.4-mm) black-base cores were tested. The cores were sawed at the interface between lifts; thus, each specimen represented 1 lift. Each specimen was approximately 2 in. (50.8 mm) thick. The paving projects were multilane roadways in which the 2 main directional lanes (for example, northbound and southbound) were treated as separate roadways. In addition, the various lifts were considered as separate roadways because they were constructed at different times during construction.

Before testing, we measured and weighed the specimen to estimate density.

Method of Test

The tensile and elastic properties of the paving materials were estimated by using the indirect tensile test procedure originally recommended by Hudson and Kennedy (8) and later modified slightly by Hadley, Hudson, and Kennedy (9). The test involved loading a cylindrical specimen with compressive loads that acted along the vertical diametral plane as shown in Figure 3. To distribute the load and maintain a constant loading area, the compressive load was applied through a ½-in.- (12.7-mm-) wide steel loading strip, which was curved at the strip-specimen interface and had a radius of curvature equal to the radius of the specimen. The loading configuration shown in Figure 3 gave a relatively uniform tensile stress perpendicular to the direction of the applied load that ultimately caused the specimen to fail by splitting or rupturing along the vertical diameter. By measuring the applied load at failure and by continuously monitoring the loads and the horizontal and vertical deformations of the specimen, the tensile strength, Poisson's ratio, and modulus of elasticity of the specimen could be estimated.

The basic test equipment used in this study was the same as that previously used at the University of Texas (9, 10) and included a loading system and a means of monitoring the applied loads, the horizontal deformation of the specimen, and the vertical deformation of the specimen (Fig. 4). In this study, a closed loop electrohydraulic system was used to accurately control the deformation rate of 2 in. (50.8 mm) per min. All tests were conducted at a room temperature of approximately 75 F (23.9 C).

The loading device that was used in this study was a modified, commercially available die set with upper and lower platens constrained to remain parallel during the test. Mounted on the upper and lower platens were ½-in.- (12.7-mm-) wide curved steel loading strips. The load was monitored with a load cell to obtain electrical readouts that could be recorded continuously. A device consisting of 2 cantilevered arms with strain gauges attached measured horizontal deformations. A direct-current, linear variable differential transformer measured vertical deformations and controlled the vertical

Figure 2. Typical core sampling plan.

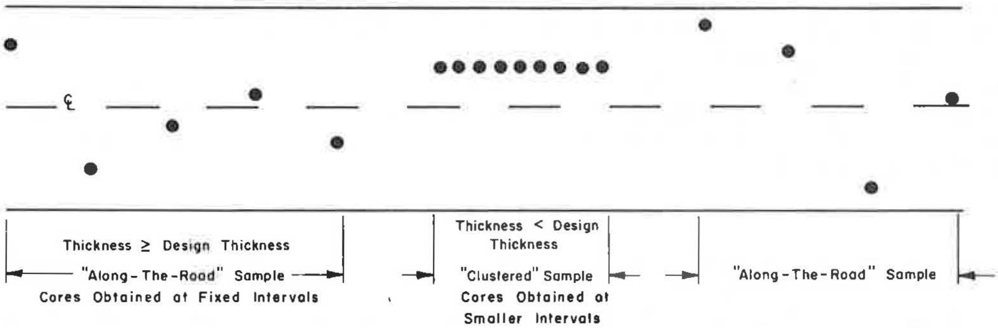


Figure 3. Specimen failing under compressive load.

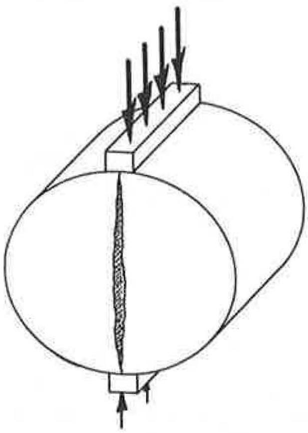
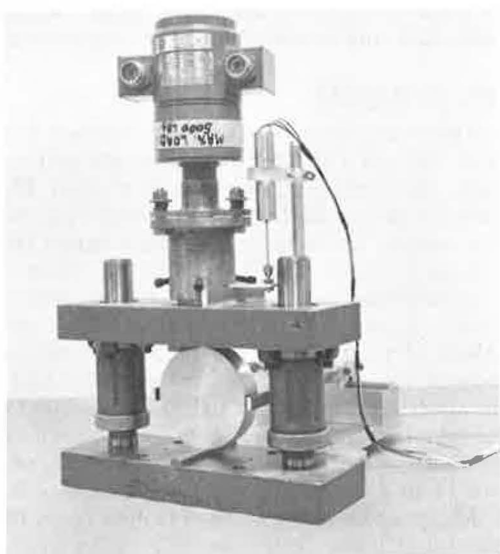


Figure 4. Indirect tensile test equipment.



deformation rate during the test by providing an electrical signal related to the movement between the upper and lower platens. The loads and deformations were monitored by 2 X-Y plotters; 1 recorded load and horizontal deformation and 1 recorded load and vertical deformation. Points picked from the X-Y plots were used as input for computer program MODLAS 9, which was developed at the Center for Highway Research to calculate the tensile and elastic properties of materials tested by the indirect tensile test. Included in the printout were estimates of Poisson's ratio, modulus of elasticity, tensile strength, and density for each specimen tested.

