The Application of Triaxial Testing to Flexible Pavement Design

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This paper presents one of the methods of flexible pavement design based on the triaxial test. The tests reported herein were conducted by C. R. Lowrie and submitted in a thesis to the graduate school of Purdue University in partial fulfillment for his degree of Master of Science in Civil Engineering (1).

These data are a portion of the results of a comprehensive study of the triaxial test. The purpose of this study has been to present and illustrate the effect of soil and base course type, and degree of compaction on the design thickness of flexible pavements.

Design of flexible pavements is complicated in that there are practically as many procedures for design as there are agencies designing pavement. In the 1945 issue of the Highway Research Board Proceedings the report of the Sub-committee on Methods of Measuring Strength of Subgrade Soils presented a summary of 22 such methods (2).

The purpose of a flexible pavement is to distribute the load imposed upon its surface, down through the pavement in such a manner so that the supporting power of the subgrade soil itself is not exceeded. The structural strength of the pavement, then, is made up of the summation of the strengths of the various components making up the pavement.

The usual high type flexible pavement is made up of several distinct materials. The uppermost of these, the bituminous wearing course, is usually a relatively thin layer, the purpose of which is to add to the stability of the total pavement, to waterproof the base and to protect the base from raveling under the abrasive effect of traffic.

The next layer is the base course. This layer can be made up of several types of materials such as waterbound macadam, penetration macadam, crushed stone, gravel, slag and stabilized soil. The base course must have sufficient stability to withstand the wheel loads imposed on the surface as well as be of sufficient depth to adequately distribute the load over the sub-base or subgrade. One of the factors affecting the stability of the base course material is that of consolidation of the base itself. This has been found to be the case in many instances when the bituminous wearing surface has been noted to distort and rut, particularly when situated on a plastic subgrade soil —one on which it is difficult to attain adequate compaction of the base.

Immediately below the base material can be either the subgrade soil or a sub-base. The sub-base, if used, generally consists of a locally available material having higher supporting power than the subgrade. Many times the sub-base consists of the subgrade soil modified by the addition of a material such as sand, portland cement or asphalts and tars.

For adequate design each of these layers must be of better quality than each preceding lower layer. The most economical design to fit any particular situation is one that has just sufficient depth of each of the layers to insure adequate support for the distributed load at its lower surface.

The above applies to the structural capacity of each of the layers in its weakest condition. The design must incorporate a sufficient factor of safety against frost damage, subgrade volume change, drainage and many of the other variables affecting pavement stability.

Up until recent years the practice many times has been to arbitrarily select a pavement thickness of from six to ten or twelve inches without giving due regard to the strength of the subgrade soil or of the various materials making up the pavement. Since the advent of higher wheel loads, many of the pavements designed in this manner have been found to be totally inadequate to support present day traffic and as a result many highway departments have developed empirical methods of approach to the design of flexible pavements, both for primary and secondary roads.

In the field of airport engineering the extremely high wheel loads of airplanes developed during the last war have necessitated the development of a design procedure that enables the engineer to design for stresses far exceeding any previously encountered. For this, the U. S. Corps of Engineers have adopted the California Bearing Ratio test (3, 4). This test is an empirical test which incorporates the use of design charts obtained from correlations of test properties of soils and base materials in actual use, with performance under actual field conditions as well as accelerated traffic tests. The design charts as developed for airport runways have been adapted by some states, after modification, to fit their particular needs.

The triaxial test which has been used in the past in research, for the determination of certain physical properties of materials, has been adopted by many agencies for design purposes (5, 6, 7). This test is particularly useful in that it is adaptable to testing most all types of materials. It can be used in the evaluation of certain fundamental properties of materials as well as have its test results correlated with field performance.

In 1940, Palmer and Barber published a theoretical means of determining stresses under circular loaded areas (8, 9). The basic formulas have since been modified and adopted by the Kansas State Highway Department for flexible pavement design (5). This method utilizes the modulus of deformation of each of the materials making up the pavement. The modulus of deformation is essentially the secant modulus of elasticity of the soil or base material.

The Texas Highway Department has also been using the triaxial test for a number of years (6, 7). Their design procedures utilize the Mohr rupture envelope obtained from performing the triaxial test under varying lateral pressures. They have correlated the slope and position of the rupture envelope for various materials with field performance.

As a part of the current research on flexible pavement design conducted by the Joint Highway Research Project, a series of triaxial tests were made on several types of base materials commonly used in the construction of flexible pavements in Indiana as well as several typical Indiana soils. This was done for the purpose of determining the suitability of triaxial testing to pavement design conditions in Indiana.

