arrived at indicates the design curve to be used. As conditions vary thruout a given project changes from one curve to another may be necessary. A study of the soil profile will show just how the preliminary design is developed.

The design is then reviewed with the construction engineer and if deemed necessary thickness of base courses may be increased. Rarely however, is the design reduced. If Federal funds are involved on the project the design is finally reviewed by a representative of the Public Roads Administration before being turned over to the plans division.

CONSTRUCTION DESIGN

More often than not, projects as awarded in this State include grading, subbase, base and surface course. In order for the plans division to arrive at proper quantities of materials as well as to insure correct grade widths for the total surfacing sections it is, of course, necessary to predicate the design on preliminary samples of the soil to be used in the grade.

Due to unavoidable blending of soils on actual construction as well as to some unforseen job conditions that develop changes in the preliminary design are sometimes necessary. Usually such changes are not sufficient to cause any difficulty as regards width of finished surface and even if so, changes in the grade width can be made if the necessary design change is recognized before construction has progressed too far. Samples of the finished grade are submitted as construction proceeds. These samples are taken for every apparent soil change thruout the project. Classification tests and California Bearing Ratios are rerun and changes in the preliminary design are made where necessary. The engineer is kept fully informed of such changes.

CONCLUSIONS

The design proceedure makes use of well established data relative to the supporting value of the soils used in construction to which has been added a method of evaluating job conditions. It is, of course, based on the assumption that the grade has been compacted to at least 95% of A.A.S.H.O. density. With proper control of moisture and rolling this degree of compaction can readily be secured. The sheepsfoot roller unit used, and paid for by the unit hour, consists of a double drum having a total width of 10 feet and a ground pressure of 325 pounds per square inch.

The method is particularly adapted to laboratory control of design in that the preliminary design can be worked out previous to construction and readily corrected wherever necessary as construction progresses. As has been stated the assigned values in the Supplemental Data table are emperical and as further experience is gained changes in these values may be indicated. The thoroughness of the field engineer in furnishing information on job conditions is, of course, very essential if the resulting design is to be reasonably accurate. This design is a decided improvement over any previously used in this State but with the interest that is being shown in the matter of design it is reasonable to expect that new and better methods will be evolved which may result in a complete change in proceedure.

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3. Fred J. Grumm, "Designing Foundation Courses for Highway Pavements and Surfaces." California Highways and Public Works, November 1941 and March 1942.
4. O.J. Porter, "Foundations for Flexible Pavements." Proceedings, Highway Research Board, Volume 22.

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KANSAS TRIAXIAL METHOD OF FLEXIBLE PAVEMENT DESIGN x)

State Highway Commission of Kansas

The triaxial compression test provides lateral support to a specimen while it is subjected to a vertical load. Water is expelled during the progress of the test, simulating field conditions. The stress coincident with strain is obtained at regular intervals. This data is used for determining the thickness of flexible pavement required, using the modulus of deformation. Proven formulas are correlated with service records of specific conditions. Variables affecting design are traffic, climate and materials involved. All conditions existing on each project are evaluated. The frequency of sampling depends upon the topography. Preliminary investigation is made to determine the locations to be sampled. Usually an average of three samples per mile are obtained on most projects in Kansas.

Subgrade soils are tested preferably with their natural or existing structures in an undisturbed condition; they may be molded for estimating purposes. Undisturbed samples are obtained by forcing a sampler into the subgrade and pulling it out with the sample contained therein. These samples are packed in damp saw dust in boxes or in galvanized metal cans, using a material similar to the sample for packing. These cans are sealed with adhesive tape.

x) A complete report on this method of design was published in September 1947 as Bulletin Number 8, Highway Research Board, National Research Council, National Academy of Sciences, 2102 Constitution Avenue, Washington 25, D.C. The title is "Design of Flexible Pavement Using the Triaxial Compression Test".