ANALYSIS AND EVALUATION

Summaries of the test results for the 10 black-base projects are given in Tables 2, 3, and 4; only 1 of the projects had clustered samples. The parameters estimated by using the indirect tensile test were tensile strength, modulus of elasticity, and Poisson's ratio. Density was estimated by measuring the dimensions and weight of the specimens.

One of the objectives of this study was to obtain an estimate of the variation in material properties existing in a highway pavement; the coefficient of variation, V (the sample standard deviation divided by the sample mean), was used because it related the variation to the mean. For the coefficient of variation to be a valid and meaningful test statistic, it must be assumed that the material property being analyzed is normally distributed about some mean value. Studies have shown that the variability of highway materials and properties follows a normal distribution (2, 7, 11).

Tensile Strength

The mean tensile strengths (Tables 2 and 3) for the various projects ranged from 53 to 157 psi (365.42 to 1082.48 kN/m^2) and averaged 102 psi (703.27 kN/m^2). The lower extreme value was from project 13, which produced very rough cores that were difficult to test and which may have produced low strength values. If project 13 is eliminated, the tensile strengths range from 84 to 157 psi (579.16 to 1082.48 kN/m^2) with an average of 105 psi (723.95 kN/m^2).

In addition to the fact that the various black-base materials were composed of different aggregates and asphalts and had different strengths, as indicated by the coefficient of variation of the means (27 percent with project 13 and 23 percent without project 13), the various projects also had different coefficients of variation. Thus, the coefficients for the individual projects are more meaningful than the overall coefficient of variation. These coefficients ranged from 14 to 40 percent and averaged 26 percent. After eliminating project 13, which exhibited larger variations, the range was 14 to 27 percent with an average of 21 percent.

Many specimens were obtained from the same core by sawing specimens from the individual lifts. Because these lifts were placed at different times, these specimens can be considered to be independent of each other. On the other hand, the properties of the material in the lifts at any given location determine the behavioral characteristics of the pavement at that location. Thus, a comparison was made to determine whether there were strength differences between layers. This comparison indicated that there was no significant difference in the tensile strength of the specimens from the various layers at a confidence level of 95 percent.

Table 4 gives the results of the analysis of the clustered samples for the 1 project that had a significant number of cores for analysis. It can be seen from Table 4 that although the mean tensile strengths essentially were unchanged, the variation for the clustered samples generally was reduced. However, because of the limited number of comparisons, no definite conclusion can be made.

Modulus of Elasticity

Mean modulus values (Tables 2 and 3) varied from 35.0×10^3 to 91.5×10^3 psi (241.32×10^3 to 630.87×10^3 kN/m^2) and averaged 58.8×10^3 psi (405.42×10^3 kN/m^2). The coefficient of variation of the mean modulus values was 36 percent indicating project differences. Eliminating project 13 did not significantly change these values, which varied from

Table 2. Test results for black-base projects.

District and Project	Specimens	Distance (miles)	Tensile Strength Mean (psi)	Tensile Strength V (percent)	Modulus of Elasticity Mean (10^3 psi)	Modulus of Elasticity V (percent)	Poisson's Ratio Mean	Poisson's Ratio V (percent)	Density Mean (pcf)	Density V (percent)
2-A	76	15.0	84	20	38.6	32	0.34	39	127.0	2.4
8-A	16	3.3	112	14	91.5	29	0.28	40	138.4	2.6
13-A	14	8.0	87	40	44.9	46	0.16	58	—[a]	—[a]
13-B	28	4.3	104	36	87.3	62	0.16	73	—[a]	—[a]
13-C	16	3.0	53	40	35.0	40	0.26	57	—[a]	—[a]
15-A	49	10.9	157	17	86.1	59	0.23	47	140.4	2.2
17-B	100	19.1	105	27	55.2	44	0.24	41	136.0	2.3
18-B	12	0.9	107	25	42.2	24	0.20	64	135.1	2.3
19-A	54	19.3	95	20	55.2	33	0.32	38	141.6	1.7
19-B	36	15.2	88	21	64.7	34	0.16	67	136.1	3.6

Note: 1 mile = 1.6 km. 1 psi = 6.9 kN/m^2. 1 pcf = 16 kg/m^3.

[a]Not attainable.

Table 3. Summary of Table 2 test results.

