Flexible Pavement Design: A Complex Combination of Theory, Testing And Evaluation of Materials

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The purpose of this report is to point out certain complexities usually encountered in attempting to develop pavement thickness design methods. No attempt is made to offer specific answers, but rather to submit concepts that might assist in understanding the many problems involved in the use of methods for design of flexible pavements. The following recommendations are made:

1. Of the strictly empirical methods only those founded on an extensive background should be acceptable.
2. All empirical methods based partially on theory require some background before being acceptable.
3. Empiricism in methods should not predominate, but its presence does not indicate the method to be unworkable.
4. Each agency, if it has not already done so, should start to investigate at least one or more methods in lieu of waiting for someone else to work out the often referred to "rational approach." This report shows why the author believes that the establishment of a workable "rational method" is still a long way off, if at all possible.

A series of test questions is presented to assist the reader in evaluating any proposed method.

●FOR MANY YEARS to come acceptable improvements in flexible pavement design techniques for pavement thickness will be developed by a few organizations and sought after by many engineers. Many methods will be cast aside for various reasons. In some cases the reasons may be due to failure to follow the intent of the originator either through lack of understanding or through belief that the method is too cumbersome. Only a few organizations have the time, personnel, and facilities to develop methods covering such a complicated subject. The subject is so highly involved that all of the better methods to date have been developed over a period of many years of continuing research. In spite of various perferences and beliefs, there are and always will be those seeking the preferred methods, and it is hoped that this report will be of some benefit to such personnel.

All of the better techniques of design must be accompanied by adequate physical testing techniques that measure various relationships of compressive, shearing, and tensile strengths. Such tests must be supplemented with good judgment in design and application. Figure 1 shows some of the most commonly used test procedures. It can be noted that these tests measure one or more of compressive, shearing, or tensile strength characteristics. The idealized Mohr diagram shown in Figure 2 is one of the most helpful tools available for presenting the three mentioned stresses. Shearing stresses can be obtained when tensile and compressive stresses are known.

Figure 3 shows the existence of tensile and compressive stresses both under a tire load and in a reversed manner some distance away from the loaded area. This example merely illustrates how pavements are subjected to many repetitions of all forms of compressive and tensile stresses.

Figure 4 shows the basic concept of the Texas method where results of triaxial tests and wheel load stresses can both be presented on the Mohr diagram. However, to

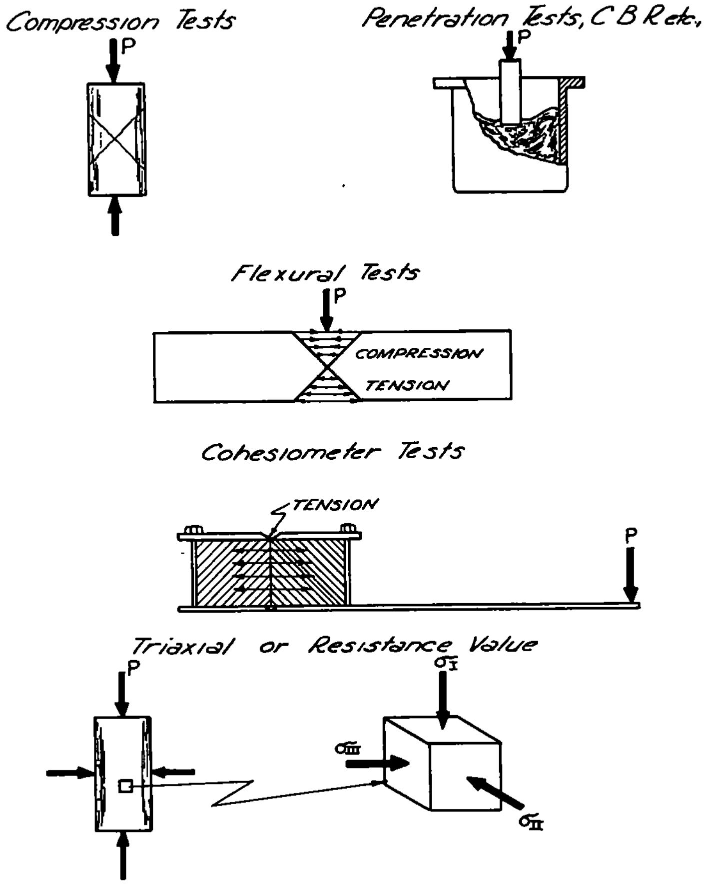

Figure 1. Tests most commonly used for pavement design.

