PUBLIC ROADS

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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A BITUMINOUS SURFACE TREATMENT OF A LIME ROCK ROAD IN FLORIDA

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AN INVESTIGATION OF OIL-TREATED EARTH ROADS IN MISSOURI

Reported by F. V. REAGEL, Engineer of Materials, Missouri State Highway Department, HENRY AARON, Assistant Highway Engineer, U. S. Bureau of Public Roads, and W. I. WATKINS, Assistant Soil Surveyor, U. S. Bureau of Chemistry and Soils

THE best efforts of almost every State highway organization in the past have been devoted to the design and the construction of high-type roads to serve the demands of ever-increasing traffic on the more important routes of the respective States. The recognition of these demands for high-type roads caused the design of feeder roads connecting with the main highways to receive but little attention. In Missouri, as in several other States, the primary road system is approaching completion and the demand for the construction of secondary, light-traffic roads is rapidly increasing.

In anticipation of this demand for low-cost roads, the Missouri State Highway Department, in cooperation with the United States Bureau of Public Roads and the United States Bureau of Chemistry and Soils, has been investigating the practicability of oil-treated roads, with or without subsequent stages of improvement, for use in those sections, comprising approximately one-third of the total area of the State, where no surfacing material of any kind is locally available. The collecting and organization of the data and observations on application of the oil and the condition surveys on the sections studied and included in this report were carried out by R. C. Schappler and C. M. Lancaster, of the division of geology and soils of the Missouri State Highway Department.

The roads included in this investigation were oiled during the months of May to November, 1928, and the condition of the surface as disclosed by condition surveys was recorded at various times up to May, 1929. The first inspection of the surface condition was made about two and one-half months after the oil was applied. A fall condition survey was made during the months of September to December, 1928, about one and one-half months after the first inspection. On several of the sections treated in the fall, the first inspection after treatment served also as the fall condition survey. The final detailed condition survey included in this report was made the following spring during the period from March to May, 1929.

During the following two years the department's program included a considerable mileage of treating and retreating earth roads with road oil. This program provided an opportunity for demonstrating and establishing the indications and conclusions developed in this study with increasing confidence in the design and methods of road oil application. A supplementary condition survey was made in the spring of 1931.

The investigation has disclosed that oils may be used satisfactorily for the treatment of earth surfaces to provide temporary all-weather roads if certain fundamental factors are recognized. The most important factors so far discovered are: (1) Physical characteristics of the soil; (2) drainage, both surface and subsurface; (3) condition of surface immediately prior to application of oil; (4) rate of penetration of oil; (5) type of traffic; and (6) methods of maintenance.

CHARACTER OF ROAD SECTIONS INVESTIGATED

Prior to 1928, in those sections of Missouri which are deficient in local road-building materials, about 200 miles of road had been constructed, consisting of 9-foot concrete pavement on one-half of the roadway and graded earth on the other half. This type of improvement was utilized in order to hasten the connection of several communities by all-weather traffic lanes. The resulting roads furnished the service expected but with a serious dust hazard on some soils during dry periods and an expensive mud nuisance in wet weather. The graded portions of these roads were then oiled in an effort to alleviate these conditions. In addition, approximately 100 miles of full-width graded earth roads have been oiled. Twenty-nine sections of road, varying in length from 2 to 21 miles, with a total length of 224 miles, were selected for special study. The locations of these sections and their approximate lengths are given in Table 1.

The topography of the area studied varies from level to rolling. The extent of the rolling character controls the relative amount of cut and fill on the sections. This feature in turn governs the amount of variation in soils in cuts due to uncovering of different soil layers at varying depths, as well as the resultant character of soil occurring in the mixture from which the fills were made.

The roads selected for oil treatment were constructed according to standard design. Drainage as a whole had been taken care of. Occasional sections which, because of improper drainage, had not been maintained to the standards of the original construction, could be readily noted by observation.

Traffic on these highways is mixed and was classed as mutilative and nonmutilative. Mutilative traffic included tractors, threshing outfits, and other machinery, the wheels of which were equipped with lugs or cleats, and also horses hoofs' and wagons having narrow-tired wheels.

TABLE 1.—*Location and mileage of sections of oiled road given special study*

Section No.	Location	Approximate length
		Miles
1	State route 6, DeKalb County, Bayfield to Oak	8
2	State route 31, DeKalb County, King City to Oak	11
3	U. S. route 69, Daviess County, Cameron north	5
4	State route 6, Daviess County, Winston to Altamont	7
5	State route 6, Daviess County, Altamont to Gallatin	8
6	U. S. route 69, Harrison County, Bethany to Iowa line	21
7	State route 59, Platte County, Parkville north	8
8	State routes 1 and 9, Atchison County, Tarkio to Rockport	10
9	State route 1, Atchison County, Fairfax north	9
10	U. S. route 65, Saline County, Marshall to Salt Fork Creek	6
11	U. S. route 65, Saline County, Salt Fork Creek to Grand Pass	9
12	U. S. route 65, Saline County, Grand Pass west	2
13	U. S. route 24, Carroll County, near DeWitt	3
14	U. S. route 63, Randolph County, Jacksonville to Moberly	10
15	U. S. route 24, Randolph County, Huntsville west	9
16	State route 10, Ray County, Richmond to Hardin	8
17	U. S. route 71, Platte County	
18	U. S. route 71, Platte County	
19	U. S. route 71, Platte County	12
20	U. S. route 71, Platte County	
21	U. S. route 71, Platte County	
22	U. S. route 63, Macon County. Extends approximately 4 miles north from Axtell	4
23	U. S. route 63, Macon and Adair Counties	17
24	U. S. route 63, Adair County	3
25	U. S. route 65, Grundy and Livingston Counties, between Chillicothe and Trenton	8
26	State route 6, DeKalb County, Maysville to Oak	7
27	U. S. route 63, Boone County, Hinton to Clark	13
28	State route 13, Lafayette County, Higginsville to Lexington	10
29	State route 10, Ray County, Excelsior Springs to Richmond	16
	Total mileage	224

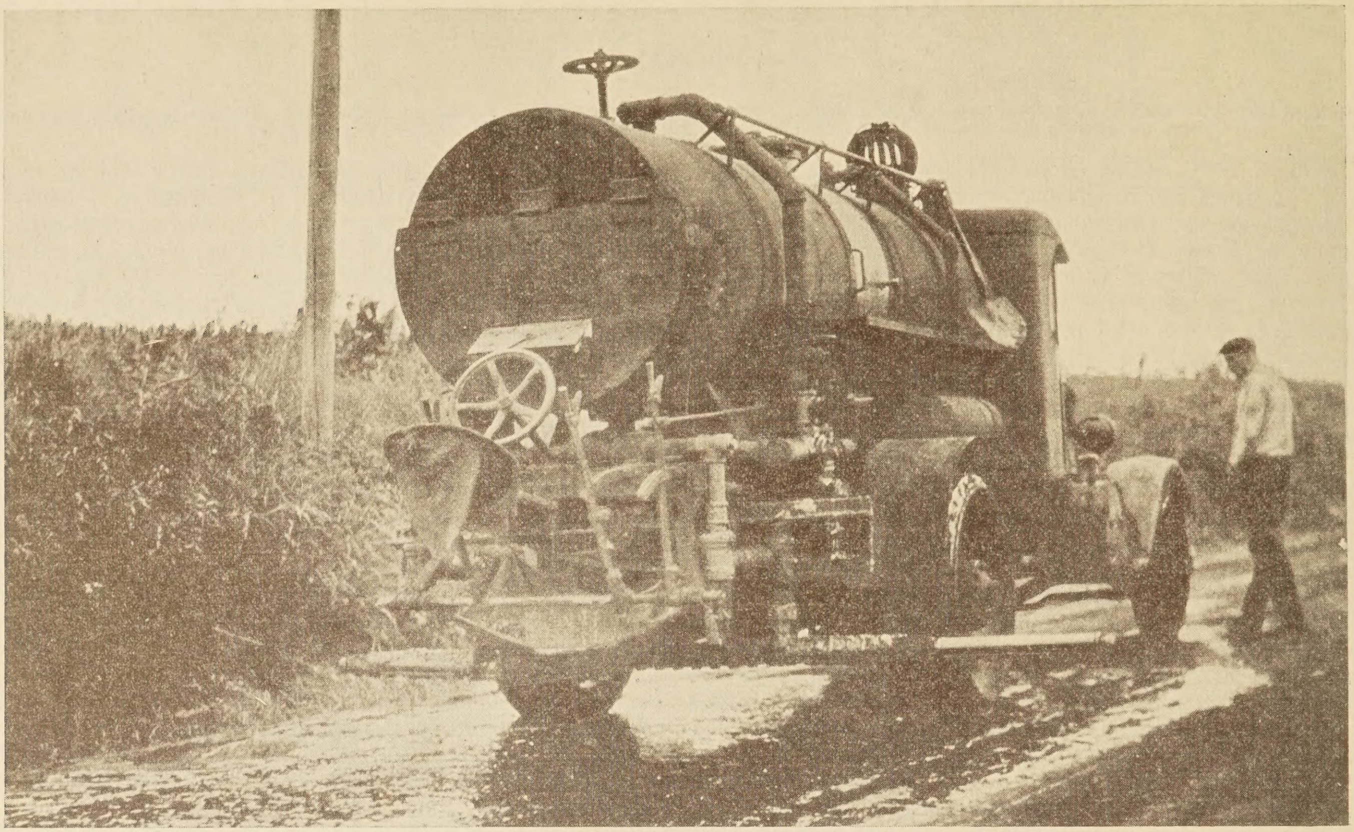


FIGURE 1.—EIGHT HUNDRED GALLON PRESSURE DISTRIBUTOR READY TO BEGIN APPLICATION. OVERLAPPING OCCURRED IN APPLYING SUCCESSIVE LOADS

TYPE OF OIL USED

On the greater portion of the mileage a single type of oil meeting the State highway specifications, and similar to oil No. 1 (Table 3) was used. On certain special sections the type of oil was made a variable, and on these sections other types of oil and combinations were used. Specifications for these oils can be found in Table 2, and typical analyses in Table 3. A brief description of the oils follows this latter table.

TABLE 2.—*Specifications for road oils*

The oil shall be homogeneous, free from water, and shall not foam when heated to 120° C. (248° F.), and shall meet the following requirements:

Item	Specification A	Specification B
1. Specific gravity 15.5°/15.5° C., not less than	0.910	1.00
2. Specific viscosity (Engler) at 60° C	10 to 20	10 to 20
3. Flash point, °C., not less than	80	90
4. Per cent loss at 163° C., 50 grams, 5 hours, not more than	----------	6
5. Total bitumen (soluble in CS_2), per cent, not less than	99.5	99.5
6. When the specific gravity of the oil at 15.5° C. is less than 0.970, the percentage of bitumen insoluble in 86° Baumé paraffin naphtha shall not exceed	8.0	----------
7. Per cent bitumen insoluble in 86° Baumé naphtha, not less than	----------	9.0
8. Residue of 100 penetration (100 grams, 5 seconds, 25° C.) per cent	50–65	50–65
9. Ductility of residue, centimeters (when 50 grams of the oil are evaporated at 250° to 260° C. until the residue has a penetration at 25° C., 100 grams, 5 seconds, of 90 to 100), not less than	----------	50

CONSTRUCTION METHODS OUTLINED

A contract was let for the oiling under the supervision of the State bureau of maintenance, and a schedule was arranged to take care of the order in which the sections would be treated. The various local maintenance forces were required to have their sections ready for oiling according to this schedule. This work was accompanied by the normal amount of confusion and delay due to unforeseen weather conditions or failure of equipment. In general, the preparation consisted of intensive blading and dragging to provide a smooth and uniform surface for the oil. Ditches were recut wherever necessary. Considerable variation was noted in the thoroughness with which this work was carried out. The variations are explained by the fact that the individual sections were prepared by different, and, to some extent, independent forces.

TABLE 3.—*Typical analyses of oils used*

Oil No.	Specific gravity, 15.5°/15.5° C.	Bitumen soluble in CS_2	Specific viscosity, Engler at 60° C.	Flash point	Residue of 100 penetration	Bitumen insoluble in 86° Baumé naphtha	Ductility of specified residue [1]	Loss at 163° C., 50 grams, 5 hours
		Per cent		*° C.*	*Per cent*	*Per cent*	*Cms.*	*Per cent*
[2] 1	.937	99.94	11.31	207	58.72	1.4	3.7	1.24
[2] 2	.949	99.77	15.00	210	62.50	2.7	150	[3]
[4] 3	1.041	99.78	10.82	180	62.34	11.82	150	4.09
[5] 4	.9415	99.96	14.97	158	58.92	2.47	150	[3]
[6] 5	.966	99.97	14.14	105	60.00	8.04	150	[3]

[1] Ductility of specified residue, in centimeters, when 50 grams of the oil are evaporated at 250° to 260° C. until the residue has a penetration, at 25° C., 100 grams 5 seconds, of 90 to 100.
[2] Topped residual from eastern Kansas crude, with a high paraffin base.
[3] Less than 5.00.
[4] Residual from cracking process from general midcontinent crude.
[5] Topped residual from southern Oklahoma crude, having a semiasphaltic base.
[6] Low pressure still product from Gulf coastal crude, having an asphaltic base.

The oil was discharged from pressure distributors as shown in Figure 1. The temperature of the oil as applied varied from 120° F. to 200° F. The rule on most sections was to obtain an oil temperature of at least 140° F. The permissible moisture in the earth was limited to the amount present when ruts did not develop under the weight of the distributor. Oil was applied at the rate of one-half gallon per square yard for the first application, followed as soon as the oil had been absorbed so that it would not be picked up by traffic by a second application of one-fourth gallon per square yard. The quantity per square yard was controlled by computing from the measured gallonage of the truck-load the length of road to be covered by the load. This distance was chained off and flag-staked for the truck-driver to reach at uniform speed while distributing the truck-load. In some instances traffic was allowed to use half of the roadway while oiling was in progress; in others, the roads were barricaded and closed to traffic until the second application had been absorbed. All sections noted as re-treated received a third application of one-fourth gallon per square yard.

In a few cases some material, generally river sand, was applied in a thin layer to the surface.

SECTIONS MAINTAINED CHIEFLY BY BLADING

Fifteen of the 29 sections investigated were bladed to some extent. On some sections the blading consisted of merely spreading a thin layer of earth from the shoulder over the treated surface, without permitting the blade to come in contact with the surface. On other sections attempts were made to eliminate defects by shaving the treated surface slightly and filling the defects with the material thus obtained.

OBSERVATIONS MADE BEFORE, DURING, AND AFTER TREATMENT

For each section studied the investigation involved the following activities:

1. Obtaining information relative to conditions existing and preparations made prior to the application of the oil.
2. Recording pertinent information at the time of treatment.
3. Making periodic surface condition surveys subsequent to treatment.
4. Making special studies of the subgrade soil.

The information relative to conditions existing and preparations made prior to the application of the oil included a record of the weather conditions existing prior to oiling, the soil types, the road profile, the drainage conditions, the type of equipment used, the surface processing, the length of time the surface was maintained at a finished grade prior to the application of oil, the final preparation of the grade, the surface contour, the state of consolidation of the soil, and the amount of moisture present in the soil immediately before the application of the oil.

The notes taken during construction included a record of prevailing weather conditions during the oiling operations; the type of oil used; the oil temperatures; the quantity of oil applied per square yard; the average depth of oil penetration 24, 48, and 72 hours after application; the character of penetration with respect to whether it was selective, uniform, or nonuniform; the length of time required for the oil to penetrate to an extent preventing the mat from peeling under traffic; and the method of traffic control utilized during the oiling operation.

Data regarding depth, rate, and character of penetration were obtained by driving a tube into the surface at desired intervals of time and examining the cylinder of treated soil so obtained.

The surveys subsequent to treatment included the making of general condition surveys, all distances being checked by speedometer readings; a record of road surface conditions; and an estimate of the probable causes of surface defects, such as mutilative traffic, insufficient oil, inadequate drainage, etc. The results of these surface condition surveys were then correlated with the information obtained prior to and during oil treatment.

In these surveys the road surfaces furnished by the bituminous treatments were arbitrarily classified with respect to their condition in the terms which are given and described below. Examples of each classification are given in Figure 2.

Mat intact, surface smooth.—This term indicates excellent bituminous mat surfaces. The oil-earth mat, or penetration layer, is pliant and possesses a tough, leathery texture. This type of mat occurs when the bituminous material penetrates the soil in such a manner as to bind the soil particles properly and seal the road surface, thus producing a compact mat which resists the effects of weather and traffic.

Surface rutted.—This term indicates the presence of indentations or grooves in the road surface. Rutting occurs when the subgrade is softened because of the presence of moisture. It is generally preceded by a decrease in the stability of the supporting soil, which can usually be traced to moisture furnished by rains or melting snow occurring on top of the road, by seepage or capillarity beneath, or by a combination of both.

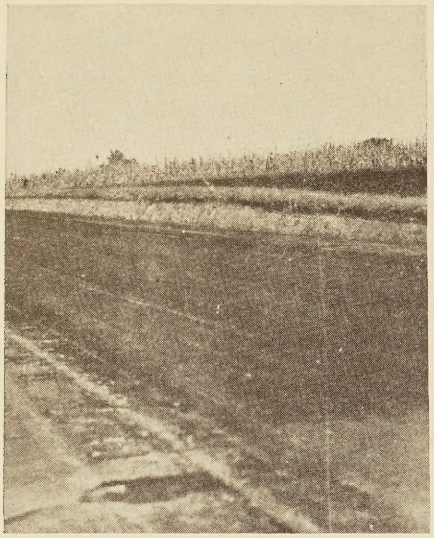
Mat crumbled.—This term indicates a crumbling of the oil-earth mat caused either by an insufficient amount of oil or by a deadening of the oil fraction. This term is not used when failure can in any way be traced to a decrease in the stability of the supporting soil. Thus, crumbling is entirely a surface defect and indicates that the applied bituminous material either has not properly penetrated the soil or does not possess cohesion in amount sufficient to bind the soil particles into a compact mat.

Mat raveled.—This term indicates a progressive breaking up, but not a crumbling of the mat. It generally occurs after periods of alternate freezing and thawing and suggests vertical displacement of the mat. This vertical displacement may be produced by expansion of the subgrade due either to increase in moisture content or to freezing followed by shrinkage of the subgrade caused by reduction in moisture content or thaw, thus leaving the mat suspended without support. Nonuniform subgrade soil is especially productive of raveling.

Mats on soils consisting of thin laminated layers of both silt and very fine sand are likely to bulge as much as one-fourth to one-half of an inch between wheel tracks 2 to 4 inches apart. It is indicated that in the silt soils the laminations may be the result of some textural assortment caused by rain, traffic, wind, or running water or by difference in degree of compaction, oil absorbed, etc. The bulging causes the different textural layers to be separated from each other.

Surface pitted.—This term indicates the presence of abrupt surface cavities. These cavities usually extend appreciably below the depth of soil penetrated with oil and do not include indentations or depressions not causing a "breaking through" of the oil-earth mat.

Surface checked.—This term indicates the occurrence of shrinkage of the surface soil disclosed by "alligator



MAT INTACT, SURFACE SMOOTH

SURFACE DEEPLY RUTTED

SURFACE RUTTED

MAT CRUMBLED

SURFACE PITTED AND RAVELED

SURFACE PITTED AND CHECKED

SURFACE CHECKED

SURFACE SCALED

FIGURE 2.—EXAMPLES OF SURFACE CONDITIONS NOTED IN SURVEYS

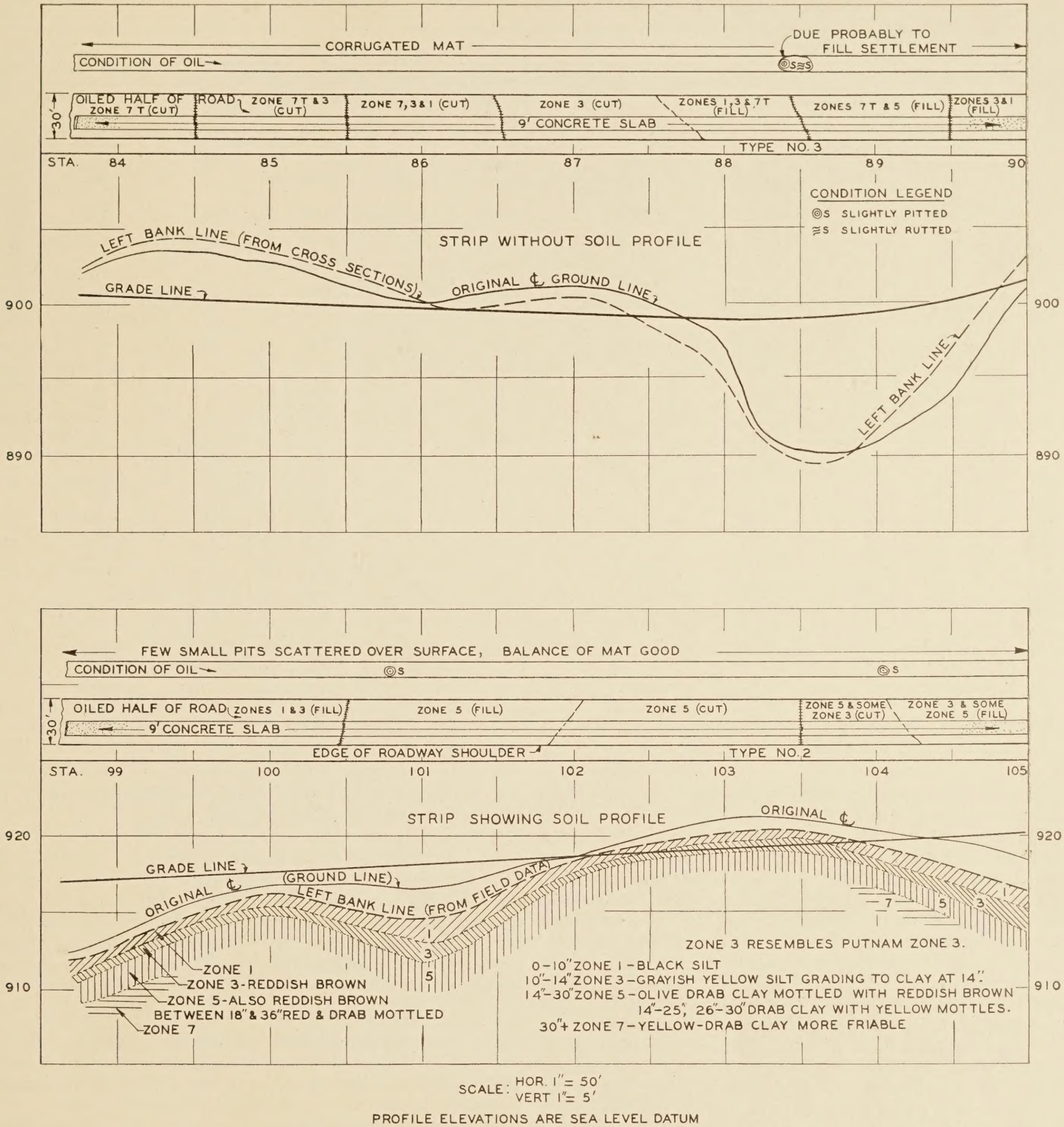


FIGURE 3.—MAP SHOWING PLAN OF ROAD, PROFILES, AND RESULTS OF CONDITION AND SOIL SURVEYS FOR U. S. ROUTE 63, MACON COUNTY, MO., 1½ MILES SOUTH OF LA PLATA

hide" cracking which separates the oil-earth mat into irregularly shaped blocks.

Surface scaled.—This term signifies the scaling off of the oil-earth mat in thin layers. Scaling is caused generally by a laminated or plated structure existing in the oil-earth mat.

SOIL SURVEYS MADE ON SEVERAL ROADS

The special studies of the subgrade soils included the surveying of certain roads with respect to the subgrade soil types and their soil zones or layers and the testing of representative samples from the various layers in the subgrade laboratory.

The subgrade survey consisted of examining the subgrade at intervals close enough (about 100 feet generally) to determine any change in the subgrade soils and examining the soils in the adjoining fields to determine the soil profiles of the soil types encountered. This information was plotted as shown in Figure 3. Included in this record are the road plan, the profile of one of the banks, the original center line grade, and the present center line grade. A soil profile such as shown in the lower strip, Figure 3, was taken only at such intervals as were necessary to disclose the arrangement of soil layers in a given soil type. In addition, the

TABLE 4.—*Record of observations on 29 oil-treated sections*

Section No.	Oil No.	General profile	Surface drainage rating[1]	Width of untreated earth shoulder	Texture classification, principal soils	Surface condition just prior to first application	Subgrade moisture, depth, 0 to 1 inch	Prevailing weather conditions during application	Air temperature range	Average oil temperature	Penetration: Average depth	Penetration: Days required	Penetration: Nature
			Per cent	Feet					° F.	° F.	Inches		
2	1	Rolling	75–100	6	Clay and silty clay	Firm	Moist	Fair	75–90	140	0.50	14–28	Uniform.
1	3	do	50–75	12	Silty clay	Retreatment, bituminous residue.		do	70–95	130		2–4	Do.
8	1	do	50–75	0	Silt	Firm	Moist	Occasional showers.	70–95	150	.40	4–7	Do.
15	1	do	75–100	12	Silt loam and silty clay.	do	do	Fair	55–85	145	.50	4–7	Do.
26	1	do	75–100	12	Clay and silty clay	Firm, some dust	do	Occasional showers.	80–95	135	.60	7–14	Do.
28	4	do	50–75	12	Silt loam	do	do	Cool and fair	45–70	190	.60	14–28	Do.
29	4	do	50–75	6	No record	No record	No record	do	45–70	(2)	(2)	14–28	No record.
4	1	do	50–75	6	Clay	Firm, some dust	Moist	Occasional showers.	60–90	200	.45	4–7	Uniform.
5	1	do	50–75	6	Silt loam and clay	do	do	do	60–90	190	.45	4–7	Do.
6	1	do	50–75	6	Silty clay and clay	Soft and loose	Wet	Frequent rains	65–85	150	.40	14–28	Do.
7	1	do	50–75	12	Silt loam	Firm, some dust	Moist	Occasional showers.	75–90	150	.70	2–4	Nonuniform.
9	1	Level	50–75	0	Silty clay	do	do	do	70–90	150	.50	4–7	Do.
14	1	do	50–75	6	Silt loam	do	Dry	Fair	60–80	160	.60	2–4	Do.
22	3	do	50–75	6	do	do	do	do	70–85	150	.85	1–2	Nonuniform and variable in color.
23	1	Rolling	50–75	6	Silt loam and silty clay.	do	do	do	65–85	150	.60	4–7	Nonuniform.
3	3	Level	25–50	6	Silt loam	Loose and dusty	do	do	60–90	200	.75	1–2	Do.
10	3	Rolling	25–50	6	do	Hard and dusty	do	Occasional showers.	80–90	160	.70	1–2	Nonuniform and selective.
11	1	Level	25–50	6	do	do	do	do	80–95	160	.65	2–4	Do.
12	3	Rolling	25–50	6	do	Very dusty	do	do	80–95	150	.70	1–2	Nonuniform.
13	3	Level	0–25	12	Silty clay	Firm	do	Fair	80–95	150	.55	4–7	Uniform.
16	3	do	25–50	12	do	Hard, partly crusted.	do	do	65–80	130	.55	4–7	Selective and variable in color.
24	2	Rolling	25–50	6	Silt loam	Hard and dusty	do	Cool and cloudy.	55–70	180	.50	2–4	Nonuniform and selective.
25	1	do	25–50	6	Silty clay and clay	Hard, partly crusted.	do	Fair	60–80	160	.40	2–4	Selective.
27	1	do	50–75	6	Silt loam and silty clay.	Very dusty	do	do	75–90	150	.50	2–4	Nonuniform.
17	1	do	0–25	12	Silt loam	Hard, partly crusted.	do	Occasional showers.	70–80	140	.70	1–2	Nonuniform and selective.
18	1, 3, 5	do	25–50	12	do	do	do	do	65–80	170	.60	1–2	Variable in color and selective.
19	1, 3	Level	25–50	12	Silty clay	do	do	do	80–95	135	.60	1–2	Do.
20	3	do	25–50	12	do	do	do	do	80–95	140	.50	1–2	Do.
21	3, 5	do	25–50	12	do	do	do	do	80–95	140	.40	1–2	Do.

[1] See text, p. 57. [2] No record.

drawings include the information furnished by the condition surveys made of the road surface.

The soil comprising the roadway is indicated by a zone number which corresponds to the same number and soil layer in the soil profile. When the subgrade consists of mixed materials from several zones, the zone numbers are shown in the order in which the materials predominate in the mixture; thus "zones 1, 3, and 5" indicates that soil material of zone 1 seems to dominate zone 3 material and that zone 3 material seems to dominate zone 5 material in amount. The numerals give only a general idea of the materials, as fills are composed of a heterogeneous instead of a homogeneous mixture of materials from the various zones. The soil profile of Figure 3 is taken along the left bank line while the soil data shown on the corresponding plan are based on an examination of the roadway.

The original center line grade was determined from the amounts of both cut and fill indicated by the original construction cross sections sheets of the roads studied. Thus the original center line grade does not necessarily mean the original ground line, except on newly located roads. In other cases the original ground line can be estimated only approximately from the present bank line profiles.

The soil profiles were determined by an examination of the back slopes and borings. The soil material in the subgrade was determined by using a pick and examining the soil to a depth of 3 or 4 inches. The soil in the oil mat was considered to be similar in character to that supporting the oil mat.

