PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 15, NO. 12 ▽ FEBRUARY 1935

A SOIL ROAD IN ONONDAGA COUNTY, NEW YORK

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 15, No. 12 February 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

In This Issue

THE BUREAU OF PUBLIC ROADS - - - - Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS - - - - - - - - - - Mark Sheldon Building, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Mark Sheldon Building, 461 Market St., San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
237 Customhouse, Nineteenth and Stout Sts., Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
907 Post Office Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
Saunders-Kennedy Building, Omaha, Nebr.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Room 502, United States Courthouse, Fort Worth, Tex

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, South Carolina, and Tennessee.
Post Office Building, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N. Y.

DISTRICT No. 10. Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D. C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah.

SOIL ROAD SURFACES

BY THE DIVISION OF TESTS, UNITED STATES BUREAU OF PUBLIC ROADS

Reported by C. A. HOGENTOGLER, Senior Highway Engineer

FIGURE 1.—A SAND-CLAY SURFACE IN MUSCOGEE COUNTY, GA.

SOIL is the oldest and probably the most used of all engineering materials. However, substantial contributions to our present knowledge of soils date only from the very recent time when the importance of the physical character of the soil and the effect of surface tension of contained moisture were first recognized.

The first studies in soil physics were inaugurated for the purpose of identifying properties important in agriculture and geology. Tests of physical properties developed in these studies were used in identifying topsoils suitable for use in road surfaces. Later these tests were used in classifying subgrades with respect to performance in supporting road surfaces. More recently they became the basis of research in soil mechanics and now they are being used in establishing the fundamental principles and construction procedures in the new field of soil stabilization.

PERFORMANCE OF SOILS DEPENDS UPON THE CHARACTER AND GRADING OF THE CONSTITUENTS

Milton Whitney in 1892, then chief of the Weather Bureau, first explained in detail the effect of surface tension in contracting, expanding, and supplying cohesion in soils.[1] He thus furnished the basis for the present method of soil identification by means of physical characteristics.

In 1898 Dr. George E. Ladd advanced two additional basic guides: That silt consists of bulky grains and clay of scalelike particles, and that shrinkage of soil is caused by surface tension when water recedes in the soil capillaries.[2]

Simple tests used in the present routine testing procedure to disclose the physical properties of road soils were devised by A. Atterberg, a Swedish scientist, as early as 1911.[3] However, it remained for A. C. Rose, of the United States Bureau of Public Roads, in 1924, to first correlate road surface performance with the results of tests devised to disclose the physical properties of subgrade soils.[4]

The publication of a treatise on soil mechanics by Charles Terzaghi in 1925 [5] marks another important step in the progress of soil studies. For the first time mathematical formulas were available for determining quantitatively the effects of surface tension on the performance of soils.

Appropriate tests based upon Terzaghi's theory of consolidation opened the way to determining properties such as compressibility, expansibility, and permeability. With such information, furnished by tests on small samples in the laboratory, it became possible to estimate the ultimate settlements to be expected in foundations constructed on soft undersoils and also the rate at which they would be likely to occur.

Investigations begun in 1906 by Dr. C. M. Strahan,[6] then county engineer of Clark County, Ga., mark the first consistent effort to correlate the performance of topsoils in road surfaces with their gradings as determined by mechanical analyses.

The name "topsoil" was applied to soil skimmed from the surface of fields to shallow depths. It was thought that during long cultivation such deposits had undergone weathering, water separation, and the probable

[1] Weather Bulletin No. 4, U. S. Department of Agriculture.

[2] Geological Phenomena Resulting from the Surface Tension of Water, by George E. Ladd, American Geologist, vol. 22, no. 5, November 1898. Clays of Georgia, by George E. Ladd, Geological Survey of Georgia, Bull. No. 6-A, 1898.

[3] Über die physikalische Bodenuntersuchung, und Über die Plastizität der Tone, by A. Atterberg, Internationale Mitteilungen für Bodenkunde, vol. 1, 1911; see also Adaptation of Atterberg Plasticity Tests for Subgrade Soils, by A. M. Wintermyer, Public Roads, vol. 7, no. 6, August 1926.

[4] Practical Field Tests for Subgrade Soils, Public Roads, vol. 5, no. 6, August 1924; and Present Status of Subgrade Studies, Public Roads, vol. 6, no. 7, September 1925.

[5] Erdbaumechanik, by Charles Terzaghi, Vienna, 1925.

[6] Research Work on Semi-Gravel, Topsoil, and Sand-Clay, and Other Road Materials in Georgia, by Dr. C. M. Strahan, Bulletin of the University of Georgia, vol. 22, no. 5a, June 1932.

109753—35——1

influence of organic acids which gave them their superior consistency and binding stability.

In Dr. Strahan's work samples were obtained from short stretches of existing roads where firmness and water-resisting qualities were noted in contrast with ordinary conditions of dirt roads. Fifty or more counties were visited during the study. The data from laboratory tests on the samples collected were related to the road behavior under varying weather conditions and traffic, and the conclusions reached became the basis for selecting materials and the adoption of laboratory standards.

The first statement of the probable mode of action of road soils under traffic and weather was prepared by Dr. Strahan in 1914 for distribution at the Fourth American Road Congress held that year in Atlanta, Ga.

After the passage of the Federal-aid act in 1916, the first conference of State highway testing engineers and chemists was called to meet in Washington, February 1917, under the auspices of the Bureau of Public Roads, to consult concerning standards and specifications for the various road building materials. A committee [7] on semigravel, topsoil, and sand-clay aggregates recommended gradings for three classes of topsoils, hard or class A, medium or class B, and soft or class C, and the recommendations were adopted.

The gradings adopted remained unchanged in subsequent reports by Dr. Strahan, the last of which was published in Public Roads, September 1929.

ROAD-SOIL GROUPINGS AND THEORY OF STABILITY DEVELOPED

A report [8] resulting from a combined attack on the road-soil problem by the soil physicist, the pedologist, and the geologist, cooperating with the highway engineer, published in 1929, added two new developments on the subject of soil studies which by this time was rapidly growing into proportions having all the semblance of a new branch of science. They were:

1. A procedure for testing soils in the laboratory and classifying them in groups according to a fixed classification schedule. All the soils in a given group have similar characteristics with regard to drainage and are similar in their effect on road design.

2. A mathematical theory of stability which gave some conception of the relative influence of such factors as the granular fraction, the cohesive fraction, the moisture content of the soil and the weight and the load distribution properties of the road surface.

The soil grouping proposed had the unique feature of indicating performance under existing conditions of traffic, construction, and climate. In this it differed from the older classifications of the geologist based upon geological origin and that of the agronomist based upon the pedologic development.

The development of this grouping was in response to the general question "What conspicuous performances of soil are of interest in the design, construction, and maintenance of highways?" Answers to this question form the basis of the group designations. Thus one group includes soils of high stability generally as distinguished from soils of other groups which may have high stability only under unusually moist conditions on one hand or unusually dry conditions on the other.

The groupings provide for separate classification of soils which are apt to heave detrimentally due to frost and the granular soils in which such trouble is not to be expected, and also the elastic soils in which special methods of preparation are required to eliminate detrimental rebound after consolidation and the compressible soils not characterized by such rebound.

In yet other groups are the soils which require special treatment in order that detrimental shrinkage or swell of the subgrade be prevented, and also the peaty and muck soils which give low support.

Within the groups of soils subject to frost heave there is the further distinction between those soils for which the corrective measure is drainage, those on which bituminous surface treatments or other impervious coverings prove beneficial and those which, because of high capillary properties, can be improved only by means of thick coverings of granular material.

The ultimate aim of this classification is to have each group designation signify characteristic performance of soils, the methods of improving performance, and the corresponding road surface requirements.

In this connection the gradings suggested by Dr. Strahan, modified in the light of new experience and supplemented by the results of simple physical tests, were adopted for use in the identification of the quality of soil mixtures and to disclose the effect of admixtures in improving the quality of the poorer soils.[9]

THE THEORY OF STABILITY DISCUSSED

Soil movement during loss of stability or rutting is illustrated by figure 2. It is assumed that the load is applied for an indefinite length over a width of $2b$. For deformation under the load to occur, the section A must shear along some plane such as S and displace laterally as indicated in figure 2, B. But for this to occur, the adjacent section marked C must shear along some surface as S' and, in consequence, displace upward forming a bulge adjacent to the loaded area as shown in figure 2, C.

Actually the surfaces S and S' may be parts of a continuously curved surface but, for mathematical treatment, they may be considered as separate plane surfaces without introducing a large error.

If rutting is to be prevented, the prism C must resist displacement sufficiently to prevent the lateral bulging of the prism A. This may be accomplished by two means, separately or in combination. The shear strength along the planes S and S' must be sufficiently high to prevent sliding of the prisms, or sufficient weight must be placed adjacent to the loaded area to prevent the upward bulging of the prism C.

Friction between the granular particles, combined with the stickiness or cohesion furnished by clay or water films in the binder, control the shear strength of the soil. The road surface furnishes the weight adjacent to the loaded area.

Table 1 gives theoretical supporting values for conditions of load as shown in figure 2, and serves to illustrate the effect of internal friction and cohesion under varying moisture conditions. These data disclose that the supporting value of clay soils may drop from as much as about 12,000 pounds per square foot to less than 400 pounds per square foot with change

[7] The committee consisted of C. M. Strahan, of Georgia; C. B. Scott, of Virginia; and I. B. Mullis, of North Carolina.

[8] Interrelationship of Load, Road and Subgrade, by C. A. Hogentogler and Charles Terzaghi, Public Roads, vol. 10, no. 3, May 1929.

[9] See Interrelationship of Load, Road, and Subgrade, by C. A. Hogentogler and Charles Terzaghi, Public Roads, vol. 10, no. 3, May 1929, p. 10; The Subgrade Soil Constants, Their Significance, and Their Application in Practice, Part 2, by C. A. Hogentogler, A. M. Wintermyer, and E. A. Willis, Public Roads, vol. 12, no. 5, July 1931, p. 134; Tar Surface Treatment of Low Cost Roads, Public Roads, vol. 14, no. 1, March 1933, p. 13.

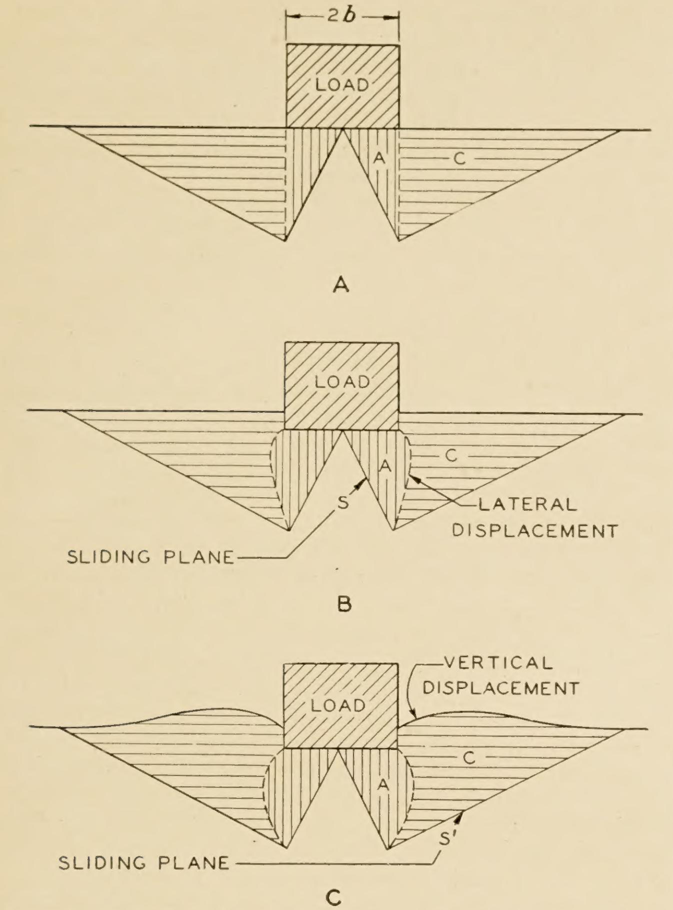

FIGURE 2.—SHEAR PLANES ALONG WHICH LATERAL DISPLACEMENT OF SOILS OCCURS.

from the dry or damp to a soft or almost liquid state. Since the computations are based on the assumption that the load is applied to a narrow strip of indefinite length, the conditions are different from those of a wheel load. The values given serve to illustrate the effect of moisture on stability and are not suggested as a basis for road design.