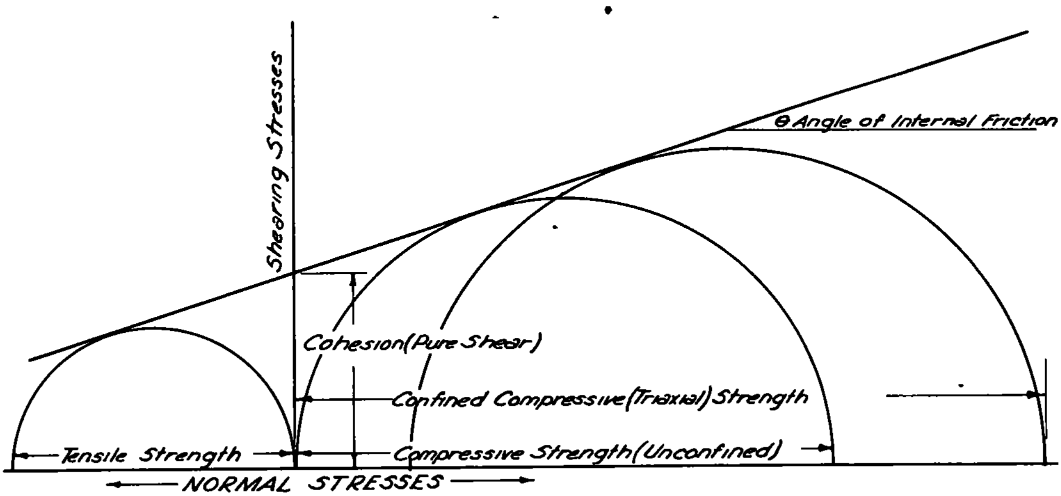

Figure 2. Idealized Mohr diagram.

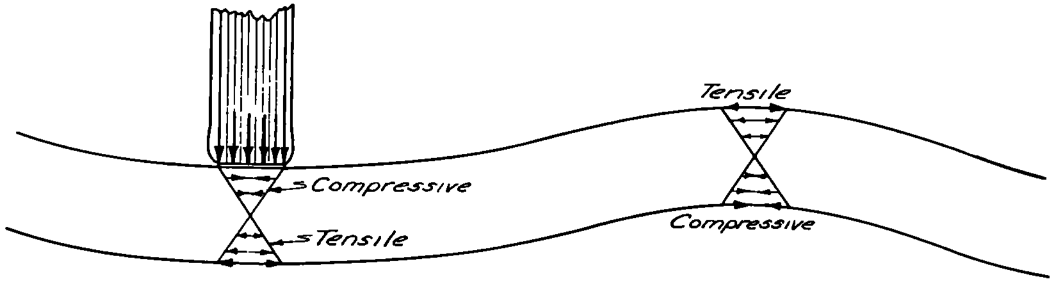

Figure 3. Stresses from wheel loads.

