CORRELATION OF TENSILE PROPERTIES WITH STABILITY AND COHESIOMETER VALUES FOR ASPHALT-TREATED MATERIALS

by

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Evaluation of Tensile Properties of Subbases
for Use in New Rigid Pavement Design

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PREFACE

This is the sixth report in a series of reports emanating from Project 3-8-66-98, "Evaluation of Tensile Properties of Subbases for Use in New Rigid Pavement Design." This report is slightly different from previous ones in that it attempts to show the relationship between tensile properties of asphalt-treated materials and the traditional tests conducted on these materials by the Texas Highway Department, including the Hveem stabilometer and cohesiometer tests. As the study of tensile properties and their use in design becomes more prevalent, it may be desirable to be able to estimate tensile properties from previously determined cohesiometer or stabilometer values. Likewise, where tensile properties are available for a material but estimates for cohesiometer and stabilometer values are needed, these results may be used.

A rather sophisticated statistical technique has been used to provide the engineer with a value judgment on the quality of the correlation for each pair of variables. The report is divided into two parts in order to document the study and at the same time make the results useful to the engineer. Chapters 1, 2, and 3 contain the information necessary for the engineer to utilize the data. The remainder of the report, including the appendices, provides background information on the statistical techniques used and details on how the tests were conducted. This information will be useful for researchers and others desiring to extend the work.

This report required the assistance of many individuals and the authors would like to acknowledge the work of all those who contributed to it. Special thanks are extended to Dr. Gerald R. Wagner and Mr. Joseph Kozuh for their help in designing the statistical experiment and in providing guidance in the analysis of the data. Special appreciation is also due Messrs. Pat S. Hardeman and James N. Anagnos for their assistance in the preparation and testing of

the lime-treated materials, and to Messrs. James L. Brown and Harvey J. Treybig of the Texas Highway Department, who provided the technical liaison for the project.

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LIST OF REPORTS

Report No. 98-1, "An Indirect Tensile Test for Stabilized Materials," by W. Ronald Hudson and Thomas W. Kennedy, summarizes current knowledge of the indirect tensile test, reports findings of limited evaluation of the test, and describes the equipment and testing techniques developed.

Report No. 98-2, "An Evaluation of Factors Affecting the Tensile Properties of Asphalt-Treated Materials," by William O. Hadley, W. Ronald Hudson, and Thomas W. Kennedy, discusses factors important in determining the tensile strength of asphalt-treated materials and reports findings of an evaluation of eight of these factors.

Report No. 98-3, "Evaluation of Factors Affecting the Tensile Properties of Cement-Treated Materials," by Humberto J. Pendola, Thomas W. Kennedy, and W. Ronald Hudson, presents factors important in determining the strength of cement-treated materials and reports findings of an evaluation by indirect tensile test of nine factors thought to affect the tensile properties of cement-treated materials.

Report No. 98-4, "Evaluation of Factors Affecting the Tensile Properties of Lime-Treated Materials," by S. Paul Miller, Thomas W. Kennedy, and W. Ronald Hudson, presents factors important in determining the strength of cement-treated materials and reports findings of an evaluation by indirect tensile test of eight factors thought to affect the tensile properties of lime-treated materials.

Report No. 98-5, "Evaluation and Prediction of the Tensile Properties of Lime-Treated Materials," by Walter S. Tulloch, II, W. Ronald Hudson, and Thomas W. Kennedy, presents a detailed investigation by indirect tensile test of five factors thought to affect the tensile properties of lime-treated materials and reports findings of an investigation of the correlation between the indirect tensile test and standard Texas Highway Department tests for lime-treated materials.

Report No. 98-6, "Correlation of Tensile Properties with Stability and Cohesiometer Values for Asphalt-Treated Materials," by William O. Hadley, W. Ronald Hudson, and Thomas W. Kennedy, presents a detailed correlation of indirect tensile test parameters, i.e., strength, modulus of elasticity, Poisson's ratio, and failure strain, with stability and cohesiometer values for asphalt-treated materials.

Report No. 98-7, "A Method of Estimating Tensile Properties of Materials Tested in Indirect Tension," by William O. Hadley, W. Ronald Hudson, and Thomas W. Kennedy, presents the development of equations for estimating material properties such as modulus of elasticity, Poisson's ratio, and tensile strain based upon the theory of the indirect tensile test and reports verification of the equations for aluminum.

ABSTRACT

This report describes a study to determine the correlation between the tensile properties of asphalt-treated materials tested in indirect tension and the stability and cohesiometer values for identical companion specimens tested in the Hveem stabilometer and cohesiometer. The parameters obtained from the indirect tensile test included tensile strength at failure, estimated tensile strain at failure, Poisson's ratio, and modulus of elasticity, each of which was compared with both the stability and cohesiometer values.

The test results for analyses found to be significantly correlated are presented in tables and displayed in scatter diagrams, with the tensile properties obtained from the indirect tensile tests plotted on the ordinate and either the stability or cohesiometer values plotted on the abscissa. The techniques used to characterize the relationship between the responses of the Hveem and indirect tensile tests as (1) no correlation, (2) a trend, or (3) acceptable correlation are also described in the report. The least squares lines of best fit between the test responses are also presented in the scatter diagrams, which also show the regions within which 95 percent of all data points would be expected to fall.

Statistical significance tests were used to determine whether or not the results of the two experiments could be combined to illustrate general relationships between tensile properties and stability and cohesiometer values.

Conclusions based on the correlation results are presented in the report and indicate that correlations between the parameters obtained from the indirect tensile test and the Hveem stability and cohesiometer values are dependent upon the confines of the study. In general, stability values correlated with Poisson's ratio and tensile strain while the cohesiometer values correlated with modulus of elasticity, tensile strength, and tensile strain.

KEY WORDS: indirect tensile test, stabilometer, cohesiometer, asphalt-treated material, modulus of elasticity, Poisson's ratio, tensile strength, tensile strain, stability, cohesiometer value, regression analysis, correlation.

SUMMARY

As the use of tensile properties of highway materials becomes more prevalent in the design and analysis of highway pavements, it may be desirable to estimate tensile properties from properties previously determined from cohesiometer and stabilometer tests. A series of correlation analyses were conducted in order to provide the engineer with a means of making such estimates.

The correlations between the responses of the indirect tensile test and Hveem tests are dependent upon the confines of the study. The first experiment exemplifies the primary realm within which the Hveem tests have been used. In this experiment five of the eight comparisons under investigation were found to exhibit no correlation:

(1) Poisson's ratio and cohesiometer value,
(2) tensile strain and cohesiometer,
(3) modulus of elasticity and stability,
(4) tensile strength and stability, and
(5) tensile strain and stability.

Thus tensile properties could not be predicted from the corresponding Hveem properties.

The following correlations were found to be acceptable for a general range of test conditions:

(1) modulus of elasticity and cohesiometer value,
(2) tensile strength and cohesiometer value,
(3) tensile strain and cohesiometer value,
(4) Poisson's ratio and stability, and
(5) tensile strain and stability.

These correlations, therefore, can be used for estimating tensile properties over a wide range of conditions, but in making such predictions one must be aware of errors associated with them as indicated by the confidence bounds. In the case of the standard test conditions utilized by the Texas Highway Department, the only acceptable correlations involved the modulus of elasticity and the cohesiometer value.

IMPLEMENTATION STATEMENT

The correlations obtained from this study can be useful in evaluating the performance of existing pavements in terms of material properties. A wealth of knowledge concerning stability and cohesiometer values is available for existing pavement, and in many cases the traffic data or load applications, performance, and possible pavement life are also available. By estimating material properties such as modulus of elasticity, Poisson's ratio, tensile strength, and tensile strain from the Hveem parameters, the performance and life of a pavement could be related to material characteristics, possibly providing a better understanding of pavement performance.

The correlation could also be useful in new pavement design by providing the capability to estimate the material characteristics. Once the estimates of modulus of elasticity and Poisson's ratio values were known, layered system analysis could be undertaken to evaluate different design sections.

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CHAPTER 1. INTRODUCTION

Previous studies (Refs 1-6) have indicated that the indirect tensile test can be used for evaluation of tensile strengths of stabilized materials. Based on research at The University of Texas at Austin (Ref 7) it appears that the test can also be used to determine other material characteristics, i.e., modulus of elasticity, Poisson's ratio, and estimated tensile strains at failure. Equations based on theoretical and experimental work conducted by Hondros (Ref 8) have been used to obtain estimates of these four parameters and are now being used for the evaluation of a variety of asphalt-treated materials.

Many design methods for bituminous materials involve the use of semi-theoretical tests such as the stabilometer and cohesiometer tests (Ref 9), which have been established through laboratory and field correlation. The relationship of the indirect tensile test and the proposed design methods to such existing tests is important and would be useful to those who want to evaluate the performance of existing pavements in terms of material properties. In many cases a wealth of information concerning cohesiometer and stabilometer values is available for existing pavements, covering a variety of pavement conditions. By estimating material properties such as modulus of elasticity, Poisson's ratio, tensile strength, and failure strain from Hveem parameters, it should be possible to relate the performance of such existing pavements to material characteristics, leading to a better understanding of pavement performance. With this in mind a correlation study was undertaken to provide a basis for relating the results of the indirect tensile test with those from the Hveem tests.