PREPARATION OF SPECIMEN

An undisturbed sample is removed from the container and the metal liner removed from around the specimen. The sample is usually approximately 6 inches in diameter and 10 inches in height. A specimen 2.8 inches in diameter by 8 inches in height is cut with knives and wire saws. Highly plastic clays having high moisture content are more readily cut with a wire saw whereas most other materials, and those in a drier condition, are more readily cut with knives. A cutting tool having inside dimensions equivalent to that desired for the specimen enables the operator more easily to obtain a specimen of the proper dimensions and shape. The specimen is encased in a rubber sleeve and put on a base plate. The base plate is connected to a water supply for saturation. Vacuum is applied through a sample cap placed on the top of the specimen. Saturation is obtained by pulling water upwards through the specimen until it collects in the water trap provided in the section line. A multiple unit saturator upon which 16 specimens may be saturated simultaneously allows the production of an average of one test per hour. Specimens of disturbed material may be prepared in a mold using either a static load or a compaction hammer.

Material for molding may be in a saturated condition or it may be at a lower water content and subsequently saturated.

CONDUCT OF TESTS

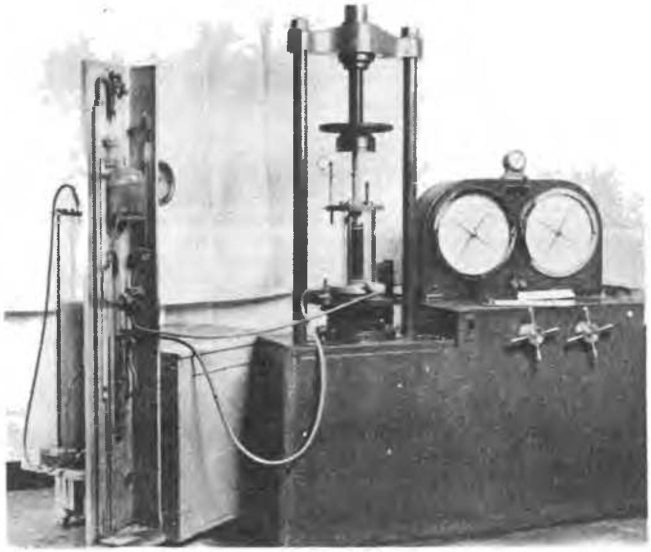
When a specimen has been conditioned for testing, it is placed in a compression chamber. A plastic cylinder such as lucite permits the specimen to be seen during the conduct of the test. Glyserin is used around the specimen in the compression chamber to provide lateral support. In Kansas, 20 psi horizontal pressure is used in testing specimens for flexible pavement design. Load is applied at a rate of strain of 0.005 inch per minute on small specimens and 0.01 inch per minute on large specimens. Large specimens 5 inches in diameter by 14 inches in height are prepared from materials having a maximum size greater than 3/8 inch. Vertical dial readings, time, vertical load and pipette readings are taken at regular intervals of deformation. The test is continued until the desired data has been obtained, usually for 0.2 inch deformation after the load begins to increase at its most rapid rate for the test.

APPLICATION OF TEST DATA

The method of applying test data used in Kansas follows a modification of the formula presented by Palmer and Barber in "Proceedings", Highway Research Board, Vol.20 (1940). This modified formula is applicable to single wheel loads and is as follows:

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

Where:
T = Thickness required
C_p = Modulus of deformation of pavement or surface course
C = Modulus of deformation of subgrade or subbase
P = Base wheel load
m = Traffic coefficient based on volume of traffic
n = Saturation coefficient based on rainfall
a = Radius of area of tire contact corresponding to Pm



Triaxial equipment assembled for test.

