

REPORT OF DEPARTMENT OF SOILS INVESTIGATIONS

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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 Ma-

terials 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.

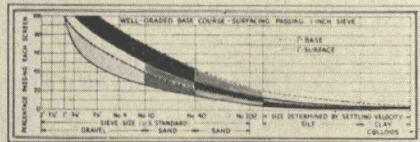
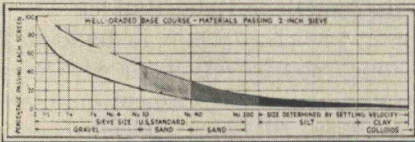


Type No. 3.- GRADED-MIX BASE WITH A BITUMINOUS SURFACE TREATMENT FOR HEAVIER TRAFFIC THAN TYPE No. 2. This is a compact, smooth-riding surface, with considerable resistance to skidding, which is free from mud or dust at all seasons of the year. This substantial surface treatment on a properly-constructed 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



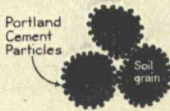
The poorly-graded bases under the Type No. 4 surfacing, described on the previous panel, may be stabilized by asphaltic, tar, and Portland-cement binders

THESE BINDERS SERVE A DOUBLE PURPOSE:

- 1.- They prevent the clay fraction from absorbing water and thereby softening the soil mass
 - 2.- They bind the soil particles together
- Thus they produce a **DENSE and STABLE, WATERPROOFED SLAB**, but **NOT** a rigid slab



COMPACTION TESTS, described in a previous panel, are used to determine: (1) the proportions of the impregnating materials and, (2) the densities to which the slabs are to be compacted

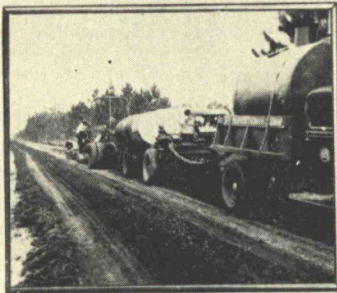


PROPER MIXING is possible when the materials are dry and powderlike so that when brought into close contact by mechanical manipulation, the Portland-cement particles thoroughly coat the soil grains. This may be accomplished by road or plant mixing

NEXT the predetermined **OPTIMUM AMOUNT OF WATER** is added and the mixture is made dense by **COMPACTION** with the aid of sheepfoot multiple wheel and similar types of rollers



BITUMINOUS MATERIAL COATS THE SOIL PARTICLES MORE READILY after the air films have been removed **BY WETTING THE SOIL GRAINS** THEREFORE, **WATER IN VARIOUS AMOUNTS** IS USED TO AID IN THE **PROPER DISTRIBUTION OF TARS, ASPHALTS, AND EMULSIONS** THROUGHOUT SOIL MIXTURES



Road-mix machine building an emulsion gravel base on U.S. Route 1, in Georgia



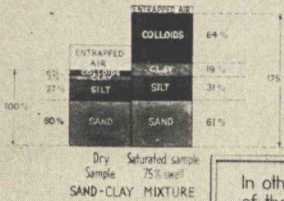
Bituminous surface treatment on U.S. Route 90, in Florida

Figure 2. Stabilization of Poorly Graded or Fine Graded Soils



NATURALLY-GRADED DEPOSITS, which make excellent sand-clay and topsoil surfaces are distributed extensively throughout the southeastern States. Where the **CLAY** in local aggregates is **DEFICIENT IN BINDING POWER**, a number of admixtures may be used such as: calcium, magnesium, or sodium chloride, the sulfate-liquor byproduct of the wood-pulp industry, the 'blackstrap' waste from molasses refineries, and the waste sizes from the manufacture of mineral aggregates

THE COLLOID FRACTION IS THE PORTION OF THE SOIL MOST SUSCEPTIBLE TO SHRINKAGE AND SWELL



In this properly graded sand-clay mixture, the **COLLOIDAL FRACTION** is only **6 PER CENT** of the total soil volume but its **SURFACE AREA** may be **146,000 SQUARE FEET** per cubic foot of the mixture.

The **SAND, SILT, and CLAY** comprising **94 PER CENT** of the mixture by volume, may have a **SURFACE AREA** of only **33,000 SQUARE FEET** per cubic foot of the mixture.

In other words the **COLLOIDS**, representing only **6 PER CENT** of the total volume, **ARE RESPONSIBLE FOR 85 PER CENT OF THE SWELL OF THE SAND-CLAY MIXTURE**



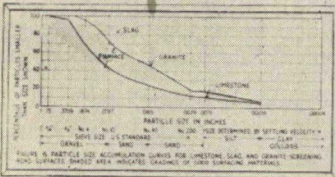
NATURAL GRAVELS COATED WITH CALCITE and other cements produce better results than similar materials without such coating.

Where **BITUMINOUS TOPS** are to be applied it is **POSSIBLE TO USE CHEMICALS** to aid in the **STABILIZED SOIL BASE** compaction of the base course under traffic.