To provide the range of comparisons needed required two experiments. The first utilized standard Texas Highway Department preparation and test procedures (Ref 10) and the second involved preparation and test procedures proposed for the indirect tensile test. The preparation and testing procedures used in these experiments are presented in Appendix 1.

CHAPTER 2. EXPERIMENTAL DESIGNS

The general approach used in this study is illustrated in Fig 1, a flow diagram in which various factors and their levels are shown. The overall analysis consisted of a correlation analysis for the parameters of the indirect tensile test with the cohesiometer and stabilometer test results.

Experiment 1

Only three factors, each at two levels, were included in this portion of the study (Table 1). An AC-10 asphalt cement was used in all specimens. The gradations investigated are indicated in Fig 2. The experiment design consisted of a 2^3 factorial arrangement, with duplicate pairs of companion specimens for each treatment combination.

Experiment 2

The factors and levels considered in Experiment 2 are presented in Table 2. The gradations were the same as those used in Experiment 1 (Fig 2). The design consisted of a quarter-fractional experiment involving seven factors, each at two levels. The treatment combinations evaluated are summarized in Table 3. Companion specimens were prepared for each of the 32 combinations, with one being tested by indirect tensile test and the other in the stabilometer and cohesiometer.

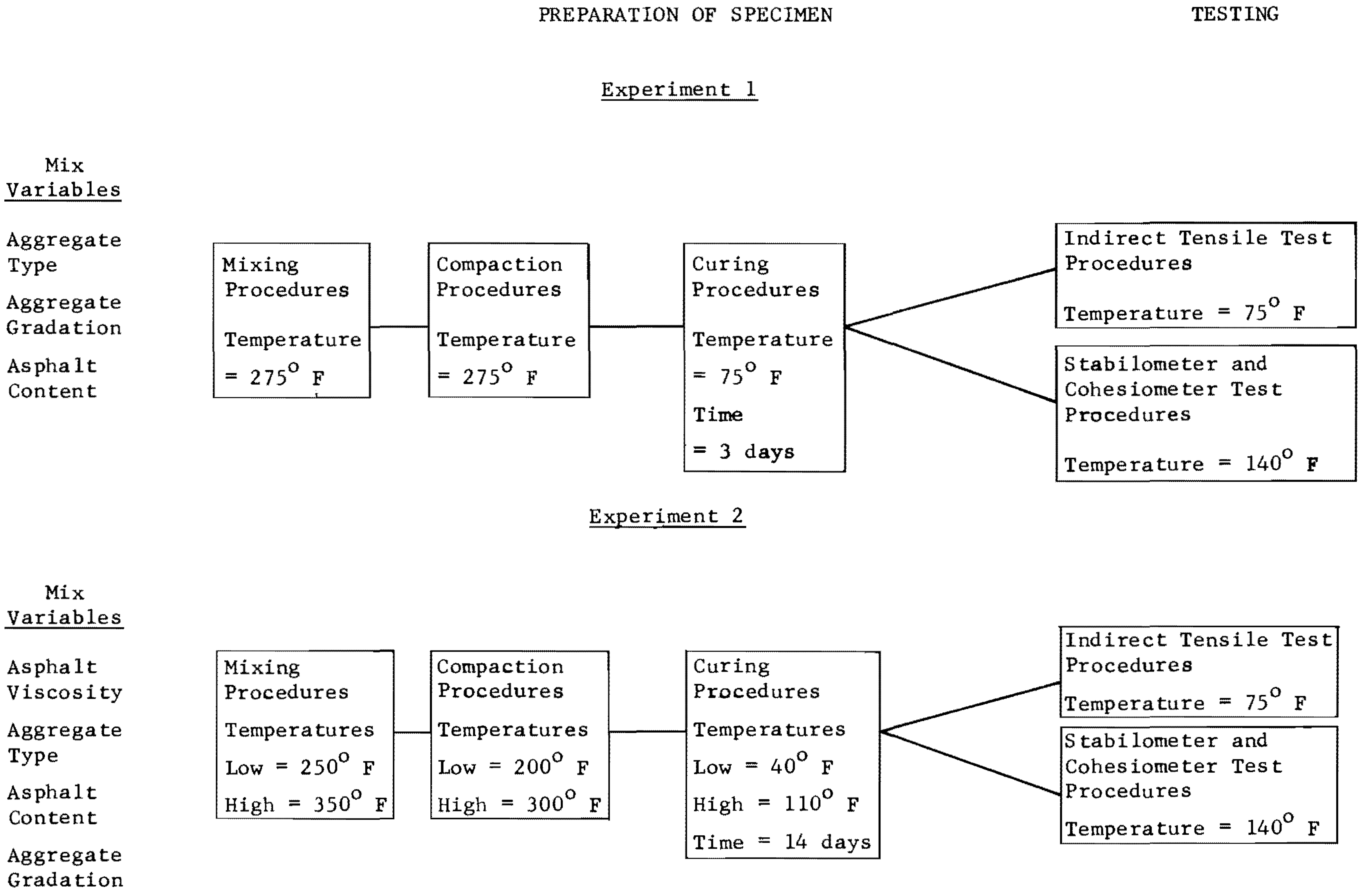


Fig 1. Experimental approach to correlation analysis.

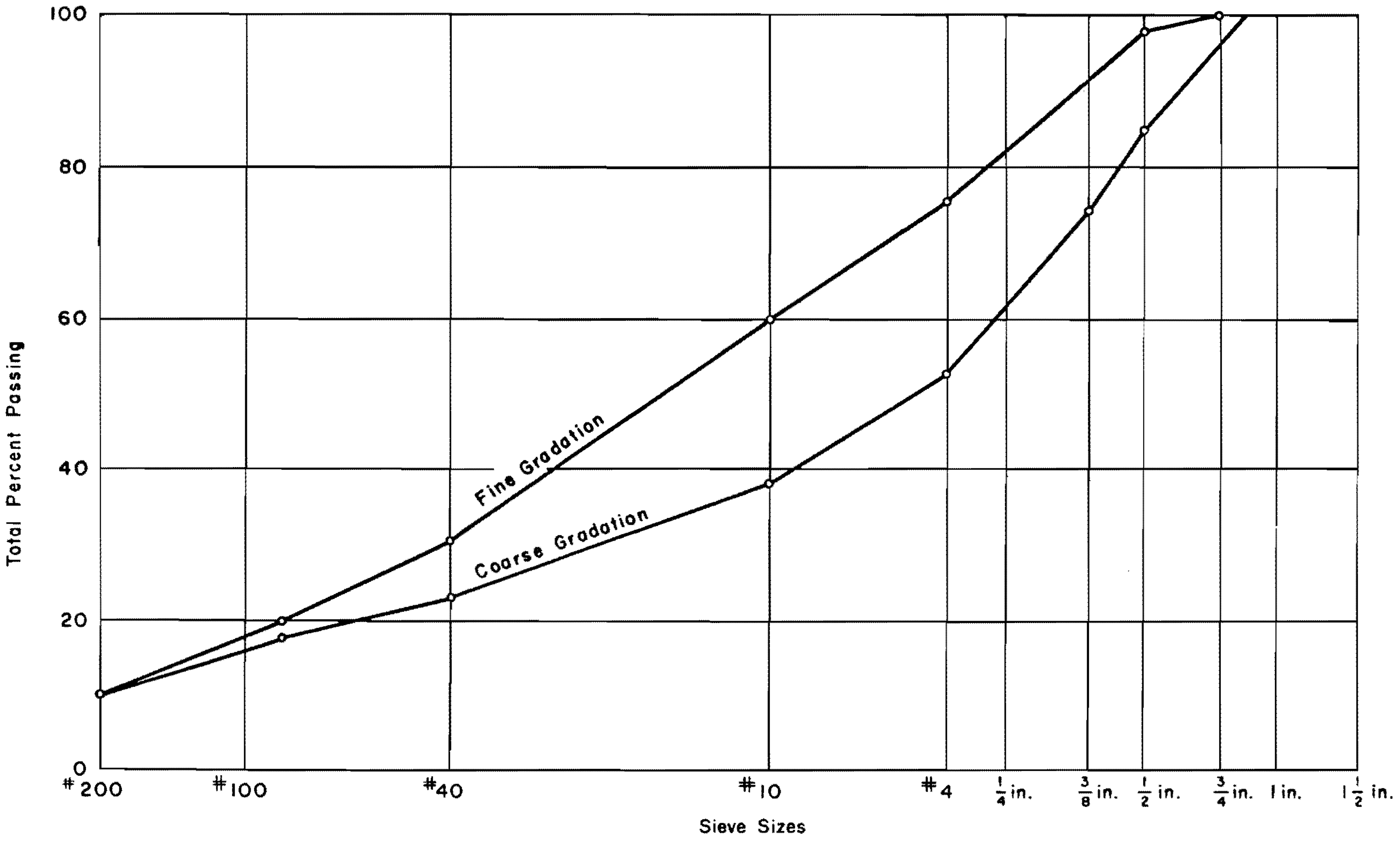


Fig 2. Gradation curves for aggregate mixtures.