The soil in the subgrade may differ from that which would be expected from the bank profile. This may be due to several factors, as follows: (*a*) The material may be fill over an old roadbed; (*b*) material from ditches or back slopes obtained from a zone above or below the zone on the level with the subgrade may have been used in finishing the road; and (*c*) the original materials may have been rearranged by blading.

DATA PRESENTED IN TABULAR FORM

For convenience of analysis the records of the observations on the 29 sections studied are given in Table 4. The sections are listed in the order of their performance as shown by the first complete condition survey.

Some of the variables studied were not determined with great accuracy. For example, variations in moisture content, because of gradations in soil type and differences in elapsed time between preparation of surface and application of oil, could not be determined readily, hence descriptive terms depicting average conditions were used. Such terms could be easily analyzed and were sufficiently accurate for the purpose at hand. Data listed as average are available in detail on specific sections, in most cases, but are more susceptible of analysis after summation.

SOILS IN TWO ROAD SECTIONS GIVEN SPECIAL STUDY

The soils encountered in the special investigation of U. S. Highway No. 65, Waverly to Marshall, stations

TABLE 4.—*Record of observations on 29 oil-treated sections*—Continued

Section No.	Oil No.	Cover material	Character of traffic after treatment	Surface after treatment: Months after	Surface after treatment: Character	Surface condition in late autumn	Surface condition in early spring	Manipulation after treatment	Remarks
2	1	None	Nonmutilative	2	Live and ductile	Excellent	Good	None	Oil applied to surface immediately after final blading.
1	3	do	do	2	Hard but malleable.	Good	Fair	do	
8	1	do	do	2	Live and ductile	do	do	do	Maintained very carefully; no blading. Defects repaired with premixed oil and earth.
15	1	do	Mutilative	1	do	do	do	do	Oil applied immediately after final blading.
26	1	do	do	3	do	do	do	do	Do.
28	4	do	do	1	do	do	do	do	Do.
29	4	do	Nonmutilative	1	do	do	do	do	Do.
4	1	do	Mutilative	5	do	Fair	do	Bladed outer edge.	Portions of surface very damp at time of application.
5	1	do	do	5	do	do	do	do	
6	1	do	Nonmutilative	3	do	do	do	None	Portions of surface very muddy at time of application.
7	1	1 inch sand.	Mutilative	2	do	Fair, retreated	Good	Dragged	Oil applied 12 to 24 hours after final blading.
9	1	None	Nonmutilative	2	do	Fair	Fair	do	Very carefully maintained.
14	1	do	Mutilative	4	Hard, some pitting.	do	Poor	Bladed	Abrupt differences in surface consolidation; numerous dust pockets.
22	3	do	do	3	Dead and dusting.	Poor, retreated	Fair	Dragged	Do.
23	1	do	do	3	do	do	do	do	Do.
3	3	do	do	5	do	do	do	Bladed	Insufficient oil to bind soil particles to depth penetrated.
10	3	do	do	3	do	do	Poor	do	Do.
11	1	do	do	3	do	do	do	do	Do.
12	3	do	do	3	do	do	do	do	Do.
13	3	2-inch sand.	do	1	Live and ductile	Poor	do	do	Unstable support due to subsurface drainage conditions.
16	3	3-inch sand.	do	1	Dead and dusting.	do	do	do	Traffic used selective lanes because of uneven and rutted surface.
24	2	None	do	3	do	Poor, retreated	do	Dragged	
25	1	do	do	4	do	do	do	Bladed	
27	1	do	Insufficient	1	do	Poor	do	do	Oil deadened rapidly because of lack of traffic during 2 months after treatment.
17	1	do	Mutilative	2	Dead and pitting.	Failed	Failed	do	Surface was prepared for treatment 1 month before oil was applied, and during this iterim no blading was done. Final preparation consisted of smoothing the surface by means of a drag and maintainer. As a result considerable portions of the surface were hard and crusted, while other portions were composed of unconsolidated material.
18	1, 3, 5	do	do	2	Malleable, some pitting.	do	do	do	
19	1, 3	do	do	2	Dead and pitting.	do	do	do	
20	3	do	do	2	do	do	do	do	
21	3, 5	do	do	2	Malleable, but pitting.	do	do	do	

0 to 980 (sections 10 to 12 in Tables 1 and 4), and U. S. Highway No. 63, Axtell to La Plata, stations 34 to 840 (sections 22 and 23 in Tables 1 and 4), belong principally to the Marshall and Putnam series as designated by the United States Bureau of Chemistry and Soils. Lesser areas of Knox silt loam, Shelby loam, an uncorrelated type designated as type No. 2 on U. S. Highway No. 63 and an uncorrelated type designated as type No. 3 on U. S. Highway No. 65, were mapped. A brief description of these soils is given here.

U. S. Highway No. 63, Axtell to La Plata.—The soil profile of the Putnam silt loam which occupies the flat prairie regions of north central and northeastern Missouri is composed of five distinct soil zones or layers. The first layer, zone 1, is a grayish brown, fine granular or crumb-structured friable silt loam. The second layer, zone 3, is a gray, laminated platy or flaky silt loam. The third layer, zone 5, is a brown, heavy, tough plastic clay which breaks into small rectangular or square particles having a smooth outer coating and are hard when dry. These particles become larger and less stable with depth. The fourth layer, zone 7, is a bluish gray structureless, heavy, sticky, plastic clay containing varying amounts of yellow mottles. Small quantities of sand may occur in spots through the lower part of the fourth layer. The fifth layer, zone 9, is a structureless yellow or yellow-and-gray-splotched, slightly oxidized, calcareous, glacial clay, or clay loam containing varying percentages of sands and silts.

Bordering the Putnam silt loam in the timbered areas, the uncorrelated type No. 2 was mapped. This type possesses the same number of soil zones as the Putnam silt loam and differs mainly in the second layer, zone 3. In place of the gray laminated silt layer of the Putnam silt loam, a yellow to yellowish-gray fine granular silty clay loam occurs.

A soil type derived from glacial drift and developed under forested conditions was mapped on the rolling topography of this highway. This type closely resembles the Shelby loam of northern Missouri. The first layer, zone 1, is a brown friable loam or silt loam of fine granular structure. The second layer, zone 3, is a brown to grayish-brown granular loam or clay loam. The third layer, zone 5, is a yellowish brown, friable, subangular-structured clay loam or clay. The fourth layer, zone 7, is a yellow-and-gray-mottled structureless glacial clay or clay loam containing varying percentagesof sand.

U. S. Highway No. 65, Waverly to Marshall.—The Marshall soils (silt loam and deep and shallow phases) of the prairie regions of central Missouri were encountered on practically the entire length of the portion of this highway studied. The first layer, zone 1, of the silt loam is a dark brown, friable, finely granular or crumb-structured silt loam. The second layer, zone 3, is a brown silt loam of slightly coarser structure and heavier texture than the first layer. The third layer, zone 5, is a brownish-yellow silt loam of no definite structure. The fourth layer, zone 7, is a gray silt loam with yellow splotches. The fifth layer, zone 9, is a gray silt with iron concretions developed along decayed roots. The deep and shallow phases of this type varied only slightly from the above description.

The Knox silt loam occupies the more rolling topography lying between the Marshall soils and the Missouri River and is very similar to the Marshall soils with the exception that it is lighter colored.

The uncorrelated type No. 3 is a prairie soil derived from loessial material. The first layer, zone 1, is a dark brown silty clay loam of granular structure. The second layer, zone 3, is a bluish drab, sticky, plastic, granular, structured clay. In the flat areas having inferior drainage another layer, zone 2, a black, slightly sticky clay of crumb structure, is found between the first and second layers. The third layer, zone 5, is a bluish-gray-and-yellow-mottled, sticky, plastic clay or silty clay loam. The fourth layer, zone 7, is a bluish gray, mottled with yellow, structurelesss clay of high silt content.

The reaction of the individual soil zones with oil as shown by the condition survey is tabulated in Table 5, together with the laboratory test results of representative samples of soil from each of the soil zones encountered. The soil zones are assigned to certain soil groups according to their physical characteristics as disclosed by laboratory tests.

BENEFITS DERIVED FROM OIL TREATMENT DEPEND ON CHARACTER OF SUBGRADE SOIL

No definite major effect of soil type is developed from a study of Table 4 but when the data in this table are combined with those obtained from the more detailed examination and mapping of soils on U. S. Highways 63 and 65, as given in Table 5, the difference in reaction of the various layers of the different soil types with oil is clearly indicated. In general, all classes of soil were benefited by the oil treatment, but the degree of success obtained varied with the physical characteristics of the subgrade soil. This fact indicates that the requisites of the various soil layers and soil types are different.

Uniformly good results, other conditions being favorable, were obtained by treating the cohesive type of soil (clay) regardless of the character of the base of the oil, whereas better results were obtained in the case of the noncohesive type of soil (silts) with the use of oil having greater viscosity and a more ductile residue, when the quantity applied was sufficient to produce a dense waterproof surface. It is believed that the ductility of the residue obtained in the manner specified in Table 2 is sufficiently indicative of the adhesive properties of the oil to justify the selection of oils showing a ductile residue for use with noncohesive soils.

A study of Table 5 indicates that with the type and quantity of oil used:

1. Group A–4 subgrades are subject to considerable surface rutting.
2. Groups A–6 and A–7 subgrades furnish good surfaces.
3. Soils which fall on the border line between A–4 and A–6 or A–7 groups give inconsistent results.

The detailed subgrade and condition survey disclosed that, in general, the stability of noncohesive soils (silts) was increased by the addition of oil, and that,

TABLE 5.—*Results of soil tests on the various layers of the different soil types and their reactions with oil*

Soil type	Route on which found	Zone	Mechanical analysis: Particles larger than 2 mm.	Mechanical analysis: Particles smaller than 2 mm.: Coarse sand 2.0 to 0.25 mm.	Fine sand 0.25 to 0.05 mm.	Silt 0.05 to 0.005 mm.	Clay smaller than 0.005 mm.	Colloids smaller than 0.001 mm.	Physical characteristics of material passing No. 40 sieve: Lower liquid limit	Plastic index	Shrinkage: Limit	Shrinkage: Ratio	Moisture equivalent: Centrifuge	Moisture equivalent: Field	Group	Reaction with oil [1]
Putnam silt loam	U. S. Route 63	1	0	3	12	66	19	6	33	9	28	1.6	32	29	A–4	Scaled, checked, pitted.
		3	1	6	12	60	21	11	33	12	29	1.6	34	28	A–4	Do.
		5	0	3	15	42	40	21	64	30	16	1.9	54	52	A–7	Mat intact.
		7	0	3	17	39	41	24	62	37	15	1.9	[2] 60	39	A–6	[3].
		9	0	2	5	60	33	19	52	31	16	1.8	[2] 53	39	A–6	[3].
Uncorrelated type No. 2.	do	1	0	4	15	65	16	5	36	12	25	1.6	29	28	A–4	[3].
		3	0	8	11	57	24	10	41	18	24	1.6	36	33	A–4	[3].
		5	0	2	9	46	43	32	64	32	15	1.8	50	51	A–7	Mat intact.
		7	0	2	8	58	32	16	49	27	16	1.8	[2] 50	34	A–6	Do.
Shelby loam	do	1	0	7	26	54	13	7	34	12	25	1.6	24	31	A–4	[3].
		3	0	5	27	51	17	11	34	14	18	1.8	28	28	A–4	[3].
		5	0	4	15	56	25	10	44	24	17	1.8	31	37	A–7	Mat intact.
		7	2	5	16	53	24	12	41	25	13	1.9	34	28	A–6	Do.
		9	1	3	32	38	26	11	42	27	11	2.0	[2] 44	30	A–6	Do.
Knox silt loam	U. S. Route 65	1	0	1	22	64	13	6	30	8	25	1.6	29	26	A–4	Rutted.
		3	0	1	19	61	19	10	37	17	21	1.7	30	29	A–4	Inconsistent.[4]
		5	0	1	9	77	13	4	39	16	23	1.6	37	30	A–4	Rutted.
		7	0	1	21	68	10	5	39	15	26	1.6	38	32	A–4	[3].
		9	0	0	16	73	11	4	35	12	23	1.6	32	30	A–4	Rutted.
Marshall silt loam	do	1	0	1	15	71	13	8	41	14	27	1.6	36	34	A–4	Inconsistent.
		3	0	0	16	67	17	8	40	17	21	1.7	34	31	[5]	Do.
		5	0	2	14	74	10	8	42	19	23	1.6	36	33	[5]	Do.
		7	0	2	17	70	11	6	42	17	26	1.6	35	33	A–4	Rutted.
		9	0	2	9	80	9	6	35	11	31	1.6	38	30	A–4	Do.
Marshall silt loam deep phase.	do	1	0	2	9	72	17	7	41	17	23	1.7	48	34	A–4	Do.
		3	0	2	16	68	14	7	44	19	22	1.7	39	35	A–7	Inconsistent.
		5	0	2	15	71	12	7	48	23	22	1.7	50	38	A–7	Do.
		7	0	1	18	69	12	6	45	22	23	1.7	39	34	[5]	[3].
		9	0	1	9	75	15	6	43	20	21	1.7	36	32	[5]	[3].
Uncorrelated type No. 3.	do	1	0	2	16	66	16	5	39	15	27	1.6	36	36	A–4	Inconsistent.
		3	0	2	16	61	21	10	54	29	19	1.8	44	40	A–7	Do.
		5	0	4	19	61	16	8	52	31	19	1.7	41	38	A–7	Do.
		7	0	2	16	66	16	5	40	19	20	1.7	45	30	[5]	Rutted.
Marshall silt loam shallow phase.	do	1	0	3	17	69	11	7	36	13	24	1.6	34	28	A–4	[3].
		3	0	3	18	63	16	5	34	15	18	1.8	28	27	[5]	Inconsistent.
		5	0	10	23	57	10	4	33	17	17	1.8	30	23	[5]	Do.
		7	0	10	38	40	12	6	24	11	15	1.9	18	19	A–4	[3].

[1] Reaction with oil is based on behavior of individual zones in cut or fill. The behavior of the various zones when combined with others is not included in this table.
[2] Waterlogged.
[3] No road surface consists of this soil layer. Soil tests results are shown to give complete information for the soil types.
[4] Inconsistent reaction with oil indicates that the condition of the oil-earth mat on this layer varied to such an extent that no condition rating could be applied as generally representative of the performance of this layer.
[5] Blank spaces under group indicate that according to laboratory tests the soils fall between the A–4 and A–6 or A–7 groups.

within the limits of the soil types encountered and with the application of the same type and quantity of oil, the layers of the silty soil types which contained the higher percentages of clay gave the best results. Also, while surface rutting was the most serious failure on the silty soils, it was of minor importance on the clay soils. The failures on the clay subgrades were in the form of surface defects, without any serious loss of stability.

The tendency of the cohesive soils (clays) to give better results than the cohesionless soils (silts) under the conditions and methods of construction may be explained when we realize that we are dealing with a soil made up of an aggregate of certain constituents to

FIGURE 4.—POORLY DRAINED SECTION. THE IRREGULAR SURFACE HAS CAUSED TRAFFIC TO FOLLOW SELECTIVE TRAFFIC LANES. AS A RESULT PORTIONS OF THE SURFACE HAVE BEEN DEPRIVED OF THE IRONING AND KNEEDING EFFECT OF TRAFFIC AND HAVE RAVELED EXTENSIVELY

which we are attempting to impart stability, and that the requisites of stability are a proper combination of internal friction and cohesion. We can do only two things by the addition of oil. One is to stabilize the moisture content by exclusion of as large a percentage as possible, and the other is to impart some cohesion. The cohesive type of soil (clay) already has sufficient cohesion and requires only the exclusion or stabilization of moisture content to furnish stable support; hence it is entirely logical that any waterproofing oil, regardless of its adhesive qualities, will, if and while present in sufficient quantities, serve as an efficient road oil. Such soils as silt or sand lacking cohesion and waterproofing will not supply this lack, although it will eliminate variations in volume due to variations in moisture content. It is therefore logical to expect that the addition of cohesion to this type of soil which can in some degree be added through the use of an oil having adhesive properties, as indicated by the ductility of the residue, will be reflected in more serviceable surfaces.

55690—31——2

Nonuniformity of subgrade soils and degree of consolidation appreciably affected the uniformity of the completed surface. The greater portions of U. S. Highways 63 and 65 on which a detailed soil survey was made consisted of fill over an old road and were composed of mixtures of the various soil layers in different percentages and degree of compaction.

Soil materials which possessed the properties of compaction in a high degree gave the best results and soil material in place reacted better with the oil treatment than the same soil in fill. This was especially true of the soils which were difficult to compact, namely, the silty soils. Of the silty soils, those with some development of field structure were the most compactable. Surface defects (raveling, crumbling, scaling, checking, pitting) were confined almost entirely to fill materials. This fact indicates that more uniform penetration and better final results may be obtained if the subgrade is prepared so that the materials are mixed and consolidated uniformly.

More uniform surfaces and consequently more uniform penetration may be obtained by scarifying the surface to a depth of about 3 inches and thoroughly mixing this loosened material by means of a multiple blade maintainer, or by blading the material back and forth across the roadway. After the soil has been thoroughly mixed it should be distributed uniformly over the surface and carefully maintained during reconsolidation for a period of six weeks prior to the final preparation for treatment.

SURFACE DRAINAGE ESSENTIAL TO GOOD RESULTS

Surface drainage was rated as follows:

0–25 ..... Side ditches shallow and poorly drained. Road crown insufficient to shed surface water, and water accumulating in slightly depressed areas either penetrated the treated surface or was eliminated by evaporation. Crown less than 0.2 of an inch per foot of width.

25–50 .... Side ditches provided satisfactory drainage. Road crown similar to that described above.

50–75 .... Side ditches provided satisfactory drainage. Road crown sufficient to shed water readily. Crown between 0.2 and 0.3 of an inch per foot of width.

75–100 ... Side ditches provided excellent drainage. Road crown sufficient to shed surface water rapidly and completely, even from slightly depressed areas. Crown in excess of 0.3 of an inch per foot of width.

In observing the ratings as shown on the charted summary under drainage, Table 4, it is noted that with only two exceptions a drainage rating of from 50 to 75 or better was accompanied by a rating, in the fall condition survey, or fair or better. All ratings poorer than 50–75 were accompanied by condition survey ratings of poor or worse. A relationship between efficiency of surface drainage and final result is suggested.

Observations in the field indicate that proper surface drainage is one of the primary requisites of satisfactory results in the oiling of earth surfaces. Figure 4 shows the results of poor drainage. In no case did the department fail to obtain an all-weather roadway during the winter following oiling if ample surface drainage had been provided. In other words, under all soil conditions and within the entire range of oils used, service consistent with the expenditure was obtained if satisfactory drainage was provided.

Many failures were caused by water from rains and melting snow being retained in slight surface depressions for extended periods of time. These failures occurred most frequently on flat grades which were entirely dependent on direct transverse drainage for the disposal of surface water. It is in this respect only that the character of the profile has any effect on the surface condition. Runoff from the treated portion often caused the untreated sholder to become very unstable and mutilation of the treated surface progressed inwardly from the outer edge.

SUBGRADE MOISTURE AT TIME OF OILING REFLECTED IN SURFACE CONDITION

Reference to Table 4 shows a consistent relationship between the character of surface just prior to treatment, the moisture content and the final results. Figures 5 and 6 illustrate the results obtained under different conditions of moisture. Sections rated as fair or better were free from excess dust and their states of consolidation varied from loose to firm. Surfaces on sections given a final rating of poor or failed, were in general more dusty and in many cases hard and crusted. All sections rated as fair or better in the first condition survey, with the exception of one, show the presence of an appreciable amount of moisture when oiled. The

FIGURE 5.—SECTION IN GOOD CONDITION THREE MONTHS AFTER TREATMENT. THE SURFACE CONTAINED AN APPRECIABLE AMOUNT OF MOISTURE WHEN OIL WAS APPLIED

one section not showing the presence of moisture was rated as poor at the time of the second condition survey. All sections rated as poor or failed, had no appreciable amount of moisture at the time of application of the oil.

If satisfactory surface drainage has been provided so that water will not stand on the surface and be forced into and through the oiled surface by the action of traffic, the next most important requisite to the successful oil treatment of earth is the proper condition of the surface as regards moisture content. For a successful oil treatment it is necessary that the oil penetrate and become intimately mixed with all soil particles by the kneading action of traffic. The mere presence of the proper quantity of oil on or near the surface is not sufficient. All particles must be coated or saturated with oil. The condition of the soil must be such that the oil can enter and mix with all the particles, either by direct penetration or by manipulation and kneading under traffic. The presence of the normal moisture content promotes the conditions just stated in that the moisture keeps open the pore spaces and facilitates the uniform distribution of the oil. By its gradual recession or elimination the moisture promotes uniformity and completeness of the contact of the oil with all particles even though the rate of penetration is retarded to some extent.

FIGURE 6.—SURFACE WAS PARTLY CRUSTED AND HARDENED AT THE TIME OIL WAS APPLIED. SHRINKAGE CRACKS ARE NUMEROUS AND PITTING IS EVIDENT

The character of surface prior to oiling as previously suggested is in a very large measure dependent upon the moisture content. The presence of dust is due to lack of moisture. Most clays exhibit considerable volume change with variations of moisture content. On drying excessive shrinkage takes place resulting in the formation of shrinkage cracks and a hardened crust separated into blocks by the cracks. This is the condition referred to as "hard and crusted" under surface condition rating. The crust has become densified and hardened, and the particles which in a moist condition were separated by films of moisture are now drawn into more intimate contact through the stresses exerted by capillary pressure as the water is eliminated. The major portion of the area of the surface is too dense and hard to receive the oil and as a result it enters the cracks between the surface blocks to remain in concentrated form or to distribute itself in the more moist and consequently more receptive underlayers. The blocks of hardened surface receive some oil by penetration around their surfaces but exhibit a dry and barren interior. If the blocks of crust are not too hard the kneading of traffic may tend to remedy the condition by helping to redistribute the oil present in the cracks but under extreme conditions the blocks remain hard and unreceptive. The impact of traffic often causes the surface-coated but unpenetrated blocks to be displaced, starting the familiar conditions of raveling and potholing.

Lack of moisture in the case of soils which have lower volume change with loss of moisture, such as the silts or sandy soils, is not so serious, as the pores vacated by moisture are occupied to a considerable extent by air and are open to the entrance of oil. Dust forms rapidly, however, on this type of soil. If this dust is not penetrated so thoroughly as to bind it to the underlying soil, it will cause serious peeling and raveling, and barren spots, insulated by dust layers against penetration, will later pit and rut or ravel.

Owing to weather and traffic conditions the surface to be treated can be maintained in the ideal condition for the reception of oil for only a very short period of time, usually not more than 24 hours.

Of sections included in this study the best results were obtained on those sections which were bladed the same day oil was applied. Blading at this time cut down to the zone of normal moisture content, and the treatment followed before the moisture had received from the exposed surface. Section 2 is an example.

The poorest sections were those which were bladed to finished grade a considerable time before oil was applied. Sections 17 to 21, inclusive, were prepared for oil one month before oil was applied and maintained during this interim by dragging, care being taken not to disturb the compacted portion of the surface. As a result the surface at the time of oiling had practically no crown and portions were dense and crusted.

The outstanding failures of sections studied in this report, excluding failures due to lack of drainage, were due to the conditions suggested above.

WEATHER CONDITIONS EFFECTIVE ONLY IN REGARD TO SUBGRADE CONDITION PRIOR TO OILING

Changes in weather seemed to be effective only to the extent that they affected the moisture content of the surface and consequently its condition prior to oiling.

Within the ranges observed in this study there was no significant effect of air temperature changes except that they might have served to speed or retard changes in the moisture content of the subgrade.

CHARACTER OF PENETRATION MORE SIGNIFICANT THAN DEPTH PENETRATED

Within the range of penetration obtained there did not seem to be any significant relation between depth of penetration and resulting service. It will be noted, however, on reference to Table 4, that the character and rate of penetration seem to be significant. With proper conditions of surface and moisture the penetration was relatively slow and uniform, an exception being a section previously treated. These conditions of penetration coincide with fair or better service ratings. Coinciding with lack of proper amounts of moisture, presence of excess dust, and hardening and cracking of the surface, nonuniform and more rapid penetration was noted. The effect of loose material on the surface prior to oiling is shown in Figure 7. The rapidity of penetration was increased by the presence of cracks. This penetration tended to be selective, however, following the cracks rather than mixing uniformly through the soil. Cores taken so as to include the cracks showed that they had contained considerable quantities of oil, as the soil on each side of a crack was impregnated with oil at depths considerably below the point of maximum penetration entering directly through the surface.

Where the crust was very hard and resistant to penetration, cores taken to the maximum depth of penetration showed a variation in color, grading from a glossy black at the surface to a very light brown at the maximum depth. Nonuniformity and rapidity of penetration, together with selective penetration and variation in color coincide with sections rated as poor or failed.

FIGURE 7.—APPEARANCE OF SURFACE AFTER FIRST APPLICATION OF OIL. NONUNIFORM PENETRATION HAS OCCURRED BECAUSE OF LOOSE MATERIAL ON THE SURFACE. THE PRESENCE OF UNABSORBED OIL ON THE SURFACE IS INDICATED BY THE LIGHT SPOTS

RELATION BETWEEN WIDTH OF UNTREATED ROADWAY ADJACENT TO OILED SECTION AND SURFACE CONDITION

A study of the summary fails to produce any definite information regarding the proper width of untreated surface adjacent to the oiled section. Observations, however, showed that there was a detrimental effect of having untreated sections adjacent to the oiled section, particularly if traffic or the method of maintenance was such as would tend to move untreated earth or dust on to the treated surface.

A development of considerable importance, although it does not have an important effect upon the efficiency of the oiled earth surface as a traffic way, was brought out by observations in connection with these untreated widths in comparison with the treating of full width. This development was the great efficiency of oil treatments as a means of stopping wash or erosion of soils of the noncohesive type such as those derived from loess. In certain areas the Missouri State Highway Department was rapidly approaching the necessity of purchasing additional widths of right of way to obtain earth for replacement of shoulders removed by erosion. Oil treatment as described in this report immediately and effectively stopped this erosion, saving many dollars in maintenance costs. In extreme cases such simple treatments enabled the holding of fills subject to overflow, which previously had periodically been lost. After oil treatment these fills resisted the water action by virtue of the thin stabilized film or layer which prevented the inception of washing and crumbling. This development leads us to include the factor of conservation of material in our future considerations for rating effectiveness of oil treatment.

EFFECTS OF VARIATION IN TYPE AND QUANTITY OF OIL AND TEMPERATURE OF OIL WHEN APPLIED

No apparent and consistent variation in results due to variation in oil type alone can be noted from the data as herein summarized.

There were, however, some indications that a larger quantity of oil per unit of surface would insure more durable surfaces than were obtained with the use of the original quantity specified, i. e., three-fourths gallon per square yard. Areas of noncohesive soils accidentally subjected at the ends of sections to overlapping treatments from two successive distributor loads invariably showed an improved character of surface over adjoining areas not covered by such overlaps.

On sections treated with No. 4 oil, which was an oil having a ductile residue and a somewhat higher viscosity than oils Nos. 1 and 3, better results were noted than was the case on sections treated with any of the other oils. In connection with the use of this oil it should be noted that very favorable penetration conditions existed.

These indications and the general conviction that somewhat richer surfaces would be beneficial led the highway department to use a larger quantity of a somewhat heavier oil during the following oiling season. In these later applications a total of 1 gallon per square yard instead of three-fourths gallon was used. The principal difference between No. 3 oil (Table 3), and the oil used during 1929 was in their viscosities. That used during 1929 had an average specific viscosity (Engler) at 60° C. of 17, while the No. 3 oil (Table 3) had an average viscosity of 10.82 by the same method of test.

The surfaces treated during 1929 in general were more serviceable and durable than those treated during 1928. This improvement is attributed largely to the increase in quantity and viscosity of the oil, although some improvement was due to better general preparation of surfaces prior to oiling, brought about by increased attention to this item.

No apparent benefit was obtained by raising the temperature of the oil for application above that required to insure against clogging of the distribution nozzles. Increasing the temperature of the oil facilitates and increases run-off from the surface due to decreased viscosity and is detrimental rather than beneficial.

EFFECTS OF VARIOUS TYPES OF TRAFFIC

Mutilative traffic seriously reduced the serviceable life of a considerable mileage of the treated roads, but was localized in effect as a rule and was not considered significant as affecting condition surveys. Figure 8 shows the effect of this type of traffic. The destructive effect was not as noticeable on those surfaces having a live, ductile surface layer. During the winter and early spring, the surface is least resistant to mutilation by traffic and during those seasons much damage is done by the hoofs of cattle and horses. Any reasonable and practical means of mitigating the effects of mutilative traffic will justify some expenditure. As stated previously, in some cases cover material, generally river sand, was applied in a thin layer to the surface. The results seemed to be uniformly beneficial except in the presence of conditions causing the failure of the oil treatment.

FIGURE 8.—MUTILATING EFFECT OF TRAFFIC AFTER RETREATMENT

Sections 16 and 27 indicate clearly that the serviceable life of the treated road is materially shortened if traffic during the first month after application of the oil is not sufficient and of such character as to knead thoroughly and incorporate the oil into the surface. Section 27 was deprived of this traffic, the road having been barricaded during the construction of higher type pavement on an adjoining section. The surface two months after treatment was dusting extensively, the oil being light brown in color and dead, almost entirely devoid of its binding properties. Section 16 is an example of what may be expected when the surface contour is so irregular that traffic uses selective lanes. Several large longitudinal ruts extended over the greater portion of this section when the final preparation was started. These ruts were filled with loose soil and oil applied before this material was compacted. As a result, several major depressions soon appeared where the ruts had been. This condition caused traffic, especially pneumatic tired traffic, to follow selective traffic lanes. The balance of the treated surface soon became dead, dusting and raveling extensively owing to lack of traffic.

