HIGHWAY RESEARCH BOARD

Bulletin No. 40

Load Carrying Capacity of Roads as Affected by Frost Action

1951

HIGHWAY RESEARCH BOARD

1951

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PRESENTED AT THE THIRTIETH ANNUAL MEETING
1951

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DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
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Washington 25, D. C.

October 1951

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CONTENTS

PROJECT NO. 7 COMMITTEE REPORT

C. L. Motl, *Chairman, Maintenance Engineer, Minnesota Department of Highways*

SYNOPSIS

This report, covering the work performed by various states on this research project, is essentially a continuation report. It should, therefore, be considered as supplementing previous reports submitted in 1948 and 1949.

The objective of the project continues to be a search for the percentage loss of strength suffered by highways subjected to freezing and thawing action.

Data gathered so far continues to indicate that there is a loss of strength, even though the extent or percent of loss varies considerably between different test points. The strength of all types of soils so far tested appears to be affected adversely by freezing and thawing action.

The following states have taken part in conducting tests during the year 1950: Iowa, Michigan, Minnesota, New York, North Dakota, and Ohio.

In this report material submitted by the contributing States is included in its entirety; and because of the interesting comments and the detailed information furnished, these reports merit careful reading and attention on the part of those interested in this subject. A few brief comments on the report submitted by each state might be helpful in directing your interest to the various reports.

In the report submitted by *Iowa*, it will be noted that testing was confined to a limited number of points, but the scope of tests includes not only plate bearings but also instrument testing with the North Dakota cone bearing machine and the Iowa subgrade resistance machine. Because this committee has included in its program a search for possible correlation of plate-bearing values with various instrument-testing values, the Iowa report is of special interest. The Iowa plate-bearing tests show loss in strength of load-carrying capacity, but a correlation between plate-bearing tests and instrument tests has so far been inconclusive.

The *Michigan* report discloses that tests conducted by this state include three types of instruments but no plate-bearing tests. The instruments used were the ring shear, the North Dakota cone, and the Housel penetrometer. A comparison of bearing results secured in the spring and fall of the year discloses a grand-average loss of strength for each type of instrument used, but the results secured at individual test points are quite erratic, indicating that this type of instrument testing, when applied to soils as they are found in the field, is likely to be seriously affected or influenced by some minor special condition encountered in the soil at the test point. It would appear that except where rather fine-grained soils of uniform texture are encountered, this type of testing is too delicate to be reliable. The supporting data furnished in the Michigan report, together with the indicated conclusions reached, is a substantial contribution to the objectives of the research project. This report should also be of special interest to soils engineers.

The *Minnesota* report covers the results secured during the fourth consecutive year of testing. During previous years, testing in Minnesota was confined to 8 locations, while during the past year tests were made at 38 locations and 126 test points scattered thruout the state. The results are similar to those secured in previous years - showing a substantial average loss of strength. Detailed information for each test point is given in tabulated form. During the past year no effort was made in Minnesota to carry on cone-bearing tests or to try to correlate them with field-bearing tests.

The *New York* report supplements information furnished by this state for previous reports. The work done in this state consists of both plate-bearing and North Dakota cone-bearing testing. The plate-bearing tests appear to indicate that some types of soils (lacustrine) suffer much greater loss in carrying capacity than do other types of soil known as alluvial or outwash, but all types of soil tested do show a loss in carrying capacity due to frost action. The cone-bearing tests quite generally disclose a loss in bearing value during the spring of the year, and the relationship between cone-bearing and plate-bearing tests is shown on the tabulations included in the report. Other interesting information relating to moisture, density, and subgrade characteristics is included in the tabulation.