TABLE 1. FACTORS AND LEVELS FOR EXPERIMENT 1

Factors	Levels	
	Low (-1)	High (+1)
Aggregate type	Crushed limestone	Rounded gravel
Aggregate gradation	Fine	Coarse
Asphalt content, %	5.5	7.0

TABLE 2. FACTORS AND LEVELS FOR EXPERIMENT 2

Factors	Levels	
	Low (-1)	High (+1)
Aggregate type	Crushed limestone	Rounded gravel
Aggregate gradation	Fine	Coarse
Asphalt viscosity*	AC-5	AC-20
Asphalt content, %	5.5	8.5
Mixing temperature, ° F	250	350
Compaction temperature, ° F	200	300
Curing temperature, ° F	40	110

* Test data for the asphalt cement are in Appendix 2.

TABLE 3. QUARTER-FRACTIONAL FACTORIAL ARRANGEMENT EVALUATED IN EXPERIMENT 2

			Aggregate Type	Limestone				Gravel			
			Aggregate Gradation	Fine		Coarse		Fine		Coarse	
Curing Temp, °F	Compaction Temp, °F	Mixing Temp, °F	Asphalt Content, % \ Asphalt Viscosity (Specs)	AC 5	AC 20	AC 5	AC 20	AC 5	AC 20	AC 5	AC 20
40	200	250	5.5								
			8.5	▨			▨		▨	▨	
		350	5.5	▨			▨		▨	▨	
			8.5								
	300	250	5.5								
			8.5		▨	▨		▨			▨
		350	5.5		▨	▨		▨			▨
			8.5								
110	200	250	5.5	▨			▨		▨	▨	
			8.5								
		350	5.5								
			8.5	▨			▨		▨	▨	
	300	250	5.5		▨	▨		▨			▨
			8.5								
		350	5.5								
			8.5		▨	▨		▨			▨

Note: The shaded areas indicate treatment combinations tested

CHAPTER 3. SUMMARY OF RESULTS

The properties for materials used in this study, as determined by tests, are contained in Appendix 2. The data include the physical properties of the asphalt cements and the test results, including modulus of elasticity, Poisson's ratio, tensile strength, tensile strain, stability value, and cohesiometer value.

Relationships between the Hveem parameters of stability and cohesiometer values and the elastic parameters were obtained by regression techniques for the two experiments discussed in Chapter 2. The correlation coefficient obtained from the regression results was used as a measure of the linear relationship between the two sets of parameters and provided an estimate of true correlation. This correlation coefficient as well as other criteria discussed in Chapter 4 was then used to classify the relationships as

(1) no correlation,
(2) a trend, or
(3) an acceptable correlation.

If the relationship was "no correlation", then there was assumed to be no relationship between the two particular variables, i.e., the value of one of the variables was independent of the value of the other. A trend was considered to be a weak correlation in which an increase in the value of one variable was accompanied by a general increase or decrease in the value of the other variable. An acceptable correlation was considered to be a relationship in which the value of one variable could be predicted from a second variable with a relatively high degree of reliability.

Classifications of the relationships between the Hveem and indirect tensile test parameters for the two experiments are presented in Table 4. Significance tests were also conducted, to determine if the results of Experiments 1 and 2 could be combined to provide a more general relationship. The results of statistical significance tests are included in Table 4. For further explanation of the technique used in the significance testing, see Chapter 5.

TABLE 4. CLASSIFICATION OF RELATIONSHIPS BETWEEN VARIABLES

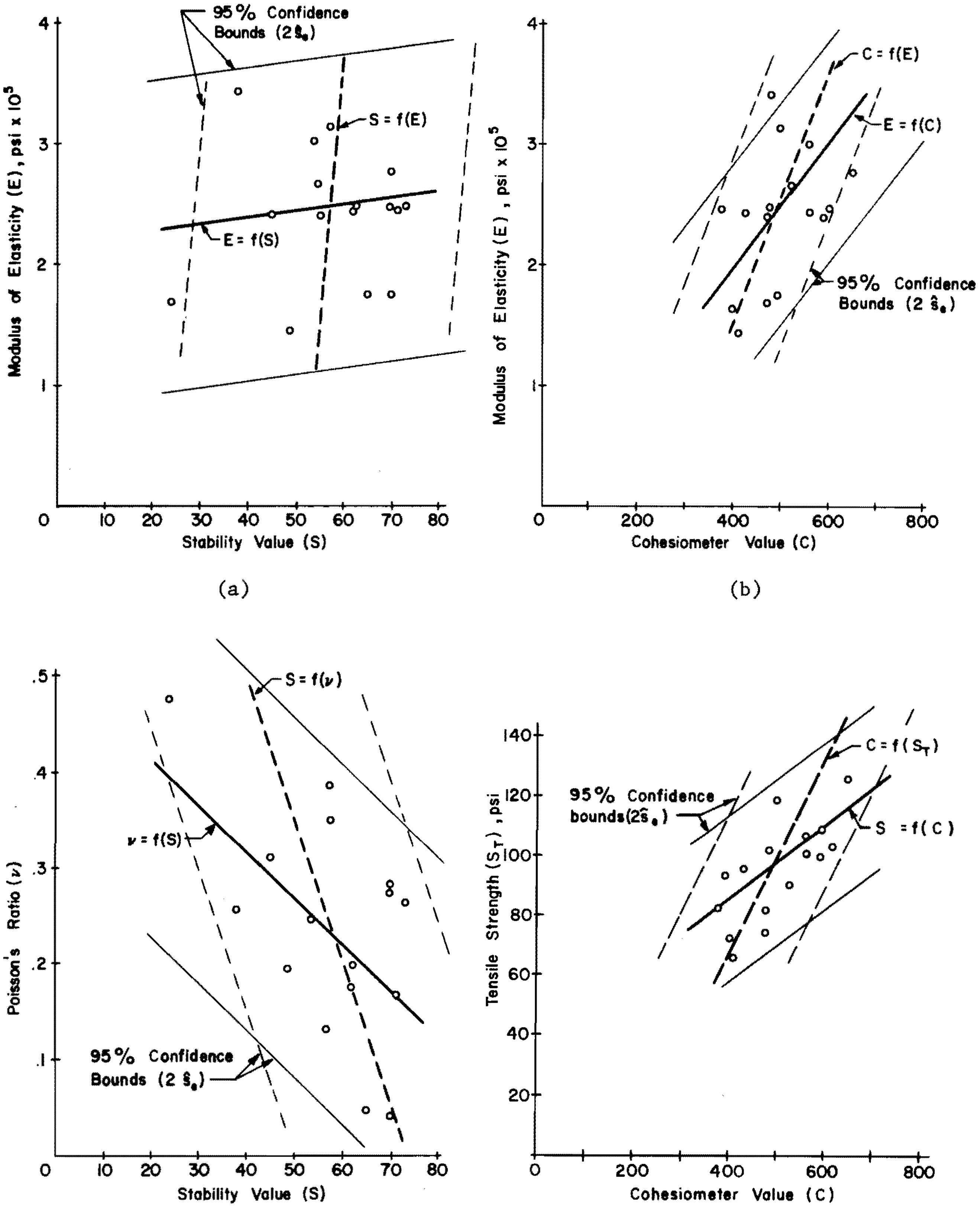
Variables	For Experiment 1 There was	For Experiment 2 There was	Can the Results be Combined?
Modulus of elasticity and stability	No correlation	A trend	Yes
Poisson's ratio and stability	A trend	Acceptable correlation	Yes
Tensile strength and stability	No correlation	A trend	Yes
Tensile strain and stability	No correlation	Acceptable correlation	Yes
Modulus of elasticity and cohesiometer value	Acceptable correlation	Acceptable correlation	Yes
Poisson's ratio and cohesiometer value	No correlation	A trend	No
Tensile strength and cohesiometer value	A trend	Acceptable correlation	Yes
Tensile strain and cohesiometer value	No correlation	Acceptable correlation	No

The regression equations for those relationships found to be correlated are presented in Table 5. In most cases the equations were obtained from combined results of Experiments 1 and 2. The prediction capability and the source of the equations are included in the last two columns of Table 5. An equation with poor prediction capability should not be used to estimate one variable from a second variable. In making predictions from equations of good prediction capability, it is necessary to know the range in the prediction, as indicated by the 95 percent confidence limits. These limits (± two standard deviations) were computed with a 95 percent certainty that the predicted value would be contained within them. It should be noted also that the correlation equations presented in Table 5 are valid only within the confines of the study. Any extrapolation outside the limitations of the study should be made with the knowledge that erroneous answers may be obtained.

The various correlation analyses which were found to be significantly correlated are displayed as scatter diagrams in Fig 3 for Experiment 1 and in Fig 4 for Experiment 2. Figure 3a is an example of a scatter diagram for an analysis from Experiment 1 for which there was no correlation. The tensile properties obtained from the indirect tensile test are plotted on the ordinate and the corresponding stability or cohesiometer values are plotted on the abscissa.