While the stability of a cohesionless sand may be less than 300 pounds per square foot and that of a fairly stiff clay about 5,000 pounds per square foot, these two materials properly combined may have a supporting value of more than 17,000 pounds per square foot. As a matter of fact, only the cohesion of an almost liquid clay, about 130 pounds per square foot, is required to increase the supporting value of cohesionless sand from 270 pounds per square foot to 2,500 pounds per square foot.

The essential consideration in stabilization is to provide the combination of internal friction and cohesion required to furnish the soil with high shearing strength. This quality is necessary in road surfaces, subgrades, and bases for thin wearing courses. Regardless of the methods used to provide high shearing strength, the success of the efforts will depend upon the permanent adhesive strength which can be developed by the minute films, whether of water or of special chemical substances which connect the soil particles.

It is well known that the denser the soil, the greater is its stability. This is due only in part to the greater mechanical bond resulting from the closer association of grains. Of more importance is the fact that the thinner the connecting films the greater is their adhesive force. Until the characteristics of materials in film phase are understood, the enormous cohesion furnished by films of molecular thicknesses cannot be visualized nor the full possibilities of soil stabilization realized.

To facilitate an understanding of the colloidal phenomena which serve as a basis for the intelligent formulation of methods of stabilization, there is presented the following digest, mainly from Bancroft [10] on the general theory of colloid chemistry as it applies to the cohesion furnished by films of submicroscopic dimensions in the soil.

TABLE 1.—*Influence of internal friction and cohesion upon the stability of soils*

Soil type	Cohesion c	Angle of internal friction ϕ	Supporting value, q [1]	Cohesion c required to increase q to 2,500 pounds per square foot
	Lbs. per sq. ft.	*Degrees*	*Lbs. per sq. ft.*	*Lbs. per sq. ft.*
Clay, liquid	100	0	400	
Clay, very soft	200	2	860	
Clay, soft	400	4	1,850	
Clay, fairly stiff	1,000	6	4,970	
Clay, very stiff	2,000	12	12,490	
Sand, dry	0	34	270	131
Cemented sand and gravel	1,000	34	17,340	

[1] Computations based on assumptions that weight of the soil equals 100 pounds per cubic foot and width of loaded area equals 3 inches.

MOISTURE IN FILM PHASE CAN GREATLY INCREASE SOIL STABILITY

All solids tend to adsorb or condense on their surfaces any gases or vapors with which they are in contact. Adsorption is specific and varies with the nature of the gas and of the adsorbing solid. With the same solid and the same gas the amount of adsorption is greater the higher the pressure of the gas and the lower the temperature.

If a liquid is adsorbed at a solid surface, it forms a liquid film there and thus wets the solid. For a liquid to wet a solid in the presence of air the liquid must be adsorbed more strongly than the air and must displace the air.

During a period of drought, drops of rain will often roll along the dust without wetting it. Even in the case of a shower the dust may be only wetted to a depth of less than ¼ inch. This has been shown to be due to the adsorbed air on the surface of the solid. Any treatment which cuts down the amount of adsorbed air makes the dust more easily wetted.

Some conception of the character of gas films is furnished by the thought that the transition of a pure liquid to its own vapor is not abrupt but that over a narrow range all the densities intermediate between those of vapor and of the liquid actually occur. One authority estimates the transition film for carbon dioxide at 20° C. to be 3 molecules or about 3 ten-millionths of an inch thick.

Williams [11] suggested in 1920 that the first layer of an adsorbed gas vapor may be under a pressure of as much as 10,000 atmospheres and have a corresponding density. From the first layer outward the density decreases to that of the liquid in bulk in the outermost layer.

[10] Applied Colloidal Chemistry by W. D. Bancroft, McGraw-Hill Book Co., Inc., 1932.
[11] Proceedings of the Royal Society, vol. 98A, 1920, p. 223.

In like manner, the character of water changes with the size of the particle. Drops $\frac{1}{40,000}$ of an inch to about $\frac{1}{1,000,000}$ inch in size, when suspended in the air, appear as fog if you walk through them and as a cloud if you look at them from a distance. Under electrical stress they coalesce to form raindrops at sizes of about $\frac{2}{1300}$ inch to $\frac{1}{4}$ inch in size, which eventually become moisture films in soils.

So long as the soils are in a liquid or a plastic state, the films have in general the evaporation and freezing characteristics and the surface tension of water in bulk. When drying or mechanical compaction reduces the density of the soil below that at the plastic limit, the boiling point of the film rises, the freezing point lowers, and the surface tension increases so that these films become somewhat tougher than water in bulk.[12] This causes the soil to change from a plastic to a semisolid material. In thicknesses below $\frac{2}{1,000,000}$ of an inch, the films behave, according to Terzaghi, like semisolid substances.[13]

The very fine vapor films have an adhesive power so great that they cannot be removed from glass by heating at a temperature up to 500° C. This high tenacity is utilized in the manufacture of frosted glass for use in office doors and windows. Rather thick glass is first coated with gelatine or glue. As the glue loses moisture it contracts, and the power of the gelatine is so great that it tears away the surface of the glass itself, chipping it into fern-like patterns. A brittle glue will give a different pattern from a tough glue, and the addition of salts also modifies the patterns.

That the properties of the minute moisture films approach those of semisolids instead of liquids accounts for the fact shown by Keen[14] that samples of sand grains with a binder of clay colloids can be 19 times as strong in compression as similar sand grains with an equal proportion of portland cement binder.

The theory of adhesion depends in part on the fact that the cementing material adheres strongly to the two surfaces and hardens there. For a given adhesive film and given materials the thinnest film gives the strongest joint. The thickness of films depends upon both the adhesive and the materials to be cemented. A slight change in the electrolytic properties of the latter is sufficient to cause a considerable variation in the thickness of the adhesive film and consequently in the strength of the resulting mixture of adhesive and aggregate.

According to Bancroft, Pettijohn[15] found about $\frac{5}{1,000,000}$ of an inch for the maximum thickness of a water film on pearls made from one type of glass and $\frac{10}{1,000,000}$ of an inch for pearls made from another type. With river sand the estimated thickness varied from $\frac{20}{1,000,000}$ with 10-mesh sand to $\frac{5}{1,000,000}$ of an inch with 60-mesh sand.

Methods utilized to obtain or maintain adhesive film strength in soils may be listed as follows:

1. Use of graded materials with granular material and binder of such character and in such proportions as to furnish the required pore size.
2. Treatment of road surface mixtures with deliquescent chemicals to stabilize the moisture content.
3. Densification of soil at optimum moisture content or treatment with chemical electrolyzers to facilitate the wetting of soil grains and decrease the thickness of the moisture films; use of bituminous materials to increase the cohesion and eliminate those properties of clay and colloids productive of detrimental volume change; and use of crystallizers to form water-resistant connecting films by hydration or base exchange.
4. Stabilization of the moisture content by waterproofing the soil with impervious surface treatments of bituminous materials.

[12] Simplified Soil Tests for Subgrades and their Physical Significance, by Charles Terzaghi, Public Roads, vol. 7, no. 8, October 1926, p. 154.
[13] Physical Review, vol. 16, 1920, p. 56.
[14] The Physical Properties of the Soil, by Bernard A. Keen, Longmans Green and Co., 1931.
[15] Journal of the American Chemical Society, vol. 41, 1919, p. 477.

WELL-GRADED MATERIALS HAVE CERTAIN ESSENTIAL FEATURES

Certain soils can be used to make a firm and hard road surface, capable of supporting the heaviest loads after long rains, free from mud or excessive dust, and which will carry traffic in both wet and dry weather without undue injury. Figure 1 is an example of such a surface.

Such materials are designated as hard or class A by Dr. Strahan and consist of coarse aggregate and soil mortar. The coarse aggregate is that portion retained on the no. 10 sieve and includes particles of natural gravel, supplemented when necessary with crushed stone or slag. Generally the largest particles should not exceed about 1 inch.

The mortar includes coarse sand or other granular material passing the no. 10 sieve and retained on the no. 60 sieve; fine sand passing the no. 60 sieve and retained on the no. 270 sieve; silt particles between 0.05 and 0.005 mm (0.002 inch to 0.0002 inch) in diameter; clay particles smaller than 0.005 mm in diameter; and moisture.

The coarse aggregate and coarse sand furnish structural strength and hardness; fine sand adds an embedment support to the coarse sand; silt acts as a filler to prevent the granular particles from rocking; and clay and colloidal particles provide pores minute enough to cause connecting moisture films which produce high cohesion.

Dr. Strahan called attention to the importance of the soil mortar as follows: "In judging these materials (road soils) full emphasis should be placed upon the soil mortar, i. e., material below no. 10 sieve. Weak soil mortars even with large amounts of coarse material often do not give proper stability under traffic."

In Dr. Strahan's reports clay is used to designate particles less than about 0.02 millimeter in diameter; silt, those particles with diameters between 0.02 and 0.07 millimeter; and sand, those particles larger than 0.07 millimeter in diameter.

In more recent work new size ranges have been adopted for several reasons:

1. The new sizes represent fractions having special physical significance. Particles larger than 0.05 millimeter have neither cohesion nor capillarity in appreciable amount; particles varying between 0.05 and 0.005 millimeter have considerable capillarity but little or no cohesion; and only particles smaller than about 0.005 millimeter can furnish cohesion.
2. The new sizes are used by the Bureau of Chemistry and Soils of the United States Department of Agriculture. The use of the same size ranges in highway work facilitates the use of the great amount of published information on soil surveys made by that bureau in which the mechanical analysis plays an important part.

3. Prior to the development of the hydrometer method of analysis, the determination of the complete grading of the subsieve fraction was so laborious as to be impractical as a routine test for highway purposes. With the hydrometer method the grading according to the new sizes may be determined with no greater effort than was required for the determination of the grading by the old method of decantation.

Experience with soils indicates that they are stable only when they contain constituents which produce the following:

1. A certain total of seating and embedment stability together with the density required to resist traffic pressures and impacts.

2. An internal bond developed from interlocking grains and capillary moisture forces sufficient to cause the coarser sizes of sand and the coarse aggregate to have high stability during wet weather when the cohesion furnished by the clay may be greatly reduced.

3. Sufficient cohesion in the binder to cement the sand and silt when in a dry or almost dry condition and thus maintain the integrity of the surface during dry weather.

4. A surface which maintains constant volume, that is, there should not be so much clay that its expansion by water will break the seating and embedment bond of the granular particles.

5. Rapid evaporation to prevent the accumulation of capillary moisture from the subgrade beneath and active percolation to dispose of the rain water which may collect on the roadway in spite of efforts to maintain a smooth surface for the prompt removal of water.

The design of soil mixtures to provide these conditions is now based on the grading of the entire soil sample as determined by mechanical analyses, and on the binding properties of the fines as disclosed by plasticity tests performed on the fraction of soil passing the no. 40 sieve.

Materials falling within the following composition limits, by weight, should produce good results:

Passing—	Percent
1-inch screen	[16] 100
¾-inch screen	85–100
No. 4 sieve	55–85
No. 10 sieve	40–65
No. 40 sieve	25–50
No. 270 sieve	10–25

The fraction passing the no. 270 sieve should be less than two-thirds of the fraction passing the no. 40 sieve. Depending upon moisture conditions as discussed below, the fraction passing the no. 40 sieve shall have a plasticity index between 1 and 15 and a liquid limit not exceeding 35 as determined by physical tests made according to the methods of the Bureau of Public Roads.[17]

As early as 1922 Dr. Straham called attention to the need for tests to disclose binding properties, suggesting that a highly colloidal clay in small amounts would evidently give adhesive strength equal to that produced by a large amount of less colloidal clay in a road soil mixture.

Another important indication was furnished by the work of the late Raymond Smith of the Ohio Department of Highways. Working with Prof. F. H. Eno of Ohio State University in constructing traffic-bound roads, he found that the stabilizing of material consisting principally of rounded particles, was greatly facilitated by additions of crushed materials or granulated slag.

As an additional guide, the field moisture equivalents may serve to indicate the tendency of binders to soften under conditions producing high moisture contents. In this connection values of 20 and less, 20 to 25 and greater than 25 indicate respectively the best, the medium, and the poorer materials.

PLASTICITY TESTS INDICATE BOTH CAPILLARITY AND COHESION

All cohesive soils have capillary properties but all soils with capillarity do not have cohesion. Liquid limits up to about 20 or slightly more generally indicate sandy materials with negligible capillarity. The more the liquid limit exceeds this amount the greater is the capillarity of the material. The plasticity index indicates the cohesion of materials but does not indicate their capillarity. Therefore the greater the plasticity index for equal liquid limits, the greater the cohesion of the material.

