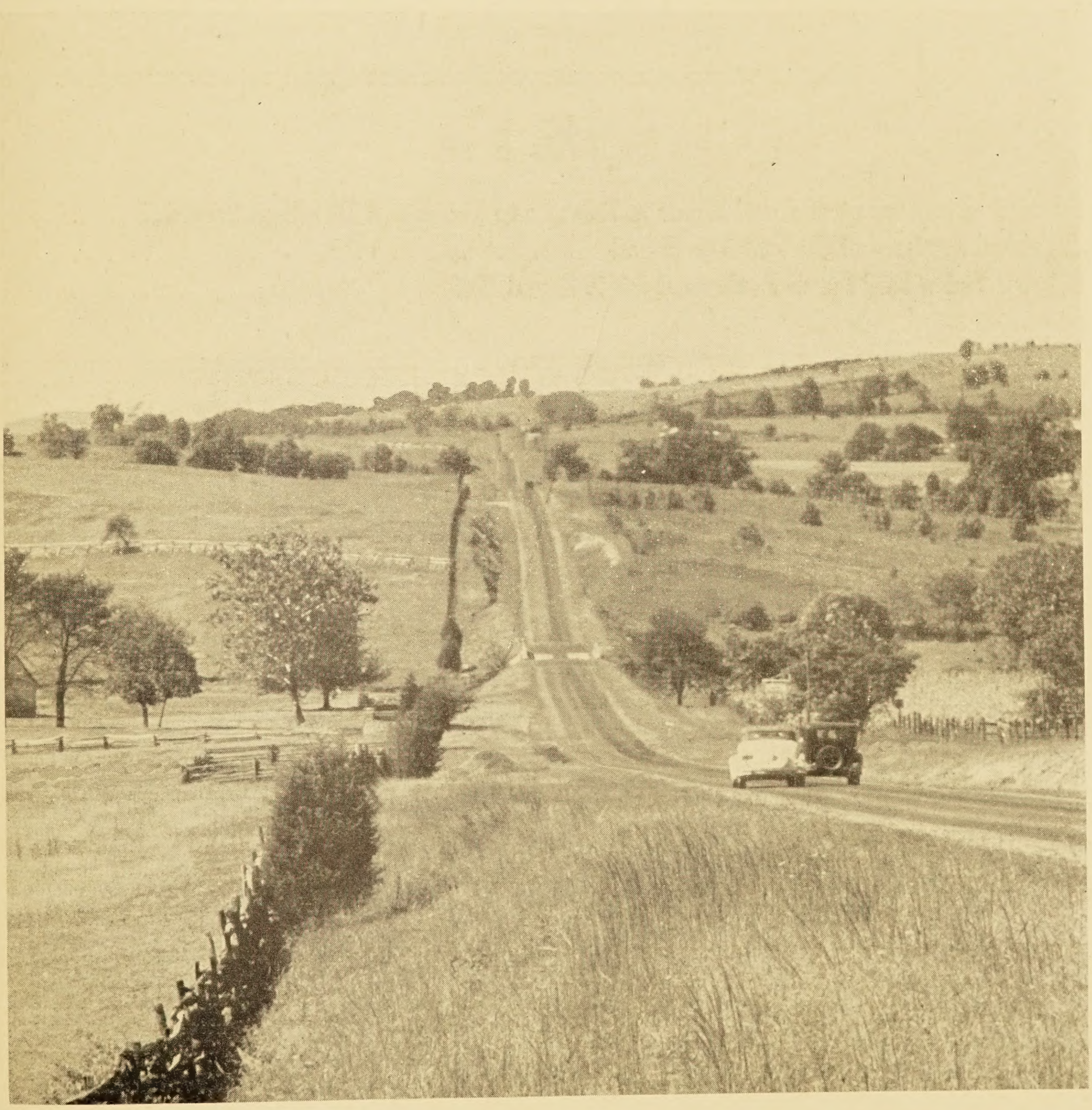
PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 21, No. 8 ▽ OCTOBER 1940



A SECTION OF U S 211 IN VIRGINIA

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

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

Issued by the

FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 21, No. 8 October 1940

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

In This Issue

THE PUBLIC ROADS ADMINISTRATION - - - - - - - - - Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS - - - - - - - - - - - - - - - - Federal Building, Civic Center, San Francisco, Calif.

▼

DISTRICT OFFICES

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

DISTRICT No. 2. California, Arizona, and Nevada.
Federal Building, Civic Center, San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
254 New Customhouse, Denver, Colo.

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

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
711 U. S. Courthouse, Kansas City, Mo.

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

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

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

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
505 Post Office Building, Albany, N. Y.

DISTRICT No. 10. Delaware, Maryland, Ohio, Pennsylvania, and District of Columbia.
Willard Building, Washington, D. C.

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

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

DISTRICT No. 14. North Carolina, South Carolina, Virginia, and West Virginia.
Montgomery Building, Spartanburg, S. C.

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institution other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain PUBLIC ROADS can do so by sending $1 per year (foreign subscription $1.50), or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington, D. C.

STATE OF IMPROVEMENT OF RURAL ROADS IN RELATION TO TRAFFIC AND DWELLINGS SERVED

BY THE DIVISION OF HIGHWAY TRANSPORT, PUBLIC ROADS ADMINISTRATION

Reported by JOHN T. LYNCH, Highway Engineer-Economist and THOMAS B. DIMMICK, Associate Highway Engineer-Economist

AN IMPORTANT PART of the State-wide highway planning surveys has been the determination of the state of improvement of rural roads in relation to the volume of travel and to the location of rural dwellings. Such a determination is basic in any appraisal of highway service in relation to needs, and in the setting up of long-range construction programs and the making of financial provisions for them.

The summarization of the data has not yet been completed in all States, but the work is sufficiently far advanced to permit the release of preliminary figures that give a reasonably accurate national picture of our highway facilities, showing the extent to which traffic and rural dwellings are served by roads having surfaces of different types. A complete appraisal of the adequacy of highways for traffic needs would necessarily take into consideration surface width, alinement, grades, and sight distances, as well as surface type. The clearances, strength, and condition of bridges, and the hazards and delays at railroad grade crossings, should also be considered. Information concerning all of these factors has been obtained in the highway planning surveys, but is not yet ready for presentation on a national basis. This article deals only with the service rendered by roads of different surface types in those States for which the information is now available.

Road construction practices vary in different sections of the country because of differences in climatic conditions, subsoil conditions, and character of available local materials as well as differences in wealth and in public policy as carried out by the State and local highway organizations. There are, then, no standards of adequacy that are generally applicable throughout the country. In one section, climatic conditions may be such that unsurfaced roads will satisfactorily serve much higher volumes of traffic than in another section. Subsoil conditions in one locality may require a higher type of surface for traffic of a given volume and weight composition than that required in another locality. Differences in available funds and mileages of roads needing improvement have caused States to adopt different standards of improvement for roads of equal traffic importance. These facts should be borne in mind in appraising the relative degrees of surface improvement shown by the tabulations in this article.

ROADS CLASSIFIED INTO FIVE GROUPS ACCORDING TO SURFACE TYPE

Because of differences in construction practices and in current terminology, considerable difficulty was experienced in classifying surface types on a comparable basis in all States. Although every effort was made to attain uniformity, minor differences in classification undoubtedly exist. In preliminary tabulations 12 classifications were used but these are combined into five groups in the accompanying tables. These five general surface type groups are defined in commonly used terms, without attempting to make precise distinctions. The terms used to describe the individual types composing each group are not, in all cases, mutually exclusive, as two or more types may be nearly identical. The distinctions between the general surface type groups, however, are reasonably definite in all cases.

1. *Pavement* includes concrete, brick, stone block, wood block, asphalt block, sheet asphalt, rock asphalt, bituminous concrete, and bituminous penetration.
2. *Other dustless surface* includes plant mix without precise control, road mix or mixed-in-place, and bituminous surface treated gravel or stone.
3. *Nondustless surface* includes plain macadam, gravel, traffic-bound crushed stone, slag, chert, caliche, iron ore, chats, sand-clay, and topsoil.
4. *Graded and drained* includes roads of natural earth, alined and graded to permit reasonably convenient use by motor vehicles, with drainage systems sufficient to prevent serious impairment of the road by surface water.
5. *Unimproved* includes primitive roads and trails usable by four-wheel vehicles and also earth roads on which some blading may have been done but which do not conform in respect to alinement, grade, and drainage to the requirement for a graded and drained road.

Roads with surfaces falling in the first three groups are called surfaced roads; roads falling in the last two groups are called unsurfaced roads.

The initial road inventory and traffic surveys were started in a few States as early as the fall of 1935 and completed toward the end of 1936. The work was started later in most States and, in a few, only very recently. The effective dates of figures in the accompanying tables vary from 1936 to 1939 and the period covered by the traffic survey does not, in all cases, coincide with that covered by the road inventory. Under the continuing survey an effort is being made to keep traffic and road inventory information current so that it should soon be possible to present up-to-date tabulations of both road inventory and traffic data for a specific year.

In interpreting the figures given in the tables and text of this report, it should be borne in mind that there are some differences in effective dates and that the data apply to different periods from 1936 to 1939. There have undoubtedly been changes since the effective dates of the data, because of the normal construction programs of Federal, State, and local agencies, and the surfacing of considerable mileages with the assistance of the Work Projects Administration in a number of States. On the whole, however, it is believed that changes have not been sufficiently large, relatively, to invalidate the general picture presented.

The total mileage of rural roads in the United States is estimated to be approximately 2,960,000 miles. Of this, approximately 1,200,000 miles, or about 40 percent, have surfaces permitting travel in all seasons of the

261154—40——1

year. Complete information on road mileage and surface type as of various dates from August 1936 to December 1939 is available for 34 States. The total road mileage reported by these States was 2,219,723 miles, of which 840,129 miles, or 37.8 percent, were surfaced. Table 1 shows the mileage of each general surface type and the percentage of the total mileage for each of the 34 States.

The percentage of the total mileage that was surfaced ranged from 85.4 percent in Ohio, to 13.5 percent in Nevada. It will be noted that most of the surfaced mileage in Ohio consisted of gravel and other nondustless types, only 25.1 percent of the total mileage in this State having dustless surfaces. In New Jersey, on the other hand, in which 62.7 percent of the total mileage was surfaced, 49.4 percent had dustless surfaces. Nine States had less than 20 percent of their total road mileages surfaced. Figure 1 shows the percentage of the total mileage surfaced, the percentage with a dustless surface, and the percentage paved, for each of the 34 States, arranged in descending order of the percentage surfaced.

TRAFFIC ON PAVED ROADS 12 TIMES THE AVERAGE FOR ALL ROADS

Naturally, travel is generally heavier on roads having high type surfaces than it is on low type surfaces or on unsurfaced roads. In the first place, high traffic volume, actual or potential, was generally the cause of the construction of the higher type surfaces. In addition, traffic tends to gravitate to the more highly improved roads.

Combined traffic and road inventory information is available for 24 States. In these States the average daily traffic was 1,232 vehicles for pavements, 413 vehicles for other dustless surfaces, 77 vehicles for nondustless surfaces, 22 vehicles for graded and drained roads, and 13 vehicles for unimproved roads. The average for all types of road was 104 vehicles. Table 2 shows average daily traffic on each general surface

TABLE 2.—*Average daily traffic on rural roads of each general surface type in each of 24 States*

State	Pavement	Other dustless surface	Nondustless surface	Graded and drained	Unimproved	All roads
Arizona	946	522	83	50	13	84
California	1,485	266	83	40	17	236
Colorado	2,096	575	84	32	10	59
Florida	988	353	47	27	10	173
Idaho	1,896	551	79	25	12	70
Indiana	1,370	370	53	10	6	165
Iowa	1,014	386	87	25	17	94
Kansas	1,239	590	98	54	16	64
Louisiana	836	789	96	12	6	113
Maryland	1,285	565	65	35	21	338
Michigan	1,525	324	84	22	10	160
Missouri	1,303	377	60	14	4	76
Montana	505	293	49	26	9	38
Nevada	1,535	233	38	22	5	33
North Dakota	1,641	484	67	11	2	17
Ohio	1,146	332	64	20	18	204
Oklahoma	1,356	638	153	24	6	78
Oregon	1,084	398	60	9	3	89
South Dakota	1,065	517	78	12	1	27
Texas	1,199	641	95	78	25	122
Utah	1,418	416	57	17	5	72
Vermont	916	535	68	11	3	111
West Virginia	992	485	105	52	26	147
Wyoming	742	357	88	27	12	56
Average	1,232	413	77	22	13	104

TABLE 1.—*Mileage of rural roads of each general surface type and percentage of total mileage of rural roads in each of 34 States*

State	Date of inventory	Pavement		Other dustless surface		Nondustless surface		Total surfaced		Graded and drained		Total improved		Unimproved [1]		Total	
		Miles	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*
Arizona	Dec. 1937	564.5	2.0	2,174.4	7.9	2,317.8	8.4	5,056.7	18.3	4,218.8	15.3	9,275.5	33.6	18,271.7	66.4	27,547.2	100.0
Arkansas	Jan. 1937	1,595.4	2.9	624.0	1.2	12,528.6	23.1	14,748.0	27.2	11,648.9	21.5	26,396.9	48.7	27,889.6	51.3	54,286.5	100.0
California	Dec. 1937	10,114.7	10.2	22,183.8	22.3	[2] 20,333.0	20.4	52,631.5	52.9	3,810.4	3.8	56,441.9	56.7	[3] 43,118.6	43.3	99,560.5	100.0
Colorado	Aug. 1939	493.4	.7	3,218.6	4.3	9,307.9	12.3	13,019.9	17.3	6,658.2	8.8	19,678.1	26.1	55,576.7	73.9	75,254.8	100.0
Florida	Dec. 1936	1,835.7	6.4	7,599.5	26.3	2,435.9	8.4	11,871.1	41.1	13,828.6	47.8	25,699.7	88.9	3,212.1	11.1	28,911.8	100.0
Idaho	Dec. 1936	171.9	.5	1,940.2	5.8	7,792.1	23.2	9,904.2	29.5	4,484.1	13.4	14,388.3	42.9	19,152.2	57.1	33,540.5	100.0
Illinois	Jan. 1937	11,390.9	11.1	678.8	.7	47,899.5	46.6	59,969.2	58.4	37,747.5	36.8	97,716.7	95.2	4,966.9	4.8	102,683.6	100.0
Indiana	Jan. 1937	5,452.4	7.1	6,390.8	8.3	49,872.6	65.1	61,715.8	80.5	5,690.4	7.4	67,406.2	87.9	9,283.9	12.1	76,690.1	100.0
Iowa	Dec. 1937	4,843.5	4.8	558.9	.5	35,077.3	33.8	40,479.7	39.1	40,794.9	40.4	81,274.6	79.5	[4] 20,624.3	20.5	101,898.9	100.0
Kansas	Dec. 1936	1,809.8	1.4	3,341.7	2.6	24,756.3	19.3	29,907.8	23.3	2,004.6	1.6	31,912.4	24.9	96,285.4	75.1	128,197.8	190.0
Kentucky	July 1938	1,910.2	3.4	5,758.0	10.2	18,741.6	34.0	26,409.8	47.6	4,033.3	7.2	30,443.1	54.8	25,837.8	45.2	56,280.9	100.0
Louisiana	Dec. 1937	3,405.4	8.8	29.9	.1	13,198.0	34.1	16,633.3	43.0	15,701.0	40.5	32,334.3	83.5	6,387.2	16.5	38,721.5	100.0
Maryland	Jan. 1938	2,447.1	15.3	3,227.7	20.2	3,243.7	20.3	8,918.5	55.8	4,684.4	29.3	13,602.9	85.1	2,380.2	14.9	15,983.1	100.0
Michigan	Dec. 1936	5,464.5	5.9	4,342.9	4.7	48,991.9	53.1	58,799.3	63.7	21,837.3	23.8	80,636.6	87.5	11,509.5	12.5	92,146.1	100.0
Missouri	Dec. 1936	3,998.0	3.4	3,117.5	2.7	29,406.1	25.2	36,521.6	31.3	60,456.3	51.8	96,977.9	83.1	19,716.0	16.9	116,693.9	100.0
Montana	July 1937	1,466.4	2.2	2,965.7	4.5	6,248.7	9.5	10,680.8	16.2	3,389.9	5.2	14,070.7	21.4	51,659.4	78.6	65,730.1	100.0
Nebraska	Dec. 1936	1,034.2	1.0	861.7	.9	16,333.8	16.3	18,229.7	18.2	9,315.3	9.3	27,545.0	27.5	72,770.0	72.5	100,315.0	100.0
Nevada	Dec. 1937	51.5	.2	2,338.6	10.0	761.2	3.3	3,151.3	13.5	865.0	3.7	4,016.3	17.2	19,257.6	82.8	23,273.9	100.0
New Hampshire	Dec. 1937	413.6	3.4	3,404.7	28.0	3,943.0	32.5	7,761.3	63.9	2,725.2	22.4	10,486.5	86.3	1,656.4	13.7	12,142.9	100.0
New Jersey	July 1939	4,852.0	26.2	4,292.2	23.2	2,475.3	13.3	11,619.5	62.7	342.2	1.9	11,961.7	64.6	6,542.1	35.4	18,503.8	100.0
North Carolina	June 1938	4,975.0	8.6	4,419.0	7.6	20,759.2	35.9	30,153.2	52.1	23,490.9	40.6	53,644.1	92.7	4,162.7	7.3	57,806.8	100.0
North Dakota	Jan. 1938	24.5	([5])	689.1	.6	16,702.2	15.2	17,415.8	15.8	19,261.5	17.5	36,677.3	33.3	73,376.2	66.7	110,053.5	100.0
Ohio	Jan. 1937	8,059.9	9.8	12,653.4	15.3	49,700.6	60.3	70,413.9	85.4	7,012.7	8.5	77,426.6	93.9	5,022.4	6.1	82,449.0	100.0
Oklahoma	Jan. 1937	2,696.3	2.7	1,369.4	1.3	11,161.8	11.0	15,227.5	15.0	65,648.5	64.7	80,876.0	79.7	20,529.3	20.3	101,405.3	100.0
Oregon	Sept. 1936	1,799.7	3.9	2,907.9	6.2	14,599.3	31.2	19,306.9	41.3	15,118.7	32.3	34,425.6	73.6	12,340.8	26.4	46,766.4	100.0
South Carolina	Dec. 1938	2,326.2	5.4	3,854.0	9.0	6,830.3	16.0	13,010.5	30.4	11,089.2	25.9	24,099.7	56.3	18,676.1	43.7	42,775.8	100.0
South Dakota	Jan. 1937	228.7	.2	895.2	.9	18,629.1	18.4	19,753.0	19.5	40,920.3	40.5	60,673.3	60.0	40,471.8	40.0	101,145.1	100.0
Texas	Sept. 1937	6,579.8	3.5	12,485.9	6.7	25,170.8	13.6	44,236.5	23.8	16,058.7	8.6	60,295.2	32.4	125,565.5	67.6	185,860.7	100.0
Utah	Jan. 1937	364.9	1.7	1,481.6	6.9	5,357.6	24.9	7,204.1	33.5	3,640.6	17.0	10,844.7	50.5	10,633.0	49.5	21,477.7	100.0
Vermont	Dec. 1938	895.2	6.6	438.0	3.3	5,659.9	42.0	6,993.1	51.9	4,384.0	32.6	11,377.1	84.5	2,092.9	15.5	13,470.0	100.0
Washington	Dec. 1939	1,972.7	4.0	2,997.2	6.2	20,034.7	41.2	25,004.6	51.4	13,258.7	27.3	38,263.3	78.7	10,377.9	21.3	48,641.2	100.0
West Virginia	Jan. 1937	2,437.4	7.5	2,053.8	6.3	6,134.2	18.8	10,625.4	32.6	6,393.0	19.6	17,018.4	52.2	15,571.7	47.8	32,590.1	100.0
Wisconsin	Dec. 1936	4,927.4	6.0	5,751.6	7.0	48,035.8	58.4	58,714.8	71.4	19,624.7	23.9	78,339.5	95.3	3,853.9	4.7	82,193.4	100.0
Wyoming	Dec. 1937	14.8	.1	2,826.1	11.4	1,200.1	4.8	4,041.0	16.3	1,185.4	4.8	5,226.4	21.1	19,498.4	78.9	24,724.8	100.0
Total		100,617.6	4.5	133,871.8	6.0	605,639.9	27.3	840,129.3	37.8	501,323.2	22.6	1,341,452.5	60.4	878,270.2	39.6	[6] 2,219,722.7	100.0

[1] Includes trails.
[2] Includes 6,727.7 miles of oiled earth.
[3] Includes 22.4 miles, surface type unreported.
[4] Includes 274.1 miles, surface type unreported.
[5] Less than 0.05 percent.
[6] States not listed estimate their total mileage at 739,154 miles, giving total for the country as 2,958,877 miles of rural highway.