TABLE 5. REGRESSION EQUATIONS FOR VARIABLES

For the Pair of Variables	There is	To Estimate	From	Use the Equation	Which has 95% Confidence Limits of	And a Prediction Capability Which is	The Relationship Source was
Modulus of elasticity E and stability S	A trend	E	S	$E = 1.449 \times 10^5 + 2.33 \times 10^3 S$	$\pm 2.040 \times 10^5$	Poor	Combined experiments (Fig 6a, p 25)
		S	E	$S = 30.96 + 8.259 \times 10^{-5} E$	± 38.4		
Modulus of elasticity E and cohesiometer value C	Acceptable correlation	E	C	$E = .613 \times 10^5 + 3.305 \times 10^2 C$	$\pm 1.434 \times 10^5$	Good	Combined experiments (Fig 6b, p 25)
		C	E	$C = 138.8 + 1.82 \times 10^{-3} E$	± 336.4		
Poisson's ratio ν and stability S	Acceptable correlation	ν	S	$\nu = .470 - .0047 S$	$\pm .184$	Good	Combined experiments (Fig 6c, p 25)
		S	ν	$S = 78.5 - 115.7\nu$	± 28.8		
Poisson's ratio ν and cohesiometer value C	A trend	ν	C	$\nu = .378 - 2.53 \times 10^{-4} C$	$\pm .237$	Poor	Combined experiments (Fig 4d, p 13)
		C	ν	$C = 839.1 - 963.6\nu$	± 463.3		
Tensile strength S_T and stability S	A trend	S_T	S	$S_T = 65.1 + .921S$	± 75.6	Poor	Combined experiments (Fig 7a, p 26)
		S	S_T	$S = 26.7 + .232 S_T$	± 37.9		
Tensile strength S_T and cohesiometer value C	Acceptable correlation	S_T	C	$S_T = 24.6 + .141C$	± 51.6	Good	Experiment No. 2 (Fig 7b, p 26)
		C	S_T	$C = 59.4 + 5.234S_T$	± 315.1		
Tensile strain ϵ and stability S	Acceptable correlation	ϵ	S	$\epsilon = .0018 - 7.71 \times 10^{-6} S$	$\pm .0005$	Good	Combined experiments (Fig 7c, p 26)
		S	ϵ	$S = 107.9 - 3.996 \times 10^4 \epsilon$	± 35.6		
Tensile strain ϵ and cohesiometer value C	Acceptable correlation	ϵ	C	$\epsilon = .0019 - 7.0 \times 10^{-7} C$	$\pm .0005$	Good	Experiment No. 2 (Fig 5d, p 14)
		C	ϵ	$C = 1654.3 - 6.746 \times 10^5 \epsilon$	± 446.8		



(a)

(b)

(c)

(d)

Fig 3. Scatter diagrams for Experiment 1.

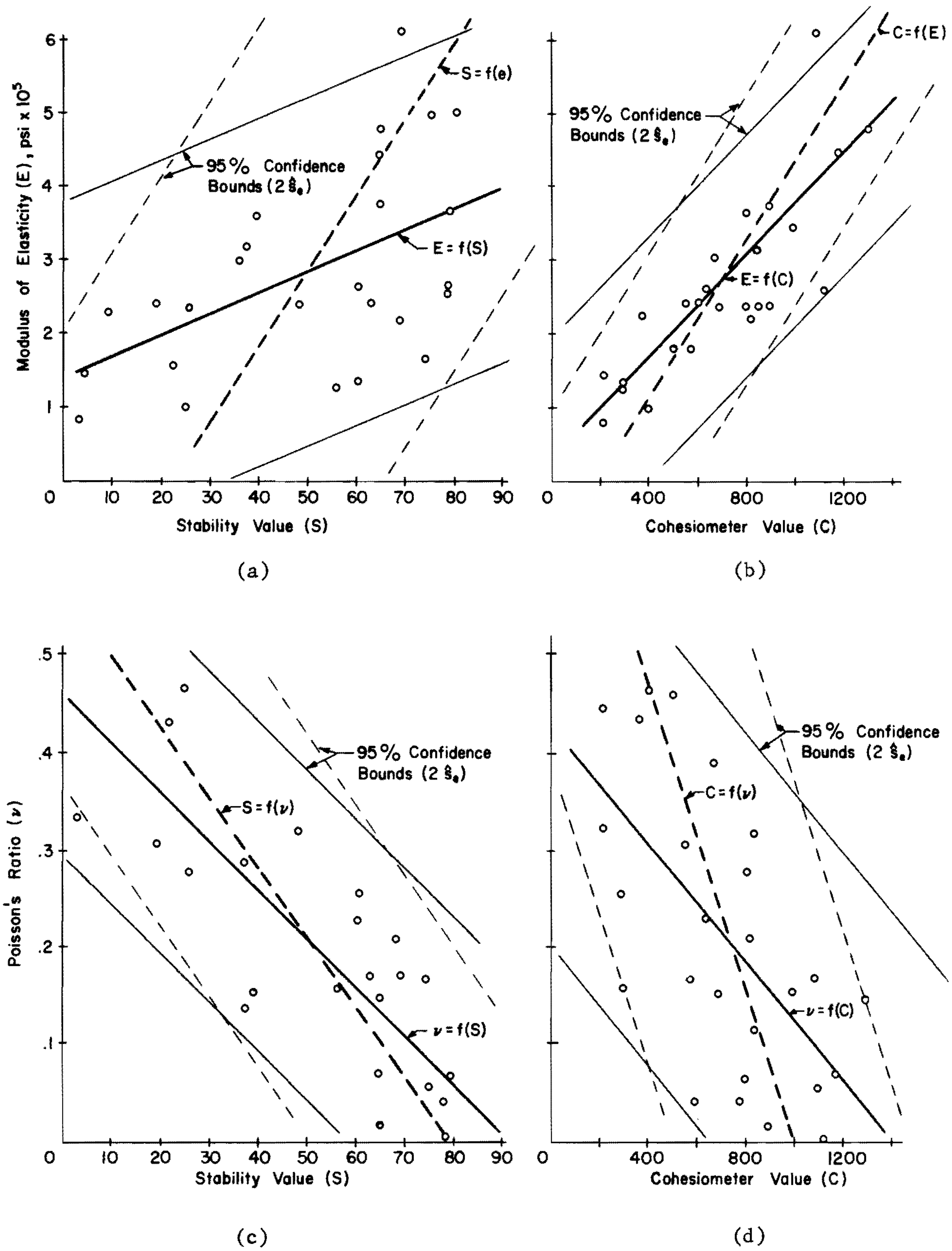
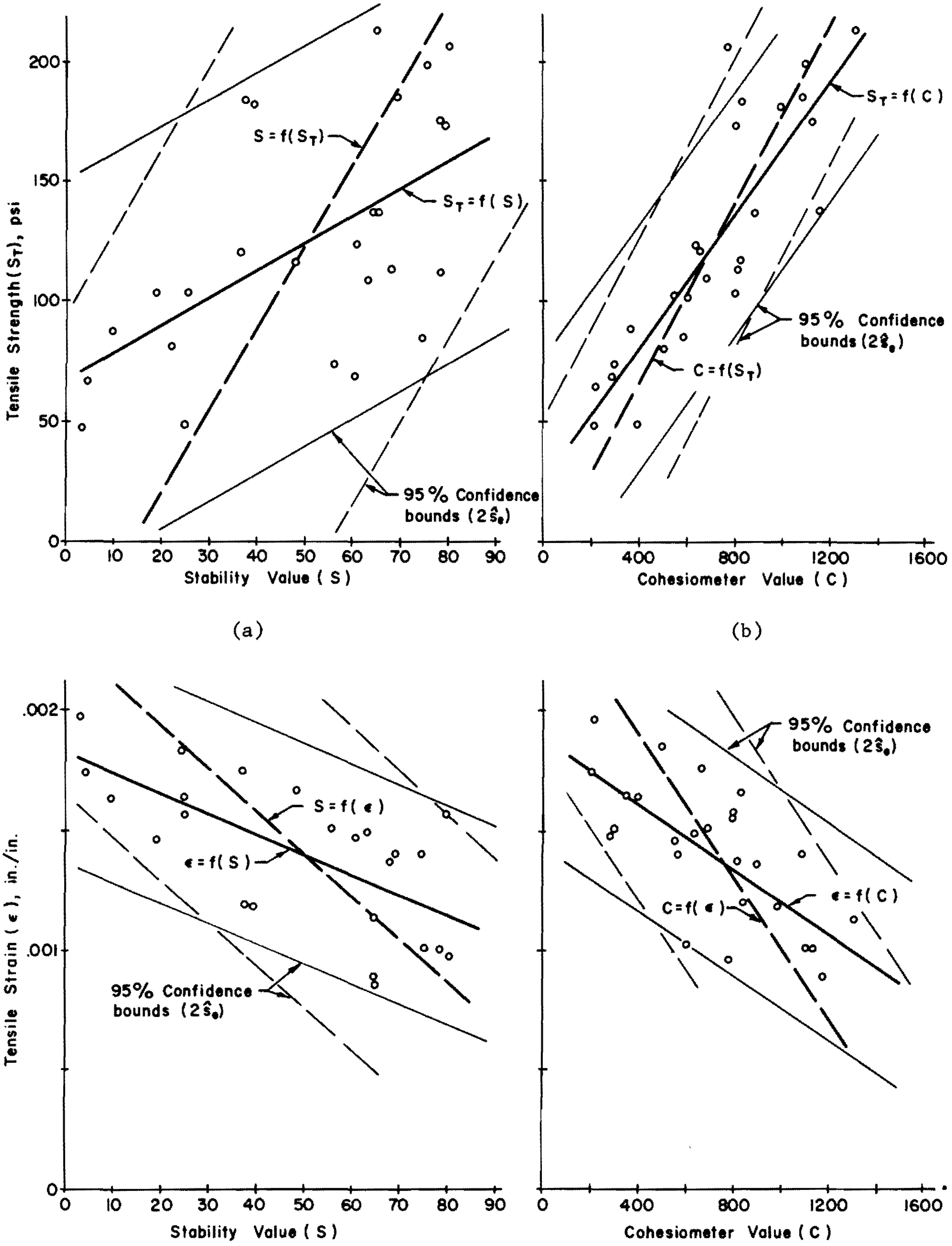


Fig 4. Scatter diagrams for modulus of elasticity and Poisson's ratio for Experiment 2.