IRON and ALUMINA CLAYS containing colloidal cements **MAY BE USED WITH GREATER TOLERANCE**, especially in base courses, than the silica clays which have a greater affinity for water.

WASTE AGGREGATES such as limestones, slags, and other **SOLUBLE MATERIALS** in combination with water, develop a gelatinous surface coating which hardens upon drying and produces a **STABLE SURFACE**. **THEREFORE, SOLUBLE MATERIALS POSSESS A WIDER RANGE OF GRADING THAN INSOLUBLE MATERIALS AS INDICATED ON THE CHART BELOW:**



The **SLIGHTLY SOLUBLE** limestone falling within the typical grading band at the left and the **SLIGHTLY SOLUBLE** slag lying outside the band were sampled both from chemically-treated and satisfactory road surfaces. The **INSOLUBLE** granite, although chemically treated, was unsatisfactory until limestone screenings were added. **THIS DEMONSTRATES THE FACT THAT GRADING FAILS TO PRODUCE A STABLE SURFACE UNLESS ADEQUATE BINDER IS PRESENT**

FOR BEST RESULTS **MATERIALS OF GOOD QUALITY** MUST BE HANDLED DURING THE CONSTRUCTION OPERATIONS SO AS TO INSURE PROPER MIXING, COMPACTION, AND CONTROL OF THE MOISTURE CONTENT, ESPECIALLY WHERE PORTLAND CEMENT AND BITUMINOUS ADMIXTURES ARE EMPLOYED.

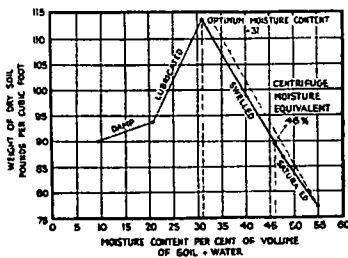
ROAD OR EVEN PLANT MIXING may produce graded mixtures such that the **VARIATION IN THE PLASTICITY INDEX** of the finished surface **SHALL NOT EXCEED 3**.

ADEQUATE COMPACTION seems to be attained in chemically-treated mixtures WITH A **MOISTURE CONTENT OF 8 TO 12 PER CENT**.

DENSITY of road surfaces **INCREASES UNDER TRAFFIC** after construction. As applied to **BASES TO BE IMMEDIATELY SURFACED**, an effort should be made to reach a **HIGH DEGREE OF COMPACTION DURING CONSTRUCTION**.

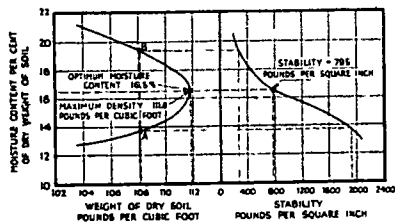
DRY WEIGHT OF **130 POUNDS PER CUBIC FOOT** of compacted materials would seem to be the **MINIMUM** before application of the bituminous surface treatment.

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	-----	99.9 and less	A-5 A-8	Unsatisfactory	-----
90.0 - 99.9	A-5 A-8	Very poor	95	100.0 - 109.9	A-6 A-7	Very poor	100.0
100.0 - 109.9	A-6 A-7	Poor	95	110.0 - 119.9	A-4	Poor	95.0
110.0 - 119.9	A-4	Fair	90	120.0 - 129.9	A-3 A-2	Fair	90.0
120.0 - 129.9	A-3 A-2	Good	90	130.0 and more	A-1	Good	90.0
130.0 and more	A-1	Excellent	90				

* For fills 10 feet or less in height the soils should have liquid limits (LL) not greater than 65 and plasticity indexes not less than 0.6 LL minus 90

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

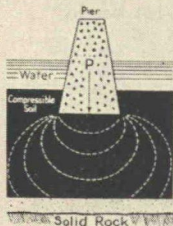


- 1.- Stresses in earth masses must be determined by the design engineer
- 2.- Information as to the strength of the soil must be supplied by the testing engineer
- 3.- Strength data must be qualified by an appropriate factor of safety

BUT Soil differs from other structural materials in the following respects:

- 1.- It has less strength
- 2.- Its deformations are enormously larger
- 3.- The factor of safety must be based on the allowable settlement or displacement of the structure instead of upon the ultimate strength of the soil, as is the case with other structural materials

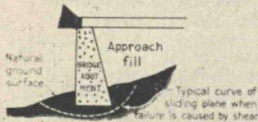
ESSENTIALS OF FOUNDATION DESIGN OF A BRIDGE PIER



In the diagram at the left the natural deposit of earth, resting upon a porous layer of sand on a solid rock foundation is old enough to have reached complete consolidation by its own weight

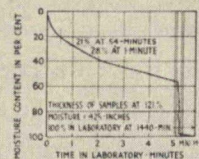
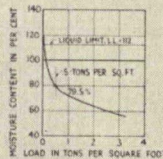
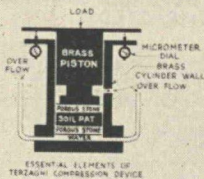
Any pier placed in such a shallow foundation that it produces greater pressure than the weight of the excavated earth causes the soil beneath to either, (a) consolidate vertically or, (b) displace laterally, the combined movement causing the pier to settle vertically