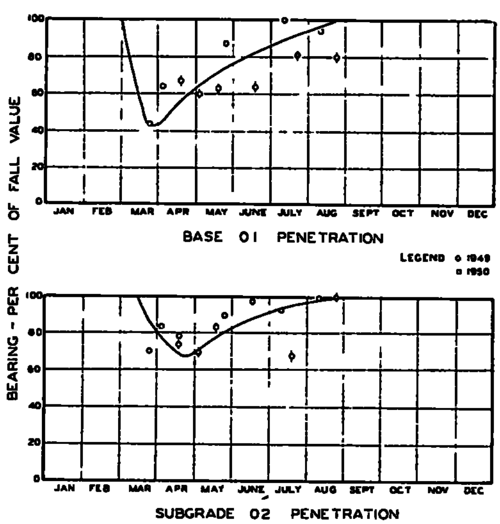
North Dakota reports that it continued with its cone-bearing tests at the 10 locations where tests had been made in previous years. The report includes a considerable number of graphs illustrating the results secured during the past year. Tests in North Dakota continued to disclose loss in carrying capacity of subgrades during the spring of the year at depths of 3, 9, 15, and 24 in. below the roadway structure. An examination of the data and graphs discloses a considerable fluctuation in percentage-loss values, but the overall average unquestionably discloses a general loss of strength. No effort has been made in North Dakota to conduct plate-bearing tests.

Ohio has made its first contribution to the work of the committee and has conducted field tests at a limited number of locations. Results of these tests show no loss in carrying capacity of the highway during the spring of the year as compared to the previous fall, but the report also points out that the particular highway tested had very little frost penetration during the previous winter because of mild weather. Of interest in this report, however, is the data secured on the bearing value of the road structure at each of the four levels tested: on the surface, on the base, on the sub-base, and on the sub-grade. Since it is reported that the sub-structure elements of the road were not frozen during the previous winter, no conclusions can be made as to whether this particular road might or might not have been affected by frost action.

In concluding the preliminary comments on test results reported by the various states, we wish to point out that it is not the objective of the committee to determine soil-bearing values which might be used for road design purposes, since all of the factors that may affect the true carrying capacity of soils have not been evaluated, e.g., load repetition and moisture content. The bearing values recorded by either the plate method or the instrument methods were used to provide information on the relationship between spring carrying capacities and fall carrying capacities of roads. The data should, therefore, not be presumed to establish basic values for soil carrying capacities.

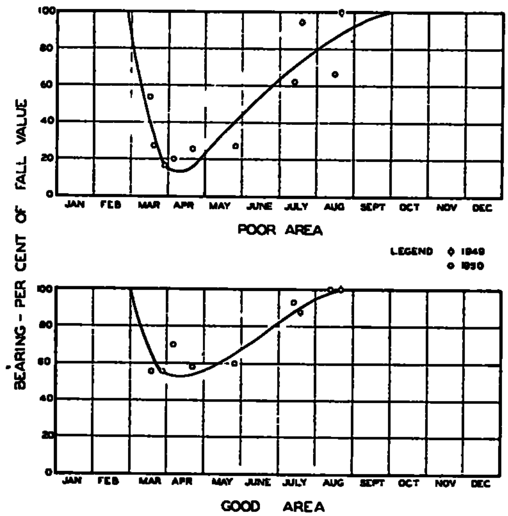
IOWA

Test Sites - Road Number Iowa 144, in Greene County, was chosen as the location for the field work, on this project. One section of this road extends southward from Grand Junction to Rippey and consists of a 6-in. gravel-clay stabilized base with an inverted penetration wearing surface. The other section of this road extends northward from Grand Junction to Dana, and consists of a 5-in. asphalt-emulsion-treated base of gravel aggregate, surfaced with an inverted-penetration wearing course. One test site on each of these roads was chosen for detailed plate-bearing tests at locations where the roadway showed evidence of good year-round servicability. At each of these locations, test sites in the opposite



ROAD NO IOWA 144 SOUTH OF GRAND JUNCTION
PLATE BEARING TEST
12 DIAM PLATE

Figure 1. Soil - Aggregate Base



ROAD NO IOWA 144 SOUTH OF GRAND JUNCTION
QUICKIE BEARING TEST
0.1" PENETRATION 12" DIAM PLATE

Figure 2. Soil - Aggregate Base

traffic lane were later selected for the performance of quickie plate-bearing tests and these tests are noted as being in "good areas." One additional site on each of the two types of roadway was selected for the quickie tests in areas where incipient failure was in evidence, and these tests are noted as being in "poor areas".