(a) (b)

(c) (d)

Fig 5. Scatter diagrams for tensile strength and tensile strain for Experiment 2.

CHAPTER 4. ANALYSIS TECHNIQUES

In routine analysis, the variable plotted on the abscissa is the independent variable, which can be measured exactly, and the one plotted on the ordinate is the dependent variable, which is usually assumed to be subject to fluctuations for a given value of the independent variable. Thus, test results from the stabilometer or cohesiometer would normally be used to estimate an indirect tensile test parameter, but there is no reason why indirect tensile test results could not be used to estimate cohesiometer or stabilometer values. In addition, there is no reason to believe that errors and variations were not associated with all parameters. Thus the responses from the tests were considered to be two independent variables and the analysis was conducted in terms of a bivariate population (Ref 11); i.e., the analysis involved two independent variables, each of which had errors associated with its determination. Therefore, the responses from the indirect tensile test as well as the Hveem tests were considered to be random variables and were analyzed as a bivariate population.

A simple linear regression analysis was used to determine a correlation coefficient between the modulus of elasticity, Poisson's ratio, tensile strength, and tensile strain, as determined from the indirect tensile test and the stability and cohesiometer values for the companion specimens in both experiments. The correlation coefficient was used as a measure of the linear relationship between parameters and provided an estimate of the true correlation. With statistical techniques presented by Snedecor and Cochran (Ref 11), significance tests were conducted on these correlation coefficients to determine whether or not a correlation between a particular set of variables actually existed at a given probability level. The results of the significance tests and a visual inspection of the scatter diagrams were used to establish the acceptability of the correlations.

Confidence limits about the sample correlation coefficients were established for those relationships which were felt to be acceptable correlations. These limits were computed with a 95 percent certainty that the interval established by these boundaries would contain the true correlation coefficient.

The correlation analysis completed in this study involved a bivariate population and was based upon correlation coefficients which were calculated by the method of least squares. This method of fitting a line to a set of data points assumes that one of the two variables under investigation can be designated as independent and can be measured without error. Relationships being evaluated in this study are between two independent variables, with random error associated with each. Since the least squares method does not fit this particular situation, it is not possible to obtain a unique equation relating the two variables.

There are two possible relationships between any two independent variables X_i and X_j using the method of least squares. The first equation is of the form $X_i = f(X_j)$ and solves for the variable X_i in terms of the second variable X_j. The assumptions for this equation are that X_j is the independent variable, which has no errors associated with it, and that X_i is the dependent or random variable. Similarly, the second equation takes the form $X_j = f(X_i)$, in which variable X_i is considered to be the independent variable and X_j the dependent variable. These two relationships are calculated for each pair of variables and superimposed on the particular scatter diagrams. The heavy solid line in the figures indicates the relationship of the tensile parameters in terms of the cohesiometer or stability value while the heavy dotted line represents the Hveem parameters in terms of tensile test parameters. The ratio of the slopes of these two lines provides an estimate of the degree of correlation between the two variables. In this study the ratio is equal to or greater than 1.0 because the larger slope is always used in the numerator. As this ratio approaches 1.0, the correlation between the variables approaches an exact relationship.

The equations which were obtained from the data by a "least squares line of best fit" technique have errors associated with them. Thus, the standard error of estimate $\hat{s}_e = \sqrt{\text{residual mean squares}}$ was calculated for each relationship and provided an estimate of the standard error for any prediction. The region within which 95 percent of the data points fall was established at a vertical distance of $\pm 2\hat{s}_e$ from the least squares line and is indicated for both equations on each of the scatter diagrams.

After the existence of correlation between a set of variables was substantiated, a second test was completed to differentiate between a trend and an acceptable correlation. In this report a trend was assumed to be a weak correlation in which an increase in the value of one variable was accompanied by a general increase or decrease in the value of the other variable. An acceptable correlation was considered to be a relationship in which the value of one variable could be predicted from a second variable with a relatively high degree of reliability. The criteria for making this determination are not available in any known statistical method or technique.

In this study three different parameters were used to establish criteria for an acceptable correlation. One of the criteria, which is discussed above, was obtained from the ratio of the slopes of the two "least squares best fit" lines for each bivariate relationship. The second criterion involved the determination of a coefficient of variation, using the standard error of estimate $\hat{s}_e$, which considered the spread in the data. The value of the coefficient was obtained from the equation

$$CV = \frac{\hat{s}_e}{\bar{X}_i} \times 100$$

where

CV = a coefficient of variation

$\hat{s}_e$ = the standard error of estimate = $\sqrt{\text{residual mean squares}}$, and

$\bar{X}_i$ = the mean of the dependent variable.

The third and most important criterion was the magnitude of the correlation coefficient; a coefficient of 1.0 means perfect correlation.

Statistical significance tests were also conducted, to determine if the results for each of the bivariate relationships of the two experiments were compatible. The significance tests were made at a 95 percent confidence level. If significance tests indicated compatibility the results of the two experiments for that particular correlation were combined to better define the general relationship between tensile test parameters and Hveem parameters. If the tests indicated noncompatibility the correlations for a particular pair of variables depended upon the fixed parameters of the experiment, i.e., mixing and preparation restrictions, and, therefore, the results of the two experiments could not be combined.

The statistical tests outlined above for the individual experiments were also completed on the data combined from both experiments.

CHAPTER 5. CORRELATION ANALYSIS AND DISCUSSION OF RESULTS

Prior to a detailed evaluation of correlation relationships between the various parameters it was necessary to determine the form of equation to be used to represent the relationship between each pair of variables. The simplest method involves a first order or linear equation of the form $T_i = f(H_j)$, where T_i is a tensile test parameter and H_j is a Hveem parameter. Other possibilities include quadratic, $T_i = f(H_j^2)$; cubic, $T_i = f(H_j^3)$; and higher order equations. Correlation coefficients for each of the comparisons were computed from the data, using the first three equation forms.

In the first experiment a linear relationship produced higher correlation coefficients than the other two for all cases except modulus of elasticity versus cohesiometer value and tensile strength versus cohesiometer value, for which a cubic relationship produced coefficients which were respectively 3.9 and 4.1 percent larger than the linear form. Even in these two cases, however, the increases were not of sufficient magnitude to warrant using the higher order equation.

Similar results were found in Experiment 2, where a linear relationship provided the best correlation coefficient for all but two cases. A quadratic relationship for Poisson's ratio versus stability and tensile strain versus stability produced negligible increases in the correlation coefficients of 0.60 and 0.93 percent, respectively.

Since the improvement, if any, in the correlation coefficients caused by using higher order equations was negligible in both experiments, all subsequent analyses concerning correlation between any two variables considered only a linear relationship.

The parameters used in determining the correlation between all pairs of variables for the two experiments are presented in Tables 6 and 7. The results of the two experiments are discussed in the following paragraphs.

TABLE 6. PARAMETERS USED IN CORRELATION ANALYSIS FOR EXPERIMENT 1

Variables	Correlation Coefficient r	Does Correlation Exist?	95% Confidence Bands About Correlation Coefficient	Slope Ratio	Coefficients of Variation,%	Acceptable Correlation?
Elasticity and stability	.1213	No				
Poisson's ratio and stability	-.5686	Yes	$-.102 \le r \le -.831$	31.0	41, 20	No
Tensile strength and stability	.3487	No				
Tensile strain and stability	-.4794	No				
Elasticity and cohesiometer value	.7238	Yes	$.356 \le r \le .898$	1.9	19, 13	Yes
Poisson's ratio and cohesiometer value	.4109	No				
Tensile strength and cohesiometer value	.6185	Yes	$.177 \le r \le .853$	2.6	15, 14	No
Tensile strain and cohesiometer value	.0578	No				

Table 7. PARAMETERS USED IN CORRELATION ANALYSIS FOR EXPERIMENT 2

Variables	Correlation Coefficient r	Does Correlation Exist?	95% Confidence Bands About Correlation Coefficient	Slope Ratio	Coefficients of Variation, %	Acceptable Correlation?
Elasticity and stability	.5278	Yes	$.176 \le r \le .760$	3.6	42, 43	No
Poisson's ratio and stability	-.8248	Yes	$-.643 \le r \le -.919$	1.5	42, 29	Yes
Tensile strength and stability	+.5768	Yes	$.244 \le r \le .789$	3.0	34, 41	No
Tensile strain and stability	-.7858	Yes	$-.573 \le r \le -.900$	1.6	20, 31	Yes
Elasticity and cohesiometer value	.8069	Yes	$.593 \le r \le .905$	1.5	29, 26	Yes
Poisson's ratio and cohesiometer value	-.6411	Yes	$-.337 \le r \le -.824$	2.4	57, 34	No
Tensile strength and cohesiometer value	.8580	Yes	$.705 \le r \le .935$	1.4	21, 23	Yes
Tensile strain and cohesiometer value	.7235	Yes	$-.467 \le r \le -.868$	1.9	22, 30	Yes

Experiment 1

The following pairs of variables did not correlate (see Table 6):

(1) Poisson's ratio and cohesiometer value,

(2) tensile strain and cohesiometer value,

(3) modulus of elasticity and stability,

(4) tensile strength and stability, and

(5) tensile strain and stability.