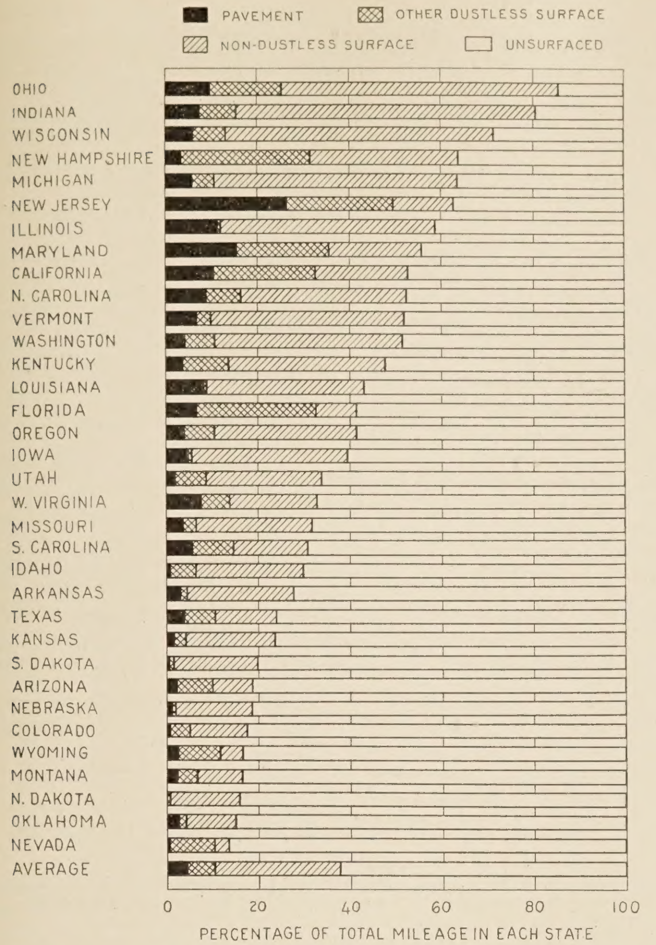


Figure 1.—Percentage of Total Rural Road Mileage in Each of 34 States With Surfaces of Each General Type.

type for each of the 24 States. Maryland had an average daily traffic on all roads of 338 vehicles, the highest of any of the States listed; while North Dakota had an average daily traffic on all roads of but 17 vehicles, the lowest of any of the States listed. In all of the States the average daily traffic was successively higher for each successively higher type surface.

Though the average daily traffic on paved roads is much greater than that on roads with lower type surfaces and on unsufraced roads, it does not follow that all of the paved mileage is more heavily traveled than any of the unpaved mileage. Table 3 shows the mileage and percentage of each general surface type in different average daily traffic volume groups in 23 of the 24 States listed in table 2. Data for Indiana are not included in table 3 because tabulations showing mileages of each surface type in traffic volume groups in that State were not available.

Table 3 shows that, in the 23 States, almost 5,000 miles of paved roads carry less than 100 vehicles per day while more than 10,000 miles of unimproved roads and nearly 12,000 miles of graded and drained roads carry higher volumes of traffic. This may reflect on the judgment exercised, in some cases, in selecting roads for improvement, or may indicate that considerations other than traffic importance influenced the selection. There are valid reasons, however, why such conditions should exist with respect to a portion of the mileage. Some of the paved mileage was lightly traveled during the period of the survey because of construction work on other parts of the road, temporarily diverting to other roads part of the normal traffic. Likewise, some of the paved sections connected with sections that are not yet improved and large traffic increases may be expected when the road is completely improved from one population center to another. On the other hand, some of the heavily traveled graded and drained mileage may have been temporarily in that status, during the course of stage construction. The true extent of overdevelopment or underdevelopment of highway facilities cannot be determined from summary tables of this kind, but can be determined only by a study of each individual road section, taking into consideration all of the pertinent circumstances. Such an approach is being used in a number of States in setting up programs for future improvement and in determining priorities for improvement.

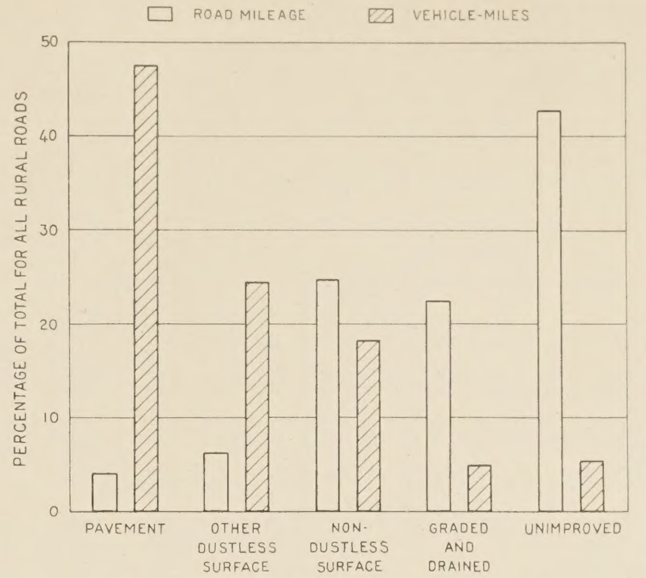


Figure 2.—Percentage of Rural Road Mileage Compared to Percentage of Vechicle-Miles of Travel for Each General Surface Type in 24 States.
States Included Are: Arizona, California, Colorado, Florida, Idaho, Indiana, Iowa, Kansas, Louisiana, Maryland, Michigan, Missouri, Montana, Nevada, North Dakota, Ohio, Oklahoma, Oregon, South Dakota, Texas, Utah, Vermont, West Virginia, and Wyoming.

PAVED ROADS CARRIED NEARLY HALF OF THE TOTAL TRAVEL ON ALL ROADS

In the 24 States listed in table 2, the average daily travel on all rural roads amounted to about 169,523,000 vehicle-miles. This is equivalent to 1,695,230 vehicles traveling an average of 100 miles each per day, or to 6,780,920 vehicles traveling an average of 25 miles each per day. About 152,309,000 vehicle-miles, or 90 percent of the total travel, was on surfaced roads, and only about 17,214,000 vehicle-miles on unsurfaced roads. The vehicle-mileages reported for each general surface type by the 24 States were as follows:

	Vehicle-miles
Pavement	80, 262, 267
Other dustless surface	40, 791, 208
Nondustless surface	31, 255, 837
Graded and drained	8, 258, 911
Unimproved	8, 955, 018
Total	169, 523, 241

Table 4 shows for each of the 24 States, the percentage distribution of the total vehicle-mileage of travel by surface types in comparison with the percentage distribution of the total road mileage by surface types. It shows that paved roads, constituting only 4.0 percent of the total rural road mileage in these States, carried 47.3 percent of the total vehicles-mileage of travel. Surfaced roads of all types, constituting 34.9 percent of the total rural road mileage, carried 89.8 percent of the total vehicle-mileage. Unimproved roads constituted 42.7 percent of the total road mileage but

TABLE 3.—*Mileage of rural roads and percentage of total rural mileage of each general surface type in different average daily traffic volume groups in 23 States* [1]

Average daily traffic	Pavement		Other dustless surface		Nondustless surface		Graded and drained		Unimproved		Total	
	Miles	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*	*Miles*	*Percent*
0-24	1,494.4	2.51	9,562.4	10.11	119,650.2	33.64	277,841.9	76.94	606,179.6	87.60	1,014,728.5	64.92
25-49	2,189.6	3.67	4,372.3	4.62	75,522.6	21.24	48,730.1	13.50	51,418.5	7.43	182,233.1	11.66
50-99	1,285.1	2.16	9,451.6	9.99	74,497.2	20.95	22,526.4	6.24	24,099.8	3.48	131,860.1	8.44
100-199	3,135.3	5.26	15,061.4	15.93	53,045.8	14.92	8,171.9	2.26	7,749.3	1.12	87,163.7	5.58
200-299	3,111.4	5.22	12,258.6	12.96	17,217.5	4.84	2,012.5	.56	1,688.6	.24	36,288.6	2.32
300-399	3,135.3	5.26	9,506.1	10.05	7,783.4	2.19	723.4	.20	477.8	.07	21,626.0	1.38
400-499	3,244.7	5.44	7,993.0	8.45	3,604.6	1.01	395.8	.11	173.5	.03	15,411.6	.99
500-599	3,410.5	5.72	6,009.4	6.35	1,900.6	.54	235.5	.07	119.4	.02	11,675.4	.75
600-699	3,434.1	5.76	4,374.6	4.63	858.3	.24	109.4	.03	62.3	.01	8,838.7	.57
700-799	3,493.0	5.86	3,702.0	3.92	575.4	.16	77.1	.02	28.3	[2]	7,875.8	.50
800-899	3,092.7	5.19	2,572.1	2.72	334.7	.09	57.7	.02	30.8	[2]	6,088.0	.39
900-999	2,682.2	4.50	1,726.3	1.83	163.8	.05	39.2	.01	14.2	[2]	4,625.7	.30
1,000-1,249	5,980.0	10.03	2,966.5	3.14	229.7	.06	40.3	.01	16.0	[2]	9,232.5	.59
1,250-1,499	4,474.5	7.50	1,940.8	2.05	127.1	.04	21.1	.01	8.7	[2]	6,572.2	.42
1,500-1,999	5,941.8	9.96	1,730.5	1.83	63.1	.02	34.9	.01	15.9	[2]	7,786.2	.50
2,000-2,999	5,243.6	8.79	928.4	.98	51.2	.01	10.9	[2]	8.2	[2]	6,242.3	.40
3,000-3,999	1,862.9	3.12	240.9	.25	17.9	[2]	24.7	.01	----	----	2,146.4	.14
4,000-4,999	1,008.7	1.69	111.3	.12	4.6	[2]	----	----	----	----	1,124.6	.07
5,000-5,999	664.0	1.11	24.8	.03	11.4	[2]	----	----	----	----	700.2	.04
6,000-6,999	282.2	.47	21.8	.02	----	----	----	----	----	----	304.0	.02
7,000-7,999	208.1	.35	4.9	.01	----	----	----	----	----	----	213.0	.01
8,000-8,999	83.3	.14	1.0	[2]	----	----	----	----	----	----	84.3	.01
9,000-9,999	44.1	.07	.3	[2]	----	----	----	----	----	----	44.4	[2]
10,000-12,499	66.9	.11	3.1	[2]	----	----	----	----	----	----	70.0	[2]
12,500-14,999	29.0	.05	5.2	.01	----	----	----	----	----	----	34.2	[2]
15,000-19,999	30.7	.05	----	----	----	----	----	----	----	----	30.7	[2]
20,000-24,999	3.5	.01	----	----	----	----	----	----	----	----	3.5	[2]
25,000-29,999	2.3	[2]	----	----	----	----	----	----	----	----	2.3	[2]
30,000 and over	----	----	----	----	----	----	----	----	----	----	----	----
Total	59,633.9	100.00	94,569.3	100.00	355,659.1	100.00	361,052.8	100.00	692,090.9	100.00	1,563,006.0	100.00
Percentage of total mileage	3.82	----	6.05	----	22.75	----	23.10	----	44.28	----	100.00	----

[1] The States included are: Arizona, California, Colorado, Florida, Idaho, Iowa, Kansas, Louisiana, Maryland, Michigan, Missouri, Montana, Nevada, North Dakota, Ohio, Oklahoma, Oregon, South Dakota, Texas, Utah, Vermont, West Virginia, and Wyoming.
[2] Less than 0.005 percent.

TABLE 4.—*Mileage of rural roads of each general surface type and vehicle-miles of travel on each, expressed as percentages of totals for all types in each of 24 States*

State	Pavement		Other dustless surface		Nondustless surface		Total surfaced		Graded and drained		Total improved		Unimproved		Total	
	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles	Percentage of mileage	Percentage of vehicle-miles
Arizona	2.0	23.1	7.9	49.0	8.4	8.3	18.3	80.4	15.3	9.1	33.6	89.5	66.4	10.5	100.0	100.0
California	10.2	63.9	22.3	25.1	20.4	7.2	52.9	96.2	3.8	.6	56.7	96.8	43.3	3.2	100.0	100.0
Colorado	.7	23.1	4.3	41.3	12.3	17.9	17.3	82.3	8.8	4.8	26.1	87.1	73.9	12.9	100.0	100.0
Florida	6.4	36.2	26.3	53.5	8.4	2.3	41.1	92.0	47.8	7.4	88.9	99.4	11.1	.6	100.0	100.0
Idaho	.5	13.9	5.8	45.6	23.2	26.3	29.5	85.8	13.4	4.7	42.9	90.5	57.1	9.5	100.0	100.0
Indiana	7.1	59.3	8.3	18.7	65.1	21.2	80.5	99.2	7.4	.4	87.9	99.6	12.1	.4	100.0	100.0
Iowa	4.8	51.4	.5	2.2	33.8	32.1	39.1	85.7	40.4	10.6	79.5	96.3	20.5	3.7	100.0	100.0
Kansas	1.4	27.2	2.6	23.9	19.3	29.4	23.3	80.5	1.6	1.3	24.9	81.8	75.1	18.2	100.0	100.0
Louisiana	8.8	65.8	.1	.3	34.1	28.7	43.0	94.8	40.5	4.3	83.5	99.1	16.5	.9	100.0	100.0
Maryland	15.3	58.3	20.2	33.8	20.3	3.9	55.8	96.0	29.3	3.0	85.1	99.0	14.9	1.0	100.0	100.0
Michigan	5.9	58.2	4.7	9.7	53.1	28.1	63.7	96.0	23.8	3.3	87.5	99.3	12.5	.7	100.0	100.0
Missouri	3.4	57.8	2.7	12.3	25.2	19.7	31.3	89.8	51.8	9.3	83.1	99.1	16.9	.9	100.0	100.0
Montana	2.2	30.1	4.5	35.2	9.5	12.4	16.2	77.7	5.2	3.6	21.4	81.3	78.6	18.7	100.0	100.0
Nevada	.2	10.2	10.0	70.2	3.3	3.8	13.5	84.2	3.7	2.5	17.2	86.7	82.8	13.3	100.0	100.0
North Dakota	[1]	2.2	.6	17.9	15.2	59.6	15.8	79.7	17.5	11.0	33.3	90.7	66.7	9.3	100.0	100.0
Ohio	9.8	54.8	15.3	24.9	60.3	18.9	85.4	98.6	8.5	.8	93.9	99.4	6.1	.6	100.0	100.0
Oklahoma	2.7	45.9	1.3	11.0	11.0	21.5	15.0	78.4	64.7	19.9	79.7	98.3	20.3	1.7	100.0	100.0
Oregon	3.9	47.0	6.2	27.9	31.2	20.9	41.3	95.8	32.3	3.2	73.6	99.0	26.4	1.0	100.0	100.0
South Dakota	.2	9.0	.9	16.9	18.4	53.6	19.5	79.5	40.5	18.3	60.0	97.8	40.0	2.2	100.0	100.0
Texas	3.5	34.7	6.7	35.2	13.6	10.5	23.8	80.4	8.6	5.5	32.4	85.9	67.6	14.1	100.0	100.0
Utah	1.7	33.4	6.9	39.9	24.9	19.7	33.5	93.0	17.0	3.9	50.5	96.9	49.5	3.1	100.0	100.0
Vermont	6.6	55.0	3.3	15.7	42.0	25.7	51.9	96.4	32.6	3.2	84.5	99.6	15.5	.4	100.0	100.0
West Virginia	7.5	50.4	6.3	20.9	18.8	13.5	32.6	84.8	19.6	6.8	52.2	91.6	47.8	8.4	100.0	100.0
Wyoming	.1	.8	11.4	72.7	4.8	7.6	16.3	81.1	4.8	2.3	21.1	83.4	78.9	16.6	100.0	100.0
Average	4.0	47.3	6.1	24.1	24.8	18.4	34.9	89.8	22.4	4.9	57.3	94.7	42.7	5.3	100.0	100.0

[1] Less than 0.05 percent.

carried only 5.3 percent of the total vehicle-mileage. This shows that the improvement of roads now unimproved would mean, in general, the construction of relatively large mileages to serve a relatively small portion of the vehicle-miles of travel. These relationships are presented graphically in figure 2.