MATERIALS TESTED

The base materials that were tested consisted of two basic types, a crushed limestone and a glacial-terrace gravel. The grain size distribution of both of these materials was varied so that one of the gradations approximated the course limits of gradation of AASHO specification B-1 for Materials for Stabilized Base Course

(AASHO Designation M56-42), one approximated the fine limits of gradation and one was of intermediate gradation (10). These gradations are referred to as coarse, fine and medium, respectively. Six different base materials (three crushed stone mixtures and three gravel mixtures) were thus tested. Limestone dust was used for the fines in the crushed stone mixtures and the soil-overburden obtained at the gravel pit was used for the fines in the gravel mixtures. Table 1 shows the grain size distribution of the base course materials.

TABLE 1

BASE COURSE MATERIALS TESTED

Sieve No.	Size Sieve Opening (MM)	Grain Size Distribution		
		Coarse Gradation (% Finer)	Medium Gradation (% Finer)	Fine Gradation (% Finer)
1"	25.4	100	100	100
½"	12.7	58	74	100
4	4.76	35	50	65
10	2.00	25	38	50
40	0.42	10	20	30
60	0.25	7	17	25
100	0.149	5	12	21
200	0.074	0	7	15

The soils tested ranged from a dune sand to a plastic drift soil. A total of five soils are presented: (1) plastic morainal clay, (2) sand from the Kankakee basin, (3) dune sand, (4) Wisconsin drift silty clay and, (5) Illinoian drift silty clay. These soils are typical of soils found in several major soil groups in Indiana. A list of the soils with the classification test results are shown in Table 2.

TEST PROCEDURES

All of the materials, soils and granular materials were molded to approximate saturation moisture content. The type of triaxial test used for the soils was one in which the soils were statically compacted to a specified percentage of standard Proctor density in molds three inches in diameter and seven inches in height. The soil specimens were then extruded from the molds, a thin rubber membrane placed over them and then placed in the triaxial testing device.

TABLE 2

SUBGRADE SOILS TESTED

Soil No.	Designation	L.L.	P.I.	Grain Size Distribution			B.P.R. Classification	
				2 mm.	0.05 mm.	0.005 mm.	Group	Group Index
		(%)	(%)	(% Finer)	(% Finer)	(% Finer)		
2846	Morainal Clay	33	18	100	78	40	A-6	10
2847	Kankakee Sand	--	N.P.	100	12	5	A-2	0
2848	Dune Sand	--	N.P.	100	3	2	A-3	0
2852	Parent Wisconsin Drift	30	17	98	55	19	A-6	9
2852	Parent Illinoian Drift	31	17	95	42	17	A-6	6

Figure 1 shows a diagram of this device as well as a picture of the completed setup in the hydraulic testing machine. Lateral confining pressures were applied by means of air pressure inside the outer lucite cylinder. Loads were measured by means of a proving ring. Tests were made under conditions of two rates of constant strain, 0.05 in. per minute and 0.005 in. per minute as well as two conditions of density.

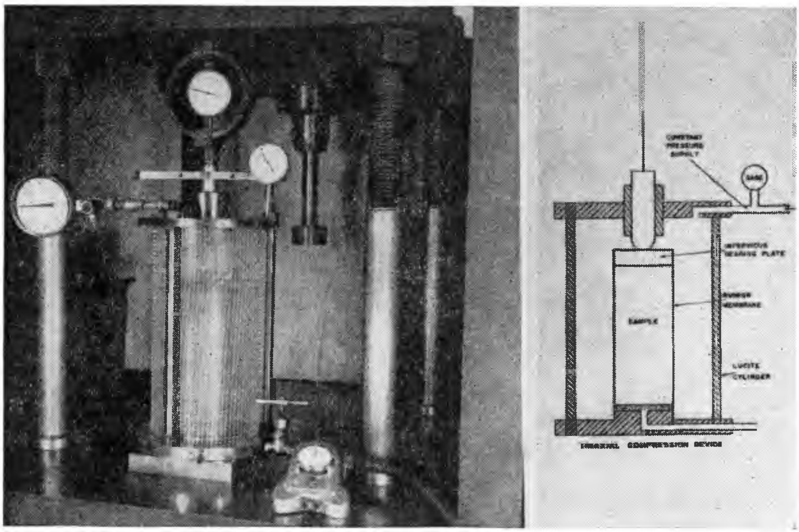


Figure 1. Triaxial Test Equipment for Testing Fine Grained Soils

The granular base materials were tested in the pressure cell type of triaxial device developed by the Texas State Highway Department. This cell consists of a stainless steel tube six inches in diameter and twelve inches in height. A rubber membrane is encased inside this tube and fastened at each end. Lateral air pressure is applied between the steel cylinder and the rubber membrane.