The properties of a mixture consisting largely of a relatively inert material such as ground quartz may be considerably changed by admixtures. As more active constituents are admixed the properties become those of the highly capillary diatoms, the moderately cohesive kaolin or the highly plastic colloidal bentonite. There are definite relationships between the test results and the percentages of the constituents which furnish the characterizing properties of soils. This is illustrated in figure 3.

The relationships between the liquid limits, LL, the plasticity indexes, PI, and the percentages of the active constituents, P, in mixtures of active materials and inert quartz are as follows:

For diatoms, $PI=0.21P=0.19\ (LL-18)$.
For kaolin, $PI=0.15P=0.71\ (LL-18)$.
For bentonite, $PI=3.3P=1.0\ (LL-18)$.

If any particular amount of cohesion is desired, say that indicated by a plasticity index of 5, the admixture according to these formulas may be 24 percent of diatoms, 33 percent of kaolin, or 1.5 percent of bentonite. The corresponding capillarities will be those indicated by a liquid limit of 44 for the mixture containing diatoms, 25 for the kaolin mixture, and 23 for the bentonite mixture.

In like manner the percentage of soil binder together with the accompanying capillarity to produce a desired plasticity can be determined by means of data furnished by the plasticity tests. The amount of inert material required to reduce excessively high plasticity can also be determined from similar data.

Generally plasticity indexes of about 3 or less indicate sufficient binder cohesion for use in road construction under unusually wet conditions; 4 to about 8, under conditions of average moisture; and 9 to 15 inclusive, only under dry or arid conditions. Plasticity indexes exceeding 15 indicate soils not suitable for road surfacing.

The presence of the undesirable micaceous, diatomaceous, peaty, or other organic substances is indicated when the liquid limit is greater than $1.6\ PI+14$.

The more the liquid limits exceed this value the more unsatisfactory the soil binder is apt to be due to detrimental sponginess and capillarity. Such properties will not be present in detrimental amount when the liquid limit does not exceed about 35.

[16] Material of greater maximum size can be used under certain conditions but the largest aggregate should never exceed ⅓ the thickness of the stabilized layer and not more than 10 percent of the material should exceed 1 inch.

[17] Procedures for Testing Soils for the Determination of the Subgrade Soil Constants, by A. M. Wintermyer, E. A. Willis, and R. C. Thoreen, Public Roads, vol. 12, no. 8, October 1931.

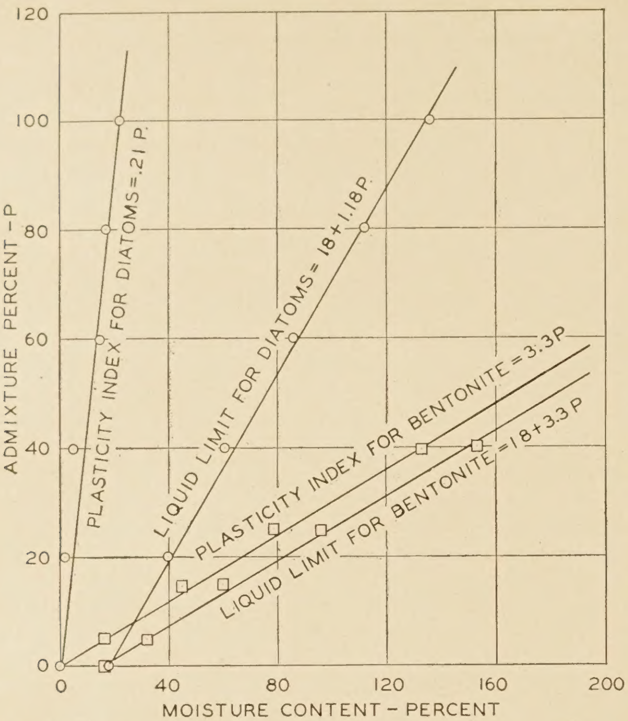

FIGURE 3.—RELATION BETWEEN PERCENTAGE OF ADMIXTURE OF INERT MATERIAL AND PLASTICITY LIMITS.

DELIQUESCENT SUBSTANCES USED TO PREVENT EXCESSIVE LOSS OF MOISTURE IN DRY WEATHER

Absence of moisture films from soil road surfaces causes dust and raveling; too much moisture causes rutting. The dryer a road surface becomes as a result of evaporation, the wetter a rain will make it. This is because extreme dryness causes small cracks and fissures to form in the clay binder through which rain water may enter and soften the interior of the road surface. Fissures do not form in damp surfaces of properly selected constituents and water will be shed from the surface without injurious effect.

Dampness of surface is desirable for another reason. All types of topsoil, gravel, traffic-bound and even water-bound macadam road surfaces acquire their final consolidation through compaction by traffic during what might be termed a period of seasoning following construction. When the surface is dry during this period the mineral binder powders under traffic and permits raveling of the surface, which requires extensive patching of the macadams and maintenance by means of mulch on the other types.

If such surfaces can be maintained in a damp or slightly moist state the moisture films in the minute pores of the binder will prevent the separation of the granular particles and the shocks and blows produced by traffic become effective in gradually wedging the granular fragments into close association. The cohesion increases as the pores in the binder become smaller and finally the coarse aggregate, the sand, the filler, and the binder are formed into a stable, durable road structure.

Calcium chloride is the principal chemical used in this type of stabilization although common salt has been used to a limited extent in experimental sections.

As early as 1907, Austin Thomas Byrne [18] discussed the use of sea-water and deliquescent salts for the suppression of dust.

The writer used calcium chloride as a dust layer on short sections of macadam streets in Pennsylvania about 1912. The value of this substance as a dust layer for gravel roads was quite generally recognized by 1916.

Sodium chloride has not received as much attention as calcium chloride although its possibilities were suggested by R. H. Phillips in 1919. [19] It was used in experiments on the Wendover cut-off in 1924 [20] and in Nova Scotia in 1931.[21]

A report resulting from an investigation of calcium chloride as a dust palliative by the Highway Research Board, [22] first suggested the possibilities of this chemical for stabilizing the moisture content of graded materials in low type roads. This investigation included observations and tests on experimental roads in South Carolina, Missouri, and Nebraska. Supplemental tests were made to obtain quantitive data on the rate of evaporation from treated and untreated soil samples, the effect of rewetting surface on the rate of evaporation and on the leaching of calcium chloride by moisture.

CHEMICAL TREATMENT USED TO PRODUCE HIGH SOIL DENSITY

A recent report by W. R. Collings and L. C. Stewart[23] gives the results of traffic tests on test roads. This investigation included tests of various combinations of soils in road sections constructed on a large indoor track on an earth subgrade.

The track was oval in shape with straight sections 120 feet long and 12 feet wide and banked curves of 40 feet radius on the ends. The individual test sections were 25 feet long and 10 feet wide. A sprinkling system and hot air blown over the road surfaces were used to produce wet and dry road conditions. Mixtures for the test sections were prepared by combining various proportions of natural silts, clay, and fine and coarse aggregates. The materials were thoroughly mixed and deposited on the subgrade. The compaction was obtained by operating trucks over the test sections. In all, there were 28 test sections included in this investigation. Encouraging results furnished by these large-scale experiments were followed by the construction of the so-called stabilized soil road surfaces in a number of States, with the largest mileages in Michigan, Indiana, and Onondaga County, N. Y.

The Highway Research Board's investigation disclosed, among other things, that calcium chloride placed upon the surface retards the evaporation of soil moisture and that the moisture film cohesion furnished by calcium chloride is more stable than that furnished by plain water. It also showed that during periods of low rainfall and high temperatures the sections treated with calcium chloride have the higher moisture content and that calcium chloride is retained best in compacted and undisturbed surfaces.

The primary reason for the decrease in rate of evaporation is the low vapor pressure of the calcium chloride. A layer of the solution on the surface of the soil particle may be conceived of as an effective semi-permeable blanket through which the moisture from

[18] Treatise on Highway Construction, 5th edition, by Austin Thomas Byrne, John Wiley and Sons, New York, 1907, pp. 901–911.

[19] Salt-Marsh Sand Clay as a Road-Building Material, Engineering News-Record, vol. 82, no. 12, Mar. 20, 1919, p. 575.

[20] A Salt Dressing for Roads, Kentucky Road Builder, vol. 3, no. 10, Oct. 1924, p. 8.

[21] Nova Scotia's Experience with Dust Layers, by Percy C. Black, Canadian Engineer, vol. 61, no. 13, Sept. 29, 1931, p. 94.

[22] Report of Investigation of the Use of Calcium Chloride as a Dust Palliative, by Fred Burggraf, Proceedings of the Twelfth Annual Meeting of the Highway Research Board, Part 2, 1932.

[23] Stabilized Soil-Bound Road Surfaces Part 2: Traffic Tests of Trial Roads, by W. R. Collings and L. C. Stewart, Engineering News-Record, vol. 112, no. 23, June 7, 1934.

the soil has difficulty in reaching the surface where evaporation takes place.

The hygroscopic property of calcium chloride causes absorption of moisture from the air during periods of high humidity and also slows up the rate at which soils lose moisture.

The high density attained during compaction by traffic is indicated by dry weights of as much as 150 pounds per cubic foot, which have been observed for wearing courses treated with calcium chloride and common salt. Retention of the material in the highly compacted state accounts for the beneficial action of the chemical upon the preservation of the road material.

MOST STABLE SOIL MIXTURES CONTAIN COARSE MATERIAL

The plasticity constants and the grading of a number of soil mixtures are shown in table 2. Mixture no. 1 shows the requirements of good mixtures as suggested on page 277 of this report. Mixture no. 2 represents the requirements of good soil mortars, based upon Dr. Strahan's work [24] assuming a coarse aggregate content of 50 percent. No. 3 is typical of the mixtures used in the construction of stabilized roads in Washtenaw County, Mich., in 1933.

Mixtures 4 to 8 are soil mortars studied by Collings and Stewart [25] in their investigation of the stability of various mixtures and the use of calcium chloride under controlled truck traffic. Mixtures 9 to 13 are of the sand-clay gravel type from the same experiments and were considerably more stable than mixtures 4 to 8. This is in line with Dr. Strahan's findings: "When coarse material is added to a good soil mortar in appreciable amount (10 percent or more) the hardness and durability of the surface is increased and continues to increase until a full gravel-type surface is reached."

Mixtures 14 to 17 are from the report on investigations by Travers and Hicks of stabilized roads in Onondaga County, N. Y.[26] Additional investigations by Collings and Stewart [27] furnished data on mixtures 18 to 30. Mixture no. 40 is typical of surfacing material used by G. A. Rahn in Pennsylvania.

Of these 10 mixtures investigated by Collings and Stewart, only nos. 4, 5, 6, 9, and 10, which have some plasticity, are considered satisfactory for surfacing. Samples 14 to 17, inclusive, representative of satisfactory mixtures reported by Travers and Hicks, had somewhat more plasticity than the 5 satisfactory soils reported by Collings and Stewart.

Of the mixtures 18 to 39, inclusive, mixtures 23 and 24, with no plasticity, and mixtures 32, 33, 38, and 39 were the least resistant.

The manner in which local materials are selected for use in soil roads was excellently described by G. A. Rahn, of the Pennsylvania Department of Highways, before the 1934 convention of the American Society for Testing Materials. In one case the soil of the original road was taken to the laboratory and on test was found to be a silt loam. Since stone screenings were available near the location of the road for use as admixture, tests were made to determine the amount of admixture required to change the soil to the more stable A–2 type. With this information as a guide the screenings were applied to the old road and worked in until tests disclosed the proper amount had been added. Some time later calcium chloride was applied to the surface. The illustration, figure 4, was taken in April 1934 and shows the manner in which the stabilized road came through the winter in comparison with the side road which was not stabilized. Mixture 40 of table 2 is representative of the mixture used.

Calcium chloride is applied to soil surfaces at the rate of about one-half pound per square yard per inch of thickness of road surface and preferably should be mixed with the graded surfacing material. Indiana requires not less than three-fourths of a pound of common salt per square yard per inch of surface thickness with the additional requirement that the salt shall be applied in a solution of about 8 pounds of salt to 5 gallons of water.

The chemically treated surfaces are firmly bound and offer great resistance to raveling under traffic. Smoothness is maintained without the loose surface mulch often used on untreated gravel roads. In fact, the presence of mulch may act as an abrasive under the wheels of vehicles and thus prove detrimental.