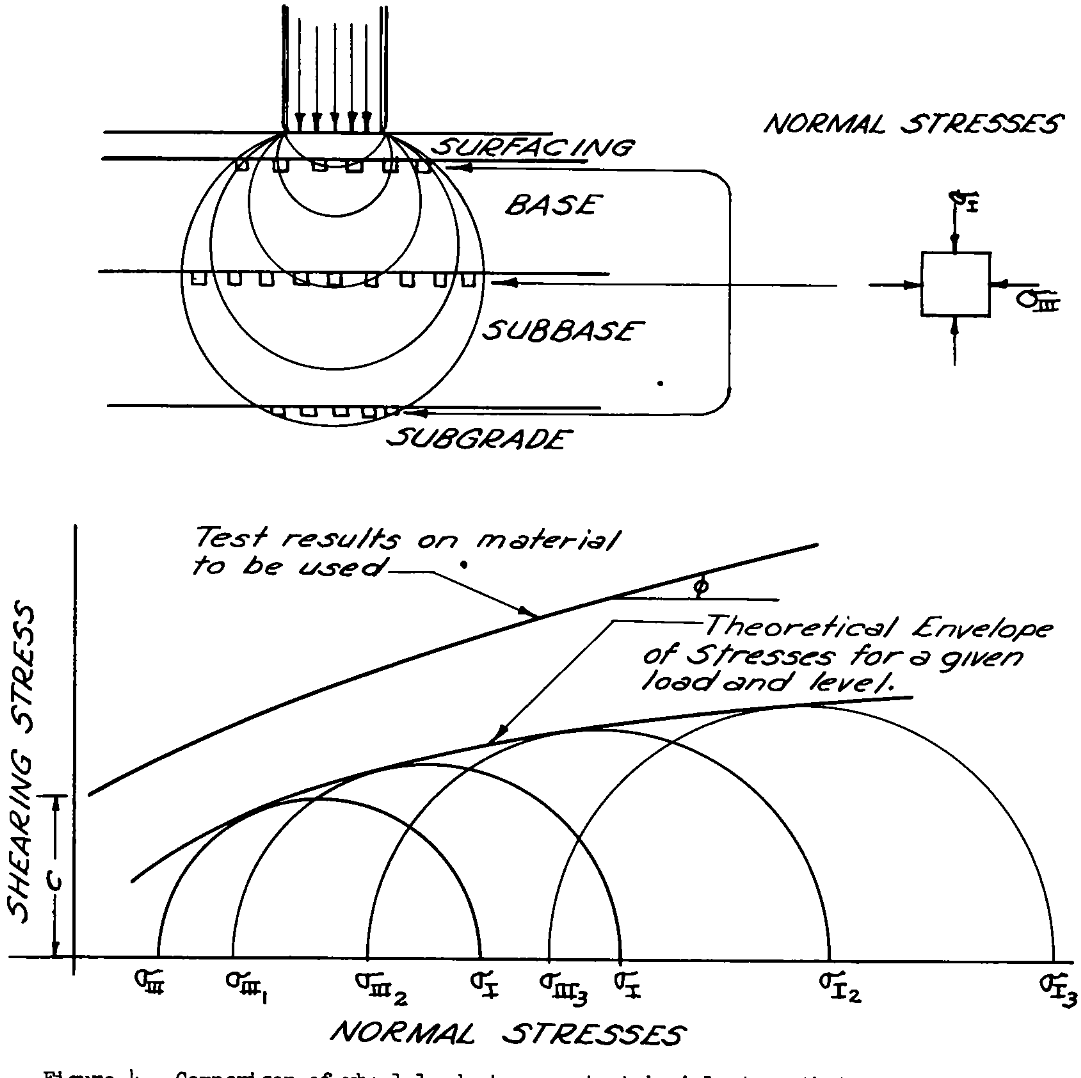

Figure 4. Comparison of wheel load stresses to triaxial strength test stresses.

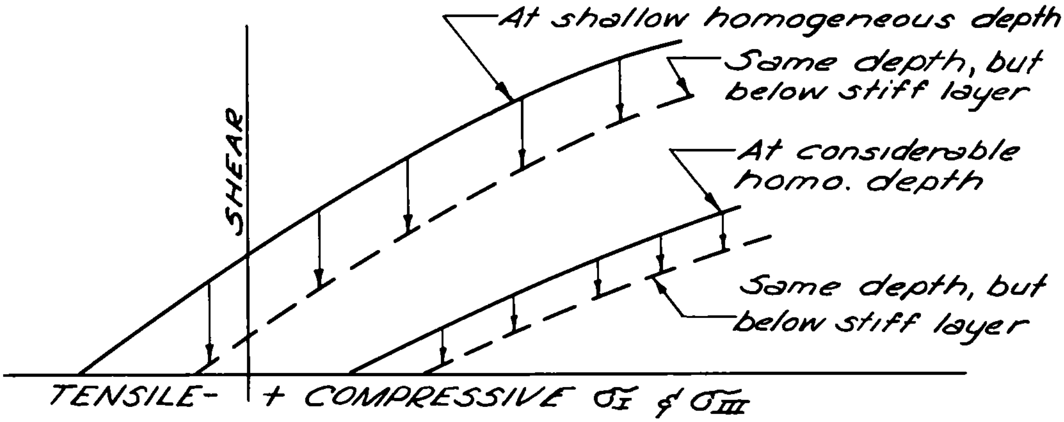

Figure 5. Stresses at different levels for a given loaded circular area.