The distribution of the soil pressure under the pier, according to Boussinesq's theory is represented graphically by the iso-pressure lines shown in the figure at the left. The effective pressure distribution is considered to be lineal from top to bottom



In the design of the typical bridge abutment shown at the left provision must be made to prevent excessive settlement as in the case of the pier and also to insure that the abutment will not be, (1) displaced laterally or, (2) rotated because of the subsoil slipping along some sliding plane as indicated in the accompanying figure

TERZAGHI COMPRESSION TESTS INDICATE THE AMOUNT AND RATE OF SETTLEMENT CAUSED BY THE CONSOLIDATION OF THE SATURATED COMPRESSIBLE FOUNDATION SOIL LAYER



The **AMOUNT** and **RATE** of settlement of the pier, caused by the consolidation of the saturated compressible soil layer, is indicated by the Terzaghi compression tests. The essentials of the device are shown in the figure above. According to the pressure-deformation curve at the left a pressure of .5 tons will compress the sample to a moisture content of 79.5 per cent. According to the time-deformation curve, 28 per cent of the consolidation will occur in one minute

The periods of load application which produce equal percentages of compression in soil strata, sandwiched between two porous layers, and in their representative laboratory samples, **VARY AS THE SQUARES** of the thicknesses of the strata and the samples, respectively. A soil stratum free to drain from but **ONE** face requires **FOUR TIMES** as long to consolidate as a similar stratum free to drain from both faces all other conditions being the same

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.

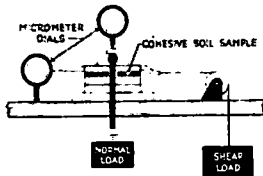
The shear strength of the soil depends upon the cohesion c , the angle of internal friction ϕ , and the pressure p upon the plane of shear, in accordance with the basic equation:

$$s = p \tan \phi + c \text{ ----- (1)}$$

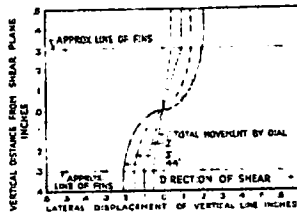
The soil must be deformed before shear strength is developed. In some soils, the horizontal deformations required to develop the ultimate shear strength indicated by test, causes the sample to be deformed as much as 60 per cent of its thickness. The characters of these deformations are shown below in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

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

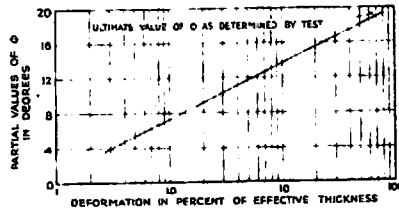
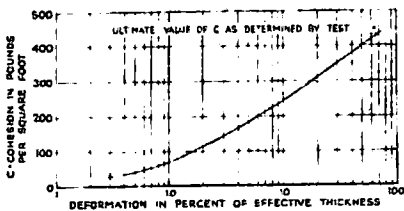
The essential features, of a simple device used for determining the shear strengths of cohesive soils is shown in the diagram below



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 FIN'S 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

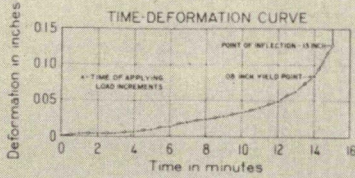
IT IS EVIDENT THAT THE POSSIBLE LATERAL DISPLACEMENT OF A BRIDGE ABUTMENT ON A SOIL LAYER 6 INCHES THICK MIGHT NOT BE DANGEROUS WHEREAS THE LATERAL DISPLACEMENT ON A SOIL LAYER 6 FEET THICK MIGHT, BE DISASTROUS

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:

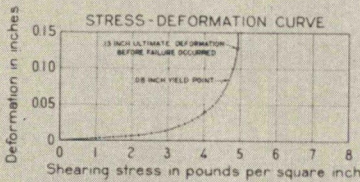
$$s = p \tan \phi + c \quad (1)$$

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

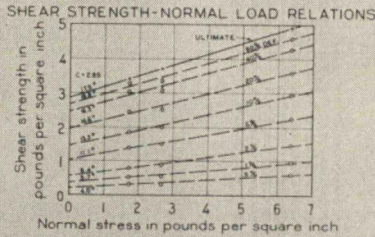


The time-deformation and stress-deformation curves at the left show the results of shear tests on a clay soil under a normal pressure of 88 pounds per square inch and at a single moisture content.

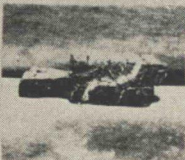
The time deformation curve shows the relation of the horizontal deformation of the sample to the periods of shear (horizontal) load applications. The ULTIMATE SHEAR STRENGTH is computed by dividing the next to the last horizontal load by the area of the unsheared portion of the sample at the time of 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 Ultimate Strengths and Deformations at which Failures Occur as Well as the Stress-Deformation Relations Less than the Ultimate