TABLE 2.—*Plasticity and grading of typical soil-road materials*

[All materials pass the 1-inch screen]

Mixture no.	Liquid limit	Plasticity index	Passing— ¾-in. screen	Passing— No. 4 sieve	Passing— No. 10 sieve	Passing— No. 40 sieve	Passing— No. 270 sieve
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1		1–15	85–100	55–85	40–65	25–50	10–25
2	14–35	4–8			50	26–34	8–15
3	20	6		73	50	38	17
4	16	1			100	75	16
5	15	4			100	77	27
6	15	1			100	73	22
7	16	0			100	77	13
8	17	0			100	76	7
9	17	4	100	72	39	25	12
10	15	3	100	62	40	29	16
11	13	0	97	53	39	22	11
12	13	1	100	78	56	33	13
13	12	0	100	69	43	20	10
14		8	98	63	51	31	14
15		7	98	73	63	39	23
16		5	97	52	39	24	17
17		7	98	65	53	28	10
18	27	14	82	57	50	41	20
19	22	11	82	58	51	43	20
20	21	10	80	56	48	38	14
21	17	5	79	54	46	36	11
22	18	5	79	54	46	34	10
23		0	82	57	50	38	10
24		0	79	54	45	34	6
25	28	15	95	68	54	46	24
26	22	11	100	68	53	45	23
27	21	10	100	77	59	48	22
28	27	15	100	71	53	43	28
29	22	11	94	64	47	39	16
30	17	6	94	64	46	36	14
31	27	15	100	70	50	38	18
32	20	10	100	71	52	40	15
33	18	6	94	65	47	56	10
34	21	10	96	77	65	53	26
35	27	15	96	77	66	58	36
36	21	10	94	65	49	40	19
37	27	15	94	63	48	41	24
38	20	10	92	57	39	28	14
39	28	15	92	52	33	28	17
40	22	5	97	66	59	46	20

[24] Subgrade Soil Constants, Their Significance, and Their Application in Practice, by C. A. Hogentogler, A. M. Wintermyer, and E. A. Willis, Public Roads, vol. 12, nos. 4 and 5, June and July, 1931.

[25] Report on Investigations of the Use of Calcium Chloride as a Dust Palliative, discussion by L. C. Stewart and W. R. Collings, Proceedings of the Twelfth Annual Meeting of the Highway Research Board, Part 2, 1932, p. 45; see also Improved Low Cost Soil and Gravel Roads, The Dow Chemical Co., 1933.

[26] Gravel Type Surfaces for Secondary Roads, by Ray B. Travers and W. B. Hicks, Proceedings of the Thirteenth Annual Meeting of the Highway Research Board, Part 1, 1933, p. 228.

[27] Stabilized Soil-Bound Road Surfaces, Part 2, Traffic Tests of Trial Roads, by W. R. Collings and L. C. Stewart, Engineering News-Record, vol. 112, no. 23, June 7, 1934.

Figure 4.—Stabilized Road in Adams County, Pa., at Its Junction with Untreated Side Road.

A good mixture for the repair of areas in which pitting has occurred consists of aggregate under one-half inch in size, mixed with at least an equal weight of stable sand-clay. To insure that the patching materials will be moist enough to stick securely in the hole, the admixture of 100 to 150 pounds of calcium chloride per cubic yard is recommended.

Figures 5 and 6 illustrate steps in the construction of roads treated with deliquescent chemicals in Michigan. Figure 7 shows similar surfaces in Indiana.

PERMANENT DENSIFICATION OF SOILS A PROMISING BUT LITTLE-EXPLORED METHOD

The purpose of this type of stabilization is to produce a semisolid and dense soil-road surface which is not affected by moisture and is capable, when suitably surface treated, of serving a considerable volume of traffic. The method is suitable for use where only fine-grained soils abound as well as in those locations having granular materials and binder available for use in graded soil mixtures.

The idea of stabilizing soils by means of admixtures of other than soil materials is not new. Prof. F. H. Eno used both hydrated lime and portland cement as admixtures to improve subgrade soils in experimental sections in 1924 and 1925.[28]

More recently, in 1929, Prof. Eno used salt, hydrated lime, calcium chloride, sodium silicate, kerosene, cold tar, crude oil, and used crankcase oil in addition to stone dust and granulated slag in experimental sections of subgrades of six traffic-bound roads in Ohio. The treatments were carried to a depth of 3 inches in the subgrade.[29]

It was not until 1932, however, that the importance of densification in connection with the use of chemical admixtures began to be realized. From experiments performed at the Arlington laboratory of the Bureau of Public Roads it became evident that when soils were treated with such materials as portland cement, bituminous materials, etc., the stabilizers could best be distributed in fine-grained soils in the form of solutions or emulsions. However, samples thus treated became porous upon drying due to the effect of the admixtures in reducing the shrinkage properties of the colloids. Thus the necessity of including mechanical compaction as part of the stabilizing procedure became evident. Experimentation was begun on procedures for compacting samples and determination of the properties of samples thus prepared.

Figure 8 shows an apparatus devised for bringing an entire sample, including the coarse fraction, to various degrees of consolidation. The apparatus is based on the principle of the sheepsfoot roller, and it appears that compaction according to this principle will be desirable in construction. Samples having various degrees of consolidation have been tested for permeability, capillarity, stability, and shrinkage.

In 1933 a definite basis was established for the intelligent incorporation of admixtures in soils; a means was provided for determining the amount of compaction required; and a method was suggested for evaluating in the laboratory the relative stabilizing effects of the various admixtures. R. R. Proctor, of the Los Angeles Bureau of Waterworks, is largely responsible for these contributions.[30]

In 1925 Milburn[31] showed that there is an optimum binder content at which maximum density of bituminous mixtures may be attained, and in 1928 Jackson[32] pointed out that concrete investigators accepted the conclusion that there is an optimum water-cement ratio for each portland cement concrete mixture. Proctor, in a series of reports, has shown that for every soil there is a moisture content at which maximum compaction can be obtained with a sheepsfoot roller during construction. The extent of this compaction is readily ascertained by testing samples at different moisture contents under impacts of a standard tamper in the laboratory.

LABORATORY TESTS SHOW IMPORTANCE OF PROPER MOISTURE CONTENT IN PRODUCING MAXIMUM DENSITY BY COMPACTION

Figures 9, 10, and 11[33] illustrate the apparatus and the significance of the Proctor tests. The soil samples are compacted at different moisture contents in a one-thirtieth cubic-foot cylinder by the impact of a 5½-pound rammer in such a manner as to duplicate the force obtained by a sheepsfoot roller in the field. The density of the compacted soil is computed from the actual weight of soil and the moisture content and expressed in pounds of soil per cubic foot. The bearing power of the compacted soil is determined for each moisture content by measuring the force needed to push a needle of known end-area into the soil at a speed of one-half inch per second.

Figure 9 shows the compacted fill material being tested with the plasticity needle. In the background is the type of sheepsfoot roller used to compact the fill.

[28] Highway Subsoil Investigation in Ohio, by F. H. Eno, Engineering Experiment Station Bulletin No. 39, Ohio State University, 1928.

[29] Subgrade Drainage and Treatment by F. H. Eno, Proceedings Eleventh Annual Meeting of the Highway Research Board, 1931, p. 192.

[30] Fundamental Principles of Soil Compaction, by R. R. Proctor, Engineering News-Record vol. 111, no. 9, August 31, 1933; Field and Laboratory Determination of Soil Suitability, by R. R. Proctor, Engineering News-Record, vol. 111, no. 10, Sept. 7, 1933; Field and Laboratory Verification of Soil Suitability, by R. R. Proctor, Engineering News-Record, vol. 111, no. 12, Sept. 21, 1933; New Principles Applied to Actual Dam Building, by R. R. Proctor, Engineering News-Record, vol. 111, no. 13, Sept. 28, 1933.

[31] A Deformation Test for Asphaltic Mixtures, by H. M. Milburn, Public Roads, vol. 6, no. 6, August 1925.

[32] The Design of Pavement Concrete by the Water-Cement Ratio Method, by F. H. Jackson, Public Roads, vol. 9, no. 6, August 1928.

[33] These figures supplied by C. A. Hogentogler, Jr., soils engineer, Back Creek Earth Dam Project, U. S. Forest Service.

FIGURE 5.—STEPS IN SOIL ROAD CONSTRUCTION IN MICHIGAN. A, SCARIFYING OLD SURFACE; B, REMOVING LARGE STONE WITH RAKE; C, SPREADING PULVERIZED CLAY ADMIXTURE; D, DEEP BLADING TO MIX CLAY WITH OLD ROAD MATERIAL; E, SPREADING CHEMICAL OVER SMOOTHED SURFACE; F, MIXING BY BLADING IN WINDROWS.

Figure 6.—A, Spreading Dry Material Over Wetted Road Bed; B, Rolling the Partially Dry Surface.

Figure 7.—Soil Surfaces in Indiana Containing Deliquescent Chemicals.

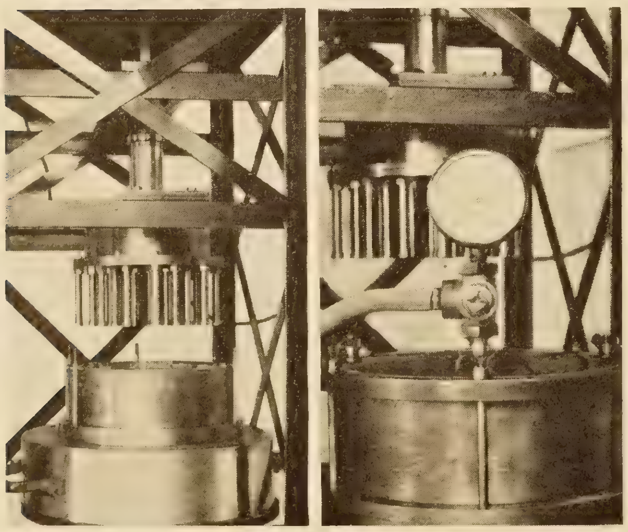

Figure 8.—Apparatus for Consolidating Sample and Testing for Permeability, Capillarity, and Shrinkage.

Figure 10 shows the two curves resulting from the test; the weight of dry soil-moisture content relation and the bearing value-moisture content relation. The weight of dry soil-moisture content curve discloses that for this soil a moisture content of about 19 percent is required if maximum compaction is to be attained. The corresponding bearing value is about 1,100 pounds per square inch.

If, at the specified compaction, the bearing value of this particular soil is indicated by the plasticity needle to be higher than 1,100 pounds, the increase can be considered as only temporary if the fill is to be unprotected from water after construction. Thus a bearing value of 1,600 pounds per square inch indicates a moisture content of slightly less than 17 percent. This corresponds to a dry weight of about 106 pounds per cubic foot. At this density the soil can take up moisture to a maximum of slightly more than 20 percent which, in turn corresponds to a bearing value of but 600 pounds per square inch.

Figure 11 illustrates how dry weight-moisture content curves may be used to disclose the effect of various admixtures in increasing or decreasing the stability of soil. It is shown that some admixtures serve to increase the optimum moisture content, others tend to

FIGURE 9.—COMPACTING SOIL IN PROCTOR CYLINDER AND DETERMINING CONSISTENCY OF FILL WITH PLASTICITY NEEDLE.

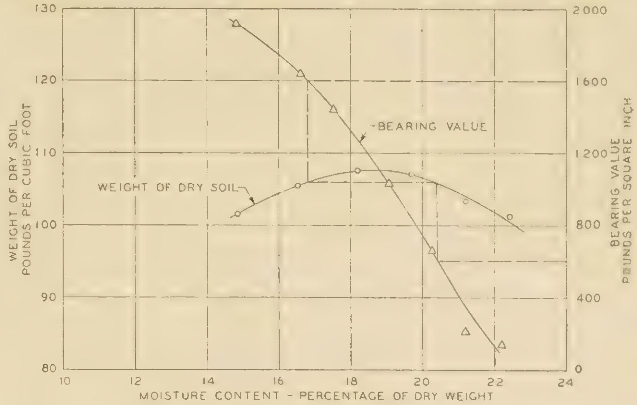

FIGURE 10.—DATA FURNISHED BY PROCTOR TESTS.

