PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 12, NO. 7 ▽ SEPTEMBER, 1931

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VOL. 12, NO. 7 **SEPTEMBER, 1931** **G. P. St. CLAIR, Editor**

TABLE OF CONTENTS

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THE SOIL PROFILE AND THE SUBGRADE SURVEY

Reported by W. I. WATKINS, Assistant Soil Surveyor, U. S. Bureau of Chemistry and Soils, and HENRY AARON, Assistant Highway Engineer, U. S. Bureau of Public Roads

SUBGRADE soil profiles, the importance of which with respect to road construction is discussed in this report, are studied and mapped in the field according to procedures suggested by the pedologist. However, the highway engineer is interested only in those soil properties upon which the service ability of pavements depend. Some of these properties are often of minor significance in an agricultural sense. In other cases the scale adopted in the publication of reports of agricultural soil surveys is too small to show all of them. For this reason attention in field and laboratory is directed specifically to those properties which are important in road construction. The final map of the subgrade soil profile discloses those engineering properties of soils which are determined by laboratory tests, as well as those physical characteristics which are identified by the soil scientist.

Information furnished by the soil scientist which assists the engineer both in the study of subgrade profiles and in the interpretation of existing soil data is contained in the reports listed in the attached bibliography.[1]

THE SOIL PROFILE DESCRIBED

According to Dr. C. F. Marbut (*1*) the soils of the United States may be divided into two large categories: (1) Pedalfers and (2) pedocals. The pedalfers are soils that tend to accumulate iron and aluminum and have no horizon[2] of lime carbonate accumulation, even if the soils have limestone as parent material. The accumulation of lime carbonate and other salts is a characteristic feature of pedocals. This discussion is based on studies covering a wide range of pedalfer and a few pedocal soil types established by the Bureau of Chemistry and Soils.

A vertical section of the weathered soil layers, having different characteristics though uniformly weathered within themselves, is known as the soil profile. In soil technology the term "soil profile" applies to the weathered layers which constitute what is known as the solum and the material immediately underlying it. In the well-drained upland soils of the humid region the solum is ordinarily less than 10 feet in thickness and is usually composed of a lighter-textured upper and a heavier-textured lower layer, both of which may have sublayers.

A soil type is the soil unit and is as definite an object as any other classified object, animal, or plant, and always presents approximately the same physical characteristics (*5*, *6*). A soil series is a group of soil types that have profiles uniform in all respects except the texture of the surface layer.

Practically all modern soil research is conducted upon the basis of the soil-type profile. There is no desire to create the impression that every soil type or soil layer differs widely from all other soil types or soil layers; but it is believed that the method of classification based on soil types furnishes the most economical basis for studying soils and utilizing the information obtained for any given purpose. After the properties or behavior of the layers of a soil type are once determined the data obtained will be immediately and continuously available and may be of use in connection with studying any branch of science in any way pertaining to soil, such as agriculture, erosion, corrosion, drainage, road construction, and so on. Such information is applicable wherever the soil type from which the information was obtained is found. The behavior of soil layers common to the individual soil types of a soil series or of a closely related soil series may thus be ascertained by determining the behavior of such a common layer in one or more of the closely related soil types. Additional discussion of the soil profile is contained in a report by Joffe (*2*). Figures 1 to 4, inclusive, illustrate the character of the material encountered in the determination of soil profile.

SOIL PROFILE AS RELATED TO ROAD CONSTRUCTION

One can readily understand that the characteristics of the soil profile control percolation, capillarity, seepage—in fact, all internal water movement except that influenced by nonsoil agencies, such as animal burrows, root holes, etc. The influence of the soil layers on the nature of water movement will change if the soil is in any way disturbed. The degree of change will depend on the extent to which the natural characteristics are destroyed. The resistance to change of the natural characteristics and the subsequent effect on soil behavior are governed largely by the relative amounts of silt and colloids, and the chemical composition of the colloids (*7*). Certain other constituents such as diatoms and mica flakes have a decided influence upon the physical behavior of a soil (*8*). The soil characteristics, their descriptive terms, and the influence they may have on subgrade soil behavior are summarized in the following paragraphs:

Texture.—For sand or sandy loams: Coarse, medium, fine, very fine. Other soils classified by texture as loam, silt loam, clay loam, silty clay loam, clay. May reflect plasticity, density, slumping, porosity, expansion, contraction, capillarity, susceptibility to compaction, elasticity, percolation, water absorption, erosion, structure.

Color.—Black, red, brown, yellow, drab, gray, mottled. May reflect organic content, oxidation, leaching, chemical content, structure, erosive qualities.

Structure.—Buckshot, granular, columnar, cloddy, crumb, adobe, dense, massive, laminated, nut, mealy, structureless. May reflect capillarity, percolation, porosity, water absorption, internal drainage, bulking on being disturbed, susceptibility to compaction, elasticity.

Consistency.—Brittle, hard, compact, tough, tenacious, sticky, plastic, cheesy, friable, mellow, loose. May reflect capillarity, percolation, porosity, water absorption, internal drainage, bulking, compactibility, elasticity, supporting power.

Compactness.—Clay pan, hardpan; soils also classified by degree of compaction. May give idea of bulking, internal water movement, degree of support.

[1] Italic figures in parentheses refer to the reports listed in the bibliography.

[2] In standard soil descriptions for humid regions the light-textured surface layer is designated the A horizon, the underlying heavier-textured layer as the B horizon, and the third layer, consisting of the unweathered or incompletely weathered geological formation, as the C horizon. The A and B horizons constitute the real soil profile, the Solum horizon of Frosterus, while the C horizon is part of the parent geological formation not made significantly lighter or heavier in texture by soil-making processes. An horizon may have subhorizons such as A_1, A_2, etc. For highway purposes, the various layers are numbered consecutively from the surface down without designating any horizon. For example, instead of layers A_1, A_2, B, etc., we have layers 1, 2, 3, etc. Some soil surveyors designate these layers as zone 1, zone 2, zone 3, etc.

Cementation.—Classified by cementing material and degree of cementation. May give idea of bulking, internal water movement, degree of support.

Chemical composition.—Significant chemicals are iron, calcium, concretions, alkali, sesquioxides, exchangeable bases, pH value. May affect structure, adhesiveness, friability, plasticity, drainage and water movement, formation of hardpans, expansion, contraction, water retention, heat of wetting.

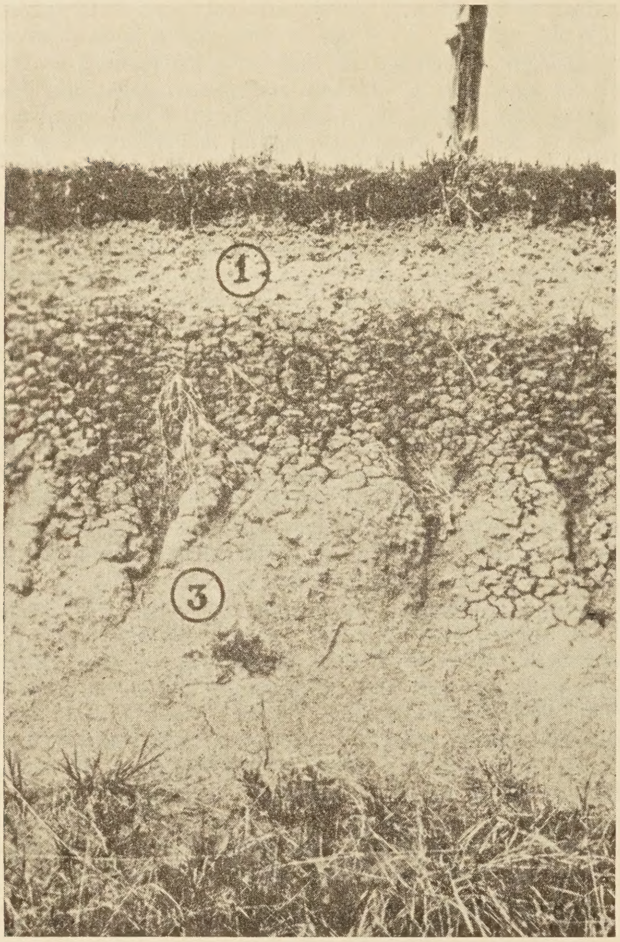

Figure 1.—Profile of Iredell Silt Loam Showing (1) Lighter-Textured Upper Soil Layer, (2) Heavy, Plastic, Sticky, Waxy Clay, and (3) Decomposed Rock

Organic content classified by kind of material and degree of decomposition; influences water absorption, temperature, firmness, stability, compactibility and springiness.

In nonalkali soils the percentage of colloids and their chemical composition are probably the most important factors controlling such soil characteristics as consistency, structure, and porosity. This is especially true of the silica sesquioxide ratio. Soils containing colloids with a low silica sesquioxide ratio, i. e., colloids high in the sesquioxides of iron and aluminum and low in the oxides of silica, shrink and expand but slightly at extremes of moisture content, are not very plastic or excessively sticky, and are more friable, more porous, and less plastic than soils containing an equal amount of colloids with a high silica sesquioxide ratio (*9, 10*). Some highly colloidal clays of low sesquioxide ratio make better road subgrades than other soils containing less colloids with a high silica sesquioxide ratio (*11*).

Texture has usually been taken as an index of the rate of percolation, but structure is now considered of equal or greater importance (*12*), and the destruction of the natural structure may increase or decrease the rate of percolation. The variability in percolation rates of the various soil layers or soil material causes and controls seepage or lateral water movement. Seepage develops when the amount of water percolating through any one soil layer exceeds the percolating rate of that below. The amount of lateral movement is governed by the amount of water and differences in rate of perco-

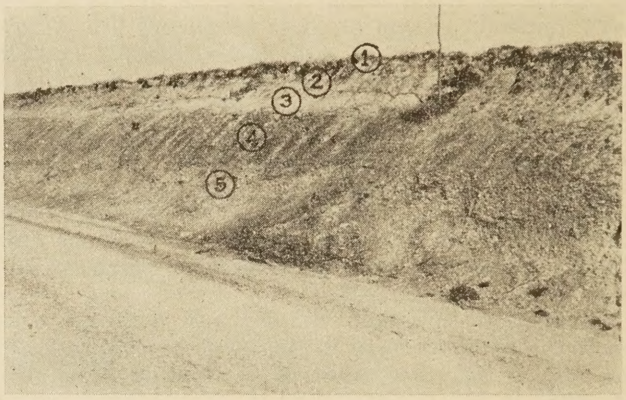

Figure 2.—Profile of Leonardtown Silt Loam Showing (1) Grayish Brown Granular Silt Loam, (2) Brown, Granular Silty Clay Loam, (3) Gray, Compact, Sandy Hardpan, (4) The Friable Clay, and (5) The Compact Clay

lation. It will be seen that water movement depends not only on the character of any particular layer but also on its relation to other associated layers and the effect of local climatic conditions. A silt loam may block or retard percolation in a soil profile where the silt is overlain by sands or may act as a water carrier if underlain by compacted sands or clays. In some soil profiles clay layers may act as water carriers if underlain by denser, less pervious layers. Stratified soils, dense clays, and hardpans are frequently causes of seepage. Silts, sands, and gravels are the most prolific carriers. Cleavage

Figure 3.—Road Cut Through a Bed of Stratified Sands and Gravels in Glacial Drift. Notice How Gravel Deposit Ends Abruptly at Right of Photograph

planes in geological materials are also channels for lateral water movement. Figure 5 shows cleavage planes in shale. The soil profile discloses these water-carrying layers in the field. Through its control of water movement, the soil profile furnishes a basis for the design of drains. The proper location of drains with respect to the soil profile is illustrated in Figure 6.