FIG. 1

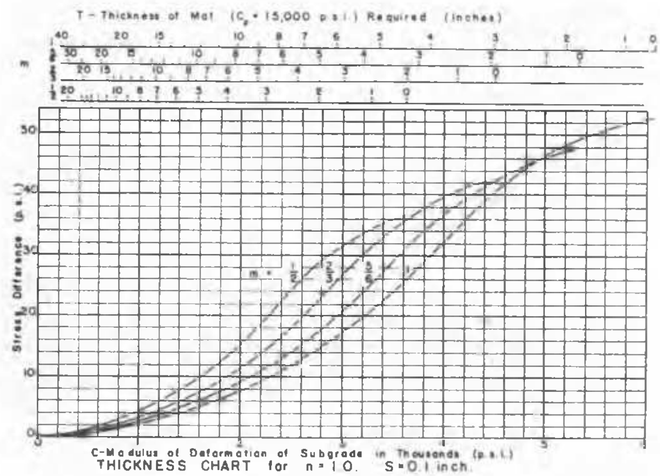


FIG. 2

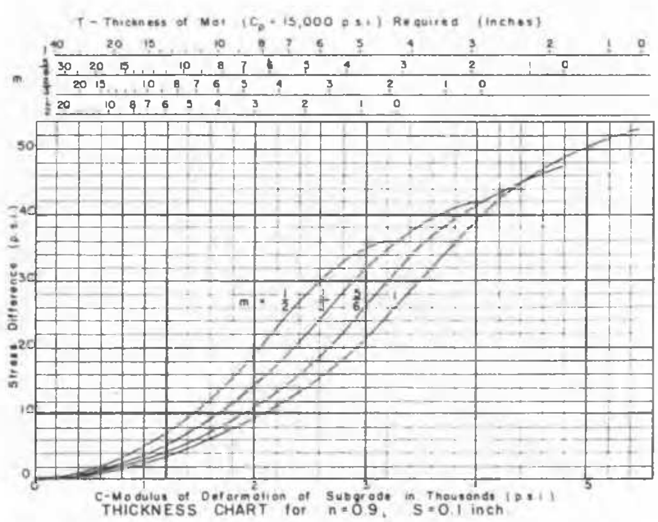
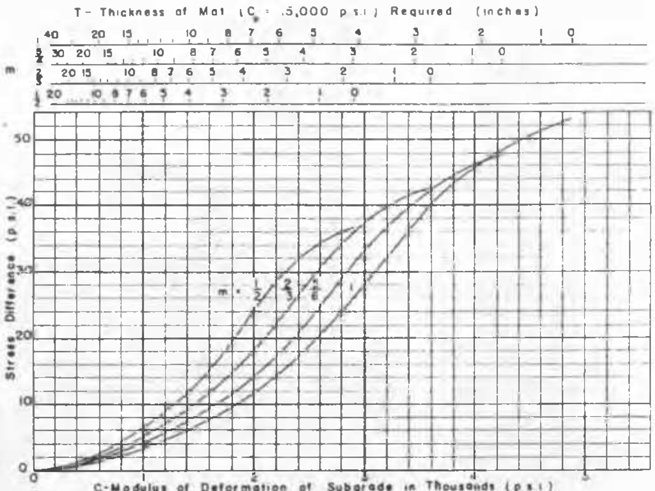
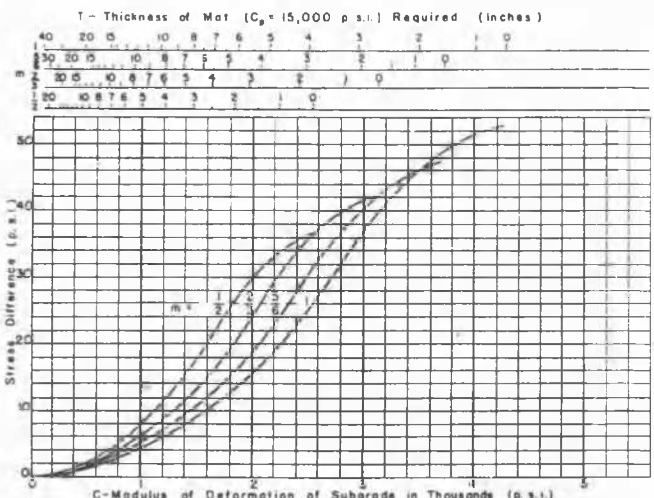