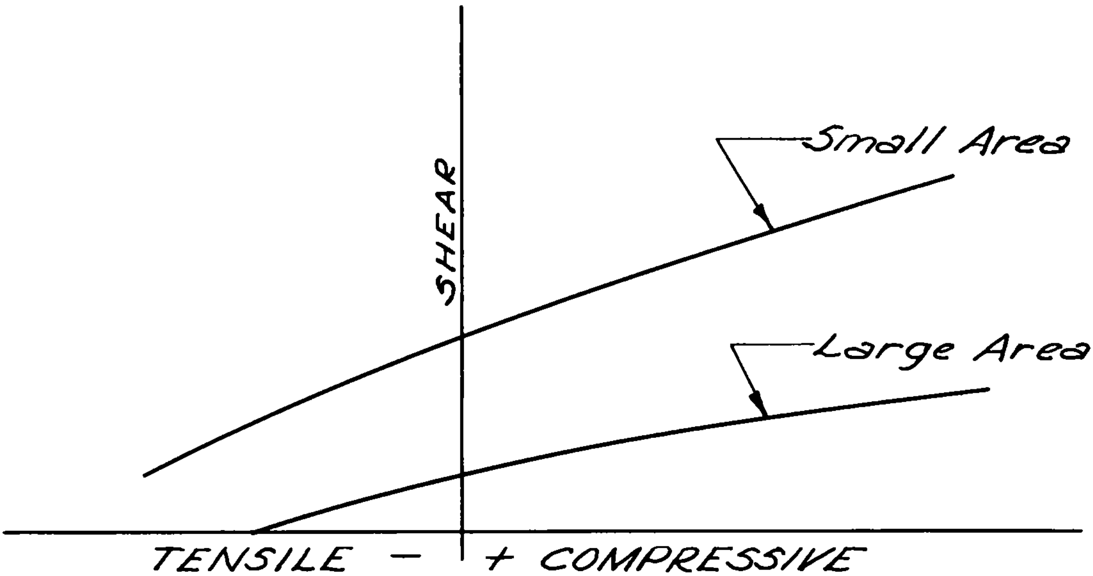

Figure 6. Stresses at a given depth level when loaded area and unit pressure varies.

present realistic values is not as easy as it first appears. The procedure usually followed is to utilize tables of influence values determined from Love's solution of Boussinesq's equations of elasticity for circular loaded areas. Because these values are for homogeneous isotropic layers, it soon becomes obvious that similar patterns of stresses can not be expected under a pavement system consisting of several layers of materials having different degrees of stiffness (1).

Figure 5 shows how stresses under a given circular loaded area will decrease with depth and will also be reduced when a stiff layer overlies a soft layer. To point out further complications, Figure 6 shows that for a given load the size of loaded area will affect stress concentrations at a given depth level. This matter is further complicated if consideration is given to adding braking and impact stresses not to mention stresses under moving wheel loads. Many complications also arise when a laboratory attempts to evaluate strength characteristics of materials.

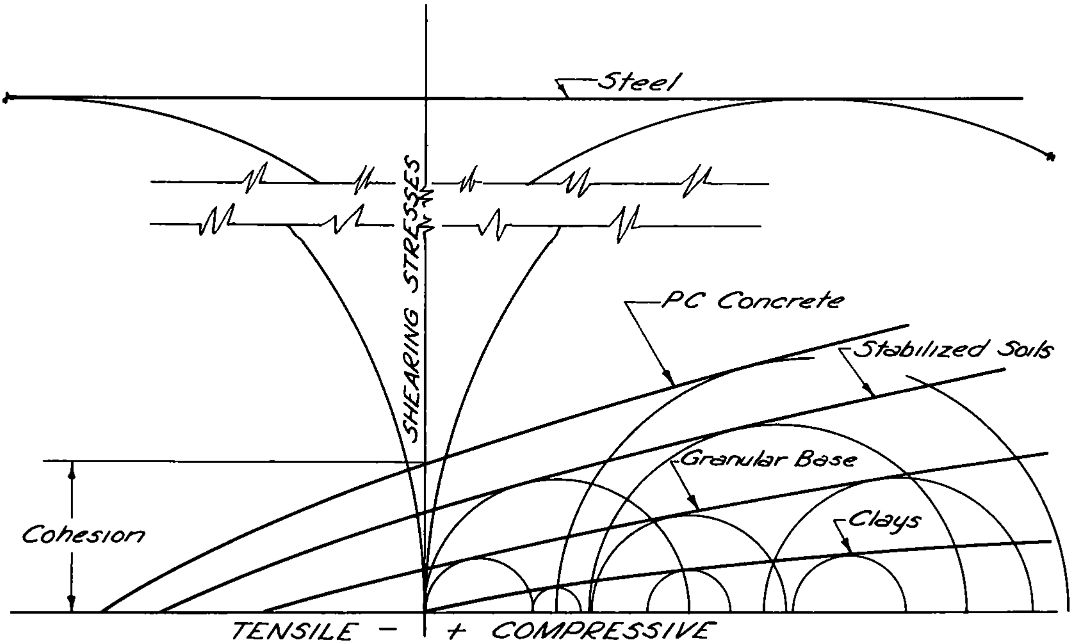

Figure 7. Triaxial test results for various typical materials.