Not only do the roads of higher type surface serve greater traffic densities than those of lower type surface, but they also, in general, pass through more densely populated rural areas. Table 5 shows the number per mile of farm units and other rural dwellings along roads with different type surfaces in each of 32 States. The States are grouped into four regions from east to west. The greatest density of dwellings along all rural roads is in the eastern region; the next greatest is in the western region; and the density is lower for the two intermediate regions. For all 32 States, there are, on the average, 2.7 rural dwellings per mile of rural road. The dwelling density along paved roads is 7.1 per mile and is lower for each successively lower general surface type, ranging down to 1.5 per mile for unimproved roads. In individual States, however, the roads of higher surface type do not always have the greater dwelling densities. In Vermont, Michigan, Illinois, Maryland, Missouri, Texas, and Louisiana for example, there are fewer houses per mile along paved roads than along roads having other dustless surfaces, and in North Dakota, Nebraska, Montana, Nevada, and Arizona there are fewer houses per mile along roads having dustless surfaces other than pavement, than along roads having nondustless surfaces. These minor variations in the general trend are caused by the building of high-type roads, important to through traffic, across relatively sparsely settled areas.

TABLE 5.—*Number of rural dwellings per mile along roads with different general surface types by States (grouped by regions)*

Region and State	Pavement	Other dustless surface	Nondustless surface	Graded and drained	Unimproved	All types
Region 1:						
New Hampshire	10.0	7.8	3.6	2.6	1.2	4.3
Vermont	7.4	8.2	4.0	2.5	1.4	3.5
Michigan	6.3	7.2	4.3	2.8	1.1	3.8
Illinois	4.6	9.8	3.2	2.4	1.7	3.1
Ohio	10.0	7.2	4.2	2.3	2.1	5.0
Maryland	10.0	10.4	6.5	4.3	3.9	6.7
West Virginia	13.9	11.2	6.4	4.0	3.3	5.4
Kentucky	9.2	8.3	5.1	4.5	4.0	5.0
North Carolina	10.8	8.1	5.4	5.5	3.4	5.8
South Carolina	9.1	7.2	5.7	5.9	4.9	5.5
Florida	7.2	4.6	3.1	2.6	2.0	3.4
Average	8.1	7.4	4.3	3.4	3.2	4.5
Region 2:						
North Dakota	1.6	1.0	1.1	.9	.6	.7
South Dakota	1.9	1.6	1.3	.9	.4	.8
Wisconsin	5.3	4.2	3.2	1.9	.9	3.0
Iowa	2.7	2.6	2.6	2.1	1.9	2.3
Nebraska	2.6	1.2	2.0	1.5	1.1	1.3
Missouri	4.0	5.6	3.2	2.5	1.6	2.7
Kansas	6.4	2.4	2.3	1.1	1.2	1.5
Arkansas	5.8	4.7	4.0	3.2	3.1	3.4
Oklahoma	3.5	3.1	2.8	2.2	1.5	2.2
Texas	4.0	4.5	3.8	2.1	2.4	2.7
Louisiana	7.5	9.7	5.9	3.2	2.9	4.4
Average	4.5	4.0	2.9	2.0	1.5	2.1
Region 3:						
Montana	1.9	1.6	1.8	1.0	.7	.9
Idaho	8.2	2.9	2.8	1.4	1.0	1.6
Wyoming	4.1	1.4	1.3	.6	.8	.9
Colorado	4.2	2.3	2.2	1.2	.9	1.2
Utah	9.8	3.6	2.0	1.1	.5	1.3
Nevada	4.8	.9	1.6	.8	.4	.5
Arizona	13.6	3.2	5.4	2.4	1.4	2.2
Average	5.6	2.1	2.3	1.4	.8	1.2
Region 4:						
Washington	9.7	4.1	3.8	1.3	.8	2.8
Oregon	6.6	3.9	3.4	.7	.4	1.9
California	10.8	6.8	2.5	2.0	1.0	3.7
Average	10.1	6.1	3.4	1.1	.9	3.0
Average for all States represented	7.1	5.6	3.5	2.3	1.5	2.7

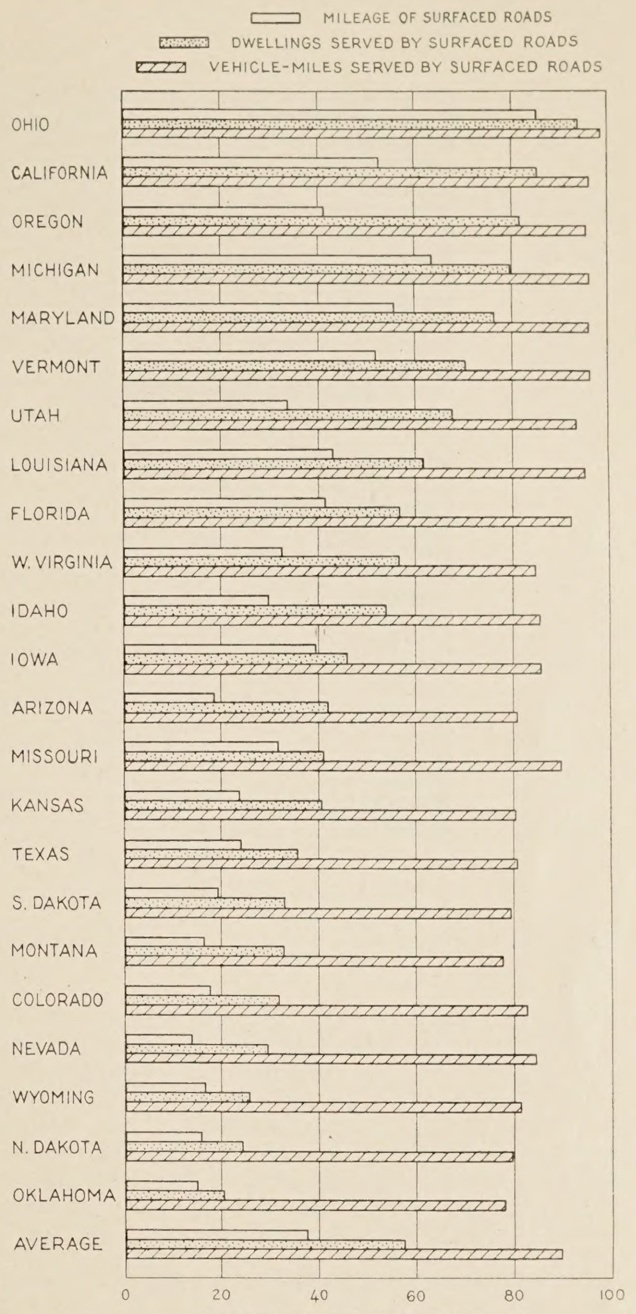


FIGURE 3.—PERCENTAGE OF RURAL ROAD MILEAGE SURFACED, PERCENTAGE OF ALL RURAL DWELLINGS DIRECTLY SERVED BY SURFACED ROADS, AND PERCENTAGE OF TOTAL TRAVEL ON RURAL ROADS, IN EACH OF 23 STATES.

In table 6, and in figure 3, a comparison is made of the percentage of the rural road mileage surfaced, the percentage of the vehicle-miles of travel served by surfaced roads, and the percentage of the rural dwellings directly served by surfaced roads, in each of 23 States. For these States, 37.8 percent of the total rural road mileage is surfaced, and this surfaced mileage serves directly 57.2 percent of the rural dwellings and accommodates 89.8 percent of the vehicle-miles of travel on rural roads. In Ohio, 93.8 percent of the rural dwellings are directly served by surfaced roads, whereas in

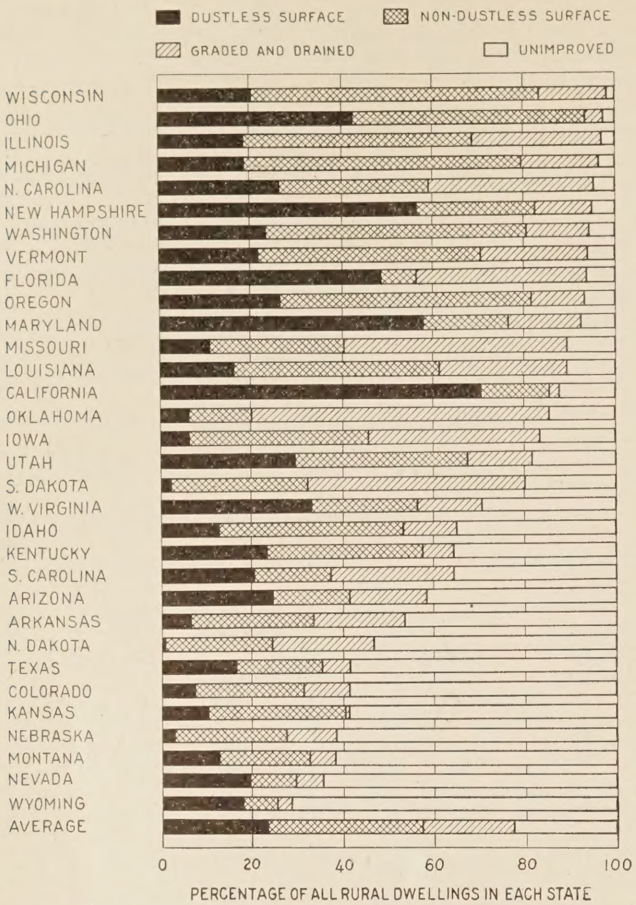


FIGURE 4.—PERCENTAGE OF ALL RURAL DWELLINGS DIRECTLY SERVED BY ROADS WITH DIFFERENT GENERAL SURFACE TYPES IN EACH OF 32 STATES.

Oklahoma only 20.1 percent are so served. The percentages of rural dwellings served by surfaced roads in other States range between these two extremes.

The percentages of all rural dwellings directly served by roads with different general surface types are shown for each of 32 States in table 7 and in figure 4. By omitting vehicle-mileage data, it was possible to include 9 more States in this table than in table 6. In these 32 States, 57.2 percent of all rural dwellings were directly served by surfaced roads, which is exactly the same percentage as that shown in table 6 for 23 States. Only 22.6 percent of the rural dwellings were located on unimproved roads. For individual States, the percentage of rural dwellings located on unimproved roads varied from 71.2 percent in Wyoming down to 1.5 percent in Wisconsin.

TWO-THIRDS OF RURAL DWELLINGS IN 10 STATES LOCATED WITHIN 1 MILE OF SURFACED ROAD

Many rural dwellings which do not front directly on improved roads are located close to them so that the occupants need travel only a short distance to get to an improved highway. Under such conditions, the actual mileage which need be driven on unimproved roads is very small in relation to the total mileage driven on an average trip. In 10 States, studies to determine the number of rural dwellings located within different travel distances of improved roads have been completed.

Table 8 and figure 5 show the percentages of all rural

TABLE 6.—*Percentage of rural road mileage surfaced, and percentage of all rural travel and of all rural dwellings directly served by surfaced roads in each of 23 States*

State	Percentage of total rural road mileage surfaced	Percentage of total rural vehicle-mileage served by surfaced roads	Percentage of all rural dwellings directly served by surfaced roads
Arizona	18.3	80.4	41.7
California	52.9	96.2	85.7
Colorado	17.3	82.3	31.5
Florida	41.1	92.0	56.7
Idaho	29.5	85.8	53.5
Iowa	39.1	85.7	45.8
Kansas	23.3	80.5	40.2
Louisiana	43.0	94.8	61.2
Maryland	55.8	96.0	76.2
Michigan	63.7	96.0	79.8
Missouri	31.3	89.8	40.9
Montana	16.2	77.7	32.4
Nevada	13.5	84.2	29.8
North Dakota	15.8	79.7	24.2
Ohio	85.4	98.6	93.8
Oklahoma	15.0	78.4	20.1
Oregon	41.3	95.8	81.5
South Dakota	19.5	79.5	32.8
Texas	23.8	80.4	35.2
Utah	33.5	93.0	67.4
Vermont	51.9	96.4	70.3
West Virginia	32.6	84.8	56.1
Wyoming	16.3	81.1	25.4
Average	37.8	89.8	57.2

TABLE 7.—*Percentage of all rural dwellings directly served by roads with different general surface types, in each of 32 States*

State	Pavement	Other dustless surfaces	Non-dustless surfaces	All surfaced roads	Graded and drained roads	All improved roads	Unimproved roads
Arizona	12.6	11.7	17.4	41.7	16.4	58.1	41.9
Arkansas	5.0	1.6	27.1	33.7	19.7	53.4	46.6
California	29.8	40.3	15.6	85.7	2.1	87.8	12.2
Colorado	2.2	5.3	24.0	31.5	9.9	41.4	58.6
Florida	13.4	35.3	8.0	56.7	36.9	93.6	6.4
Idaho	2.6	10.2	40.7	53.5	11.5	65.0	35.0
Illinois	16.7	2.1	49.7	68.5	28.7	97.2	2.8
Iowa	5.7	.6	39.5	45.8	37.4	83.2	16.8
Kansas	6.0	4.2	30.0	40.2	1.1	41.3	58.7
Kentucky	6.3	17.0	34.6	57.9	6.4	64.3	35.7
Louisiana	16.3	.1	44.8	61.2	28.3	89.5	10.5
Maryland	24.3	33.6	18.3	76.2	16.4	92.6	7.4
Michigan	9.9	8.9	61.0	79.8	16.7	96.5	3.5
Missouri	5.2	5.6	30.1	40.9	48.8	89.7	10.3
Montana	4.8	8.1	19.5	32.4	5.8	38.2	61.8
Nebraska	2.0	.8	25.1	27.9	10.7	38.6	61.4
Nevada	2.1	17.3	10.4	29.8	5.6	35.4	64.6
New Hampshire	7.6	48.9	25.9	82.4	12.9	95.3	4.7
North Carolina	15.7	10.4	32.9	59.0	36.9	95.9	4.1
North Dakota	.1	.8	23.3	24.2	22.7	46.9	53.1
Ohio	20.0	22.3	51.5	93.8	3.8	97.6	2.4
Oklahoma	4.3	1.9	13.9	20.1	65.5	85.6	14.4
Oregon	13.4	12.7	55.4	81.5	11.9	93.4	6.6
South Carolina	8.9	11.7	16.6	37.2	27.1	64.3	35.7
South Dakota	.6	1.8	30.4	32.8	47.2	80.0	20.0
Texas	5.2	11.0	19.0	35.2	6.5	41.7	58.3
Utah	10.0	19.9	37.5	67.4	14.2	81.6	18.4
Vermont	14.2	7.7	48.4	70.3	23.6	93.9	6.1
Washington	14.2	9.3	57.4	80.9	13.2	94.1	5.9
West Virginia	19.6	13.4	23.1	56.1	14.8	70.9	29.1
Wisconsin	10.7	10.0	62.6	83.3	15.2	98.5	1.5
Wyoming	.3	17.7	7.4	25.4	3.4	28.8	71.2
Average	11.3	12.2	33.7	57.2	20.2	77.4	22.6

dwellings within various travel distances of surfaced roads, in the 10 States in which this information is available. In these States 65.0 percent of the rural dwellings were within 1 mile of a surfaced road, and 77.5 percent were within 2 miles of a surfaced road.

(Continued on page 158)

GRAPHICAL ANALYSES OF THE STABILITY OF SOIL

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by E. S. BARBER, Junior Highway Engineer, and C. E. MERSHON, Junior Engineer

TO FURTHER the development of rational procedures for use in the design and construction of highways during the past two decades, the Public Roads Administration has made comprehensive studies of published material and conducted supplementary laboratory research on the stability of soil. Results of this work, published in PUBLIC ROADS and in the Proceedings of the Highway Research Board, include the interpretation of test data, the evaluation of pressure against retaining walls, the design of cuts and embankment cross sections, and the estimation of the supporting value of undersoil.

In an effort to expedite a general use of the theories as a basis of correlation with experience, this report presents methods of analyses in which charts are used to facilitate computations and thus greatly reduce the time and labor required in the application of the formulas. A summary of the development of the formulas and a brief discussion of the assumptions on which the theories are based are first presented. An explanation of the construction and use of the charts then follows.

STABILITY OF SOIL DEPENDS UPON ITS SHEARING RESISTANCE

The stability of a soil is assumed to depend upon its shearing resistance which, according to Coulomb's classical theory published in 1773 (*1*),[1] is expressed by the relation

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

in which

s = unit shearing resistance,
c = unit cohesion,
n = stress normal to the plane of shear, and
ϕ = angle of internal friction.

Cohesion is defined as that component of shearing resistance which is independent of the stress normal to the plane of shear. (See fig. 1.) Internal friction is defined as that component of shearing resistance which is directly proportional to the stress normal to the plane of shear.

A factor of safety with respect to total strength may be applied by dividing c and $\tan \phi$ by the desired factor (*2*). For a deformation less than that at failure, the corresponding c and ϕ (*3*) may be used by assuming a hypothetical soil with these ultimate values.

Compressive strength.—The relation between the unit compressive strength, v_0, of an unconfined cylindrical soil sample, its cohesion, and its angle of internal friction, was discussed in the Proceedings of the Nineteenth Annual Meeting of the Highway Research Board (*4*). The formula is

$$v_0=2c \tan \alpha \quad (2)$$

where

$$\alpha=45°+\frac{\phi}{2}$$

[1] Italic figures in parentheses refer to bibliography, page 155.

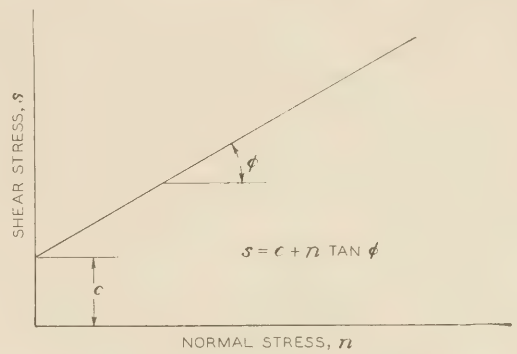


FIGURE 1.—RELATION OF SHEAR STRESS TO NORMAL STRESS IN A SOIL SAMPLE AT FAILURE.

