REPORT OF DEPARTMENT OF SOILS INVESTIGATIONS

C A HOGENTOGLER, *Chairman*

Progress has been made during the past year in the following lines of endeavor (1) Stabilized roads, including both base and surface courses, (2) Fill construction, and (3) Tests of soils for foundation purposes

Specifications have been prepared and submitted to the American Association of State Highway Officials The following have been approved by the Committee on Materials of the Association

(1) Standard Specifications for Materials for Stabilized Surface Course, including

Type A—Sand—clay mortar

Type B—Coarse graded aggregate

Type C—Gravel, stone or slag screenings or sand

(2) Standard Specifications for Materials for Stabilized Base Course, including

Type A—Sand—clay mortar

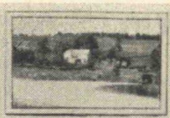
Type B—Coarse graded aggregate

Type C—Gravel, stone or slag screenings or sand

(3) Standard Specifications for Material for Use in Embankment Construction

The essential features of these developments are given in the following seven plates which are taken from the exhibit prepared by the U S Bureau of Public Roads for the convention and Road Show of the American Road Builders' Association in Cleveland, Ohio, in January 1938

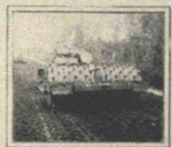
Four reports presented at the open meeting of the Department on Tuesday, November 30, are appended to this general report



Type No. 1.- **GRADED MIX, FOR LIGHT TRAFFIC, BUILT WITH BEST LOCAL MATERIALS AVAILABLE.** The main purpose of the type is to provide an inexpensive all-weather surface for the light traffic on the land-service roads. This surface may become dusty or muddy and portions may get rough or remain smooth. It may be built to serve all-year-round travel at costs ranging up to **$1,500** a mile.

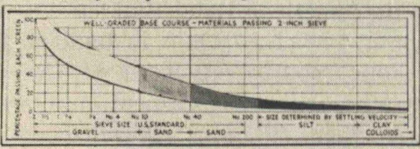
Type No. 2.- **GRADED MIX, FOR MEDIUM TRAFFIC, BUILT WITH A DESIGNED AND PROPORTIONED MIX.** This type provides adequate service for heavier traffic than Type No. 1 because the surface is wider and thicker, the mixture is designed carefully, and the various steps in the construction are controlled so as to produce a dense mix. This surface may be built for costs varying from **$1,500** to **$2,500** a mile

Type No. 3.- **GRADED-MIX BASE WITH A BITUMINOUS SURFACE TREATMENT FOR HEAVIER TRAFFIC THAN TYPE No. 2.** This is a compact, smooth-riding surface, with considerable resistance to skidding, which is free from mud or dust at all seasons of the year. This substantial surface treatment on a properly-constructed base may be built for **$3,500** to **$5,000** a mile. When all new material is used the costs may exceed **$5,000**

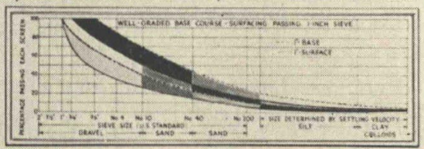


Type No. 4.- **STABILIZED SOIL BASE WITH A BITUMINOUS-MAT SURFACE TREATMENT - FOR HEAVIER TRAFFIC THAN TYPE No. 2.** The poorly graded soil base is stabilized with bituminous binder or Portland cement. This surface when properly built is suitable for relatively heavy traffic. The meager data available indicates that it may be built for prices varying from **$4,500** to **$7,000** a mile. If new aggregate is required to improve the grading of the fine-grained material, the cost may exceed **$7,000** a mile

TYPES NUMBER 1, 2, AND 3 require **WELL-GRADED MATERIALS** such as are indicated on the chart below, within the typical grading band, for road surfaces with clay binders enclosed within the **RED** dashed lines. The grading band for good base materials with clay binders is enclosed by the **BLUE** full lines



PARTICLE-SIZE ACCUMULATION CURVE



PARTICLE-SIZE ACCUMULATION CURVE

BEWARE! GOOD SURFACES MAY BECOME UNSTABLE BASE COURSES

BASE COURSES.- All good surfaces do NOT make good bases because the plasticity index and liquid limit are generally LOWER for a base than for a surface: Except for those gradings shown within the overlapping bands on the chart above, good base soils are coarse and contain smaller amounts of silt and clay. Highly stabilized surfaces often become unstable when covered with impervious bituminous surface mats and used thus as bases