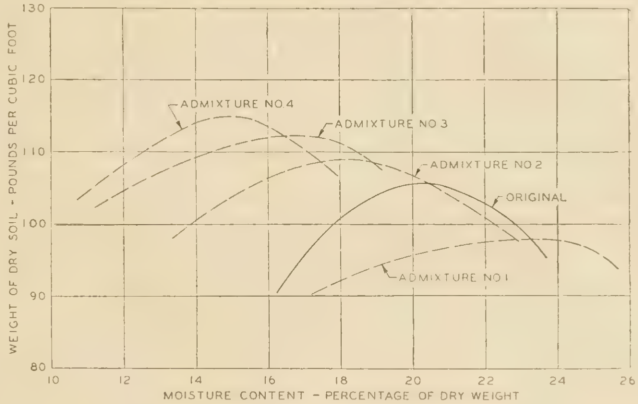

FIGURE 11.—EFFECT OF CHEMICAL ADMIXTURES IN REDUCING OPTIMUM MOISTURE CONTENT AND INCREASING THE DENSITY OF COMPACTED SAMPLES.

decrease it. As the optimum moisture content increases, the maximum density decreases.

By incorporating certain elements of the Proctor tests in a modified compression and permeability test, it seems possible to predetermine how well soils with admixtures, compacted according to current construction methods, will retain a high density under varying climatic and load conditions. The procedure is to compact the sample at optimum moisture content and then transfer it in the compacted state to the Terzaghi compression test apparatus and observe the compression and expansion characteristics.

The results of such tests are shown in figure 12, upper left. This curve is representative of one of the most troublesome of subgrade soils—due to shrinkage and plasticity—the highly colloidal, sticky, tenacious soil in zone B of the Iredell series. The curve shows that maximum density is reached at a moisture content equal to about 16 percent of the weight of the dry soil. At this moisture content a density indicated by a dry weight of 106 pounds per cubic foot is obtained. Results of compression and expansion tests on a sample of soil compacted at this moisture content are shown in the lower left of figure 12. The sample was placed in the apparatus, without having access to water, and a load applied in increments up to 8.2 tons per square foot. The load was then reduced to 0.05 ton per square foot. The results are shown by the broken lines. Water was then allowed to enter the testing apparatus and after a considerable interval of time the load was again increased to 8.2 tons per square foot and then reduced to 0.05 ton per square foot. These results are indicated by the full line which represents both load application and load removal.

Figure 12, C, D, and E shows results of similar tests on samples of the same soil in dust phase, at optimum moisture content but uncompacted, and on a sample wetted to about the liquid limit. In these curves volume change is indicated by the voids ratio. The small change in volume of the compacted sample resulting from wetting and change in load, as compared with that of the same soil in the other states, is striking. This is further emphasized by figure 13 which shows the same test results in terms of thickness of soil layer per unit thickness of solids in the layer.

The results shown in figure 13 indicate that subgrades comprised of the highly plastic soils, such as the black waxy soils, the adobes and the gumbos, when manipulated at the proper moisture content, may be compacted to high densities which will remain fairly constant under widely changing conditions of load and access to water.

The consolidations shown were produced by load periods of 72 hours on samples about 1 centimeter thick. Expansions were measured after loads had been removed for periods of 24 to 48 hours. To produce an equal degree of consolidation in soil layers thicker than 1 centimeter, the duration of the load would vary as the square of the thickness of the layer.

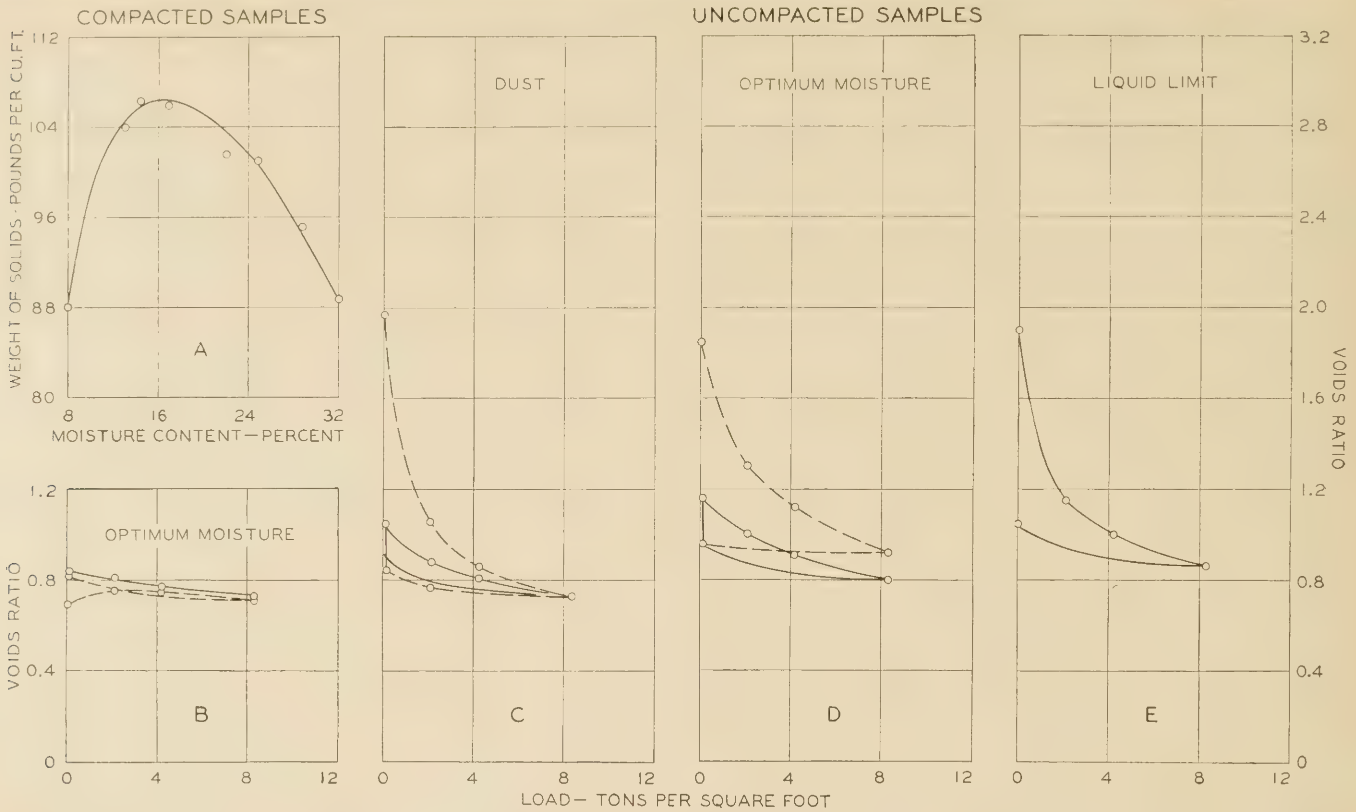

Figure 12.—Relation Between Moisture Content and Density after Compaction of Iredell Clay and Results of Compression Tests on Compacted and Uncompacted Samples.

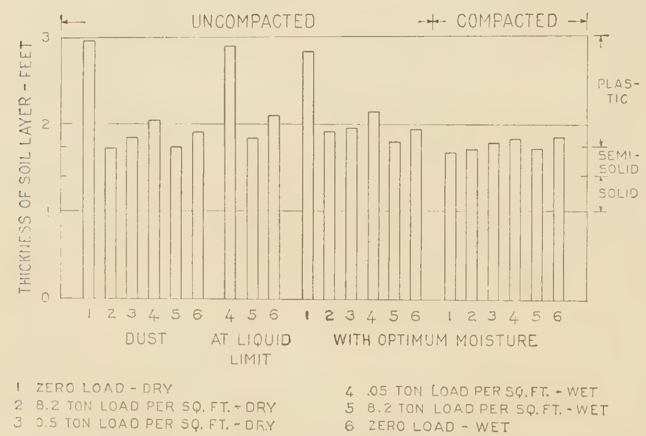

Figure 13.—Thickness of a Layer of Iredell Clay Containing the Equivalent of 1 Foot of Solids Under Different Test Conditions. The Terms "Wet" and "Dry" Refer to Conditions Surrounding the Sample.

APPLICATION OF SURFACE CHEMISTRY TO SOIL STABILIZATION BEING STUDIED

The great possibilities in the application of surface chemistry to soil stabilization are indicated by the reports of Winterkorn,[34] Reagel and Schappler,[35] of the Missouri State Highway Department. Their work discloses that some bases have greater affinity for bitumen than for water and that the reverse is true for other bases. The use of soap as an electrolyzer facilitates the mixing of some soils with bituminous materials. The benefit of the soap treatment was demonstrated in an experiment in which soap was used on one section of an earth-gravel-oil mixture and omitted on another section. A heavy rain washed the oil from the latter section but did not wash it from the soap-treated section. It is indicated that different soaps may be desirable for different soils. Ions from different bases may either increase or decrease shrinkage, plasticity and other properties on which stability depends. For every soil it is possible to select a cation for exchange which will adjust the properties of the soil as desired.

Among the substances suggested as having possible use as admixtures in soil densification are bituminous materials, portland cement, hydrated lime, calcium chloride, calcium silicate, calcium carbonate, soda ash, sodium silicate, and sodium chloride.

It is believed that the high densities of road surfaces treated with calcium chloride and salt are not due entirely to the deliquescence of these materials but are in part due to electrolytic effect in reducing the thickness of the moisture films. A limited number of compaction curves, such as shown in figure 11, support this conclusion.

It is possible that chemicals such as calcium chloride and common salt, which serve to lower the freezing temperature, might be beneficial in the colder climates in their effect on freezing.

STABILIZATION BY SURFACE TREATMENTS EFFECTIVE ONLY FOR SOILS OF GOOD QUALITY

The preceding discussion discloses methods of determining densities which can be produced by special methods and which can be maintained under a wide range in moisture and load conditions. The mainte-

[34] Oiling Earth Roads, Application of Surface Chemistry, by Hans Winterkorn, Industrial and Engineering Chemistry, vol. 26, August 1934.

[35] Stabilizing Sand and Gravel Surfaces, by R. C. Schappler, Kansas Highway Conference, Manhattan, Kans., Feb. 5, 1934.

nance of high density in a road surface, however, requires that subgrades and bases for thin wearing courses be constructed in such a manner as to prevent damage by water coming from beneath the surface and also that loss of moisture from the densified soil by evaporation be prevented. It is because of this requirement that a discussion of the benefits of waterproofing by surface treatment is included in this report.

Two conditions are essential if the waterproofing of a soil surface is to be worth while. The materials of the surface and base must be either impervious enough, or have sufficiently low capillarity to prevent the accumulation of enough capillary moisture to cause instability. The quality of materials necessary will be affected by climate, topography, and traffic. The surface treatment must be maintained sufficiently impervious to prevent the surface water entering clay soils from above and to prevent the evaporation of the cohesive moisture films from sandy soils.

Stabilization by surface treatment is excellently illustrated by the blotter-type tar and asphalt surface treatments on the heavy gumbo soil roads of western Minnesota and eastern North Dakota.[36] The top view of figure 14 shows a condition in the spring of a road west of Ada, Minn., prior to the first treatment in 1924. Gravel used for surfacing was found to have penetrated to depths as great as 3 feet. The lower view of figure 14 is a picture taken in the spring of the year and shows the condition of a similar road after receiving a surface treatment of bituminous material with gravel covering. On inspection in 1932, the total thickness of the surface treatment was found to be slightly less than 1 inch.

Bituminous surface treatments have long been used in the Southern States to change loose sandy and dusty materials into firm, stable, durable road surfaces. Prevention of evaporation accounts for at least part of this benefit.[37]

LOW-COST ALL-WEATHER ROADS REQUIRED IN HIGHWAY PROGRAM

Only a small percentage of natural soils are of good quality for road surfacing. Even in Georgia, where soil conditions are particularly favorable, soils of the best quality are more the exception than the rule. Of 29 sand-clay Federal-aid projects reported by Dr. Strahan, but 3 had strong, hard surfaces, free from ruts, holes, or corrugations, indicative of class A material. Admixtures and chemical treatments are most often used to give low-grade materials those qualities naturally present in class A topsoils as a result of long cultivation and weathering and in well-graded gravels as a result of their composition. The admixtures and treatments have the additional advantage that they avoid the necessity of a dust-producing mulch surface.

Substantial progress has been made in the design of soil mixtures, and in the use of bituminous surface treatments and stabilization of the moisture content by means of treatment with deliquescent substances.

The tentative requirements for the design of stable mixtures given on page 277 are based upon extensive laboratory experiments, and observations of roads in service and represent a step toward the simplification of test procedure for identifying road soils for use in construction.

Selected soil surfaces are suitable for temporary surfacing on important roads. They can be placed immediately after the grading for use during the period of settlement and will give substantial support and increased life to pavements placed upon them.

FIGURE 14.—A TYPICAL MINNESOTA GUMBO ROAD IN EARLY SPRING AND A ROAD ON SAME TYPE OF SOIL AFTER BEING TREATED WITH BITUMINOUS MATERIAL AND COVERED WITH A THIN LAYER OF GRAVEL.