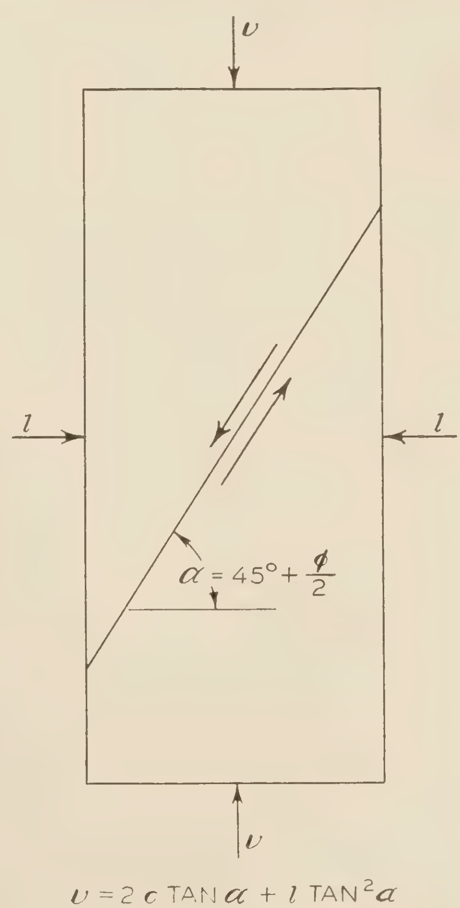


FIGURE 2.—RELATION OF PRINCIPAL STRESSES AT FAILURE OF ANY POINT IN A STRESSED EARTH MASS.

If a unit lateral pressure, l, is applied to a sample as in figure 2, the expression for its unit compressive strength, v, as published in PUBLIC ROADS, December 1938 (*5*), becomes

$$v=2c \tan\alpha+l \tan^2\alpha \quad (3)$$

Tangent functions of α and its complement β are given in table 1.

The relation between the maximum height, H, at which an unrestrained embankment will stand vertically, the unit weight of the soil, w, and its shearing resistance, was discussed in PUBLIC ROADS, December 1929 (*6*). The expression is

$$H=\frac{v_0}{w}=\frac{2c}{w}\tan\alpha \qquad (4)$$

Table 1.—*Tangent functions of α and β*

ϕ, degrees	$\tan\phi$	$\alpha=45°+\frac{\phi}{2}$		$\beta=45°-\frac{\phi}{2}$	
		$\tan\alpha=\cot\beta$	$\tan^2\alpha=\cot^2\beta$	$\tan\beta=\cot\alpha$	$\tan^2\beta=\cot^2\alpha$
0	0	1.000	1.000	1.000	1.000
1	0.017	1.018	1.036	.983	.966
2	.035	1.036	1.072	.966	.933
3	.052	1.054	1.110	.949	.901
4	.070	1.072	1.150	.933	.870
5	.087	1.091	1.191	.916	.840
6	.105	1.111	1.233	.900	.811
7	.123	1.130	1.278	.885	.783
8	141	1.150	1.323	.869	.756
9	.158	1.171	1.371	.854	.729
10	.176	1.192	1.420	.839	.704
11	.194	1.213	1.472	.824	.680
12	.213	1.235	1.525	.810	.656
13	.231	1.257	1.580	.795	.633
14	.249	1.280	1.638	.781	.610
15	.268	1.303	1.698	.767	.589
16	.287	1.327	1.761	.754	.568
17	.306	1.351	1.826	.740	.548
18	.325	1.376	1.894	.727	.528
19	.344	1.402	1.965	.713	.509
20	.364	1.428	2.040	.700	.490
21	.384	1.455	2.117	.687	.472
22	.404	1.483	2.198	.675	.455
23	.424	1.511	2.283	.662	.438
24	.445	1.540	2.371	.649	.422
25	.466	1.570	2.464	.637	.406
26	.488	1.600	2.561	.625	.390
27	.510	1.632	2.663	.613	.376
28	.532	1.664	2.770	.601	.361
29	.554	1.698	2.882	.589	.347
30	.577	1.732	3.000	.577	.333
31	.601	1.767	3.124	.566	.320
32	.625	1.804	3.255	.554	.307
33	.649	1.842	3.392	.543	.295
34	.675	1.881	3.537	.532	.283
35	.700	1.921	3.690	.521	.271
36	.727	1.963	3.852	.510	.260
37	.754	2.006	4.023	.499	.249
38	.781	2.050	4.204	.488	.238
39	.810	2.097	4.395	.477	.228
40	.839	2.145	4.599	.466	.217
41	.869	2.194	4.815	.456	.208
42	.900	2.246	5.045	.445	.198
43	.933	2.300	5.289	.435	.189
44	.966	2.356	5.550	.424	.180
45	1.000	2.414	5.828	.414	.172

Active and passive pressures.—Formulas for finding the lateral pressures of soils against retaining walls were published in PUBLIC ROADS, December 1938 (*5*). For the simplest case of a cohesive soil with level backfill, vertical back of wall, no surcharge, and swelling phenomena neglected, the total active horizontal pressure, L, per unit length of wall is obtained from the expression

$$L=h\left(\frac{wh}{2}\tan^2\beta-2c\tan\beta\right) \qquad (5)$$

in which

h=height of backfill, and

$\beta=45°-\frac{\phi}{2}$.

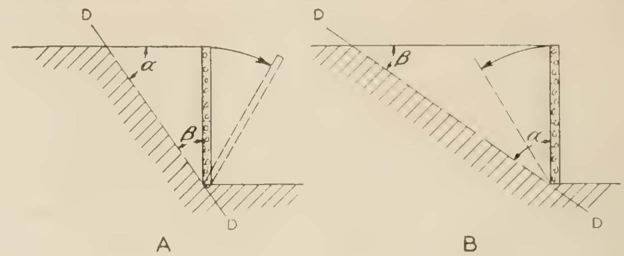


Figure 3.—Surfaces of Slip Behind Walls.

For the same conditions, the total passive earth pressure, P, per unit length of wall is given by the formula

$$P=h\left(\frac{wh}{2}\tan^2\alpha+2c\tan\alpha\right) \qquad (6)$$

The significance of the terms "active" and "passive" earth pressure has been described in PUBLIC ROADS (*3*) as follows:

In the design of retaining walls, three types of earth pressure may be considered.

Without movement of the earth, pressures against the walls, figures 3–A and 3–B, become the "earth pressures at rest" which depend upon the coefficient K, expressed by the relation: $K=l/v$. (K depends on the soil's elasticity.)

However, soil must deform to fail. The pressures it produces at maximum deformation without failure are termed active or passive, depending on the directions of the applied forces responsible.

Wedges assumed in the design of retaining walls, figure 3, have lower boundaries, D–D, on which the soil slips when it shears. Weight of the earth in figure 3–A produces the active earth pressure which forces walls outward and causes D–D to incline at an angle α with the horizontal and β with the vertical. Forcing walls backward as in figure 3–B produces the passive earth pressure which causes D–D to incline at an angle β with the horizontal and α with the vertical.

A cable anchorage would exert passive pressure on the soil in front of it. The surface shear test apparatus developed by Burggraf (*7*) measures a similar passive resistance.

FORMULAS GIVEN FOR BEARING CAPACITY AND DISTORTION OF SOILS

Bearing capacity under strip load.—It will be noted that equations 5 and 6 have two parts. The first depends on the weight of the earth in the wedge and the second on the cohesion. As shown in figure 4–A, the bearing capacity, q, of soil under a long, uniform, strip load depends on an active wedge being held in equilibrium by a passive wedge. Since the passive pressure, P, is always greater than the active pressure, L, an additional pressure, q, can be supported at the surface of the active wedge. Then at equilibrium

$$q=\left(\frac{P-L}{h}\right)\tan^2\alpha \qquad (7)$$

By substituting equations 5 and 6 for L and P in equation 7 there is obtained

$$q=w_fH=c\frac{2\tan\alpha}{\cos^2\alpha}+w_uB\frac{\tan^4\alpha-1}{2\cot\alpha} \qquad (8)$$

in which

w_f=unit weight of embankment material,

H=critical height of embankment,

w_u=unit weight of undersoil, and

B=width of active wedge at the subgrade surface, figure 4–A.

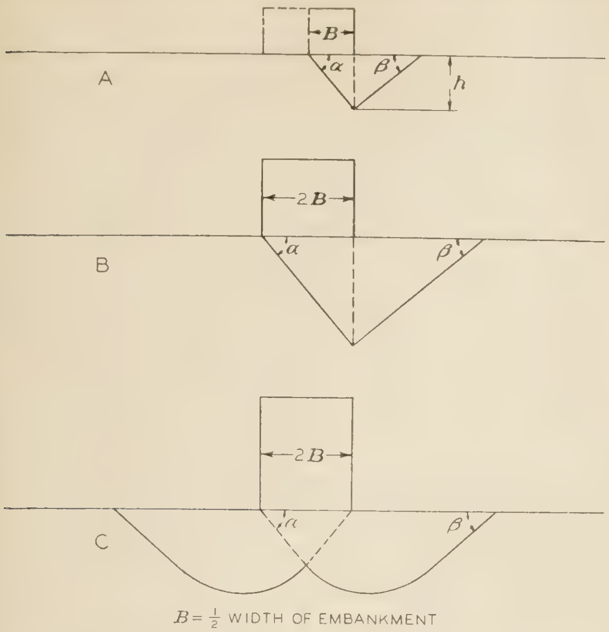


FIGURE 4.—SURFACES OF SLIP UNDER EMBANKMENTS ($\phi=10°$).

If a surcharge of thickness T is applied to the surface of the passive wedge, figure 5–A, the load on the active wedge may be increased by $w_sT \tan^4 \alpha$, where w_s is the unit weight of the surcharge material. The total bearing capacity (*8*) then becomes

$$q=w_fH=c\,\frac{2 \tan \alpha}{\cos^2 \alpha}+w_uB\,\frac{\tan^4\alpha-1}{2 \cot \alpha}+w_sT \tan^4 \alpha \text{---}(9)$$

For zero cohesion, the first term is zero; for zero friction, the second term is zero; and for zero surcharge, the third term is zero. If B is taken as zero in equation 9, the bearing capacity becomes equivalent to

$$q=2c\,(\tan^3 \alpha+\tan \alpha)+w_sT \tan^4 \alpha \text{------}(10)$$

which gives the maximum allowable vertical pressure under the edge of a footing (*9*). Equation 9 has been suggested for use in estimating the supporting value of a homogeneous subgrade under a symmetrical strip load which divides in the center as it fails.

To apply the formula to a long fill, the cross section of the fill must be modified. With reference to figure 5, it should be noted that B is the width of the active wedge whereas b is one-half the top width of the fill. One method of solution is to assume a rectangular cross section of width $2B$ and an area equal to the area of the fill as shown by figure 5–B. This solution considers no surcharge. Another method is to assume a rectangle of width $2B$ with equal surcharges on each side as shown by figure 5–C. The area of the rectangle plus the area of the surcharges is equal to the actual area of the fill cross section.

If the embankment can be considered rigid enough to settle as a unit and the undersoil moves out on one side only as in figure 4–B, the full width, $2B$, is used in place of B and equation 9 becomes

$$q=c\,\frac{2 \tan \alpha}{\cos^2 \alpha}+w_uB\,\frac{\tan^4 \alpha-1}{\cot \alpha}+w_sT \tan^4 \alpha \text{-----}(11)$$

A different problem is presented by a fill, figure 4–C, which is rigid enough to settle vertically without tilting and without breaking in the middle, forcing the undersoil out on both sides. Prandtl's formula with a term

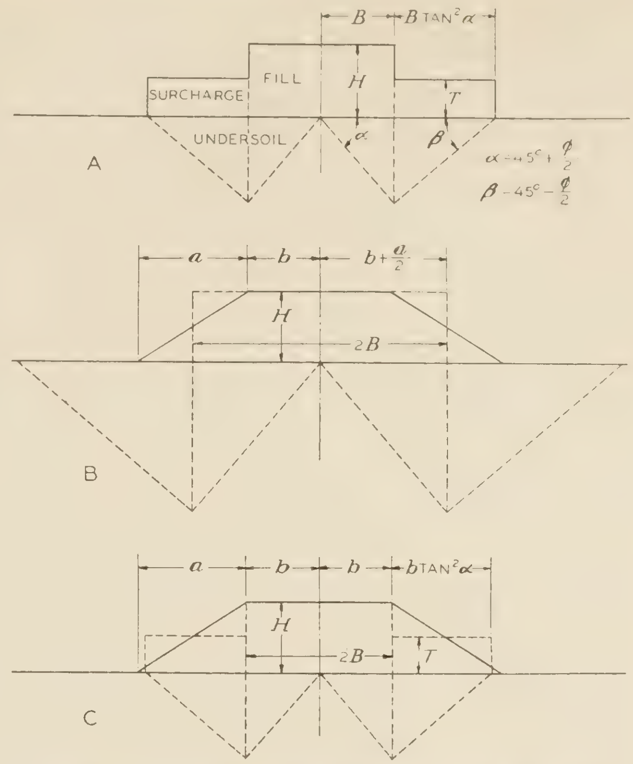


FIGURE 5.—MODIFIED EMBANKMENT CROSS SECTIONS.

added to include the weight of the supporting soil (*10*) may be used to find the supporting power of the undersoil under these circumstances. The formula considers no surcharge and is

$$q=(c \cot \phi+w_uB \tan \alpha)\,(\tan^2 \alpha \times e^{\pi \tan \phi}-1)\text{-}(12)$$

Distortion of soil.—If the amount of distortion in the soil behind a retaining wall were relatively the same as in a shear sample and the wedge of soil behind a rotating wall deformed in pure shear parallel to the plane of failure, figure 6, the average movement of the top of the soil wedge h feet high as the wall rotates about its base (*4*) would be:

For walls moving out (active pressure), figure 6–A.

$$d_l=\frac{mh}{200} \sin^2 \beta \text{ feet}=0.03mh(1-\sin \phi) \text{ inches---}(13)$$

$$d_v=\frac{mh}{200} \sin \beta \cos \beta \text{ feet}=0.03mh \cos \phi \text{ inches---}(14)$$

For walls moving in (passive pressure), figure 6–B.

$$d_l=\frac{mh}{200} \cos^2 \beta \text{ feet}=0.03mh(1+\sin \phi) \text{ inches---}(15)$$

$$d_v=\frac{mh}{200} \sin \beta \cos \beta \text{ feet}=0.03mh \cos \phi \text{ inches---}(16)$$

where

d_l=average lateral soil movement,

d_v=average vertical soil movement, and

m=shear strain in percent$=\frac{\text{tangential movement}}{\text{thickness}}\times 100.$

In a direct shear test, the shear strain may be taken as the shear movement divided by the effective thickness of the sample. For constant volume and small strains the maximum shear strain in a uniformly stressed cylinder is 1.5 times the vertical strain (*11*). The average

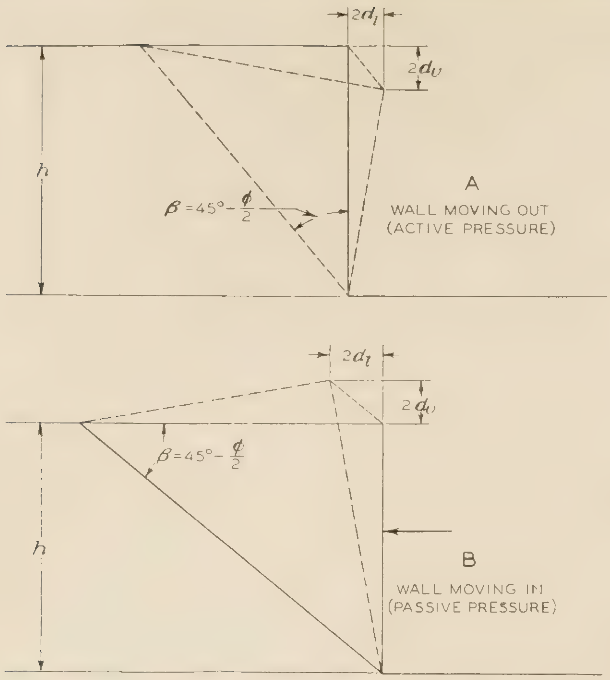


FIGURE 6.—DISTORTION OF SOIL BEHIND WALL.

settlement due to lateral movement of the soil supporting a long nonrigid embankment may be estimated by using B, the half width of the fill, in place of h in equation 15.

Bearing capacity of thin layer.—For a plastic material squeezed between two parallel rigid plates, the theory of plasticity indicates that the bearing capacity varies directly as the shearing resistance and as the ratio of the width of the plates to the distance between them if this ratio is at least four (*12, 13*). For the case of a triangular load of relatively firm material resting on a soft layer which is underlaid by relatively firm material, figure 7–A, the expression for the unit bearing capacity, q, of the soft undersoil is

$$q = W_f H_0 = s\frac{x}{D} \quad \text{(17)}$$

where

w_f = unit weight of fill material,
H_0 = height of triangular fill,
s = unit shearing resistance of soft layer,
x = width of fill at base, and
D = depth of soft layer.

By assuming a triangular embankment, figure 7–A, and substituting $c+\frac{w_u D}{2}\tan\phi$ (that is, $c+n\tan\phi$ of the soft undersoil) for s and $2H_0S_0$ for x, a formula was derived for calculating the critical slope, S_0, of the embankment. The expression thus obtained is

$$S_0 = \frac{Dw_f}{2c + Dw_u \tan\phi} \quad \text{(18)}$$

in which

w_u = unit weight of soft undersoil.

The critical slope of a trapezoidal fill may be estimated from equation 18 by considering a triangle, figure 7–A, with the same base and slope as the embankment. In the case of low, wide fills, the results obtained by this procedure may be too conservative. Another method (*13*) is to consider a triangle with an area equal to the trapezoidal area of the fill as in figure 7–B. For this assumption, the relation between the slope, S, of the

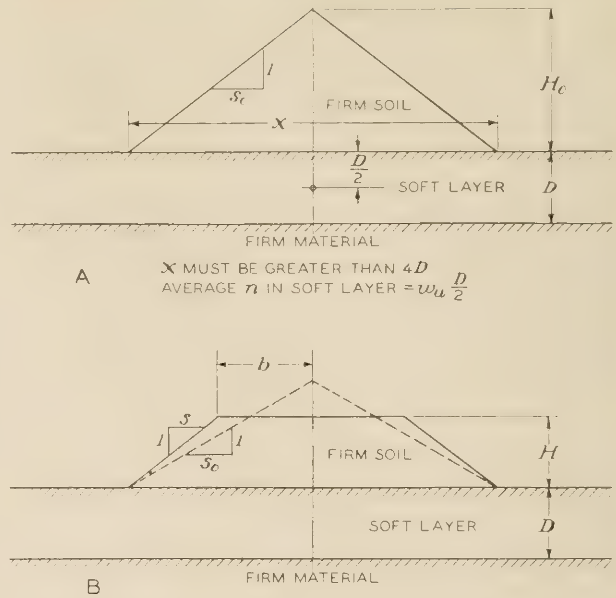


FIGURE 7.—FILL ON SOFT LAYER.

fill and the slope, S_0, of the triangle is

$$S_0 = S + \frac{\left(\frac{b}{H}\right)^2}{2\frac{b}{H}+S} \quad \text{(19)}$$

where

b = top half-width of fill, and
H = height of fill.