The study of soil profiles has shown frost boils to be confined to certain soil materials or soil layers by themselves, or in combination with other soil materials or

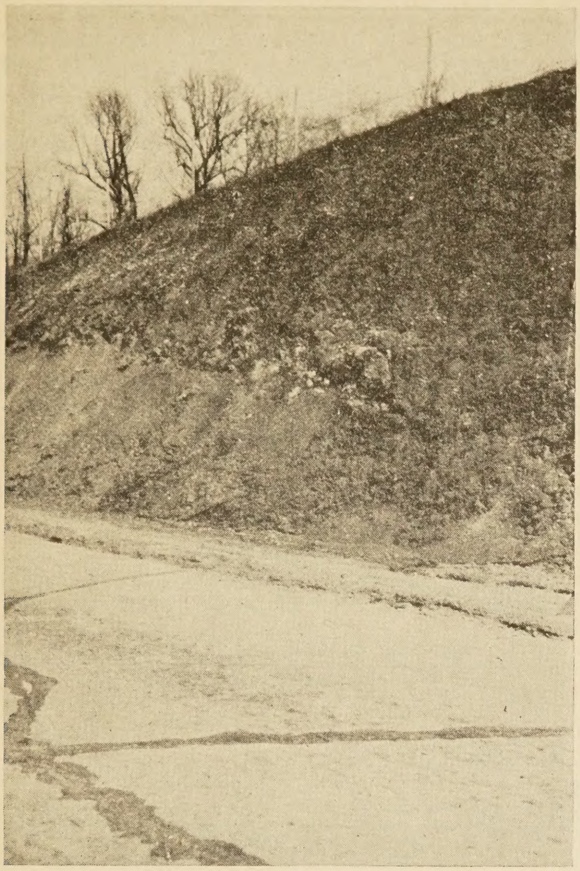

FIGURE 4.—A CUT THROUGH COLLINGTON LOAM. THE MATERIAL OUTLINED IN THE LOWER PART OF THE PHOTOGRAPH CONTAINS DIATOMS, IS POROUS AND LIGHT IN WEIGHT IN ITS NATURAL CONDITION, HOLDS ENORMOUS AMOUNTS OF WATER, HAS LITTLE STABILITY WHEN WET AND IS DISTINGUISHED BY A SOAPY FEEL

layers possessing certain definite characteristics. These studies have shown the very fine sands, silt loams, and silty clay loams having little or no apparent soil structure to be the greatest sources of frost boils where these soils or soil materials are found associated with water carriers or where they act as water carriers themselves. In New Hampshire, for example, frost boils were found to be associated mainly with stratified silty clay loams and very fine sandy loams that retarded percolation or had seepage characteristics, and carried the water into the subgrade, where it froze.

In Minnesota frost boils are found to occur most frequently in soil material having no readily determinable structure, and vary in degree of severity depending on the soil material and source of water. The more variable the soil and the more water available, the more severe the frost boil development. The extremely variable glaciated soil materials of this region probably develop the most severe heaving. Less severe heaving occurs in the structureless loessial soil material of southeastern Minnesota. Figure 7 is a diagrammatic illustration of a frost boil and its relation to the soil profile of a glaciated soil, while Figure 8 shows the same for a loessial soil. These drawings represent actual cases.

This structureless loessial soil material is a silt loam containing a high percentage of very fine sand, has a high water-holding capacity, is unstable when wet, and has a texture likely to produce maximum active capillarity. The material is underlain by a heavy, slightly pervious clay that restricts percolation and causes a water table to develop just above the clay. This water table may supply the water to the road surface by capillarity.

Capillarity is controlled by structure and density as well as by texture. The soil types overlying the loessial soil material seldom develop frost boils if in their natural condition, but if disturbed and used as fill in poorly drained areas are likely to become soft during the spring, as silty soils do not have resistant structure and are likely to have more active capillarity when the structure is destroyed.

FIGURE 5.—STRATIFICATIONS IN SHALE. THE CONTACT PLANES BETWEEN THE DIFFERENT SHALE STRATA ARE POTENTIAL PLANES OF WATER SEEPAGE

The soil profile offers a means for the study of the design and construction of fills and back slopes in different soil types and under different drainage conditions. With a knowledge of the physical characteristics of the various layers of the soil profile, the stability of the different layers in place or when combined in fill may be determined. This information will establish the slope of fills and back slopes which will

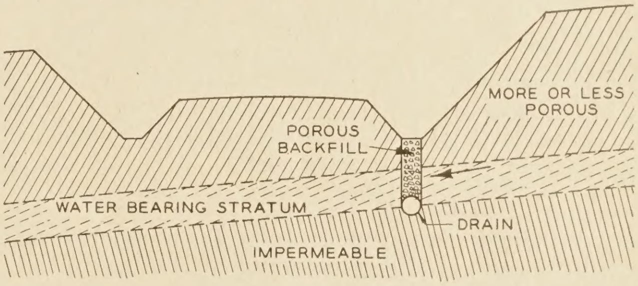

FIGURE 6.—DRAINS SHOULD EXTEND THROUGH THE ENTIRE DEPTH OF THE PERVIOUS LAYER AND INTO THE IMPERVIOUS LAYER

have to conform to the layer or material having the smallest angle of repose; or remedies will have to be adopted to increase its angle of repose. There is a possibility of establishing fairer grading contracts through a knowledge of the amount of the various soils or soil materials which are to be moved, as such data make possible a closer estimate of the cost of handling.

The characteristics of a soil and its value as a subgrade under different conditions are directly reflected in the condition of the road surface. Rigid pavements are affected by inequalities of subgrade support. Non-rigid pavements are chiefly affected by low road supporting power. Studies have shown that the subgrade

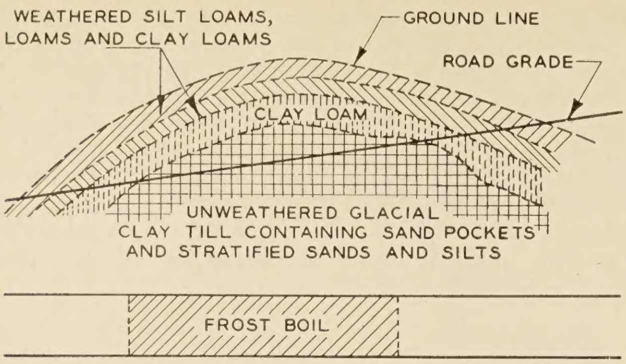

Figure 7.—Frost Boil in Glaciated Soil Materials

soil exerts important influence upon the distance between transverse cracks in concrete roads, and that excessive longitudinal cracking develops on definite layers of certain soil types. Other soil characteristics, such as swelling, affinity for water, rebound, etc., are detrimental to concrete before it sets as it is then a flexible pavement. Figures 9 and 10 show the relation which exists between the various soil zones of a soil type and the pavement condition. In addition to the effect of the soil itself, these results are affected by climate, rainfall and temperature range. With a knowledge of these factors it is possible to control the effects on the pavement by subgrade preparation and slab design. The importance of the subgrade soil properties is especially observed in the performance of oil and gravel road surfaces, since a portion of the soil is incorporated with the surfacing material. By using the soil profile as a basis for correlating the different types of road deterioration or condition, it has been

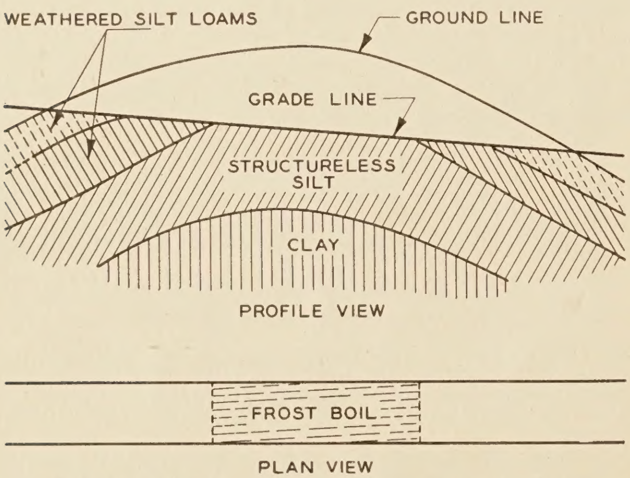

Figure 8.—Frost Boil in Structureless Silt

possible to determine under what conditions and upon what soil layer or soil material of a soil type the different kinds of road failures can be expected.

The correlation of the condition of roads in service with the soil profile and the determination of the physical characteristics of the layers composing the profile as disclosed by laboratory tests form the basis for the grouping of subgrade soils according to performance. The success obtained by these correlation studies shows that the soil profile is a reliable, scientific, and economical means of approaching and solving subgrade soil problems. Furthermore, the soil profile offers a method for the practical application of subgrade research to highway construction.

DETERMINATION OF THE SOIL PROFILE

The soil profile is determined by examining the soil in its natural field condition. This work is best accomplished by examining excavations, road cuts, etc., but the method of using a soil auger is the most common. There is no definite rule to follow in making these examinations, except that the soil should be examined at intervals close enough to determine the soil type and by borings deep enough to penetrate the more or less non-uniform layers of soil or soil material.

According to Doctor Marbut (*4*) the examination of the soil section, after the locality has been determined upon, should proceed in a systematic way somewhat as follows:

1. Texture.[3]—The successive layers or horizons differing in texture, or in fineness or coarseness of the material, should be carefully examined. The examination should extend to a depth of at least 5 or 6 feet. The texture of each layer and its thickness should be described.

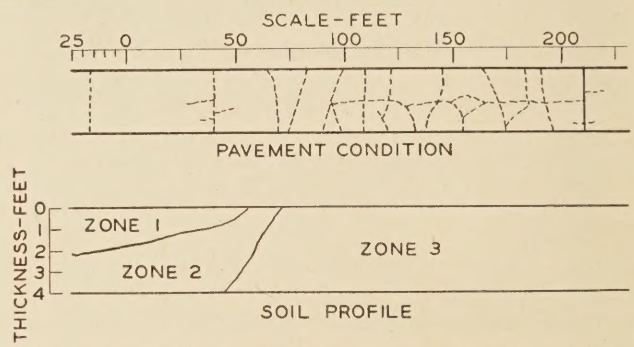

Figure 9.—Relation of Various Soil Zones to Pavement Condition

2. Color.—The successive layers which can be differentiated according to differences in color, should be noted. Each layer should be described and its thickness given.

3. Structure.—The several layers that differ according to structure should be examined carefully, structure being defined as the kind and size of soil particle aggregation. Special note should be made of horizons with (*a*) fine granular structure (granules about the size of bird shot or smaller); (*b*) coarse granular structure (granules ranging up to half an inch or more in diameter and usually more angular or irregular in shape than the granules making up the fine granular structure); (*c*) layered or platy structure, in which the material splits into thin plates (not to be confused with stratification); (*d*) buckshot structure, in which the soil on drying breaks up into angular fragments (found to characterize heavy clays usually having a considerable percentage of lime); and (*e*) single-grain structure in which the material is like flour or sand with no aggregation of particles.

4. Consistency.—A determination should be made of the successive layers or horizons differing in consistency (stickiness, friability, plasticity). A description of each should be given and its thickness noted.

5. Compactness.—The relative compactness of the several layers should be determined, as measured by the degree of resistance to the penetration of a pointed instrument.

6. Cementation.—It should be determined whether or not resistance to penetration is due in any horizon to

[3] The terms used by the pedologist in describing the various layers of the soil profile are defined in Appendix A of this report.