Figure 2 shows a view of the steel cylinder being placed over a compacted specimen. The load is applied through the porous stones located at each end of the specimen. One disadvantage of this test is that a considerable, but indeterminate amount of friction, is developed between the porous stones and the rubber membrane. The granular materials were tested under two conditions of density, but just one rate of strain—0.05 in. per minute.

Figure 2. Placing Triaxial Cell Over Specimen

RESULTS

Figure 3 shows a set of typical stress-strain curves. These particular curves are for the Illinoian Drift soil. The increase in ultimate compressive stress with increasing lateral pressure is noticeable. The dashed line is the curve resulting from the test with 20 pounds per square inch lateral pressure and a rate of strain of 0.005 in. per minute.

The design procedures developed by the Kansas Highway Department utilize a test performed at a unit lateral pressure of 20 pounds per square inch and a rate of strain of 0.005 in. per minute. The rate of strain and lateral confining pressure at which a soil is tested will determine, to a large extent, the compressive strength of the soil and the design test should duplicate, in so far as practicable, actual conditions as they will occur under the pavement. The need for further study in this connection is indicated.

The modulus of deformation of the soils was determined as the secant modulus at the range of stress to be considered under the pavement.

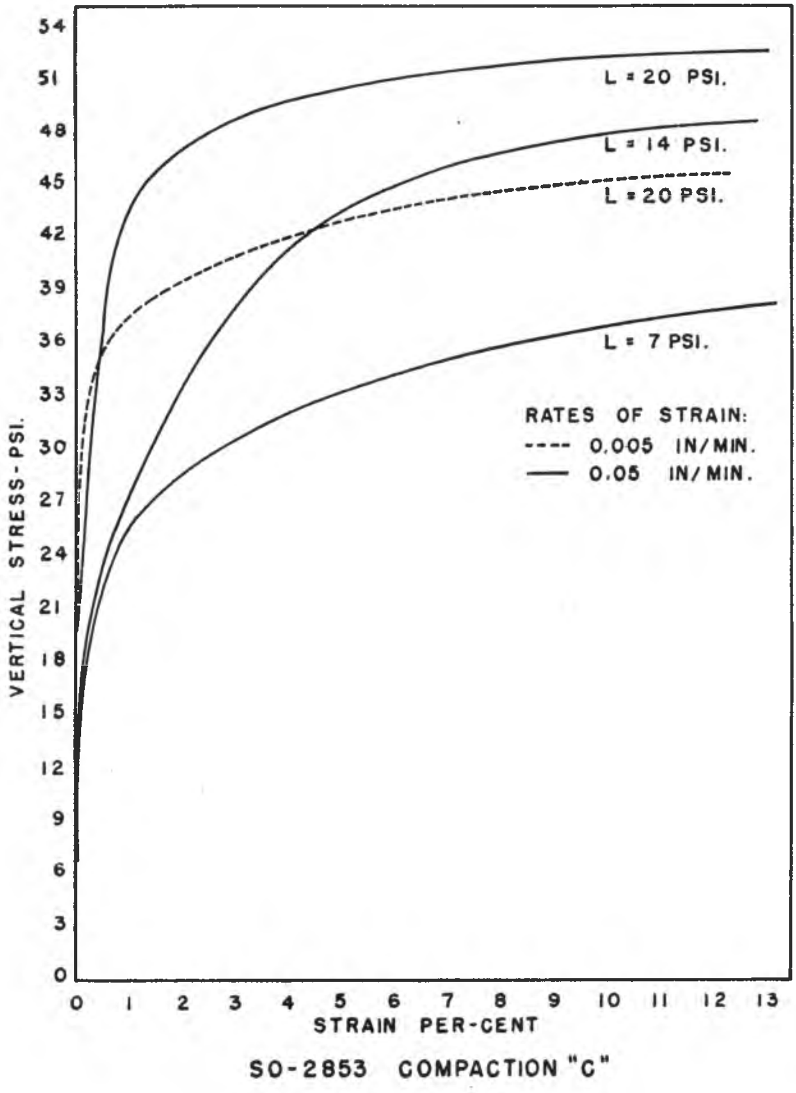


Figure 3. Typical Stress-Strain Curves

Figure 4 shows a set of Mohr circles for the same soil with the Mohr rupture envelope drawn in as a straight line. For the soils tested the values of internal friction and cohesion varied from 3° and 3 pounds per square inch, respectively, for the most plastic soil (Valparaiso Moraine Clay) to 38° and 2 pounds per square inch for the Kankakee Sand sample.