FORMULA FOR GREATEST SHEARING STRESS UNDER FILL PRESENTED

Critical height of slopes.—A graphical method for determining the critical height of slopes was published in PUBLIC ROADS, December 1929 (*6*). It assumes a circular surface of sliding as shown in figure 8 and compares the moment of the shear resistance along this surface with the moment of the weight of soil bounded by the surface. Moments are taken about the center of curvature. The most dangerous circle is determined by trial. Various analyses of the critical height, H, of cuts and embankments of homogenous material with level tops have been compared and tabulated by Taylor (*14*). His tables give the dimensionless ratio $\frac{c}{wH}$ for various values of ϕ and slope angle i. For a vertical slope, the critical height becomes approximately $\frac{3.83c}{w}$ $\tan\alpha$ which is greater than that given by equation 4, based on different assumptions.

Greatest shear stress under fill.—Applying the theory of elasticity to a semi-infinite, homogeneous, isotropic material, it is found that the greatest shear stress, s_G, under a symmetrical, trapezoidal strip load, figure 9, is on the centerline and is expressed by the formula (*15, 5*)

$$s_G = \frac{2.3zp}{\pi a}\log\frac{z^2+(a+b)^2}{z^2+b^2} \quad \text{(20)}$$

where

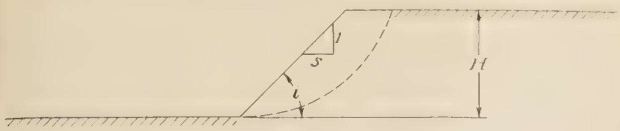


FIGURE 8.—SLIDING SURFACE IN HOMOGENEOUS SLOPE.

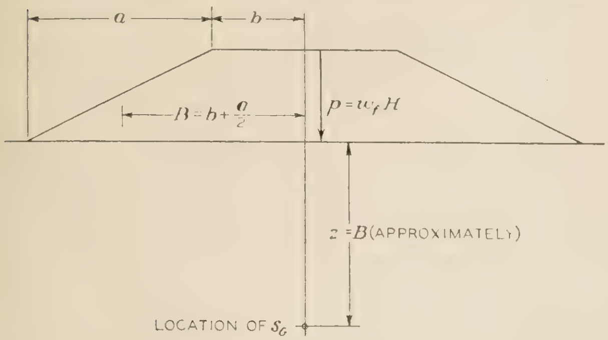


FIGURE 9.—TRAPEZOIDAL LOAD ON ELASTIC MATERIAL.

z=depth below the surface, chosen to make s_G a maximum,
p=pressure on centerline at the surface of the supporting material,
a=width of one side slope of trapezoidal fill,
b=half width of fill at top, and

$$B=b+\frac{a}{2}=z \text{ (approximately).}$$

For the special case of a rectangular strip load, $a=0$, the shear stress is maximum and equal to p/π at all points on the circumference of a semicircle passing through the edge of the load. If there is a rigid layer at some depth below the load, then according to D. L. Holl (*16*), the greatest shear stress is nearer the surface and of greater magnitude than for a homogeneous supporting material of infinite depth.

The load producing a greatest shearing stress equal to the cohesion of the supporting soil is less than the ultimate bearing capacity, computed for conditions of failure. That is, the load which causes failure at a single point or localized region is less than the load which will cause total failure throughout the supporting soil. Design based on stresses causing failure at restricted regions under a finite area is illustrated by considering the stresses under a circular load.

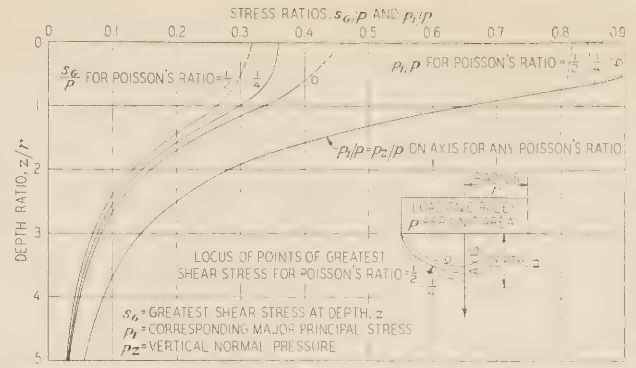


FIGURE 10.—GREATEST STRESSES DUE TO UNIFORM CIRCULAR LOAD ON A SEMI-INFINITE SOLID FOR DIFFERENT POISSON'S RATIOS.

Stresses under loaded circular areas.—A complete analysis of the stresses below a uniformly loaded circular area, using the theory of elasticity, has been presented by Love (*17, 18*) and includes a tabulation of stresses for Poisson's ratio equal to one-fourth. This analysis was discussed in PUBLIC ROADS (*19*) Figure 10 shows the location and magnitude of the greatest shear stress and the corresponding major principal stress at any level in the undersoil. The influence of Poisson's ratio on these stresses is also shown. The greatest shear stress anywhere under a uniformly loaded circular area is at the surface, just beneath the perimeter. For a Poisson's ratio of one-half, the greatest shearing stress is on the axis for all depths where z/r is greater than 0.7. Broken lines in figure 10 were interpolated. Figure 11 shows the effect upon the greatest shearing stress at any level of varying the applied load when the total load or the area of the circle or the unit pressure is kept

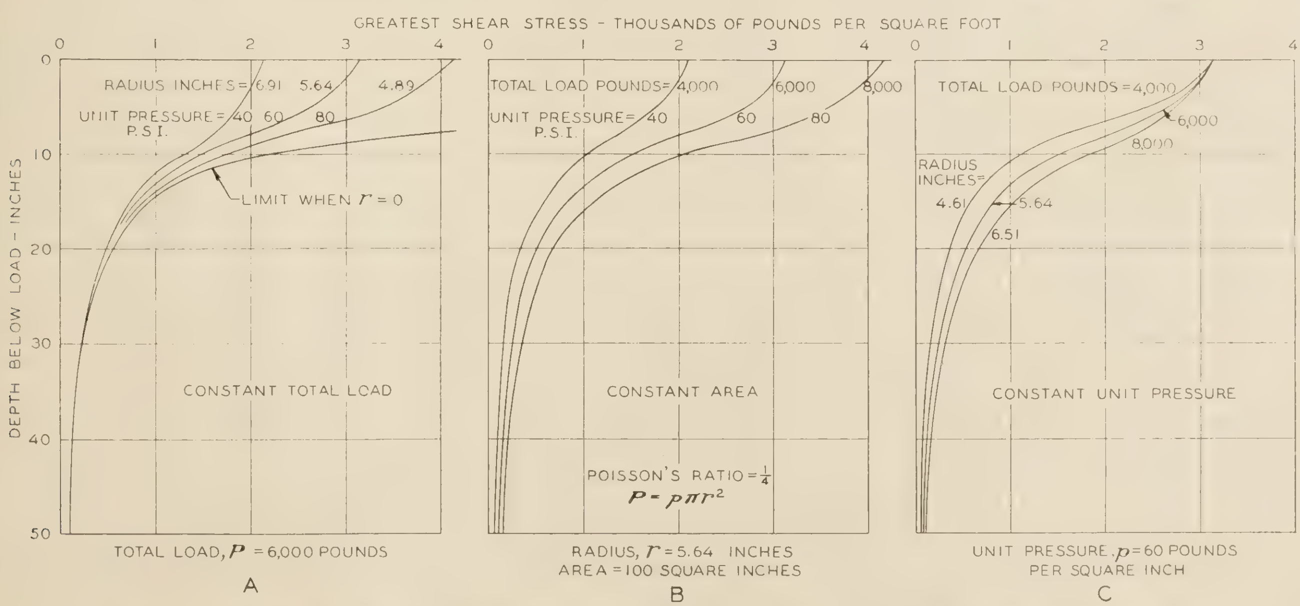


FIGURE 11.—GREATEST SHEAR STRESSES DUE TO UNIFORM CIRCULAR LOAD ON A SEMI-INFINITE SOLID.

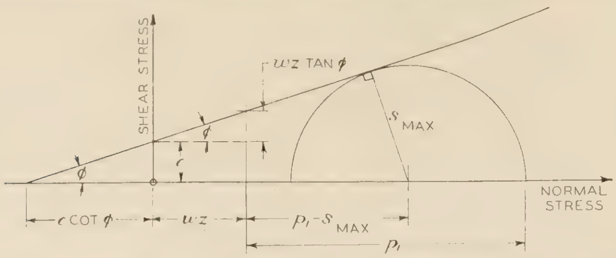


FIGURE 12.—RELATION OF STRENGTH TO STRESSES AT A POINT.

constant. For ϕ equal to zero and Poisson's ratio equal to one-half, a point at the edge of the load is overstressed if the unit load exceeds 3.14*c* (see fig. 10) whereas, according to H. Hencky (*12*), the ultimate bearing capacity under a rigid circular load is not reached until the average unit pressure is 5.64*c*.

To determine the cohesion required to prevent overstress at any point at a given level below a uniformly loaded circular area in a material wherein ϕ is greater than zero, account must be taken of the weight, *w*, of the material and the normal stresses produced by the load (*20*). Mohr's diagram, figure 12, shows the cohesion required to prevent overstressing at any point and was used in deriving the formula,

$$c=pF-wz\tan\phi \qquad (21)$$

where

$$F=\frac{s_{max}}{p\cos\phi}-\left(\frac{p_1-s_{max}}{p}\right)\tan\phi$$

in which s_{max} and p_1 are the stresses s_G and p_1 shown in figure 10 except for certain values of ϕ for which stresses at points off the axis required the greatest cohesion.

This analysis may be useful as a qualitative indication of the shearing strength required in flexible pavements and subgrades under pneumatic tire loads. However, as in other soil stability problems, due consideration must be given to such factors as wetting and drying, freezing and thawing, swelling and consolidation, distortion, and nonuniformity.

CHARTS USED TO FACILITATE COMPUTATIONS

The charts used in the solution of the foregoing formulas are of the simplest types and, in general, permit the determination of any one variable if the others are given (*21*). Supplementing the method of constructing each chart is an illustrative example which demonstrates its use.

Principal stresses at failure.—If equal lateral and vertical pressures are applied to a right circular cylinder and the vertical pressure then increased to failure, these stresses are related to *c* and ϕ by equation 3. This formula may be used to determine either the major principal stress, *v*, or the minor principal stress, *l*. To construct the graph, each term was evaluated separately. Thus, in the left chart of figure 13, tan α is plotted on the vertical axis, marked with the corresponding values of ϕ, and is multiplied by the sloping lines for various values of *c* to determine 2*c* tan α on the horizontal axis. On the right chart $\tan^2\alpha$ is plotted on the vertical scale. An illustrative problem in which *c*, ϕ, and *l* are given is shown on the figure.

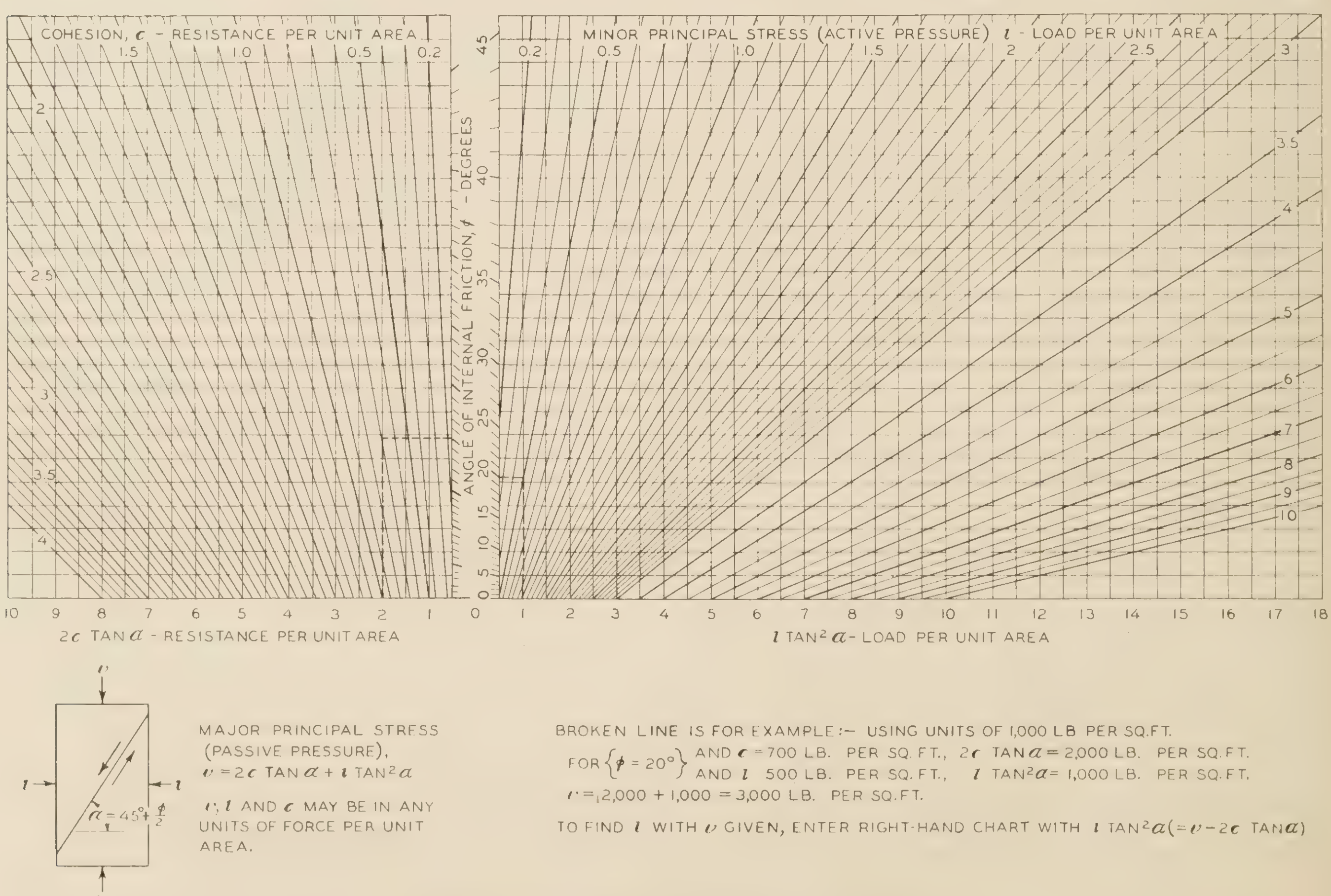


FIGURE 13.—PRINCIPAL STRESSES AT FAILURE.

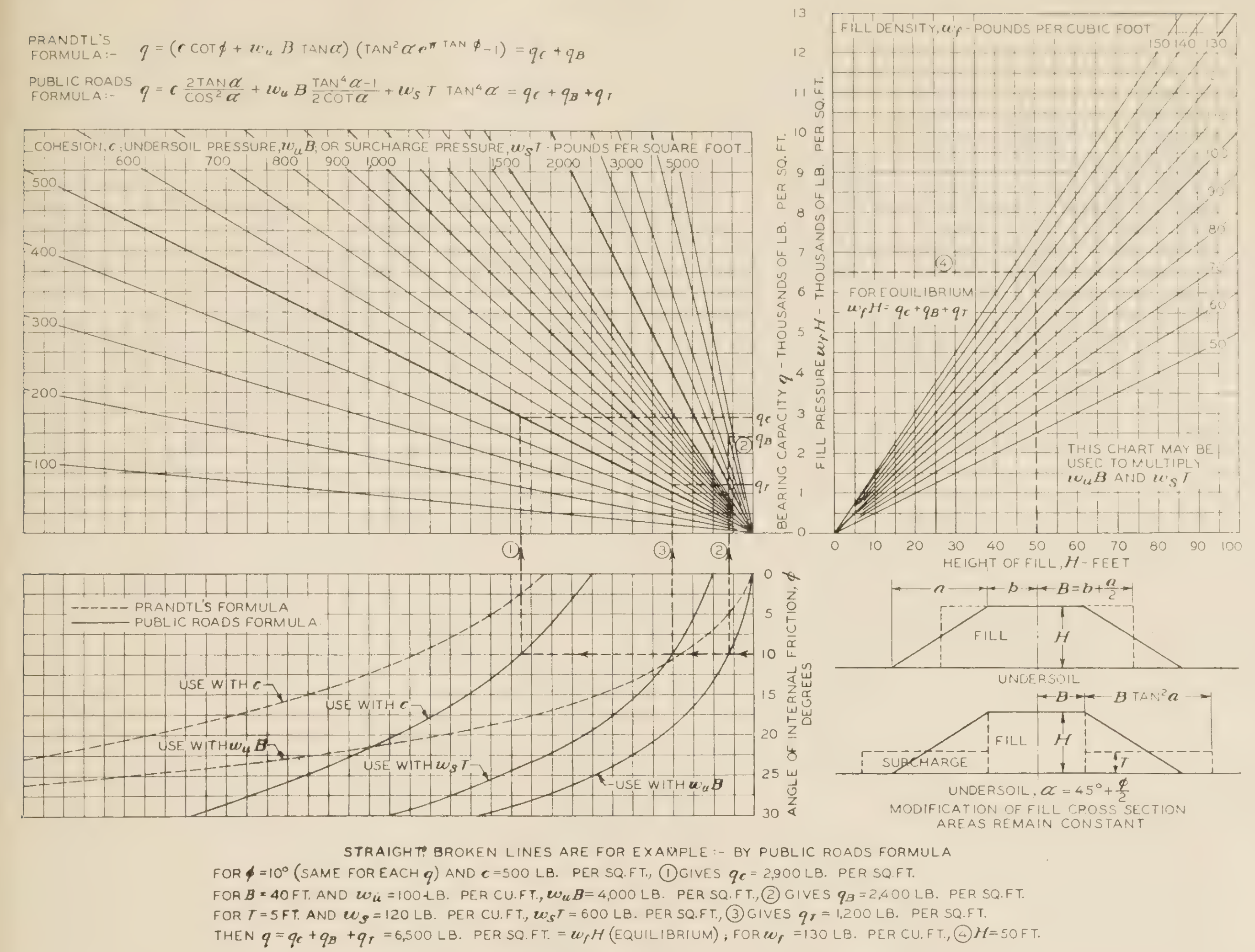


FIGURE 14.—BEARING CAPACITY OF SOIL UNDER LONG FILL.

To solve for v, start at $\phi=20°$ and follow the dotted lines to obtain the two terms of equation 3 which are added to determine v. The necessary additions or subtractions as well as the reading of the charts may be done with the aid of temporary marks on a straightedge.