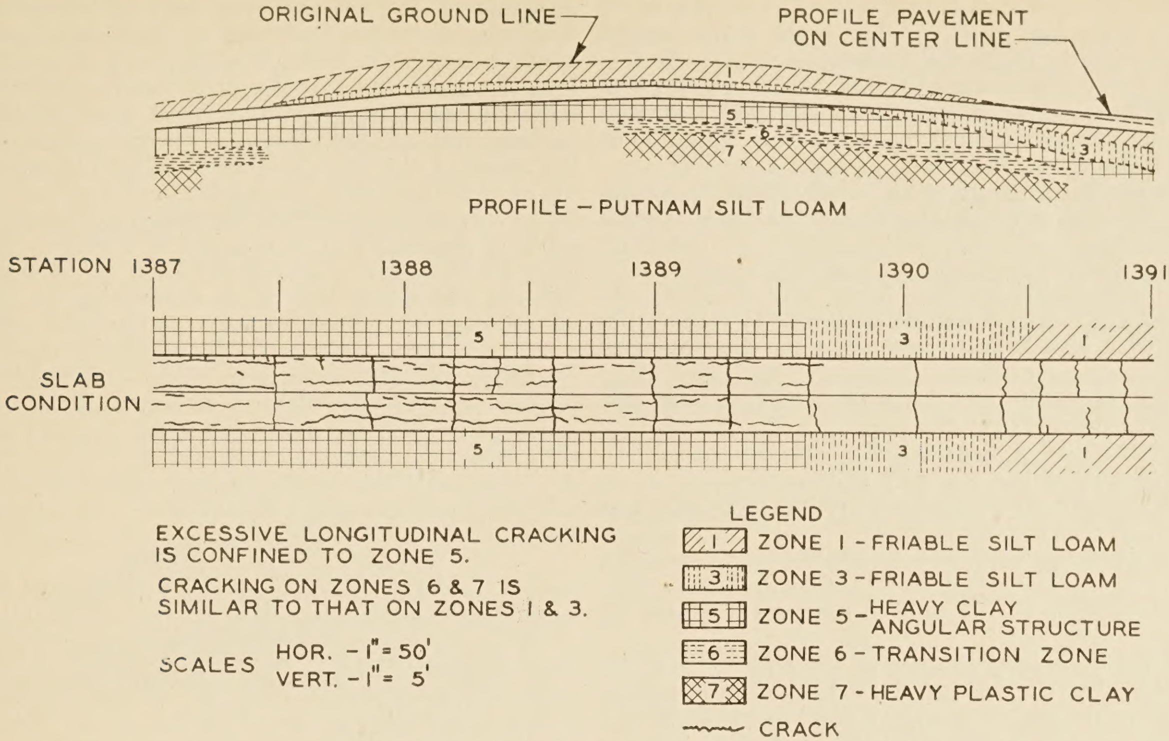

FIGURE 10.—CRACKING WHICH DEVELOPED DURING CURING PERIOD

cementation. If so, the probable cementing material (light colored or reddish, very strongly cemented or weakly cemented) should be ascertained.

7. *Chemical composition.*—While the determination of the chemical composition of the various parts of the soil section or profile can not be performed in the field by the usual field methods, there are certain features that may be determined in at least a qualitative way. Field examination can detect the presence of horizons with concentrations of organic matter or of salts of the alkalies and alkaline earths.

The organic matter referred to here is that contained in the soil and not that lying on the soil. Of this there are two kinds to be looked for. (*a*) The organic matter in the surface soil is recognized by the dark color, and the approximate relative percentage present is indicated by the intensity of the dark color. The determination of the thickness of the dark-colored layer in the virgin soil is very important. (*b*) In some soils, usually confined to regions with a cool, moist climate, there is present, at a depth ranging from 6 inches or less to somewhat more than a foot, a layer of brown or coffee-brown organic matter forming a film 6 or 8 inches in thickness.

The salts of the alkalies and alkaline earths accumulate in the soil under favorable conditions. Since the work here contemplated is general and the soil characteristics dealt with are those of wide regional distribution, we may practically neglect all salts except the carbonate of lime. The more soluble salts constituting what is usually known as "alkali" are present in relatively small areas and may be neglected, or the soils in which they occur may be designated merely as alkali soils.

Horizons of lime carbonate accumulation may be identified readily by anyone and should be looked for where the rainfall is less than 17 to 18 inches per year in cool to cold climates and 30 inches per year in hot or very warm climates. The unweathered material beneath the soil in any region, arid, subhumid, or humid may have a high percentage of lime carbonate, but such material should not be confused with the horizon of true lime carbonate accumulation.

Sesquioxides accumulate in the soil under favorable conditions. Since accumulations of aluminum hydroxide are not readily identified by the usual field methods these may be left out of consideration. We are concerned, therefore, with accumulations of iron oxides.

Iron oxides occur in two forms: The first form consists of accumulations of finely divided or colloidal iron oxide (hydroxide). The degree of concentration may be determined, within a rather wide range of error, by the intensity of the red color. The existence of red horizons in the soil profile should be noted and should be illustrated with samples, even though they be small. The second type consists of accumulations of iron oxide concretions or large masses, usually porous or slaglike. This statement does not refer to ironstone slabs or ferruginous sandstone layers which may be found in many places in the parent geological formations. The accumulations referred to here are to be found either in the B horizon or at the top of the C horizon. In hot countries they take the form of thick masses of porous slaglike iron oxide lying at depths ranging from somewhat less than 3 to more than 15 feet. They may consist of fragments scattered over the surface.

MAPPING THE SOIL PROFILE

The detailed mapping of soil profiles is accomplished in the following manner:

1. Vertical soil sections are examined at frequent intervals and classified into layers according to the method described above (*4*). The interval at which soil examinations are made depends on the uniformity of the soil examined.

2. The limits of the various layers are plotted as shown in Figure 11, A, alternate numbers being used to indicate the layers. At test hole No. 1, the con-

secutive layers are numbered 1, 3, 5, etc., so as to allow the inclusion of any other layer which might enter the profile within the section mapped. At test hole No. 4, layer 2 is mapped between layers 1 and 3. This requires the examination of another test hole (No. 5), or perhaps several, between Nos. 3 and 4, to determine the horizontal limits of layer 2.

3. The profile is completed by connecting the points marking the limits of the layers as shown in Figure 11, B.

DETAILS OF THE SUBGRADE SURVEY DESCRIBED

The purpose of the subgrade survey is to furnish the engineer with significant information on the following subjects:

1. The final location of the road both vertically and horizontally.
2. The selection of suitable fill material.
3. The design of the roadway section.
4. The design and location of ditches, culverts, and drains.
5. The need for subgrade treatment and the type required.
6. The selection of the type of road surface and its design.

The subgrade survey consists of three parts: (*a*) The determination of the soil profile, (*b*) the determination of the physical properties of the soils included in the profile, and (*c*) the mapping of the profile in order to supply information important to road design.

The determination of the physical properties of soils and soil materials and their grouping according to performance has been discussed in previous reports (*8*, *13*).

The method of making the subgrade survey depends on the type of information required. Two types of subgrade survey are made, (*a*) surveys to furnish information with respect to roads in service, and (*b*) surveys to furnish information with respect to the design of new roads.

EQUIPMENT

The following equipment is required to make subgrade surveys:

One 3-foot soil auger and three 3-foot extensions as illustrated in Figure 12.
Two small pipe wrenches.
One light pick.
One shovel.
A supply of sample bags.
A supply of tags for marking samples.
A ball of twine.
One engineer's level.
One hand level.
One 12-foot level rod, three-section.
One 100-foot metallic tape.
One 12 by 15 inch strip of stiff cardboard.
One roll of 20-inch cross-section paper, 10 divisions to the inch each way.
Notebooks.
A supply of survey stakes.
One camera and supply of films.
A supply of keel.

SUBGRADE SURVEY TO OBTAIN INFORMATION REGARDING ROADS IN SERVICE

The section for study having been selected, the procedure is carried out in the following manner:

1. The section is staked out, the original construction stations being used if possible. Arbitrary stations will serve the purpose when it is not convenient to locate original stations.

2. Cross-sections are taken every 50 feet along the center line or oftener if topography requires, and for a distance of 150 feet on each side of the center line. Elevations are obtained with an engineer's level to the nearest tenth of a foot. The accuracy of an engineer's level is necessary for the construction of center-line and bank-line profiles, but a hand level is sufficiently accurate for the topography adjacent to the highway. An assumed elevation may be used as a bench mark.

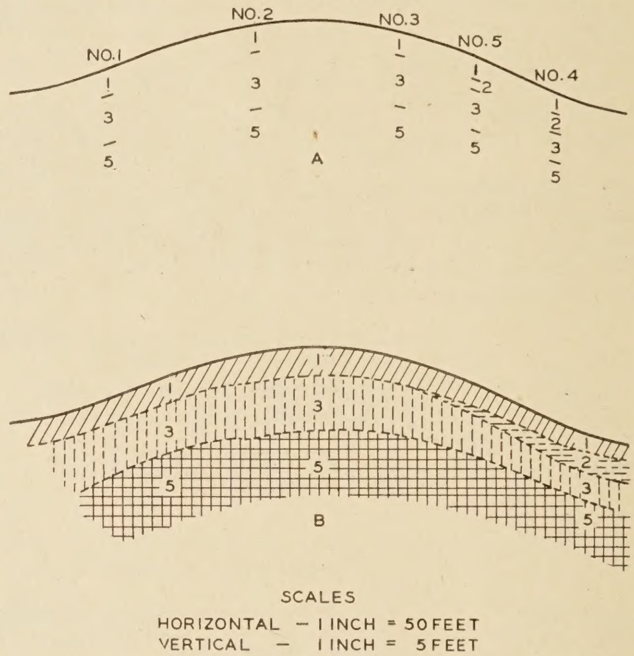

FIGURE 11.—EXAMPLE OF SOIL PROFILE MAPPING, ILLUSTRATING THE DETERMINATION OF LIMITS OF INTERMEDIATE LAYERS BY SUPPLEMENTARY BORINGS

3. A plan of the roadway is drawn, showing the type of pavement, type of failure, portion of roadway which is built over an older road, if any, and any special construction. A scale of 50 feet to the inch is used.

4. Cross-section notes are plotted to the same scale as the plan of roadway and contours are drawn in by interpolation.

5. The bank-line profiles are drawn and the center-line profile is projected upon them, as well as the grade line of the preexisting road, if any. The horizontal scale is 50 feet to the inch. The vertical scale is 5 feet to the inch. Ordinary cross-section paper, 20 inches wide with 10 divisions to the inch each way, is the most convenient type of record sheet. Sheets are cut to a length of 30 inches, folded two ways and clamped to the sheet of stiff cardboard 12 inches wide and 15 inches long.

6. The soils are mapped and the profiles plotted according to the procedure outlined previously. The desired information is obtained and recorded in the following manner:

a. The back slopes are scraped down so that the original undisturbed material is exposed and the limits of the various layers are plotted on the prepared profile sheet. This work is supplemented by soil-auger boring so that a profile is obtained to a depth of at least 3 to 5 feet below the center-line grade. Any variations in moisture content are specially noted. The depth will vary with the uniformity of the soil layers or soil material. The elevations of the limits of the different layers in the exposed back slopes are obtained by means of a hand level, the elevation of the center line being used as a bench mark.

b. In a separate notebook each layer is described in detail according to the nomenclature of the committee on terminology (*3*). (See Appendix A.) The relative imperviousness or porosity is also recorded.

c. Examinations of the soil are made every 50 feet or less, depending upon the uniformity of the profile. (See discussion of Figure 11.)

d. On the plan of the roadway are plotted the limits of the various soil layers found directly under the surfacing material. When the roadway is cut through uniform layers of soil material, the limits are obtained by constructing cross-sections from the bank-line profiles. When the roadway is constructed of fill material or cut through a heterogeneous soil material, the limits are determined by soil-auger borings in the shoulder.

7. A 5-pound sample of soil from each layer is obtained from the exposed back slopes with a pick and shovel, placed in a canvas bag, tied securely, marked with proper identification, and shipped to the laboratory. A sufficient number of samples are taken to determine the range in test results for what appears to be the same layer.

8. Photographs are taken illustrating the condition of the pavement, the shoulders, the back slopes, the ditches, and the appearance of the soil layers.

9. The data collected in the manner described above are analyzed, together with the laboratory test results, and information on the following subjects is developed:

a. The relation that exists between the pavement condition, the field characteristics of the soil, and the physical properties of the soil as determined in the laboratory.

b. The possible reasons for failure.

c. Possible curative measures for the case under examination.

d. Preventive measures which may be applied in the future.

A sample report of a subgrade survey of a road in service is given in Appendix B of this report to illustrate the above procedure.

SUBGRADE SURVEY TO OBTAIN INFORMATION WITH RESPECT TO THE DESIGN OF A NEW ROAD

Before starting a subgrade survey of this kind the engineer should make a study of all the existing information on the soil types in that vicinity. Wherever maps prepared by the Bureau of Soils[4] are available, they should be carefully studied, and the limits of the various soil types and their characteristics should be noted. It must be kept in mind that the detail to which such maps are carried is not particularly adapted to a subgrade survey. Nevertheless they give a clear idea of the variations which will be encountered. Where this information is not available, a reconnaissance survey should be made of the soil materials on existing highways which parallel the new highway, noting the changes in soil as shown in exposed cuts. The notes should include a description of each soil type according to the nomenclature of the committee on terminology. (*3*) The value of the information obtained from this rough survey lies in the fact that similar soil conditions may be expected to accompany similar topographic features.