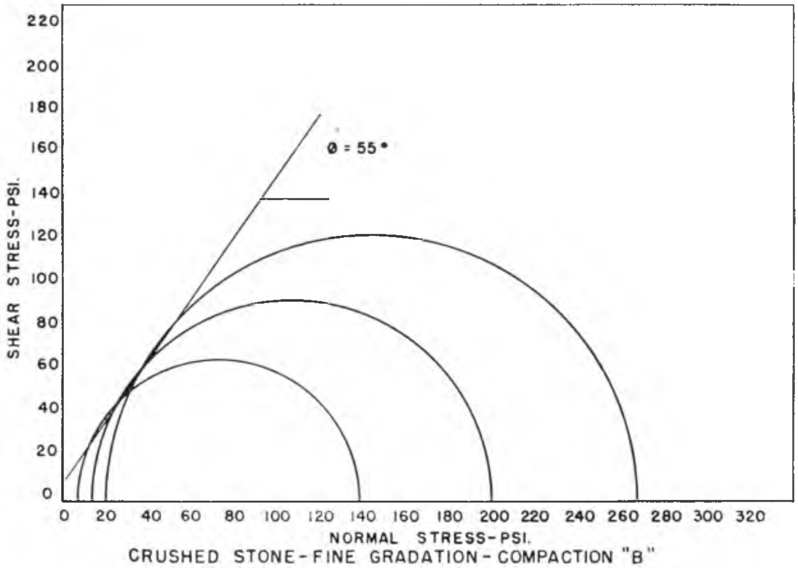


FIG. 4 **TYPICAL MOHR DIAGRAM**

Figure 5 shows the Mohr diagram for the crushed stone of fine gradation. One disadvantage of the conventional type of triaxial test is that of determining the exact shape and slope of the Mohr rupture line. For example, all of the crushed stone samples resulted in a Mohr envelope that indicated some cohesion existed in the material.

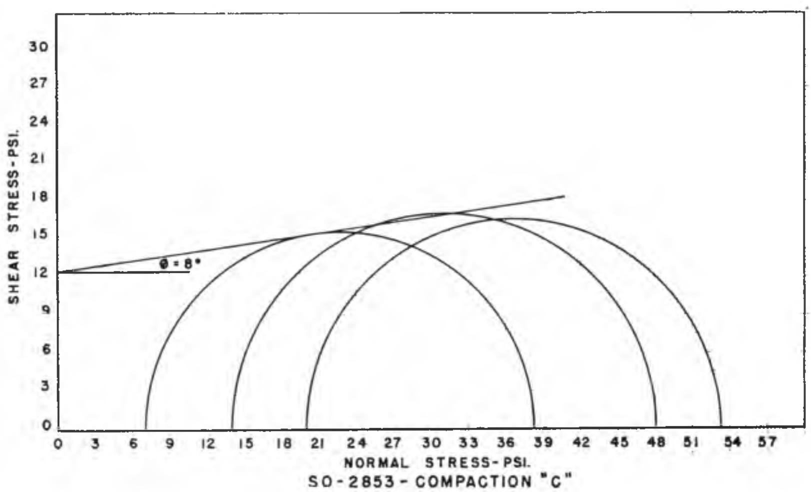


Figure 5. Typical Mohr Diagram

Each of the granular materials was a noncohesive material and as such, the Mohr envelope should pass through the origin. For purposes of this project each of the rupture lines was interpreted as a straight line drawn tangent to the stress circles.

The results showed the angle of friction of the gravel to vary from 54° to 50°, and the crushed stone from 55° to 50°. The material shown on this slide indicates the angle of internal friction to be 55°.

The formula from which pavement thickness is determined was first developed by Palmer and Barber (8, 9) and modified by the Kansas Highway Department (4). The formula for determining the thickness of pavement required is as follows:

$$T = \left[\sqrt{\left[\frac{3P}{2\pi CS}\right]^2 - a^2}\,\right]\left[\sqrt[3]{\frac{C}{Cp}}\,\right]$$

Where:

T = Thickness required in inches

C_p = Modulus of deformation of pavement or surface course in p.s.i.

C = Modulus of deformation of subgrade or subbase in p.s.i.

