TRIAXIAL TESTING METHODS USABLE IN FLEXIBLE PAVEMENT DESIGN

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SYNOPSIS

Triaxial testing provides lateral support to a specimen which at the same time is subjected to a vertical load. It also allows expulsion of water from the specimen as the test progresses. A value of total stress coincident with strain is obtained at regular intervals. From these data a stress-strain curve is drawn, which in turn is used for the determination of the modulus of deformation.

The paper presents the results of experience in Kansas with the triaxial method of test and the steps taken to evolve a comprehensive and accurate method of design for flexible pavements.

Triaxial tests may be conducted upon each component of both the road surface and the foundation individually and calculations made to determine the thickness of each material which is required upon the subgrade. Any desired lateral pressure may be applied and maintained throughout the test. The triaxial apparatus as used by the Kansas Highway Commission permits a comprehensive method of design and enables the engineer to evaluate each of the components separately, finally combining them to form a full road structure.

The items of wheel load, deflection, sampling, saturation, and lateral pressure are discussed. Test data are obtained which permit the determination of volume, area, stress, and strain. Curves are drawn using the values of stress and strain obtained. These, in turn, are used for the calculation of the modulus of deformation.

This is used for the calculation of the required thickness of each component of the road structure, and is a most useful tool in obtaining comparative values of various types of mixtures. Another important use of the triaxial testing method is the determination of permissible loads on existing highways and airports.

At the meeting of the Highway Research Board last year several excellent papers were presented demonstrating various methods for the design of flexible pavements. Each of these papers contributed some valuable facts which have application to the problem as a whole.

The proposed methods have differed in their conception of the procedure necessary to accomplish the desired end, that is, to provide sufficient yet economical thickness of flexible surfaces for given subgrades. Some of the methods base their solutions on a wealth of data obtained over a long period of time together with a convenient tool by which to apply the data collected Others have based their solutions on theoretical conceptions revised to comply with the more complex relationship involved when soils are considered. Others have been proposed which combine both systems in some degree or another.

Most of these methods have a tool by which a measurement is made of some characteristic (usually a form of strength) of the material under consideration. Some of the tools which have been proposed are needles of various shapes, loaded pistons, loaded plates, and shear machines.

Kansas has had extensive experience during the past three years with the use of the triaxial compression apparatus and method of testing.

The equipment used by the Kansas Highway Commission is shown in Figures 1 and 2. It is patterned after that used by the U. S. Corps of Engineers at their Vicksburg Experiment Station. The apparatus as designed for our purpose can be used for testing both soils and aggregate mixtures. Small specimens 2.8 in. by 8 in. are used for soil and small aggregate mixtures with No. 4 maximum size. Large specimens 5 in. by 14 in. are used for larger aggregate mixtures. Aggregate with a maximum size of 1½ in. can be tested. The load is applied by a 60,000-lb. hydraulic compression machine. Most of the other equipment is mounted on or may be stored in a convenient cabinet provided with rollers so that it can be readily moved to any position in the laboratory. An air compressor with motor is mounted inside the cabinet.

The items pictured in Figure 1 are as follows: (1) loading device; (2) triaxial compression chamber; (3) manometer board; (4) glycerin reservoir; (5) equipment cabinet; (6) water hose; (7) glycerin hose.

Figure 2 pictures these items: (A) base plate; (B) head plate; (C) compression cylinder; (D) sample cap; (E) porous stones; (F) rubber sleeve; (G) piston; (H) dial arm; (I) Ames dial; (J) feeler gauge; (K) gauge stocks;

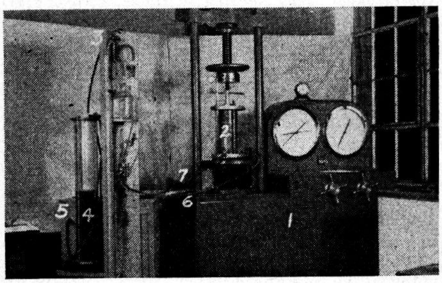

Figure 1. Equipment for Kansas Triaxial Compression Test Method

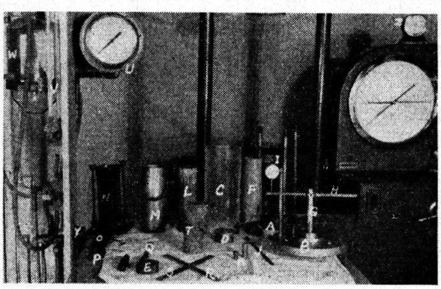

Figure 2. Equipment for Kansas Triaxial Compression Test Method

(L) forming core; (M) forming jacket; (N) compaction mold; (O) calipers; (P) piano wire saw; (Q) knife; (R) steel rule; (S) straight edge; (T) failed specimen; (U) pressure gauge; (V) pipettes; (W) aspirator bottle; (X) mercury manometer; (Y) control switch for air compressor; (Z) Kodak timer.