FIG. 3



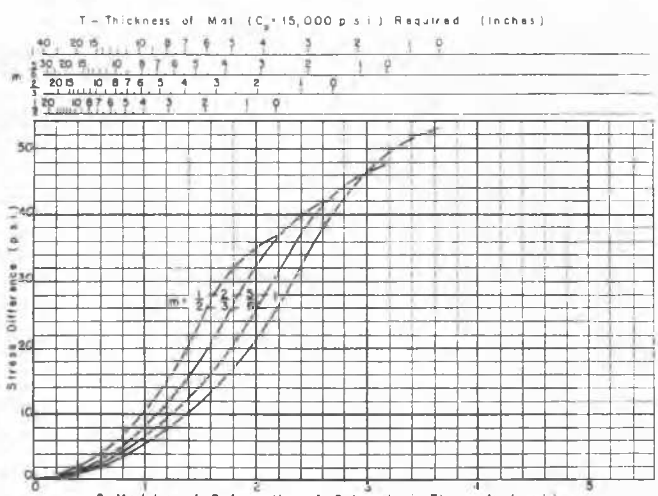
THICKNESS CHART for n = 0.8, S = 0.1 inch

FIG. 4



THICKNESS CHART for n = 0.7, S = 0.1 inch

FIG. 5



THICKNESS CHART for n = 0.6, S = 0.1 inch

FIG. 6

S = Permitted deflection of surface

When the load is applied by dual wheels, the effective radius of tire contact area is not easily determined. This difficulty is overcome by computing the stresses imposed by each tire separately and deriving charts.

Traffic coefficients. A state law in Kansas (and laws in many other states) limits vehicles to an 18,000 pound axle load. This results in a maximum wheel load of 9,000 pounds, usually carried on dual tires. Ordinarily rigid pavements are designed for highways with less heavy traffic. The percentage of vehicles carrying maximum loads as related to the total number of vehicles is fairly constant over most of the State's highways. The variation affecting design occurs mostly in the total volume of traffic. Coefficients have been determined according to the volume of traffic, shown in Table 1.

TABLE 1

Traffic Coefficient "m"	Wheel Load "Pm" (lbs.)	Total Traffic (Vehicles per day)
1	9,000	1500 - up
5/6	7,500	900 - 1500
2/3	6,000	300 - 900
1/2	4,500	50 - 300

Area of Contact

Dual wheel loads are transmitted to the pavement as one-half the wheel load on each of two tires. The area of contact for each of these tires is determined from actual tire contact data. For use in calculations, this area is considered equivalent to a circle of the same area.

Saturation Coefficients

Service records of highways which have been under traffic for a number of years were studied to arrive at values of the saturation coefficients which are used in evaluating thickness of flexible pavements. Values of the saturation coefficients are based on average annual rainfall, shown in Table 2.

TABLE 2.

Saturation Coefficient -- n	Average Annual Rainfall (Inches)
1.0	35.0 - 45.0
0.9	30.0 - 34.9
0.8	25.0 - 29.9
0.7	20.0 - 24.9
0.6	15.0 - 19.9

Permitted Deflection

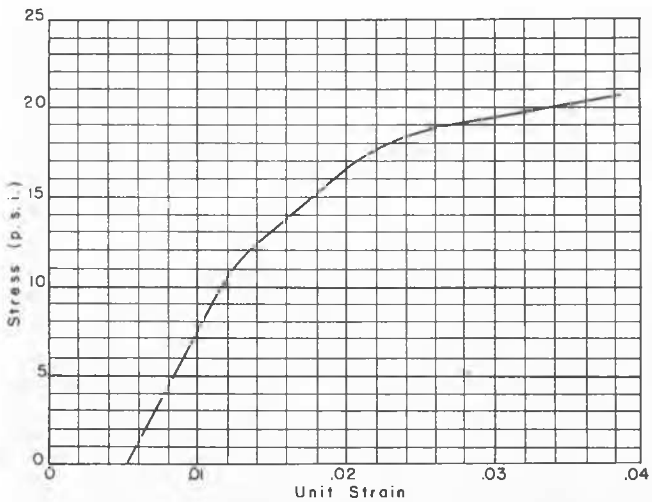
The permitted deflection of the surface is 0.1 inch for flexible pavements in Kansas. This value was determined from measurements of flexible pavements in various conditions and correlated with other values in the formulae.

Modulus of Deformation

The stress-strain curve obtained from a triaxial compression test is used for determining the modulus of deformation of the material tested for certain conditions of stress. The modulus of deformation is the secant modulus between the two points on the stress strain curve limiting the range of stress determined, or the stress difference divided by the net strain.