After this information has been digested the survey proceeds in the following manner:

1. The profile of the ground line and the proposed grade line are constructed on the same type of sheet as was specified for subgrade surveys of existing pavements.

2. Borings are made with a soil auger at frequent intervals and each soil type is classified into layers, as described under the heading "Determination of the Soil Profile" (p.184).

a. Spacing of borings.—The spacing of the borings will vary with the uniformity of the profile and the topography. A convenient interval, such as the even stations, may be assumed at the beginning. This interval may be varied under the following conditions: (1) If the profile is uniform, the interval may be increased. (2) When the character of the profile changes, intermediate borings should be made until it is clear that all variations have been mapped. (3) Where topography is rolling and grade changes rapidly from cut to fill, borings are necessary only in the cuts. (4) Where the original ground line or old road grade is to be covered with fill material, no examination is necessary except to determine the character of the support. If the fill material is to be obtained from borrow ditches along the road, the soil should be examined to the entire depth of the borrow.

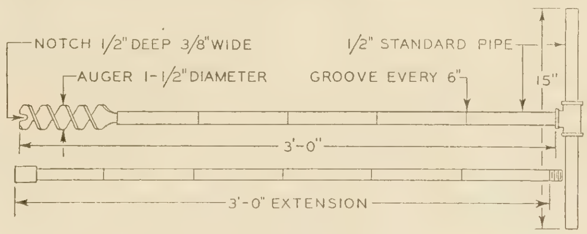

FIGURE 12.—SOIL AUGER AND EXTENSION

b. Depth of borings.—The borings should generally be carried to a depth of at least 3 feet below the grade line. The depth may vary in accordance with the following stipulations: (1) When the road lies within the uniform layers of the soil profile, the boring should extend down to the first layer below the ditch line which would block percolation, or through a pervious layer which would carry water. (2) When fill material is to be borrowed from ditches alongside the road, the boring should extend at least to the estimated depth of borrow. (3) In the study of frost action the borings should extend to the mean depth of frost in those soil materials showing a high affinity for frost accumulation (see p. 183) and in localities where high water tables prevail.

c. When the located line is over an old road, the soils are mapped by examining the exposed cuts. This work is supplemented by borings.

3. A notation is made of the direction of surface drainage with respect to the proposed roadway.

4. The data obtained from the borings is plotted on the prepared profile sheet. On this sheet are indicated the limits of the several types and layers, the relative moisture content at various depths, and the location of culverts and drains.

5. In a separate notebook the field characteristics of each layer are described according to the nomenclature prepared by the committee on terminology. The relative imperviousness or porosity of each layer is indicated.

6. From each layer and type encountered at least a 2-pound sample of soil is taken for laboratory classification. A sufficient number of samples should be obtained to determine the range in test results for what

[4] The former Bureau of Soils is now a part of the Bureau of Chemistry and Soils.

appears to be the same layer. These samples are placed in canvas bags, tied securely, marked with station number and layer, and shipped to the laboratory. The boring of more than one hole may be necessary to obtain the required sample.

7. Recommendations regarding the design of the road surface are made on the basis of the known behavior of pavements for which the conditions of soil, climate and topography are similar.

8. After the road is graded, a final check is made on the soil as exposed by grading operations.

The final form of a subgrade survey sheet submitted to the engineer in charge of design is included in Appendix B of this report.

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APPENDIX A

TERMS IDENTIFYING SOILS IN THE PROFILE

The following terms [1] are among those used in describing the various layers of the soil profile. They definitely identify the field characteristics of the soil material as found in its natural state. In the compilation of these terms the report of the committee on terminology of the American Soil Survey Association was largely used.

[1] The terms describing structure, consistency, compactness, cementation, and chemical composition have not yet been standardized, nor have they been adopted by the division of soil survey, Bureau of Chemistry and Soils. They may be considered tentative and approximate. More accurate definitions are not yet available.

TEXTURE

Texture is a term indicating the size of the individual soil grains or particles and the proportions of material of each size present in any given case.

As the soil is usually made up of particles of widely varying size, the textural terms express the average effect or the combined effect of all these grain sizes. They may indicate the predominance (in quantity or in textural effect) of a certain group of grains.

Texture is determined by mechanical analysis, a laboratory process of separating the soil into groups of grain sizes. The system of mechanical analysis used by the Bureau of Chemistry and Soils separates the soil material into seven grain sizes or "separates" having the following sizes and names:

- 2 to 1 millimeter, fine gravel.
- 1 to 0.5 millimeter, coarse sand.
- 0.5 to 0.25 millimeter, sand.
- 0.25 to 0.10 millimeter, fine sand.
- 0.10 to 0.05 millimeter, very fine sand.
- 0.05 to 0.005 millimeter, silt.
- Below 0.005 millimeter, clay.

In the following paragraphs are given the proportions of certain of the grain sizes found in the major soil textures:

Sands contain less than 20 per cent of silt and clay. (Include coarse, fine, and very fine sands.)

Sandy loams contain from 20 per cent to 50 per cent of silt and clay but do not have over 15 per cent of clay. (Include coarse, fine, and very fine sandy loams.)

Loams have more than 50 per cent of silt and clay combined but have less than 50 per cent of silt and less than 20 per cent of clay.

Silt loams have more than 50 per cent of silt and less than 20 per cent of clay.

Clay loams have more than 50 per cent of silt and clay combined but less than 50 per cent of silt and between 20 per cent and 30 per cent of clay. (Include sandy clay loams, clay loams, and silty clay loams.)

Clays have more than 50 per cent of silt and clay combined and more than 30 per cent of clay. (Include sandy clays and silty clays.)

In the field texture is determined by the feel of the soil mass when rubbed between the fingers. The following statements give the obvious physical characteristics of the basic textural groups:

Sand.—Sand is loose and granular. The individual grains can readily be seen or felt. Squeezed in the hand when dry it will fall apart when the pressure is released. Squeezed when moist, it will form a cast, but will crumble when touched.

Sandy loam.—A sandy loam is a soil containing much sand but having enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart, but if squeezed when moist a cast can be formed that will bear careful handling without breaking.

Sands and sandy loams are classed as coarse, medium, fine, or very fine, depending on the proportion of the different sized particles that are present.

Loam.—A loam is a soil having a relatively even mixture of the different grades of sand and of silt and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly plastic. Squeezed when dry, it will form a cast that will bear careful handling, while the cast formed by squeezing the moist soil can be handled freely without breaking.

Silt loam.—A silt loam is a soil having a moderate amount of the fine grades of sand and only a small amount of clay, over half of the particles being of the size called "silt." When dry it may appear quite cloddy, but the lumps can be readily broken, and when pulverized it feels soft and floury. When wet the soil readily runs together and puddles. Either dry or moist it will form casts that can be freely handled without breaking. If squeezed between thumb and finger it will not "ribbon" but will give a broken appearance.

Clay loam.—A clay loam is a fine-textured soil which breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger it will form a thin ribbon which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy compact mass.

Clay.—A clay is a fine-textured soil that forms very hard lumps or clods when dry. When the moist soil is pinched out between the thumb and fingers it will form a long, flexible ribbon.

Gravelly or stony soils.—All of the above classes of soils, if mixed with a considerable amount of gravel or stone, may be classed as gravelly sandy loams, gravelly clays, etc., as stony sandy loams, stony loams, etc., or as sandy clay loams, sandy clays, etc.

Floury.—Fine-textured soil consisting predominantly of silt (or flocculated clay with aggregates of silt size) which when dry is incoherent, smooth, and dust-like.

Gritty.—Containing a sufficient amount of angular grains of coarse sand or fine gravel, so that these dominate the "feel." Usually applied to medium-textured soils (loams) where the actual quantity of these coarse grains is rather small.

Heavy (*textured*).—Applied to soils of fine texture in which clay predominates, with dense structure and firm to compact consistency. The term is also applied to soils containing a somewhat higher proportion of the finer separates than is typical of that textural class (as a "heavy sandy loam").

Light (*textured*).—Applied to soils of coarse to medium texture with very low silt and clay content, incoherent, single-grained structure, and loose consistency. The term is also applied to soils containing somewhat higher proportions of the coarser separates than is typical of that textural class (as a "light loam").

Sharp.—Containing angular particles in sufficient amount to dominate the "feel." Abrasive.

Smooth.—Containing well-rounded coarser particles and a predominance of the finer separates. Not abrasive.

COLOR

In order to recognize the same soil in some other locality, the color should be clearly stated. This statement should give the range of color included, for classification purposes. By range of color is meant such terms as black or dark brown, brown to reddish brown, etc. The color may indicate the drainage conditions under which the soil was formed and the chemical composition of the soil.

In using such terms as grayish brown, brownish gray, etc., the adjective is recognized as a modifying term. The grayish brown soil is a brown soil with a grayish cast sufficiently noticeable to require recognition; the brownish gray soil is a gray soil with a brown cast.

Other color terms are as follows:

Mottled.—The presence of spots, streaks, or splotches of one or more colors in a soil mass of another predominant color. In mottled soils the colors are not mixed and blended, but each is more or less distinct in the general ground color. In color descriptions the ground color and the color of the included spots should be designated. Mottling is usually but not necessarily associated with poor drainage. The use of the term should not be confined to poorly drained soils but should be applied wherever the term fits.

Marbled.—The presence of two or more distinct colors in approximately equal amounts not blended but more or less mixed in occurrence in the soil mass. In a marbled soil there is no general or predominant color, as in the case of a mottled soil.

Spotted, speckled, streaked, variegated.—Such terms can be used when their generally accepted meaning describes the color distributions that occur in the soils.

STRUCTURE

The term "soil structure" expresses the arrangement of the individual grains and aggregates that make up the soil mass. The structure may refer to the natural arrangement of the soil when in place and undisturbed (as structural profile) or to the soil at any degree of disturbance. The terms used indicate the character of the arrangement, the general shape and the size of the aggregates, and in some cases may indicate the consistency of those aggregates.

Adobe structure.—This term describes a soil which on drying cracks and breaks into irregular but roughly cubical blocks. The cracks are usually wide and deep and the blocks are from 20 to 50 or more centimeters across. (Adobe soils are usually heavy-textured and high in content of colloidal clay.)

Amorphous structure.—A soil of fine texture having a massive or uniform arrangement of particles throughout the horizon. Structureless. Found only in soils of finest texture, where individual grains can not be recognized.

Clod (*or cloddy*) *structure.*—Aggregates of irregular, angular shape, usually 4 centimeters or more in diameter and of a hard consistency.

Fine cloddy structure.—When most of the clods are close to the minimum size.

Coarse cloddy structure.—When most of the clods are 10 centimeters or more in diameter.

Columnar structure.—A natural arrangement of the soil mass in more or less regular columns separated by vertical cleavage lines, and usually broken by horizontal cracks into sections with longer vertical than horizontal axes, the tops of the columns being rounded.

Prismatic columnar structure.—Term used when the sections are very regular in size, straight-sided, with the vertical axes much longer than the horizontal axes and the tops of the columns flat.

Crumb structure.—Porous aggregates of irregular shape, rarely over 2 centimeters in diameter and of a medium to soft consistency.

Fine crumb structure.—Crumbs 5 millimeters or less in diameter.

Coarse crumb structure.—Crumbs 2 centimeters or more in diameter.

Crust (*or crusted*) *structure.*—This term is used where the upper or surface horizon coheres into plate or crust distinct from the horizon immediately below it.

Crust-mulch structure.—An arrangement where a surface crust is underlain by a horizon of loose, incoherent particles of mealy, crumb, or granular structure.

Fluffy structure.—A surface condition where the aggregates are loose, of light weight and fine texture, with no cohesion or evidence of arrangement; floury.

Dense structure.—Having a minimum of pore space and an absence of any large pores or cracks. Approaching amorphous.

Granular structure.—Aggregates varying in size to 2 centimeters in diameter, of medium consistency, and more or less subangular or rounded in shape.