Triaxial testing essentially provides lateral support to a specimen which at the same time is subjected to a vertical load. It also allows expulsion of water from the specimen as the test progresses in a manner corresponding to the loss of water from material under actual conditions. The total stress coincident with strain is obtained at regular intervals. From these data a stress-strain curve is drawn, which in turn is used for determining the modulus of deformation.

The U. S. Army Engineers in their laboratory at Vicksburg have used a similar apparatus for soil testing in connection with levee construction. Mr. V. A. Endersby of the Shell Development Company has used triaxial apparatus for evaluating asphaltic mixtures. The Highway Departments of the states of Nebraska and Michigan each have similar apparatus which they are using experimentally. This apparatus has also been used extensively by the Delft Laboratories of Holland. Others have reported its use in connection with various soil problems including embankment construction and foundation investigation.

It is our purpose in this paper to present the results of our experience with the triaxial method of test and the steps taken to evolve a comprehensive and accurate method of design for flexible pavements. We believe we are the first to adapt this method of testing to the full problem of design of this type of roadway. We are wholly satisfied with our progress and results to date. There are several phases of the over-all problem which we wish to work out more completely before making a full presentation of the solution. This we hope to do in the immediate future. We feel we have information of value to others interested in the general problem and more specifically in the triaxial method of testing.

In order to have definite understanding of the terms used in this paper, it is necessary to assume the tentative responsibility for defining each component. In so doing it is intended to follow the usage in the Highway Research Board Bulletin, "Granular Stabilized Roads," No. 5 of a series on Wartime Road Problems.

This bulletin divides the road structure into two parts: (1) the road surface, (2) the foundation. These in turn can each be divided into two components. Whether or not every component exists in a given road structure depends upon the requirements of the case at hand. One component may be absent and others present depending upon the requirements of the proposed structure. The road surface may consist of a pavement and a base course combined or either one used separately.

The foundation may consist of a subbase and a subgrade combined or may be only a subgrade.

For the purpose of this paper each component which may exist in a road structure will be defined as follows.

Pavement: A top course composed of an aggregation of inert particles together with a binder. The mixture should be placed at such thickness as to impart added strength to the road structure and be strongly resistant to wear.

Base Course: A granular stabilized layer covered with an impervious layer. A base course must have high internal stability.

Subbase: A layer or layers of material placed between the subgrade and the base course having greater stability than the subgrade but usually less stability than the base course. This may involve a modification of the existing subgrade, in which case the modified portion of the subgrade thus becomes the subbase.

Subgrade: The existing or natural material upon which the other component parts of the road structure are placed.

To evaluate this problem completely it is first necessary to understand the functions of the component parts of the full structure. By full structure is meant the pavement, base course, subbase, and subgrade taken as a unit. It is relatively easy to describe the requirements of a base course for a given subgrade subjected to normal traffic solely by experience. However, it is not easy to design a base course for exceptional conditions, such as muck spots, frost heave areas, weak structured shales, etc, over which most failures occur even for normal road traffic. It is not simple to design a flexible structure over a given soil for wheel loads exceeding those with which one is familiar Neither is it often economical to design a stable aggregate mixture with the thickness necessary for such conditions Hence, for heavy loads on poor subgrades one or more subbases are usually employed. These are an improvement over the existing subgrade, but are not of sufficient strength to act as the main load-carrying component These subbases allow more economical construction than the use of a base course only.

A comprehensive method of design must enable the engineer to evaluate each of these components separately and combine them to form a full road structure.