Item	Tensile Strength Mean (psi)	Tensile Strength V (percent)	Modulus of Elasticity Mean (10^3 psi)	Modulus of Elasticity V (percent)	Poisson's Ratio Mean	Poisson's Ratio V (percent)	Density Mean (pcf)	Density V (percent)
Weighted average								
With project 13	102	26	58.8	40	0.25	52	–	–
Without project 13	105	21	58.2	36	0.27	48	–	2.4
Range								
With project 13	104	26	56.5	38	0.18	35	–	–
Without project 13	73	13	52.9	35	0.18	29	–	1.9
V of Means, percent								
With project 13	27	–	36	–	28	–	–	–
Without project 13	23	–	33	–	25	–	–	–

Note: 1 psi = 6.9 kN/m^2. 1 pcf = 16 kg/m^3.

Table 4. Clustered and along-the-road test results for district 15, project 15-A.

Sample	Specimens	Distance	Tensile Strength Mean (psi)	Tensile Strength V (percent)	Modulus of Elasticity Mean (10^3 psi)	Modulus of Elasticity V (percent)	Poisson's Ratio Mean	Poisson's Ratio V (percent)	Density Mean (pcf)	Density V (percent)
Along the road	49	10.9 miles	157	17	86.1	59	0.23	47	140.4	2.2
Cluster 1	7	250 feet	146	11	73.2	42	0.21	44	141.7	1.2
Cluster 2	6	250 feet	151	18	71.6	36	0.31	41	140.2	2.9
Cluster 3	7	250 feet	159	9	75.8	20	0.33	24	142.0	0.8

Note: 1 psi = 6.9 kN/m^2. 1 pcf = 16 kg/m^3. 1 mile = 1.6 km. 1 ft = 0.3 m.

38.6×10^3 to 91.5×10^3 psi (266.14×10^3 to 630.87×10^3 kN/m^2) and averaged 58.2×10^3 psi (401.28×10^3 kN/m^2). Coefficients of variation within projects ranged from 24 to 62 percent and averaged 40 percent. After eliminating project 13, the coefficients ranged from 24 to 59 percent and the average was reduced to 36 percent. A comparison of the moduli of the layers comprising a given core indicated no significant differences existed between layers at a confidence level of 95 percent.

An analysis of the clustered samples (Table 4) indicates that the variation of modulus values for the clustered samples was reduced. But as with tensile strength it is felt that no definite conclusion could be made.

Poisson's Ratio

Mean Poisson's ratio values (Tables 2 and 3) ranged from 0.16 to 0.34 and averaged 0.25 with project 13 and 0.27 without project 13. The coefficient of variation of these means was 25 percent, which was approximately the same magnitude as the coefficient for strength. The variation in Poisson's ratio for each project was large, ranging from 39 to 73 percent with an average of 52 percent. With the elimination of project 13, the range was 39 to 67 percent and the average was reduced to 48 percent. This large range of coefficients probably resulted because the Poisson's ratio is very sensitive to small errors in the deformation measurements. Once again the comparison of values from the layers comprising a core indicated no significant differences between layers; the analysis of clustered samples (Table 4) indicated that the variation was reduced although the mean values for the clusters varied.

Density

A comparison of the mean densities for each project (Tables 2 and 3) has no meaning because different aggregates were used. The coefficients of variation of the densities for each project were generally small; they ranged from 1.7 to 3.6 and averaged 2.4 percent. The magnitudes of these variations were consistent with values reported from previous studies (12), which indicated low coefficients of variation for density.

General Discussion

The following values and ranges are based on the results of this study:

1. Average tensile strength was 105 psi (723.95 kN/m^2) in a range from 84 to 157 psi (579.16 to 1082.48 kN/m^2);
2. Average modulus of elasticity was 58.2×10^3 psi (401.28×10^3 kN/m^2) in a range from 38.6×10^3 to 91.5×10^3 psi (266.14×10^3 to 630.87×10^3 kN/m^2); and
3. Average Poisson's ratio was 0.27 in a range from 0.16 to 0.34.

For design purposes, estimates of variation also must be obtained for each property. The coefficient of variation for various projects ranged from 14 to 27 percent for tensile strength, 24 to 59 percent for modulus of elasticity, and 38 to 67 percent for Poisson's ratio. This large range of values coupled with the different mean values indicates that the amount of variation is project dependent and that a given value cannot be assigned for the state.

The coefficients of variation as given in Table 4 for tensile strength, modulus of elasticity, and Poisson's ratio for the clustered samples were somewhat smaller than for the along-the-road sample, indicating that additional variation was introduced by along-the-road changes. But, because of the limited number of projects, no definite conclusions could be made.