Fine granular structure.—Aggregates under 5 millimeters diameter.

Coarse granular structure.—Aggregates close to maximum size.

Honeycomb structure.—A natural arrangement of the soil mass in more or less regular five or six sided sections separated by narrow or hairline cracks. Usually found as a surface structure or arrangement.

Hardpan.—An horizon of accumulation that has been thoroughly cemented to an indurated, rock-like layer that will not soften when wet. The term hardpan is not properly applied to hard clay layers that are not cemented, nor to those layers that may seem indurated when dry but which soften and lose their rock-like character when soaked in water. The true hardpan is cemented by materials that are not readily soluble, and is a hard layer that definitely and permanently (in nature) limits downward movement of roots and water.

Clay pan.—An horizon of accumulation or a stratum of stiff, compact, and relatively impervious clay. The clay pan is not cemented, and if immersed in water can be worked to a soft mass. Its presence may interfere with water movement or root development the same as a true hardpan. It is more difficult to overcome, for, whereas a hardpan can be shattered by explosives, the clay pan, after breaking by any means, will run together and re-form as soon as thoroughly wetted. The distinction between hardpan and clay pan is an important one in the soil classification.

Laminated structure.—An arrangement of the soil mass in very thin plates or layers, less than 1 millimeter in thickness, lying horizontal or parallel to the soil surface. Usually medium to soft consistency.

Massive structure.—A soil mass showing no evidence of any distinct arrangement of the soil particles. Structureless. May be found in soils of any structure.

Mealy structure.—A crumb-like structure in which the aggregates are of soft to very soft consistency and usually less than 5 millimeters in diameter.

Nut structure.—Compact aggregates, more or less rounded in shape, of hard to medium consistency, and from one-half to 4 centimeters in diameter.

Fine nut structure.—Aggregates below 1 centimeter in diameter.

Coarse nut structure.—Aggregates over 3 centimeters in diameter.

Plate (*or platy*) *structure.*—An arrangement of the soil mass in plates or layers 1 to 5 millimeters or more in thickness, lying horizontal or parallel to the soil surface. Usually medium to hard consistency.

Single-grained structure.—An incoherent condition of the soil mass with no arrangement of the individual particles into aggregates. Structureless. Usually found in soils of coarse texture.

Structureless.—Without any discernible structure or arrangement of the soil particles into aggregates. This condition is better expressed by the terms single-grained, massive, amorphous, etc.

Vesicular structure.—A soil horizon or soil aggregate containing many small rounded cavities smooth on the inside as though formed by gas bubbles.

CONSISTENCY

"Soil consistency" is a term expressing the degree of cohesion of the soil particles and the resistance offered to forces tending to deform or rupture the aggregates. Consistency and structure are closely related and frequently interdependent. The terms expressing consistency and structure are distinct, however, and need not be confused or used with double meaning. A study of published reports shows a general use of terms expressing both the consistency and the structure in nearly all soil descriptions.

Brittle.—A soil which when dry will break with a sharp, clean fracture. If struck a sharp blow, it will shatter into cleanly broken hard fragments.

Mellow.—Soil particles or aggregates are weakly adhered in a rather porous mass, readily yielding to forces causing rupture. A consistency softer than friable. Without tendency to pack.

Plastic.—Readily deformed without rupture. Pliable but cohesive. Can be readily molded. Puttylike. This term applies to those soils in which at certain stages of moisture the grains will readily slip over each other without the mass cracking or breaking apart.

Soft.—Yielding readily to any force causing rupture or deformation. Aggregates readily crushed between fingers.

Sticky.—Applied to soils showing a decided tendency when wet to adhere to other materials and foreign objects.

Firm.—Resistant to forces tending to produce rupture or deformation. Moderately hard. Aggregates can be broken between fingers.

Friable.—Aggregates readily ruptured and crushed with application of moderate force. Easily pulverized or reduced to crumb or granular structure.

Hard.—Resistant to forces tending to cause rupture or deformation. Difficult or impossible to crush aggregates with fingers only.

Tenacious.—Soils showing a decided resistance to rupture. Soil mass adheres firmly.

The terms "sticky" and "tenacious" are often used as synonyms, but in soil usage the former is taken to refer to adhesion, the latter to cohesion. Both terms may be applicable to a soil at the same time.

Stiff.—Resistant to rupture or deformation. A soil stratum or horizon that is firm and tenacious, and tending toward imperviousness. Usually applied to condition of the soil in place and when moderately wet.

Tight.—A stratum or horizon that is compact, impervious and tenacious, and usually plastic.

Tough.—Resistant to rupture. Tenacious. A stratum or horizon that can be readily bored into with the auger but which requires much force in breaking loose and pulling out the core of soil.

COMPACTNESS

Compactness is the degree of resistance offered by a soil to the penetration of a pointed instrument.

Impervious.—Highly resistant to penetration by water and usually resistant to penetration by air and plant roots. Impenetrable. In field practice the term is applied to strata or horizons that are very slowly penetrated by water and that retard or restrict root penetration.

Indurated.—(See under cementation).

Loose.—Soil particles or small aggregates are independent of each other or cohere very weakly with a maximum of pore space and a minimum resistance to forces tending to cause rupture.

Cheesy.—Having a more or less elastic character, deforming considerably without rupture, yet broken without difficulty or the application of much force. (Characteristic of certain highly colloidal soils when thoroughly wet.)

Compact.—The soil packed together in a dense, firm mass, but without any cementation. Noticeably resistant to forces tending to cause rupture or deformation. Coherent. Hard.

Relative degree of compactness may be expressed by terms as slightly compact, very compact, etc.

CEMENTATION

Cementation.—A condition occurring when the soil grains or aggregates are caused to adhere firmly and are bound together by some material that acts as a cementing agent (as colloidal clay, iron or aluminum hydrates, lime carbonate, etc.).

The degree of cementation or the persistence of the cementation when the soil is wetted should be stated. Some terms indicate the permanence, as "indurated," "hardpan," etc.

Firmly cemented.—Cementing material of considerable strength requiring considerable force to rupture the mass. Usually breaks, with clean though irregular fractures, into hard fragments.

Indurated.—Cemented into a very hard mass which will not soften or lose its firmness when wet, and which requires much force to cause breakage. Rock-like.

Weakly cemented.—Term applied when cementing material is not strong, and the aggregates can be readily broken into fragments with a more or less clean fracture.

Softly cemented.—Term applied when cementing material is not strong nor evenly diffused throughout the mass. Aggregates are readily crushed, but do not break with a clean fracture.

CHEMICAL COMPOSITION

Peat soil.—Composed predominantly of organic material, highly fibrous, with easily recognized plant remains.

Muck soil.—Composed of thoroughly decomposed black organic material, with a considerable amount of mineral soil material, finely divided and with a few fibrous remains.

Leaf mold.—The accumulation on the soil surface of more or less decomposed organic remains, usually the leaves of trees and remains of herbaceous plants. The A horizon.

Alkaline soil.—A soil containing an excessive amount of the alkaline (in true chemical sense) salts.

Saline soil.—A soil containing excessive amounts of the neutral or non-alkaline salts.

Calcareous soil.—A soil containing sufficient calcium carbonate to effervesce when tested with weak (N/10) hydrochloric acid. Depending on the amounts present, these soils may be designated as slightly calcareous, strongly calcareous, etc.

Acid soil.—A soil which is deficient in available bases, particularly calcium, and which gives an acid reaction when tested by standard methods. Field tests are made by the use of litmus, of Soiltex, and of other indicators. There is no full agreement on the most satisfactory test for acidity or as to the actual character of an acid soil. The intensity or degree of acidity may be expressed by qualifying words, "strongly," "moderately," etc.

APPENDIX B

SAMPLE REPORT OF A SUBGRADE SURVEY OF A ROAD IN SERVICE

ROAD DESCRIPTION

Designation.—United States Highway No. 51, Federal aid project 82–A, situated two miles south of Jackson, Hinds County, Miss.

Date constructed.—1927.

Width.—Roadway, 26 feet; pavement, 18 feet.

Pavement thickness.—Seven inches at the edges and 6 inches at the center, stations 97+00 to 108+88; 9 inches at the edges and 6 inches at the center, stations 108+88 to 112+50.

Joints.—One-half inch transverse expansion joints spaced about 30 feet apart, stations 97+00 to 108+88; tongue-and-groove longitudinal center joint with metal center strip and ½-inch transverse expansion joints spaced about 50 feet apart, stations 108+88 to 112+50.

Reinforcement.—Welded fabric placed 2 inches from the top of the slab.

Concrete design.—One part Portland cement, 2 parts local sand, and 3 parts local gravel.

Curing.—Two per cent calcium chloride admixture.

Compressive strength of concrete.—Average of sixteen 6 by 12 inch cylinders tested at the end of 28 days equaled 3,230 pounds per square inch.

Drainage.—Eight-inch bell-and-spigot concrete drain placed in west ditch at a depth of 3 feet below subgrade elevation. Trench is back filled with washed gravel as shown in Figure 1.

Reasons for survey.—(*a*) To determine if the detrimental distortion suffered by an appreciable number of the pavement slabs comprising this project was related to the subgrade, and (*b*) to determine what precautions might be taken to prevent this type of failure from occurring in pavements laid on similar subgrades in the future.

Cooperating agencies.—The Mississippi State Highway Department and the Portland Cement Association.

DATA FURNISHED BY THE SURVEY

The soil profile.—The profile consists of five layers designated as layer 1, layer 3, layer 5, layer 6, and layer 7, shown in Figure 1.

Layer 1, averaging about 18 inches in thickness, consists of a light brown to reddish or grayish brown mellow silt loam of fine crumb structure containing both black and brown iron concretions. The grayish brown color becomes rather pronounced in the lower 10 inches of layer 1 where it grades into layer 3.

Layer 1 soil is friable when dry, has a pasty consistency when wet, and according to Table 2, it has characteristics similar to those of the plastic varieties of the group A–4 subgrades.