METHODS OF MAINTENANCE COMPARED

Sections 10 and 11 are typical examples of the effects of blading a thin layer of earth in from the shoulder, and section 14 is an example of the effects of shaving the treated surface and filling the defects with the material thus obtained.

Both methods, although improving the riding surface temporarily, materially shortened the serviceable life of the treated surface. The dust superimposed on the surface acted somewhat as a blotter, absorbing a portion of the oil, after which it was washed or blown from the surface, carrying this portion with it. The dust also insulated the treated surface against the kneading and solidifying effect of traffic and as a result the oil deadened rapidly. This method of maintenance probably has a more injurious effect when the soil of the oil-earth mat is a silt or silt loam, as this type of soil does not possess appreciable cohesion and is relatively open and porous.

The other method, that of shaving the treated surface and filling the depressions, invariably resulted in considerable scabbing of the surface and the material deposited in the depressions lacked the binding properties necessary to prevent its being whipped out by traffic.

Not only was the life of the roads maintained in this manner shortened, but the surfaces were dusty during dry weather and portions of their length became muddy during wet weather.

THE 1930 OILING PROGRAM

The work and observations outlined in this report gave indications of possible improvements in the treating of earth roads with oil. This resulted in a further revision of practice in oiling earth roads, together with some changes in the road oil specifications during the 1930 season.

The 1930 oiling program consisted of surface treating 287 miles of roads. Of this total mileage 143 miles were re-treated and 144 miles received original treatment. In addition to this mileage, short experimental sections were constructed in accordance with a mixed-in-place method, which involved the mixing of oil with river sand, bank sand, and natural soils.

As regard the specifications, a ductility requirement of over 20 centimeters for the 100 penetration residue was included in the requirements of specification A of Table 2. This change resulted in obtaining an oil with an average ductility of about 30 centimeters. This oil was a topped residual of Arkansas crude with a semi-asphaltic base. The bulk of the oil applied, about 80 per cent, conforms to specification B. This corresponds to oil No. 3 in Table 3, a cracking-process residual of general mid-continent crude, having a ductility of more than 100 centimeters for 100 penetration residue. The revised specifications required oil of both types to have a higher viscosity than formerly, averaging around 16, a greater amount of 100-penetration residue, between 55 and 70 per cent, and allowed for as much as 10 per cent loss after five hours at 163° C.

ORIGINAL TREATMENT AND RE-TREATMENT DESCRIBED

The preparation of the road surface for the reception of the oil continued to be a function of the various local maintenance forces, and the fact that those responsible appreciated the importance of surface preparation and the other conclusions and indications contained in this report was very apparent, and to a considerable extent is reflected in the superior results obtained.

Earth-oiling practice in 1930 as compared with that of previous years included better surface drainage of both roadway and side ditches and more uniform cross-section, free from depressions. In the case of original treatment, road surfaces were prepared so that final preparation was completed immediately before the initial application of oil. The temperature of the oil at the time of application was controlled to prevent run-off on steep grades. The entire width of roadway was treated on those sections composed of loess soil lacking sufficient clay to resist erosion.

The quantity of oil on sections given original treatment was increased from three-fourths gallon per square yard to 1 gallon. This increase was decided upon because previous observations had indicated that the slightly inferior results obtained on soils deficient in cohesion was in a great measure due to their relatively greater porosity, which permitted the penetration of the oil to such a depth that the quantity of oil was insufficient to bind adequately the particles of soil included within the penetration horizon.

The quantity of oil per square yard for re-treatment varied according to the general conditions of the surface soon after the final spring thaw. Some sections were re-treated with one-half gallon per square yard or slightly less, while other sections which were almost completely unserviceable were scarified, bladed, and re-treated, using 1 gallon per square yard.

The number of applications and quantity of each application varied in relation to the total quantity to be applied. Distributions of three-fourths gallon or more per square yard were made in three applications; first application, four to six tenths gallon per square yard; second and third application, two to three tenths gallon per square yard each. Distributions of less than three-fourths and more than four-tenths gallon per square yard were made in two applications, the quantity of each application being designated by the engineer. Distributions of less than four-tenths gallon per square yard were made in one application.

PREPARATION FOR RETREATMENT VARIED ACCORDING TO NEEDS

The preparation of the surface for additional oil varied from a light disking and dragging to complete scarification of the previously treated oil surface. In the northwestern section of the State a considerable mileage of road surfaces was prepared by a light planing of the surface, the loose material thus obtained being utilized in eradicating pits and other surface depressions.

The object of this method was to facilitate the penetration of the new oil by removing the glazed surface and at the same time reclaiming as much as possible the compaction, stability, and waterproofing qualities of the existing mat. This planing was accomplished by means of a special disk planer followed by a multiple-blade maintainer. Each of these pieces of equipment was so constructed that the cutting depth could be accurately controlled. The number of trips necessary to prepare the surface depended upon the type and condition of the existing surface as well as upon the skill of the operator. Care was taken that the bond between the existing oil mat and the underlying soil was not destroyed. The preparation of the old surfaces for retreatment, either by light harrowing or disk planer, both followed by a multiple-blade maintainer to correct irregularities in the surface, almost immediately developed the fact that, if the road thus prepared were subjected to the kneading action of traffic during a series of warm days, the oil would freshen and reassimilate the loosened material, furnishing a smooth surface in excellent condition for retreatment. Figure 9 shows the disk planer and multiple-blade maintainer in operation.

FIGURE 9.—PREPARATION FOR RETREATMENT: TRACTOR HAULING SPECIAL DISK PLANER AND MULTIPLE-BLADE MAINTAINER

Five experimental sections were designed in order to study the feasibility of mixing oil in place with sand or soils. These sections involved three variations in the type of oil used, and three different classes of material were treated. The processing consisted of blading the subgrade to a depth of from 2 to 4 inches, leaving the loosened material in a windrow on the shoulder, applying a primary coat of one-half gallon per square yard to the subgrade, blading the loosened material back and forth, applying oil at the rate of one-half gallon per square yard three or four times, and continuing the blading until the whole mass had a uniform dark brown color. The material was then bladed to a uniform thickness across the roadway and given to traffic for compaction.

The experimental sections are listed as follows:

Section A. Subgrade: A residual soil from weathering of sandstone; soil group A–3.
Oil: Revised type No. 3 of Table 3.

Section B. Subgrade: A clayey silt; soil group A–5.
Oil: Revised type No. 3 of Table 3.

Section C. Subgrade: A sandy flood-plain soil; soil group A–3.
Oil: Type No. 3 of Table 3 with 70 per cent residue and specific viscosity of 30.

Section D. Subgrade: Fine river sand added to clay subgrade; soil group A–3.
Oil: Topped residual of Arkansas crude.

Section E. Subgrade: A silty clay: soil group A–6.
Oil: Topped residual of Arkansas crude.

CONDITION SURVEY MADE IN SPRING OF 1931

Following the abnormally mild winter of 1930–31 two heavy snowfalls accompanied by freezing weather occurred during the month of March. A condition survey made the first week in April showed all oil-treated earth roads on constructed grades to be in serviceable condition. Re-treated roads on which the multiple-disk planer had been used preliminary to re-treatment were in excellent condition, and it is felt that the type of equipment used for this preparation has demonstrated itself as especially adaptable for the preparation of oiled roads prior to re-treatment. On several of the re-treated jobs a tendency for a mat to form accompanied by corrugation of the mat was noted indicating that one-half gallon per square yard was an excessive application in those cases.

A consideration of weather conditions during the 1930 season develops something more than coincidence. A general drought condition prevailed. It was noted, however, that the portion of the State in which oiling of earth roads was carried on could be divided into three fairly distinct sections according to the amount of rainfall. During five months, May to September, inclusive, the northwestern section had a rainfall 3.95 inches below normal. The rainfall in the north-central section was 6.59 inches below normal and in the west-central section it was 7.92 inches below normal. Without exception the oiled roads in the section having the nearest to normal rainfall were markedly superior to those in the other two sections.

The results obtained on the mixed-in-place sections indicate that a more permanent form of surfacing in proportion to the extra cost involved in additional oil and manipulation can be obtained by developing a mixture as described. Little success was had with oils having a residue of low ductility. No difference was noted in the results obtained from the 55 per cent and the 70 per cent residue. Lack of ductility in the oil residue does not show up as a weakness in the oil when mixed with clay or clayey silts.

Figure 10 shows the condition, in the spring of 1931, of a section consisting of 9-foot concrete on one side and an oiled road on the other.

CONCLUSIONS DRAWN FROM INVESTIGATION

1. Road oil of the types included in this study is an efficient material for use in the treatment of earth surfaces to provide all-weather roads provided applications are made to suitable surfaces, adequately drained, and repeated as needed.

2. The type of oil, as regards basic crude source, is not a major factor, all types yielding fairly satisfactory results with all types of soils, other conditions being favorable.

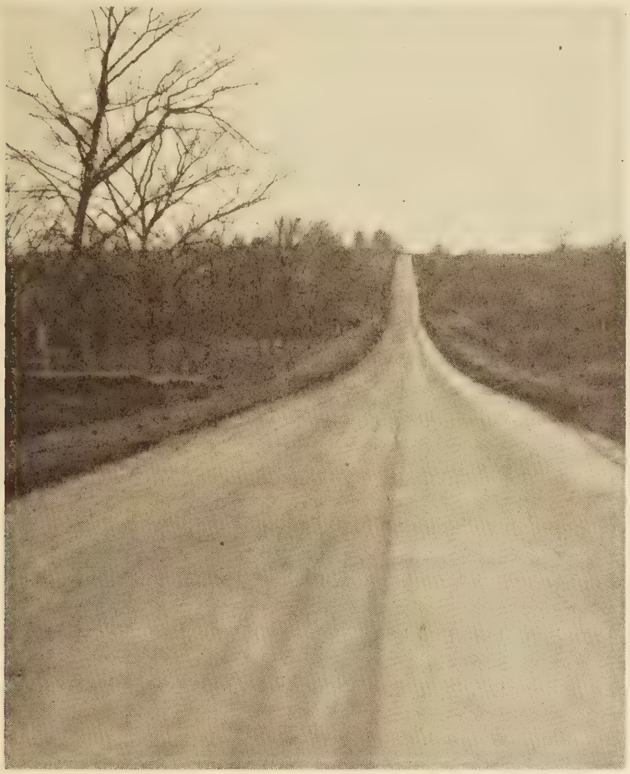


FIGURE 10.—NINE-FOOT CONCRETE ROAD ON ONE SIDE, OILED EARTH ROAD ON THE OTHER. PHOTOGRAPH TAKEN IN SPRING OF 1931

3. Adequate drainage, both subsurface and surface, is essential to the satisfactory service of oiled earth surfaces. Adequate drainage, on flat topography, requires greater crown than ordinarily constructed on graded earth sections.

4. General profile is not a factor affecting the service of oiled earth surfaces except as it may influence the efficiency of drainage and the character of the subgrade material.

5. To reduce the effects of erosion on noncohesive types of soils, oil should be applied on the full width of roadway.

6. All types of soil included in this study can be efficiently treated with road oil.

7. The soil type is an effective factor because of the physical characteristics of the various soil layers exposed to the application of oil. The physical characteristics of the subgrade soils affect the final results according to whether the soils require only the water-proofing qualities of the oil or in addition require an increase in their cohesive properties. The condition of the surface with respect to dust, hardness of crust, and moisture content at the time of application of the oil is directly reflected in the physical characteristics of the soils. The uniformity of penetration is controlled by the uniformity, texture, and density of the several layers of a soil type.

8. Soils lacking cohesion and inclined to absorb water very readily in quantities sufficient to cause rapid loss of stability (represented in this study by A–4 subgrades), may be more effectively treated with oils having ductile and cohesive bases. Soils which possess cohesion in a high degree and which, when in a stiff or plastic state, do not absorb additional water unless manipulated (represented in this study by A–6 soils), do not require treatment with oils having cohesive bases, as waterproofing without binding will insure fairly satisfactory results. Soils which possess properties from each of the groups mentioned above but can not be placed definitely in either one may give better results if the quantity of oil applied is increased.

9. The character of the surface immediately prior to application of the oil is of major importance. Surfaces to which oil is to be applied should be fairly free from dust and should have pore spaces open to receive the oil. Final preparation of surface for treating should consist of blading to eliminate all dust, crust, and depressions of the road surface, rather than the movement of loosened material to obtain uniform cross-section. A uniformly smooth surface to insure uniform distribution of traffic over the entire roadway is essential for proper development of the surface.

10. The presence of sufficient moisture in the surface is essential in order that the pore spaces be kept open and free to receive the oil. Surfaces free from moisture tend to become dusty and hardened, causing nonuniform and selective penetration.

11. Weather conditions are a factor to the extent that they may influence the moisture content of the surface, the rate of penetration, and the quantity of oil, if loss occurs due to rainfall immediately following application.

12. Within the ranges observed in this study there did not seem to be any significant effect of air temperatures except that they might have served to speed or retard changes in the moisture content of the soil.

13. There was no apparent benefit obtained by raising the temperature of the oil for application above that required for uniform distribution. Increasing the temperature of the oil increased the tendency to flow along or from the surface by decreasing the viscosity of the oil and was detrimental rather than beneficial.

14. A retarded rate of penetration tends to improve the uniformity of distribution of the oil thereby promoting the intimate mixture of oil and soil particles which is desired. Nonuniform penetration, which usually accompanied a rapid rate of penetration, failed to produce the results desired.

15. The presence of untreated earth surfaces adjacent to oiled earth surfaces reduces to a varying extent the effectiveness of oiled surfaces particularly if the untreated surfaces are manipulated, as the untreated earth tends to deaden the treated surfaces.

16. Nonmutilative traffic is highly beneficial to oiled earth surfaces as such traffic tends to knead the oil into intimate contact with the soil particles. This intimate association is a primary requisite for successful treatment of earth with oil.

17. Mutilative traffic seriously impairs the service rendered. Such traffic should be prevented or minimized to the extent possible.

18. Dragging or blading of a good oiled earth surface is harmful. When reshaping is necessary a re-treatment must be given to restore the oiled surface.

THE ACTION OF SULPHATE WATER ON CONCRETE[1]

RECENT TESTS OF SPECIMENS IMMERSED IN MEDICINE LAKE, S. DAK.

Reported by DALTON G. MILLER, Senior Drainage Engineer, United States Bureau of Public Roads, and PHILIP W. MANSON, Division of Agricultural Engineering, University of Minnesota Agricultural Experiment Station, and Minnesota State Department of Drainage and Waters

TESTS of many cylinders stored in Medicine Lake have been made since those reported in Public Roads of October, 1925,[2] and November, 1927.[3] The new tests include some at 3 and 5 years of cylinders from the earlier series and 1 and 3 year tests of cylinders installed in the lake since 1927. The number of cylinders that have been made for the Medicine Lake experiments now totals well in excess of 20,000, of which more than 9,000 have been actually stored in the lake for time periods up to seven years, and nearly 11,000 stored in fresh water in the laboratory for comparison tests up to five years.

These experiments were designed principally to aid in the general improvement of farm drain tile and particularly to develop tile that will endure under the wide range of soil conditions peculiar to Minnesota. The results are applicable, however, to many other sections of the United States and to concrete culvert, water, and sewer pipe exposed to the action of sulphate soils and waters similar to those to which drain tile are subjected.

MEDICINE LAKE

Medicine Lake is a body of clear alkali water located 18 miles northwest of Watertown, S. Dak. Since it has stretches of gravel beach, conditions for installing and examining field specimens are almost ideal. Analyses of water samples collected at different seasons of the year have shown a total salt content that ranges between 2.34 and 4.72 per cent, consisting almost entirely of the sulphates of magnesium and sodium. An average of four analyses taken December 10, 1923, February 14, 1924, April 29, 1924, and July 1, 1925, is given in Table 1. Medicine Lake freezes over during winter months, but all cylinders of these experiments have been installed at depths well below any frost action, as it was not desired to introduce this variable.

TABLE 1.—*Average of four analyses of water from Medicine Lake, S. Dak.*[1]

RADICALS

Na (Calc)	Ca	Mg	NO_3	Cl	SO_4	CO_3	HCO_3	Total
MILLIGRAMS PER LITER (PARTS PER 1,000,000)								
3,036	717	5,079	1	509	27,021	88	313	36,764
PERCENTAGE REACTING VALUES								
10.38	2.93	36.69	0.01	1.01	48.22	0.30	0.46	100.00

[1] Analyses by the water and beverage laboratory, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

CONCRETE TEST CYLINDERS USED

Two by four inch cylinders have mostly been used for a number of reasons, among which is the fact that the 2-inch diameter roughly approximated the thickness of the walls of many of the tile used in public ditches of Minnesota and other States of the Middle West. Special attention is directed to the fact that these cylinders, while small, have been for the most part made of concrete, not mortar, although in none have there been used pebbles coarser than three-eighths inch. The aggregate passed all standard physical tests and was separated into screen sizes and recombined to produce a fineness modulus of 4.67.

The cylinders, with some exceptions, were made in batches of nine, of a 1:3 mix, with a relative consistency of 1.00, and a water-cement ratio averaging about 0.62. They were cured the first 24 hours in a moist closet at room temperatures. Such mortar cylinders as were made of standard Ottawa sand fairly well represent very poorly graded aggregate such as is too frequently used in smaller size tile.

No attempt has been made in this work to show the direct influence of aggregate grading, water-cement ratio, quantity of cement in the mix, and those other factors well recognized as greatly affecting the 28-day strength. Instead a 1:3 concrete with the highest unit strength and lowest absorption obtainable for the particular aggregate, within the limits of grading permissible for 2 by 4 inch cylinders, was adopted as the laboratory standard. It was assumed that, for any given set of conditions, concrete with the highest 28-day strength is most resistant to disintegration and, therefore, that comparative tests to show the influence of a single variable, using this type of concrete, would give the most consistent results possible.

Results of all tests are recorded in Table 2; and in order to group properly the essential data for convenient study, they have been divided into six parts, as follows:

- Part 1.—Curing in water vapor or steam between temperatures of 100° and 350° F.
- Part 2.—Portland cements from different mills
- Part 3.—Special cements other than high alumina
- Part 4.—High alumina cements
- Part 5.—Surface treatment or impregnation
- Part 6.—Admixtures.

A few series naturally fell under more than one heading and have been so listed. In the following pages the results of these six studies are discussed.

CURING IN WATER VAPOR EFFECTIVE AT HIGH TEMPERATURES

A total of 5,850 cylinders in 130 series were cured in water vapor or steam at temperatures of 100°, 155°, 190°, 212°, 230°, 260°, 285°, 315°, and 350° F. for time periods, at most temperatures, ranging between 45 minutes and eight days. The data obtained from 15 series cured in air and water only are also given in Table 2, Part 1, for purposes of comparison. One-year tests have now been completed for all 145 series and 5-year tests have been completed for 83 of them. The only series in which 5-year tests have not been made are those cured at temperatures of 315° and 350° F.

A number of points of interest have developed as a result of this phase of the work, many of which have been previously discussed [4] in detail and will not be

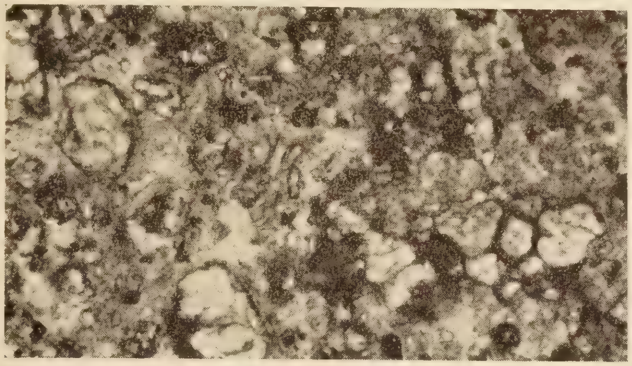
[1] University of Minnesota Paper No. 1012, Journal Series. This paper is a report of progress of experiments at University Farm, St. Paul, Minn., in the drain tile laboratory conducted by the department of agriculture of the University of Minnesota, the department of drainage and waters of the State of Minnesota, and the U. S. Department of Agriculture.

[2] The Action of Sulphate Warer on Concrete, Public Roads, vol. 6, No. 8, October 1925, p. 174.

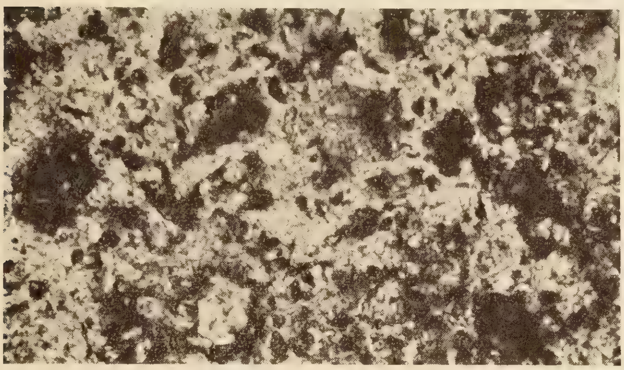
[3] The action of Sulphate Water on Concrete, Public Roads, vol. 8, No. 9, November, 1927, p. 203.

[4] Strength and Resistance to Sulphate Waters of Concrete Cured in Water Vapor at Temperatures Between 100 and 350° F., by Dalton G. Miller, Proceedings, Am. Soc. Testing Mats. vol. 30, Part II, 1930, p. 636.

repeated here. It was noted, among other things, that 7-day compression test results of cylinders cured at a temperature of 315° F. were somewhat more erratic than were those for cylinders cured at other temperatures between 100° and 350° F. It is not yet possible to formulate an opinion as to the significance of this phenomenon as related to the resistance to disintegration of concrete in the presence of sulphate waters, for the reason that tests of cylinders at these higher temperatures have been made only after one year's exposure. Study of the data of Part 1, Table 2, shows that the greatest range in strength ratio values at one year was given by the cylinders cured at 315° F. in series 841–849



Neat cement briquet cured 12 days in water at room temperature



Neat cement briquet cured 24 hours in steam at 212° F.

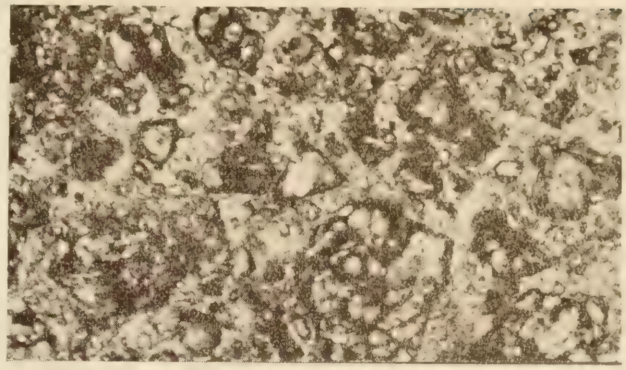
Figure 1.—Photomicrographs of Neat Cement Briquets Showing Physical Changes Resulting from Different Conditions of Curing. Note That Hydration Has Been Much More Nearly Complete in the Steam-Cured Briquet

but, regardless of this, the following general conclusions have been drawn, based on the tests to date.

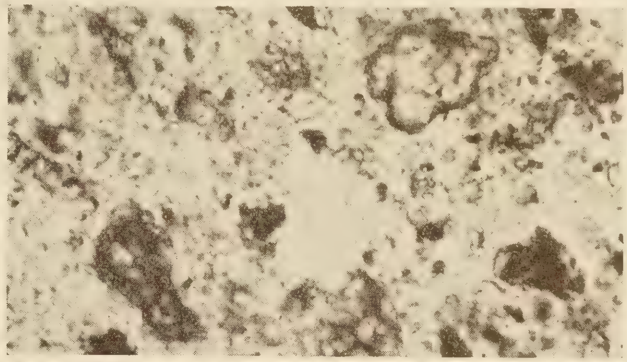
1. Curing in water vapor at temperatures between 100° and 190° F. did not generally increase resistance of concrete to the action of sulphate waters; on the contrary, in some cases a decrease was indicated. An exception to this occurred where certain admixtures were used, as later discussed.

2. Curing concrete in water vapor at temperatures of 212° F. and upward markedly increased resistance to the action of sulphate waters with the data definitely indicating increase of resistance with increase of curing temperatures between 212° and 285° F. for a 12-hour curing period.

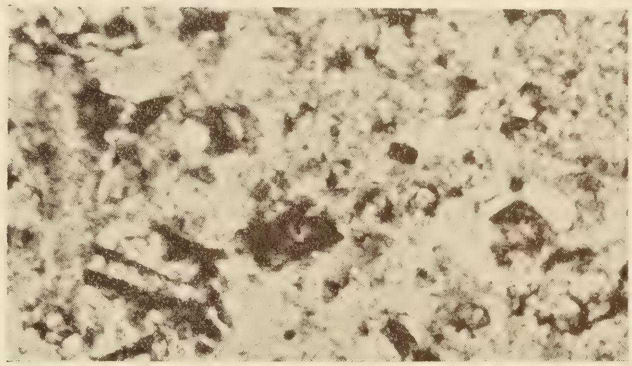
3. Curing concrete in water vapor at 212° F. has been more effective in developing resistance to the action of sulphate waters when continued for six days than when continued but two days.



Neat cement briquet cured 12 days in water at room temperatures



Neat cement briquet cured 24 hours in steam at 212° F.



Neat cement cylinder stored 8 years in water

Figure 2.—Photomicrographs of Neat Cement Specimens Showing Physical Changes Resulting From Different Conditions of Curing. Note That Hydration Has Been Least Complete in the 12-Day Water Cured Briquet and About Equally Complete in the 24-Hour Steam-Cured Briquet and the 8-Year Water-Cured Cylinder

4. Until more 5-year tests are completed for specimens cured at the higher temperatures it is not possible at this time closely to correlate curing temperatures and lengths of curing period with resistance to sulphate waters of concrete cured in water vapor at all temperatures between 100° and 350° F. It is significant, though, to note that for temperatures between 100° and 285° F. those specimens cured at the highest temperatures and for the longest periods have made the most favorable showings.

5. Regardless of whatever chemical or physical changes in Portland cement increase resistance, following curing in water vapor at temperatures of 212° F. and upward, hydration of the cement grains is very greatly accelerated. This fact is well illustrated in Figures 1 and 2 by the photomicrographs of thin sec-

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tions of specimens in which it may be seen that the steam-cured cement grains are greatly altered and reduced in size, within a few hours, to a degree only approached in the water-cured specimens after seven years, as shown in Figure 2. Portland cement I of Part 2, Table 2, was used in the briquets of Figure 1 while equal parts of cements A and B were used in the specimens of Figure 2. Figures 3 and 4 indicate the trend of results from this part of the investigation.

SUPERIORITY OF CERTAIN CEMENTS INDICATED BY RESULTS FROM DIFFERENT MILLS

There were 5,400 cylinders in 120 series in which were used standard Portland cements from 34 different mills. One-year tests have been completed for all 120 series and 5-year tests have been made for 76 series, including 73 series that have completely failed at five years. Giving due weight to those cylinders that have disintegrated, and considering such compression tests as have been made, conclusions relative to this group may be stated as follows:

1. Enough difference exists in the resistance of cylinders of standard Portland cements from different mills to justify specifying particular cements for concrete that must withstand such conditions and also to warrant further investigation regarding the constitution and manufacture of the cements found best qualified to withstand alkali action. The marked differences in resistance of these cements are evidenced by appearances of the cylinders at all ages, by such 3 and 5 year compression tests as have been made, and by actual comparative strength ratios at one year.
2. The resistance of different lots of cement from any plant is fairly constant.

Figure 5 illustrates the variations in resistant properties of cements from different mills.

SPECIAL CEMENTS SHOW LITTLE SUPERIORITY OVER STANDARD BRANDS

Eighteen hundred cylinders fall into this group of 40 series in which were used 12 special cements, and, for comparison tests, 6 standard Portland cements. These cements include the five high early strength cements listed as D, E, F, H, and I, each of the last four of which was tested parallel with its companion Portland cement AA, BB, CC, and I, in the order named; the special cement G, which is Portland cement X specially factory treated for waterproofing qualities; cement B, a reground Portland cement; cement C, which is the same as B with an addition of a carborundrum preparation added during regrinding; cements A1, A2, and A3, which are standard Portland cements to which has been added during the grinding process gypsum treated with tannic acid, of which A2 is standard Portland cement Y, treated; and special cement X, which is an imported mason's cement containing about 30 per cent of diatomaceous silica mixed with the cement clinker before grinding.

None of the 12 special cements forming the basis of Part 3, Table 2 have shown sufficient increased resistance to warrant specifying them for concrete to be exposed to the action of sulphate water. Although it is doubtful, completion of the 5-year tests may possibly make necessary a revision of this statement. The results of tests with special cements are shown in Figure 6.

HIGH ALUMINA CEMENTS SHOW REMARKABLY HIGH RESISTANCE

One American and two French manufactured high alumina cements were used in the experiments for which were made 2,520 concrete and Ottawa sand cylinders in 56 series, covering a rather wide range of curing conditions, a number of mixes, and combinations in different proportions with standard Portland cement. One-year, 3-year, and 5-year compression tests have been completed for cylinders from all 56 series.