THEREFORE, THE DESIGN OF A BASE COURSE IS DIFFERENT FROM A SURFACE

SURFACES.- In the construction of surfaces, especially Type No. 1, more latitude may be used in the selection of materials than in the base courses for high-type surfaces. The reason for this is that an error in the design may be corrected later by proper maintenance measures. In contrast, an error in the design of a base course means failure of the pavement laid thereon. A road surface, exposed to evaporation, requires more clay to hold sufficient film moisture to insure adhesion of the particles. On the contrary, evaporation from a base course is cut off by the impervious surface. THEREFORE, THE INCREASED MOISTURE in a GOOD SURFACE used as a base course causes all but the best of clays to swell and BECOME UNSTABLE

Figure 1. Four Types of Low Cost Surfaces which May Be Stabilized by Proportioning the Materials or by Treating with Admixtures

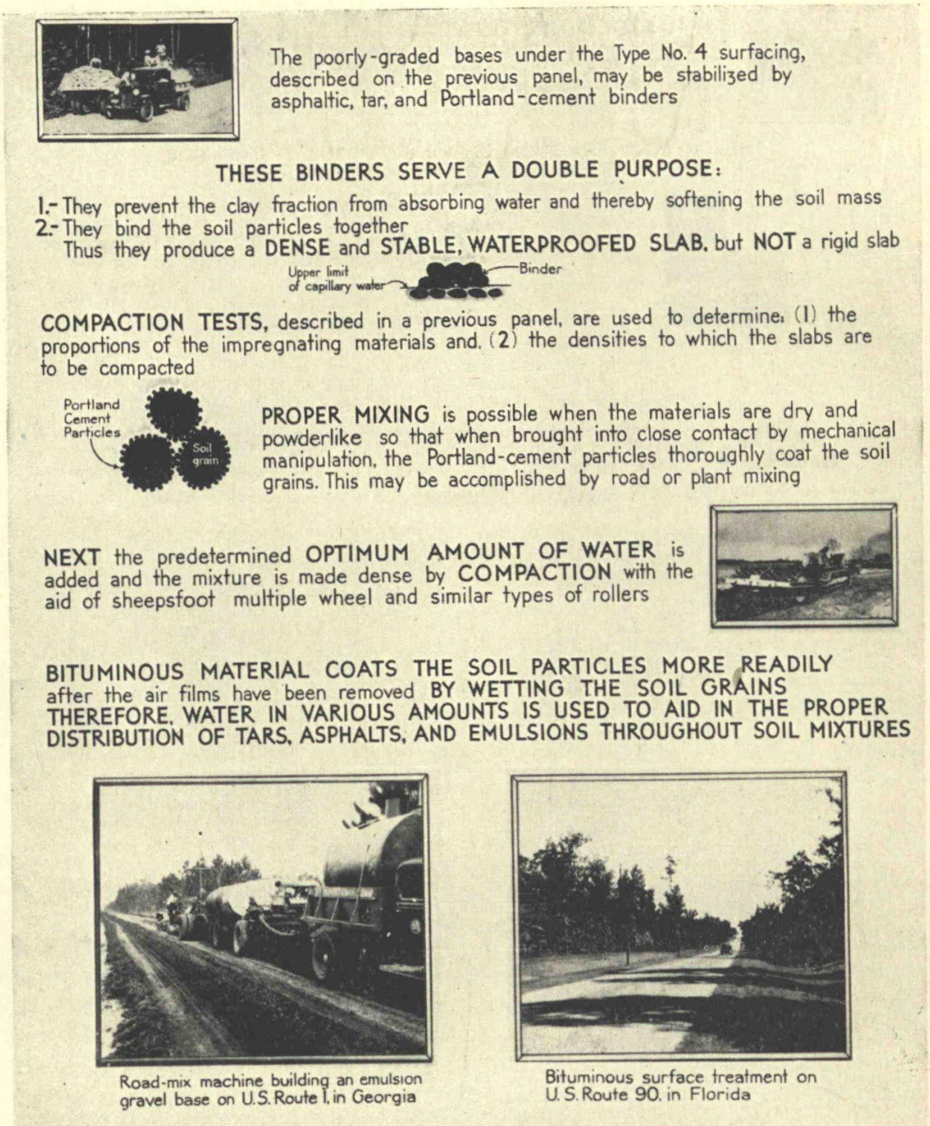


Figure 2. Stabilization of Poorly Graded or Fine Graded Soils

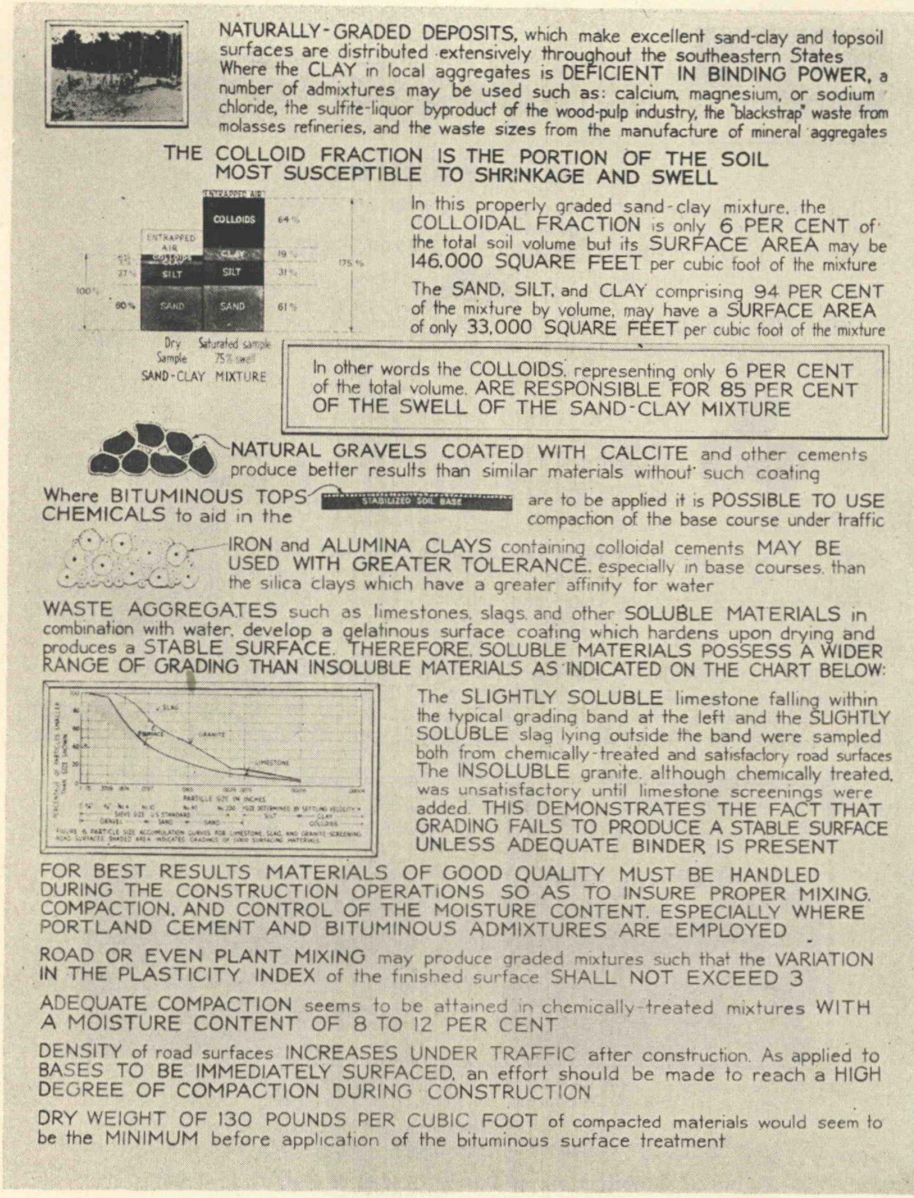
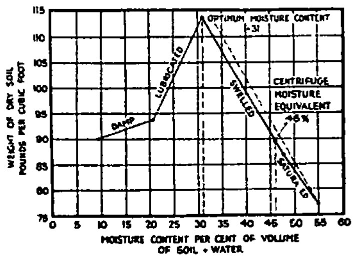
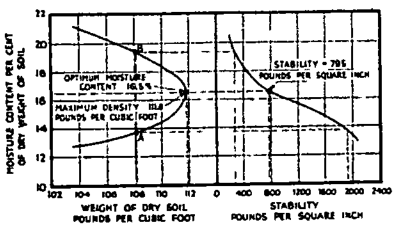