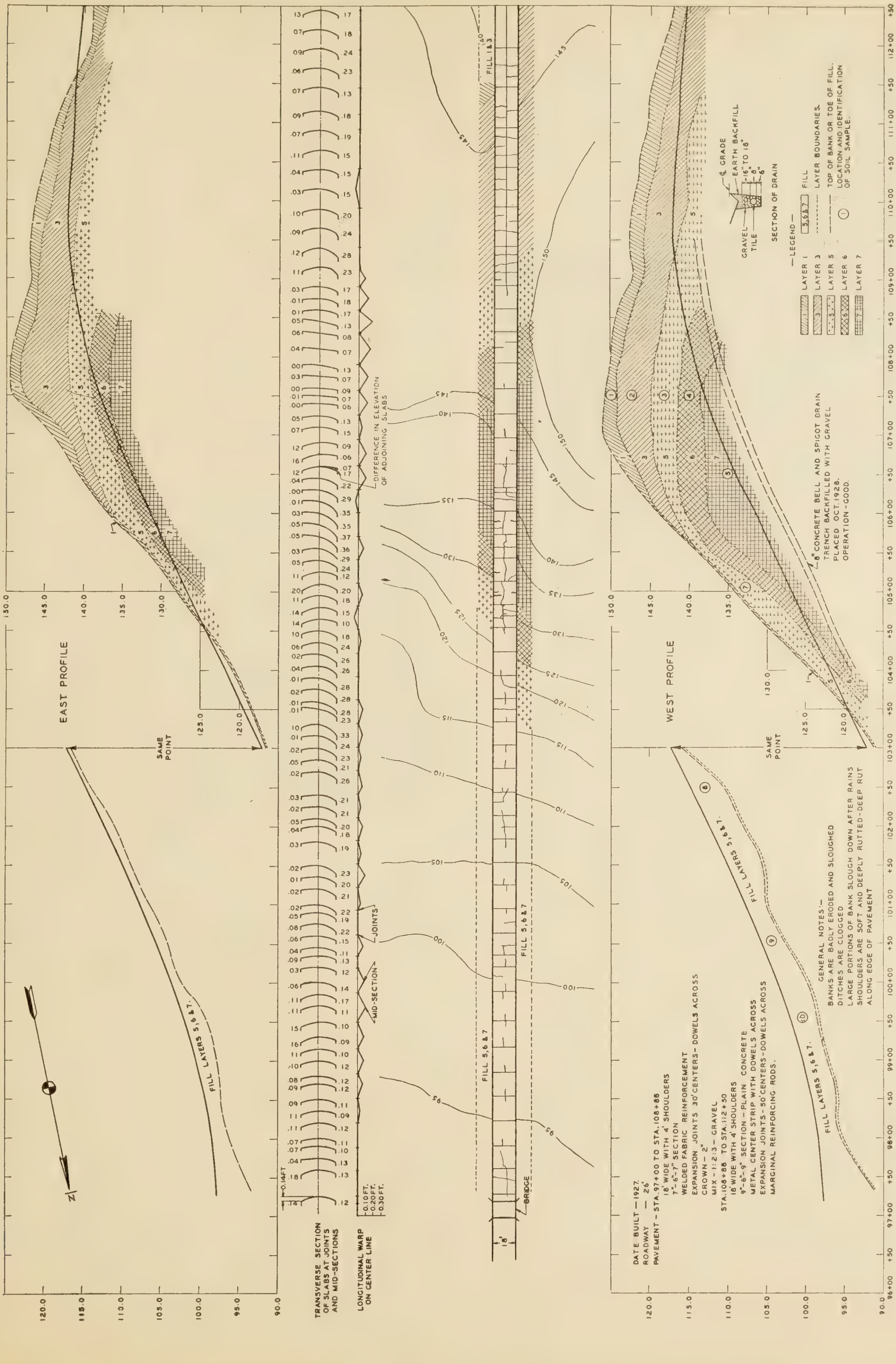


Figure 1.—Subgrade Survey Sheet for Road in Service

Layer 3 grades from layer 1 into a brown and gray mottled silty clay loam or silty clay of moderately compact structure. The upper 10 inches of layer 3 is a transition from layer 1, but is much more dense and compact. This compactness increases with increasing depth until at about 5½ feet layer 3 has a higher moisture content and grades into the angular-structured layer 5.

The soil of layer 3 is friable when dry and very plastic when wet and is permeable regardless of its compactness. Bank erosion, shown in Figure 2, causes the soil of layer 3 to be fissured and to assume the form of pinnacles upon drying. According to Table 2, layer 3 consists of a more plastic variety of the Group A–4 subgrade than layer 1.

Layer 3, like layer 1, contains dark-brown and black concretions in large amounts.

FIGURE 2.—EROSION OF BACK SLOPES IS VERY IRREGULAR ANDTHERE IS CONSIDERABLE SLOUGHING OF MATERIAL INTO DITCHES

TABLE 1.—*Mechanical analyses of soils found in soil profile*

Identification No.	Layer	Percentage of particles having diameters smaller than— 2 mm.	0.5 mm.	0.25 mm.	0.05 mm.	0.005 mm.	0.001 mm.
1	1	100	98	97	86	23	12
2	3	100	97	95	93	27	15
3	5	98	92	89	89	36	16
4	6	100	100	99	81	43	17
5	7	100	100	97	93	72	47
7	5	100	100	99	98	74	(1)
8	[2] 5, 6, 7	100	100	99	92	(1)	----------
9	[2] 5, 6, 7	100	98	97	91	(1)	----------
10	[2] 5, 6, 7	100	98	97	90	(1)	----------

[1] Flocculated. [2] Fill.

TABLE 2.—*Physical characteristics of particles passing the 0.5 millimeter sieve*

Identification No.	Layer	Liquid limit	Plastic index	Shrinkage		Moisture equivalent		Group
				Limit	Ratio	Centrifuge	Field	
		Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	
1	1	39	17	20	1.8	31	31	A–4
2	3	45	22	22	1.7	37	35	A–4
3	5	50	33	12	2.0	[1] 50	34	A–6
4	6	85	51	12	2.0	[1] 98	52	A–7
5	7	112	77	11	2.0	[1] 125	71	A–7
7	5	98	64	12	2.0	[1] 98	59	A–7
8	[2] 5, 6, 7	102	67	12	1.9	[1] 101	70	A–7
9	[2] 5, 6, 7	104	72	13	2.0	[1] 92	60	A–7
10	[2] 5, 6, 7	76	44	12	1.9	[1] 95	59	A–7

[1] Water-logged. [2] Fill.

Layer 5 consists of brown and gray mottled heavy, plastic, sticky clay, with well-defined particles of angular structure about one-eighth inch in diameter or larger, which have a wet, shiny, and slick surface. This layer is very much wetter than overlying zones, is open-structured, and permits the movement of water. In some portions of layer 5 bright red mottlings are found. According to Table 2, the soil of this layer has characteristics common to the highly plastic varieties of the Group A–6 subgrades (sample 3), but when calcium compounds are present in appreciable amounts (sample 7), it exhibits characteristics similar to those of the Group A–7 subgrades.

Layer 6 grades from layer 5, at a depth of about 9 feet below the ground surface, into a very sticky plastic clay, bluish gray in color, mottled with brown. As shown in Figure 3 it exists in the face of cuts as slick and shiny angular particles or clods, ¼ inch to 2 inches in the longest dimension. These clods, the larger of which are dense and have a fibrous structure, are similar to putty in consistency and are easily crushed. Water moves through this layer at a rate much slower than it moves through layer 5. The characteristics of the soil of this layer are similar to those of the Group A–7 subgrades.

Layer 7, at a depth of about 10 or 11 feet below the ground surface, grades gradually from layer 6 into a bluish gray, sticky, plastic and very dense indurated clay containing both black and brown stains. In cut faces this material, similar to that of layer 6, exists as clods or chunks, fibrous in structure and easily crushed. The soil of layer 7 is impervious, holds absorbed water tenaciously, shrinks in appreciable amount when dried, slakes readily in the presence of water and exhibits characteristics generally indicative of the Group A–7 subgrades.

FIGURE 3.—RIGHT BANK AT STATION 105+16 SHOWING STRUCTURE OF LAYER 6 MATERIAL, AND SLOUGHED MATERIAL ON SURFACE

The soils of layers 5, 6, and 7 effervesce strongly when treated with dilute hydrochloric acid, thus indicating the presence of lime in appreciable amount.

Condition of shoulders and banks.—The shoulders are very soft and badly rutted as shown in Figure 4, at those locations where the road traverses the clays of layers 5, 6, and 7. In the same locations the back slopes are badly eroded (see Figure 2) and after rains are apt to slide and clog the side ditches.

Condition of pavement.—Typical pavement condition with respect to both slab distortion and cracking is disclosed by Figure 5 and Tables 3, 4, and 5.

The longitudinal warp referred to in Table 3 is defined as the difference between the average elevation of the ends of the slab and the elevation at a point midway between the ends of the slab measured at the center line. Corrections were made for vertical curvature.

The transverse warp referred to in Table 4 is defined as the present crown of the pavement at the transverse joints subtracted from the original which, exclusive of superelevated curves, was assumed to be 2 inches.

Warp, either transverse or longitudinal less than 0.03 ft. is neither shown on Figure 1 nor included in the computation of the averages in Tables 3 and 4. The apparent bumps appearing in the pavement at the transverse joints and caused by the distortion of the slabs longitudinally is illustrated in Figure 4. An analysis of the longitudinal and transverse cracking is given in Table 5.

TABLE 3.—*Longitudinal warp on center line*

Layer	Length	Total warp	Maximum warp	Total slabs	Number of slabs warped	Percentage of slabs warped	Average [1] warp per slab	Average [2] warp per slab
	Feet	*Feet*	*Feet*				*Feet*	*Feet*
5, 6, 7	497	1.50	0.18	16	13	81	0.12	0.09
5, 6, 7, fill	664	.97	.10	21	16	76	.06	.05
3 [3]	311	.04	.04	6	1	17	.04	.01

[1] Based on number of slabs warped.
[2] Based on total number of slabs.
[3] Center-joint section.

TABLE 4.—*Transverse warp from center line*

Layer	Number of joints	Total warp	Maximum warp	Average warp
		Feet	*Feet*	*Feet*
5, 6, 7	16	3.03	0.23	0.19
5, 6, 7, fill	23	2.78	.15	.12
3 [1]	5	.64	.13	.13

[1] Center-joint section.

TABLE 5.—*Longitudinal and transverse cracking*

Layer	Length	Number of joints	Transverse				Londitudinal		
			Number	Length	Length per slab	Average slab length	Length	Per cent	Length per slab
	Feet			*Feet*	*Feet*	*Feet*	*Feet*		*Feet*
5, 6, 7	497	16	8	147	9	21	225	45	14
5, 6, 7, fill	650	21	5	89	4	25	269	41	13
3 [1]	311	6	9	162	27	21			
5 [1]	51	1	3	58	58	13			

[1] Center-joint section.

FIGURE 4.—SHOULDERS ARE RUTTED TO A DEPTH OF 4 INCHES BELOW BOTTOM OF SLAB

SUMMARY

The results obtained from the survey may be summarized as follows:

1. Distortion both longitudinal and transverse occurred in greatest amount in the pavement slabs 18 feet wide and about 30 feet long laid on soil layers 5, 6, and 7 when in cut, and in but slightly less amount in similar slabs laid on mixtures of layers 5, 6, and 7 used in fills.

2. The slabs containing a center joint and transverse joints spaced about 50 feet apart laid primarily on layers 1 and 3 suffered warping in very much less amount than the slabs about 30 feet long laid on layers 5, 6, and 7.

3. The slabs of another pavement (18 feet wide and about 30 feet long) separated from layers 5, 6, and 7 of these soils by several feet of good top soil did not suffer distortion in detrimental amount.

4. Longitudinal cracks occurred only in those slabs constructed without center joint, and were either short cracks beginning at expansion joints or cracks extending throughout the lengths of the slabs. In every case, however, the longitudinal cracks were situated above dowels extending across the transverse joints. In many instances a longitudinal crack was found over one dowel on one side of a joint and over the next dowel on the other side of the joint.

FIGURE 5.—WARPED SLABS. TRANSVERSE JOINTS ARE MARKED WITH STICKS

5. More transverse cracks occured in the slabs about 50 feet long than in the slabs 30 feet long. The greatest concentration of combined longitudinal and transverse cracking occured in the slabs without center joint laid in cut on a subgrade consisting of either layer 7 or a combination of layers 5, 6, and 7. (See station 104+50 to station 106+50, Figure 1.)

6. Longitudinal cracking was not important in the slabs which warped in greatest amount. Even at several joints where the slabs had faulted in amounts equal to as much as 2 inches no cracks occurred above the dowels.

7. Neither the longitudinal nor the transverse cracks were of appreciable width. This fact indicates that the mesh reinforcement has served to prevent the separation of the cracked fragments of slabs.