These tests have developed the surprising fact that, excepting for the 1:5 mix standard Ottawa sand cylinders of series 280 and 292, the very wet mixed cylinders of series 400, and the cylinders of series 435, 436, and 437, in which were used combinations of high alumina and standard Portland cement, the high alumina cement cylinders in Medicine Lake generally had higher compressive strength at one year than did the check cylinders stored in tap water in the laboratory. At five years the difference in favor of the Medicine Lake cylinders was even more pronounced than at one year as shown by strength ratios of 151 per cent, or greater, for the cylinders of 24 series and of 191 per cent or greater for the cylinders of six series, with a high value of 272 per cent for the cylinders of one series. These high strength ratios are not the result of abnormally high compression tests of the Medicine Lake cylinders at one and five years, but are due to the fact that while the Medicine Lake cylinders increased in strength following the 28-day tests, the check cylinders stored in the tap water in the laboratory decreased in strength. No completely satisfactory explanation can be offered for this. It is known, however, that the reaction to temperature of high alumina cement is considerably different from that of standard Portland cement; and it is entirely probable that the comparatively low temperature of the water of Medicine Lake has afforded conditions more favorable for high alumina cement concrete than has the warmer tap water in the laboratory tank. The following facts, brought out by collateral tests conducted by the laboratory tend to support this view.

(*a*) High alumina cement cylinders buried 4 to 5 feet deep in neutral soils have consistently increased in strength up to five years, with no tests yet available for longer periods.

(*b*) High alumina cement cylinders stored in the laboratory in 1 per cent solutions of sodium sulphate have shown no tendency to test stronger at any age than check cylinders stored in tap water in the same room.

(*c*) High alumina cement cylinders stored in tap water in the laboratory have, in several instances, increased in volume, as measured, as much as 0.6 of 1 per cent. Portland cement cylinders under identical storage conditions have rarely increased in volume as much as 0.1 of 1 per cent, and where, following storage in sulphate solutions, they have increased in volume as much as 0.6 of 1 per cent the compressive strength has been only about 50 per cent of normal.

The general behavior of the high alumina cement cylinders stored in Medicine Lake after periods of exposure up to 6½ years, are briefly summarized in the following paragraph. It should be noted that none of these cylinders have been exposed to frost action, to alternate wetting and drying, or to other than very mild temperatures during the most of the year. Experience has shown that the performance of concrete made with high alumina cement depends to a marked degree on the curing of the concrete, and it should be noted that these specimens were carefully cured.

High alumina cement cylinders stored in the sulphate water of Medicine Lake have displayed remarkable resistance to disintegration as indicated by compression tests up to five years and by visual appearance up to six and one-half years. So pronounced has been this resistance that cylinders from 34 series of a total of 53 series made with only high alumina cement showed higher crushing strength after five years in the lake than they did at one year, while the loss of strength was less than 9 per cent for 10 of the remaining 19 series. Of the other 9, the cylinders of series 142, 147, and 156, which had no air hardening previous to exposure, showed respective strength losses of 10, 15, and 12 per cent; those of series 291 of 1:5 concrete showed a loss of strength of 22 per cent; those of series 254–255 of 1:3 standard Ottawa sand mortar showed a strength loss of 27 per cent. Cylinders of series 280, 292, and 400 were the only ones that have shown any appreciable visual evidence of deleterious action. Cylinders of series 280 and 292 were lean-mixed, 1:5 mortar of standard Ottawa sand with high water cement ratios, and failed the first year. The very wet mixed 1:3 concrete cylinders of series 400 gave a fairly satisfactory 3-year test, although some of the cylinders were then showing considerable action. It is evident from these results that, within the limits of exposure represented by Medicine Lake, the behavior of high alumina cement has, to date, very nearly approached the ideal. Figures 7 and 8 show the excellent results obtained with this material.

SURFACE TREATMENT OR IMPREGNATION GIVES FAIR RESULTS

Comparatively few tests are listed under this heading as this group consists of but 810 cylinders in 18 series, of which 5 are untreated series included for purposes of comparison. Experiments were conducted with but the four products, Inertol, linseed oil, McEverlast, and sulphur. One-year tests have been completed for all 18 series, 3-year tests for 11 series, and 5-year tests for 6 series. On the basis of these limited data the results are very generally summarized as follows:

1. Inertol-tested Medicine Lake cylinders gave 86 per cent of normal strength at 5 years. It is evident that Inertol has appreciably retarded deterioration of the concrete.
2. Linseed oil treated Medicine Lake cylinders of 4 series averaged 97 per cent normal strength at one year and were 95 per cent as strong at three years as at one year.
3. McEverlast-coated Medicine Lake cylinders of 6 series averaged 93 per cent of normal strength at one year.
4. The sulphur treatment accorded the cylinders of series 294 gave negative results as the treated cylinders failed more quickly than did the untreated ones of series 293.

The results obtained with surface-treated or impregnated cylinders are shown in Figure 9.

SOME ADMIXTURES SHOW SLIGHT POSITIVE EFFECT

This is the third largest of the six groups of cylinders discussed in this report and under this heading are the records of 5,031 cylinders in 120 series, of which 26 are series in which no admixture was used, included for purposes of comparison. In the remaining 94 series the following 19 admixtures were used: Alkagel A, barium chloride, Barnsdall Admix. blast furnace slag, Cal, calcium chloride, Celite, Colloy, Earthcrete, powdered fuel ash, Ironite, kerosene, Medusa Waterproofing, oil, Omicron, sulphur, Trass, Truscon, and volcanic ash. Each admixture was added to the batch as an extra ingredient, and, when necessary, the quantity of mixing water was increased to produce the desired workability. The amount of admixture used is expressed, in all cases, as a percentage of the dry weight of the cement. The relatively high temperatures of 100°, 155°, and 212° F. were introduced in the curing of cylinders of certain admixture groups, and, in view of some of the interesting developments, it is regretted that all these temperatures were not used with each of the admixtures as, generally speaking, admixtures in normally cured concrete have not been particularly encouraging.

Most of the admixtures, except as the quantities became excessive, did not greatly influence the compressive strength and absorption of the concrete, although the four admixtures, kerosene, Medusa Waterproofing, oil, and Truscon Waterproofing Paste very definitely reduced absorption. It is not yet known as to what effect on resistance to disintegration this reduction in absorption has had in the case of the kerosene and oil-mixed concretes; but the data of Table 2, Part 6 relating to the other two products clearly show that lowering the absorption of concrete does not, in itself, necessarily increase resistance to the sulphates of sodium and magnesium.

In considering the results obtained with admixtures it is well to keep in mind that in all cases the Portland cement used was a combination of two brands, neither of which had displayed a high degree of resistance to the sulphates of magnesium and sodium. It is believed the test results are truly comparable for the different admixtures but it is admittedly possible that using a more resistant cement might have better emphasized any merit, if slight, actually possessed by a particular product. In other words, starting with a resistant cement, anything that increased resistance of the concrete might have displayed considerable better net value than the same treatment accorded concrete in which was used a cement of low resistance. There follows a brief summary of results obtained with each admixture.

1. Alkagel A is the trade name of a colloidal paste of copper and iron soaps, together with paraffin, which smells strongly of ammonia and loses 81 per cent of its weight on drying. Under the condition of these tests this product proved valueless.
2. Barium chloride was without value when 6 per cent was used; and 12 per cent was only of slight value.
3. Barnsdall Admix is described as a "pure, finely ground, meta-colloidal Tripoli silica." According to published analyses it is about 97 per cent silica. It was used in quantities varying from 3.75 to 30 per cent and in 1:3, 1:2:3, and 1:2:4 concretes. Two aggregates and three brands of Portland cement were used in these experiments. This material does not appear to have appreciably influenced the resistance of any of the specimens in which it was used, as indicated by tests at one year.
4. Blast furnace slag ground, screened and recombined in proportions of one part passing the No. 100, and retained on the No. 200 sieve, and five parts passing the No. 200 sieve, slightly increased resistance when 10 per cent was used, and gave nominally better results when 40 per cent was used, in normally cured cyclinders. The cylinders of series 161 cured 48 hours at 155° F. in which was used 40 per cent of blast furnace slag, tested 48 per cent of normal strength at five years. These were the only cylinders of this group that showed real improvement.

5. Cal is a material obtained by pulverizing the dried or undried product resulting from a mixture of either quicklime or hydrated lime, calcium chloride, and water.[5] Additions of 4 or 8 per cent to cylinders normally cured slightly increased resistance with little in favor of 8 per cent. Additions of 4 and 8 per cent to cylinders cured at 155° F. markedly increased resistance, giving 5-year strength ratios of 82 and 93 per cent, respectively.

6. Calcium chloride gave substantially the same results as did Cal, except that 4 per cent made slightly better showings than did 8 per cent. Additions of 4 and 8 per cent to cylinders cured at 155° F. gave 5-year strength ratios of 84 and 82 per cent, respectively.

7. Celite is a diatomaceous silica that did not appreciably increase the resistance of any of the cylinders in which it was used.

8. Colloy is a fine grained siliceous material containing about 30 per cent alumina. It did not appreciably increase the resistance of any of the cylinders in which it was used.

9. Earthcrete is a powder that, used in proportions of 0.27 and 1.06 per cent, did not appreciably increase the resistance of any of the cylinders in which it was used.

10. Powdered fuel ash used in the proportion of 2½, 5, and 10 per cent did not increase the resistance of any of the cylinders in which it was used.

11. Ironite is the trade name for a finely ground product of heavy unit weight, consisting largely of iron and iron oxide with some ammonium chloride. Twenty per cent of it appreciably increased the resistance of three series of cylinders in which it was used. A strength ratio of 27 per cent at five years was obtained for normal curing conditions, 87 per cent when cured at 100° F., and 94 per cent when cured at 155° F.

12. Kerosene used in quantities of 1, 2, 4, and 8 per cent appreciably reduced absorption of the cylinders; but, in proportions under 8 per cent, it had slight effect on the 28-day strength. Use of 8 per cent decreased the strength. Its effect on resistance to disintegration has not yet been determined.

13. Medusa Waterproofing, a powdered product used in proportions of 1, 2, and 4 per cent, has not increased resistance, if the tests at one year may be taken as conclusive. This is true in spite of the fact that absorption of the cylinders decreased as the quantity of the admixture was increased.

14. Medium grade automobile oil, used in quantities of 1, 2, 4, and 8 per cent, greatly reduced absorption of the cylinders, but, in proportions under 8 per cent, it had slight effect on the 28-day strength. Use of 8 per cent decreased the strength. Its effect on resistance to distintegration has not yet been determined.

15. Omicron, a powdered product used in proportions of 3.75 and 7.5 per cent, did not appreciably increase resistance. When used in proportions of 15 and 30 per cent it made fairly favorable showings at one year with strength ratios of 62 and 89 per cent, respectively, although these cylinders show considerable action. (See fig. 12, left.)

16. Sulphur used in proportion of 10 per cent gave negative results.

17. Trass is a fine silicous material of volcanic origin, containing some 20 per cent alumina which, added in proportions of 33 and 66 per cent to cylinders mixed 1:3, 1:4, and 1:5, somewhat retarded disintegration as indicated by tests at one, three, and five years.

18. Truscon Waterproofing Paste, concentrated, added in proportions of 1, 2, and 4 per cent, did not appreciably increase the resistance of any of the cylinders in which it was used, although absorption of the cylinders decreased as the quantity of the admixture was increased. Those cylinders with 4 per cent of Truscon had an absorption only 59 per cent that of cylinders without any admixture.

19. Volcanic ash from west-central Nebraska added in proportion of 20 per cent did not appreciably increase the resistance of those cylinders normally cured. The results were only slightly more favorable for the cylinders cured at temperatures of 100° and 155° F.

Figures 10, 11, and 12 illustrate the results obtained from the use of the various admixtures.

RESULTS OF INVESTIGATION SUMMARIZED

The essentials of the foregoing conclusions as to the influence of the various factors considered, on the resistance of concrete to the sulphate water of Medicine Lake, are condensed into the following statements:

1. Resistance has been markedly increased by curing in water vapor at temperatures of 212° F. and upward, almost to the point of immunity to action for the most favorable temperatures and curing periods.

2. Enough difference exists in the resistance of standard Portland cements from different mills to justify specifying particular cements for concrete to be subjected to these special conditions of exposure.

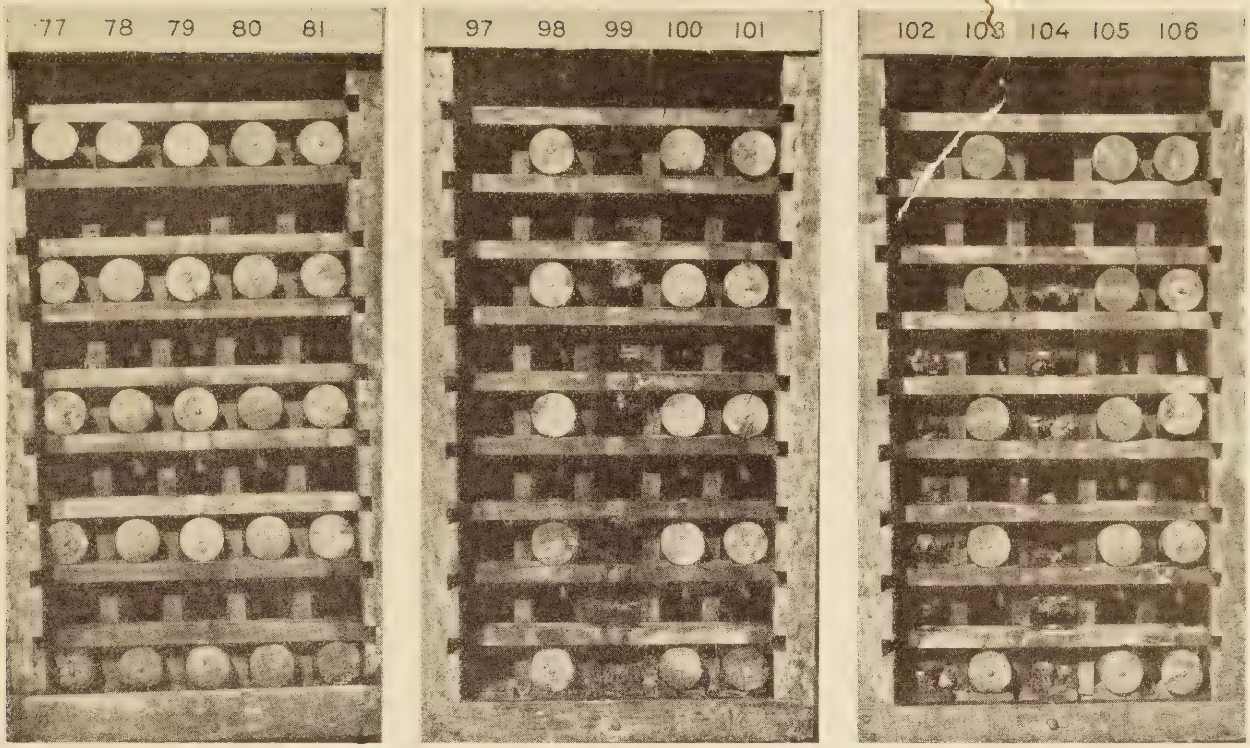
3. Special cements, other than high alumina, have been of little or no value.

4. Within the limits of exposure conditions represented by these tests, the behavior of high alumina cement has to date very nearly approached the ideal.

5. From the results of tests up to three years it appears that surface treatments of linseed oil have been of considerable value, with indications that later tests may be less favorable. The Interol treatment was of appreciable value up to five years. The McEverlast treatment showed up favorably at one year, but displayed surface indications of less favorable results at three years and later.

6. Only the four admixtures, Cal, calcium chloride, Ironite, and Trass, appreciably retarded action on normally cured concrete, and these to very limited degrees. The use, however, of Cal, calcium chloride, and Ironite in cylinders cured 48 hours in water vapor at temperatures of 155° F. increased resistance to such a degree that at five years cylinders containing 8 per cent of Cal had 93 per cent normal strength, those containing 4 per cent calcium chloride had 84 per cent, and those containing 20 per cent Ironite had 94 per cent. Cylinders of the latter type cured at 100° F. had 87 per cent of normal strength at five years. Some benefit was also noted by curing at 100° and 155° F. cylinders containing 20 per cent of volcanic ash. Appreciably increased resistance following curing at temperatures of 100° and 155° F. has only been noted in the cylinders containing these admixtures. This suggests the practical possibility of a combination of certain admixtures and moderately high curing temperatures for concrete products to be subjected to the action of sulphate waters.

[5] Technologic Paper No. 174, U. S. Bureau of Standards.

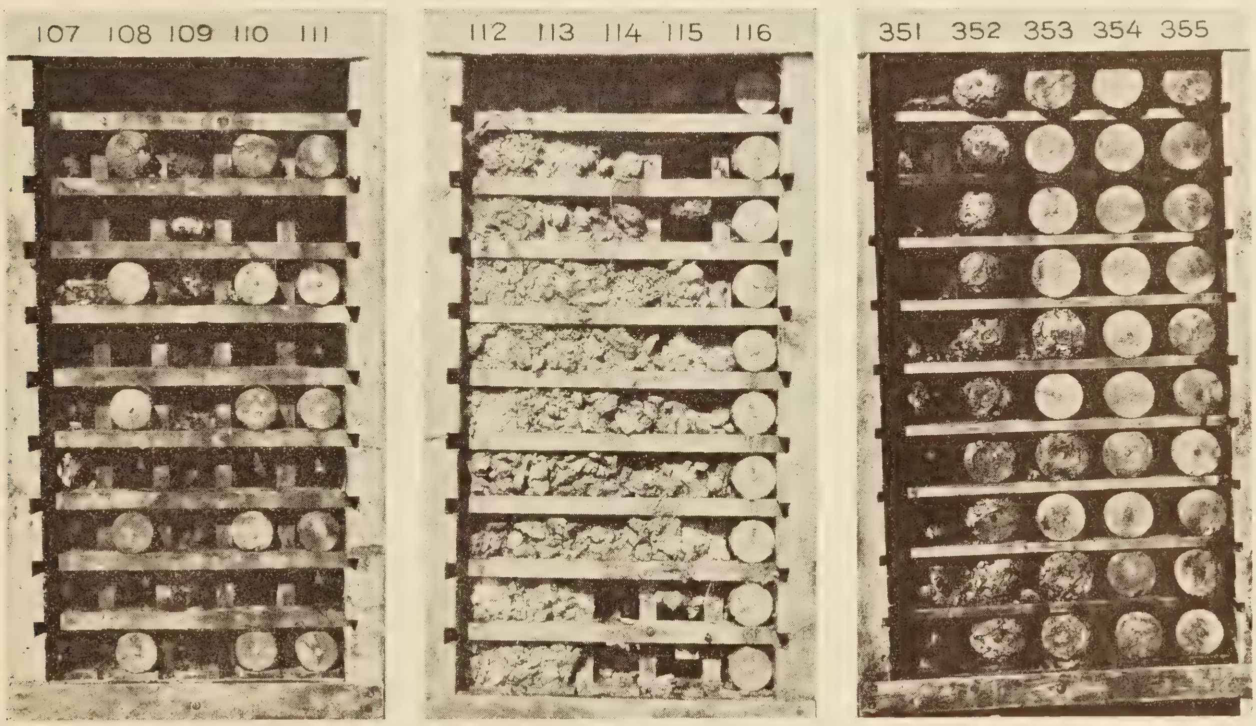


Cylinders cured in steam at 212° F., after six and one-half years in lake

Cylinders cured in water vapor at 155° F., after six and one-half years in lake. Series 98, 100 and 101 received additional curing in steam at 212° F.

Cylinders cured in water vapor at 155° F., after six and one-half years in lake. Series 103, 105 and 106 received additional curing in steam at 212° F.

Figure 3.—Cylinders of Various Series Cured in Water Vapor or Steam, After Six and One-Half Years in Lake. All the Cylinders in Any Vertical Row Are of the Same Series and the Series Number is Shown at the Top

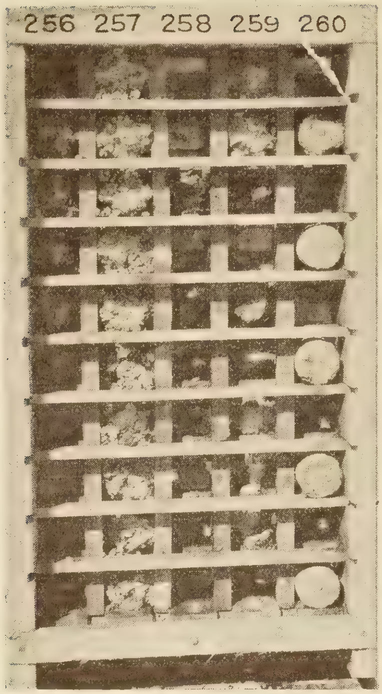


Ottawa sand mortar cylinders cured in water vapor at 155° F., after six and one-half years in lake. Series 108, 110, and 111 received additional curing in steam at 212° F.

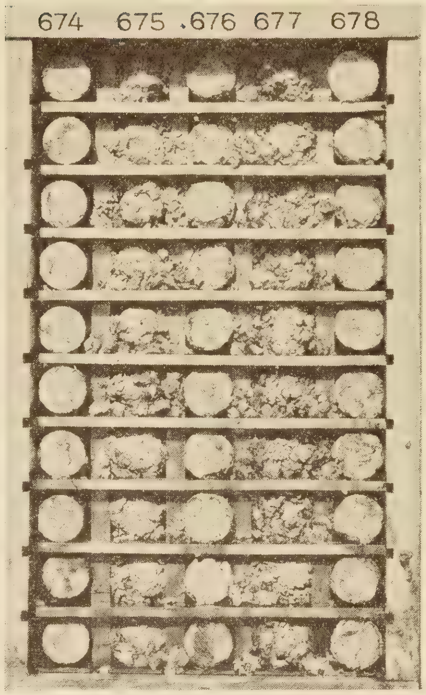
Ottawa sand mortar cylinders cured as follows, after four years in lake:
- Series 112.—Moist closet, 24 hours, tap water 27 days
- Series 113.—Moist closet, 72 hours, air 25 days
- Series 114.—Moist closet, 24 hours, water vapor at 100° F., 48 hours, air 25 days
- Series 115.—Moist closet, 24 hours, water vapor at 155° F., 48 hours, air 25 days
- Series 116.—Moist closet, 24 hours, steam at 212° F., 48 hours, air 25 days

Cylinders cured in water vapor or steam for 12 hours at the following temperatures, after five years in lake:
- Series 351.—190° F.
- Series 352.—212° F.
- Series 353.—235° F.
- Series 354.—260° F.
- Series 355.—285° F.

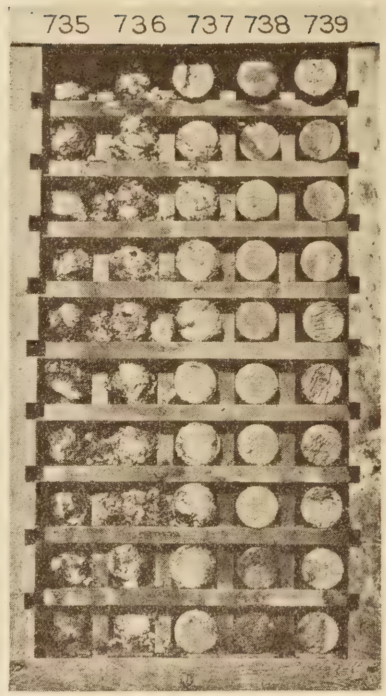
Figure 4.—Cylinders Illustrating the Effects of Curing in Water Vapor and Steam



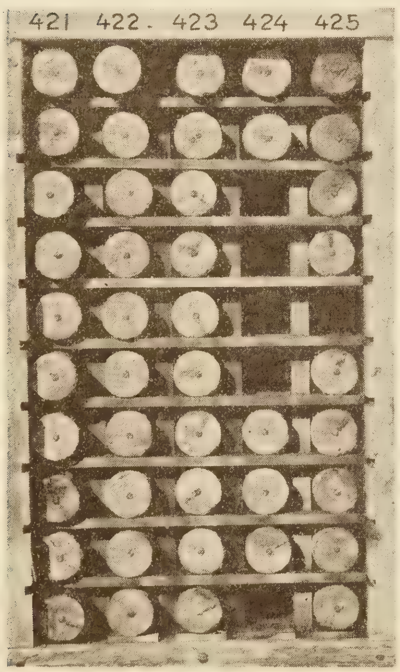
Cylinders made from different brands of standard Portland cement, after five and one-half years in lake



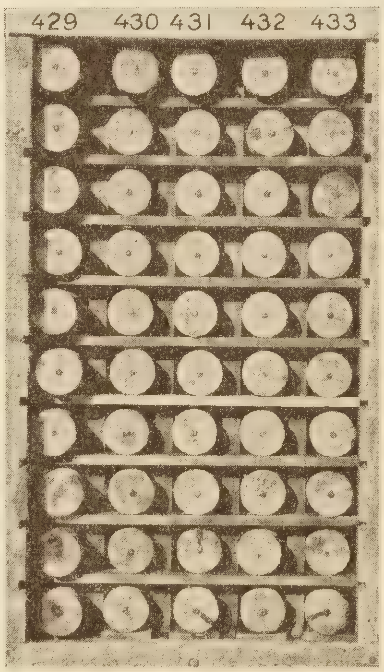
Cylinders made from different brands of standard Portland cement and cured in distilled water 20 days, air 35 days, after three years in lake



Cylinders made from different brands of standard Portland cement and cured in distilled water 20 days, air 35 days, after two years in lake



Neat cement cylinders made from different brands of standard Portland cement, after four years in lake

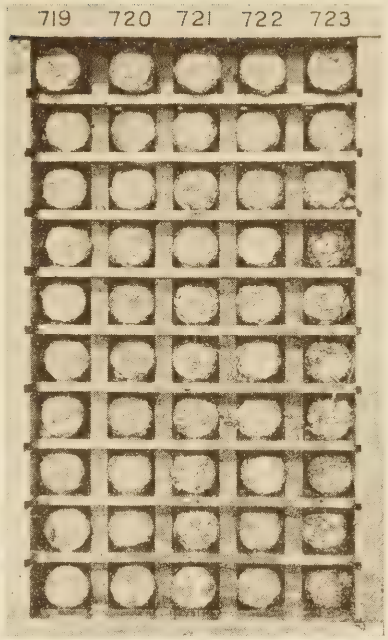


Series 429, neat cement cylinders made from high alumina cement B; series 430–433, concrete cylinders made from different brands of Portland cement, after four years in lake

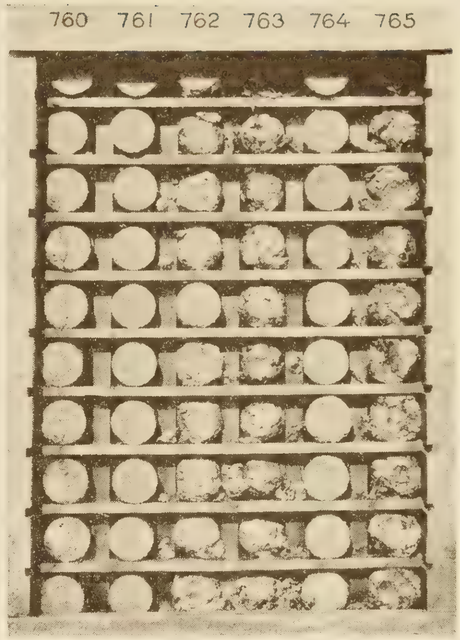
Cylinders of different brands of standard Portland cement cured in distilled water 20 days, after three years in lake

FIGURE 5.—COMPARISON OF CYLINDERS MADE FROM DIFFERENT BRANDS OF PORTLAND CEMENT

Cylinders made up as follows, after three years in lake:
Series 554—One-half Portland A, one-half Portland B
Series 555 and 557.—Portland Y
Series 556 and 558.—Special A2



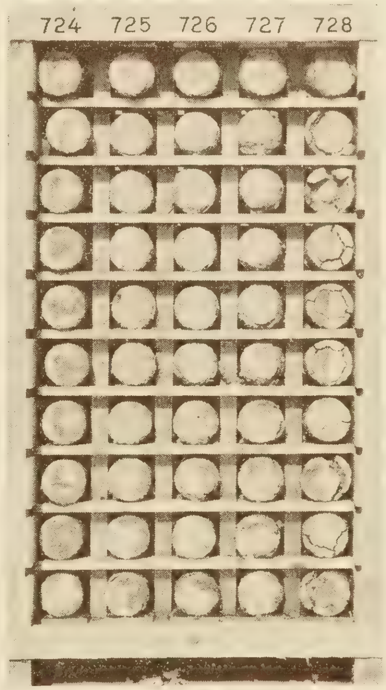
Cylinders made up in following proportions by volume, after three years in lake: Series 719—1:0.94; series 720—1:1.88; series 721—1:1.88; series 722—1:2.82; series 723—1:4.70



Cylinders of series 761, 763, and 765 made from standard Portland cement; series 760, 762, and 764 made from special cements from the same mills, respectively. After one and one-half years in lake

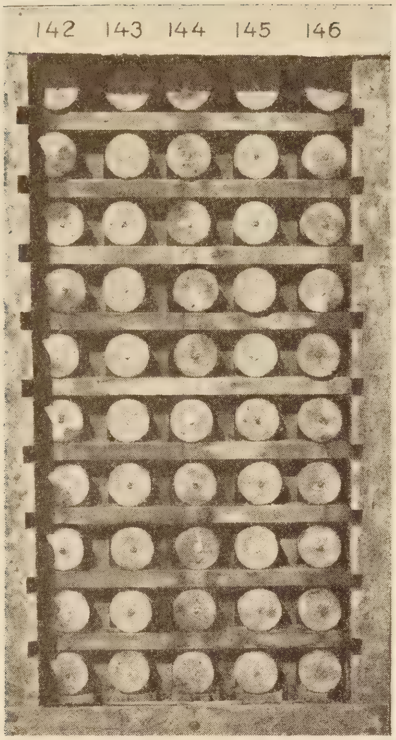
Series 559, 560, and 562, sand cylinders made from standard Portland cement; series 561 and 563, sand cylinders made from special cement A2. After two years in lake

Series 573 and 574 made from special cements; series 575 to 577 made from standard Portland cements. After three years in lake

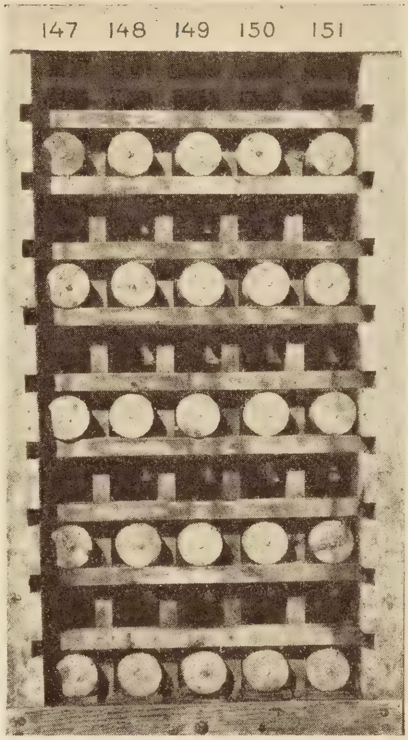


Ottawa sand mortar cylinders made with special cement X in following proportions by volume, after three years in lake: Series 724—1:0.94; series 725—1:1.88; series 726—1:1.88; series 727—1:2.82; series 728—1:4.70

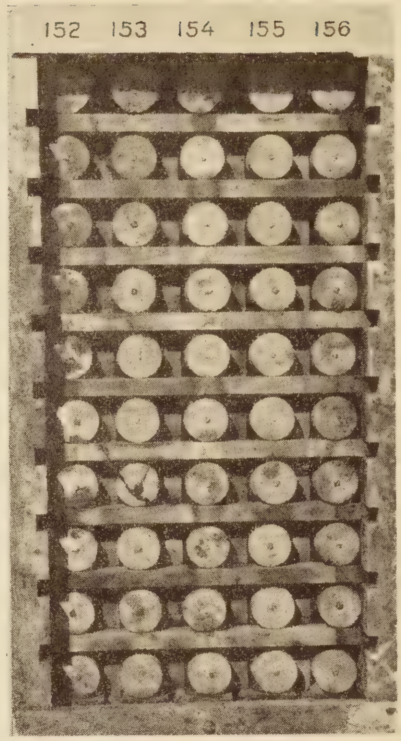
Figure 6.—Results Obtained With Cylinders Made From Special Cements Other Than High Alumina



Ottawa sand mortar cylinders made from high alumina cement A, cured as follows, after six years in lake:
Series 142.—Distilled water, 27 days
Series 143.—Moist air, 72 hrs.
Series 144.—Water vapor at 100° F., 48 hrs.
Series 145.—Water vapor at 155° F., 48 hrs.
Series 146.—Steam at 212° F., 48 hrs.