Figure 3. For Stability and Long Life Use the Best Materials Available within the Allowable Cost Per Mile of the Road



Consider the typical soil sample shown in the diagram at the left
Up to 20.7 per cent moisture - The soil is damp and the moisture films are highly-cohesive but have sufficient friction to prevent high density From 20.7 to 31.1 per cent moisture - The soil reaches maximum density
The moisture films have less cementing value but greater lubricating properties From 31.1 to 47.7 per cent moisture - Swell occurs, but stability and density drop The sample is wet
Above 47.7 per cent moisture - Water gradually replaces the air content until at 54.3 per cent moisture, the soil becomes completely saturated

RELATION BETWEEN DENSITY MOISTURE CONTENT, AND STABILITY



In the typical diagram at the left stability drops off rapidly as moisture contents are increased above the optimum and vice versa
At every density less than the maximum there is a moisture content below the optimum at A corresponding to one above the optimum at B, which the wet soil can attain without changing volume
BUT THE CORRESPONDING STABILITY AT A IS 1900 AND AT B IS 270 POUNDS PER SQUARE INCH

SUITABILITY OF SOILS FOR FILL CONSTRUCTION DEPENDS UPON THE DENSITY TO WHICH THEY MAY BE COMPACTED

HEIGHT OF FILLS							
10 FEET OR LESS *				MORE THAN 10 FEET			
Maximum Dry Weight	Approximate Bureau Public Roads Classification	Rating	Maximum Field Compaction Requirements	Maximum Dry Weight	Approximate Bureau Public Roads Classification	Rating	Maximum Field Compaction Requirements
Pounds per cubic foot			Per cent of Dry Weight	Pounds per cubic foot			
89.9 and less	A-5 A-8	Unsatisfactory	----				
90.0 - 99.9	A-5 A-8	Very poor	95	99.9 and less	A-5 A-8	Unsatisfactory	----
100.0 - 109.9	A-6 A-7	Poor	95	100.0 - 109.9	A-6 A-7	Very poor	100.0
110.0 - 119.9	A-4	Fair	90	110.0 - 119.9	A-4	Poor	95.0
120.0 - 129.9	A-3 A-2	Good	90	120.0 - 129.9	A-3 A-2	Fair	90.0
130.0 and more	A-1	Excellent	90	130.0 and more	A-1	Good	90.0

* For fills 10 feet or less in height the soils should have liquid limits (L.L.) not greater than 65 and plasticity indexes not less than 0.6 L.L. minus 9.0

Figure 4 Density of a Compacted Soil Depends upon the Thickness of the Moisture Film Surrounding the Soil Particles