Topographically speaking, the detailed tests were performed at the approximate center of level stretches of road at least 1/4-mi. long, where the centerline of the roadway was raised 4 to 5 ft. above the original ground line. This condition applies, of course, to the quickie tests performed in the good areas. The quickie tests in the poor areas were performed near the top of gentle grades, the test site being located near the end of the cut section through the low hills.

Since this entire area is located within the Mankato lobe of the Wisconsin glacial period, uniformity of material between the two sections of roadway and, as a matter of fact,

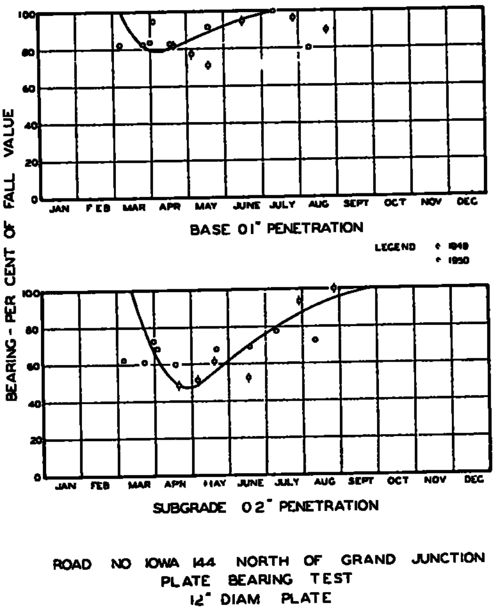


Figure 3. Emulsion Treated Base

within a given section on either road, is poor. Generally speaking, the fill materials might be called a clay loam (P.R.A. classification A-2 to A-4-2) which varies locally to sandy loam or to gravelly clay loam.

Tests Performed - Approximately 50 detailed bearing tests have been completed on the two test sites. Each of these tests includes plate-bearing tests on the mat, on top of the base, and on the surface of the subgrade, together with North Dakota cone-bearing tests and tests with the Iowa Highway Commission subgrade resistance machine. Soil samples for laboratory tests and undisturbed soil specimens for density and moisture determinations are also obtained at various depths. Approximately 50 quickie-bearing tests have been performed at the above described sites, including some parallel-instrument tests.

Results of Tests - Results of the detailed plate-bearing tests on the soil-aggregate base south of Grand Junction have been summarized graphically in Figure 1. The quickie tests on this road are shown in Figure 2. Results of the detailed plate-bearing tests on the asphalt-emulsion base north of Grand Junction are shown in Figure 3, and the quickie tests on this road are shown in Figure 4. It will be noted that the curves for the tests on top of the base, including those for the quickie tests, have been based on a deflection of 0.1 in. due to the lack of capacity of our equipment to produce a deflection of 0.2 in. in every test attempted.

A thermocouple system for measurement of sub-surface soil temperatures was installed near the detailed bearing-test site south of Grand Junction, but an undetermined electrical or instrument defect rendered the results confusing. This installation has been dug up and checked and will be re-installed for use this next winter and spring.

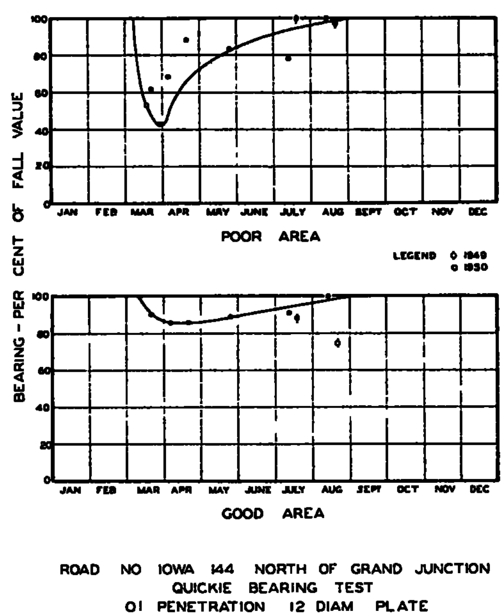


Figure 4. Emulsion Treated Base

CONCLUSIONS

No exhaustive analysis of the data accumulated has thus far been attempted. Preliminary studies indicate that the correlation between the various instrument tests and the plate-bearing tests leaves much to be desired, although the present information is not thought sufficient to draw even tentative conclusions in this regard. It is hoped that the completion of another annual cycle of tests will help to clarify the situation.