The method of stabilization by densification at optimum moisture content has been utilized principally in connection with the construction of embankments for use as earth dams, although it is equally applicable for use in any kind of fill, subgrade or soil base-course construction.

Water attracted by the adsorptive affinity of soil particles for moisture cannot enter and soften the soil mass when the particles are covered with moisture films and the soil is compacted to maximum density at optimum moisture content. Under these conditions the tendency to expand and lose stability in the presence of moisture may be eliminated from highly plastic soils when protected by surface treatment. Densification will not be effective with soils in which the tendency to expand is due to elastic rebound such as those containing mica.

Field experimentation in the use of chemical admixtures which change the character of the soil include the use of portland cement, bituminous emulsions, and treatment with sodium silicate and calcium chloride in combination to produce calcium silicate precipitate.

Several sections of soil road stabilized with cement and given a bituminous surface treatment were constructed by the South Carolina State Highway Department during 1934. A bituminous emulsion was mixed with the soil in constructing an airport runway in Baltimore, Md. The use of the silicate-chloride method of treatment has been confined largely to the

[36] Blotter Treatment of Gravel Roads in the State of Minnesota, by F. C. Lang, Eighth Annual Asphalt Paving Conference, 1929.

[37] Tar Surface Treatment of Low Cost Roads, Public Roads, vol. 14, no. 1, March 1933.

stabilization of soil supporting buildings and other structures.

The stability furnished by compaction of soils at optimum moisture content suggests that vastly greater benefits may be expected when the interfacial colloidal films are stabilized by proper use of bitumen, portland cement, and the ions of sodium, potassium, and calcium.

New developments can be expected as progress is made in this vast and but little-explored field. The materials being investigated are low in cost and widely different in character. They are subjected to varying weather conditions and traffic loads. The results obtained should be evaluated on the basis of the benefit rendered by the stabilizing procedure in comparison with its cost.

More than 2,000,000 miles of rural roads are unimproved. On much of this mileage surfacing is not economically justified, but there is a considerable mileage which should be surfaced and the extent to which this is done will depend on the cost.

PUBLICATION ON TREE WOUNDS

Questions concerning the proper treatment of wounds in roadside, shade, ornamental, street, and park trees are considered in Farmers' Bulletin No. 1726 of the United States Department of Agriculture. The publication is intended primarily for persons in charge of public or private property with little or no knowledge concerning the normal processes of a healthy tree or why and how wounds endanger the health of trees.

The simpler types of treatment for tree wounds, the bulletin explains, are within the range of almost any practical man who is familiar with the use of a saw, gouge, mallet, and paintbrush. Two axioms that should be borne in mind constantly are (1) that proper treatment of fresh-made wounds is the surest and best method of preventing disease or decay and needless expense in the future, and (2) that all old wounds should be treated by some proper method. The practice of treating tree wounds is very old and, according to the bulletin, it is not a secret art, probably all of the best methods are well known.

The structure and life processes of trees are described and causes of injury discussed. What trees are worth treating, when the work may be done, and detailed methods are discussed. Numerous illustrations show the recommended methods of wound treatment.

Copies of this publication on tree wounds may be obtained free of charge from the Office of Information, United States Department of Agriculture, Washington, D. C., until the free supply is exhausted, or copies may be obtained for 5 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JANUARY 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$3,947,753	$2,129,921	$5,225,767	$2,835,989	$35,889	294.6	$2,326,458	$976,738	$534,211	133.6	$58,042	$573,840	31.8	$76,984	$985,981
Arizona	3,878,555	1,338,712	4,346,144	3,697,024	49,025	290.8	975,791	157,724	789,185	68.2	4,655	116,880	15.7	19,152	383,622
Arkansas	3,334,167	1,714,000	2,891,476	2,306,771	137,101	152.0	1,301,464	881,319	194,072	36.0	39,563	844,227	47.8	106,514	538,600
California	7,912,928	3,713,643	9,080,780	6,828,601		277.2	3,177,682	1,076,204	881,600	51.6		941,950	39.5	8,123	1,890,093
Colorado	3,437,265	2,424,504	3,800,099	3,366,958	350,780	174.5	1,684,744	16,425	1,649,339	84.8	53,882	92,549	11.8		331,836
Connecticut	1,404,213	607,500	620,538	618,204		10.7	1,501,976	786,009	453,399	25.4		154,100	1.8		1
Delaware	892,544	461,697	877,890	873,987		33.4	465,318		450,140	15.4				18,557	11,557
Florida	2,519,011	1,116,600	2,845,504	2,091,539		103.4	742,834	350,264	273,046	27.4	3,231	511,958	21.0	73,977	331,595
Georgia	5,045,592	2,556,745	3,641,356	3,452,584		252.7	1,528,756	1,246,635	282,121	76.7	211,955	1,040,306	57.5	134,418	1,234,318
Idaho	2,166,858	1,131,910	2,152,272	1,984,973	97,326	184.1	533,694	171,151	350,349	28.1		81,272	13.3	10,734	602,964
Illinois	4,442,467	3,060,041	1,777,709	1,767,055		32.2	3,040,703	2,615,136	425,567	39.0	36,045	823,818	18.5	24,232	1,810,655
Indiana	5,018,921	2,843,478	3,066,653	3,052,979		102.7	1,916,356	1,915,616		38.0	50,326	939,387	117.8		1,904,091
Iowa	5,027,830	2,217,361	4,854,228	4,611,845	42,120	277.4	1,789,712	380,600	1,314,277	122.8		546,418	24.6	35,386	314,546
Kansas	5,044,802	2,558,837	5,306,941	4,936,822	162,941	536.9	1,425,666	56,400	1,369,266	151.9		1,021,307	66.6	51,580	5,324
Kentucky	3,751,605	1,527,324	3,626,938	3,358,981	33,571	243.9	606,582	260,655	293,774	49.7	109,476	355,126	37.3	22,493	844,853
Louisiana	2,711,152	1,380,419	1,756,275	1,752,495		73.9	1,833,571	905,474	406,070	11.9	44,383	674,906	11.9	8,800	299,442
Maine	1,617,560	793,644	1,352,859	1,317,292		43.8	805,536	239,455	566,081	13.5		197,402	6.8	60,813	30,161
Maryland	1,782,263	289,609	791,624	778,132	3,843	15.1	886,878	771,460	115,418	20.0	39,135	97,729	1.7	193,536	72,620
Massachusetts	1,101,716	1,632,874	1,409,030	1,016,079		37.4	493,554	52,687	389,045	9.2		433,106	3.3	32,950	810,723
Michigan	6,051,532	3,226,284	4,772,814	4,696,316		223.4	2,712,925	1,348,200	1,349,925	101.5		1,584,925	60.2	7,016	291,434
Minnesota	4,561,011	2,642,244	5,606,216	4,331,330	1,180,063	850.0	921,564	179,056	677,108	144.8		317,832	42.8	50,625	467,240
Mississippi	3,489,337	2,301,148	3,991,149	2,186,609		204.6	2,467,179	1,134,596	414,197	135.0	19,165	787,369	39.2	148,966	1,099,582
Missouri	5,237,532	2,132,426	4,652,876	4,118,028		187.9	2,170,258	813,729	1,058,737	68.7	293,639	765,427	20.7	12,136	308,262
Montana	4,463,849	2,714,208	5,266,931	4,435,113	190,457	394.7	1,652,792	4,129	1,579,705	189.2		805,333	47.0	24,607	138,713
Nebraska	3,914,481	1,982,182	5,112,823	3,892,837	42,406	371.7	1,298,005	21,644	953,818	58.3		949,886	51.4		36,071
Nevada	2,909,387	1,350,356	2,861,718	2,736,177	76,039	268.7	733,660	91,948	641,712	100.9	34,558	14,755	2.6	46,704	617,850
New Hampshire	725,739	484,731	638,684	612,389		10.8	425,572	79,730	324,780	11.2		133,511	1.3	33,620	26,440
New Jersey	3,173,019	951,379	1,711,841	1,692,308		31.6	1,488,098	1,296,101	24,919	15.4	175,941	103,000	2.6	8,669	823,461
New Mexico	2,846,648	1,676,769	3,029,320	2,760,948	124,443	297.5	1,078,627	17,929	1,060,698	91.6	67,771		5.0		491,628
New York	10,465,672	3,521,450	10,197,935	8,416,188	53,000	210.3	7,632,928	2,010,070	2,391,600	134.8		277,850	8.9	39,414	799,000
North Carolina	4,761,147	2,040,068	4,388,332	3,558,353	104,959	576.4	1,333,818	646,965	319,554	124.3	253,983	264,479	49.4	301,846	1,351,077
North Dakota	2,902,224	1,469,484	3,133,056	2,665,441	39,051	1007.7	329,512	53,772	215,946	117.4	40,312	476,769	264.2	142,700	737,716
Ohio	7,277,758	3,539,256	7,482,755	7,061,148		193.2	1,570,870	18,020	1,360,460	39.6		1,700,051	27.0	198,589	478,744
Oklahoma	4,608,399	2,342,590	3,659,685	3,581,276		272.9	1,541,939	758,239	754,977	69.4	258,976	1,037,521	54.9	9,908	550,092
Oregon	3,053,448	1,452,741	3,334,673	3,017,287		183.0	1,146,893	13,619	1,076,274	48.8		84,352	8.2	22,542	292,115
Pennsylvania	6,691,194	4,554,082	5,533,040	5,339,313	17,389	120.0	3,910,648	1,250,052	2,465,401	67.4	17,361	1,797,852	33.7	84,468	273,441
Rhode Island	979,367	464,572	969,058	903,567		20.5	494,172	46,205	405,569	10.8		33,755	3.5	29,596	25,248
South Carolina	2,729,583	1,385,477	1,994,909	1,990,668		168.4	1,054,855	671,572	366,849	97.7	20,920	56,214	1.3	46,423	962,413
South Dakota	3,005,739	1,523,821	2,814,888	2,305,738	20,017	440.6	698,768	580,520	106,594	183.3	92,267	931,740	150.1	27,213	465,471
Tennessee	4,246,309	2,105,453	4,010,320	3,388,831		171.0	1,256,704	689,207	471,096	28.1	146,355	827,297	33.7	21,916	807,060
Texas	11,588,643	6,858,253	11,184,806	10,709,724		972.5	3,157,663	811,259	2,309,404	248.7	52,785	923,283	73.8	14,874	3,625,566
Utah	2,367,205	1,066,345	2,757,590	2,279,074	365,500	237.8	695,401	84,632	410,100	57.9		82,373	3.9	3,499	208,373
Vermont	928,184	466,042	973,160	912,749	28,464	47.9	277,219	10,670	249,114	13.9		142,265	5.3	4,766	46,199
Virginia	3,708,379	1,882,693	3,561,573	3,347,008		143.7	1,028,959	76,416	890,514	49.9	107,130	617,288	32.2	177,825	374,892
Washington	3,057,934	1,553,206	2,594,663	2,578,369		95.6	1,259,658	434,929	784,260	28.1	30,664	151,075	4.5	13,972	617,871
West Virginia	2,013,405	1,140,167	1,947,968	1,876,440	60,892	71.2	543,180	111,669	414,619	20.0		287,325	9.2	25,296	377,331
Wisconsin	4,697,518	1,865,947	4,441,736	4,321,782	3,324	213.1	802,396	239,441	457,852	42.8	50,000	663,176	26.2	86,294	741,595
Wyoming	2,250,663	1,692,907	2,290,223	2,025,440	67,583	469.8	1,107,512	209,202	872,144	132.2		499,822	100.4	16,020	253,358
District of Columbia															
Hawaii	1,683,956	598,778	353,056	253,748		12.4	1,826,261	1,428,169		27.2				2,040	598,778
TOTALS	185,426,464	94,483,878	174,691,881	152,642,509	3,286,183	11,605.6	73,655,311	27,991,642	35,144,886	3,462.1	2,312,520	25,762,806	1,691.9	2,479,793	30,290,003