P = Single wheel load in pounds

a = Radius of area of tire contact in inches

S = Permitted surface deflection in inches

The Kansas Highway Department then introduced the coefficient m and n to modify the formula as follows

$$T = \left[\sqrt{\left[\frac{3\,P\,mn}{2\pi CS}\right]^2 - a^2}\,\right]\left[\sqrt[3]{\frac{C}{Cp}}\right.$$

Where:

m = Traffic coefficient varying from 1.0 to 0.5 depending on type and volume of traffic

n = Saturation coefficient varying from 1.0 for 45 inches annual rainfall to 0.6 for 15 inches of annual rainfall

When a combination of two types of flexible material is desirable, the following formula is also used:

$$t_t = (t_s - t_p) \sqrt[3]{\frac{C_p}{C_t}}$$

Where:

t_t = Thickness of base course in inches

t_s = Thickness of bituminous pavement required directly on the subgrade in inches

t_p = Thickness of bituminous surface in inches

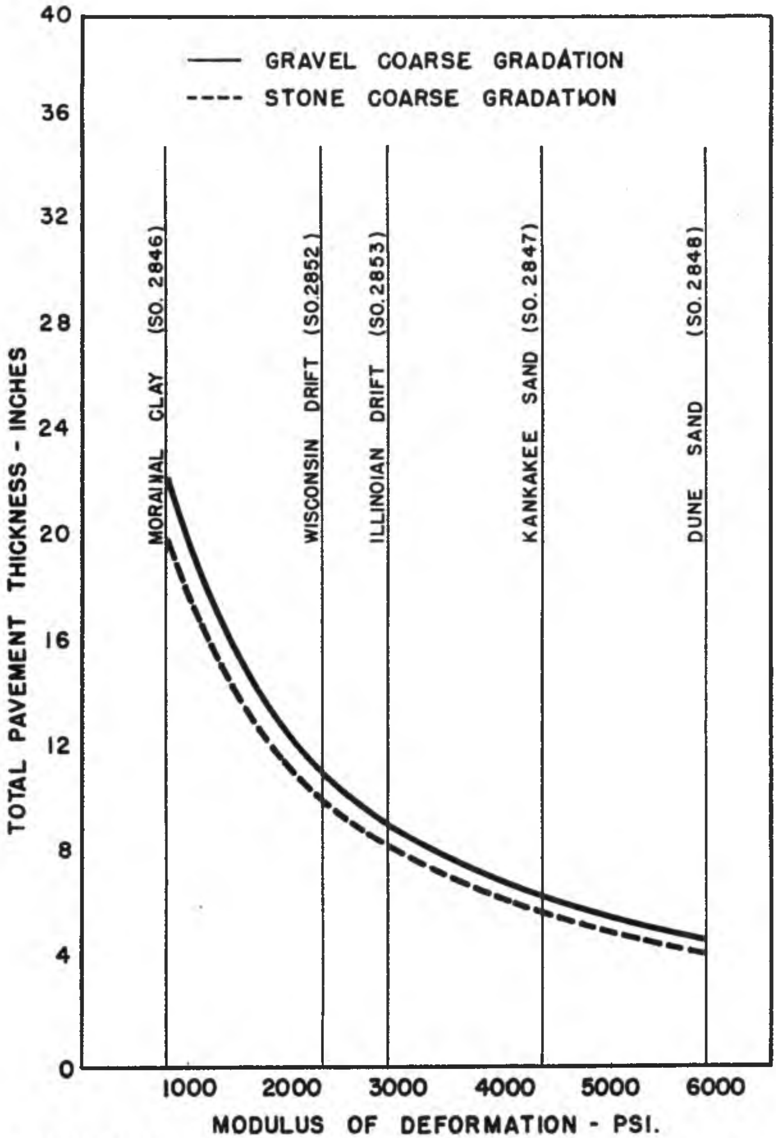
c_p = Modulus of deformation of bituminous surface in p.s.i.

c_t = Modulus of deformation of base course in p.s.i.

Figure 6 shows a comparison of pavement thickness required for the coarse gravel and crushed stone mixtures. All soils and base materials were compacted to approximately 100 per cent Proctor density. In all cases a two-inch bituminous mat with a modulus of deformation of 15,000 pounds per square inch was assumed. A 9000-pound single wheel load was used, and the rainfall and traffic coefficients were taken as unity. On this figure total pavement thickness (pavement plus base) is plotted against modulus of deformation of the soil. These curves are not presented as design curves but rather as an illustration of the use of the triaxial test to pavement design.

It will be noted that the gravel base course used on the plastic clay (Valparaiso Moraine clay) requires the greatest thickness, requiring 22½ inches. Also the crushed stone used with this clay requires 20 inches. It is further noted that for the better subgrade soils the difference between the required depth of gravel base and required depth of stone base decreases. For the plastic clay the difference is 2½ inches and for the dune sand they require approximately the same thickness.

Figure 7 shows the required thickness for the two base materials of medium gradation. The required thickness varies from a maximum of 27½ inches for the gravel base on the plastic clay soil to 4½ inches of stone and surface on the dune sand. Here again, the greatest difference between the two base materials resulted when used on the plastic clay (a difference of 5½").