The road north of Grand Junction, taken as a whole, is in very excellent condition. This is attributed, in part, to the tendency of the emulsion-treated base to retain a major portion of its strength through the thawing period, due to the stiffening of the asphalt during cool weather. The rather definite sag of the plate-bearing curves during the hot, summer months is thought to be the result of a weakening of the base caused by softening of the asphalt with increased temperature.

MICHIGAN

During the spring break-up period of 1950, the Michigan State Highway Department conducted the third in a series of field tests undertaken to study the effect of frost action on the load carrying capacity of roads. The first investigation by the Department was made in the spring of 1949. The second of the series followed in the late summer and early fall of that same year.

This report records the results of the third set of tests taken between April 6 and 28, 1950. Identical test procedures were followed throughout in each series. For comparative purposes the road projects and test sites were the same as those investigated in the first and second series of tests. A general map, together with vicinity and detailed sketch maps, showing the locations of the test areas and precise locations of the test points are shown in the figures. The test holes in this report are numbered the same as corresponding test holes in the first and second reports, except that the figure 3, followed by a dash, precedes the original test hole number. This identifies the test and data as belonging to the third series of tests taken immediately adjacent to the points of the first and second series of tests.

General view pictures taken at the test sites on each project, supplement the detailed sketch maps. They show the local topography and general character of the roads under investigation.

In order to insure working in undisturbed materials, the exact points of the 1950 spring tests were located 18 in. to the right of the second series of test holes. The

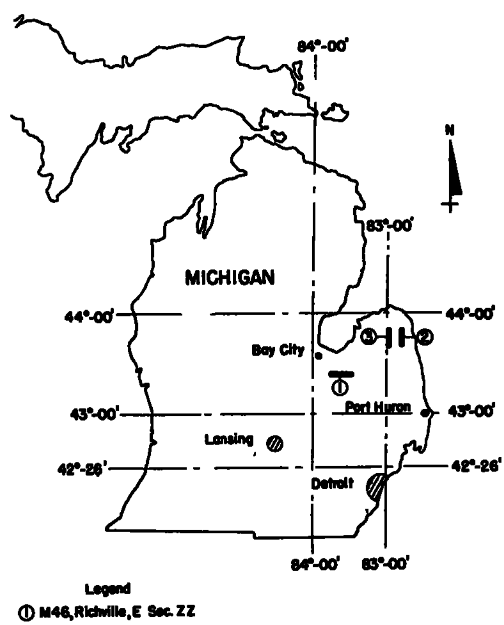


Figure 1. Map Showing Location of Michigan Field-Research Locations for Carrying Capacity of Frost Affected Roads

test pit openings were all 16 in. wide and 30 in. long (the length being parallel to the centerline of the road) and the maximum depths varied from 24 in. to 29 in. These depths represent the lower floor of the pits, from which level one set of the various tests was conducted. The testing and sampling operations extended these pit depths 6 to 10 in. A complete set of tests was also run at a level 12 in. above these maximum depths as the pits were being developed. This upper level was normally the first clean exposure or contact with the natural subgrade soil after the road metal (and often