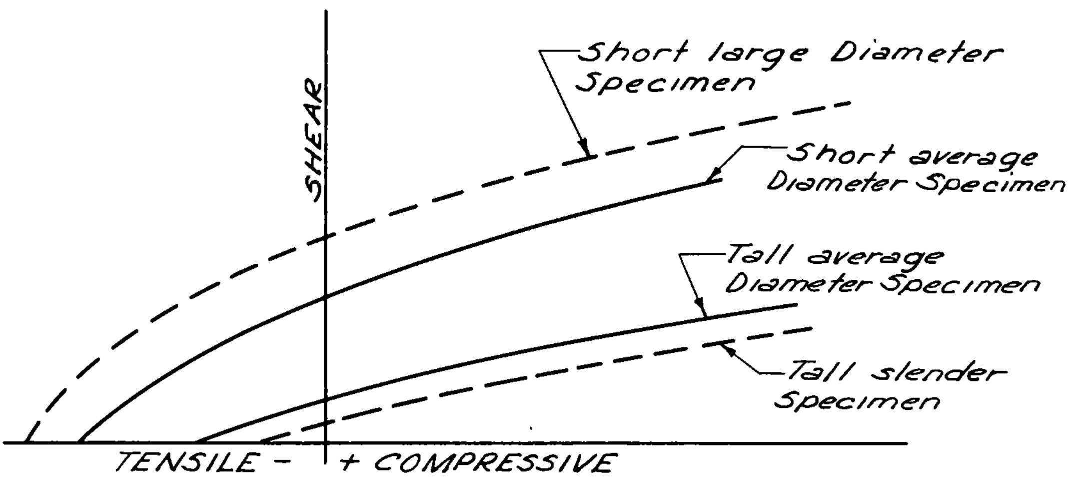

Figure 8. Effect of height of specimen on triaxial tests.

Figure 7 shows characteristics of various types of some materials when presented on the Mohr diagram. In order to present proper data, consideration should be given to a number of variables.

Figure 8 shows how height-to-diameter ratio affects strength results which are generally accepted. The lower dashed line in the figure suggests a condition not generally known, where specimens have a satisfactory height-to-diameter ratio that may

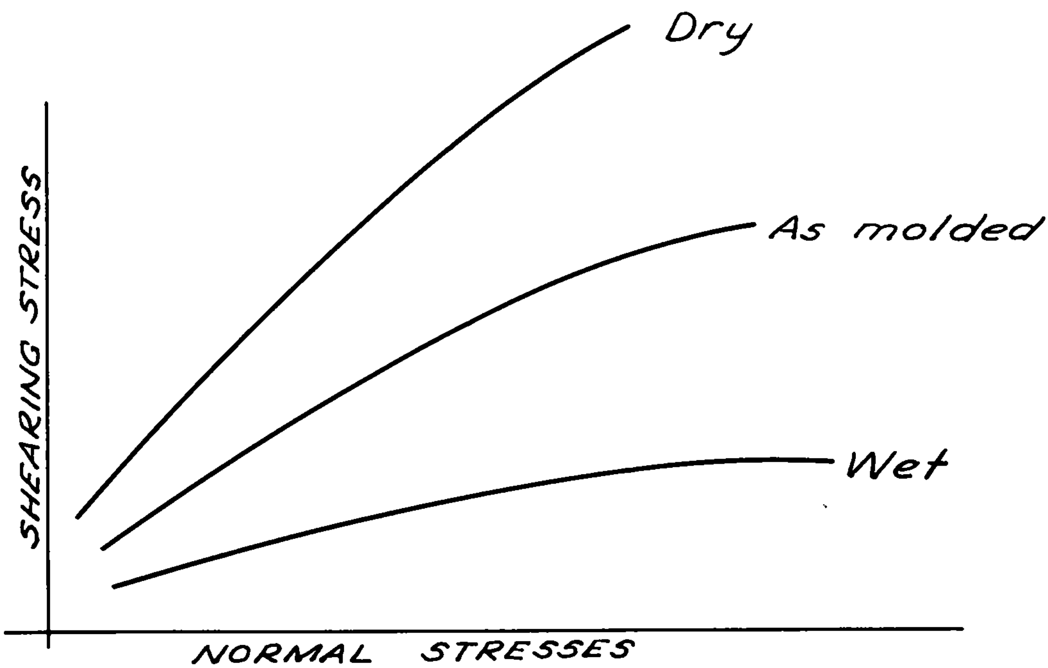

Figure 9. Effect of moisture on triaxial tests.