The triaxial apparatus as used by the Kansas Highway Commission permits this Of course, each component does not exist in every case, in fact, many cases involve only the base course and subgrade, where comparatively low wheel loads are used on good foundations

Wheel Load

In general a 5,000-lb. wheel load is used as the basis of design for highways in Kansas at the present time. Of course, many wheel loads exceed 5,000 pounds But from a study of traffic data obtained by the highway planning department this wheel load is the heaviest occurring at such frequency as to entitle it to be used as a basis of design.

Deflection

The deflection allowable for bases and subbases has been recently fairly well established as being between 0 05 in and 0 2 in. Some of the contributors towards establishing these limits have been O. J. Porter, California Division of Highways working on a western Airport in 1943, T. A. Middlebrooks, Principal Engineer, United States Engineer Department and Captain G E Bertram, Air Forces, U. S. Army, Proceedings of the Highway Research Board, Vol. 22, pp. 144–173, and Prevost Hubbard, in the Asphalt Institute Publication of May 5, 1943. Deflection has been a controversial subject for many years and these investigators are to be complimented upon their work in narrowing these limits as far as they have. It is to be hoped that further investigation will show whether or not it is practicable to expect narrower limits. Kansas at present uses 0 1 in. deflection for design purposes. This value was arrived at through a study of our flexible surfaces and from experimental data obtained at the outset of our work with triaxial testing as applied to the design of flexible pavements.

Sampling

We prefer to use, in so far as possible, undisturbed samples of subgrade as found in the roadbed. We have detected certain differences in test results when soils are compacted in the laboratory to the same densities and at the same moistures as exist in the field.

For estimating and plan design purposes, however, laboratory compacted samples may be used, provided there is a follow-up by tests of undisturbed samples of the roadbed after construction of the subgrade. Realization of the need for obtaining undisturbed roadbed samples for testing purposes has come about by a study of numerous field samples.

Traffic and weather act to give certain soil materials much higher densities than anything that has been obtained by laboratory compaction. Some of these densities exceed by a considerable amount those attained by rolling with heavy equipment. This dense material can be utilized to considerable advantage in flexible pavement design due to the fact that it provides a layer of exceedingly strong material upon which to place the road surface. Usually this highly dense layer is not of very great thickness (3 to 4 in.) and therefore the undisturbed samples from such strata are taken horizontally, parallel to the road surface, rather than vertically.

Saturation

The Kansas procedure calls for all samples to be tested in a saturated condition. Saturation is deemed desirable in order to obtain a direct comparison for all types of materials, at the same time obtaining a measure of the strength when the material is in its weakest condition. Materials such as soils and stable mixtures seldom fail when dry. These materials usually fail when quite wet. To definitely determine the degree of saturation which may occur for all materials and soils is a task of such proportions that it is doubtful if the true answer could ever be obtained for a very wide area. To reproduce this condition in the laboratory, even if known, is also a very difficult problem and our results indicate that this reproduction differs to some extent from the condition actually obtained under traffic, even though the exact values for moistures and densities are the same. For these reasons it is very important that samples taken for testing be removed in a relatively undisturbed state from the roadbed and subsequently saturated before testing begins.

For many areas saturation presents a considerable factor of safety. It proves more of a factor of safety than economical construction might dictate in areas where field moisture conditions are not as serious as this saturated condition imposed on the samples tested. This situation is conveniently dealt with, however, by varying the wheel load designed for in those areas. As the maximum wheel load is not used in any case, some judgment must be exercised in determining the proper figure to use for design by any method. The principle of further adjusting the design value in accordance with other conditions is not unsound. The test conditions and methods remain constant, hence the test values remain comparative and an economical design is still possible. Such procedure does not differ materially from that used by designers of other types of structures.

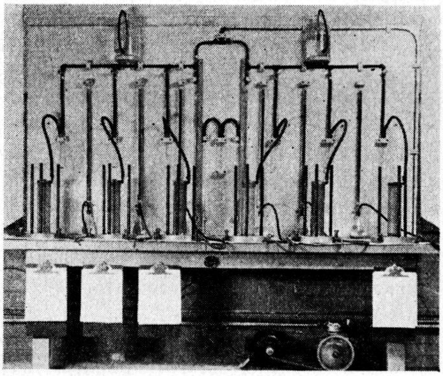

Figure 3. Battery Saturator for Triaxial Specimens. This shows the equipment used by the Kansas Highway Commission for saturating from one to six triaxial test specimens simultaneously. Vacuum furnished by the pump is applied to each specimen through steel tubing connected to the long manifold at the top of the panel. The vacuum which is applied to each side of the saturator is controlled by an oxygen valve. The amount of this vacuum is indicated by mercury manometers. Water is made available to each specimen through a rubber hose from an Erlenmeyer flask. At the beginning of each test the flask is filled to a definite mark. The amount of water taken at any time may be measured by re-filling the flask to the mark from the 100 cc burette mounted above each flask. Two aspirator bottles serve as reservoirs. These have a short section of tubing attached for convenience in filling the burettes.