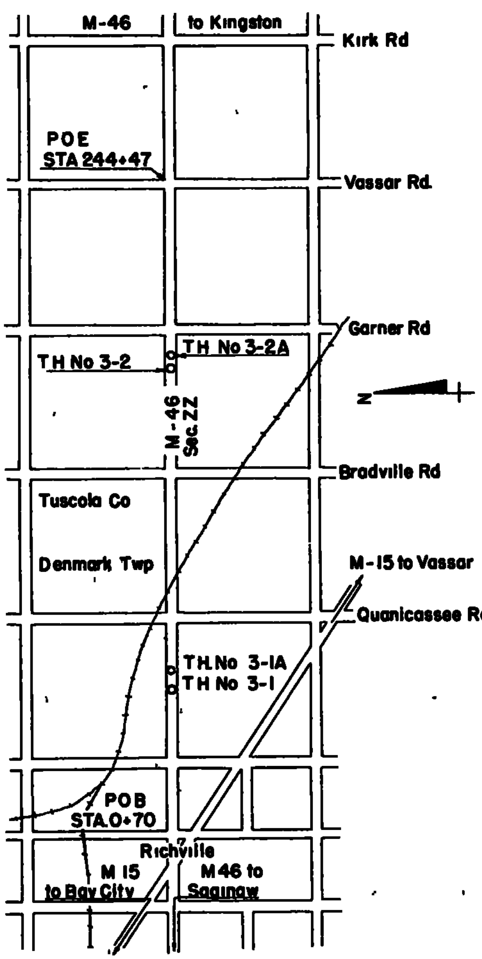


Figure 2. Map of Richville, Michigan, and Vicinity

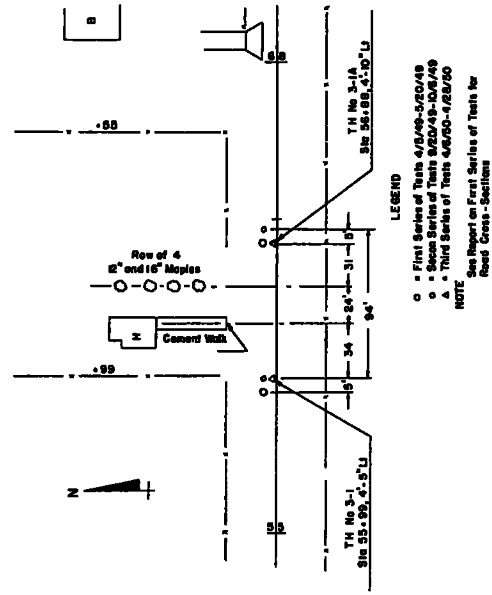


Figure 3. Map of Test Sites on M-46 Richville, E. for Third Series

a granular sub-base of imported material) had been removed.

In general, the tests were conducted at the pit elevations established in the earlier series.

A detailed drawing of the log and soil profile of each test hole is included in this report. The soil structure and textures should be similar to those found in the corresponding test holes of the first and second series of tests, being approximately 5 ft. from the former and 18 in. from the latter; however, disparities exist in some instances.

The methods of test adopted and used throughout the series to measure the relative bearing capacities of the subgrade soils are generally referred to as the indirect methods, or common denominator type of tests. These were namely, the Housel penetrometer test, the ring-shear test and the North Dakota cone test. Independent soil density tests were also taken by the steel-cylinder core method.

Tests by these methods were taken in duplicate at each of the two levels investigated in all test pits. The results obtained from these individual tests were tabulated and are shown in Tables I, II, and III.

Duplicate soil specimens were taken at most of the points tested. This operation was coincident with the Housel penetrometer test. From these specimens, the soil texture, field density, moisture, shear value, and, in some instances, the unconfined compression strength of the subgrade soils was determined. These data are recorded on Tables IV, V, VI, and VII.

A final tabulation sheet (Table VIII) shows a comparison between the bearing values obtained in the late summer and early fall of 1949 and those measured during the spring break-up period of 1950 by each of the three indirect methods of test. The amount of loss, or gain, in spring bearing-capacity is expressed as a percent of the corresponding fall value. The final figure at the bottom of Table VIII is the difference between the 1949 fall and 1950 spring bearing values averaged for the three projects and expressed as a percent of the average fall value as determined by each of the three individual methods of test.