An example of lack of correlation can readily be seen in Fig 3a, where modulus of elasticity was plotted versus stability and the data generally fell in a shotgun pattern.

The three pairs of variables which correlated were (1) modulus of elasticity and cohesiometer value (Fig 3b), (2) Poisson's ratio and stability (Fig 3c), and (3) tensile strength and cohesiometer value (Fig 3d). Of the three only the correlation between the modulus of elasticity and the cohesiometer value was considered to be acceptable (see Fig 3b).

The correlation coefficient for the relationship, 0.724, was relatively high and the values of slope ratio, 1.9, and coefficient of variation, 19 and 13 percent, were small.

For Poisson's ratio versus stability, 13 of the 16 points fell roughly within a circle near the center of the plot (Fig 3c). The correlation coefficient was higher than would be expected from a visual inspection of the scatter diagram because of the relative positions of the data points located at Poisson's ratio values of 0.46 and 0.05, which were generally on opposite sides of the interior circle of data. The values for the other two parameters of this particular relationship (Table 6) were also important in the decision that the correlation was unacceptable for practical purposes.

The correlation between tensile strength and cohesiometer value, shown in Fig 3d, was considered to be unacceptable for practical use because of the low correlation coefficient. The other two parameters are low, as required, but do not compensate for the low correlation coefficient of 0.619.

Experiment 2

The results of the correlation analysis for Experiment 2 (Table 7) indicate that there was correlation between the parameters of the indirect tensile test and the Hveem stability and cohesiometer values in all cases evaluated.

Of the eight relationships evaluated, five correlations were considered to be acceptable. The three which were considered to be trends only, because of their low correlation coefficients, were (1) modulus of elasticity and stability (Fig 4a), (2) Poisson's ratio and cohesiometer value (Fig 4d), and (3) tensile strength and stability (Fig 5a).

The following five comparisons exhibited acceptable correlations:

(1) modulus of elasticity and cohesiometer value (Fig 4b),
(2) Poisson's ratio and stability (Fig 4c),
(3) tensile strength and cohesiometer value (Fig 5b),
(4) tensile strain and stability (Fig 5c), and
(5) tensile strain and cohesiometer value (Fig 5d).

All the parameters listed in Table 5 were adequate for an acceptable correlation.

Combining the Results of the Two Experiments

The results of the significance tests which were conducted to determine if the data from two experiments could be combined are presented in Table 8.

There are two comparisons for which the results of the two experiments could not be combined: (1) Poisson's ratio and cohesiometer value and (2) tensile strain and cohesiometer value. The correlation for these was positive for Experiment 1 and negative for Experiment 2, indicating a lack of correlation between the pair of variables over the two experiments.

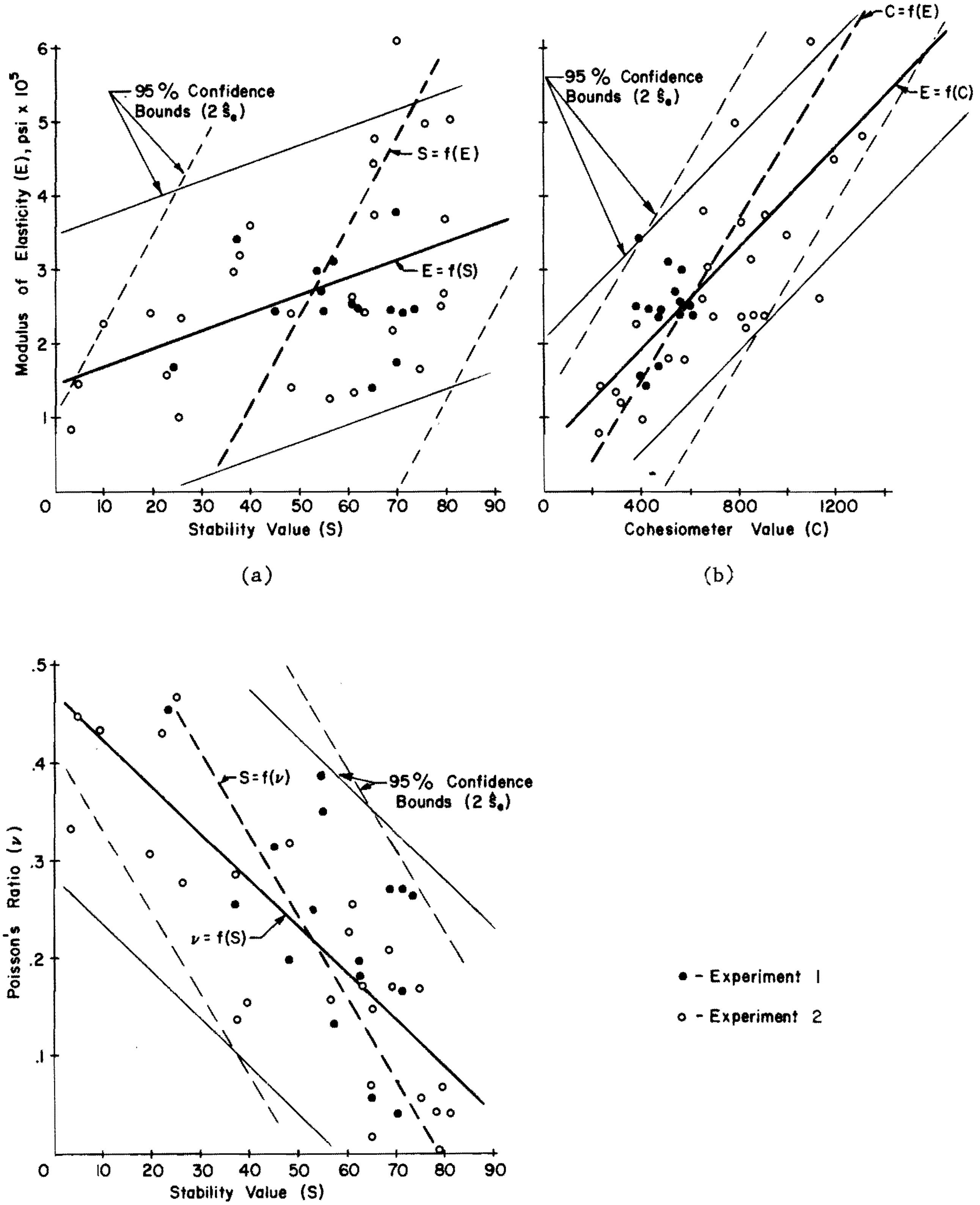
Those comparisons for which there was common correlation were

(1) modulus of elasticity and cohesiometer value,
(2) tensile strength and cohesiometer value,
(3) modulus of elasticity and stability,
(4) Poisson's ratio and stability,
(5) tensile strength and stability, and
(6) tensile strain and stability.

Scatter diagrams for the combined experiments are presented in Figs 6 and 7. The acceptability of the correlation for these six comparisons was determined and is presented in Table 8. The 95 percent confidence limits for the correlation coefficients were calculated to provide, with 95 percent certainty, the range within which the true correlation coefficient exists. These limits are also given in Table 8.

TABLE 8. PARAMETERS USED IN CORRELATION ANALYSIS FOR COMBINED DATA

Variables	Correlation Coefficient Ex 1	Correlation Coefficient Ex 2	Can Results be Combined?	Combined Correlation Coefficient	95% Confidence Bands About Correlation Coefficient	Slope Ratio	Coefficients of Variation,%	Acceptable Correlation?
Elasticity and stability	.1213	.5278	Yes	.4388	$-.156 \leq r \leq .655$	5.2	39, 37	No
Poisson's ratio and stability	-.5686	-.8248	Yes	-.7391	$-.561 \leq r \leq -.852$	1.8	43, 28	Yes
Tensile strength and stability	.3487	.5768	Yes	.4621	$.183 \leq r \leq .672$	4.7	34, 36	No
Tensile strain and stability	-.4794	-.7858	Yes	-.7423	$-.566 \leq r \leq -.854$	3.2	18, 34	Yes
Elasticity and cohesiometer value	.7238	.8069	Yes	.7754	$.617 \leq r \leq .874$	1.7	27, 27	Yes
Poisson's ratio and cohesiometer value	.4109	-.6411	No	-	-	-	-	-
Tensile strength and cohesiometer value	.6185	.8580	Yes	.8607	$.754 \leq r \leq .923$	1.4	19, 22	Yes
Tensile strain and cohesiometer value	.0578	-.7235	No	-	-	-	-	-