COMPARISON OF REQUIRED TOTAL PAVEMENT THICKNESS FOR SEVERAL SOILS

Figure 6. Comparison of Required Total Pavement Thickness for Several Soils

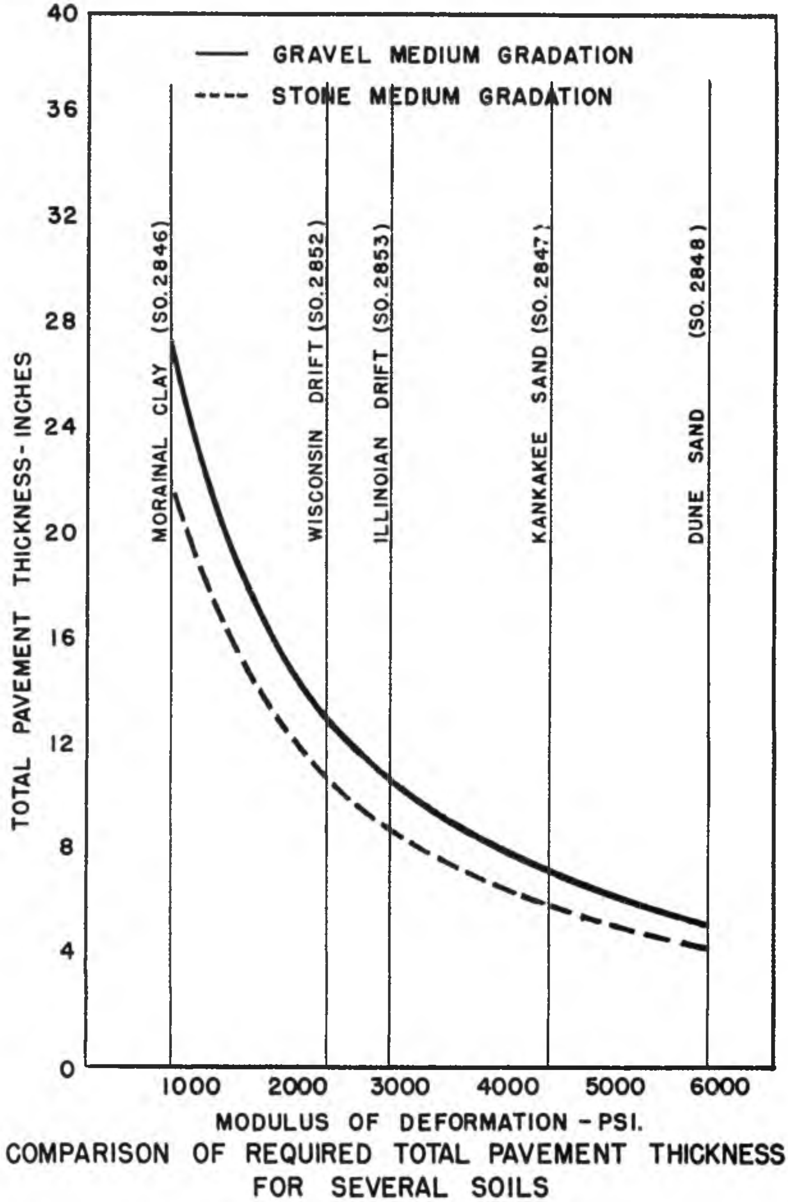
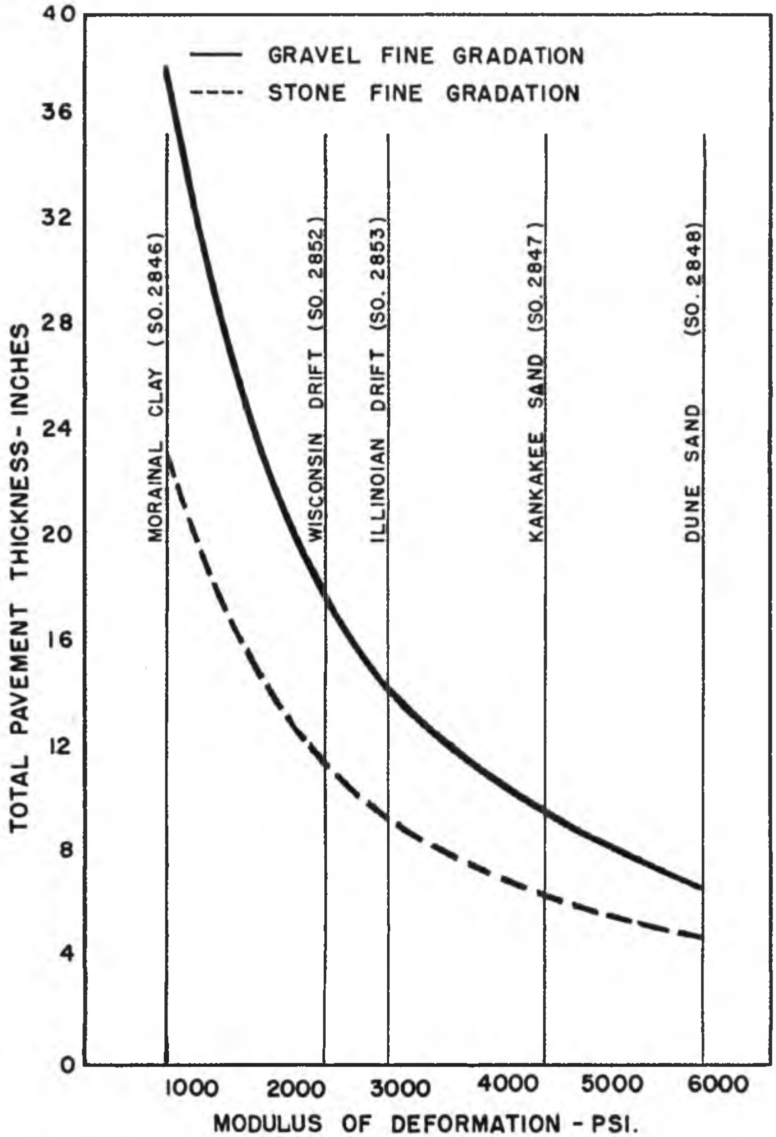