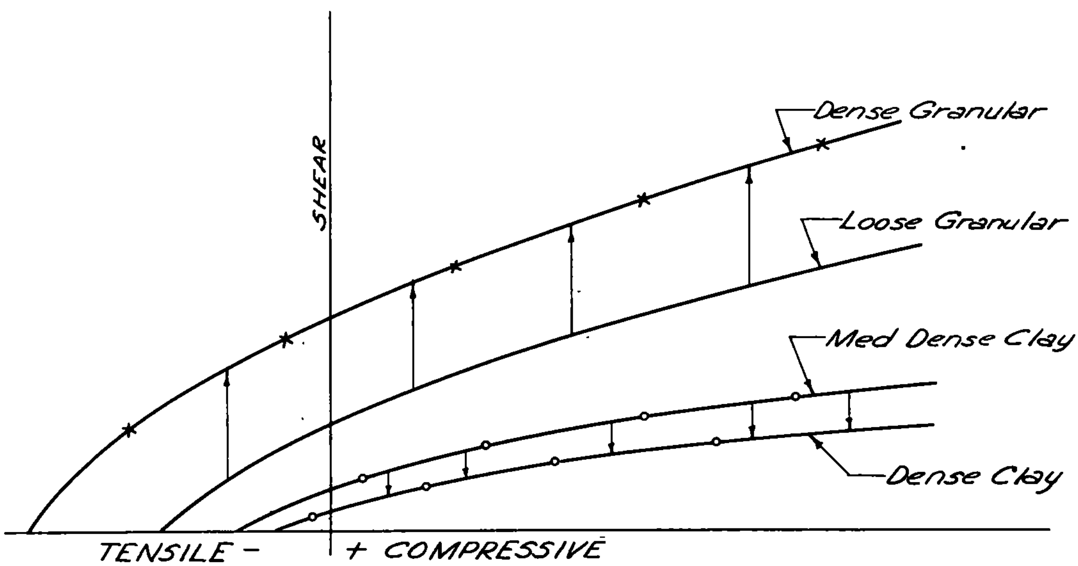

Figure 10. Effect of density on triaxial tests.

be too slender. In other words, for granular materials some 10- by 20-in. height specimens test stronger than some identical 6- by 12-in. height specimens. This suggests that specimens exceeding approximately 8 to 10 in. in height should have diameters in excess of 6 in.

If enough confusion does not already exist, the selection of moisture content of soil materials at time of testing should complicate things even more. As would be expected, strength varies with moisture content similar to the results in Figure 9. Selection of proper moisture content at time of testing is not a simple matter, and laboratory technicians have to select some degree of wetting at time of testing before they obtain acceptable data. To attain the desired moisture content for testing, some use capillary wetting (2, 3), some use inudation or soaking, and some use exudation plus soaking. All hope that the condition of moisture reached is comparable to severe conditions of the prototype, which may or may not be true.

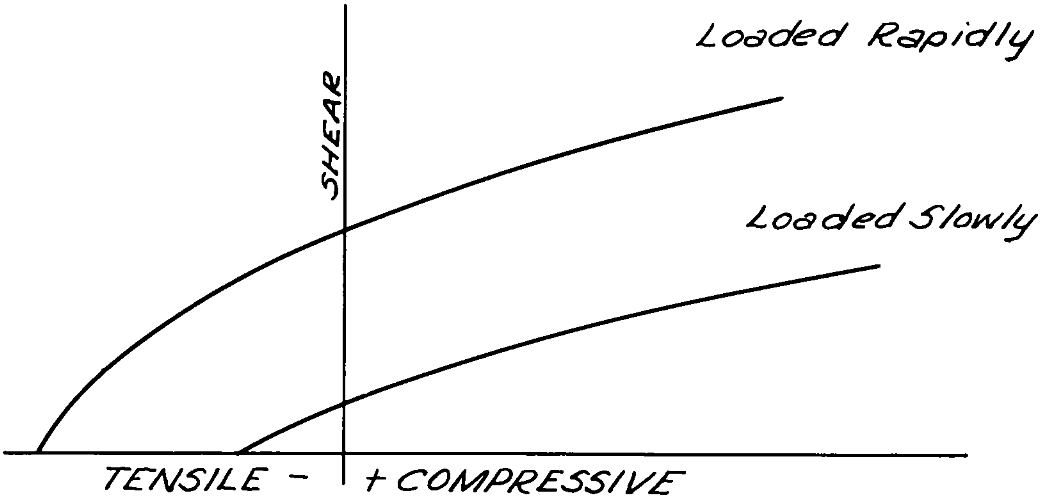

Figure 11. Effect of rate of loading on triaxial tests for natural or asphaltic bound mixtures.