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JANUARY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,054,361	$ 1,094,208	$ 1,094,205		30.6	$ 1,212,243	$ 1,139,050	$ 73,193	35.2		$ 65,845	1.9	$ 156,670	$ 925,922
Arizona	807,982	305,191	624,318	616,215	$ 6,592	12.3	20,819	500	15,124	.7	$ 149,322	15,894	1.1	41,946	267,582
Arkansas	1,964,534	857,025	1,380,209	1,280,982		39.5	555,758	555,431		5.5	101,076	117,754	4.6	27,045	739,271
California	4,213,986	2,219,360	3,901,155	3,402,117		46.7	1,332,468	789,009	301,900	10.3		320,632	6.8	22,859	1,596,828
Colorado	1,718,633	190,000	1,769,448	1,704,869	13,406	35.9	5,716		5,716	1.2		170,878	2.0	13,764	
Connecticut	802,407	426,500	802,159	798,075		10.2	144,632		144,632	1.2				4,332	281,867
Delaware	477,680	230,849	474,326	466,045		7.4	54,180		54,180	.7	4,323		.7	7,313	176,669
Florida	1,410,008	501,200	1,244,727	1,004,216		13.2	470,605	399,716	70,889	7.4		24,263	.6	6,075	406,048
Georgia	2,724,620	1,278,373	1,335,128	1,333,015		57.2	897,741	894,100	3,641	14.4	286,820	148,880	10.7	210,684	1,125,852
Idaho	1,197,829	321,126	1,159,884	1,121,373	2,643	19.4	67,654	45,372	22,282	1.4		2,156	.1	31,084	294,045
Illinois	7,476,075	2,515,835	5,819,861	5,730,675		62.9	1,777,874	1,681,538	96,336	9.1	57,163	771,430	6.7	6,698	1,648,069
Indiana	4,287,050	2,035,585	2,853,955	2,825,775		61.3	1,216,466	1,216,316		10.1	216,396	233,401	6.5	28,563	1,802,184
Iowa	2,614,472	1,311,000	1,935,688	1,839,364	6,655	53.3	727,154	629,108	63,367	9.2	146,000	415,285	10.3		825,693
Kansas	2,522,401	1,279,419	2,105,658	2,085,677	2,443	38.6	871,787	410,998	315,936	5.7	25,726	961,040	10.4		
Kentucky	1,927,828	954,578	1,352,542	1,332,461		30.8	589,028	495,167	89,533	4.1	94,506	240,182	5.9	5,695	624,863
Louisiana	1,718,577	744,560	671,616	670,482		17.6	902,654	853,474	20,000	10.3	181,597	317,818	9.5	13,024	406,742
Maine	909,878	490,045	821,221	815,428		16.4	38,605	38,605		.4		111,539	.8	55,845	378,506
Maryland	891,132	452,515	388,284	384,134		4.1	911,650	98,129		.4	54,838		.2	354,031	452,515
Massachusetts	5,007,199	847,600	1,915,107	1,873,562		12.3	3,073,328	2,996,104	52,248	5.4		196,438	1.3	137,533	598,913
Michigan	3,500,638	1,613,142	3,198,155	3,070,806	101,950	39.0	1,356,500	412,750	931,250	8.8	14,950	370,850	9.8	2,131	209,092
Minnesota	3,719,143	1,421,494	3,243,807	3,018,187	194,608	108.5	368,938	155,856	204,882	10.7		32,618	4.7	545,100	989,386
Mississippi	1,744,669	885,056	564,834	552,374		20.0	716,195	653,171	63,024	23.6	314,318	69,289	8.9	224,807	752,743
Missouri	4,019,501	1,617,451	2,124,406	2,054,266		48.7	1,981,693	1,834,510	101,345	12.4	53,877	86,105	2.3	76,848	1,430,001
Montana	1,115,962	113,092	1,059,272	1,056,876		32.4	65,264	34,716	5,994	4.5	8,796	33,230	3.2	15,574	73,868
Nebraska	1,957,240	991,091	2,072,077	1,953,553	104,535	35.7	247,684		247,684	3.5		508,365	10.5	3,687	130,508
Nevada	500,051	100,000	502,397	483,944		8.8	65,438	16,107	49,331	1.5		1,000			49,668
New Hampshire	706,640	242,366	726,187	668,776	54,054	15.9	131,823		131,613	3.0				37,864	56,699
New Jersey	3,117,921	1,809,500	2,383,244	2,284,751		20.0	1,293,051	813,546	334,714	6.6		81,070	.4	19,625	1,393,716
New Mexico	1,674,158	529,506	1,379,467	1,379,467		31.3	373,264	193,167	180,097	8.9		69,432	1.7	101,524	279,977
New York	8,255,661	3,940,621	6,247,552	5,890,351		53.2	4,170,403	2,296,556	1,708,900	23.5		782,000	5.6	68,753	1,449,721
North Carolina	2,380,573	1,210,236	1,949,871	1,920,950	26,797	73.9	347,120	270,214	33,338	8.5	161,387	199,017	6.5	28,022	951,084
North Dakota	1,451,112	734,742	1,028,561	1,024,706		43.4	197,078	121,828	75,250	7.2	277,222	90,732	20.3	27,356	568,760
Ohio	4,335,686	2,359,503	4,561,839	4,047,107	15,000	57.8	446,280	226,500	219,780	5.3		1,015,240	13.9	62,079	1,109,484
Oklahoma	2,304,200	1,171,295	1,753,096	1,723,984		38.3	635,412	535,691	95,756	9.7	1,326	294,807	3.2	43,198	780,732
Oregon	1,526,724	867,977	1,495,885	1,472,859		27.8	112,979		112,979	1.6	47,611	217,689	7.3	6,254	537,309
Pennsylvania	4,854,988	2,397,703	3,449,546	3,248,347	66,031	54.7	1,838,894	1,512,490	244,527	15.8	32,000	1,457,065	15.0	62,151	630,079
Rhode Island	579,625	255,000	527,914	527,015		7.4	36,001		36,001	.6				52,609	218,999
South Carolina	1,364,791	692,738	862,541	861,123		28.9	387,514	383,370	4,144	14.9	42,750	17,957	.7	77,549	670,638
South Dakota	1,502,870	761,911	1,046,266	1,046,266		35.0	111,901	111,732	169	5.5	82,065	37,522	6.4	262,806	724,221
Tennessee	2,123,155	1,121,790	1,548,267	1,542,456		22.8	580,587	475,617	104,970	5.2	94,256	199,446	3.4	10,827	817,373
Texas	6,642,863	1,795,000	4,107,900	4,003,156		104.1	2,441,789	2,274,377	3,122	17.3	254,300	114,196	10.9	111,030	1,677,682
Utah	778,826	533,173	748,473	649,487	65,900	20.2	200,559	124,000	71,000	2.3	5,130	245,000	6.3	209	151,273
Vermont	500,509	240,611	461,194	441,585		12.9	112,923	58,924	47,000	2.4		78,000	1.1		115,611
Virginia	2,008,458	941,347	1,305,950	1,236,736	39,687	25.2	839,582	458,925	189,433	6.2	32,213	168,480	3.9	280,585	543,748
Washington	1,977,260	776,603	1,949,664	1,931,928		32.4	215,895		215,895	5.9	36,458	244,141	6.9	8,874	316,567
West Virginia	1,342,270	570,085	875,139	861,846	13,293	16.1	493,653	453,304	14,816	5.3		16,863	.6	27,120	525,113
Wisconsin	2,596,143	1,293,455	2,515,141	2,455,395	15,575	52.3	382,698	116,488	241,393	7.0		194,881	4.5	24,260	841,606
Wyoming	1,125,332	22,877	1,027,545	1,025,209		22.3	107,334	100,123	6,629	2.6		10,287	.7		5,961
District of Columbia	968,235	243,460	933,385	704,306	229,079	6.5	250,164	250,164		.2				13,766	14,381
Hawaii															
TOTALS	115,737,423	49,278,547	87,299,069	83,516,485	958,248	1,665.2	35,378,978	26,126,743	7,004,013	363.2	2,776,426	10,748,717	238.8	3,317,769	30,567,569

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JANUARY 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,032,452	$1,064,960	$697,830	$697,830		46.0	$1,442,743	$1,300,029	$142,714	109.3		$348,192	22.1	$34,593	$574,055
Arizona	525,423	998,032	530,237	517,610		42.3	306,633	7,813	260,093	21.5		81,538	8.7		656,401
Arkansas	1,449,634	857,024	925,387	923,201		124.8	518,293	447,626	70,182	40.4	$5,473	102,484	28.2	73,334	684,358
California	3,480,440	1,999,203	3,436,627	2,881,768		161.2	1,110,649	598,046	361,800	29.4		424,856	12.9	626	1,212,547
Colorado	1,718,632	871,502	1,721,308	1,608,632	$11,800	170.7	933,719	110,000	419,020	154.4		82,520	3.6		358,162
Connecticut	659,120	420,868					887,796	659,120	222,880	19.0		11,129	.4		186,859
Delaware	448,864	230,849	285,891	218,551	63,291	24.1	390,690	228,623	127,893	35.6				1,690	39,665
Florida	1,302,815	1,043,543	1,280,232	1,274,186		77.5	358,943		358,943	21.0		73,559	1.9	28,630	611,041
Georgia	2,320,973	1,278,373	1,159,297	1,158,044		81.2	932,462	923,310	9,152	72.2	79,928	183,703	10.8	159,691	1,085,519
Idaho	1,121,562	824,450	1,307,631	1,118,961	60,449	156.5	382,738		377,447	42.5		51,700	6.8	2,601	334,854
Illinois	5,652,228	3,345,525	1,901,589	1,888,614		119.0	4,567,887	3,648,860	919,027	258.6	99,933	2,288,358	102.7	14,821	138,140
Indiana	731,872	209,900	404,572	404,572		44.2	272,102	272,102		40.7	48,450	16,356	3.5	6,749	193,544
Iowa	2,413,358	1,590,000	2,064,021	1,932,895	67,450	295.1	1,129,334	424,850	550,100	192.2		724,150	167.7	55,613	248,300
Kansas	2,522,401	1,279,419	1,945,421	1,876,032	65,467	202.0	1,172,290	637,717	534,573	72.8	8,652	679,379	42.2		
Kentucky	1,837,926	1,336,409	1,802,617	1,724,078	16,263	210.0	712,944	85,833	606,379	74.5	21,369	279,000	51.1	6,645	434,767
Louisiana	1,398,862	838,953	950,765	949,942		45.1	326,143	323,941		14.3	123,793	334,474	24.5	1,185	504,479
Maine	842,479	427,897	1,060,215	835,952	146,555	90.4	282,470	5,000	256,412	21.4		16,526	.7	1,527	8,404
Maryland	891,132	1,067,934	661,949	640,929		49.8	447,351	224,250	223,101	25.5	20,419	413,720	12.1	5,534	431,113
Massachusetts	488,185	870,000	469,741	469,741		15.2						49,403	2.0	18,444	820,597
Michigan	3,184,057	1,613,142	2,867,212	2,837,586	16,400	205.6	1,032,877	341,727	676,250	41.1		447,450	27.6	4,744	473,042
Minnesota	2,376,415	1,361,813	2,314,276	2,218,135	63,116	242.8	789,631	141,133	503,698	98.5		479,720	50.3	17,148	315,279
Mississippi	1,744,669	354,023	693,388	693,388		86.2	767,895	767,895		61.7	187,185		12.8	96,201	354,023
Missouri	2,923,273	2,423,863	2,848,374	2,667,484	106,368	584.5	699,562	158,005	496,304	177.3	77,547	594,427	84.2	20,238	1,226,765
Montana	1,859,937	942,434	1,814,177	1,813,058		226.0	216,652		216,652	12.8		343,679	35.2	46,879	382,103
Nebraska	1,957,240	991,091	2,078,186	1,956,356	118,655	339.8	470,756		470,756	93.9		321,529	55.3	884	80,151
Nevada	1,136,479	852,000	1,232,741	1,112,162	75,272	140.1	281,012		281,012	25.9		20,000	10.0	24,317	475,716
New Hampshire	477,460	242,365	521,263	476,963		25.6	85,607		82,590	4.6		57,479	3.4	497	102,296
New Jersey	55,099	460,000	56,528	55,099		.5									460,000
New Mexico	1,272,129	735,425	1,226,434	1,226,434		207.4	357,791	35,000	322,791	52.2	10,695	194,235	15.9		218,399
New York	3,608,768	3,865,850	3,320,536	2,957,818	28,200	83.8	3,709,270	625,700	2,284,350	165.6		1,247,368	120.9	25,250	305,932
North Carolina	2,380,573	1,590,637	2,006,317	2,005,539		212.4	979,356	364,701	608,564	102.4		391,717	36.7	10,333	590,355
North Dakota	1,451,112	734,741	895,842	895,842		283.1	274,969	274,969		70.3	220,451	189,033	118.9	59,850	545,709
Ohio	3,871,148	1,966,253	4,055,935	3,767,315	2,100	297.9	515,010	73,810	439,200	78.1		384,170	22.4	30,023	1,140,783
Oklahoma	2,304,199	1,171,295	1,580,960	1,493,471		206.0	1,186,172	780,467	304,896	76.8	28,270	447,179	29.2	1,991	419,219
Oregon	1,526,724	777,096	1,709,157	1,507,198	23,904	112.0	452,348	19,526	392,441	35.3		233,254	16.7		127,497
Pennsylvania	7,344,822	2,639,003	6,397,236	6,177,827	81,002	542.8	2,843,900	1,162,995	1,646,825	204.8	4,000	686,002	18.0		225,174
Rhode Island	439,716	295,000	414,250	404,768		33.2	39,789		39,789	1.0		222,350	5.6	34,948	32,860
South Carolina	1,364,791	692,739	1,116,509	1,060,256	56,253	119.6	647,405	255,654	370,646	89.0		265,840	33.3	48,882	
South Dakota	1,502,870	761,911	1,164,126	1,115,952	48,151	330.1	331,687	331,687		97.1	55,231	94,193	52.5		619,567
Tennessee	2,123,155	1,075,748	1,241,068	1,210,241		102.6	1,122,787	834,756	288,031	61.9	4,503	149,662	4.9	73,654	638,055
Texas	6,012,518	3,638,000	5,876,171	5,450,782		750.6	1,392,548	500,417	840,893	71.6	43,305	235,713	38.0	18,014	2,561,394
Utah	1,048,677	533,173	1,185,881	955,732	114,800	185.6	238,999	92,945	108,000	40.4		185,373	32.4		125,000
Vermont	438,880	241,354	473,091	437,162	16,569	37.2	118,931		113,646	8.4		94,956	7.0	1,718	16,183
Virginia	1,699,920	941,347	1,602,318	1,533,987	8,753	210.4	269,543	107,265	151,095	13.5	21,527	252,555	22.9	37,141	528,943
Washington	1,080,673	776,603	990,303	969,480		62.6	430,041	103,666	326,375	37.0		234,253	11.2	7,526	215,976
West Virginia	1,118,559	570,083	733,349	701,137		41.9	359,084	359,084		15.1	25,237	178,802	5.5	33,101	391,281
Wisconsin	2,431,220	1,782,435	2,323,522	2,156,632	48,583	170.4	491,465	202,460	232,848	14.5	68,000	303,365	24.7	4,128	1,197,638
Wyoming	1,125,332	571,928	1,077,254	1,058,834		148.5	90,037		90,035	12.3	30,935	224,994	37.4	35,563	256,899
District of Columbia	950,234	730,382	1,071,502	931,582	139,920	8.7	234,139		234,139	2.6		147,150	1.6	18,651	209,173
Hawaii	187,106	351,000	177,718	177,718		4.9								9,388	351,000
TOTALS	92,836,113	56,237,575	77,670,954	73,147,476	1,379,321	7,957.9	36,604,450	17,430,982	16,961,542	3,011.0	1,184,903	14,787,495	1436.4	1,072,752	23,109,217