Figure 7. Comparison of Required Total Pavement Thickness for Several Soils



COMPARISON OF REQUIRED TOTAL PAVEMENT THICKNESS FOR SEVERAL SOILS

Figure 8. Comparison of Required Total Pavement Thickness for Several Soils

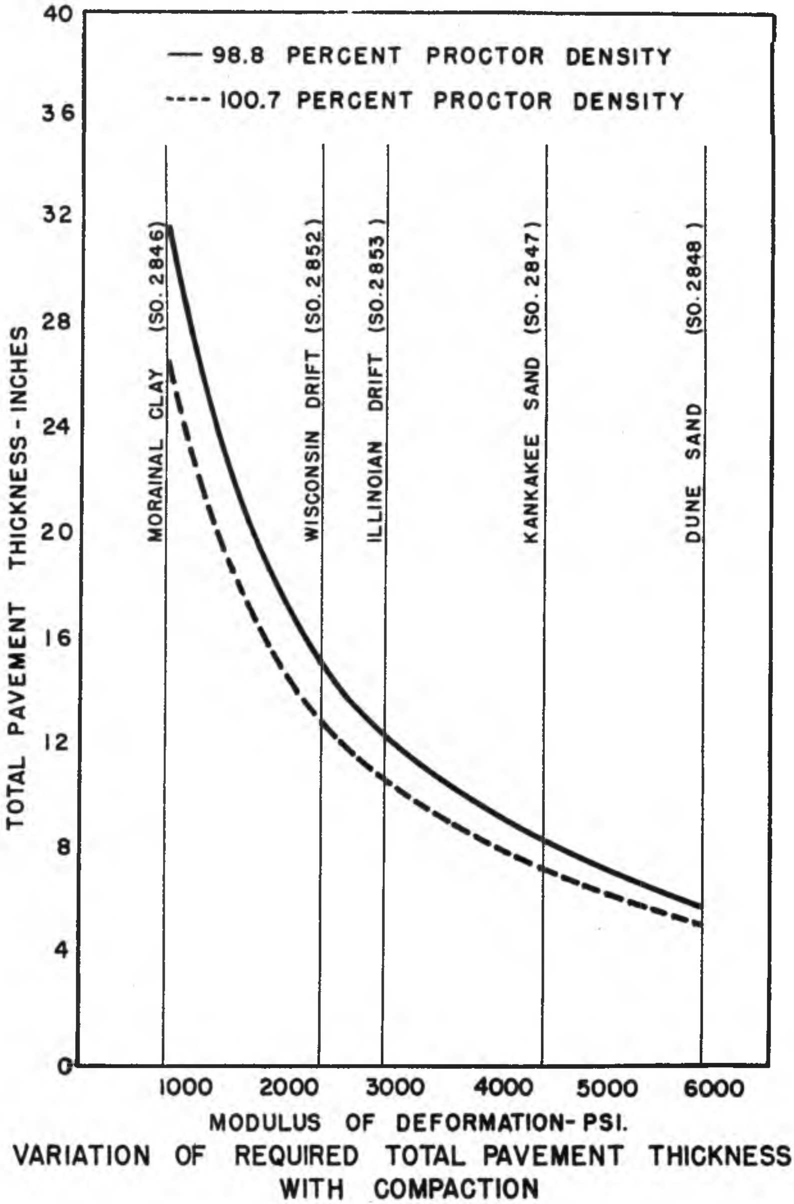


Figure 9. Variation of Required Total Pavement Thickness With Compaction

Figure 8 shows the required thickness for the two base materials of fine gradation. In this instance the required thickness varies from 38 inches for the gravel plus surface, when used on the clay subgrade, to 5 inches of stone and surface when used on sand.

Comparison of the three graphs indicates that of the materials tested the gravel required the greatest thickness and also that the difference between the stone and gravel was greatest for the fine gradation base materials. For example, the greatest difference in required thickness for the two materials of comparable gradation (when used on the plastic clay) resulted from the fine gradation—a difference in thickness of 15 inches—while for the medium gradation the difference was 5½ inches and for the coarse 2½ inches. In other words, the difference between the merit of stone and gravel was more noticeable for the finer limits of gradation.

Figure 9 shows a comparison of required pavement thickness for the medium graded gravel under conditions of two densities. It will be noted that a very small decrease in the density (two per cent) results in an appreciable increase in pavement thickness (an increase of five inches on the plastic soil, and one inch on the sand).

SUMMARY

On the basis of these tests it is indicated that the triaxial test is particularly adaptable to flexible pavement design in that it takes into account the structural qualities of the surface and base course as well as that of the subgrade soil. It is a test which can be made equally well on all the component layers.

In the final analysis a test of this type must be correlated in some manner with actual field performance and climatic conditions. The matter of intensity of traffic and rainfall can well be handled much in the manner as used by the Kansas Highway Department. The same type of factor would be used to insure an adequate factor of safety against frost action and spring breakup.

The purpose of a design test of this sort is to take into account variations in soil texture as it occurs in nature. For a given highway, design testing brings out the need for greater thickness on one section, while thinner more economical sections can be used on others.