Cylinders made from high alumina cement A, cured as follows, after six years in lake:
Series 147.—Distilled water, 27 days
Series 148.—Moist air, 72 hours
Series 149.—Water vapor at 100° F., 48 hrs.
Series 150.—Water vapor at 155° F., 48 hrs.
Series 151.—Steam at 212° F., 48 hrs.



Cylinders made from high alumina cement A, cured as follows, after six years in lake:
Series 152.—Distilled water 20 days, dry air 344 days
Series 153.—Distilled water 20 days, dry air 56 days
Series 154.—Distilled water 20 days, dry air 28 days
Series 155.—Distilled water 20 days, dry air 14 days
Series 156.—Distilled water 20 days

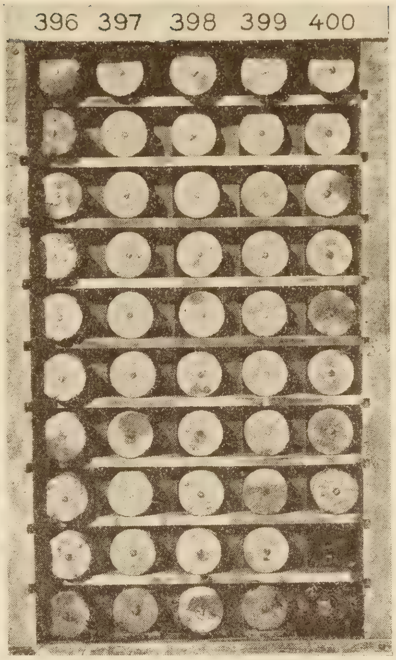
Cylinders made from high alumina cement C, after five and one-half years in lake

Ottawa sand mortar cylinders made from high alumina cement B in following proportions by volume, after five years in lake: Series 276—1: 2; series 277—1:3; series 278—1:3; series 279—1:4; series 280—1: 5

Cylinders made from high alumina cement B in following proportions by volume after five years in lake: Series 286—1: 2; series 287—1: 3; series 288—1: 3; series 289—1: 4; series 290—1: 5

FIGURE 7.—RESULTS OBTAINED WITH CYLINDERS MADE FROM HIGH ALUMINA CEMENTS

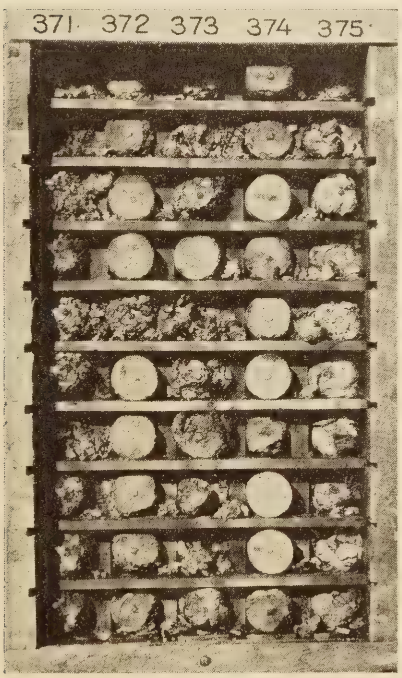
Cylinders made up as follows, after five years in lake:
Series 291.—High alumina C, 1:5 concrete
Series 292.—High alumina C, 1:5 mortar
Series 293.—Portland cement mortar
Series 294.—Portland cement mortar, sul phur impregnated
Series 295.—Portland cement mortar, 10 per cent sulphur admixed



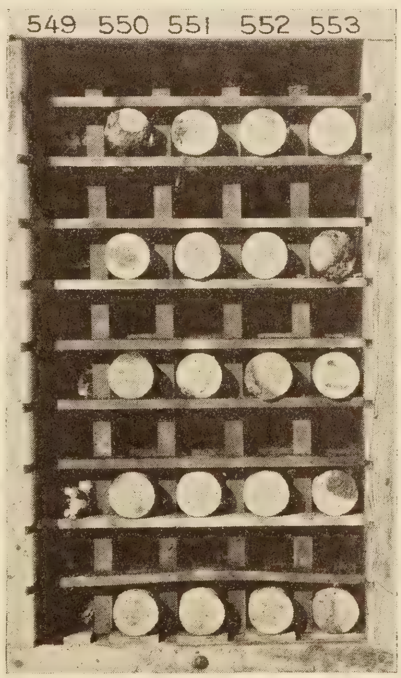
Cylinders made from high alumina cement B with various consistencies, as follows, after five years in lake:
Series 396.—Relative consistency 0.75, water ratio 0.44
Series 397.—Relative consistency 0.90 water ratio 0.53
Series 398.—Relative consistency 1.00, water ratio 0.59
Series 399.—Relative consistency 1.25, water ratio 0.73
Series 400.—Relative consistency 1.50, water ratio 0.88

Cylinders using a mixture of Portland cement and high alumina cement B in the following proportions, after four years in lake:
Series 434.—100 per cent Portland
Series 435.—5 per cent high alumina B; 95 per cent Portland
Series 436.—10 per cent high alumina B; 90 per cent Portland
Series 437.—20 per cent high alumina B; 80 per cent Portland
Series 438.—100 per cent high alumina B

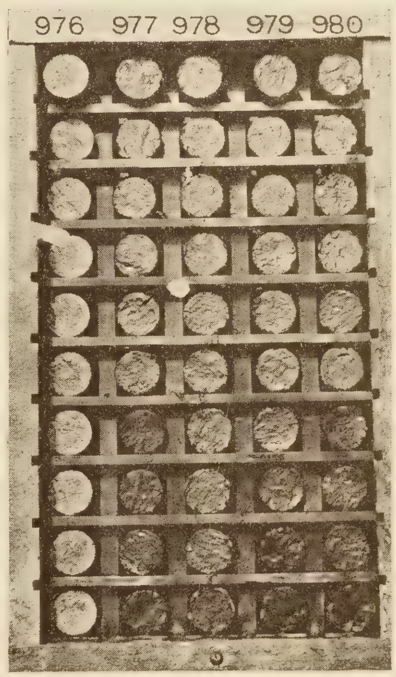
FIGURE 8.—VARIOUS COMPARISONS SHOWING FAVORABLE RESULTS OBTAINED WITH HIGH ALUMINA CEMENTS



Series 371 to 373, concrete cylinders made from standard Portland cement; series 374 and 375, concrete and mortar cylinders, respectively, treated with Inertol. After four and one-half years in lake



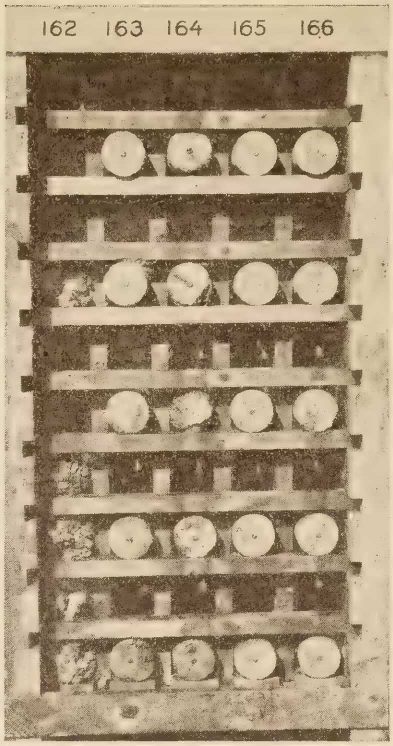
Cylinders surface-treated as follows, after three and one-half years in lake:
Series 549.—Boiling water ½-minute
Series 550.—Linseed oil, 70° F., ½-minute (1 coat)
Series 551.—Linseed oil, 70° F., ½-minute (2 coats)
Series 552.—Linseed oil, 225° F., ½-minute (1 coat)
Series 553.—Linseed oil, 225° F., ½-minute (2 coats)



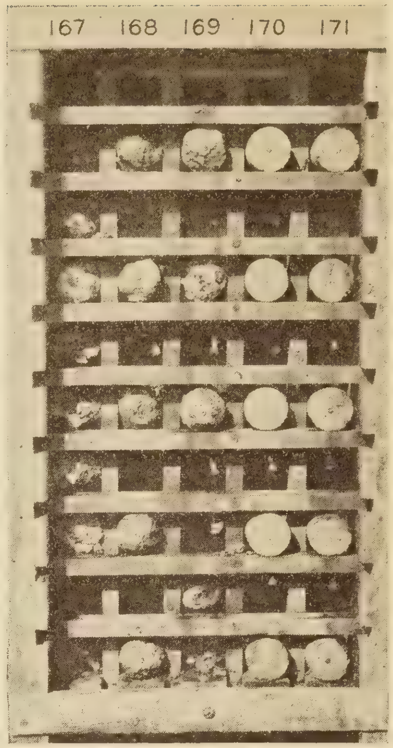
Cylinders with McEverlast protective coatings, after one year in lake

FIGURE 9.—RESULTS OBTAINED FROM SURFACE-TREATED OR IMPREGNATED CYLINDERS

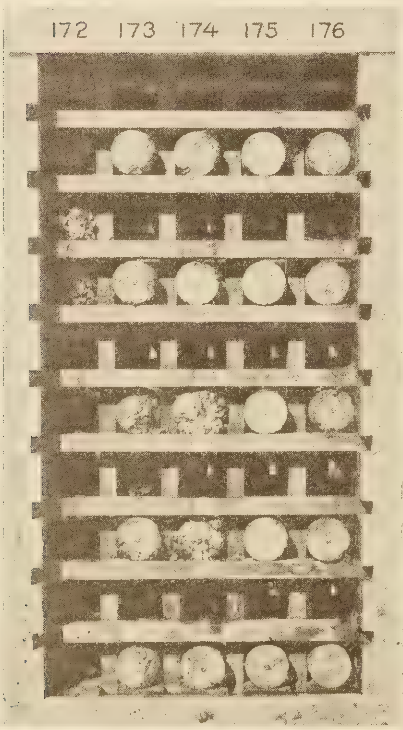
Cylinders with blast furnace slag admixed in following proportions, after five years in lake:
Series 157.—40 per cent
Series 158.—10 per cent
Series 159.—40 per cent
Series 160.—10 per cent (cured in water vapor at 155° F., 48 hrs.)
Series 161.—40 per cent (cured in water vapor at 155° F., 48 hrs.)



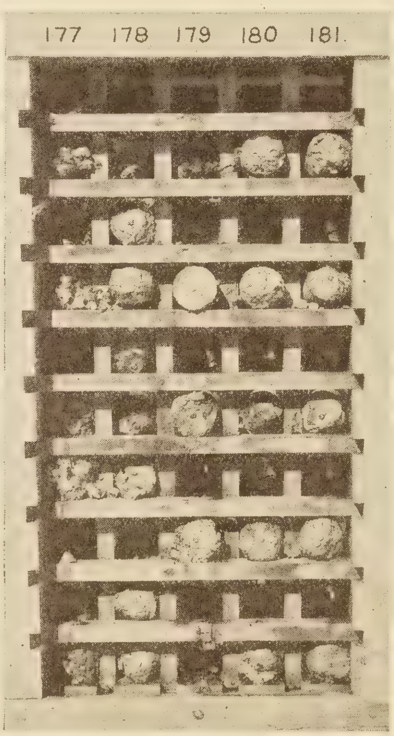
Cylinders with calcium chloride admixed in following proportions, after six years in lake:
Series 162.—4 per cent
Series 163.—8 per cent
Series 164.—4 per cent
Series 165.—8 per cent (cured in water vapor at 155° F., 48 hrs.)
Series 166.—4 per cent (cured in water vapor at 155° F., 48 hrs.)



Cylinders with Cal admixed and cured as follows, after six years in lake:
Series 167.—4 per cent
Series 168.—8 per cent
Series 169.—4 per cent
Series 170.—8 per cent (cured in water vapor at 155° F., 48 hrs.)
Series 171.—4 per cent (cured in water vapor at 155° F., 48 hrs.)



Cylinders with Ironite admixed in following proportions, after six years in lake:
Series 172.—No admixture
Series 173.—20 per cent
Series 174.—No admixture (cured in water vapor at 155° F., 48 hrs.)
Series 175.—20 per cent (cured in water vapor at 155° F., 48 hrs.)
Series 176.—20 per cent (cured in water vapor at 100° F., 48 hrs.)

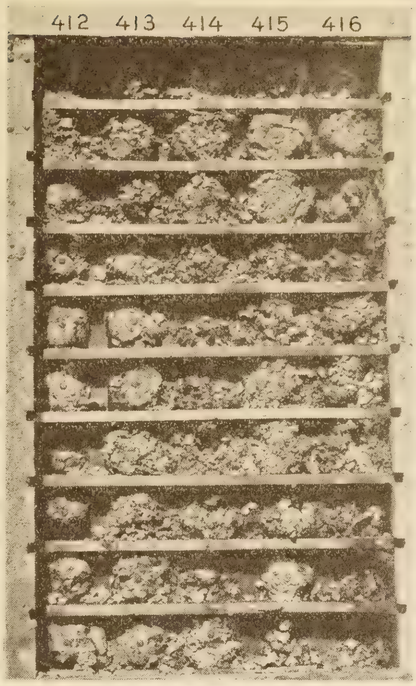


Cylinders with volcanic ash admixedin following proportions, after six years in lake:
Series 177.—No admixture
Series 178.—20 per cent
Series 179.—No admixture (cured in water vapor at 155° F., 48 hrs.)
Series 180.—20 per cent (cured in water vapor at 155° F., 48 hrs.)
Series 181.—20 per cent (cured in water vapor at 100° F., 48 hrs.)

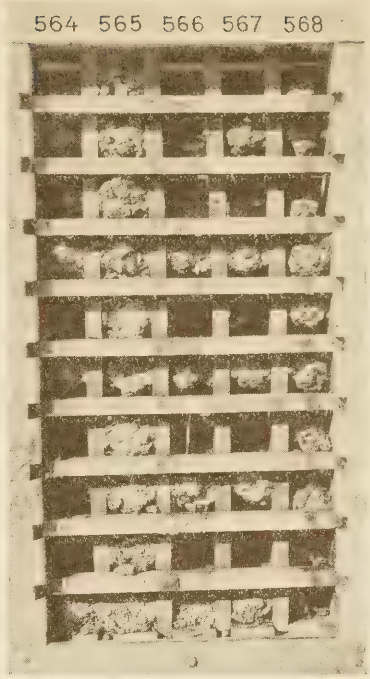
Cylinders with Alkagel "A" admixed in following proportions, after five years in lake:
Series 182.—No admixture
Series 183.—3 per cent
Series 184.—No admixture (cured in water vapor at 155° F., 48 hrs.)
Series 185.—3 per cent (cured in water vapor at 155° F., 48 hrs.)
Series 186.—3 per cent (cured in water vapor at 100° F., 48 hrs.)

Figure 10.—Results Obtained by the Use of Various Admixtures

Cylinders with Trass admixed as follows, after four and one-half years in lake:
Series 391.—No admixture
Series 392.—33 per cent
Series 393.—66 per cent
Series 394.—33 per cent
Series 395.—66 per cent

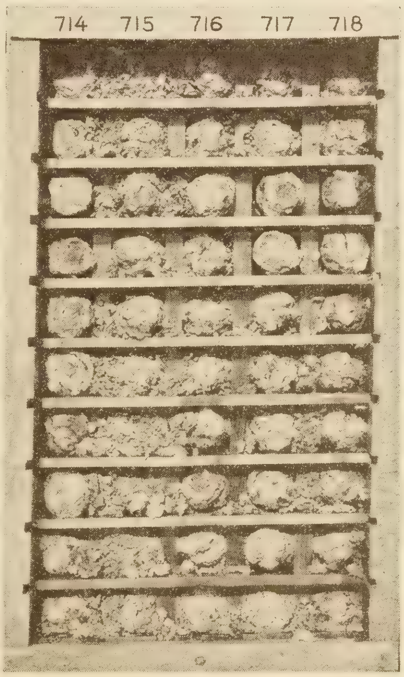


Cylinders of Series 412, 2½ per cent Celite admixed; cylinders of Series 413 to 416 made from different brands of standard Portland cement. After three years in lake

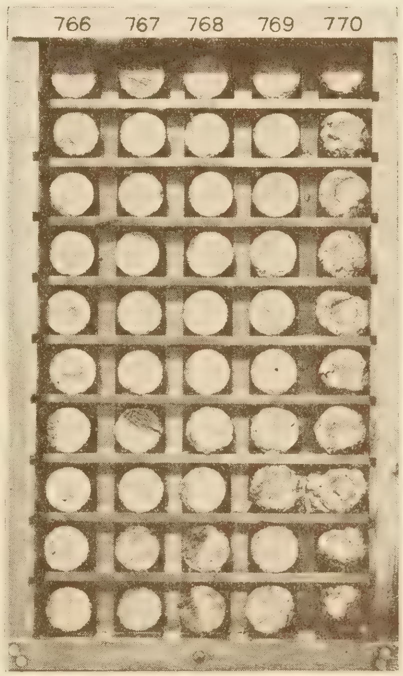


Cylinders with powdered fuel ash admixed as follows, after three years in lake:
Series 564 and 565.—2.5 per cent
Series 566.—5 per cent
Series 567 and 568.—10 per cent

Cylinders with Truscon and $BaCl_2$ admixed as follows, after three years in lake:
Series 578.—1 per cent Truscon
Series 579.—2 per cent Truscon
Series 580.—4 per cent Truscon
Series 581.—6 per cent $BaCl_2$
Series 582.—12 per cent $BaCl_2$

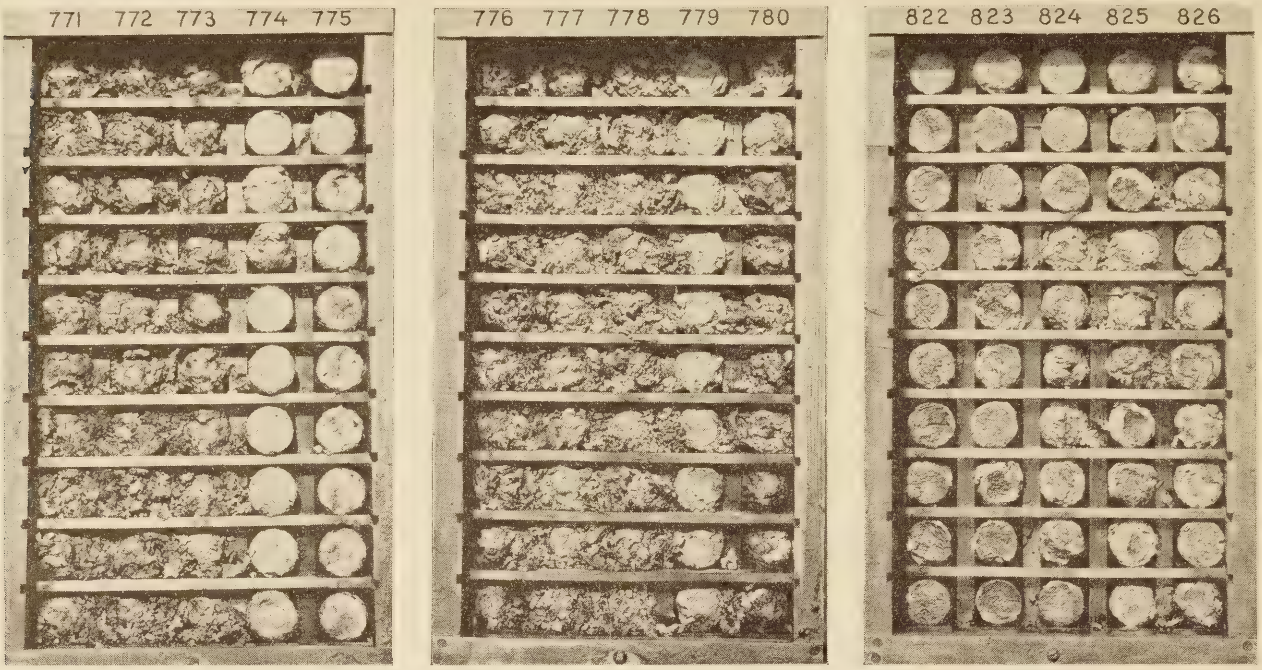


Cylinders made from special cement D and cylinders with Earthcrete admixed, after three years in lake:
Series 714.—Special cement D, distilled water 20 days, air 35 days
Series 715.—Portland cement, distilled water 20 days, air 35 days
Series 716.—Portland cement, 0.27 per cent Earthcrete, distilled water 20 days, air 35 days
Series 717.—Portland cement, 1.06 per cent Earthcrete, distilled water 20 days, air 35 days
Series 718.—Portland cement, 0.27 per cent Earthcrete, water vapor at 155° F., 48 hrs., air 53 days



Cylinders of Series 767 and 769 were made from standard Portland cement. Series 766 and 768 were made from special cements from the same respective mills. Series 770 contained a 2 per cent admixture of Medusa waterproofing. After one and one-half years in lake

Figure 11.—Results Obtained by the Use of Various Admixtures



Cylinders with Omicron, admixed as follows, after one and one-half years in lake:
Series 771.—No admixture
Series 772.—3.75 per cent
Series 773.—7.5 per cent
Series 774.—15 per cent
Series 775.—30 per cent

Cylinders with Colloy and Medusa waterproofing admixed as follows, after one and one-half years in lake:
Series 776.—No admixture
Series 777.—2 per cent Colloy
Series 778.—4 per cent Colloy
Series 779.—1 per cent Medusa waterproofing
Series 780.—4 per cent Medusa waterproofing

Cylinders with Barnsdall admixed as follows, after one year in lake:
Series 822.—No admixture
Series 823.—3.75 per cent
Series 824.—7.5 per cent
Series 825.—15 per cent
Series 826.—30 per cent

FIGURE 12.—RESULTS OBTAINED BY THE USE OF VARIOUS ADMIXTURES

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1:3. Each test result, with a few exceptions, is an average of five cylinders made on different days]

PART 1.—CURING IN WATER VAPOR OR STEAM BETWEEN TEMPERATURES OF 100° AND 365° F.

Series No.	Cement laboratory No.	Cement	Water ratio	Curing method					Absorption at 21 days	Average of compression tests								
										Tank specimens				Lake specimens				
				Time in moist closet	Time in water	Time in water vapor or steam	Temperature of water vapor or steam	Time in air		7 days	28 days	1 year	5 years	1 year	Percentage of normal strength as indicated by tank specimens at 1 year	3 years	5 years	Percentage of normal strength as indicated by tank specimens at 5 years
				Hours	*Days*	*Hours*	°*F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
87	11	½ Portland A, ½ Portland B	0.59	3	------	69	100	25	6.6	3,730	4,120	5,110	5,470	1,430	28	0	0	---------
88	11	do	.59	6	------	66	100	25	6.7	3,590	4,320	4,960	5,450	1,370	28	0	0	---------
89	11	do	.59	12	------	60	100	25	6.7	4,050	4,680	5,270	5,200	1,290	25	0	0	---------
90	11	do	.59	24	------	48	100	25	6.7	4,080	4,220	5,240	6,270	1,630	31	0	0	---------
91	11	do	.59	48	------	24	100	25	6.8	3,510	4,060	5,010	4,970	1,920	38	0	0	---------
92	11	do	.59	24	27	--------	--------	28	6.7	2,620	4,540	5,690	5,400	3,780	66	0	0	---------
93	11	do	.59	72	------	--------	--------	25	7.0	3,380	3,560	5,120	5,140	3,150	62	0	0	---------
94	11	do	.59	24	------	48	100	25	6.8	3,810	4,000	5,640	5,910	2,020	36	0	0	---------
313	65	M	.60	24	20	--------	--------	35	5.9	3,150	3,950	6,050	5,680	2,250	37	0	0	---------
315	65	do	.60	24	------	48	100	53	6.2	3,740	3,800	5,970	6,320	4,230	71	3,390	3,330	53
[1] 112	17	½ Portland A, ½ Portland B	.64	24	27	--------	--------	------	10.0	1,650	2,630	3,540	2,790	1,790	51	0	0	---------
[1] 113	17	do	.64	72	------	--------	--------	25	10.7	2,000	2,000	2,980	2,940	840	28	0	0	---------
[1] 114	17	do	.64	24	------	48	100	25	10.1	2,270	2,790	3,040	3,050	630	21	0	0	---------
82	11	do	.59	3	------	69	155	25	6.9	3,360	4,210	5,380	5,550	500	9	0	0	---------
83	11	do	.59	6	------	66	155	25	6.9	3,840	4,720	5,700	5,620	490	9	0	0	---------
84	11	do	.59	12	------	60	155	25	6.7	4,440	4,960	5,250	5,920	1,030	20	0	0	---------
85	11	do	.59	24	------	48	155	25	6.6	4,350	4,550	6,460	5,830	1,220	19	0	0	---------
86	11	do	.59	48	------	24	155	25	6.7	3,540	4,210	6,250	6,320	1,660	27	0	0	---------
92	11	do	.59	24	27	--------	--------	28	6.7	2,620	4,540	5,690	5,400	3,780	66	0	0	---------
93	11	do	.59	72	------	--------	--------	25	7.0	3,380	3,560	5,120	5,140	3,150	62	0	0	---------
95	11	do	.59	24	------	48	155	25	6.4	4,240	4,370	5,510	5,510	1,660	30	0	0	---------
97	11, 8	do	.59	24	------	48	155	25	6.3	3,900	4,770	5,690	5,970	1,880	33	0	0	---------
99	11, 8	do	.59	24	------	72	155	24	6.4	4,490	4,830	5,410	5,990	1,530	28	0	0	---------
102	17	do	.59	24	------	48	155	25	6.2	4,550	4,730	5,580	5,960	980	18	0	0	---------
104	17	do	.59	24	------	72	155	24	6.1	4,910	5,180	5,180	5,630	1,270	25	0	0	---------
174	18	do	.59	24	------	48	155	35	6.1	4,020	4,390	4,330	5,650	3,910	90	--------	2,740	48
179	18	do	.59	24	------	48	155	35	5.8	4,110	4,510	5,210	6,460	3,820	73	--------	1,750	27