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF JANUARY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 7,017,804	$ 4,628,027	$ 35,889	371.2	$ 4,981,444	$ 3,415,817	$ 750,118	278.1	$ 58,042	$ 987,877	55.8	$ 268,247	$ 2,485,958
Arizona	5,211,960	2,641,935	5,500,699	4,830,848	55,617	345.3	1,303,243	166,037	1,064,402	90.4	153,977	214,311	25.5	61,098	1,307,605
Arkansas	6,748,335	3,428,049	5,197,072	4,510,954	137,101	316.3	2,375,515	1,884,376	264,254	81.9	146,112	1,064,465	80.6	206,893	1,962,229
California	15,607,354	7,932,206	16,418,562	13,112,487		485.2	5,620,799	2,463,259	1,545,300	91.3		1,687,438	59.2	31,608	4,699,468
Colorado	6,874,530	3,486,006	7,290,855	6,680,459	375,986	381.1	2,624,179	126,425	2,074,075	240.4	53,881	345,947	17.4	13,764	689,998
Connecticut	2,865,740	1,454,868	1,422,697	1,416,280		21.0	2,534,404	1,445,129	820,911	45.7		165,229	2.2	4,332	468,727
Delaware	1,819,088	923,395	1,638,107	1,558,582	63,291	64.9	910,188	228,623	632,213	51.6	4,323		.7	27,560	227,891
Florida	5,231,834	2,661,343	5,370,464	4,369,941		194.1	1,572,382	749,980	702,878	55.8	3,231	609,780	23.5	108,682	1,348,684
Georgia	10,091,185	5,113,491	6,135,781	5,943,644		391.2	3,358,958	3,064,045	294,913	163.3	578,703	1,372,889	79.1	504,793	3,445,689
Idaho	4,486,249	2,277,486	4,619,786	4,225,307	160,418	360.1	984,086	216,522	750,078	72.0		135,128	20.2	44,419	1,231,863
Illinois	17,570,770	8,921,401	9,499,158	9,386,344		214.2	9,386,465	7,945,535	1,440,930	306.7	193,141	3,883,606	127.8	45,751	3,596,864
Indiana	10,037,843	5,088,963	6,325,180	6,283,326		208.3	3,404,924	3,404,034		88.8	315,171	1,189,144	127.8	35,312	3,899,819
Iowa	10,055,660	5,118,361	8,853,937	8,384,103	116,225	625.8	3,646,200	1,434,558	1,927,743	324.3	146,000	1,685,853	202.6	90,999	1,388,539
Kansas	10,089,604	5,117,675	9,358,020	8,898,530	230,850	777.5	3,469,744	1,105,115	2,219,775	230.4	34,379	2,661,726	119.3	51,580	5,324
Kentucky	7,517,359	3,818,311	6,782,097	6,415,520	49,834	484.7	1,908,553	841,654	989,686	128.3	225,352	874,308	94.3	34,833	1,904,483
Louisiana	5,828,591	2,963,932	3,378,656	3,372,920		136.6	3,062,369	2,082,889	426,070	36.4	349,773	1,327,199	45.8	23,009	1,210,663
Maine	3,369,917	1,711,586	3,234,295	2,968,672	146,555	150.5	1,126,612	283,061	822,493	35.2		325,467	8.3	118,185	417,071
Maryland	3,564,527	1,810,058	1,841,856	1,803,195	3,843	69.0	2,245,878	1,093,839	338,518	45.9	114,392	511,450	14.0	553,101	956,248
Massachusetts	6,597,100	3,350,474	3,793,878	3,359,383		65.0	3,566,882	3,048,791	441,294	14.6		678,947	6.5	188,927	2,230,233
Michigan	12,736,227	6,452,568	10,838,181	10,604,709	118,350	468.0	5,102,302	2,102,677	2,957,425	151.4	14,950	2,403,225	97.6	13,891	973,568
Minnesota	10,656,569	5,425,551	11,164,300	9,567,651	1,437,787	1201.2	2,080,134	476,045	1,385,689	253.9		830,170	97.8	612,873	1,771,905
Mississippi	6,978,675	3,540,227	5,249,371	3,432,371		310.8	3,951,269	2,555,662	477,221	220.3	520,668	856,658	60.9	469,974	2,206,348
Missouri	12,180,306	6,173,740	9,625,656	8,839,778	106,368	821.1	4,851,513	2,806,243	1,656,386	258.3	425,062	1,445,958	107.2	109,222	2,965,028
Montana	7,439,748	3,769,734	8,140,380	7,305,046	190,457	653.0	1,934,707	38,846	1,802,351	206.4	8,796	1,182,242	85.4	87,060	594,684
Nebraska	7,828,961	3,964,364	9,263,087	7,802,747	265,595	747.1	2,016,446	21,644	1,672,259	155.7		1,779,780	117.2	4,571	246,730
Nevada	4,545,917	2,302,356	4,596,856	4,332,283	151,311	417.6	1,080,110	108,055	972,055	128.3	34,558	35,755	12.6	71,021	1,143,234
New Hampshire	1,909,839	969,462	1,886,134	1,758,128	54,054	52.4	643,002	79,730	538,983	18.8		190,991	4.7	71,981	185,435
New Jersey	6,346,039	3,220,879	4,151,613	4,032,158		52.1	2,781,150	2,109,646	359,633	22.0	175,941	184,069	3.0	28,294	2,677,177
New Mexico	5,792,935	2,941,700	5,635,221	5,366,849	124,443	536.2	1,809,683	246,096	1,563,586	152.7	78,466	263,667	22.5	101,524	990,004
New York	22,330,101	11,327,921	19,766,023	17,264,358	81,200	347.3	15,512,601	4,932,326	6,384,850	323.9		2,307,218	135.5	133,417	2,554,653
North Carolina	9,522,293	4,840,941	8,344,520	7,484,842	131,756	862.7	2,660,293	1,281,880	961,456	235.2	415,370	855,213	92.5	340,201	2,892,516
North Dakota	5,804,448	2,938,967	5,057,459	4,585,989	39,051	1334.2	801,559	450,569	291,196	194.9	537,985	756,534	403.4	229,906	1,852,185
Ohio	15,484,592	7,865,012	16,100,528	14,875,571	17,100	548.9	2,532,160	318,330	2,019,440	123.1		3,099,461	63.2	290,691	2,729,011
Oklahoma	9,216,798	4,685,180	6,993,741	6,798,731		517.1	3,363,522	2,074,397	1,155,630	156.0	288,573	1,779,507	87.4	55,097	1,750,043
Oregon	6,106,896	3,097,814	6,539,716	5,997,344	23,904	322.8	1,712,221	33,145	1,581,694	85.7	47,611	535,295	32.2	28,796	956,921
Pennsylvania	18,891,004	9,590,788	15,379,822	14,765,488	164,423	717.4	8,593,441	3,925,537	4,356,754	288.0	53,361	3,940,918	66.7	146,619	1,128,694
Rhode Island	1,998,708	1,014,572	1,911,223	1,835,350		61.1	569,962	46,205	481,359	12.5		256,106	9.2	117,153	277,107
South Carolina	5,459,165	2,770,954	3,973,959	3,912,046	56,253	316.9	2,089,774	1,310,595	741,639	201.6	63,669	340,010	35.3	172,854	1,633,051
South Dakota	6,011,479	3,047,643	5,025,280	4,467,956	68,168	805.7	1,142,356	1,023,940	106,762	285.9	229,564	1,063,454	209.1	290,019	1,809,259
Tennessee	8,492,619	4,302,991	6,799,655	6,141,528		296.4	2,960,078	1,999,580	864,098	95.2	245,114	1,176,406	42.0	106,397	2,262,488
Texas	24,244,024	12,291,253	21,168,878	20,163,662		1827.2	6,991,999	3,586,052	3,153,418	337.7	350,391	1,273,192	122.6	143,918	7,864,642
Utah	4,194,708	2,132,691	4,691,944	3,884,292	546,200	443.6	1,134,959	301,577	589,100	100.6	5,130	512,746	42.6	3,708	484,646
Vermont	1,867,573	948,007	1,907,445	1,791,495	45,033	98.0	509,072	69,594	409,760	24.7		315,221	13.4	6,484	177,993
Virginia	7,416,757	3,765,387	6,469,841	6,117,731	48,440	379.2	2,138,084	642,605	1,231,042	69.6	160,869	1,038,323	59.0	495,551	1,447,583
Washington	6,115,867	3,106,412	5,534,631	5,479,778		190.6	1,905,594	538,595	1,326,530	71.0	67,122	629,468	22.6	30,372	1,150,414
West Virginia	4,474,234	2,280,335	3,556,455	3,439,422	74,185	129.2	1,395,917	924,058	429,435	40.4	25,237	482,990	15.3	85,517	1,293,725
Wisconsin	9,724,881	4,941,837	9,280,399	8,933,809	67,483	435.8	1,676,559	558,390	932,092	64.4	118,000	1,161,423	55.4	114,682	2,780,839
Wyoming	4,501,327	2,287,712	4,395,022	4,109,483	67,583	640.6	1,304,883	309,326	968,808	147.0	30,935	735,104	138.6	51,583	516,218
District of Columbia	1,918,469	973,842	2,004,887	1,635,888	368,999	15.2	484,303	250,164	234,139	2.8		147,150	1.6	32,417	223,554
Hawaii	1,871,062	949,778	530,773	431,465		17.3	1,826,261	1,428,169		27.2				11,428	949,778
TOTALS	394,000,000	200,000,000	339,661,904	309,306,470	5,623,752	21,228.7	145,638,739	71,549,367	59,110,441	6,836.3	6,273,849	51,299,018	3,367.1	6,870,314	83,966,789