Saturation is obtained by drawing water through a specimen enclosed in a rubber sleeve, by a vacuum, using the multiple saturation set-up shown in Figure 3. Many samples can be saturated simultaneously and the time required for saturation does not become a "bottleneck" to the laboratory procedure Saturation may be attained in from 20 min to 2 weeks depending on the density and the characteristics of the material. Commonly about one day is required for compacted soils and somewhat less for compacted base materials

Since sample preparation has a profound effect on test results, it is desirable to call your attention to a condition encountered in our laboratory and also to show steps taken to correct it. When water under head is admitted to the bottom of the specimen more rapidly than it is dispersed by the vacuum which is applied at the top it may result in an abnormal moisture condition. This is explained by considering that the soil particles in the lower portion of the specimen are disturbed considerably and are broken free from one another by water pressure. This results in an increase in pore space greater than that which might be expected from normal swell of the soil. This condition may be readily detected through a study of moistures and densities before and after saturation together with a knowledge of the volume change characteristics of the soil. It may be prevented by decreasing the head of water or by using a water supply which is not provided with a head

Table 1 shows a number of soil densities and moistures both before and after saturation. A study of this table will provide the reader with some interesting facts regarding the effect of initial density and moisture on saturation, as well as the effect of saturation on final density and moisture. A study of the zero air voids curve in connection with each sample under consideration serves as a means by which one can determine whether or not saturation had been attained and as a check on incompatible moisture-density relations which might occur through an error in weights or measurements of the specimen or the added water.

TABLE 1
MOISTURE AND DENSITY DATA SHOWING VALUES BEFORE AND AFTER SATURATION

Laboratory Number	Sample Number	Classification	Plasticity Index	Specific Gravity	Density lb. per cu. ft		Moisture Percent of Dry Weight				Variation in % from Complete Saturation
									At Zero Air Voids		
					As Sampled	After Saturation	As Sampled	After Saturation	As Sampled	After Saturation	
AA-3016	110	C	22	2 67	97	96	25	27	27	27	0
AA-2973	4B	SiL	16	2 59	101	100	16	24	23	24	0
AA-3017	119	C	22	2 62	100	97	15	25	24	26	−1
AA-3017	123	SiCL	20	2 51	86	85	16	32	33	34	−2
AA-3014	103	L	10	2 59	107	107	13	20	20	20	0
AA-2957	6–8	L	10	2 55	99	102	12	22	24	22	0
AA-2969	34	CL	13	2 78	116	115	15	18	18	18	0
AA-2957	6–10	S	0	2 63	117	117	6	15	16	16	−1
{AA-2957	6–11	SL	7	2 63	108	108	10	19	20	20	−1
AA-2957	6–12	CL	17	2 63	100	100	7	24	24	24	0
AA-3088	56	SiCL	16	2 53	89	90	18	30	31	30	0
AA-3063	18	SiL	10	2 54	83	86	10	32	36	33	−1

Lateral Pressures

The lateral pressure which is applied to the specimen is comparable to the lateral support or horizontal resistance which is normally provided by the adjacent similar material under field conditions. The effect of lateral support is not generally realized by the average person. An example may serve to clarify the situation. Consider a normal subgrade upon which is laid a plate 9 in. in diameter. Apply a load of 5,000 lb. to this plate resting upon the subgrade. Some settlement will likely occur. Now remove the material surrounding the cylinder of soil directly below the plate and reapply the load of 5,000 lb The cylinder will probably collapse. The load has not been increased but the horizontal resistance has been removed, allowing the sides of the soil cylinder to move outward uncontrolled. When similar material surrounded the cylinder such horizontal movement was resisted. The lateral pressure applied to a specimen in a triaxial compression test is similar to this horizontal resistance.