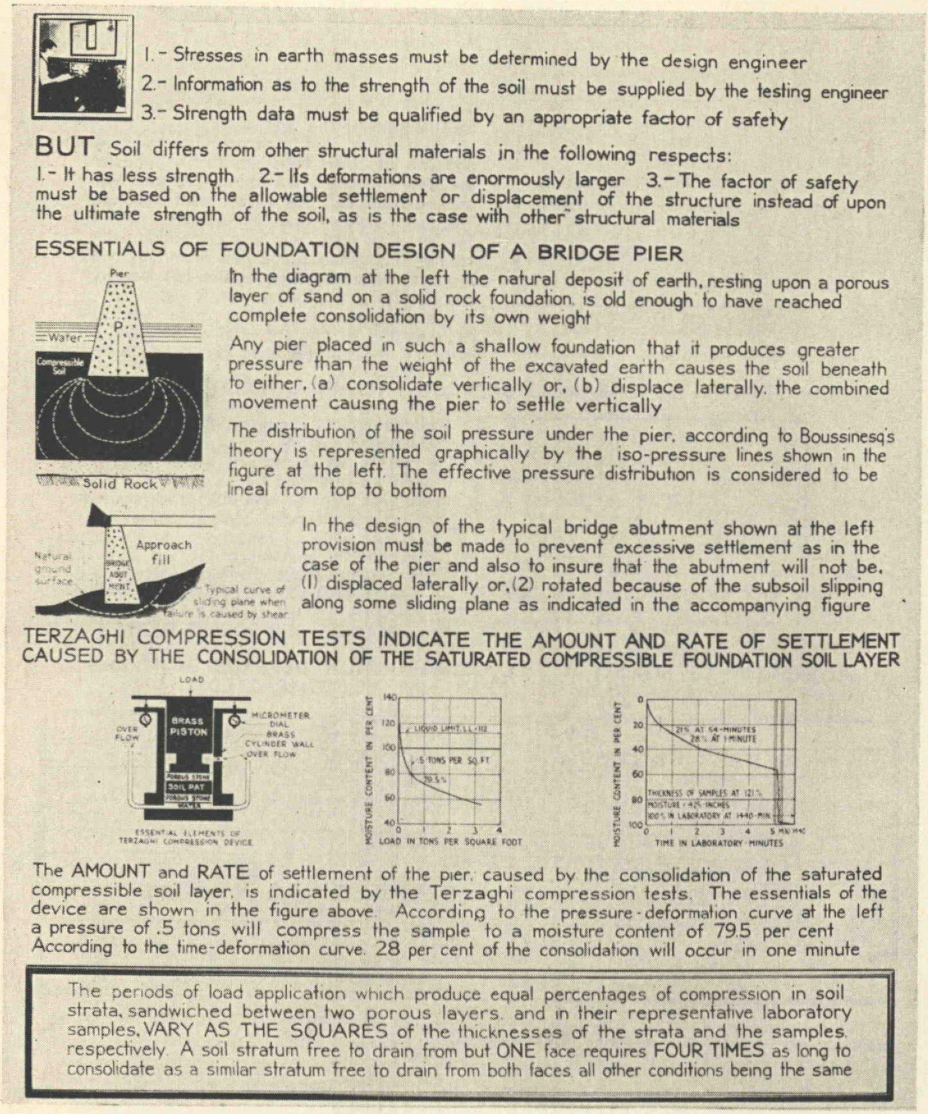


Figure 5. Soil Test Data Yield Like Information when Analyzed in Accordance with the Same Engineering Principle Used for Other Structural Materials Such as Concrete, Wood and Steel.

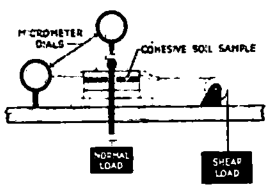
The shear strength of the soil depends upon the cohesion c, the angle of internal friction ϕ, and the pressure p upon the plane of shear, in accordance with the basic equation:

$$s = p \tan \phi + c \qquad (1)$$

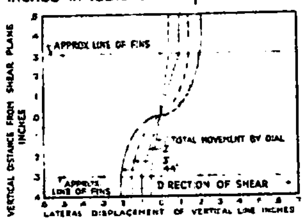
The soil must be deformed before shear strength is developed. In some soils, the horizontal deformations required to develop the ultimate shear strength indicated by test, causes the sample to be deformed as much as 60 per cent of its thickness. The characters of these deformations are shown below in the upper right hand figure

THEREFORE, the ultimate $c + \phi$ determined by test cannot be used but instead values at which ALLOWABLE deformatioms occur, and consequently relations of deformation to $c + \phi$ are necessary

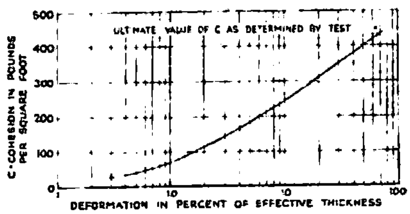
The essential features, of a simple device used for determining the shear strengths of cohesive soils is shown in the diagram below

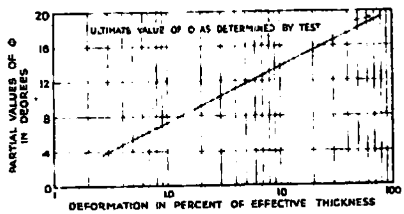


The chart below shows the data obtained for the maximum horizontal deformations of 0.1, 0.2, 0.3 and 0.44 inches in tests of samples 1-inch thick