Equation 5 may be rewritten in the form

$$\frac{wh}{2} = 2c \tan\alpha + \frac{L}{h}\tan^2\alpha$$

The active horizontal thrust, L, against a retaining wall may then be determined from figure 13 by using $\frac{wh}{2}$ for v and $\frac{L}{h}$ for l.

As an example, find L for a wall 20 feet high; given $w=100$ pounds per cubic foot, $c=200$ pounds per square foot, $\phi=10°$, $\frac{wh}{2}=\frac{100\times 20}{2}=1{,}000$ pounds, per square foot.

From the left chart, $2c \tan\alpha = 480$ pounds per square foot. Then $\frac{L}{h}\tan^2\alpha = 1{,}000-480=520$ pounds per square foot.

From the right-hand chart for $\tan^2\alpha=520$ and $\phi=10°$, $\frac{L}{h}=370$ pounds per square foot.

Thus $L=7{,}400$ pounds per foot of wall.

Similarly, the passive pressure, P, back of a retaining wall as expressed by equation 6, may be obtained from figure 13 by substituting P/h for v and $wh/2$ for l. A nomograph of the general formula for pressures on a wall with a cohesionless backfill has been published by Taylor (*22*).

Bearing capacity of soil under long fill.—Figure 14 may used to compute the bearing capacity of a homogeneous subgrade under a symmetrical strip load The figure solves equations 9, 11, and 12 by dividing the total bearing capacity, q, into components—q_c involving c; q_B involving the pressure in the supporting soil, w_uB; and q_T involving the surcharge pressure w_sT. The total bearing capacity is the sum of the components. The lower-left chart gives the value of a function of ϕ and the upper-left chart multiplies this value by the appropriate values of c, w_uB, or w_sT. The values of w_u, w_s, and w_f which are selected should represent the most unfavorable conditions to be anticipated.

The illustrative example shown on figure 14 considers a nonrigid fill with surcharges for which c, ϕ, w_u, w_s, T, w_f, and B are given. In the problem H is solved for by means of equation 9.

Values for a multiplying factor not on the chart such as c equals 50 may be determined by using the line for c

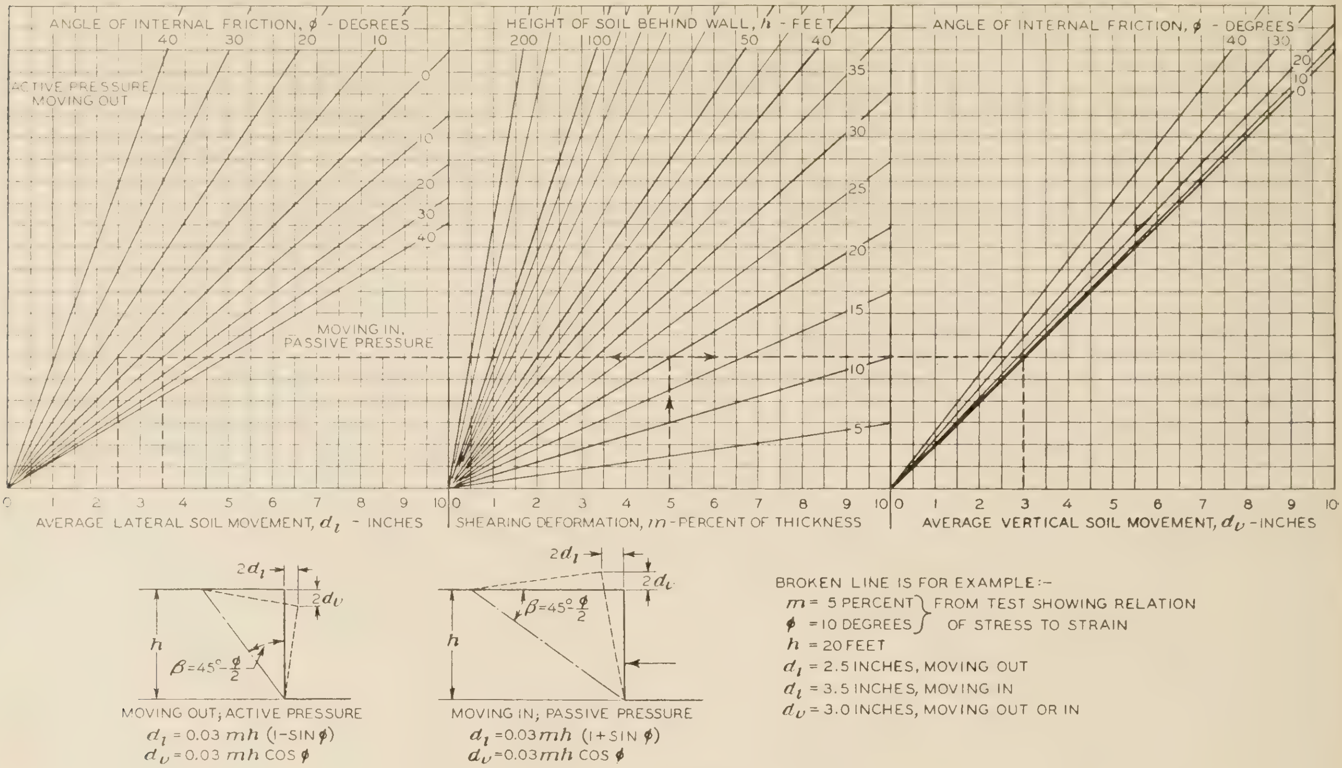


FIGURE 15.—SOIL MOVEMENT BEHIND WALL.

equals x times 50 and dividing the resulting q_c by x. This same device may also be used for w_uB, w_sT, H, w_f, or similar factors on other charts.

Soil movement behind wall.—The movement of the faces of the wedge of soil behind a rotating wall as given by equations 13 to 16 may be determined from figure 15. The middle chart multiplies m by h, and the left and right charts multiply this product by the appropriate functions of ϕ. The arrows and broken lines indicate the use of the chart in an example to solve for the average lateral and vertical movements of the soil of height h for a given shear strain or deformation and the corresponding ϕ.

Critical slope of fill on soft layer.—Figure 16 may be used in solving equations 18 and 19. The three terms of equation 18 as rearranged on figure 16 are solved separately and must be added or subtracted as required. The lower-left chart is used for obtaining w_f/S_0 and $w_u \tan \phi$. The right-hand chart divides $2c$ by D. The small chart in the upper left is used for obtaining S_0, the slope of the triangle, when the equal area method is used.

In the illustrative example, b, H, S, w_f, w_u, ϕ, and D are given and the c required for equilibrium is to be found. Using method I, enter the upper-left chart with b/H and S to get S_0. The lower chart divides w_f by S_0 and multiplies w_u by $\tan \phi$. Next enter the right-hand chart with $2c/D$ (which equals $w_f/S_0 - w_u \tan \phi$), and with the given D find the required c. One may solve for S, if the other factors are known, by going through the chart in the reverse direction. If the slopes of the fill are assumed to be continued to form a triangle as in method II, $S = S_0$ and the upper-left chart may be disregarded.

Critical height of slopes.—The lower-left chart of figure 17 was constructed from Taylor's table of values of $\frac{c}{wH}$ for various values of slope angle and ϕ. The abscissas in the lower-left chart are $\frac{wH}{c}$ and the ordinates of the upper charts are wH. The curved lines in the lower-left chart are for circles through the toe of the slope when a more dangerous circle exists which passes below the toe.

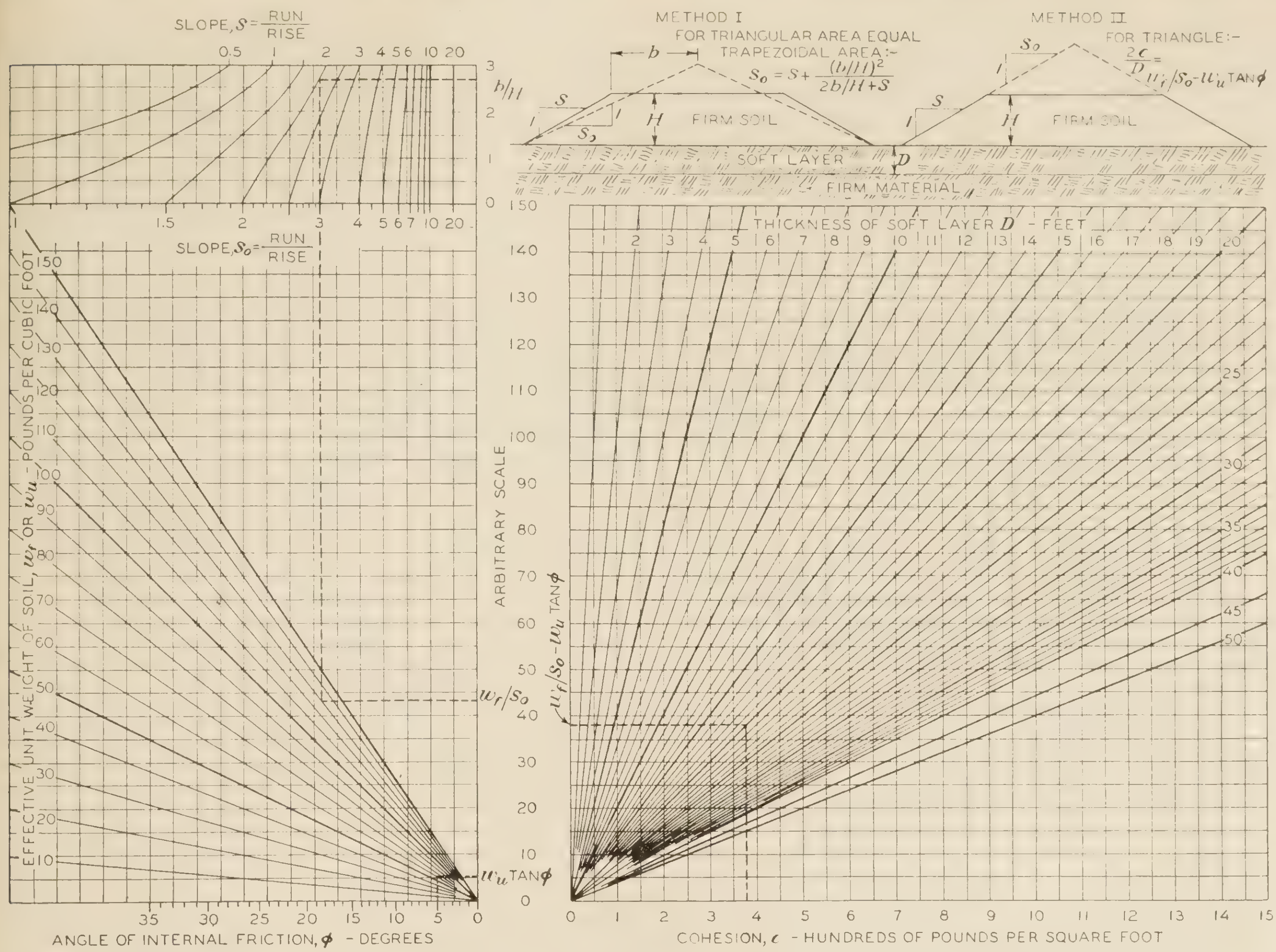
In the first example, find H when S is $1\frac{1}{2}:1$, $\phi = 7.6°$, $c = 100$ pounds per square foot, and $w = 100$ pounds per cubic foot. By following the broken lines marked 1, H is found to be 10 feet. If H is 20 feet, one can go through the chart in reverse direction and find that the critical slope is 3.4:1.

The critical height of cohesionless materials is, according to this analysis, zero for slopes greater than ϕ and unlimited for slopes less than ϕ.

Greatest shear stress under long fill.—Equation 20 was solved for variously proportioned trapezoids and figure 18 was constructed for calculating the greatest shear stress produced by a given fill pressure. The left chart determines $\frac{s_G}{p}$ for given ratios of b/B. The right-hand chart multiplies $\frac{s_G}{p}$ by p.

Cohesion required under uniform circular load.—Figure 19 may be used to determine F in equation 21. Values of s_G/p and p_1/p for substitution in the expression for F were taken from figure 10 for Poisson's ratio equals one-half. Broken lines on figure 19 represent values of F which were interpolated between values on the axis and values at the surface.

As an example of the use of figure 19, take $p = 8{,}000$ pounds per square foot, $r = 8$ inches, $w = 100$ pounds per cubic foot, and $\phi = 10°$. Then, to determine the required c at a depth of 16 inches, enter the chart at



BROKEN LINE IS FOR EXAMPLE :- TO SOLVE FOR c

METHOD I - FOR $b/H = 2.7$ AND $S = 2{:}1$, $S_o = 3{:}1$ AND FOR $w_f = 130$ LB. PER CU. FT., $w_f/S_o = 43$; FOR $\phi = 5°$ AND $w_u = 60$ LB. PER CU. FT., $w_u \tan\phi = 5$; THEN FOR $\frac{2c}{D}$ $(=43-5) = 38$ AND $D = 20$ FT., $c = 380$ LB. PER SQ. FT.

METHOD II - TAKE $S_o = S$, THAT IS USE $S_o = 2{:}1$ IN THE ABOVE EXAMPLE.

FIGURE 16.—CRITICAL SLOPE OF FILL ON SOFT LAYER.

$z/r = 16/8 = 2$, go over to the curve marked $\phi = 10°$ and up to $F = 0.11$. Substitute in equation 21 and obtain $c = 8{,}000 \times 0.11 - 100 \times 16 \times 0.015 = 880 - 24 = 856$ pounds per square foot. $\frac{\tan\phi}{12}$ is used to change z from inches to feet.

BIBLIOGRAPHY

(1) FELD, JACOB.
1940. GENERAL WEDGE THEORY OF EARTH PRESSURE. Discussions, Proceedings, A. S. C. E., p. 349, February.

(2) TAYLOR, D. W.
1939. LIMIT DESIGN OF FOUNDATIONS AND EMBANKMENTS. Proceedings, Highway Research Board, vol. 19.

(3) HOGENTOGLER, C. A., AND BARBER, E. S.
1939. ESSENTIAL FEATURES OF TRIAXIAL SHEAR TESTS. PUBLIC ROADS, September.

(4) HOGENTOGLER, C. A., AND BARBER, E. S.
1939. PRESENT STATUS OF SOILS INVESTIGATIONS. Proceedings, Highway Research Board, vol. 19.

(5) PALMER, L. A.
1938. PRINCIPLES OF SOIL MECHANICS INVOLVED IN THE DESIGN OF RETAINING WALLS AND BRIDGE ABUTMENTS. PUBLIC ROADS, December.

(6) TERZAGHI, CHARLES.
1929. THE MECHANICS OF SHEAR FAILURES ON CLAY SLOPES AND THE CREEP OF RETAINING WALLS. PUBLIC ROADS, December.

(7) BURGGRAF, FRED.
1938. COMPENDIUM ON SOIL TESTING APPARATUS. Proceedings, Highway Research Board, vol. 18 pt. II.

(8) HOGENTOGLER, C. A., AND TERZAGHI, CHARLES.
1929. INTERRELATIONSHIP OF LOAD, ROAD AND SUBGRADE. PUBLIC ROADS, May.

(9) PLUMMER, F. L., AND DORE, S. M.
1940. SOIL MECHANICS AND FOUNDATIONS. Pitman Publishing Corporation, p. 178.

(10) PALMER, L. A., AND BARBER, E. S.
1937. PRINCIPLES OF SOIL MECHANICS INVOLVED IN FILL CONSTRUCTION. Proceedings, Highway Research Board, vol. 17.

(11) TAYLOR, D. W.
1939. A COMPARISON OF RESULTS OF DIRECT SHEAR AND CYLINDRICAL COMPRESSION TESTS. Proceedings, A. S. T. M., vol. 39.

(12) JURGENSON, LEO.
1934. THE APPLICATION OF THEORIES OF ELASTICITY AND PLASTICITY TO FOUNDATION PROBLEMS. Journal, Boston Society of Civil Engineers, July.

(13) PALMER, L. A.
1939. DESIGN OF A FILL SUPPORTED BY CLAY UNDERLAID BY ROCK. PUBLIC ROADS, October.

(14) TAYLOR, D. W.
1937. STABILITY OF EARTH SLOPES. Journal, Boston Society of Civil Engineers, July.

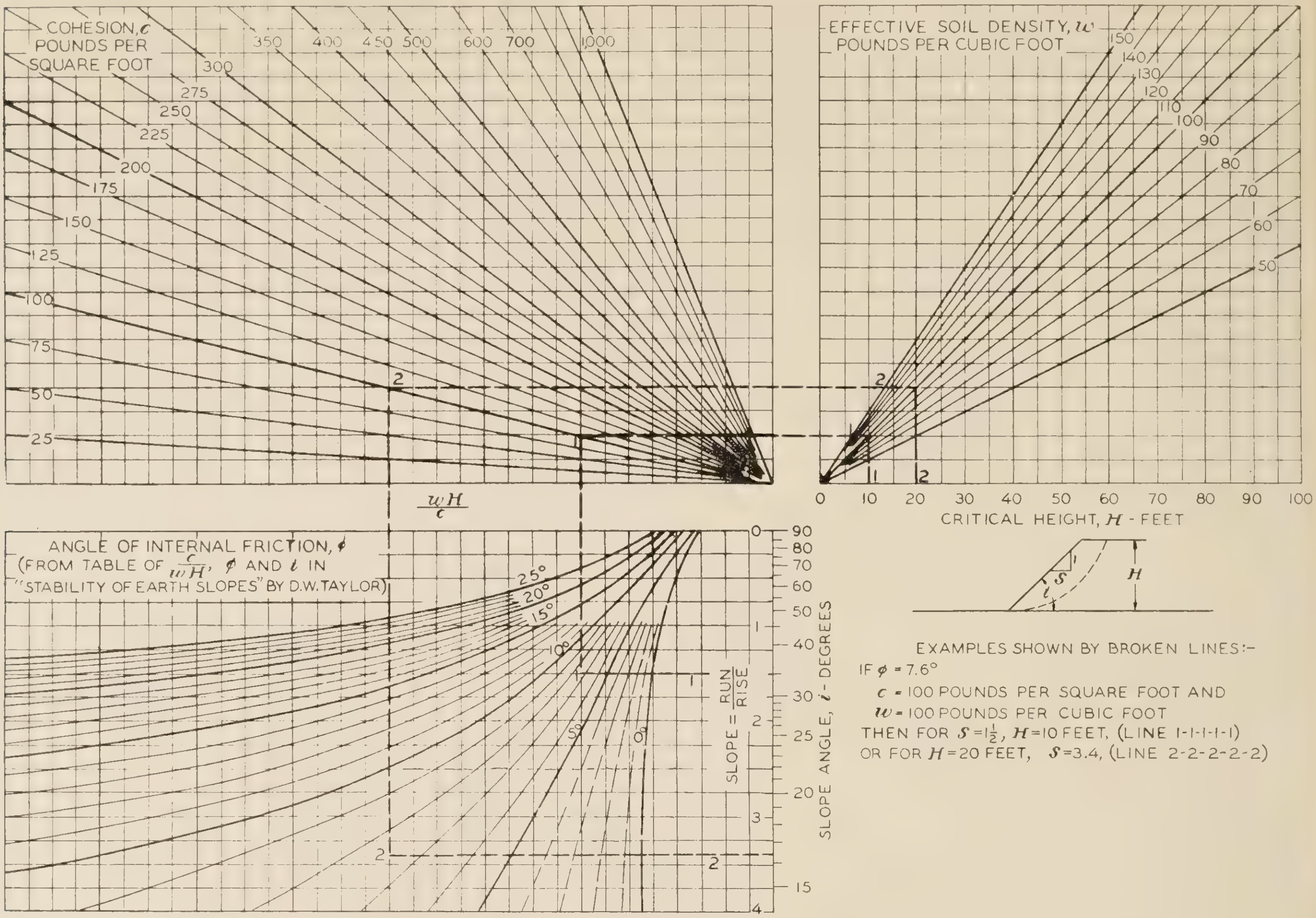


Figure 17.—Chart for Critical Height of Slopes.