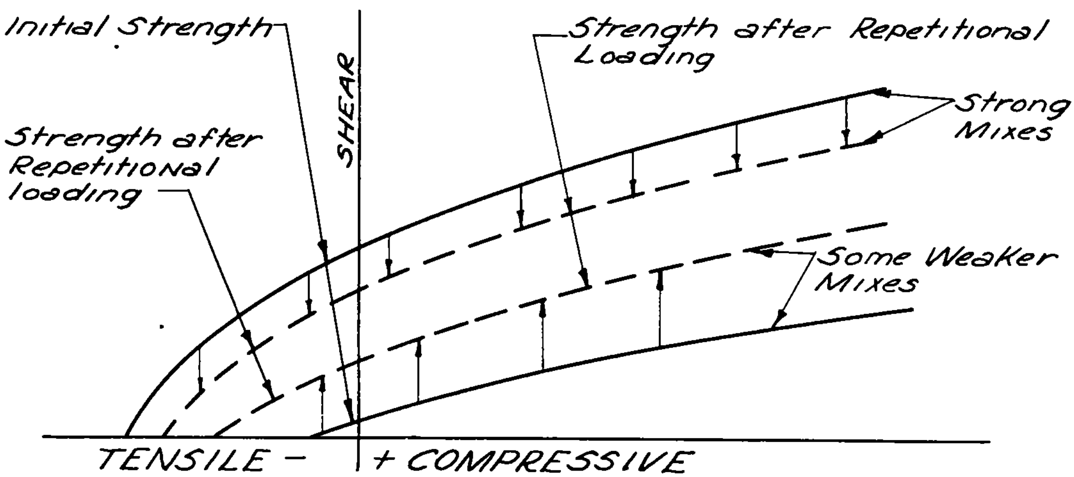

Figure 12. Effect of repetition of loads on triaxial tests.

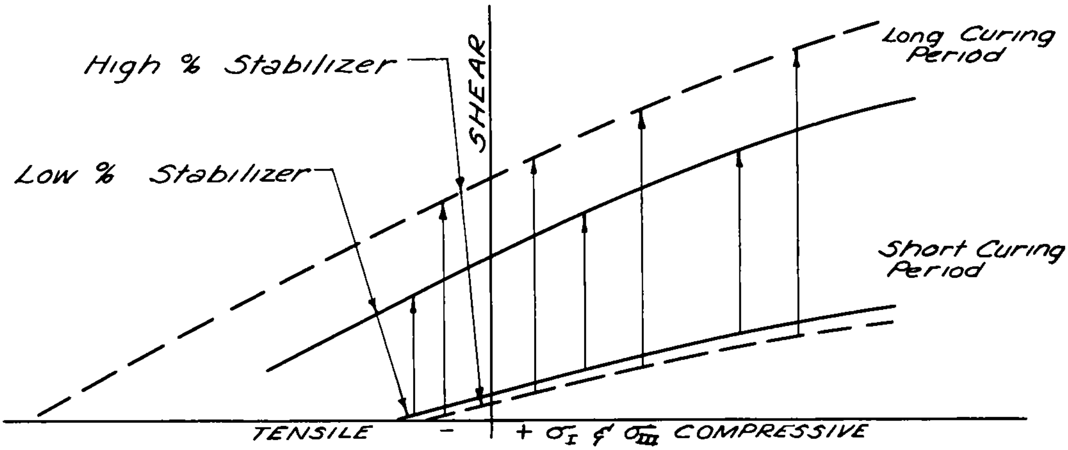

Figure 13. Curing of chemically cemented mixtures.

If prototype testing is followed, as desired by many, it is necessary to test specimens at densities comparable to road conditions (4, 5) because data will tend to vary, as shown in Figure 10. In the cases shown, a granular material gains in strength when accompanied by increased density; however, a clay may be stronger when compacted to a medium high density than when compacted to a higher density. Strengths referred to are after curing and capillary wetting.

Additional confusion arises when the rate of load applied during testing is considered. Figure 11 shows fast loadings on a given soil produce higher strengths than do slow rates of loading on the same soil. This may be obvious but the laboratory engineer must establish some standard rate for use in routine testing.

The next step to worry about is the effects of repetitional loading. Figure 12 shows some dense strong soils containing soft aggregates may weaken when subjected to repetitional loadings and some other weaker soils will gain in strength from repetitional loadings.

As if the pavement testing and design problems are not already complicated enough, there is the soil stabilization problem. Contrary to the expected, some stabilized mixtures containing high percentages of admixture may be weaker at early stages of curing but become much stronger after long periods of curing than do the mixtures containing low percentages of the same stabilizer, as shown in Figure 13.

Although contrary to most thinking, some cemented mixtures with fairly low compressive strengths may have greater tensile strengths than do some fairly high compressive strength mixtures (see Fig. 14). Soil and asphalt mixtures need to be tested to determine properties pertaining to absorption and shearing strengths of mixture selected for use.

Next to be considered is compatibility of materials; for instance, when two or more adjacent cemented layers having different linear coefficients of expansion and contraction tend to destroy each other, or when stable base materials feed excessive water to soils having little permeability. Then there is the wearing course or surfacing problem. It is suggested that the same type of surfacing should not be used on all types of designs. Most low-cost roads are designed for a limited life or number of load applications; therefore, deflections will be greater because base depths are thinner than if thicknesses were designed for long life. In these cases, penetration surface treatments will seal out water more effectively and last longer than premixes. This leads us to the complicated problem of selection of materials and application of surface treatments that have been the subject matter for numerous reports. If thick asphaltic concrete surfacings are to be used, an increase in aggregate size should accompany increasing thicknesses of surfacing. The need for stability tests and compaction by increased amounts of rolling to improve durability of such mixtures is becoming more