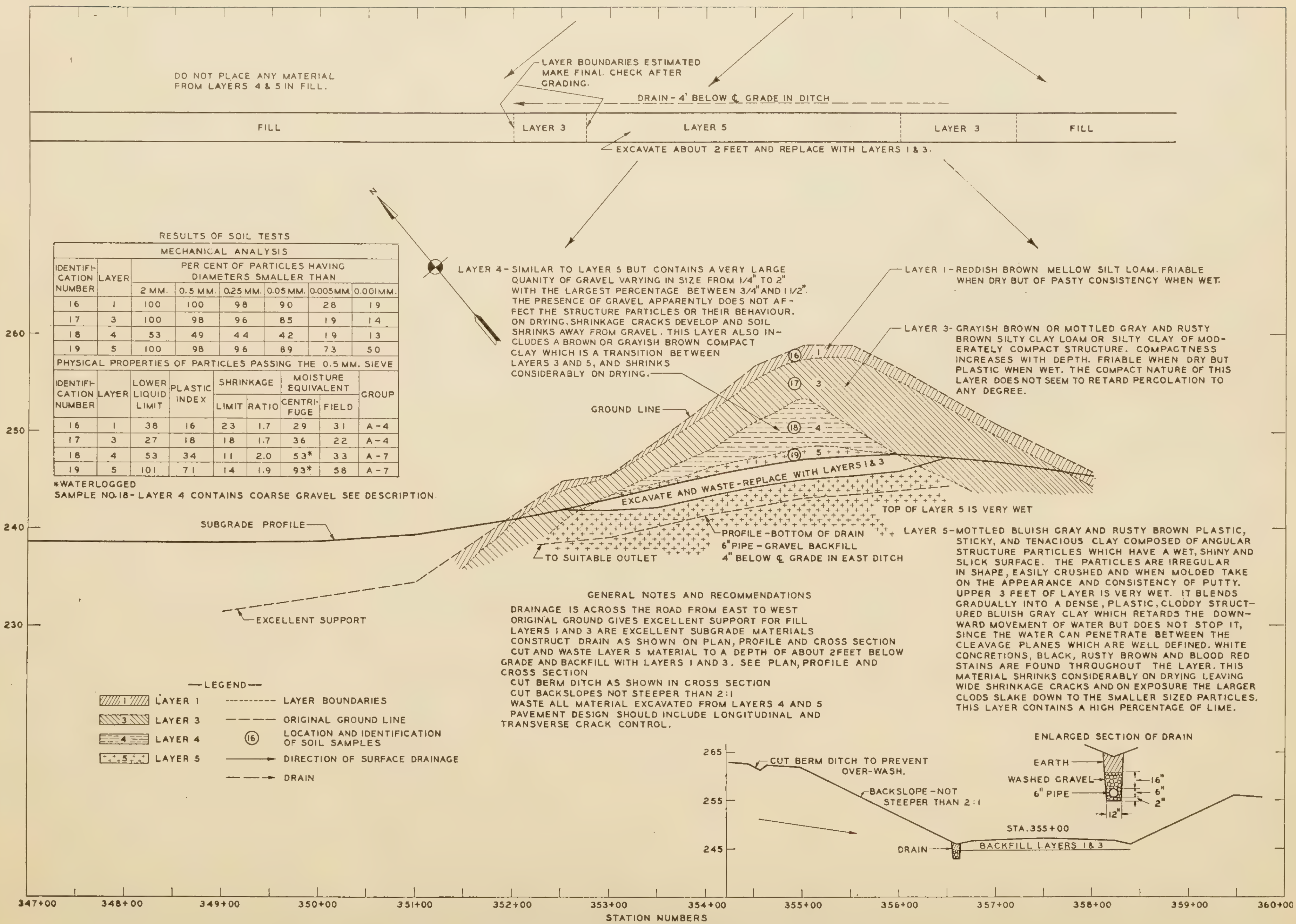
8. Generally the subgrade soil was found to be in a very soft and wet condition. Frequently when the filler was removed from the expansion joints water rose quickly to the surface of the pavement.

9. The drain serves to carry a large flow of water for several days after rains, but does not eliminate the slab movements or prevent the subgrade from becoming wet.

10. The sliding of layers, 5, 6 and 7 when occurring in the face of cuts constitutes a serious maintenance problem. In this connection a scrutiny of records covering a period of 50 years, which were furnished by a railway company operating in this region, indicates that when used in fills the soils of these layers are likely to prove troublesome until the slope becomes approximately 1:5.

SUBGRADE SURVEY SHEET GIVING INFORMATION FOR THE DESIGN OF NEW ROADS

Figure 6 is an example of the final form of survey sheet submitted to the engineer in charge of design. This form was prepared from a survey of approximately 14 miles of graded highway in Mississippi. The recommendations are based on data furnished by the behavior of existing pavements on similar subgrades. The location, grades and type of surfacing had already been established on this highway.



RESULTS OF SOIL TESTS

MECHANICAL ANALYSIS

Identification number	Layer	Per cent of particles having diameters smaller than 2 mm.	0.5 mm.	0.25 mm.	0.05 mm.	0.005 mm.	0.001 mm.
16	1	100	100	98	90	28	19
17	3	100	98	96	85	19	14
18	4	53	49	44	42	19	13
19	5	100	98	96	89	73	50

PHYSICAL PROPERTIES OF PARTICLES PASSING THE 0.5 MM. SIEVE

Identification number	Layer	Lower liquid limit	Plastic index	Shrinkage limit	Shrinkage ratio	Moisture equivalent centrifuge	Moisture equivalent field	Group
16	1	38	16	23	1.7	29	31	A-4
17	3	27	18	18	1.7	36	22	A-4
18	4	53	34	11	2.0	53*	33	A-7
19	5	101	71	14	1.9	93*	58	A-7

*WATERLOGGED
SAMPLE NO. 18 - LAYER 4 CONTAINS COARSE GRAVEL SEE DESCRIPTION.

FIGURE 6.—SUBGRADE SURVEY SHEET FOR THE DESIGN OF NEW ROAD

SOME OBSERVATIONS ON THE MODULUS OF RUPTURE OF FROZEN CONCRETE BEAMS

Reported by Andrew P. Anderson, Highway Engineer, Division of Management, U. S. Bureau of Public Roads

NEAR the close of some extensive field studies of efficiency in concrete road construction during the fall of 1929, the temperature dropped below 20° F., with the result that four regular 6 by 8 inch concrete beams were apparently frozen through when they were broken 24 hours after they had been removed from the curing tank. A long series of exactly similar beams had previously been broken on this same job during the course of several months. The indicated modulus of rupture of these frozen beams, in comparison with those not frozen, was so large that when an opportunity arose in the summer of 1930 to make some further and better controlled observations on the modulus of rupture of frozen beams it was at once accepted.

It happened that a production study was being conducted on the construction of a concrete road which passed directly by an ice-making plant with facilities available for storing a considerable number of beams and cylinders at a temperature never higher than 28° F., and at night as low as 25° F. Seventeen standard 6 by 8 by 36 inch beams, comprising five sets of 3 beams each and one 2-beam set, were therefore prepared at once. These beams were all made from the concrete regularly used on the job and the samples for each set of beams were obtained in exactly the same manner as were the regular test beams which were made daily for controlling the strength and quality of the concrete, and for determining when the pavement could be opened to traffic. Each set of three beams for the freezing test was made from one batch of concrete as it was dumped over the molds placed side by side on the subgrade, and in all but one case two beams were sooner or later placed in the cold room. In every case one beam from each set was kept as a control and cured 24 hours along the roadside under damp burlap and then stored under water until broken on the 28th day.

Since the work was carried on during midsummer, considerable care was necessary to prevent thawing during the flexure tests. The beams were wrapped in ice and burlap; and the clamps of the breaking machine and the top of the beam were kept covered with ice during the progress of the breaking. Some thawing probably did occur, especially on the first beams tested, before the completion of the second break. This is indicated by the fact that the second break on several of the frozen beams gave considerably lower results than the first break. For the beams broken during the 1930 job (job B, Table 1) the first break probably more nearly represents the condition of a thoroughly frozen beam.

Figure 1 shows clearly how each of the 17 beams of job B was treated in curing, and the length of time of each treatment. The modulus of rupture in pounds per square inch for each break is given in Table 1. The two sets of job A are those frozen during the 1929 job. They were removed from the water on the 27th day; and as the outside temperature during the night fell to about 12° F., these beams, which were stored in an unheated frame structure, were apparently frozen through when they were broken the following day. The third beam in each of these two sets was not made from the same batch, but is a representative beam from those broken a few days before the freeze occurred. All the beams on job A were broken on a multiple-lever field beam-breaking machine which had been used by the same men in breaking a large number of beams during the previous three months. The beams on job B also were all broken by the same men, but on a simple cantilever apparatus which gave very consistent results, of practically the same value as those given by the standard two-point loading in a universal testing machine. A good grade of gravel aggregate was used on both jobs. Job A was designed to give a modulus of rupture of about 800 pounds per square inch as compared with about 550 pounds for job B. The proportions by volume were 1:1.55:3.50 for job A and 1:2.20:3.98 for job B.

TABLE 1.—*Results of modulus of rupture tests of frozen concrete beams and control specimens not subjected to freezing*

Set No.	Beam No.	Modulus of rupture in pounds per square inch			
		First break	Second break	Third break	Average
JOB A					
1	1	1,152	1,172	----------	1,162
	2	969	1,014	----------	992
	3	843	861	----------	852
2	1	993	1,046	----------	1,019
	2	1,072	1,046	----------	1,059
	3	825	782	----------	803
JOB B					
1	1	1,010	824	----------	917
	2	558	560	511	543
2	1	962	793	----------	877
	2	273	362	----------	315
	3	556	561	601	575
3	1	1,185	1,005	----------	1,095
	2	545	446	504	498
	3	510	503	528	514
4	1	665	618	757	680
	2	501	430	402	444
	3	506	482	493	494
5	1	428	510	475	471
	2	257	307	----------	282
	3	597	549	----------	573
6	1	440	459	434	444
	2	404	445	433	427
	3	562	528	----------	545

The apparent strength gained by the frozen beams is very striking—in some cases, more than 100 per cent above the corresponding control beam (job B, set 3). In but one case (job A, set 1, beam 2) is the apparent gain in strength imparted by complete freezing less than 25 per cent of the strength of the corresponding unfrozen beam. One of the beams (job B, set 2, No. 1) which was placed in the cold room but three hours after it was made and before it had attained its final set gave a surprisingly high figure for both breaks—962 and

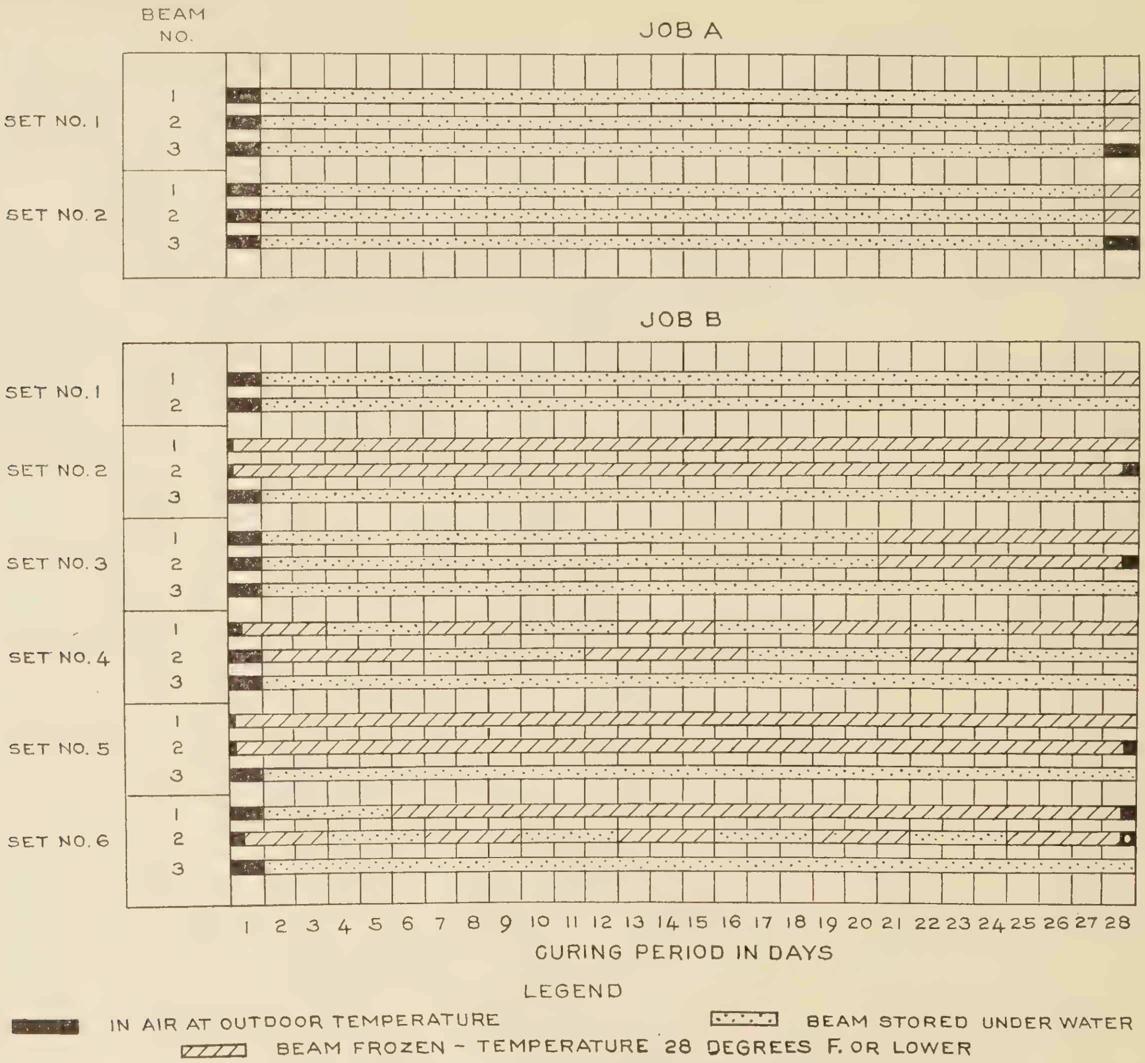


FIGURE 1.—DIAGRAM SHOWING CURING TREATMENT OF CONCRETE BEAMS SUBJECTED TO FREEZING AND CORRESPONDING CONTROL SPECIMENS

793 pounds per square inch. The contrast with the companion beam which was treated in exactly the same manner, except that it was taken from the cold room and left in the open summer air for about six hours before it was broken, is most striking, for the latter beam gave moduli of only 273 and 362 pounds per square inch for the two breaks. This would seem to indicate rather clearly that the concrete gained but little actual strength while stored in the cold room. On the other hand, beams 2 of job B, sets 4 and 6, apparently suffered only a moderate reduction in modulus of rupture from being alternately frozen and thawed after they had attained their final set. These beams were placed in the cold room 24 and 7 hours, respectively, after they were molded. Beam 1 of set 5, job B was stored at some distance from the freezing coils and appeared to be only partly frozen when broken.