[1] Standard Ottawa sand cylinders.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 1.—CURING IN WATER VAPOR OR STEAM BETWEEN TEMPERATURES OF 100° AND 365° F.—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor or steam	Curing method: Temperature of water vapor or steam	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
				Hours	Days	Hours	°F.	Days	Per cent	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.		Lbs. per sq. in.	Lbs. per sq. in.	
184	18	½ Portland A, ½ Portland B	0.59	24		48	155	35	6.0	4,070	4,530	5,100	6,110	4,240	83		800	13
313	65	M	.60	24	20			35	5.9	3,150	3,950	6,050	5,680	2,250	37	0	0	
314	65	do	.60	24		48	155	53	6.0	4,460	4,010	6,170	6,810	5,430	88	3,920	3,690	54
[1] 107	17	½ Portland A, ½ Portland B	.64	24		48	155	25	9.8	2,660	3,080	3,580	3,580	770	22	0	0	
[1] 109	17	do	.64	24		72	155	24	9.6	2,670	3,220	3,490	3,580	930	27	0	0	
[1] 112	17	do	.64	24	27				10.0	1,650	2,630	3,540	2,790	1,790	51	0	0	
[1] 113	17	do	.64	72				25	10.7	2,000	2,000	2,980	2,940	840	28	0	0	
[1] 115	17	do	.64	24		48	155	25	10.1	2,730	2,900	3,400	3,020	860	25	0	0	
[1] 127	17	do	.64	24		48	155	53	9.1	2,530	2,710	3,460	3,290	2,280	66		0	
[1] 129	17	do	.64	24		72	155	52	9.0	2,700	3,120	3,320	3,230	1,970	59		0	
351	74	do	.62	24		12	190	54	6.6	2,650	2,940	5,320	6,870	1,730	33	0	0	
391	74	do	.62	24	20			35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	
77	11	do	.59	3		69	212	25	7.9	1,110	1,250	1,250	2,810	1,210	97	1,340	2,630	94
78	11	do	.59	6		66	212	25	7.2	2,260	3,040	3,130	5,900	2,840	91	2,930	4,120	70
79	11	do	.59	12		60	212	25	6.9	3,400	4,120	4,550	6,020	4,410	97	4,940	5,400	90
80	11	do	.59	24		48	212	25	6.9	3,060	4,020	4,600	5,790	4,330	94	4,860	5,150	89
81	11	do	.59	48		24	212	25	6.7	2,910	3,850	4,630	6,730	4,410	95	5,340	6,000	89
92	11	do	.59	24	27			28	6.7	2,620	4,540	5,690	5,400	3,780	66	0	0	
96	11	do	.59	24		48	212	25	6.5	3,770	4,410	4,560	5,720	4,300	94		4,930	86
98	11, 8	do	.59	24		24 24	155 212	25	6.7	4,180	4,120	5,020	6,190	4,340	87		5,310	86
100	11, 8	do	.59	24		48 24	155 212	24	6.2	4,310	4,960	5,730	5,750	5,540	97		5,890	102
101	11, 8	do	.59	24		24 48	155 212	24	6.3	4,110	4,710	4,890	6,490	4,640	95		5,330	82
103	17	do	.59	24		24 24	155 212	25	6.0	4,600	5,510	5,290	6,280	4,980	94	5,510	4,910	78
105	17	do	.59	24		48 24	155 212	24	6.0	4,820	5,070	4,910	6,720	5,220	106	6,000	5,680	85
106	17	do	.59	24		24 48	155 212	24	5.7	5,110	5,900	5,320	6,020	5,250	99	5,830	5,720	95
296	61	do	.62	24		48	212	53	6.5	3,330	3,660	5,020	5,760	4,390	88	5,840	5,950	103
297	63	Portland A	.60	24		48	212	53	6.4	3,650	3,660	4,680	6,020	4,600	98	4,960	5,480	91
298	62	Portland B	.62	24		48	212	53	6.9	3,700	3,830	4,580	6,440	4,480	98	4,840	5,600	87
299	33	Portland D	.60	24		48	212	53	6.4	3,690	3,770	4,620	6,330	4,270	92	4,910	5,900	93
300	34	Portland C	.67	24		48	212	53	6.6	3,880	4,540	4,940	6,110	4,890	99	5,690	5,810	95
301	61	½ Portland A, ½ Portland B	.62	24		48	212	53	6.5	3,690	3,610	4,500	4,840	4,480	100	5,160	5,300	110
302	35	Portland E	.60	24		48	212	53	6.2	3,540	3,530	4,550	5,040	4,450	98	4,660	4,640	92
303	37	Portland F	.60	24		48	212	53	6.0	3,550	3,900	5,060	4,890	4,920	97	5,920	5,470	112
304	39	Portland G	.60	24		48	212	53	6.2	3,740	3,920	4,990	5,870	4,680	94	5,060	5,060	86
305	41	Portland H	.60	24		48	212	53	6.1	3,730	3,840	4,860	5,380	4,410	91	4,340	5,100	95
306	61	½ Portland A, ½ Portland B	.62	24		48	212	53	6.2	3,280	3,920	4,480	6,570	4,410	98	5,990	5,230	80
307	40	Portland I	.60	24		48	212	53	5.9	3,420	4,150	5,090	5,850	4,190	82	4,990	4,530	77
308	42	Portland J	.62	24		48	212	53	6.4	2,650	3,240	4,680	5,310	3,480	74	4,440	4,580	86
309	55	Portland K1	.62	24		48	212	53	6.5	3,260	4,200	4,950	5,800	4,910	99	4,910	4,960	86
310	60	Portland L	.60	24		48	212	53	6.2	3,260	3,870	5,060	6,380	4,460	88	4,720	5,770	90
311	65	Portland M	.60	24		48	212	53	5.5	4,660	5,580	5,810	6,740	5,570	96	5,420	5,960	88
313	65	do	.60	24	20			35	5.9	3,150	3,950	6,050	5,680	2,250	37	0	0	
352	74	½ Portland A, ½ Portland B	.62	24		12	212	54	6.9	2,450	2,910	5,230	6,070	4,240	81	3,850	0	
391	74	do	.62	24	20			35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	
584	139	do	.62	24	20	1 min.	212	35	6.3	3,740	5,150	5,790		3,350	58	0	0	
585	139	do	.62	24		1 min.	212	55	6.4	2,770	2,860	5,430		5,370	99	0	0	
586–587	139	do	.62	24		1 min.	212	1 54	6.6	2,970	2,920	5,800		4,400	76	0	0	
635–636	139	do	.64	24		48	212	53	6.3	3,960	4,330	4,250		4,370	103	5,950		
640	139	do	.64	24	20			35	6.5	3,320	4,470	5,800		4,530	78	0	0	
641	139	do	.64	24		48	212	53	6.9	3,590	3,760	4,530		3,740	83	5,360		
830	232	do	.62	24	20			35	5.9	3,230	4,720	6,360		3,950	62			
831	232	do	.62	24		¾	212	55	6.9	3,020	2,880	5,740		4,210	73			
832	232	do	.62	24		1½	212	55	7.4	2,590	2,400	5,890		4,610	78			
833	232	do	.62	24		3	212	55	7.2	2,890	3,130	6,350		4,510	71			
834	232	do	.62	24		6	212	55	7.0	3,220	3,470	5,730		4,970	87			
835	232	do	.62	24		12	212	55	7.1	3,570	3,580	5,070		5,250	104			
836	232	do	.62	24		24	212	54	7.2	3,960	4,190	5,750		5,770	100			
837	232	do	.62	24		48	212	53	6.6	4,360	4,670	4,860		4,620	95			
838	232	do	.62	24		96	212	51	6.1	4,330	4,990	5,030		4,210	84			
839	232	do	.62	24		192	212	47	6.1	5,180	6,050	5,130		4,550	89			
[1] 108	17	do	.64	24		24 24	155 212	25	9.8	2,590	2,910	2,930	2,880	2,540	87	3,390	2,580	90
[1] 110	17	do	.64	24		48 24	155 212	24	9.5	2,600	3,160	2,940	2,590	2,720	93	3,160	2,360	91
[1] 111	17	do	.64	24		24 48	155 212	24	9.7	2,510	3,130	2,630	3,020	2,450	93	2,820	2,320	77
[1] 112	17	do	.64	24	27				10.0	1,650	2,630	3,540	2,790	1,790	51	0	0	
[1] 113	17	do	.64	72				25	10.7	2,000	2,000	2,980	2,940	840	28	0	0	
[1] 116	17	do	.64	24		48	212	25	10.3	2,220	2,470	2,500	3,250	2,430	97		2,460	76

[1] Standard Ottawa sand cylinders.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 1.—CURING IN WATER VAPOR OR STEAM BETWEEN TEMPERATURES OF 100° AND 365° F.—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor or steam	Curing method: Temperature of water vapor or steam	Curing method: Time in air	Absorption at 21 days	Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
				Hours	Days	Hours	°F.	Days	Per cent	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.		Lbs. per sq. in.	Lbs. per sq. in.	
[1] 128	17	½ Portland A, ½ Portland B	0.64	24	------	24 24	155 212	53	9.1	2.350	2,480	2.830	3,340	3,180	112	--------	2,040	61
[1] 130	17	do	.64	24	------	48 24	155 212	52	9.1	2,750	2,720	2,830	3,130	3,080	109	--------	1,740	56
[1] 131	17	do	.64	24	------	24 48	155 212	52	9.2	2,630	2,470	2.600	2,940	2.560	98	--------	1.730	59
[2] 353	74	do	.62	24	------	12	235	54	7.3	1,900	2,750	4,780	5,410	3,800	79	3,970	2,480	46
391	74	do	.62	24	20	--------	--------	35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	--------
811	219	do	.62	24	20	--------	--------	35	5.5	3,620	4,930	6,350	--------	0	--------	0	0	--------
812	219	do	.62	24	------	¾	230	55	7.0	2,060	2,170	5,530	--------	5,160	93	--------	--------	--------
813	219	do	.62	24	------	1½	230	55	6.9	1,830	2,190	5,620	--------	4,530	81	--------	--------	--------
814	219	do	.62	24	------	3	230	55	6.7	2,180	2,320	6,020	--------	4,860	81	--------	--------	--------
815	219	do	.62	24	------	6	230	55	6.6	2,390	2,990	5,520	--------	5,320	96	--------	--------	--------
820	222	do	.62	24	------	12	230	103	6.8	2,640	3,200	5,260	--------	4,990	95	--------	--------	--------
821	222	do	.62	24	------	24	230	102	6.6	3,560	3,250	4,740	--------	4,520	95	--------	--------	--------
829	225	do	.62	24	------	48	230	87	6.9	3,900	4,650	4,640	--------	4,360	94	--------	--------	--------
855	232	do	.62	24	20	--------	--------	35	5.7	3,840	5,310	5,540	--------	4,070	73	--------	--------	--------
869	232	do	.62	24	------	96	230	46	6.1	4,480	4,600	4,480	--------	4,600	103	--------	--------	--------
870	232	do	.62	24	------	192	230	42	6.2	3,830	4,450	3,360	--------	3.560	106	--------	--------	--------
[3] 354	74	do	.62	24	------	12	260	54	7.1	2,270	2,490	4,880	5,570	3,760	77	4,160	3,320	60
391	74	do	.62	24	20	--------	--------	35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	--------
806	219	do	.62	24	20	--------	--------	35	5.8	3,450	4,620	6,110	--------	1,620	27	--------	--------	--------
807	219	do	.62	24	------	¾	260	55	7.4	1,960	1,930	5,400	--------	4,610	85	--------	--------	--------
808	219	do	.62	24	------	1½	260	55	7.1	2,000	2,130	5,490	--------	4,990	91	--------	--------	--------
809	219	do	.62	24	------	3	260	55	7.2	2,170	2,460	5,090	--------	5,200	102	--------	--------	--------
810	219	do	.62	24	------	6	260	55	7.0	2,790	2.870	5,380	--------	4,940	92	--------	--------	--------
818	222	do	.62	24	------	12	260	97	6.7	3,190	3,380	5,560	--------	4,630	83	--------	--------	--------
819	222	do	.62	24	------	24	260	95	6.7	3,480	3,810	4,620	--------	4,520	98	--------	--------	--------
828	225	do	.62	24	------	48	260	83	6.6	3,720	3,880	3,990	--------	3,790	95	--------	--------	--------
855	232	do	.62	24	20	--------	--------	35	5.7	3,840	5,310	5,540	--------	4,070	73	--------	--------	--------
867	232	do	.62	24	------	96	260	48	6.4	3,820	3,810	3,460	--------	3,550	103	--------	--------	--------
868	232	do	.62	24	------	192	260	44	6.6	3,260	3,690	3,420	--------	2,940	86	--------	--------	--------
[4] 355	74	do	.62	24	------	12	285	54	7.2	2,260	2,870	4,340	5,250	3,870	89	3,970	4,190	80
391	74	do	.62	24	20	--------	--------	35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	--------
430	97, 98	Portland K1	.64	24	------	12	285	54	6.6	2.960	3,470	3,950	4,830	3,680	93	5,000	4,210	87
431	86, 99	Portland I	.64	24	------	12	285	54	6.1	3,650	4,150	4,470	5,330	4,290	96	5,440	5,440	102
432	82, 95	Portland C	.67	24	------	12	285	54	6.9	3,330	3.820	5,530	6,550	4,930	89	5,460	5,410	83
433	83	Portland H	.64	24	------	12	285	54	6.5	3,460	3,950	5,110	6,520	4,840	95	5,510	5,980	92
801	219	½ Portland A, ½ Portland B	.62	24	20	--------	--------	35	5.8	3,740	6,260	5,790	--------	2,820	49	--------	--------	--------
802	219	do	.62	24	------	¾	285	55	7.3	1,780	1,740	5.240	--------	5,570	106	--------	--------	--------
803	219	do	.62	24	------	1½	285	55	7.2	2.010	2,220	6,550	--------	5,560	85	--------	--------	--------
804	219	do	.62	24	------	3	285	55	7.3	2,420	2,590	5,560	--------	5,650	102	--------	--------	--------
805	219	do	.62	24	------	6	285	55	6.8	3,080	3,370	5,860	--------	5,600	96	--------	--------	--------
816	222	do	.62	24	------	12	285	87	6.5	3,320	3,420	4,940	--------	4,510	91	--------	--------	--------
817	222	do	.62	24	------	24	285	85	6.3	3,740	4,160	4,540	--------	4,750	105	--------	--------	--------
827	225	do	.62	24	------	48	285	64	6.7	3,300	3,600	3,200	--------	3,170	99	--------	--------	--------
855	232	do	.62	24	20	--------	--------	35	5.7	3,840	5,310	5,540	--------	4,070	73	--------	--------	--------
865	232	do	.62	24	------	96	285	45	6.5	3,550	4,230	3,550	--------	4,190	118	--------	--------	--------
866	232	do	.62	24	------	192	285	41	6.5	3,540	4,300	4,270	--------	4,530	106	--------	--------	--------
[5] 840	232	do	.62	24	20	--------	--------	35	5.8	3,810	5,050	6,010	--------	3,060	51	--------	--------	--------
841	232	do	.62	24	------	¾	315	55	6.9	2,010	2,020	5,680	--------	5,130	90	--------	--------	--------
842	232	do	.62	24	------	1½	315	55	6.8	2,490	2,640	5,550	--------	5,390	97	--------	--------	--------
843	232	do	.62	24	------	3	315	55	6.5	3,090	3,030	5,620	--------	5,220	93	--------	--------	--------
844	232	do	.62	24	------	6	315	55	6.8	3,560	3,900	5,110	--------	5,100	100	--------	--------	--------
845	232	do	.62	24	------	12	315	55	6.5	3,410	3,780	4,150	--------	4,340	105	--------	--------	--------
846	232	do	.62	24	------	24	315	54	6.8	3,180	3,750	3,440	--------	2,770	81	--------	--------	--------
847	232	do	.62	24	------	48	315	53	6.8	3,440	3,970	3,160	--------	3,240	103	--------	--------	--------
848	232	do	.62	24	------	96	315	51	6.6	3,430	4,280	3,090	--------	3,620	117	--------	--------	--------
849	232	do	.62	24	------	192	315	47	6.8	3,580	4,640	3,130	--------	4,470	143	--------	--------	--------
[6] 855	232	do	.62	24	20	--------	--------	35	5.7	3,840	5,310	5,540	--------	4,070	73	--------	--------	--------
856	232	do	.62	24	------	¾	350	55	7.3	1,670	1,940	5,710	--------	4,790	84	--------	--------	--------
857	232	do	.62	24	------	1½	350	55	7.0	2,500	2,800	5,950	--------	5,350	90	--------	--------	--------
858	232	do	.62	24	------	3	350	55	6.7	3,210	3,310	5,610	--------	5,170	92	--------	--------	--------
859	232	do	.62	24	------	6	350	55	6.8	3,110	3,540	4,300	--------	4,130	96	--------	--------	--------
860	232	do	.62	24	------	12	350	55	6.7	3,280	3,470	3,880	--------	3,760	97	--------	--------	--------
861	232	do	.62	24	------	24	350	54	6.8	3,830	3,840	4,700	--------	4,220	90	--------	--------	--------
862	232	do	.62	24	------	48	350	53	6.5	3,530	4,710	4,580	--------	4,800	105	--------	--------	--------
863	232	do	.62	24	------	96	350	51	6.3	4,140	4,320	4,670	--------	4,530	97	--------	--------	--------
864	232	do	.62	24	------	192	350	47	6.2	3,770	4,260	5,000	--------	4,310	86	--------	--------	--------

[1] Standard Ottawa sand cylinders.
[2] For all series cured in steam at 230° or 235° F. the gauge pressure was 6.1 lbs. per sq. in.
[3] For all series cured in steam at 260° F. the gauge pressure was 20.7 lbs. per sq. in.
[4] For all series cured in steam at 285° F. the gauge pressure was 38.5 lbs. per sq. in.
[5] For all series cured in steam at 315° F. the gauge pressure was 68.7 lbs. per sq. in.
[6] For all series cured in steam at 350° F. the gauge pressure was 119.8 lbs. per sq. in.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 2.—PORTLAND CEMENTS FROM DIFFERENT MILLS

Series No.	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
				Hours	*Days*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
172	18	½ Portland A, ½ Portland B	0.59	24	20	35	5.6	2,870	4,190	5,300	5,400	4,370	82		0	
177	18	do	.59	24	20	35	5.9	2,520	4,200	4,930	6,120	3,670	74		0	
256	61	do	.59	24	20	35	5.8	2,780	3,950	5,200	6,520	1,480	28	0	0	
391	74	do	.62	24	20	35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	
434	74	do	.66	24	20	35	6.4	2,590	4,030	5,050	5,830	4,870	96	0	0	
554	129	do	.64	24	20	35	6.3	3,570	4,760	5,980		3,530	59	0	0	
583	139	do	.62	24	20	35	6.3	3,810	4,950	6,420		3,650	57	0	0	
640	139	do	.64	24	20	35	6.5	3,320	4,470	5,800		4,530	78	0	0	
715	176	do	.62	24	20	35	5.6	3,830	5,100	6,420		4,550	71	0	0	
771	204	do	.62	24	20	35	5.9	3,450	4,440	5,870		0		0	0	
776	204	do	.62	24	20	35	6.2	3,400	4,420	6,480		0		0	0	
801	219	do	.62	24	20	35	5.8	3,740	6,260	5,790		2,820	49			
806	219	do	.62	24	20	35	5.8	3,450	4,620	6,110		1,620	27			
811	219	do	.62	24	20	35	5.5	3,620	4,930	6,350		0		0	0	
822	225	do	.62	24	20	35	5.3	3,220	5,230	6,250		3,800	61			
830	232	do	.62	24	20	35	5.9	3,230	4,720	6,360		3,950	62			
840	232	do	.62	24	20	35	5.8	3,810	5,050	6,010		3,060	51			
855	232	do	.62	24	20	35	5.7	3,840	5,310	5,540		4,070	73			
976	237	do	.62	24	20	35	6.0	3,700	4,590	5,750		4,650	81			
258	62	Portland B1	.59	24	20	35	5.8	2,960	3,790	4,580	5,780	800	17	0	0	
655	156	do	.62	24	20	35	6.4	3,670	5,070	5,800		2,870	50	0	0	
665	156	do	.62	24	20		5.9	3,500	5,020	5,820		3,860	66	0	0	
670	161	do	.62	24	20		6.2	3,550	5,470	7,100		3,050	43	0	0	
675	161	do	.62	24	20	35	5.8	3,490	5,320	6,450		3,870	60	0	0	
690	166	do	.62	24	20		6.4	2,830	4,580	6,150		3,810	62	0	0	
695	166	do	.62	24	20	35	6.8	2,960	4,340	6,510		4,210	65	0	0	
699	170	do	.62	24	20	35	5.8	3,660	5,580	6,250		3,130	50	0	0	
709	170	do	.62	24	20		5.8	4,020	4,910	6,940		2,930	42	0	0	
730	178	do	.62	24	20		5.6	3,400	4,610	5,780		2,580	45	0	0	
735	178	do	.62	24	20	35	5.6	3,820	4,660	5,450		5,360	98	0	0	
750	183	do	.62	24	20		5.9	3,810	5,340	5,740		1,790	31	0	0	
755	183	do	.62	24	20	35	5.7	3,500	5,190	5,650		5,430	96	0	0	
464	109	Portland B2	.64	24	20	35	5.8	3,740	5,010	7,070	5,940	5,950	84	920	0	
465	110	do	.64	24	20	35	5.5	3,660	4,920	6,910	6,070	4,850	70	0	0	
466	111	Portland B3	.64	24	20	35	5.7	3,810	5,020	5,860	5,790	3,960	68	0	0	
257	63	Portland A	.59	24	20	35	5.8	2,720	4,290	5,490	6,440	3,190	58	0	0	
657	158	do	.62	24	20	35	6.5	4,080	4,560	4,920		0		0	0	
667	158	do	.62	24	20		6.0	3,450	4,570	6,280		790	13	0	0	
672	163	do	.62	24	20		6.0	3,790	5,240	6,070		1,880	31	0	0	
677	163	do	.62	24	20	35	5.9	3,670	4,460	6,070		1,630	27	0	0	
692	168	do	.62	24	20		5.6	3,760	5,520	5,760		680	12	0	0	
697	168	do	.62	24	20	35	5.9	3,970	5,440	5,820		1,670	29	0	0	
700	171	do	.62	24	20	35	5.8	3,950	5,360	6,190		1,830	30	0	0	
710	171	do	.62	24	20		5.6	4,090	4,700	5,260		1,940	37	0	0	
731	179	do	.62	24	20		5.7	3,500	4,770	6,430		810	13	0	0	
736	179	do	.62	24	20	35	5.8	3,680	5,030	5,080		2,620	52	0	0	
751	184	do	.62	24	20		5.8	4,200	5,580	6,090		2,310	38	0	0	
756	184	do	.62	24	20	35	5.7	3,830	5,140	5,850		4,420	76	0	0	
369	86, 99	Portland I	.64	24	20	35	6.1	3,590	4,370	6,110	6,650	4,470	73	2,500	0	
703	174	do	.62	24	20	35	6.2	4,480	5,610	7,040		6,240	89	4,150		
713	174	do	.62	24	20		5.7	4,370	4,790	6,330		5,800	92	5,600		
734	182	do	.62	24	20		6.0	4,040	5,580	5,940		6,230	105	6,740		
739	182	do	.62	24	20	35	5.8	3,620	5,2[illegible]0	5,810		6,930	119	6,180		
754	187	do	.62	24	20		6.2	3,980	5,050	6,770		5,950	88	6,130		
759	187	do	.62	24	20	35	5.7	3,840	5,380	6,210		6,040	97	6,810		
761	199	do	.62	24	20	35	6.0	4,160	4,830	7,560		6,900	91			
372	97	Portland K2	.64	24	20	35	6.4	3,120	4,440	5,720	7,350	4,600	80	2,260	1,450	2
658	159	do	.62	24	20	35	6.5	3,990	5,170	6,290		5,490	87	1,740		
668	159	do	.62	24	20		6.0	3,140	5,240	5,980		5,790	97	4,410		
673	164	do	.62	24	20		6.0	4,260	5,340	6,800		5,830	86	2,690		
678	164	do	.62	24	20	35	5.9	3,770	5,580	6,270		5,640	90	2,710		
693	169	do	.62	24	20		6.2	3,280	5,370	5,740		5,460	95	5,060		
698	169	do	.62	24	20	35	6.2	3,400	4,730	6,350		6,580	104	4,610		
373	98	Portland K1	.64	24	20	35	6.1	4,220	4,970	7,050	6,520	3,400	48	0	0	
364	81	Portland E	.62	24	20	35	5.8	3,340	4,770	7,320	7,540	2,910	40	0	0	
404	103	Portland S	.62	24	20	35	6.0	3,010	4,380	5,470	6,310	3,160	58	1,230	0	
413	105	Portland Q2	.62	24	20	35	5.7	3,520	5,390	6,500	6,350	4,300	66	0	0	
401	100	Portland Q1	.62	24	20	35	6.4	2,900	4,310	5,110	5,960	0		0	0	
370	87, 88	Portland P	.64	24	20	35	6.1	3,730	5,040	6,540	6,700	810	12	0	0	
371	84	Portland L	.64	24	20	35	5.8	3,690	5,000	5,770	6,230	3,170	55	250	0	
260	34	Portland C	.66	24	20	35	6.1	3,340	4,540	5,980	6,850	5,090	85	4,390	4,290	63
367	82, 95	do	.67	24	20	35	6.8	3,220	4,320	6,270	7,760	4,790	76	2,280	0	
654	155	do	.66	24	20	35	6.6	3,580	5,150	6,220		5,910	95	3,260		
664	155	do	.66	24	20		6.5	3,220	4,890	6,590		6,250	95	4,820		
669	160	do	.66	24	20		6.8	3,150	5,180	5,900		6,190	105	5,120		
674	160	do	.66	24	20	35	6.5	3,430	5,480	7,030		5,610	80	5,820		
689	165	do	.66	24	20		6.3	3,200	5,600	7,390		5,670	77	4,960		
694	165	do	.66	24	20	35	6.5	3,480	5,520	6,780		5,910	87	4,400		
365	83	Portland H	.62	24	20	35	6.1	3,940	4,770	6,280	7,250	3,680	59	290	0	
656	157	do	.62	24	20	35	6.5	3,230	5,090	5,670		4,510	80	0	0	
666	157	do	.62	24	20		6.0	3,520	5,120	6,640		5,490	82	0	0	
671	162	do	.62	24	20		6.7	3,380	4,690	6,260		5,550	89	4,140		
676	162	do	.62	24	20	35	6.5	3,330	4,490	5,830		5,870	101	3,900		
691	167	do	.62	24	20		6.9	2,360	3,760	5,040		4,150	82	610	0	
696	167	do	.62	24	20	35	6.6	3,080	4,570	5,510		5,490	100	2,290		
259	33	Portland D	.59	24	20	35	5.4	3,340	4,780	5,900	6,230	1,590	27	0	0	

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 2.—PORTLAND CEMENTS FROM DIFFERENT MILLS—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
				Hours	*Days*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
368	85, 94	Portland D	0. 64	24	20	35	6. 4	3, 390	4, 130	5, 730	6, 770	2, 980	52	0	0	
701	172	do	. 62	24	20	35	6. 1	4, 040	5, 600	6, 170		5, 750	93	2, 170		
711	172	do	. 62	24	20		5. 8	3, 950	5, 380	7, 050		4, 980	71	2, 070		
732	180	Portland D	. 62	24	20		5. 9	3, 780	5, 400	6, 620		4, 750	72	0	0	
737	180	do	. 62	24	20	35	6. 2	3, 960	5, 130	5, 580		4, 760	85	1, 100		
752	185	do	. 62	24	20		5. 8	4. 390	5, 290	6, 090		3, 850	63	0	0	
757	185	do	. 62	24	20	35	5. 7	4, 080	5, 530	6, 160		4, 860	79	3, 490		
763	196	Portland BB	. 62	24	20	35	5. 9	4, 030	5, 060	6. 360		2, 830	44			
361	80	Portland F	. 62	24	20	35	6. 3	2, 870	4, 320	6, 350	5, 730	0		0	0	
769	201	Portland X	. 62	24	20	35	6. 3	3, 050	4, 960	6, 440		4, 440	69			
576	133	Portland AA	. 62	24	20	35	6. 0	3 460	4, 820	5, 850		3, 440	59	0	0	
765	197	do	. 60	24	20	35	5. 8	3, 750	5, 430	4, 820		0		0	0	
402	101	Portland R	. 62	24	20	35	6. 3	3, 680	4, 940	6, 290	5, 900	2, 440	39	0	0	
415	107	Portland V	. 62	24	20	35	6. 5	2, 830	4, 540	5, 920	5, 550	2, 940	50	0	0	
555	128	Portland Y	. 64	24	20	35	6. 0	3, 780	4, 670	5, 480		3, 510	64	0	0	
557	128	do	. 73	24	20	35	6. 4	2, 760	4, 250	4, 690		1, 800	38	0	0	
313	65	Portland M	. 60	24	20	35	5. 9	3, 150	3, 950	6, 050	5, 680	2, 250	37	0	0	
366	77. 96	Portland G	. 64	24	20	35	6. 0	4, 050	4, 820	5, 900	6, 690	1, 930	33	0	0	
577	134	do	. 62	24	20	35	6. 3	3, 910	5, 610	6, 730		6, 140	91	3, 340		
702	173	do	. 62	24	20	35	6. 1	3, 530	5 330	6, 510		5, 290	81	3, 270		
712	173	do	. 62	24	20		5. 7	3, 630	4, 910	6, 120		5, 880	96	5, 660		
733	181	do	. 62	24	20		6. 0	4, 070	5, 190	5, 710		6, 040	106	4, 150		
738	181	do	. 62	24	20	35	5. 9	3, 810	5, 080	6, 290		5, 960	95	5, 170		
753	186	do	. 62	24	20		5. 9	3, 750	5, 420	6, 290		5. 890	94	5, 670		
758	186	do	. 62	24	20	35	5. 6	3, 860	5, 020	5, 930		5, 800	98	7, 290		
363	89	Portland O1	. 62	24	20	35	5. 9	4, 010	5, 220	6, 730	6, 430	670	10	0	0	
468	113	Portland O2	. 64	24	20	35	6. 3	2, 140	3, 940	6, 000	5, 260	5, 590	93	5, 580	3, 550	67
767	198	Portland CC	. 62	24	20	35	6. 2	3, 440	5, 540	6, 650		5, 330	80			
405	104	Portland T	. 62	24	20	35	6. 4	2, 940	4, 380	5, 530	5, 860	280	5	0	0	
416	108	Portland W	. 62	24	20	35	5. 8	3, 670	5, 010	6, 510	5, 240	1, 490	23	0	0	
414	106	Portland U	. 62	24	20	35	6. 1	3, 030	4, 410	6, 430	5, 900	2, 490	39	0	0	
362	79	Portland N1	. 62	24	20	35	6. 1	3, 220	4, 600	6, 970	6, 550	4, 000	57	950	0	
403	102	Portland N2	. 62	24	20	35	5. 9	3, 860	5, 640	6, 630	5, 720	4, 410	67	1, 860	0	
575	132	Portland Z	. 62	24	20	35	6. 0	4, 760	5, 160	6, 490		4, 970	77	2, 210		