TEST DATA

At frequent intervals throughout the testing of each specimen, readings are taken simultaneously of the vertical applied load, vertical deformation, and the amount of water in the pipettes, denoting increase or decrease in the volume of the specimen For each reading calculations are made of the corresponding volume, area, stress, and strain. A number of these determinations permit the drawing of stress-strain curves. The stress-strain graphs for soils and soil mixtures usually are in the form of a curved line with a gradual increase in curvature rather than an abrupt divergence from a straight line as is found in stress-strain curves for steel and similar materials.

Modulus of Deformation

The stress-strain curve is used in the determination of the modulus of deformation of the material being tested For steel and other similar materials the modulus of elasticity is defined as the ratio of the increment of unit stress to the increment of unit deformation within the elastic limit These materials have a straight line graph up to the elastic limit The slope of any portion of the straight line gives the modulus of elasticity. If the stress-strain graph is curved as is usual in the case of soils and soil mixtures, the modulus of deformation is not a constant but a variable depending upon the range of stress for which the modulus is calculated.

The modulus of deformation is the secant modulus between the two points on the stress-strain curve limiting the range of stress determined. The determination of the range of stress for which the modulus of deformation is desired will be explained presently in this discussion.

USE OF DATA

The results which are obtained in triaxial testing may be interpreted in various ways but the interpretation should always include all of the variables which affect the service of the road bed structure

A flexible pavement must be designed for some particular wheel load with a given area of contact If both the wheel load and the area of contact are known it is then quite simple to determine the unit pressure which exists at the surface of the pavement

The stress applied to the roadbed structure decreases with the depth The amount of stress for each component is dependent upon the distance that each strata exists below the plane of application of the load

The decrease in stress as depth increases has been explained by some investigators as a distribution of the load over an increased area Some statements have been made to the effect that this increase is at 45 deg. Other formulas have been developed which do not limit the spread of the load to 45 deg. or any other specific angle. In these formulas the distribution is dependent upon the modulus of deformation for each material through which the load is applied. By utilizing this simple fact, the principal stress difference at any depth may be determined. The stress difference which is found in this way is the range of stress used to calculate the proper modulus of deformation to use in the design of the thickness of each type of material

Effect of Lateral Pressures

At least two tests at different lateral pressures are conducted on each material to be considered in the roadway structure Usually these pressures are 10 and 30 lb. per sq. in The magnitude of these lateral pressures has been a subject of considerable discussion for those interested in testing by the triaxial method.

In order to demonstrate the effect of using these lateral pressures consider the following example. For the purpose of this demonstration a formula which has been used in Kansas with considerable success for the purpose of designing flexible pavements is presented:

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

in which

P = Wheel load.
C_p = Modulus of deformation of pavement.
C = Modulus of deformation of soil
S = Assumed settlement of pavement.
a = Radius of assumed area of tire contact

This formula was presented in 1940[1] by Mr. C A Hogentogler, Jr., of the University of

[1] Discussion on Flexible Surfaces, *Proceedings*, Highway Research Board, Vol. 20, p 329

Maryland. Mr. Hogentogler was discussing an article by L A. Palmer and E S Barber entitled, "Soil Displacement Under a Circular Loaded Area" which appeared in *Proceedings*, Highway Research Board, Vol 20, p 279.

A sample of subgrade material represented by Laboratory Number AA-3016, Sample Number 110, was tested at 30 and 10 lb. per sq in. lateral pressures under test numbers 248 and 249. The stress-strain curves for these

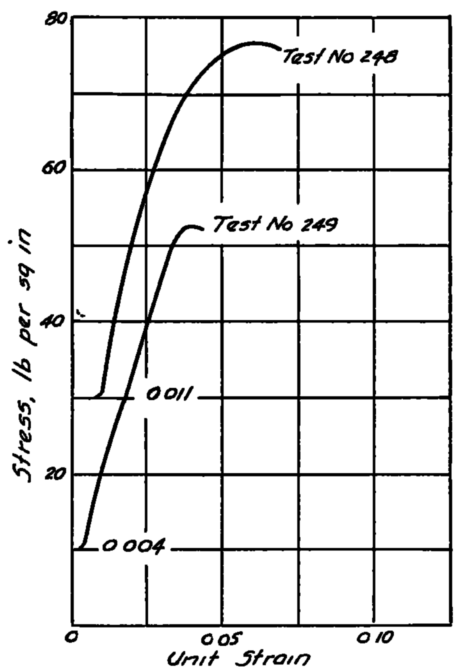

Figure 4. Stress-Strain Curves for Triaxial Tests, Subgrade Material, Undisturbed, Saturated.