(15) Gray, Hamilton.
1936. stress distribution in elastic solids. Proceedings, International Conference on Soil Mechanics and Foundation Engineering, vol. II, p. 157.

(16) Holl, D. L.
1939. shearing stresses and surface deflections due to trapezoidal loads. Proceedings, Highway Research Board, vol. 19.

(17) Love, A. E. H.
1929. the stress produced in a semi-infinite solid by pressure on part of the boundary. Philosophical Transactions, Royal Society of London, Series A, vol. 228.

(18) Timoshenko, S.
1934. theory of elasticity. McGraw-Hill Book Company, Inc., New York City.

(19) Palmer, L. A.
1940. stresses under a loaded circular area. PUBLIC ROADS, February.

(20) Jurgenson, Leo.
1936. on the stability of foundations of embankments. Proceedings, International Conference on Soil Mechanics and Foundation Engineering, vol. II, p. 194.

(21) Lipka, Joseph.
1918. graphical and mechanical computation. John Wiley and Sons, Inc., New York City.

(22) Taylor, D. W.
1936. lateral pressures of cohesionless soils in retaining wall designs. Engineering News-Record, p. 76, July 16.

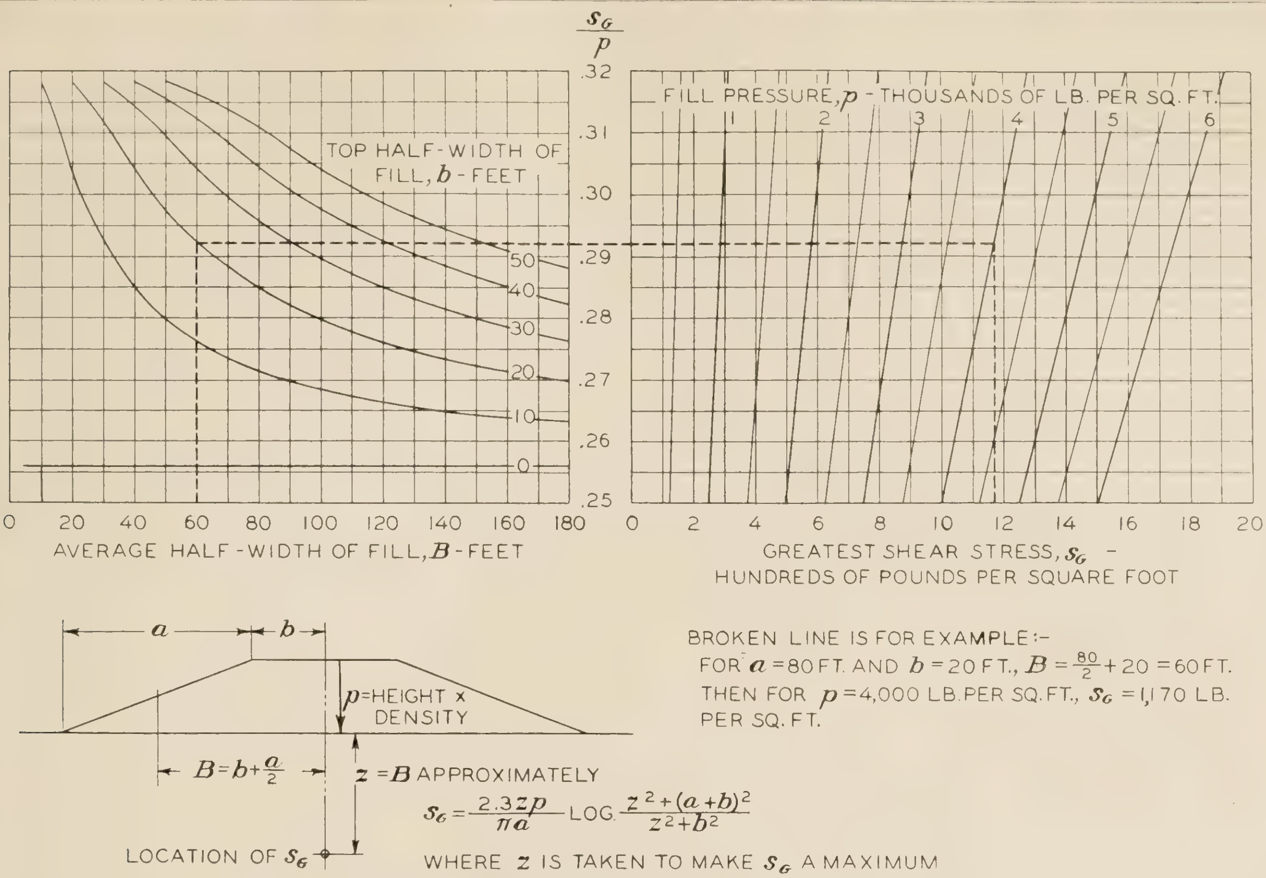
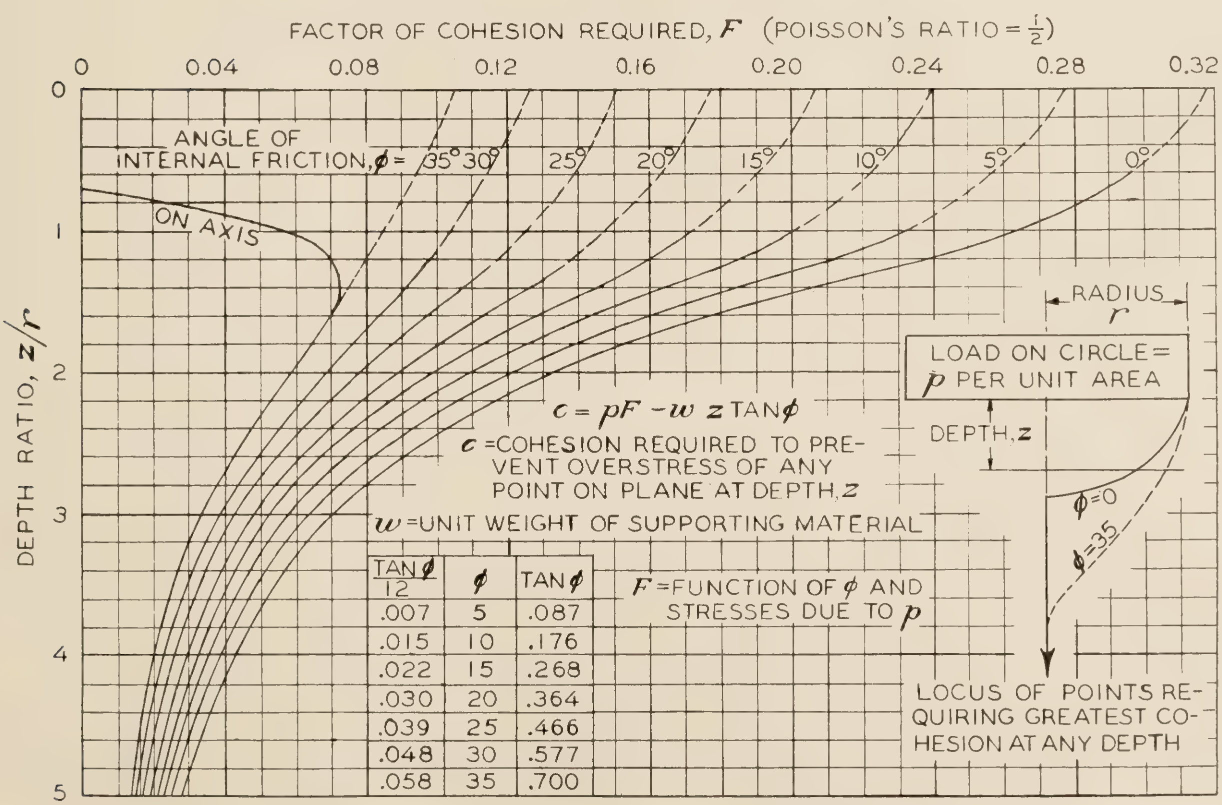


Figure 18.—Greatest Shear Stress Under Long Fill.



TAN φ / 12	φ	TAN φ
.007	5	.087
.015	10	.176
.022	15	.268
.030	20	.364
.039	25	.466
.048	30	.577
.058	35	.700

Figure 19.—Graph of Factor for Determining Cohesion Required in Solid Supporting a Uniform Circular Load.

(Continued from page 146)

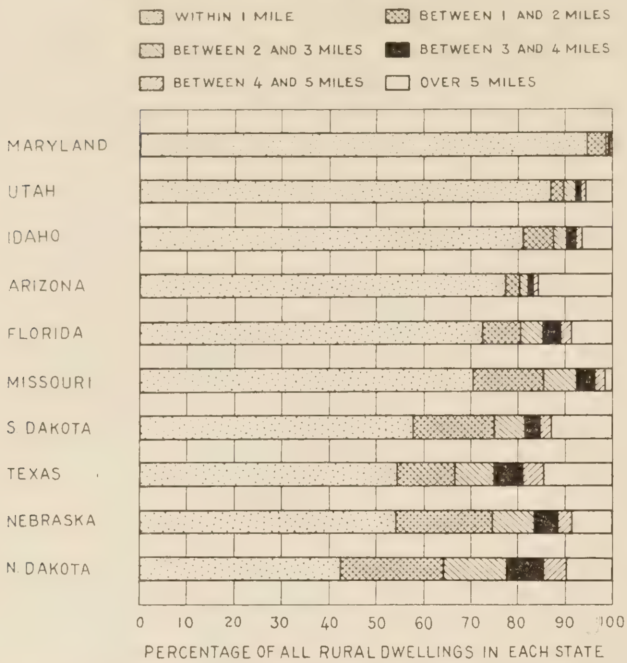


Figure 5.—Percentage of All Rural Dwellings Within Various Travel Distances of Surfaced Roads in Each of 10 States.

The percentage of all rural dwellings within 1 mile of a surfaced road ranged from 94.9 percent in Maryland, down to 42.2 percent in North Dakota.

Table 9 and figure 6 show, for the same 10 States, the percentage of all rural dwellings within various travel distances of either a surfaced road or a graded and drained road or, in other words, of an improved road. In these States, 80.9 percent of the rural dwellings were within 1 mile of an improved road. In Maryland, 99.1 percent of the rural dwellings were within 1 mile of an improved road and all of them were within 2 miles of an improved road. In Texas, on the other hand, the percentages of the rural dwellings within 1 mile and within 2 miles of improved roads were 62.0 percent and 73.9 percent, respectively. In all of the States for which the information was obtained, only a very small percentage of the rural residents need travel more than 1 or 2 miles from their homes to reach an improved road.

Table 8.—*Percentage of all rural dwellings within various travel distances of surfaced roads, in each of 10 States*

State	Within 1 mile	Within 2 miles	Within 3 miles	Within 4 miles	Within 5 miles
Arizona	77.1	80.4	82.1	83.1	84.2
Florida	72.6	80.5	85.6	89.1	91.4
Idaho	81.1	87.3	90.2	92.3	93.8
Maryland	94.9	98.9	99.7	99.9	100.0
Missouri	70.7	85.4	92.7	96.6	98.4
Nebraska	54.0	74.2	83.4	88.5	91.5
North Dakota	42.2	64.3	77.7	85.3	90.1
South Dakota	57.8	75.0	81.4	84.9	87.0
Texas	54.6	66.6	75.0	81.2	85.8
Utah	85.7	89.9	92.1	93.3	94.4
Average	65.0	77.5	84.4	88.7	91.5

In this report, all of the rural roads within a State have been considered as constituting a single system of

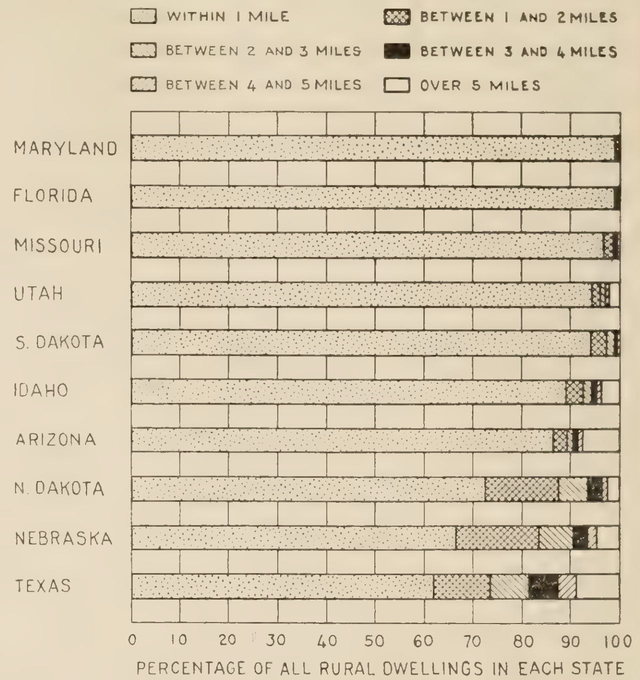


Figure 6.—Percentage of All Rural Dwellings Within Various Travel Distances of Improved Roads in Each of 10 States.

roads. This is the concept of the average motorist since he generally does not know or care what administrative system or systems of roads he travels over in driving from one place to another. To those charged with the responsibility of financing, building, and maintaining roads, however, distinction between administrative systems is of the utmost importance. In nearly all States one group of public officials is responsible for State roads and other groups for county roads or township roads. The Federal Government has assumed responsibilities with respect to the 7 percent Federal-aid system, the 10 percent Federal-aid secondary system, and several systems or groups of roads serving national reservations, such as national forest highways, national forest development roads, national park roads, Indian roads, roads through public lands, and recently, roads of major importance from the standpoint of national defense. The sources and amounts of funds made available for each administrative system are responsibilities of legislative bodies. The segregation of road mileages into administrative systems is complicated because of overlapping juris-

Table 9.—*Percentage of all rural dwellings within various travel distances of improved roads, in each of 10 States* [1]

State	Within 1 mile	Within 2 miles	Within 3 miles	Within 4 miles	Within 5 miles
Arizona	86.7	89.5	90.9	91.8	92.4
Florida	99.1	99.6	99.7	99.8	99.8
Idaho	89.1	92.8	94.5	95.5	96.3
Maryland	99.1	100.0	100.0	100.0	100.0
Missouri	96.9	99.1	99.6	99.8	99.9
Nebraska	66.9	83.9	90.6	93.8	95.5
North Dakota	72.8	87.9	93.8	96.4	97.8
South Dakota	94.3	97.8	98.8	99.2	99.4
Texas	62.0	73.9	81.9	87.5	91.3
Utah	94.3	96.3	97.2	97.6	98.0
Average	80.9	88.2	92.1	94.5	96.1

[1] Improved roads include graded and drained roads and surfaced roads.

dictions. Also, significant comparisons of systems between States are difficult because of differences in the extent of the responsibilities of different jurisdictions. For example, in several States the State government assumes responsibility for all rural public roads, in others the responsibility is divided between the State and the counties, and in still others it is divided between the State, counties, and townships.

A complete and detailed analysis of roads by administrative system is being made in each State. For the reasons cited, such an analysis does not lend itself well to presentation on a national basis. Significant nationwide comparisons can be made, however, for the 7 percent Federal-aid system, for a group of the most important roads in each State designated as State highways in some and as primary State highways in others, and for all other rural roads regardless of jurisdiction which are mainly local roads in the sense that interest in them is not State-wide. Such comparisons will be made in a subsequent article.

REGULAR FEDERAL-AID FUNDS AUTHORIZED FOR 1942 AND 1943

The Federal Highway Act of 1940, which authorizes regular Federal-aid funds for highways, secondary or feeder roads, and grade crossings for the fiscal years 1942 and 1943, was approved on September 5, 1940. The act is in conformity with the congressional policy of authorizing in advance of the period for which they are available the Federal-aid funds for 2 years, enabling the various State legislatures, many of which meet biennially, to plan their highway budgets with foreknowledge of their approximate Federal-aid apportionments. Federal funds for other classes of road work are also provided by the act, the amounts provided for each fiscal year being as follows:

Item	Amount for each fiscal year
Federal-aid system	$100, 000, 000
Secondary or feeder roads	17, 500, 000
Elimination of hazards at grade crossings	20, 000, 000
National forest highways	7, 000, 000
National forest development roads	3, 000, 000
National park roads	4, 000, 000
Parkways	7, 500, 000
Public land roads	1, 500, 000
Indian roads	3, 000, 000

As in previous years, the Federal-aid highway and secondary road funds must be matched with State funds, and the grade crossing funds are outright grants to the States. Funds for these three classes of work for the fiscal year 1942 are required by law to be apportioned to the States, the District of Columbia, Hawaii, and Puerto Rico, by the Federal Works Administrator before next January 1. Formulas for apportioning the funds among the States remain unchanged.

Section 12 of the act specifically authorizes the Reconstruction Finance Corporation "to cooperate with States to finance, or to aid in financing, the acquisition of real property or interests in property * * * necessary or desirable for road projects eligible for Federal aid under the Federal Highway Act * * *." This provision will enable the long-term financing of highway rights-of-way through cities, thereby facilitating the early completion of necessary improvements that heretofore have not been undertaken because of the lack of sufficient current funds to pay both right-of-way and construction costs. High right-of-way costs, in many cases amounting to several times the actual construction costs, have retarded improvements to main routes through cities needed to eliminate traffic congestion and attendant danger and delay.