PART 3.—SPECIAL CEMENTS OTHER THAN HIGH ALUMINA

Series No.	Cement laboratory No.	Cement	Water ratio	Time in moist closet	Time in water	Time in air	Absorption at 21 days	Tank 7 days	Tank 28 days	Tank 1 year	Tank 5 years	Lake 1 year	Percentage at 1 year	Lake 3 years	Lake 5 years	Percentage at 5 years
573	130	Special B	0. 62	24	20	35	6. 3	4, 140	4, 800	5, 610		5, 880	105	3, 710		
714	175	Special D	. 64	24	20	35	5. 6	5, 080	6, 040	6, 250		5. 620	90	0	0	
574	131	Special C	. 62	24	20	35	6. 6	3, 490	4, 580	6, 100		5. 680	93	3, 360		
764	191	Special E	. 62	24	20	35	3. 8	4, 480	5, 280	5, 990		3, 570	60			
765	197	Portland AA	. 60	24	20	35	5. 8	3, 750	5, 430	4, 820		0		0	0	
762	200	Special F	. 62	24	20	35	5. 6	5, 390	6, 610	6, 660		3, 830	58			
763	196	Portland BB	. 62	24	20	35	5. 9	4, 030	5, 660	6, 360		2, 830	44			
768	193	Special G	. 62	24	20	35	5. 9	2, 910	4, 410	5, 930		4, 410	74			
769	201	Portland X	. 62	24	20	35	6. 3	3, 050	4, 960	6, 440		4. 440	69			
[1] 467	112	Special X	. 54	24	20	35		2, 830	4, 390	4, 820	4, 350	4, 830	100	3, 570	2, 640	61
[2] 719	177	do	. 44	24	20	35	10. 7	3, 940	5, 200	5, 660		4, 940	87	4, 520		
720–721	177	do	. 54	24	20	35	8. 0	3, 000	4, 400	5, 100		4, 340	85	3, 730		
[3] 722	177	do	. 61	24	20	35	6. 6	2, 690	4, 020	4, 220		3, 710	88	3, 500		
[4] 723	177	do	. 90	24	20	35	8. 2	860	1, 530	2, 230		1, 700	76	210	0	
[2,5] 724	177	do	. 42	24	20	35	9. 5	4, 280	5, 900	6, 680		6, 070	91	6, 220		
[1,5] 725–726	177	do	. 51	24	20	35	9. 4	2, 450	4, 080	4, 240		3, 960	93	3, 760		
[3,5] 727	177	do	. 70	24	20	35	13. 3	1, 200	2, 370	3, 050		2, 150	70	1, 400		
[4,5] 728	177	do	1. 08	24	20	35	15. 8	320	780	990		0		0	0	
766	192	Special H	. 62	24	20	35	6. 0	6. 360	6, 480	7, 570		6, 520	86			
767	198	Portland CC	. 62	24	20	35	6. 2	3, 440	5, 540	6, 650		5, 330	80			
760	190	Special I	. 64	24	20	35	4. 7	4, 920	5, 570	5, 780		4, 810	83			
761	199	Portland I	. 62	24	20	35	6. 0	4. 160	4, 830	7, 560		6, 900	91			
243–247	28	Special A1	. 62	24	20	35	6. 2	2, 910	3, 770	5, 370	5, 960	4, 030	75	0	0	
248–250	10	Special A3	. 63	24	20	35	9. 5	1, 430	2, 730	3, 750	3, 620	3, 280	87	800	0	
556	127	Special A2	. 64	24	20	35	6. 0	3, 200	4, 720	5, 950		5, 330	90	0	0	
555	128	Portland Y	. 64	24	20	35	6. 0	3 780	4, 670	5, 480		3. 510	64	0	0	
558	127	Special A2	. 73	24	20	35	6. 6	2, 280	4, 480	5, 290		3, 080	58	0	0	
557	128	Portland Y	. 73	24	20	35	6. 4	2, 760	4, 250	4, 690		1, 800	38	0	0	
[6] 561	127	Special A2	. 62	24	[7] 20	35	7. 9	3, 260	4, 720	5, 860		6, 090	104	4, 120		
[6] 560	128	Portland Y	. 62	24	[7] 20	35	8. 2	3, 550	5, 160	6, 120		5, 270	86	4, 040		
[6] 563	127	Special A2	. 71	24	[7] 20	35	9. 1	2, 290	4, 520	4, 960		3. 960	80	1, 140		
[6] 562	128	Portland Y	. 71	24	[7] 20	35	9. 2	2, 720	4, 290	5, 450		3, 920	72	900		

[1] Mix — 1: 1.88.
[2] Mix — 1: 0.94.
[3] Mix — 1: 2.82.
[4] Mix — 1: 4.70.
[5] Standard Ottawa sand cylinders.
[6] Mix—1: 2.25.
[7] In damp sand.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 4.—HIGH ALUMINA CEMENTS

Series No.	Cement laboratory No.	Cement	Water ratio	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water vapor or steam	Curing method: Temperature of water vapor or steam	Curing method: Time in air	Absorption at 21 days	Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 2 or 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
				Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
137	14	High alumina A	0.64	24		48	155	25	6.2	3,250	3,550	2,830	2,850	3,400	120	4,510	4,290	151
138	14	do	.64	24		24 24	155 212	25	6.2	3,150	3,670	2,860	2,510	3,320	116		4,960	198
139	14	do	.64	24		72	155	24	6.1	3,160	3,840	2,640	2,460	3,790	144		4,560	185
140	14	do	.64	24		48 24	155 212	24	6.1	3,190	3,890	2,730	2,570	3,790	139		5,040	196
141	14	do	.64	24		24 48	155 212	24	6.1	3,360	3,800	3,020	2,700	3,670	121		4,920	182
147	14	do	.62	24	27				6.3	4,560	4,890	4,560	3,460	5,220	114	[1] 6,410	4,460	129
148	14	do	.62	72				25	7.0	5.020	4,810	5,310	3,710	5,960	112	[1] 6,300	6,230	168
149	14	do	.62	24		48	100	25	6.5	5,370	5,510	5,240	2,650	5,450	104	[1] 5,300	5,330	201
150	14	do	.62	24		48	155	25	6.2	3,360	3,870		2,640	3.400		[1] 4,060	3,690	140
151	14	do	.62	24		48	212	25	6.1	3,300	3,750	2,840	2,660	3,650	129	[1] 4,110	4,090	154
152	14	do	.62	24	20			344	6.3	4,570	5,040	5,100	3,780	5,040	99		6,240	165
153	14	do	.62	24	20			56	6.5	4,830	4,910	5,120	3,690	6,280	123		6,720	182
154	14	do	.62	24	20			28	6.5	4,760	4,850	5,450	3,380	5,620	103		6,460	191
155	14	do	.62	24	20			14	6.5	4,250	4,960	4,570	3,590	5,770	126		6,420	179
156	14	do	.62	24	20				6.3	4,710	4,860	4,380	3,160	4,960	113		4,390	139
132	14	do	.65	24		48	155	25	8.1	2,250	2,910	2,760	2,830	2,790	101	[1] 2,930	2,940	104
133	14	do	.65	24		24 24	155 212	25	8.0	2,280	2,680	2,080	2,690	2.900	139	[1] 3,140	2,840	106
134	14	do	.65	24		72	155	24	8.0	2,470	2,850	2,440	2,640	2,840	116	[1] 3,120	3,090	117
135	14	do	.65	24		48 24	155 212	24	7.8	2,620	2,960	2,650	2,910	2,590	98	[1] 2,930	3,340	115
136	14	do	.65	24		24 48	155 212	24	7.8	2,550	2.930	2,630	2,650	2,580	98	[1] 3,170	3,030	114
142	14	do	.63	24	27				8.7	2,910	3,600	3,590	2,240	4,060	113		3,640	162
143	14	do	.63	72				25	9.3	4,220	4,430	4,220	2,160	4,310	102		5,880	272
144	14	do	.63	24		48	100	25	9.1	4,320	4,640	3,750	1,880	4,490	120		4,120	219
145	14		.63	24		48	155	25	8.1	2,200	2,760	2,780	2,930	2,620	94		3,760	128
146	14	do	.63	24		48	212	25	7.8	2,500	2,870	2,500	2,400	3,010	120		3,960	165
208–212	25	High Alumina B	.51	24	20			35	4.9	6,700	6,780	6,260	7,770	7,420	118	7,240	8,950	115
[2, 3] 276	27	do	.44	24	20			35	6.3	6,210	7,680	6,490	6,390	8,000	123	7,370	7,970	125
277–278	27	do	.59	24	20			35	8.3	5,060	4,830	5,110	3,640	5,560	109	5,350	5,690	156
[2, 4] 279	27	do	.73	24	20			35	10.2	3,380	3,090	3,250	2,380	3,730	115	3,350	3,830	161
[2, 5] 280	27	do	.99	24	20			35	11.8	2,160	1,920	1,680	1,130	700	42	0	0	
[3] 286	27	do	.44	24	20			35	5.1	7.490	6,820	8,080	8,100	8,460	105	8.080	8,210	101
287–288	27	do	.53	24	20			35	4.9	7,080	6,620	8,160	6,880	8,210	101	6,710	7,830	114
[4] 289	27	do	.67	24	20			35	5.3	6,560	5,680	6,290	4,090	6,160	98	5,460	6,310	154
[5] 290	27	do	.81	24	20			35	5.8	4,640	4,840	4,150	2,520	5,080	122	4,080	4,770	189
396	70, 71	do	.44	24	20			35	5.6	5,300	5,760	6,110	4,040	5,780	95	6,040	5,920	147
397	70, 71	do	.53	24	20			35	4.9	6,660	7,120	8,100	7,040	7,580	94	8,660	7,710	110
398	70, 71	do	.59	24	20			35	5.3	6,890	7,210	8,630	6,280	7,390	86	8,300	6,780	108
399	70, 71	do	.73	24	20			35	6.3	5,950	5,710	6,440	3,700	5,400	84	6,690	5,790	156
400	70, 71	do	.88	24	20			35	7.6	5,140	4,230	3,480	2,550	3,790	109	2,950	3,200	125
[6] 429	70, 71	do	.35	24	20			35	9.7	9,460	8,420	10,440	6,620	9,330	89	10,160	8,510	129
435	70, 71, 74	High alumina B, 5 per cent, Portland B, 47.5 per cent, and Portland A, 47.5 per cent	.66	24	20			35	6.3	2,630	3,880	5,490	5,970	4,100	75	0	0	
436	70, 71, 74	High alumina B, 10 per cent, Portland B, 45 per cent, and Portland A, 45 per cent	.66	24	20			35	6.2	2,260	3,760	4,820	5.420	2,720	56	0	0	
437	70, 71, 74	High alumina B 20 per cent, Portland B, 40 per cent, and Portland A, 40 per cent	.66	24	20			35	7.0	1,360	2,830	3,640	3,060	3,320	91	0	0	
438	70, 71	High alumina B	.66	24	20			35	5.8	7,080	7,790	7,820	6,440	7,220	92	8,130	7.810	121
252–253	58	High alumina C	.53	24	20			35	5.4	7,730	7,230	7,480	4,030	7,010	94	7,230	7,340	182
[5] 291	58	do	.79	24	20			35	6.5	4,360	4,630	2,910	2,190	4,370	150	3,330	3,410	156
[2] 254–255	58	do	.60	24	20			35	9.3	5,010	4,850	2,920	2,020	4,340	149	3,690	3,170	157
[2, 5] 292	58	do	.90	24	20			35	12.3	2,130	1,820	1,130	1,230	920	81	0	0	

[1] Two-year tests. [2] Standard Ottawa sand cylinders. [3] Mix — 1:2. [4] Mix — 1:4. [5] Mix — 1:5. [6] Neat cement.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 5.—SURFACE TREATMENT OR IMPREGNATION

Series No.	Cement laboratory No.	Cement	Water ratio	Surface treatment or impregnation	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
					Hours	*Days*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
374	74	½ Portland A, ½ Portland B.	0.62	Inertol, first coat at 22 days, second at 26 days.	24	20	35	6.7	2,930	4,870	5,570	6,200	5,390	97	3,310	5,320	86
[1] 375	74	do	.64	do	24	20	35	10.5	1,430	2,790	3,640	3,740	2,970	82	0	0	
391	74	do	.62	No treatment	24	20	35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	----
549	129	do	.62	No treatment. Dipped in boiling water ½ minute at 28 days and ½ minute at 31 days.	24	20	35	5.8	3,790	4,770	6,550	----	1,620	25	0	0	----
550	129	do	.62	Boiled linseed oil at 70° F., dipped ½ minute at 28 days.	24	20	35	5.8	3,540	4,960	6,040	----	5,520	91	5,220	----	----
551	129	do	.62	Boiled linseed oil at 70° F., dipped ½ minute at 28 days and ½ minute at 31 days.	24	20	35	5.8	3,730	5,260	5,520	----	5,730	104	5,560	----	----
552	129	do	.62	Boiled linseed oil at 225° F., dipped ½ minute at 28 days.	24	20	35	5.8	3,430	4,680	5,970	----	5,330	89	5,260	----	----
553	129	do	.62	Boiled linseed oil at 225° F., dipped ½ minute at 28 days and ½ minute at 31 days.	24	20	35	5.8	3,750	4,960	5,510	----	5,650	103	5,050	----	----
554	129	do	.64	No treatment	24	20	35	6.3	3,570	4,760	5,980	----	3,530	59	0	0	
934	245	do	.62	McEverlast "Special Paving Coating," one brush coat at 24 hours.	24	----	55	4.0	4,370	5,270	6,030	----	5,610	93	----	----	----
935	245	do	.62	McEverlast "Special Paving Coating," one brush coat at 21 days.	24	20	35	5.8	4,340	5,640	5,440	----	5,710	105	----	----	----
976	237	do	.62	No treatment	24	20	35	6.0	3,700	4,590	5,750	----	4,650	81	----	----	----
977	237	do	.62	McEverlast "Penetration," one brush coat at 24 hours, followed by one brush coat, "Concrete Cover Coat" at 48 hours.	24	----	55	2.7	2,890	4,180	5,660	----	4,710	83	----	----	----
978	237	do	.62	McEverlast "Penetration," one brush coat at 21 days followed by one brush coat, "Concrete Cover Coat" at 22 days.	24	20	35	2.1	3,670	4,650	5,740	----	5,550	97	----	----	----
979	237	do	.62	McEverlast "Paving Special," one brush coat at 24 hours followed by one brush coat "Concrete Cover Coat" at 48 hours.	24	----	55	4.5	3,200	4,410	5,620	----	4,920	88	----	----	----
980	237	do	.62	McEverlast "Paving Special," one brush coat at 21 days followed by one brush coat "Concrete Cover Coat" at 22 days.	24	20	35	2.0	3,410	4,450	5,780	----	5,250	91	----	----	----
[1] 293	19	do	.64	No treatment	24	20	35	9.9	1,420	2,240	3,850	3,740	2,140	56	0	0	----
[1] 294	19	do	.64	Sulphur impregnated	24	20	35	9.9	1,350	2,210	3,130	2,610	1,500	48	0	0	----

[1] Standard Ottawa sand cylinders.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 6.—ADMIXTURES

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture	Curing method: Time in moist closet	Curing method: Time in water or damp sand	Curing method: Time in water vapor or steam	Curing method: Temperature of water vapor or steam	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 2 or 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
					Hours	Days	Hours	°F.	Days	Per cent	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.		Lbs. per sq. in.	Lbs. per sq. in.	
182	18	½ Portland A, ½ Portland B.	0.59	None	24	20			35	6.0	2,800	4,010	5,780	5,790	4,450	77	[1] 2,100	0	
183	18	do	.63	3 per cent Alkagel A.	24	20			35	5.3	2,260	3,560	4,570	4,670	3,520	77	[1] 2,140	0	
184	18	do	.59	None	24		48	155	35	6.0	4,070	4,530	5,100	6,110	4,240	83	[1] 4,700	800	13
185	18	do	.63	3 per cent Alkagel A.	24		48	155	35	5.0	3,280	3,940	4,570	5,050	3,300	72	[1] 3,900	1,090	22
186	18	do	.63	do	24		48	100	35	5.4	3,120	3,730	3,820	4,420	3,550	93	[1] 3,060	0	
554	129	do	.64	None	24	20			35	6.3	3,570	4,760	5,980		3,530	59	0	0	
581	129	do	.62	6 per cent barium chloride.	24	20			35	6.5	3,530	4,570	5,870		3,730	64	0	0	
582	129	do	.62	12 per cent barium chloride.	24	20			35	6.7	3,240	4,460	5,100		4,420	87	2,800	0	
822	225	do	.62	None	24	20			35	5.3	3,220	5,230	6,250		3,800	61			
823	225	do	.62	3.75 per cent Barnsdall.	24	20			35	5.2	3,440	4,660	7,090		3,050	43			
824	225	do	.64	7.5 per cent Barnsdall.	24	20			35	5.5	2,970	5,070	6,480		3,000	46			
825	225	do	.72	15.0 per cent Barnsdall.	24	20			35	6.0	3,060	4,490	5,350		2,130	40			
826	225	do	.79	30.0 per cent Barnsdall.	24	20			35	6.8	2,310	3,790	5,410		1,450	27			
[2] 981	263	do	.64	None	24	27			28	5.9		5,440	7,100		5,030	71			
[2] 982	263	do	.67	4 per cent Barnsdall.	24	27			28	6.1		5,630	6,610		4,590	69			
[2] 983	263	do	.69	6 per cent Barnsdall.	24	27			28	6.0		5,140	6,050		4,060	67			
[2] 984	263	do	.71	8 per cent Barnsdall.	24	27			28	6.1		5,560	5,950		3,800	64			
[2] 985	274	Portland I	.64	None	24	27			28	5.9		5,330	7,190		7,170	100			
[2] 986	274	do	.67	4 per cent Barnsdall.	24	27			28	6.0		5,370	7,890		6,170	78			
[2] 987	274	do	.69	6 per cent Barnsdall.	24	27			28	6.1		5,480	7,680		5,460	71			
[2] 988	274	do	.71	8 per cent Barnsdall.	24	27			28	6.3		5,310	7,080		6,610	93			
[3] 989	263	½ Portland A, ½ Portland B.	.80	None	24	27			28	6.2		4,850	5,540		1,570	28			
[3] 990	263	do	.82	4 per cent Barnsdall.	24	27			28	6.6		5,010	5,770		630	11			
[3] 991	263	do	.83	6 per cent Barnsdall.	24	27			28	6.4		4,770	5,340		980	18			
[3] 992	263	do	.84	8 per cent Barnsdall.	24	27			28	6.2		4,660	6,050		570	9			
[3] 993	274	Portland I	.80	None	24	27			28	6.5		3,980	6,610		3,970	60			
[3] 994	274	do	.82	4 per cent Barnsdall.	24	27			28	6.4		4,740	6,540		4,650	71			
[3] 995	274	do	.83	6 per cent Barnsdall.	24	27			28	6.8		4,440	5,990		4,850	81			
[3] 996	274	do	.84	8 per cent Barnsdall.	24	27			28	6.6		4,500	6,010		4,260	71			
[4] 997	263	½ Portland A, ½ Portland B.	.94	None	24	27			28	6.7		3,640	4,370		2,840	65			
[4] 998	263	do	.95	4 per cent Barnsdall.	24	27			28	6.8		3,570	4,640		2,700	58			
[4] 999	263	do	.96	6 per cent Barnsdall.	24	27			28	6.9		4,020	4,510		1,510	33			
[4] 1000	263	do	.97	8 per cent Barnsdall.	24	27			28	6.9		3,610	4,650		830	18			
[4] 1001	274	Portland I	.94	None	24	27			28	6.5		3,370	4,880		4,360	89			
[4] 1002	274	do	.95	4 per cent Barnsdall.	24	27			28	6.6		3,480	4,730		4,080	86			
[4] 1003	274	do	.96	6 per cent Barnsdall.	24	27			28	6.6		3,560	4,360		3,950	91			
[4] 1004	274	do	.97	8 per cent Barnsdall.	24	27			28	6.7		3,570	4,780		5,020	105			
157	18	½ Portland A, ½ Portland B.	0.74	40 per cent blast furnace slag.	24	20				6.5	2,420	3,960	6,030	6,200	4,230	70	[1] 2,340	0	
158	18	do	.63	10 per cent blast furnace slag.	24	20			35	6.0	2,880	4,180	5,440	6,260	5,170	95	[1] 3,930	0	
159	18	do	.74	40 per cent blast furnace slag.	24	20			35	6.7	2,410	4,190	5,670	5,600	5,560	98	[1] 5,220	690	12
160	18	do	.63	10 per cent blast furnace slag.	24		48	155	35	6.4	3,850	4,010	5,300	4,060	4,800	91	[1] 3,540	0	
161	18	do	.74	40 per cent blast furnace slag.	24		48	155	35	6.9	3,800	4,020	5,450	5,710	4,830	89	[1] 5,640	2,760	48
172	18	do	.59	None	24	20			35	5.6	2,870	4,190	5,300	5,400	4,370	82	[1] 2,050	0	

[1] Two-year tests.
[2] Special high silica aggregate, 1:3 Mix. Two by four inch cylinders cured in damp sand.
[3] Special high silica aggregate, 1:2:3 Mix. Two by four inch cylinders cured in damp sand.
[4] Special high silica aggregate, 1:2:4 Mix. Four by eight inch cylinders cured in damp sand.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 6.—ADMIXTURES—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture	Curing method					Absorption at 21 days	Average of compression tests								
											Tank specimens				Lake specimens				
					Time in moist closet	Time in water or damp sand	Time in water vapor	Temperature of water vapor	Time in air		7 days	28 days	1 year	5 years	1 year	Percentage of normal strength as indicated by tank specimens at 1 year	2 or 3 years	5 years	Percentage of normal strength as indicated by tank specimens at 5 years
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
167	18	½ Portland A, ½ Portland B.	0.59	4 per cent Cal	24	20	------	------	------	5.7	3,200	4,150	4,860	5,600	3,910	80	[1]1,380	0	---------
168	18	do	.60	8 per cent Cal	24	20	------	------	35	5.8	3,180	4,290	5,570	6,370	4,620	83	[1]3,690	1,570	25
169	18	do	.59	4 per cent Cal	24	20	------	------	35	5.8	3,250	4,280	4,550	5,580	4,800	105	[1]3,620	1,090	20
170	18	do	.60	8 per cent Cal	24	------	48	155	35	6.0	4,990	4,670	5,030	5,960	5,010	100	[1]6,200	5,540	93
171	18	do	.59	4 per cent Cal	24	------	48	155	35	6.0	4,550	4,690	5,140	5,730	4,980	97	[1]5,560	4,690	82
172	18	do	.59	None	24	20	------	------	35	5.6	2,870	4,190	5,300	5,400	4,370	82	[1]2,050	0	---------
162	18	do	.63	4 per cent calcium chloride.	24	20	------	------	------	5.7	2,870	4,330	5,530	5,130	3,910	71	[1]1,710	0	---------
163	18	do	.79	8 per cent calcium chloride.	24	20	------	------	35	7.1	2,200	3,010	4,280	4,220	3,550	83	[1]3,130	1,040	25
164	18	do	.63	4 per cent calcium chloride.	24	20	------	------	35	5.9	2,940	4,000	5,450	5,790	5,050	93	[1]5,240	2,200	38
165	18	do	.79	8 per cent calcium chloride.	24	------	48	155	35	7.1	3,800	3,640	4,600	4,620	3,300	72	[1]3,860	3,770	82
166	18	do	.63	4 per cent calcium chloride.	24	------	48	155	35	5.8	4,840	4,920	4,990	5,970	4,460	89	[1]5,840	4,990	84
172	18	do	.59	None	24	20	------	------	35	5.6	2,870	4,190	5,300	5,400	4,370	82	[1]2,050	0	---------
412	105	Portland Q2	.66	2½ per cent Celite	24	20	------	------	35	6.4	3,530	5,050	6,670	6,280	3,760	56	0	0	---------
413	105	do	.62	None	24	20	------	------	35	5.7	3,520	5,390	6,500	6,350	4,300	66	0	0	---------
583	139	½ Portland A, ½ Portland B.	.62	do	24	20	------	------	35	6.3	3,810	4,950	6,420	-------	3,650	57	0	0	---------
634	139	do	.64	2 per cent Celite	24	20	------	------	35	6.1	3,260	5,340	6,180	-------	5,290	86	0	0	---------
635-636	139	do	.64	None	24	------	48	212	53	6.3	3,960	4,330	4,250	-------	4,370	103	5,950	-------	---------
637-638	139	do	.64	2 per cent Celite	24	------	48	212	53	6.2	4,160	4,730	5,300	-------	4,410	83	5,020	-------	---------
639	139	do	.64	2 per cent Colloy	24	20	------	------	35	6.5	3,630	4,610	5,250	-------	4,630	88	0	0	---------
640	139	do	.64	None	24	20	------	------	35	6.5	3,320	4,470	5,800	-------	4,530	78	0	0	---------
641	139	do	.64	do	24	------	48	212	53	6.9	3,590	3,760	4,530	-------	3,740	83	5,360	-------	---------
642-643	139	do	.64	2 per cent Colloy	24	------	48	212	53	6.8	3,870	4,100	4,420	-------	3,800	86	5,510	-------	---------
776	204	do	.62	None	24	20	------	------	35	6.2	3,400	4,420	6,480	-------	0	---------	0	0	---------
777	204	do	.64	2 per cent Colloy	24	20	------	------	35	6.4	3,160	4,640	5,270	-------	0	---------	0	0	---------
778	204	do	.65	4 per cent Colloy	24	20	------	------	35	6.4	3,200	4,540	6,110	-------	0	---------	0	0	---------
715	176	do	.62	None	24	20	------	------	35	5.6	3,830	5,100	6,420	-------	4,550	71	0	0	---------
716	176	do	.62	0.27 per cent Earthcrete.	24	20	------	------	35	5.6	4,460	5,160	5,780	-------	4,630	80	0	0	---------
717	176	do	.62	1.06 per cent Earthcrete.	24	20	------	------	35	5.8	3,530	5,120	6,950	-------	4,860	70	0	0	---------
718	176	do	.62	0.27 per cent Earthcrete.	24	------	48	155	53	5.6	5,210	5,550	5,370	-------	5,150	96	0	0	---------
554	129	do	.64	None	24	20	------	------	35	6.3	3,570	4,760	5,980	-------	3,530	59	0	0	---------
564-565	129	do	.62	2½ per cent fuel ash.	24	20	------	------	35	6.3	3,580	5,100	6,710	-------	2,840	42	0	0	---------
566	129	do	.64	5 per cent fuel ash	24	20	------	------	35	6.4	3,300	4,760	5.850	-------	2,670	46	0	0	---------
567-568	129	do	.67	10 per cent fuel ash	24	20	------	------	35	6.3	3,390	5,080	6,570	-------	3,660	56	0	0	---------
172	18	do	.59	None	24	20	------	------	35	5.6	2,870	4,190	5,300	5,400	4,370	82	-------	0	---------
173	18	do	.61	20 per cent ironite	24	20	------	------	35	5.9	2,950	3,980	4,890	5,800	5,020	102	-------	1,590	27
174	18	do	.59	None	24	------	48	155	35	6.1	4,020	4,390	4,330	5,650	3,910	90	-------	2,740	48
175	18	do	.61	20 per cent ironite	24	------	48	155	35	6.1	3,880	4,440	5.510	5,630	4,630	84	-------	5,280	94
176	18	do	.61	do	24	------	48	100	35	6.1	3,680	4,220	5,250	5,770	5,190	99	-------	5,020	87
1141	287	do	.62	None	24	20	------	------	35	5.6	4,560	5,400	-------	-------	-------	---------	-------	-------	---------
1142	287	do	.62	1 per cent kerosene	24	20	------	------	35	5.3	3,930	5,760	-------	-------	-------	---------	-------	-------	---------
1143	287	do	.62	2 per cent kerosene	24	20	------	------	35	5.1	3,790	5,740	-------	-------	-------	---------	-------	-------	---------
1144	287	do	.62	4 per cent kerosene	24	20	------	------	35	4.4	3,800	5,530	-------	-------	-------	---------	-------	-------	---------
1145	287	do	.62	8 per cent kerosene	24	20	------	------	35	4.8	3,740	4,870	-------	-------	-------	---------	-------	-------	---------
769	201	Portland X	.62	None	24	20	------	------	35	6.3	3,050	4,960	6,440	-------	4,440	69	-------	-------	---------
770	201	do	.62	2 per cent Medusa Waterproofing.	24	20	------	------	35	5.0	3,220	4,750	5,930	-------	3,020	51	-------	-------	---------
779	201	do	.62	1 per cent Medusa Waterproofing.	24	20	------	------	35	5.2	3,030	4,690	5,480	-------	2,750	50	-------	-------	---------
780	201	do	.65	4 per cent Medusa Waterproofing.	24	20	------	------	35	4.0	2,780	4,700	5,340	-------	2,190	41	-------	-------	---------

[1] 2-year tests.