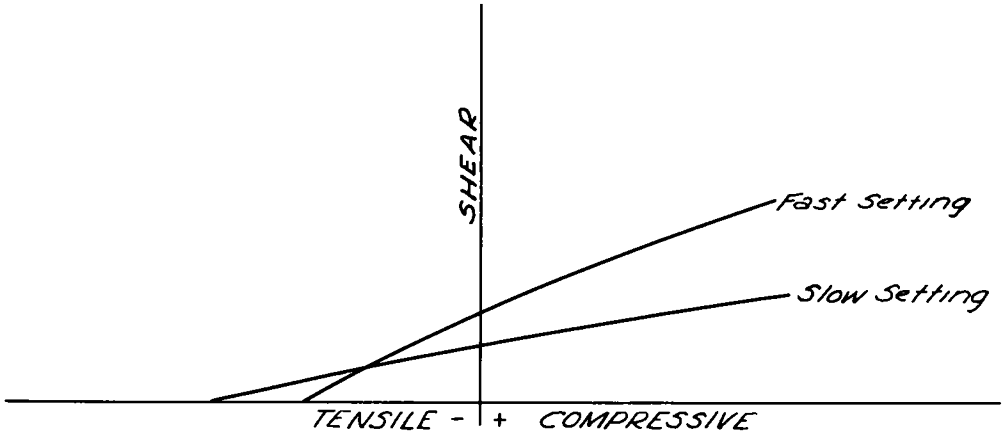

Figure 14. Curing of chemically cemented mixtures.

evident every day. This phase has also been subject matter for a voluminous number of reports.

Another factor often overlooked is the volume change of soils. Many pavements are badly cracked and their riding surfaces distorted regardless of thicknesses and types of pavements used without the builders or owners ever knowing the causes. This subject has been reported upon (3, 6) far less frequently than have other subjects discussed herein. This is unfortunate because many pavements in high volume change soil areas frequently develop cracks before traffic is ever allowed to use them.

This report may be thoroughly confusing with respect to the use of flexible pavement design methods, but that neither theory alone nor testing alone is sufficient within itself to furnish a means of coping with the design and construction of pavements. Good construction, drainage, evaluation of materials and their compatibility with other neighboring layers are also important, and these matters are not usually expressed in available theories and test methods. It seems rather remote to expect to find a truly rational approach to all of these problems. Through continued research, some methods can be correlated with field performance sufficiently for the user to expect good results in many cases, but he should study their application to his own particular problems.

In evaluating any method of design for flexible pavements, it is suggested that answers to the following questions be sought:

1. Does the method involve the use of theoretical wheel load shearing stresses from static plus impact loads?
2. Does the method account for wheel load repetitions or life of pavement?
3. Does the method evaluate the effects of tensile or flexural strength in certain portions of the pavements' structure?
4. Is there a sufficient background of actual experience?

No design method is any better than the test method that accompanies it and the following questions should be asked about the test method:

1. Are effects of both moisture and density registered in the test, and for routine testing are samples tested at conditions comparable to those of an adverse nature expected in the roadway?
2. Can aggregate-bearing samples up to 1 1/2- or 2-in. top size be tested so as to evaluate base and subbase materials?
3. Will the test indicate density desired during rolling?
4. Can test results be obtained within a reasonable time?
5. Can the test data be interpreted easily?
6. Can the amounts and affects of volumetric swell be measured?
7. Will the tests tell you how thick the surfacing should be and what characteristics it should have?

8. In the case of soil stabilization, will the test tell you the type of stabilizer and amount and thickness to use?

9. Are the test method results applicable to pedology and geology?

If all answers to these questions are yes, a mistake has been made, because no method is that good. If very few answers in the affirmative can be made about a proposed method, consideration should be given to use of other methods or to the fact that development of a considerable number of improvements through experience and research with one's own materials will be required to make the method work for you. One of the worst things that can be done is to adopt some method then change it so completely that its originator can no longer recognize it, because then it will have to be experimented with for 20 years before one can be sure whether it is any good or not. Perhaps it is even worse to do nothing while wishfully waiting for someone to come forth with rational approaches to all pavement problems.

Much has been done to improve the Texas triaxial method with respect to speed of testing, affect of load repetitions, and tensile-flexural strength on depths of pavement. Details relative to these matters are being given in another report (7).

CONCLUSIONS

From the voluminous data published on this subject, one cannot but help come to the conclusion that flexible pavement design is a complex combination of theory, testing, and evaluation of materials that has not and probably will never be resolved into a purely rational method. The enormous costs of pavements in current programs have created so great a need for good methods of design that use of the best methods obtainable must be started without waiting for the idealistic rational methods to be developed.

ACKNOWLEDGMENTS

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