Then, too, if sufficient data for a given soil area are obtained, with a knowledge of soil types and their variations, and when used in conjunction with field performance records, an economical standard design might be evolved for this area.

A serious problem for the immediate future is that of developing a design procedure to fit conditions in Indiana. Much experimental work is indicated in the development of test procedures to evaluate subgrade soils and granular base materials so that an economical design may be obtained to fit the needs of each particular job. At the same time pavement depth and quality must be sufficiently great to withstand present day heavy wheel loads.

BIBLIOGRAPHY

1. Lowrie, Charles R., "Application of Triaxial Testing to the Design of Flexible Pavements," a thesis submitted to Purdue University in partial fulfillment for the degree of Master of Science in Civil Engineering, 1951. (Unpublished).
2. "Progress Report of Subcommittee on Methods of Measuring Strength of Subgrade Soils—Review of Method of Design of Flexible Pavements," *Proceedings,* Highway Research Board, Vol. 25, pp. 8-18, 1945.
3. Porter, O. J., "Foundations for Flexible Pavements," *Proceedings,* Highway Research Board, Vol. 22, pp. 100-136, 1942.
4. "The California Bearing Ratio Test as Applied to the Design of Flexible Pavements for Airports," War Department, Corps of Engineers, Technical Memorandum No. 312-1, 1945.
5. State Highway Commission of Texas, "Design of Flexible Pavement Using the Triaxial Compression Test," *Highway Research Bulletin No. 8,* 1947.
6. McDowell, Chester, "Progress Report on Development and Use of Strength Tests for Subgrade Soils and Flexible Base Materials," *Proceedings,* Highway Research Board, Vol. 26, pp. 484-506, 1946.
7. McDowell, Chester, "Application of Triaxial Testing to Flexible Pavement and Bridge Foundations," Texas Engineering Experiment Station, Agriculture and Mechanical College of Texas, *Bulletin No. 112,* pp. 57-71, August, 1947.
8. Palmer, L. A. and Barber, E. S., "Soil Displacement Under a Circular Loaded Area," *Proceedings,* Highway Research Board, Vol. 20, pp. 279-286, 1940.
9. Palmer, L. A., "Soil Displacement Under a Loaded Circular Area," *Public Roads,* Vol. 21, No. 10, December, 1940.
10. "Standard Specification for Materials for Stabilized Base Course," AASHO, Designation M56-42, American Association of State Highway Officials, 1942.