FOR AN ACCURATE CONCEPTION OF THE EFFECT OF THE STRESS-STRAIN RELATION THE SAMPLE THICKNESS MAY BE TAKEN INTO CONSIDERATION BY EXPRESSING THE HORIZONTAL DEFORMATIONS AS PERCENTAGES OF THE VERTICAL THICKNESSES OF THE SAMPLES BETWEEN THE EDGES OF THE FINS OR GRIDS





The curves in the two figures above represent test values on a sample of clay soil 0.2 of an inch thick between fins; moisture content of 27 per cent; liquid limit of 43; and a plasticity index of 24

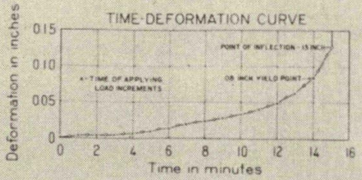
IT IS EVIDENT THAT THE POSSIBLE LATERAL DISPLACEMENT OF A BRIDGE ABUTMENT ON A SOIL LAYER 6 INCHES THICK MIGHT NOT BE DANGEROUS WHEREAS THE LATERAL DISPLACEMENT ON A SOIL LAYER 6 FEET THICK MIGHT BE DISASTROUS

Figure 6. Shear Strength Determines the Resistance of Soil to Lateral Displacement from Beneath Piers and Along Planes Beneath Abutments

The SHEAR STRENGTH of the soil depends upon the COHESION and the ANGLE OF INTERNAL FRICTION of the soil according to the basic equation:

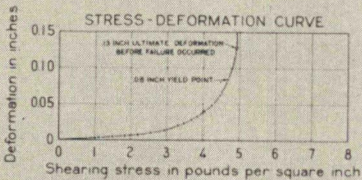
$$s = p \tan \Phi + c \tag{1}$$

in which s = shear strength or stress in pounds per square inch
p = pressure normal to shearing plane in pounds per square inch
Φ = angle of internal friction in degrees
c = cohesion in pounds per square inch

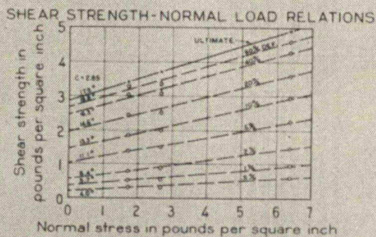


The time-deformation and stress-deformation curves at the left show the results of shear tests on a clay soil under a normal pressure of 6.8 pounds per square inch and at a single moisture content.

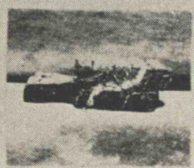
The time-deformation curve shows the relation of the horizontal deformation of the sample to the periods of shear (horizontal) load applications. The ULTIMATE SHEAR STRENGTH is computed by dividing the next to the last horizontal load by the area of the unsheared portion of the sample at the time of application of the last load.



The relation of shear stresses to horizontal deformations for any constant load may then be shown by the STRESS-DEFORMATION curve at the left. This shows how the shear stresses increase with the deformation until the maximum shear strength that would NOT cause failure was reached at a deformation of 0.08 inch.



By testing samples under different vertical loads, plotted as normal pressures, the relation of shear strength to normal pressure may be obtained as shown by the TOP line in the diagram at the left. The relations for deformations less than the ultimate are shown by the lines BELOW.



The photograph above shows how a vertical plane, in a sample before a test, was distorted after the sample was sheared to failure.

Design data for all other engineering materials except soils include stress-strain relations showing the ultimate strengths and deformations at which failures occur as well as the relation of stress to deformation for all points below the ultimate. In the case of soil materials it has been customary to use principally the value for the ultimate shear strength together with the corresponding angle of internal friction and the cohesion. As a result entirely erroneous conclusions have been reached with regard to the shear-strength relations where the deformations were less than the ultimate.

Available data indicate that the horizontal deformations of a soil under test are caused largely by accumulations of distortions distributed vertically through the sample. CONSEQUENTLY, THE MAGNITUDES OF THE RECORDED DEFORMATIONS ARE DEPENDENT MAINLY ON THE THICKNESS OF THE SAMPLE.

Figure 7. Shear Tests Show the Ulimate Strengths and Deformations at which Failures Occur as Well as the Stress-Deformation Relations Less than the Ultimate