tests are shown on Figure 4. The modulus of deformation for the principal stress difference at a depth of 7 in below the plane of application of a load of 5,000 lb. over a contact area of 56 sq in. is 1820 lb per sq in. for the 30-lb. test and 1,350 lb per sq in for the 10-lb test. The average of these two is 1,585 lb per sq. in, the modulus of deformation which would be used for this material under the given conditions. Assume that a surface course will be placed upon this subgrade having a modulus of deformation of 15,000 lb per sq in. Substituting these values in the formula we have.

$$T = \left[\sqrt{\left(\frac{3 \times 5000}{2 \times \pi \times 1585 \times 0.1}\right)^2} - 17\,6\right] \cdot \left[\sqrt[3]{\frac{1585}{15000}}\right]$$

Solving, $T = 6\,9$ in.

For demonstration only, substitute the values for the modulus of deformation obtained for each of the tests (1820 and 1350 lb per sq in.) separately in the formula This gives $T = 6\,2$ in. for the 30-lb. test, and 7.7 in. for the 10-lb. test Remember that these are all calculated for a stress difference at a depth of 7 in Soils and related materials are so heterogeneous and construction procedures so unrefined that it is not consistent to attempt to design thicknesses to the tenth of an inch and the next full inch is used For all practicable purposes 7 in of material would be constructed. Often the modulus of deformation on tests of subgrade material varies less at lateral pressures of 10 and 30 lb per sq in. than shown in this case It is true that in some materials greater differences exist between the results obtained by using the 10 and the 30-lb. per sq. in lateral pressure. However, the average result of at least two tests is taken for the purpose of design.

Comparative Mix Values

In addition to its application to a specific problem of flexible pavement design, triaxial testing is also a most useful tool in obtaining comparative values of various types of mixtures such as soil-aggregate and bituminous-aggregate, in differentiating between rounded-aggregates and crushed aggregates, and also for comparing combinations of these materials One is able in these cases to differentiate between mixtures of more or less fines, more or less binder, and compare the strengths of various binders. A definite value of modulus of deformation may be determined for each mixture for any given condition of loading. The fact that it is possible to test mixtures having a great deal of coarse material in them permits an evaluation of the mixture as a whole Heretofore most laboratory test methods have used only the portions passing a certain fine screen, disregarding the coarser portions of the mixture.

Permissible Loads

The practice of posting bridges for maximum loads is quite common but very seldom is this done for the roadways. One excessive load passing over a highway ordinarily does not cause failure but too many heavy loads will cause the roadbed to fail rapidly if it does not have the necessary strength to handle such a volume of traffic. By the use of this particular test method the strength value of the existing roadbed structure may be determined and limits established for permissible loads. This use can be applied readily in the case of airports with flexible type surfaces. Some older air fields were not designed to support the loads imposed by present day aircraft. With the current increase in the size of planes some of the more recent airports may need to be evaluated as to their ability to permit heavy planes to make use of their facilities. Such an evaluation provides rather definite values for determining the need of improving the strength of the structure or of limiting the sizes of the loads permitted thereon.

CONCLUSION

In this paper we have touched upon some of the phases of triaxial testing as related to the design of flexible pavements. We have not attempted to present an over-all method of design, but have simply expressed our thoughts on the problem and presented some of our experiences with this type of testing equipment At this time we are well satisfied that a definite design method is available by this means. The flexibility of the method is wholly desirable. The proposition here is, in effect, to develop a method that uses representative field sampling combined with the advantage of laboratory testing. The disadvantages of field testing are overcome and the ability of the materials to withstand field conditions is determined

Further advance and developments in design methods are certain to be made due to rapidly changing conditions and loadings. Continual progress is necessary in road and airport flexible pavement design The method of design must be accommodative if these changes be accounted for as they become known The method used must permit both the proper design of new construction and the suitable redesign of old. In our opinion the triaxial testing method provides the necessary flexibility and adaptability to meet these conditions.

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