TABLE 2.—*Record of tests of 2 by 4 inch concrete cylinders exposed to the action of sulphate water of Medicine Lake, S. Dak., and parallel tests of cylinders stored in tap water in laboratory tanks*—Continued

PART 6.—ADMIXTURES—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture	Curing method: Time in moist closet	Curing method: Time in water or damp sand	Curing method: Time in water vapor	Curing method: Temperature of water vapor	Curing method: Time in air	Absorption at 21 days	Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Tank specimens: 5 years	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at 1 year	Lake specimens: 2 or 3 years	Lake specimens: 5 years	Lake specimens: Percentage of normal strength as indicated by tank specimens at 5 years
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*	
1146	287	½ Portland A, ½ Portland B.	0.62	None	24	20	------	------	35	5.3	4,280	5,960	------	------	------	------	------	------	------
1147	287	do	.62	1 per cent oil	24	20	------	------	35	2.8	4,580	5,260	------	------	------	------	------	------	------
1148	287	do	.62	2 per cent oil	24	20	------	------	35	2.4	4,460	5,990	------	------	------	------	------	------	------
1149	287	do	.62	4 per cent oil	24	20	------	------	35	2.0	4,180	5,530	------	------	------	------	------	------	------
1150	287	do	.62	8 per cent oil	24	20	------	------	35	1.8	3,390	4,720	------	------	------	------	------	------	------
771	204	do	.62	None	24	20	------	------	35	5.9	3,450	4,440	5,870	------	0	------	0	0	------
772	204	do	.65	3.75 per cent Omicron.	24	20	------	------	35	6.1	3,510	4,480	6,010	------	0	------	0	0	------
773	204	do	.69	7.5 per cent Omicron.	24	20	------	------	35	6.5	3,240	4,710	5,370	------	0	------	0	0	------
774	204	do	.74	15.0 per cent Omicron.	24	20	------	------	35	7.6	3,430	4,360	5,510	------	3,440	62	------	------	------
775	204	do	.86	30.0 per cent Omicron.	24	20	------	------	35	9.9	3,050	4,220	4,980	------	4,430	89	------	------	------
[5] 293	19	do	.64	None	24	20	------	------	35	9.9	1,420	2,240	3,850	3,740	2,140	56	0	0	------
[5] 295	19	do	.67	10 per cent sulphur	24	20	------	------	35	9.7	1,150	1,250	1,810	2,610	0	------	0	0	------
391	74	do	.62	None	24	20	------	------	35	6.3	3,130	4,890	6,060	6,430	2,480	41	0	0	------
392	74	do	.76	33 per cent Trass	24	20	------	------	35	7.3	2,710	3,830	5,790	5,620	5,040	87	2,810	1,750	31
[6] 392a	74	do	.85	do	24	20	------	------	35	7.1	2,430	3,450	5,260	5,540	4,170	79	2,060	1,300	23
393	74	do	.93	66 per cent Trass	24	20	------	------	35	9.1	1,930	3,350	4,600	5,100	4,400	96	3,510	2,140	42
[7] 393a	74	do	1.09	do	24	20	------	------	35	8.4	1,440	2,670	4,270	4,740	3,660	86	2,650	1,830	39
394	86	Portland I	.78	33 per cent Trass	24	20	------	------	35	6.8	3,330	4,690	6,620	7,180	5,300	80	2,940	1,260	18
[6] 394a	86	do	.87	do	24	20	------	------	35	6.7	3,000	3,850	6,170	5,410	4,140	67	1,080	0	------
395	86	do	.95	66 per cent Trass	24	20	------	------	35	7.6	2,710	3,770	6,060	4,970	4,300	71	2,570	2,110	42
[7] 395a	86	do	1.09	do	24	20	------	------	35	7.3	2,280	3,380	4,090	4,990	3,810	93	1,140	1,620	32
554	129	½ Portland A, ½ Portland B.	.64	None	24	20	------	------	35	6.3	3,570	4,760	5,980	------	3,530	59	0	0	------
578	129	do	.62	1 per cent Truscon	24	20	------	------	35	4.7	3,370	4,700	5,320	------	3,750	70	0	0	------
579	129	do	.62	2 per cent Truscon	24	20	------	------	35	4.1	3,370	4,580	4,980	------	3,280	66	0	0	------
580	129	do	.62	4 per cent Truscon	24	20	------	------	35	3.7	3,020	3,980	4,630	------	2,420	52	0	0	------
177	18	do	.59	None	24	20	------	------	35	5.9	2,520	4,200	4,930	6,120	3,670	74	[1] 1,910	0	------
178	18	do	.74	20 per cent volcanic ash.	24	20	------	------	35	6.8	1,900	3,210	5,450	5,670	2,960	54	[1] 1,970	0	------
179	18	do	.59	None	24	------	48	155	35	5.8	4,110	4,510	5,210	6,460	3,820	73	[1] 2,380	1,750	27
180	18	do	.74	20 per cent volcanic ash.	24	------	48	155	35	7.6	3,240	3,340	4,440	5,560	3,600	81	[1] 4,510	1,760	32
181	18	do	.74	do	24	------	48	100	35	7.3	2,710	2,820	5,130	5,670	4,290	84	[1] 3,590	2,430	34

[1] 2-year tests. [5] Standard Ottawa sand cylinders. [6] Mix 1 : 4. [7] Mix 1 : 5.

GASOLINE TAXES, 1930

Total tax earned on motor vehicle fuel, etc., refunds, disposition of fund, and gallons taxed

[From reports of State authorities]

State	Gross tax assessed prior to deduction of refund	Exemption refund: (Deducted from gross tax)	Total tax earning on fuel for motor vehicles [1]	Other receipts under tax law (licenses)	Grand total earning (tax and other receipts)	Disposition of grand total earnings: Collection cost [2]	Construction and maintenance on rural roads: State highways	Construction and maintenance on rural roads: Local roads	State and county road bond payments [3]	For miscellaneous purposes	Tax rates, 1930: Cents per gallon: Jan. 1	Tax rates, 1930: Cents per gallon: Dec. 31	Tax rates, 1930: Date of rate change	Net gallons of gasoline taxed, and used by motor vehicles
Alabama	$6, 901, 491		$6, 901, 491	$1	$6, 901, 492	$34, 064	$1, 958, 478	$3, 439, 493	$1, 469, 457		4	4		172, 537, 281
Arizona	3, 011, 844	$341, 825	2, 670, 019		2, 670, 019	([4])	1, 682, 596	987, 423			4	4		66, 750, 478
Arkansas	6, 702, 273	275, 000	6, 427, 273		6, 427, 273	47. 908	4, 505, 108		[5] 1, 802, 755	[6] $71, 502	5	5		128, 545, 469
California	38, 603, 808	3, 733, 682	34, 870, 126		34, 870, 126	[7] 51, 532	23, 212, 396	11, 606, 198			3	3		1, 162, 337, 545
Colorado	6, 834, 198	689, 372	6, 144, 826		6, 144, 826	[8] 54, 750	4, 263, 053	1, 644, 321		[9] 182, 702	4	4		153, 620, 645
Connecticut		([10])	4, 465, 933	49, 130	4, 515, 063	([11])	4, 515, 063				2	2		223, 296, 627
Delaware	1, 071, 363	58, 006	1, 013, 357		1, 013, 357		864, 170		149, 187		3	3		33, 778, 561
Florida	13, 622, 215		13, 622, 215	32, 960	13, 655, 175	13, 280	4, 540. 738	756, 790	[12] 4, 540, 738	[13] 3, 803, 629	6	6		227. 036, 915
Georgia	13, 391, 079		13, 391, 079	43, 983	13, 435, 062	4, 200	8, 953, 908	2, 238, 477		[14] 2, 238, 477	6	6		223, 184, 648
Idaho	2, 941, 124	272, 542	2, 668, 582	62, 280	2, 730, 862	12, 752	2, 674, 080		35, 609	[15] 8, 421	4	5	Mar. 1	[16] 54, 422, 752
Illinois [17]	28, 612, 269	1, 139, 849	27, 472, 420		27. 472, 420	61, 724	18, 273, 797	9, 136, 899			3	3		915, 747, 319
Indiana	18, 247, 078	1, 088, 332	17, 158, 746	88	17, 158, 834	40, 958	12, 838, 407	3, 209, 602		[18] 1, 069, 867	4	4		428, 968, 653
Iowa	11, 793, 452	1, 209, 384	10, 584, 068		10, 584, 068	32, 524	[19] 5, 242, 393	5, 309, 151			3	3		352, 802, 277
Kansas	10, 853, 021	1, 732, 530	9, 120, 491		9, 120, 491	([20])	7, 370, 491	1, 750, 000			3	3		304, 016, 374
Kentucky	8, 414, 733		8, 414, 733		8, 414, 733	28, 364	8, 386, 369				5	5		168, 294, 655
Louisiana	7, 547, 292	844	7, 546, 448		7, 546, 448	([21])	5, 543, 453		1, 847, 817	[22] 155, 178	4	5	Nov. 27	184, 781, 753
Maine	4. 347, 071	237, 575	4, 109. 496	[23] 59, 394	4, 168, 890	28, 847	2, 070, 022	2, 070, 021			4	4		[24] 102, 737, 416
Maryland	7, 285, 117	293, 929	6, 991, 188		6, 991, 188	9, 000	5, 525, 750			[25] 1, 456, 438	4	4		174, 779, 706
Massachusetts	10, 721, 664	158, 717	10, 562, 947		10, 562, 947	20, 000	7, 407, 323	2, 500, 000	635, 624		2	2		528, 147, 350
Michigan	23, 783, 308	2, 109, 429	21. 673, 879	39, 610	21, 713, 489	41, 373	1, 508, 626	6, 623, 880	3, 000, 000	[26] 539, 610	3	3		722, 462, 626
Minnesota	11, 432, 686	1, 073. 575	10, 359. 111		10, 359, 111		6, 906. 074	3. 453, 037			3	3		345, 303, 709
Mississippi	6, 791, 177		6, 791, 177	[27] 126, 398	6, 917, 575	6, 645	2, 848, 126	3, 855, 364		[28] 207, 440	5	5		135, 823, 574
Missouri	8, 901, 169	262, 008	8, 639, 161		8, 639, 161	56, 760	8, 582, 401				2	2		431, 958, 060
Montana	3, 873, 713	931, 834	2, 941, 879		2, 941, 879	13, 500	2, 928, 379				5	5		58, 837, 575
Nebraska	9, 149, 484	89, 062	9, 060, 422		9, 060, 422	7, 500	6, 789, 691	2, 263, 231			4	4		226, 510, 543
Nevada	744, 615	69, 603	675, 012		675, 012	([29])	675, 012				4	4		16. 875, 292
New Hampshire	2, 589, 833	90, 355	2, 499, 478		2, 499, 478		1. 874, 608		624, 870		4	4		62, 486, 940
New Jersey		([30])	11, 342. 896	37, 335	11, 380, 231	18, 660	11, 268, 571			[31] 93, 000	2	3	Dec. 1	546, 685, 108
New Mexico	2, 719, 281		2, 719, 281	42, 606	2, 761, 887	55, 238	1, 842, 649		864. 000		5	5		54, 385, 614
New York	29, 536. 436	[32] 1, 060. 146	28, 476, 290		28, 476, 290	([33])	21, 319, 718	5, 685, 258		[34] 1, 471, 314	2	2		[35] 1, 438, 582, 716
North Carolina	13, 174, 064	640. 610	12, 533, 454		12, 533, 454	([36])	8, 845, 113		3, 688, 341		5	5		250, 669, 089
North Dakota	3, 405, 212	1, 435, 908	1, 969, 304	2, 682	1, 971, 986	25, 000	1, 290, 000	645, 000		[37] 11, 986	3	3		65, 643, 460
Ohio	39, 023, 304	1, 941, 853	37, 081, 451		37, 081, 451		23, 175, 907	7, 416, 290		[18] 6, 489, 254	4	4		927, 036, 272
Oklahoma	12, 924, 521	832, 101	12, 092, 420		12, 092, 420	62, 684	9, 022, 302	3, 007, 434			4	4		302, 310, 488
Oregon	6, 787, 295	588, 518	6, 198, 777		6, 198, 777	14, 967	6, 183, 810				4	4	1/1	[39] 154, 986, 497
Pennsylvania	33, 482, 609	166, 880	33, 315, 729	[39] 307, 781	33, 623, 510	[40] 278, 875	25, 250. 576	4, 644. 213	3, 449, 846		4	3	7/1	928, 842, 534
Rhode Island	1, 776, 773	44, 514	1, 732, 259	3, 488	1, 735, 747		1, 301, 810		433, 937		2	2		86, 612, 980
South Carolina	7, 162, 945	18, 635	7, 144. 310	1, 401	7, 145, 711		3. 475, 756	1, 190, 952	[41] 2, 479, 003		6	6		119, 071, 835
South Dakota	5, 149, 295	1, 645, 413	3, 503, 882		3, 503, 882	12, 750	2, 715, 155		775, 977		4	4		87, 597, 064
Tennessee	10, 719, 195		10, 719, 195		10, 719, 195	53, 596	6, 399, 359	2, 133, 120	[12] 2, 133, 120		5	5		214, 383, 900
Texas	32, 341, 499	2, 814, 401	29, 527, 098		29, 527, 098		22, 145, 324			[42] 7, 381, 774	4	4		738, 177. 457
Utah		([43])	2, 104, 823	706	2. 105, 529	3, 836	1, 663, 193		438, 500		3½	3½		60, 137, 811
Vermont	1, 879, 921		1, 879, 921		1, 879, 921	([44])	1, 879, 921				4	4		46, 998, 012
Virginia	11, 426, 066	651, 008	10, 775. 058		10, 775, 058	([45])	7, 542, 541	3, 232, 517			5	5		215, 501, 157
Washington	7, 951, 587	698, 338	7, 253, 249		7, 253, 249	([46])	4, 835, 499	2, 417, 750			3	3		241, 774, 964
West Virginia	5, 615, 926	257, 298	5, 358, 628	8. 450	5, 367, 078		2, 686, 823		2, 680. 255		4	4		133, 965, 701
Wisconsin	8, 757, 555	442, 714	8, 314, 841		8, 314, 841	10, 900	3, 057, 771	4, 647, 465		[18] 598, 705	2	2		415, 742, 027
Wyoming	1, 447, 005		1, 447, 005		1, 447, 005		1, 085, 254	361, 751			4	4		36, 175, 118
District of Columbia	1, 610, 770	11, 081	1, 599, 689		1, 599, 689					[47] 1, 599, 689	2	2		79, 984, 431
Total			493, 865, 117	818, 293	494, 683, 410	1, 102, 187	338, 927, 564	96, 225, 637	[48] 31, 049, 036	[49] 27, 378, 986	Average 3.35 cents			14, 751, 308, 978

[1] Net gasoline tax earned after deduction of refunds allowed by law.
[2] Many States pay collection costs from other State funds, and amounts reported are noted.
[3] Payments for State highway bonds except as noted.
[4] Paid from State budget, $14,685.
[5] Includes $1,326,274 for county bonds.
[6] Includes $50,227 for State highway commission office expenses, and $21,275 for city streets.
[7] Includes administrative costs of State board of equalization which controls fuel tax and transportation tax
[8] Includes all expenses of State inspector of oils.
[9] For town and city streets.
[10] Exemptions made at time of purchase on 9,349,546 gallons.
[11] Paid from motor vehicle receipts, $30,000.
[12] Payments on county road bonds.
[13] For schools and school buildings, $3,783,949, and for reserve fund, $19,680.
[14] For public Schools.
[15] Aviation gas tax fund, for aviation purposes.
[16] Omits 173,975 gallons sold for aviation purposes.
[17] The 2 per cent allowance for evaporation and loss on gross purchases by retailers not shown here.
[18] For city streets.
[19] Includes $3,000,000 formerly a reserve for refunds on right of way, bridges, and culverts.
[20] Paid from State general fund, $15,000.
[21] Paid from State appropriation, $57,500.
[22] For dock board.
[23] Consists of 1 cent tax on all gasoline not used by motor vehicles (3 cent refund).
[24] Excludes gallonage taxed 1 cent, not used by motor vehicles.
[25] Includes $1,381,438 to Baltimore streets and grade separations; also $75,000 for oyster propagation.
[26] Includes $500,000 for city streets, $35,350 for aviation fund, and $4,260 to State general fund.
[27] Receipts from extra 2 cent tax in Harrison County and 3 cent tax in Hancock County for sea-wall.
[28] Allotted to sea-wall financing (largely from extra tax receipts).
[29] Paid from tax commission fund, $1,500.
[30] Exemption made at time of purchase on 96,681,081 gallons.
[31] Includes $90,000 for free bridge commission and department of navigation and commerce, also $3,000 for public utility commission.
[32] Includes $764,782, refunded and an allowance to distributors of $295,364.
[33] Paid from State appropriation of $65,497.
[34] Includes $50,000 to reserve for refunds and $1,421,314 to New York City funds.
[35] Includes 14,768,218 gallons taxed, but taxes returned to distributors for collection costs.
[36] Paid from State highway commission maintenance fund, $8,686.
[37] Includes $11,334 to reserve for refunds, and $652 (license fees) to State general fund.
[38] Includes approximately 136,579 gallons of distillate taxed 3½ cents per gallon.
[39] Includes $299,591 for previous years' taxes.
[40] Collection bonus to dealers deducted before payment of tax to State.
[41] Payments of $300,000 on State highway bonds and $2,179,003 on county road bonds.
[42] For free school fund.
[43] An allowance of 2 per cent for evaporation and handling exempts 1,227,178 gallons from tax.
[44] Paid from motor vehicle funds, $1,000.
[45] Paid from State appropriations of $15,144.
[46] Paid from motor vehicle fund, $5,000.
[47] For repair and improvement of Washington streets.
[48] Includes payments of $10,179,135 on county bonds, and $20,869,901 on State bonds.
[49] Includes $11,842,930 for city streets, $13,404,200 for schools, and $2,131,856 for various items.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

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

ANNUAL REPORTS

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

DEPARTMENT BULLETINS

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

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

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

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

*660D. Highway Cost Keeping. 10c.

1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.

1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.

1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55T. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

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

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

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

MISCELLANEOUS PUBLICATIONS

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

SEPARATE REPRINTS FROM THE YEARBOOK

No. *914Y. Highways and Highway Transportation. 25c.

937Y. Miscellaneous Agricultural Statistics.

1036Y. Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

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

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

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

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

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

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

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

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

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

Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.

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

*Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID AND EMERGENCY ROAD CONSTRUCTION

AS OF

APRIL 30, 1931

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION						APPROVED FOR CONSTRUCTION						BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	BALANCE OF EMERGENCY ADVANCE FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid Allotted	Emergency Advance Fund	Mileage			Estimated Total Cost	Federal Aid Allotted	Emergency Advance Fund	Mileage				
					Initial	* Stage	Total				Initial	*Stage	Total		
		$	$	$				$	$	$				$	$
Alabama	2,143.1	6,304,189.02	3,069,860.09	992,086.47	200.2	87.4	287.6	1,355,314.95	676,962.70	678,352.25	36.0	35.6	71.6	3,345,444.97	28,206.28
Arizona	869.6	4,898,026.08	3,383,483.05	836,633.18	182.2	176.8	359.0	596,972.77	318,491.96	233,199.25	18.8	42.4	61.2	1,150,275.97	100,648.57
Arkansas	1,789.6	7,738,949.88	3,584,532.80	1,088,157.00	207.5	58.7	266.2	1,509,354.70	726,026.23	195,000.00	36.2	22.3	58.5	877,549.70	105,000.00
California	1,963.6	10,293,716.50	4,353,834.51	1,245,006.40	271.2	39.3	310.5	2,724,850.51	1,044,300.99	840,762.51	44.7	17.9	62.6	1,864,286.08	1,022,464.09
Colorado	1,291.0	4,572,913.12	2,420,239.55	691,801.62	157.0	89.0	246.0	2,054,705.69	1,123,232.45	637,297.67	89.1	21.4	110.5	2,135,633.62	178,732.71
Connecticut	258.2	4,643,863.46	1,755,735.33	520,491.00	43.9		43.9	484,683.59	120,645.53		5.5		5.5	107,026.70	
Delaware	302.4	1,102,292.38	550,391.68	400,000.00	56.2		56.2	81,139.00	40,569.50		3.0		3.0	122,256.86	
Florida	540.0	5,066,324.11	2,396,159.84	521,899.76	132.0		132.0	685,590.17	281,222.78	404,367.39	18.6		18.6	1,985,953.95	160,170.85
Georgia	2,765.4	8,374,440.27	4,081,666.28	1,687,033.71	304.4	94.5	398.9	1,741,483.89	835,386.80	353,570.10	47.8	24.3	72.1	1,716,298.30	37,392.19
Idaho	1,296.9	2,573,027.93	1,515,037.43	246,498.74	175.3	11.7	187.0	1,701,383.25	881,190.89	699,952.02	114.8	24.9	139.7	922,358.35	61,584.24
Illinois	2,196.5	21,855,064.75	9,934,551.88	877,000.00	617.8	57.3	675.1	9,348,294.61	4,268,455.74	2,360,111.72	300.2	4.7	304.9	2,527,670.77	163,004.28
Indiana	1,579.1	6,246,533.83	3,216,459.72	479,512.51	162.7		162.7	5,563,006.99	2,430,596.62	1,169,068.74	168.1		168.1	1,097,142.51	397,347.75
Iowa	3,177.3	5,989,497.33	2,524,410.99	1,518,369.00	142.7	52.7	195.4	2,051,840.25	831,065.00	598,000.00	24.5	40.8	65.3	4,069.10	
Kansas	3,117.8	7,327,770.42	3,510,584.26	751,047.91	421.1	25.8	446.9	3,487,053.39	1,628,416.07	425,503.96	173.8	52.9	226.7	849,244.37	985,747.33
Kentucky	1,555.6	5,739,096.45	2,461,851.51	511,676.40	206.0	81.1	287.1	4,024,035.81	1,234,349.03	925,517.33	91.2	83.9	175.1	339,392.32	67,521.27
Louisiana	1,420.9	7,600,450.04	3,632,125.18	1,037,343.87	255.0	18.6	273.6	1,742,075.81	702,705.82	105,000.00	21.1	1.4	22.5	179,490.69	5,583.13
Maine	591.3	2,825,951.90	999,545.62	178,467.36	48.9		48.9	2,668,149.89	1,078,930.97	537,331.64	78.5		78.5	791,969.44	
Maryland	704.8	283,984.10	78,782.10	116,578.60		3.9	3.9	1,582,502.10	791,251.02	562,173.40	55.4	.4	55.8	209,817.29	
Massachusetts	711.7	8,401,439.13	2,095,208.23	1,141,460.00	73.6		73.6	1,615,946.93	309,421.80		17.2		17.2	2,260,942.96	
Michigan	1,798.1	9,411,819.32	3,957,290.06	661,000.00	256.6	21.1	277.7	1,020,317.20	445,587.65	228,000.00	35.0	9.7	44.7	3,347,325.47	1,632,382.00
Minnesota	4,123.5	3,539,813.19	1,414,910.51	635,000.00	44.5	147.4	191.9	5,545,487.59	2,329,661.41	1,614,993.00	35.4	168.0	203.4	66,623.49	
Mississippi	1,778.7	2,929,325.94	1,447,936.40	870,283.73	108.0	69.1	177.1	1,291,465.78	630,108.69	490,924.16	62.4	22.8	85.2	3,939,513.29	73,528.11
Missouri	2,659.5	7,645,366.06	2,886,098.37	469,653.74	166.4	42.4	208.8	3,073,500.32	1,305,677.14	1,441,033.33	97.9	40.6	138.5	1,356,149.00	616,135.93
Montana	1,856.3	10,136,708.24	5,705,452.50	1,233,498.56	803.3	77.7	881.0	2,002,676.54	1,128,161.21	431,200.00	116.0	109.5	225.5	2,468,078.33	7,231.44
Nebraska	3,856.6	6,922,801.61	3,231,832.73	891,135.36	231.5	151.1	382.6	2,827,101.19	1,354,433.39	758,698.38	30.6	133.1	163.7	1,726,016.79	58,197.26
Nevada	1,249.4	1,367,326.09	1,053,793.26	164,966.13	62.6	91.3	153.9	1,497,973.65	867,359.50	590,674.25	11.6	147.4	159.0	805,204.61	293,997.62
New Hampshire	392.0	609,439.04	229,098.40		9.7		9.7	208,447.30	98,355.00	75,000.00	6.5		6.5	470,344.65	325,000.00
New Jersey	555.2	4,566,555.45	1,406,315.02	923,770.59	64.0		64.0	1,704,508.24	350,474.32	180,000.00	10.9		10.9	1,081,497.42	4,036.41
New Mexico	1,965.2	5,855,661.33	3,802,565.82	1,052,226.97	214.5	106.1	320.6	482,095.12	306,646.46	117,130.42	31.3	10.6	41.9	231,258.14	133,930.61
New York	2,694.9	30,385,970.33	9,406,537.00	2,448,566.00	469.7		469.7	17,102,696.00	6,690,314.00	1,527,000.00	290.9	7.0	297.9	21,062.84	75,000.00
North Carolina	1,924.6	6,398,222.39	3,091,145.32	1,192,797.65	205.9	31.8	237.7	2,237,928.69	1,105,805.98	704,516.53	86.0	27.9	113.9	1,676,726.25	29,460.82
North Dakota	4,519.6	2,638,746.24	1,360,215.43	410,587.00	352.9	192.2	545.1	1,828,232.18	898,264.86	664,837.09	152.6	327.3	479.9	1,799,745.46	223,107.91
Ohio	2,558.8	12,670,669.49	3,928,628.88	837,225.35	187.3	6.9	194.2	4,876,958.16	1,363,576.86	2,161,312.65	61.4	23.7	85.1	2,861,396.51	
Oklahoma	1,974.9	5,280,941.80	2,571,557.49	555,955.16	235.0	83.3	318.3	3,888,410.57	2,122,878.78	1,370,395.84	117.7	54.9	172.6	28,144.99	
Oregon	1,262.3	7,103,184.83	3,972,035.22	634,946.08	221.7	90.5	312.2	672,687.73	373,513.95	173,241.28	41.2		41.2	844,510.89	517,099.64
Pennsylvania	2,658.1	7,709,665.31	2,669,533.37		49.9		49.9	2,720,215.63	1,228,183.52	1,287,072.66	79.4		79.4	3,953,431.45	2,225,870.34
Rhode Island	209.5	2,858,872.53	1,078,494.76	375,000.00	44.2		44.2	242,238.02	121,119.01	25,000.00	3.8		3.8	118,603.85	
South Carolina	1,825.7	6,503,546.65	2,910,046.87	1,114,636.00	84.1	179.3	263.4							126,684.51	
South Dakota	3,748.8	4,802,106.99	2,723,709.78	908,987.85	393.6	121.5	515.1	258,998.58	144,248.79	72,065.15	29.2	29.9	59.1	1,361,783.20	356,920.00
Tennessee	1,458.1	3,013,294.18	1,505,323.22	819,748.88	124.6	7.9	132.5	1,768,167.43	865,567.66	825,940.52	85.7	5.5	91.2	2,018,727.20	96,192.60
Texas	7,074.5	14,243,803.00	6,363,979.14	2,104,039.16	636.5	177.9	814.4	7,043,830.62	3,367,618.00	2,981,556.54	260.3	144.3	404.6	4,394,816.28	2,484.30
Utah	997.4	2,017,298.85	1,299,282.44	350,060.07	127.1	53.8	180.9	988,001.62	465,015.55	494,928.82	39.4	82.3	121.7	839,989.22	81,532.11
Vermont	306.3	996,110.09	408,025.95	248,117.02	23.3		23.3	102,493.27	51,246.63	25,034.78	.4		.4	159,236.45	126,848.20
Virginia	1,628.4	5,599,046.17	2,597,504.39	1,006,955.70	241.0	30.5	271.5	1,080,293.43	418,205.97	452,857.60	28.1	18.3	46.4	801,472.15	45,688.70
Washington	1,013.1	4,129,428.77	1,845,198.55	540,846.04	131.4	7.7	139.1	1,309,671.27	550,833.75	641,937.52	41.9	14.4	56.3	1,445,443.98	88,149.44
West Virginia	768.2	4,461,883.16	1,688,289.31	400,766.85	100.2	12.5	112.7	1,398,672.84	526,528.57	345,799.49	36.6		36.6	511,214.60	128,817.66
Wisconsin	2,476.3	3,662,575.37	1,577,374.55	323,000.00	90.6	13.0	103.6	4,311,220.81	1,801,937.37	1,530,500.00	98.2	55.4	153.6	978,267.97	138,910.00
Wyoming	1,692.1	3,273,782.97	2,103,688.10	310,650.35	204.2	162.7	366.9	1,187,894.33	618,498.28	499,831.51	103.1	99.4	202.5	522,818.89	218,901.14
Hawaii	46.3	790,777.25	361,304.04		26.6		26.6	746,899.90	260,361.36	375,983.99	17.2		17.2	1,580,221.20	24,016.01
TOTALS	89,347.2	303,362,273.34	134,161,626.93	36,325,483.77	9,568.6	2,674.5	12,243.1	118,437,468.31	51,113,405.55	32,812,673.49	3,355.2	1,904.9	5,260.1	63,823,123.03	10,831,840.94

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