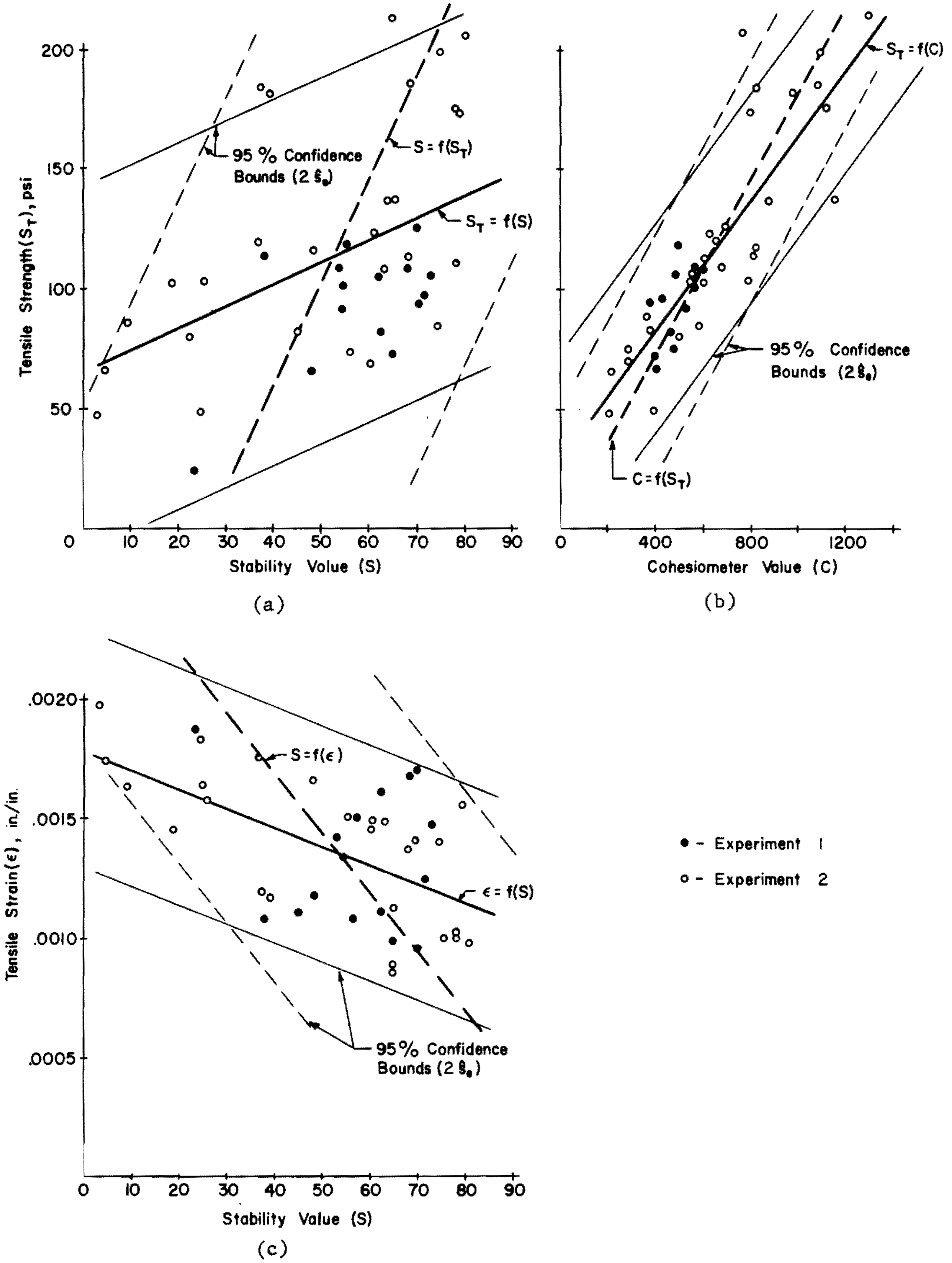


(a)

(b)

(c)

Fig 6. Scatter diagrams for modulus of elasticity and Poisson's ratio values for combined data.



(a)

(b)

(c)

Fig 7. Scatter diagrams for tensile strength and tensile strain for combined data.

Two of these six correlations were considered to be trends only, primarily because of relatively low correlation coefficients: (1) modulus of elasticity and stability and (2) tensile strength and stability. The slope ratio for each was relatively high, an additional cause for their unacceptability.

The other four comparisons were determined to provide an acceptable correlation between the particular variables. The correlation between modulus of elasticity and cohesiometer value was considered acceptable because of the relatively high correlation coefficient, 0.775, and the low values of slope ratio, 1.7, and coefficients of variation, 27 and 27 percent, for the two regression equations. The scatter diagram (Fig 6b) further substantiates the acceptable correlation.

There is an apparent linear relationship between Poisson's ratio and stability (Fig 6c), with an increase in stability value associated with a decrease in Poisson's ratio. The combined correlation coefficient, 0.739, was fairly high and the values of the two remaining criteria were adequate.

The relationship between tensile strength and cohesiometer value provided the highest correlation coefficient, 0.861, and the lowest slope rate, 1.4, in the study. In addition the coefficients of variation were small when compared collectively with the others. The strong linear relationship can be seen in Fig 7b, where high cohesiometer values correspond to high modulus of elasticity values.

The fourth correlation involved tensile strain and stability value (Fig 7c) and was also acceptable. This determination was based on the combined correlation coefficient, -.724, since the slope ratio was relatively high, 3.2.

CHAPTER 6. A DISCUSSION OF POSSIBLE CORRELATIONS

The existence of correlations may be best explained by a discussion of the responses of the Hveem tests as they relate to the elastic parameters.

The stabilometer value or Hveem stability value for asphalt-treated materials is obtained from a special triaxial-type testing cell which indicates the ability of a mix to resist deformation under load. Since the resistance of materials to deformation can be related to material properties, the stabilometer test should provide some measure of the effect of such parameters as stiffness, which is analogous to modulus of elasticity, Poisson's ratio, and material strains. An indicator of these parameters is obtained from the pressure created in the oil cell surrounding the test specimen. The lateral pressure is caused primarily by the lateral deformation of the specimen created by the corresponding vertical load and deformation. The magnitude of the lateral pressure provides some idea of the material stiffness. Under a high vertical pressure a low lateral pressure indicates a stiff mixture while a high lateral pressure indicates a less stiff mixture. This stiffness, however, is confounded with the effect of Poisson's ratio. A low value of Poisson's ratio for a specimen would generally mean a low lateral movement for a given vertical movement while a larger value would mean a larger lateral deflection. The oil pressure in the device is also related to this movement and thus the factors are further confounded.

The lateral deformation of a specimen tested in the stabilometer cell is probably caused by the cumulative effect of shear, compressive, and tensile stresses. The stability, then, provides some measure of the tensile strain created in the specimen during testing, but other types of strain are expected to be confounded with them.

The Hveem cohesiometer value is obtained by measuring the force required to break or bend a circular specimen acting as a cantilever beam in the Hveem cohesiometer. Thus this test is similar to a beam test and primarily provides a measure of the flexural strength of the material. If the material is assumed to be linear elastic and to obey Hooke's law, stress is related to strain according to the equation

$$\sigma = \epsilon E$$

where

σ = stress,

ϵ = strain,

E = modulus of elasticity.

If a correlation exists between the cohesiometer value and tensile strength it follows from considering the above equation that there could also be correlation of the cohesiometer value with both the modulus of elasticity and tensile strain.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The correlations between the responses of the indirect tensile test and Hveem tests are dependent upon the confines of the study. The first experiment exemplifies the primary realm within which the Hveem tests have been used. In this experiment five of the eight comparisons under investigation were found to exhibit no correlation:

(1) Poisson's ratio and cohesiometer value,
(2) tensile strain and cohesiometer,
(3) modulus of elasticity and stability,
(4) tensile strength and stability, and
(5) tensile strain and stability.

In these five cases the responses were truly independent, and, therefore, the tensile properties could not be predicted from the corresponding Hveem parameters.

On the other hand, a range of test conditions was evaluated in Experiment 2 and correlation between the variables was found to exist for all comparisons.

The following correlations were found to be acceptable for a general range of test conditions:

(1) modulus of elasticity and cohesiometer value,
(2) tensile strength and cohesiometer value,
(3) tensile strain and cohesiometer value,
(4) Poisson's ratio and stability, and
(5) tensile strain and stability.

These can be used for estimating properties over a wide range of conditions, but in making such predictions one must be aware of errors associated with them, as indicated by the confidence bounds. It would be expected that primary interest would involve predictions of tensile parameters from Hveem parameters, but in special cases Hveem parameters would be predicted from indirect tensile parameters.

In the specific case of the sponsor's standard test conditions, the only acceptable correlation found involved the modulus of elasticity and the cohesiometer value.

The tests reported here were conducted to fulfill a special need, and it is, therefore, not recommended that further correlation be pursued. Time and money can better be spent on the development of a design method based on the indirect tensile test.

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APPENDIX 1

PREPARATION AND TESTING PROCEDURES

APPENDIX 1. PREPARATION AND TESTING PROCEDURES

All asphalt-treated materials were mixed for three minutes and compacted in a Texas gyratory shear molding press to form a cylindrical specimen with a nominal 4-inch diameter and 2-inch height. The molded specimens were allowed to cool to room temperature and their densities were determined (Ref 10). The specimens were cured, for three or fourteen days, at the designated curing temperature. At the end of the curing period the specimens to be tested in the stabilometer and cohesiometer were brought to the standard test temperature of 140° F ± 2° F (Ref 10), and the indirect tensile test specimens were brought to the proposed standard temperature of 75° F.