From these data it would appear that during cold weather a reasonable amount of care should be exercised in breaking any field beams which may form a criterion for establishing the time when the pavement can be thrown open to traffic. Unless the beams have been well protected, they should not be broken except at times when the air temperature has been well above the freezing point for at least five or six hours. A temperature of only 5° or 6° F. below the freezing point, if of sufficient duration, might readily freeze an exposed green concrete beam sufficiently to indicate a modulus of rupture for the frozen beam 50 per cent or more above what the same beam would give if broken when thawed. An otherwise properly cured beam will show a large increase in apparent strength if frozen immediately prior to breaking. This fact is shown by both sets of job A and set 1 of job B. These beams were properly cured until 24 hours prior to breaking. It is practically certain that the beam of job B, set 1, was frozen through, but it is not equally certain that this was the case with the beams of job A, since the temperature within the building in which the beams were stored may have been several degrees higher than the recorded outdoor temperature. To all appearances, however, the beams were frozen through.

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ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently rquested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.
Report of the Chief of the Bureau of Public Roads, 1928.
Report of the Chief of the Bureau of Public Roads, 1929.
Report of the Chief of the Bureau of Public Roads, 1930.

DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c.

*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.

*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.

*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.

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DEPARTMENT CIRCULARS

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TECHNICAL BULLETIN

No. 55T. Highway Bridge Surveys.

SEPARATE REPRINTS FROM THE YEARBOOK

No. 1036Y. Road Work on Farm Outlets Needs Skill and Right Equipment.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.

*93M. Direct Production Costs of Broken Stone. 25c.

109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters.

MISCELLANEOUS PUBLICATIONS

No. 76MP. The Results of Physical Tests of Road-Building Rock.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio. (1927)

Report of a Survey of Transportation on the State Highways of Vermont. (1927)

Report of a Survey of Transportation on the State Highways of New Hampshire. (1927)

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio. (1928)

Report of a Survey of Transportation on the State Highways of Pennsylvania. (1928)

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D-2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.

Vol. 5, No. 19, D-3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.

Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.

Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

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* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

AUGUST 31, 1931

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal-aid allotted	MILEAGE			Estimated total cost	Federal-aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,133.2	$ 6,845,545.26	$ 3,387,168.08	231.2	104.6	335.8	$	$				$ 3,306,198.88	Alabama
Arizona	885.3	5,735,381.77	3,930,790.43	258.0	189.9	447.9						313,320.07	Arizona
Arkansas	1,786.8	7,402,833.56	3,964,135.82	175.1	112.6	287.7	869,006.72	434,503.34	24.2	15.7	39.9	77,185.05	Arkansas
California	1,962.6	12,621,031.84	5,188,777.55	316.1	110.8	426.9	1,742,651.42	733,146.72	54.8		54.8	159,422.84	California
Colorado	1,350.1	6,520,694.36	3,464,439.46	249.1	96.9	346.0	1,737,465.18	916,974.61	91.7	17.5	109.2	545,403.58	Colorado
Connecticut	263.4	4,878,672.93	1,815,984.63	47.9		47.9							Connecticut
Delaware	310.4	1,114,638.43	556,564.71	55.5		55.5						73,516.71	Delaware
Florida	554.4	6,161,508.65	2,872,456.15	174.4		174.4						1,609,098.91	Florida
Georgia	2,835.4	8,855,196.24	4,214,619.21	298.8	121.4	420.2	2,731,318.54	1,155,022.02	40.1	69.3	109.4	153,554.66	Georgia
Idaho	1,303.2	4,083,064.28	2,309,426.34	262.5	81.2	343.7	258,799.81	146,901.28	11.3	9.8	21.1	295,826.04	Idaho
Illinois	2,362.6	26,335,289.15	12,227,814.13	797.2	31.9	829.1	4,828,273.38	2,140,947.41	171.3	4.7	176.0	172,233.90	Illinois
Indiana	1,588.1	11,614,982.98	5,709,520.06	357.7		357.7	1,345,212.33	672,604.14	61.7		61.7	253,991.08	Indiana
Iowa	3,142.8	7,716,753.31	3,218,939.30	160.1	89.5	249.6	359.21	179.60				4,059.10	Iowa
Kansas	3,288.9	7,902,980.10	3,784,107.14	455.6	50.5	506.1	501,661.94	231,572.11	34.9	14.7	49.6	140,384.42	Kansas
Kentucky	1,576.5	6,378,644.10	2,792,008.17	273.6	125.8	399.4	423,506.25	204,025.56	35.1	1.8	36.9	65,279.39	Kentucky
Louisiana	1,466.4	7,154,869.99	3,373,317.99	189.0	19.9	208.9	751,852.47	307,329.64		.4	.4	135,581.56	Louisiana
Maine	623.5	4,080,022.00	1,645,510.88	98.2		98.2	1,171,868.57	485,461.29	15.0		15.0	336,834.16	Maine
Maryland	715.9	2,034,351.48	879,413.15	57.6	4.2	61.8	115,380.15	57,690.07	6.2		6.2	15,212.22	Maryland
Massachusetts	733.8	10,461,240.03	2,870,892.05	91.1		91.1	1,591,817.19	600,333.58	16.6		16.6	782,822.90	Massachusetts
Michigan	1,792.5	12,746,800.06	5,453,280.21	398.9	51.2	450.1	752,402.22	317,371.60	20.7	1.8	22.5	1,499,657.62	Michigan
Minnesota	3,954.0	8,371,816.88	3,661,797.71	75.4	317.7	393.1	247,646.39	73,028.32	4.5	1.2	5.7	14,252.31	Minnesota
Mississippi	1,765.3	4,398,921.97	2,160,957.43	184.6	87.9	272.5	242,383.87	119,750.39		12.6	12.6	3,693,892.99	Mississippi
Missouri	2,688.0	9,359,726.04	3,722,843.44	259.0	64.2	323.2	331,772.63	165,886.30	13.0		13.0	153,166.99	Missouri
Montana	2,008.7	10,350,196.87	5,809,641.29	747.8	137.6	885.4	1,516,250.48	854,573.90	66.1	51.0	117.1	1,389,879.52	Montana
Nebraska	3,863.5	10,529,886.16	4,920,147.04	278.1	224.0	502.1	1,318,421.27	642,490.66	66.0	51.0	117.0	393,839.99	Nebraska
Nevada	1,088.5	3,205,089.67	2,110,197.39	108.6	269.9	378.5	219,286.77	160,677.03		20.7	20.7	180,328.97	Nevada
New Hampshire	385.9	1,697,842.77	591,926.77	30.7	8.2	38.9						96,284.13	New Hampshire
New Jersey	571.2	4,988,514.39	1,711,603.78	58.7		58.7	1,419,234.56	652,946.01	7.6	.9	8.5	322,156.21	New Jersey
New Mexico	2,028.1	5,164,755.69	3,122,562.98	198.0	98.9	296.9	138,374.83	85,156.34	.3	1.7	2.0	120,752.84	New Mexico
New York	2,728.1	38,319,721.40	14,006,619.98	737.7	7.0	744.7	3,606,900.00	1,325,975.00	59.4		59.4	61,650.24	New York
North Carolina	2,027.9	5,659,111.65	2,735,593.12	171.8	36.8	208.6	318,797.14	151,373.14	25.7	8.0	33.7	1,625,359.86	North Carolina
North Dakota	4,547.0	4,121,489.14	2,101,066.56	425.5	388.2	813.7	725,895.44	382,269.37	52.1	182.7	234.8	796,377.77	North Dakota
Ohio	2,611.6	15,945,746.68	5,397,367.21	262.4	34.4	296.8	2,535,044.97	1,025,072.62	52.5	14.0	66.5	381,084.75	Ohio
Oklahoma	2,014.6	7,322,837.10	3,752,419.05	266.3	127.1	393.4	1,013,749.65	242,857.93	27.7	4.6	32.3	72,517.96	Oklahoma
Oregon	1,325.6	6,765,365.28	3,754,867.93	252.8	62.2	315.0	250,591.00	152,785.03	25.3		25.3	351,040.53	Oregon
Pennsylvania	2,683.9	13,877,971.48	6,113,674.43	352.5		352.5	888,060.04	312,897.80	18.2		18.2	516,420.00	Pennsylvania
Rhode Island	234.9	1,724,033.60	596,921.92	22.8		22.8	37,587.29	18,793.64	.1		.1	99,339.73	Rhode Island
South Carolina	1,890.0	4,510,632.52	2,052,898.52	78.2	116.3	194.5						255,046.71	South Carolina
South Dakota	3,876.5	5,204,653.80	2,720,350.50	265.0	223.5	488.5	452,606.14	195,527.81	4.1	64.2	68.3	50,633.20	South Dakota
Tennessee	1,600.7	1,972,218.13	956,800.30	63.6	9.5	73.1	380,641.70	180,320.84	26.0		26.0	1,827,439.03	Tennessee
Texas	7,101.8	18,930,576.83	9,197,564.83	763.8	307.9	1,071.7	4,251,779.67	1,805,300.78	198.6	62.3	260.9	1,855,537.30	Texas
Utah	1,062.1	2,048,368.38	1,123,194.11	108.5	80.2	188.7	496,494.08	365,591.64	23.1	13.7	36.8	306,642.55	Utah
Vermont	301.9	1,431,371.38	579,130.72	36.8	4.7	41.5						3,136.16	Vermont
Virginia	1,681.1	5,133,255.93	2,361,239.75	218.5	37.9	256.4	906,977.38	453,488.67	45.3		45.3	294,505.28	Virginia
Washington	994.7	6,239,912.08	2,748,272.97	178.4	43.7	222.1	502,213.33	270,500.00	18.6		18.6	627,729.64	Washington
West Virginia	786.4	5,355,065.35	2,222,847.69	132.4	25.4	157.8	576,382.90	276,018.26	18.0		18.0	53,090.85	West Virginia
Wisconsin	2,438.2	9,213,143.74	3,778,534.39	280.2	81.5	361.7	379,356.87	113,297.61	16.1	4.5	20.6	408.69	Wisconsin
Wyoming	1,683.2	4,484,065.69	2,639,186.89	335.4	221.4	556.8	140,754.29	81,093.75	19.7	21.9	41.6	136,088.22	Wyoming
Hawaii	47.8	1,505,295.22	614,635.17	43.2		43.2	160,999.13	62,206.07	1.7		1.7	1,506,746.30	Hawaii
TOTALS	90,636.8	378,476,076.34	170,924,029.38	11,884.3	4,206.5	16,090.8	41,679,777.20	18,504,139.86	1,373.3	650.7	2,024.0	27,124,941.80	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal-aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

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