These estimates of variation included a number of components such as testing, inherent, construction, and along-the-road variation. Ideally, estimates of these components should be made to separate the variation for testing and sampling from that for material and construction because testing and sampling variation should not enter into design considerations. Results from previous studies (13) indicated that at least 50 percent or more of overall variation could be assigned to sampling and testing. Thus, for design purposes it might be desirable to reduce the magnitude of the variance.

The reduction probably should be greater for modulus and Poisson's ratio than for strength because additional error is introduced in deformation measurements.

CONCLUSIONS

General

Because the projects were different, and because different types of asphalt and aggregate were used, the coefficients of variation for individual projects were more meaningful than an overall coefficient for all projects. Very little variation in density (generally less than 3 percent) was encountered. Results of the clustered sample analyses indicated that additional variation was introduced along the roadway, but no definite conclusions could be made without additional investigation involving a more carefully designed core sampling plan to obtain clustered samples.

Tensile Strength

Mean tensile strength values varied from 84 to 157 psi (579.16 to 1082.48 kN/m^2) and averaged 105 psi (723.95 kN/m^2). The coefficient of variation of the mean values was 23 percent. No significant differences in tensile strength were found between the various layers or lifts at a confidence level of 95 percent. The within-project coefficients of variation were moderate; they ranged from 14 to 27 percent and averaged 21 percent.

Modulus of Elasticity

Mean modulus values varied from 38.6×10^3 to 91.5×10^3 psi (266.14×10^3 to 630.87×10^3 kN/m^2) and averaged 58.2×10^3 psi (401.28×10^3 kN/m^2). The coefficient of variation of the mean modulus values was 33 percent, which was slightly higher than that for tensile strength.

No significant differences in modulus of elasticity were found between the various layers or lifts at a confidence level of 95 percent. Coefficients of variation for each project ranged from 24 to 59 percent and averaged 36 percent.

Poisson's Ratio

Mean Poisson's ratio values ranged from 0.16 to 0.34 and averaged 0.27. The coefficient of variation of the mean values was 25 percent, which was approximately equal to those obtained for strength and modulus. Coefficients of variation for each project ranged from 38 to 67 percent and averaged 48 percent.

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REFERENCES

1. Structural Design of Asphalt Concrete Pavement Systems. HRB Spec. Rept. 126, 1971, 207 pp.
2. Darter, M. I., and Hudson, W. R. Probabilistic Design Concepts Applied to Flexible Pavement System Design. Texas Highway Department, Austin; Texas Transportation Institute, Texas A&M Univ., College Station; and Center for Highway Research, Univ. of Texas at Austin, Prelim. Res. Rept. 123-18, May 1973.
3. Hudson, W. R., McCullough, B. F., Scrivner, F. H., and Brown, J. L. A Systems Approach Applied to Pavement Design and Research. Texas Highway Department, Austin; Texas Transportation Institute, Texas A&M Univ., College Station; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-1, March 1970.

4. Brown, J. L., Buttler, L. J., and Orellana, H. E. A Recommended Texas Highway Department Pavement Design System User's Manual. Texas Highway Department, Austin; Texas Transportation Institute, Texas A&M Univ., College Station; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-2, March 1970.
5. Haas, R. C. G. Developing a Pavement Feedback Data System. Texas Highway Department, Austin; Texas Transportation Institute, Texas A&M Univ., College Station; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-4, Feb. 1971.
6. Strom, O. G., Hudson, W. R., and Brown, J. L. A Pavement Feedback Data System. Texas Highway Department, Austin; Texas Transportation Institute, Texas A&M Univ., College Station; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-12, May 1972.
7. McCullough, B. F., Brown, J. L., Hudson, W. R., and Scrivner, F. H. Annual Report to Area III Research Advisory Committee on Important Pavement Research Needs, 1970-1971. Texas Highway Department, Austin; Texas Transportation Institute, Texas A&M Univ., College Station; and Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 123-7, April 1971.
8. Hudson, W. R., and Kennedy, T. W. An Indirect Tensile Test for Stabilized Materials. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 98-1, Jan. 1968.
9. Hadley, W. O., Hudson, W. R., and Kennedy, T. W. Evaluation and Prediction of the Tensile Properties of Asphalt-Treated Materials. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 98-9, May 1971.
10. Hadley, W. O., Hudson, W. R., and Kennedy, T. W. A Method of Estimating Tensile Properties of Materials Tested in Indirect Tension. Center for Highway Research, Univ. of Texas at Austin, Res. Rept. 98-7, July 1970.
11. Sherman, G. B. In Situ Materials Variability. HRB Spec. Rept. 126, 1971, pp. 180-188.
12. The AASHO Road Test: Report 2—Materials and Construction. HRB Spec. Rept. 61B, 1962.
13. McMahon, T. F., and Halstead, W. J. Quality Assurance in Highway Construction: Part 1—Introduction and Concepts. Public Roads, Vol. 35, No. 6, Feb. 1969, pp. 129-134.