Companion specimens were prepared for each treatment combination. One specimen was tested in a carefully controlled indirect tensile test (Refs 4 and 5) and the other specimen was tested in the stabilometer, returned to the test temperature, and finally tested in the cohesiometer.

APPENDIX 2

TEST DATA FOR ASPHALT CEMENT
AND
TEST RESULTS FOR EXPERIMENTS 1 AND 2

TEST DATA FOR COSDEN ASPHALT CEMENTS
(Source: Cosden Petroleum Corporation, Big Springs, Texas)

Asphalt	AC-5	AC-10	AC-20
Water, %	NIL	NIL	NIL
Viscosity at 275° F, Stokes	2.45	2.6	3.6
Viscosity at 140° F, Stokes	773	1088	2532
Flash point C.O.C., ° F	560	570	565
Ductility, 77° F, 5 cm/min, cm	141+	141+	141+
Relative viscosity (after oxidation, 15μ films for 2 hours at 225° F, viscosities determined at 77° F)	3.87	4.0	2.7
Penetration at 77° F, 100g, 5 sec.	112	92	64
Specific gravity at 77° F	1.003	1.006	1.009
Solubility in CCl_4, %	99.7+	99.7+	99.7+

INDIRECT TENSILE TEST RESULTS FOR EXPERIMENT 1

Specimen Number	Treatment Combination*			Modulus of Elasticity, psi ($\times 10^5$)	Poisson's Ratio	Tensile Strength, psi	Tensile Strain, micro-units
	A	B	C				
1	-1	-1	-1	2.489	.2646	106.1	1474
6	+1	-1	-1	2.479	.1985	82.2	1100
3	-1	+1	-1	2.490	.2723	108.9	1682
8	+1	+1	-1	2.545	.1779	105.8	1610
13	-1	-1	+1	2.398	.3510	100.8	1506
14	+1	-1	+1	3.791	.2828	126.2	1697
11	-1	+1	+1	1.687	.4568	73.9	1846
12	+1	+1	+1	3.415	.2560	112.8	1076
21	-1	-1	-1	1.754	.0396	93.9	948
18	+1	-1	-1	2.455	.1653	96.0	1249
23	-1	+1	-1	1.551	.0487	72.3	989
24	+1	+1	-1	3.139	.1290	119.1	1088
25	-1	-1	+1	2.406	.3137	82.2	1107
30	+1	-1	+1	2.955	.2468	107.8	1426
27	-1	+1	+1	1.430	.1983	66.2	1174
28	+1	+1	+1	2.686	.3877	91.4	1343

* Factors and levels are as follows:

Factor	Description	Low Level (-1)	High Level (+1)
A	Aggregate	limestone	gravel
B	Gradation	fine	coarse
C	Asphalt content, %	5.5	8.5

STABILOMETER AND COHESIOMETER RESULTS FOR EXPERIMENT 1

Specimen Number	Treatment Combination* A	B	C	Stabilometer Value	Cohesiometer Value
5	-1	-1	-1	73.0	482.7
2	+1	-1	-1	62.5	378.4
7	-1	+1	-1	68.7	596.3
4	+1	+1	-1	62.2	560.6
9	-1	-1	+1	55.1	584.9
10	+1	-1	+1	70.0	652.4
15	-1	+1	+1	23.7	477.7
16	+1	+1	+1	37.8	613.7
17	-1	-1	-1	70.5	393.9
22	+1	-1	-1	71.2	432.1
19	-1	+1	-1	65.1	401.8
20	+1	+1	-1	56.9	503.5
29	-1	-1	+1	45.2	477.8
26	+1	-1	+1	53.8	561.9
31	-1	+1	+1	48.6	412.8
32	+1	+1	+1	54.7	529.4

* Factors and levels are as follows:

Factor	Description	Low Level (-1)	High Level (+1)
A	Aggregate	limestone	gravel
B	Gradation	fine	coarse
C	Asphalt content, %	5.5	8.5

INDIRECT TENSILE TEST RESULTS FOR EXPERIMENT 2

Specimen Number	Treatment Combinations*							Modulus of Elasticity, psi (x10^5)	Poisson's Ratio	Tensile Strength, psi	Center Tensile Strain, micro-units
	A	B	C	D	E	F	G				
242	-1	-1	-1	+1	-1	-1	-1	0.977	.4637	48.3	1639
210	+1	-1	+1	+1	-1	-1	-1	2.269	.4324	87.3	1645
249	-1	-1	-1	-1	+1	-1	-1	1.351	.2541	68.4	1477
233	+1	+1	-1	-1	+1	-1	-1	2.986	.3855	120.4	1757
217	+1	-1	+1	-1	+1	-1	-1	1.821	.1673	84.7	1399
201	-1	+1	+1	-1	+1	-1	-1	2.194	.2103	114.3	1384
252	+1	-1	-1	+1	-1	+1	-1	4.799	.1477	213.3	1136
220	-1	-1	+1	+1	-1	+1	-1	3.442	.1542	181.6	1188
243	+1	-1	-1	-1	+1	+1	-1	2.415	.0401	110.8	1016
227	-1	+1	-1	-1	+1	+1	-1	4.275	.0720	137.2	889
211	-1	-1	+1	-1	+1	+1	-1	3.651	.0663	173.2	1560
195	+1	+1	+1	-1	+1	+1	-1	4.983	.0565	198.6	1008
224	-1	-1	-1	-1	-1	-1	+1	1.263	.1568	74.4	1511
208	+1	+1	-1	-1	-1	-1	+1	2.631	.2278	122.7	1485
256	+1	-1	+1	-1	-1	-1	+1	2.376	.1711	107.9	1505
240	-1	+1	+1	-1	-1	-1	+1	2.378	.3213	115.9	1669
215	-1	-1	-1	+1	+1	-1	+1	1.806	.4606	79.9	1845
247	+1	-1	+1	+1	+1	-1	+1	2.374	.3084	102.9	1463
231	-1	+1	+1	+1	+1	-1	+1	1.462	.4462	65.5	1745
214	+1	-1	-1	-1	-1	+1	+1	3.737	.0177	137.1	857
198	-1	+1	-1	-1	-1	+1	+1	6.133	.1711	185.2	1398
246	-1	-1	+1	-1	-1	+1	+1	2.569	-.0897	174.9	1006
230	+1	+1	+1	-1	-1	+1	+1	5.005	.0443	206.1	957
221	+1	-1	-1	+1	+1	+1	+1	2.341	.2773	102.9	1576
205	-1	+1	-1	+1	+1	+1	+1	0.830	.3322	47.5	1978
253	-1	-1	+1	+1	+1	+1	+1	3.169	.1225	183.7	1200

* See Table 2 for factors and levels

STABILOMETER AND COHESIOMETER RESULTS FOR EXPERIMENT 2

Specimen Number	Treatment Combinations* A	B	C	D	E	F	G	Stabilometer Value	Cohesiometer Value
281	-1	-1	-1	+1	-1	-1	-1	25.61	395.4
265	+1	-1	+1	+1	-1	-1	-1	9.13	370.1
285	-1	-1	-1	-1	+1	-1	-1	61.19	287.1
277	+1	+1	-1	-1	+1	-1	-1	36.90	666.5
269	+1	-1	+1	-1	+1	-1	-1	74.39	577.1
261	-1	+1	+1	-1	+1	-1	-1	68.67	811.9
286	+1	-1	-1	+1	-1	+1	-1	65.00	1296.0
270	-1	-1	+1	+1	-1	+1	-1	39.35	993.4
282	+1	-1	-1	-1	+1	+1	-1	78.67	603.6
274	-1	+1	-1	-1	+1	+1	-1	64.77	1170.0
266	-1	-1	+1	-1	+1	+1	-1	79.39	801.9
258	+1	+1	+1	-1	+1	+1	-1	75.79	1102.0
272	-1	-1	-1	-1	-1	-1	+1	56.55	297.9
264	+1	+1	-1	-1	-1	-1	+1	60.79	631.1
288	+1	-1	+1	-1	-1	-1	+1	62.98	679.4
280	-1	+1	+1	-1	-1	-1	+1	48.05	837.6
268	-1	-1	-1	+1	+1	-1	+1	22.24	503.4
284	+1	-1	+1	+1	+1	-1	+1	18.78	549.8
276	-1	+1	+1	+1	+1	-1	+1	4.76	216.3
267	+1	-1	-1	-1	-1	+1	+1	65.32	895.0
259	-1	+1	-1	-1	-1	+1	+1	69.22	1082.0
283	-1	-1	+1	-1	-1	+1	+1	78.25	1125.0
275	+1	+1	+1	-1	-1	+1	+1	80.84	772.3
271	+1	-1	-1	+1	+1	+1	+1	26.23	796.3
263	-1	+1	-1	+1	+1	+1	+1	3.37	220.7
287	-1	-1	+1	+1	+1	+1	+1	37.58	845.3

* Factors and levels are as follows:

Factor	Description	Low Level (-1)	High Level (+1)
A	Aggregate	limestone	gravel
B	Gradation	fine	coarse
C	Viscosity (specs)	AC-5	AC-20
D	Asphalt content, %	5.5	8.5
E	Mixing temp., °F	250	350
F	Compaction temp., °F	200	300
G	Curing temp., °F	40	110

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