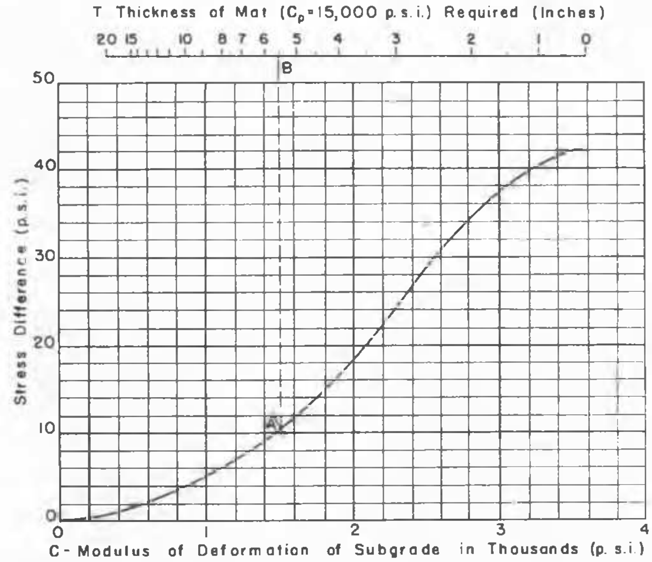
Thickness Required

The thickness of any desired type of surface course, base course, or subbase upon a subgrade may be determined from charts more



Stress-strain curve for subgrade test 2955.

FIG.7



Thickness chart for m= 2/3, n = 0.8, S = 0.1 inch.

FIG. 8

easily than by the use of a formula alone. Figures 2 to 6 show a set of thickness charts.

Sample Calculations

In order to demonstrate the practical application of the method, a specific example is given in which a base course and surface course are to be placed upon a subgrade. Figure 7 gives a stress-strain curve for this subgrade. Traffic is expected to increase so that in 10 to 15 years, it will be approximately 320 vehicles per day on this project. Therefore, from Table 1 the traffic coefficient m is 2/3. The average annual rainfall at the location of this project is 26 inches. The saturation coefficient n is 0.8 from Table 2. The thickness chart for these coefficients is plotted separately in Figure 8. The modulus of deformation of the subgrade is desired for stress differences corresponding with the curve of the thickness chart. For a stress difference of 10 pounds per square inch, the modulus of deformation is 1520 pounds per square.inch and for a stress difference of 12 p.s.i. the modulus of deformation if 1460 p.s.i. A line connecting these two points intersects the curve at "A" on figure 8. A vertical line drawn to the scale at the top of the chart falls at the point "B". This indicates a thickness of 6 inches of a flexible pavement having a modulus of deformation of 15,000 p.s.i. is required over this subgrade. It is desirable to place a bituminous mat surface course 2 inches thick over a base course having a modulus of deformation of 6,000 p.s.i. The thickness of base course required is determined from the following formula:

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

Where:

t_t = thickness of base course or subbase

t_s = thickness of flexible pavement required directly on the subgrade

t_p = thickness of flexible pavement desired in the combination

C_p = modulus of deformation of flexible pavement

C_t = modulus of deformation of base course or subbase

Substituting in the formula

$$t_t = (6 - 2)\left(\sqrt[3]{\frac{15000}{6000}}\right) = 6 \text{ inches}$$

Therefore the combined design over this subgrade will be a six-inch base course and a two-inch bituminous mat.

CONCLUSION

Over 7,000 triaxial compression tests have been conducted in the Soils Laboratory of the Kansas Highway Commission during the past seven years. Most of these tests have been in connection with flexible pavement studies. These have included several hundred tests of samples procured from highways which have been in service with flexible pavements for a number of years. Considerable research has been conducted to correlate test results with service conditions. The two coefficients for traffic and rainfall make this method of design adaptable to many conditions. This method of design is now the basis upon which the Public Roads Administration of the Federal government approves all projects for flexible pavements in Kansas which are deemed eligible for dederal aid. The flexibility of this method of design makes it adaptable to other conditions which may be found elsewehre.

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