Section 19 of the act provides that: "In approving Federal-aid highway projects to be carried out with any unobligated funds apportioned to any State, the Commissioner of Public Roads may give priority of approval to, and expedite the construction of, projects that are recommended by the appropriate Federal defense agency as important to the national defense."

Under this provision of the law it should be possible to make an immediate beginning on the strategic highway program. A system of 75,000 miles of main highways has been selected by military and naval authorities as highly important for definite strategic reasons. Many sections of the system are already in satisfactory condition but there are also numerous substandard sections. Replacing weak bridges and widening and strengthening road surfaces and shoulders will be important parts of the work. The program is aimed at the elimination of critical weaknesses and restrictions on main highways.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF SEPTEMBER 30, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,705,324	$ 847,917	49.1	$ 4,642,001	$ 2,308,053	164.0	$ 1,837,290	$ 914,440	76.1	$ 2,166,993
Arizona	550,885	390,645	29.9	1,147,222	712,144	44.2	507,140	275,016	32.0	1,225,492
Arkansas	2,503,775	1,121,535	26.2	2,681,494	1,333,794	128.0	381,484	189,448	22.1	393,072
California	3,129,803	1,630,057	49.8	8,035,542	4,150,579	128.0	2,085,955	1,138,550	43.9	1,855,907
Colorado	1,171,028	658,169	108.0	2,227,256	1,237,574	114.6	513,621	289,477	77.6	2,173,268
Connecticut	15,000	7,500		2,706,448	1,320,856	21.9	264,250	124,573	4.7	1,052,590
Delaware	52,661	26,330	.9	1,969,981	984,211	31.6	155,407	51,044		1,048,125
Florida	732,053	366,026	20.1	3,232,131	1,605,786	96.8	840,971	420,485	17.4	2,313,581
Georgia	875,168	437,584	53.3	7,396,295	3,682,230	316.4	3,727,435	1,864,217	167.6	4,685,263
Idaho	518,918	317,895	52.6	1,393,325	856,177	122.3	378,325	162,646	17.7	1,581,336
Illinois	2,041,318	999,099	46.1	9,425,200	4,711,705	196.9	1,869,392	873,696	62.7	2,700,572
Indiana	2,242,510	1,121,255	58.9	6,537,321	3,118,504	112.8	3,461,808	1,698,749	52.1	884,241
Iowa	1,985,091	879,440	53.5	5,463,365	2,508,062	195.4	2,130,594	1,000,950	71.2	401,368
Kansas	601,220	300,610	38.4	7,516,257	3,757,784	449.6	2,866,854	1,433,426	256.3	3,236,143
Kentucky	1,233,766	615,327	19.0	3,948,134	1,974,067	108.0	661,649	330,825	53.5	2,893,632
Louisiana	643,730	316,311	5.4	12,720,814	3,405,451	64.7	1,170,213	577,418	27.3	2,863,497
Maine	750,620	374,022	15.8	1,068,408	534,203	29.5	243,710	121,855	5.0	604,532
Maryland	345,000	172,500	10.1	3,665,230	1,824,197	40.2	489,303	244,651	5.1	1,237,233
Massachusetts	553,156	276,153	4.7	3,672,471	1,827,381	31.0	177,871	88,935	.3	2,836,471
Michigan	1,085,862	542,931	37.9	11,593,150	5,708,474	334.2	1,623,316	794,758	50.1	288,080
Minnesota	2,067,822	983,419	173.7	7,522,270	3,748,500	491.9	803,941	401,971	29.5	3,155,788
Mississippi	763,732	305,416	30.5	7,013,274	3,141,143	335.3	1,943,060	948,730	112.5	1,454,294
Missouri	1,880,717	940,354	94.9	7,596,672	3,477,199	206.1	3,269,330	1,202,672	112.8	3,939,547
Montana	2,658,568	1,506,079	183.4	2,460,575	1,390,039	149.2	880,862	483,552	48.8	3,470,304
Nebraska	2,464,333	1,232,166	298.2	5,384,664	2,604,315	619.3	1,236,985	618,492	150.9	2,362,913
Nevada	1,196,352	1,029,857	60.9	1,374,094	1,194,076	62.1	5,600	4,881		759,186
New Hampshire	487,278	238,155	12.6	1,361,162	668,546	32.9	14,007	7,004		899,329
New Jersey	1,089,800	544,670	8.9	4,416,148	2,208,074	32.9	1,295,710	647,855	5.5	1,586,676
New Mexico	1,133,944	700,925	89.6	1,480,152	900,375	88.3	622,420	375,195	38.5	1,124,863
New York	2,008,626	992,285	41.7	16,742,726	8,187,377	242.3	4,096,017	1,519,684	46.0	925,195
North Carolina	2,782,105	1,390,055	130.5	3,891,121	1,946,132	187.3	2,261,000	1,102,970	104.1	1,321,066
North Dakota	1,055,750	565,838	101.5	2,684,408	1,509,122	211.0	3,169,464	1,621,950	269.1	3,197,318
Ohio	1,805,773	902,886	23.8	13,637,102	6,794,222	124.4	2,953,710	1,476,580	24.9	4,281,168
Oklahoma	866,292	459,550	50.0	3,486,033	1,843,453	112.9	1,395,085	686,614	50.9	4,092,767
Oregon	1,513,189	909,630	108.9	2,724,902	1,619,495	56.4	1,311,660	602,750	30.2	871,464
Pennsylvania	1,977,624	961,473	26.8	12,841,490	6,377,960	127.4	3,564,299	1,774,179	29.2	1,868,526
Rhode Island	292,212	145,890	2.5	1,457,124	727,160	15.1	300,411	150,180	1.9	852,533
South Carolina	518,801	241,980	36.5	2,605,266	1,261,281	176.5	933,689	416,210	69.7	2,139,230
South Dakota	1,557,814	881,564	235.7	4,338,480	2,567,480	582.6	1,239,140	749,990	225.2	2,448,861
Tennessee	524,608	262,304	10.4	3,646,358	1,823,179	106.6	1,547,042	773,521	61.6	3,708,269
Texas	3,321,834	1,636,523	231.2	7,788,195	3,861,187	364.4	3,965,998	1,878,790	172.2	6,033,154
Utah	412,082	300,075	32.5	1,237,235	918,263	61.8	677,430	276,330	26.3	733,481
Vermont	214,830	107,415	11.1	1,499,414	748,058	40.7	320,628	160,314	5.7	263,842
Virginia	1,288,200	597,453	41.1	2,556,897	1,236,647	62.5	2,117,568	1,040,995	27.1	1,204,406
Washington	1,678,909	884,294	25.5	2,990,562	1,582,235	69.1	776,697	413,400	12.4	754,323
West Virginia	507,150	252,395	16.6	3,531,880	1,757,741	107.3	666,530	333,265	12.9	1,671,200
Wisconsin	3,142,906	1,533,610	94.9	3,791,451	1,883,380	158.3	325,553	153,950	14.4	3,407,486
Wyoming	1,290,783	814,104	142.2	1,003,016	638,987	108.1	536,608	342,993	65.8	649,481
District of Columbia	154,300	77,150	1.2	383,942	191,971	3.3	250,100	117,016	1.5	325,209
Hawaii	29,184	11,010		354,190	179,072	5.2	546,461	273,046	9.2	1,498,907
Puerto Rico	20,338	9,980	.3	1,597,615	790,710	26.0	106,769	52,580	1.9	717,500
TOTALS	63,442,744	32,819,811	2,997.3	234,440,463	115,338,611	7,697.3	68,520,362	33,202,818	2,803.4	98,159,682

U S GOVERNMENT PRINTING OFFICE: 1940

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF SEPTEMBER 30, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 175,144	$ 87,363	9.4	$ 1,065,679	$ 531,120	48.6	$ 257,167	$ 128,233	12.2	$ 354,133
Arizona	58,228	21,068	4.7	282,532	203,973	13.9				234,685
Arkansas	331,054	154,443	7.7	280,505	140,041	27.8	101,825	68,376	6.7	72,639
California	341,885	185,938	10.5	722,425	390,814	31.4	108,742	40,601	.7	808,868
Colorado				199,428	89,535	1.9	71,801	40,467	3.0	160,220
Connecticut	52,818	25,299	.8	317,216	154,114	3.8	102,386	48,738	1.8	165,663
Delaware	69,537	34,768	7.8	98,995	41,350	7.7				268,125
Florida	12,030	6,015		408,106	204,053	.3	537,863	243,458	19.8	175,237
Georgia	38,761	19,381	5.5	633,812	301,906	59.2	506,881	253,441	42.7	1,039,418
Idaho	27,402	16,902	6.0	88,521	54,574	13.0	208,304	95,931	10.3	136,439
Illinois	724,335	361,655	46.4	1,496,050	731,363	41.5	451,400	225,700	20.8	210,877
Indiana	346,670	172,131	23.0	195,102	97,516	11.7	91,936	45,900	4.4	916,997
Iowa	1,179,975	561,025	201.4	1,050,588	499,676	243.1	681,738	322,680	218.2	159,685
Kansas	221,992	110,996	17.5	728,915	367,366	45.0	485,580	242,789	45.9	1,109,693
Kentucky	506,671	148,835	40.9	636,726	214,195	35.0	388,174	95,751	18.0	284,327
Louisiana	41,637	20,819	3.7	256,292	128,091	22.0				458,796
Maine	115,010	56,716	7.6	189,314	89,248	9.7	29,000	14,500	1.3	8,024
Maryland				177,996	88,998	8.2				427,378
Massachusetts	110,536	54,886	2.7	521,271	258,386	10.7				498,612
Michigan	186,548	93,274	22.1	1,456,329	731,554	113.2	244,200	122,100	18.5	511,141
Minnesota	190,545	91,761	16.7	753,335	375,951	118.6	568,703	284,352	73.4	845,959
Mississippi	172,962	86,481	10.6	671,452	330,226	31.4	414,400	195,665	19.8	424,732
Missouri	206,794	103,397	29.9	500,342	249,798	47.9	434,949	139,947	53.8	668,229
Montana	458,768	259,458	63.7	249,798	140,969	19.2	22,269	12,566	1.2	644,158
Nebraska	328,695	164,188	53.7	660,960	324,496	89.0	143,879	71,940	24.4	231,413
Nevada	151,328	130,622	33.6	126,614	104,928	12.9	40,504	35,310	2.1	55,950
New Hampshire	48,387	23,241	2.2	97,444	46,738	1.2				167,812
New Jersey	319,500	159,750	10.6	264,090	131,965	9.0	61,333	30,660	2.4	499,449
New Mexico	101,564	63,386	13.1	396,987	244,848	14.7	273,612	100,232	14.1	85,190
New York	981,201	490,601	40.8	2,065,875	997,860	54.2	366,640	149,143	11.4	72,269
North Carolina	472,550	236,275	48.0	627,203	314,568	49.7	23,680	10,500	.8	317,257
North Dakota	39,433	21,136	.3	145,151	79,399	1.1	27,520	14,750	2.4	1,014,688
Ohio	413,957	206,913	14.6	2,808,570	1,403,025	91.8	271,880	135,940	7.1	741,852
Oklahoma	536,288	284,638	37.9	254,865	134,374	19.2	112,680	35,269	3.1	945,470
Oregon	276,538	147,840	43.6	281,370	125,830	23.0	101,801	58,990	11.3	207,154
Pennsylvania	755,242	371,516	30.6	1,572,441	785,312	39.3	42,000	21,000	.3	214,836
Rhode Island	107,556	53,749	1.8	130,339	65,143	1.8				91,158
South Carolina	92,800	43,750	8.9	633,123	236,366	72.2	188,647	80,250	50.0	193,595
South Dakota				3,624	3,624					1,280,913
Tennessee	105,038	52,519	7.9	48,612	24,306	3.0	186,188	93,094	7.2	909,350
Texas	983,983	483,876	138.4	665,963	328,010	70.6	392,750	181,475	26.5	845,653
Utah	3,767	2,500		240,082	151,040	25.9	31,200	23,000	5.7	121,152
Vermont	139,900	48,305	5.4	366,408	103,750	14.0				22,500
Virginia	168,540	80,212	9.0	460,344	211,971	25.1	112,476	46,810	1.2	286,029
Washington	159,951	83,988	5.8	462,792	245,539	25.2	277,321	144,800	25.0	119,534
West Virginia	154,950	76,950	9.6	155,669	77,834	7.1	79,808	39,904	4.4	446,556
Wisconsin	180,214	89,751	2.2	758,070	378,910	27.7				649,380
Wyoming	389,348	229,898	39.0	114,117	72,162	7.9				117,160
District of Columbia				130,684	64,842	1.4				22,150
Hawaii	170,361	85,037	6.4	108,585	54,841	2.2				158,778
Puerto Rico				302,225	147,640	14.0	55,188	27,140	2.1	80,408
TOTALS	12,650,393	6,303,252	1,102.0	26,862,936	13,274,129	1,668.0	8,496,425	3,921,402	774.0	20,481,691

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF SEPTEMBER 30, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,100	$ 4,100			1	$ 717,904	$ 697,827	6			$ 16,800	$ 16,800			5	$ 943,965
Arizona	363,787	356,072	4			7,592	7,592				6,006	6,006			2	242,091
Arkansas	77,452	77,452	1		5	1,090,995	1,086,848	7	1		210,067	209,848	5		11	430,330
California	181,075	181,075	2		3	886,145	707,664	3	1		26,464	26,464			12	1,688,531
Colorado						283,222	283,222	1			3,401	3,401			1	919,512
Connecticut	153,792	148,343		1		633,988	628,437	7								449,334
Delaware	45,759	45,759			9	137,499	137,499	1		7	13,839	13,839	4		1	467,605
Florida	203,348	198,849	2		1	37,626	37,626	1			127,859	127,334		1	15	1,290,976
Georgia	98,753	98,753	2		11	765,788	765,788	9	5	1	607,118	607,118	4	3	5	1,792,357
Idaho	104,842	104,237	1			102,897	100,072	4			85,358	85,358			33	424,756
Illinois	431,062	377,451	3	1	16	2,374,331	2,171,855	9	1	42	235,161	200,862	1		65	2,028,650
Indiana	237,674	237,674	1	1	28	892,262	892,262	6	1	43	86,166	86,166			27	1,002,549
Iowa	160,688	151,600	1		29	394,280	316,258	4		44	96,576	90,456	1		24	1,217,969
Kansas	426,425	426,425	5		5	531,945	531,467	7	1	1	205,254	205,254	3	1	18	1,089,153
Kentucky	161,777	161,777	4		10	1,042,369	1,042,369	11			9,457	9,457			3	567,149
Louisiana	95,496	95,496	1			345,122	291,627	2			627,885	570,153	11			804,609
Maine	149,214	149,214	1	1	4	26,841	26,841		1	1	128,350	128,350	1		1	251,016
Maryland	180,996	180,993	1		2	472,109	440,316	2	2	5	15,600	15,600			3	771,815
Massachusetts	15,710	15,710				336,591	326,168	1			1,034	1,034			1	2,024,008
Michigan	682,519	682,519	4	1	13	1,466,427	1,466,427	5	4	2	197,698	197,698		1	22	822,730
Minnesota	515,366	507,509	4	1	2	1,472,970	1,472,970	12	3	8	244,644	244,644	1	3	8	1,010,984
Mississippi	23,760	23,760				494,634	494,634	7	1		166,500	166,500	3		3	741,349
Missouri	150,832	150,832		2		1,843,554	1,555,174	7	3		1,057,603	829,073	4	2	1	973,697
Montana	276,720	276,720	5		2	154,873	85,232				99,948	96,681	1		2	410,875
Nebraska	195,478	195,478		1	5	737,924	737,924	10	1	5	132,930	132,930	4		1	441,925
Nevada						115,732	115,732	2		5	42,138	42,138			20	115,071
New Hampshire	100,989	100,953	3			82,452	82,452	1			82,358	81,538	2		1	309,842
New Jersey						772,219	772,219	5			75,490	75,490		1	4	1,207,397
New Mexico	140,504	140,504	1		6	110,443	110,443	1			189,836	164,453	3			482,206
New York	307,110	306,000	2	1		3,875,479	3,807,413	10	18		283,405	279,305		2	8	2,824,415
North Carolina	112,535	112,535	1	1	7	1,007,343	1,007,103	13	3	6	94,050	94,050		2	18	852,601
North Dakota	432,190	432,190	5		11	103,750	103,750	2		6	132,270	108,473	1		6	741,485
Ohio	369,098	347,336	4		2	2,462,415	2,413,225	10	3	13	654,157	628,380	3		2	2,397,021
Oklahoma	245,798	244,771	2	1	22	594,442	593,095	10		2	200,773	197,357	1		41	1,890,452
Oregon						462,847	315,518	4			5,790	5,790			2	357,935
Pennsylvania	528,871	528,871	4	1		1,563,370	1,553,894	14	1		1,446,614	1,446,409	9	2		3,359,718
Rhode Island	3,831	3,750				191,039	191,039		1							95,913
South Carolina	120,394	120,394	2	2	6	365,705	365,705	3	1	8	175,150	174,748			33	927,058
South Dakota	72,600	72,600	1	1	2	281,762	280,902	7		2	462,535	446,585	10			740,832
Tennessee	204,265	204,265	1	2		48,523	48,523	1			159,203	159,203		2		1,715,788
Texas	959,152	957,100	8		3	1,367,684	1,354,563	12	1	6	70,450	70,450	1		2	2,006,230
Utah	9,569	9,358			2	40,813	40,813			11	76,367	76,260	2		27	276,632
Vermont	2,969	2,969			1	209,428	209,428		2	1	34,546	34,546			7	223,562
Virginia	81,101	80,765	1	2	3	216,368	215,038	3			608,649	608,649	3	2	8	601,096
Washington	199,253	199,253	2	1	4	166,673	165,173	2	1	1	135,862	135,862	1	1	5	449,464
West Virginia						229,982	229,982	2			8,220	8,220			3	1,141,717
Wisconsin	743,581	728,501	6	2	7	541,103	512,062	3	2	3	17,167	17,167			5	1,358,033
Wyoming						540,923	540,923	5								193,577
District of Columbia						59,061	59,061	1								150,010
Hawaii						194,036	194,028	2			9,494	9,494			2	292,509
Puerto Rico						584,007	579,336	11								414,857
TOTALS	9,570,435	9,439,913	85	23	222	33,437,487	32,165,519	246	58	223	9,366,242	8,935,593	79	23	458	47,933,356