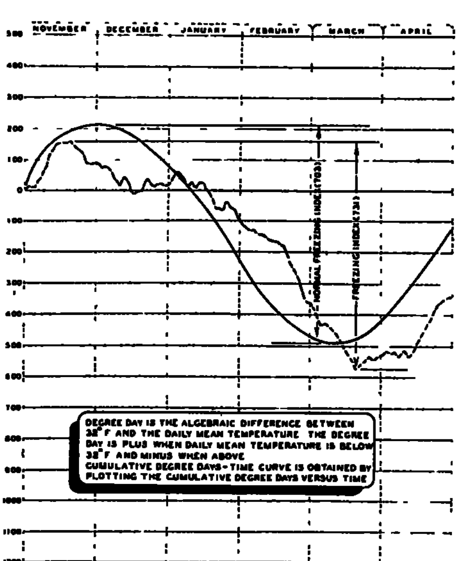


Figure 4. Determination of Freezing Index, Saginaw, 1949-50

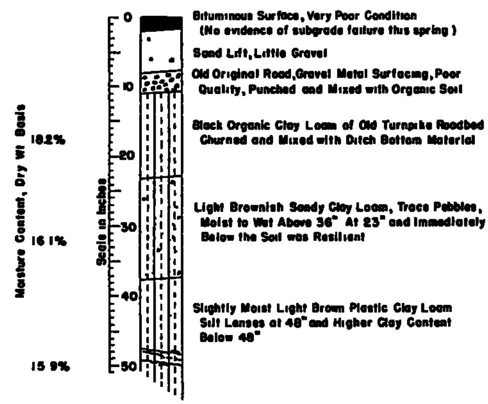


Figure 5. Bituminous Surface Failure Area Soil Profile

According to soundings taken by the local road-maintenance crews, the frost penetration into the road subgrades during the winter of 1949-50 extended to depths of 15 to 20 in. The maximum depths were reached late in February and early in March. The winter weather up to February was considered mild for this climate. The weather following this period for a month or better was generally cold and wet with intermittent sharp, low freezing temperatures.

On two projects the frost extended into the road subgrades 25 to 33 in., as recorded between March 15 and 18, 1950. As late as March 22, 1950, the frost in the vicinity of Ubly and Ruth extended to depths of 15 to 20 in. in the fence lines; however, it was softening and in a "honey-comb" condition.

Between March 15 and 23, 1950, the period of maximum frost heaving, percise levels were taken at the Ruth and Ubly test sites on road-center lines. These levels were later plotted against the summer profiles, illustrating the extent of subgrade expansion due to frost. There was no pronounced differential frost heaving on any of the projects.

TABLE I

THIRD SERIES OF TESTS

SUBGRADE BEARING VALUES IN POUNDS PER SQ. INCH
DERIVED FROM HOUSEL PENETROMETER TESTS

Project	Test Hole No.	Depth Tested Inches	Maximum Bearing		Minimum Bearing		Average Bearing Each Level psi.	Average Bearing Subgrade psi.
			N'	psi.	N'	psi.		
Richville E. Sec. ZZ	3-1 3-1	14-24 27-37	16.5 5	76 23	16 5	74 23	75) 23)	49
	3-1A 3-1A	17-27 29-39	14.5 9.5	67 44	11.5 8	53 37	60) 41)	51
	3-2 3-2	14-21 26-33	13.5 9.5	62 44	11 8	51 37	57) 41)	49
	3-2A 3-2A	15-23 27-35	8.5 11	39 51	6.75 7	31 32	35) 42)	39
Ruth N. & S.	3-1 3-1	13-23 25-35	14 5.5	76 30	13 4.75	70 26	73) 28)	51
	3-1A 3-1A	14-24 25-35	11.5 7	62 38	10 6.25	54 34	58) 36)	47
	3-2 3-2	13-23 25-35	14 6.25	76 34	13 5.75	70 31	73) 32.5)	53
	3-2A 3-2A	14-24 26-36	8.25 8.75	45 47	7.25 7	39 38	42) 42.5)	42
Ubly N. & S.	3-1 3-1	13-23 25-35	13.5 6.5	62 30	13.5 6	62 28	62) 29)	46
	3-1A 3-1A	16-25 27-37	12 7.5	55 35	9 7.5	41 35	48) 35)	42
	3-3 3-3	12-22 24-34	19 7.5	87 35	N.T. 7	- - 32	87) 33.5)	60
	3-3A 3-3A	15-25 25-35	11.25 8.75	52 40	10 7	46 32	49) 36)	43

Formulae used to convert driving resistance of Penetrometer to Bearing in psi.

P_o = Bearing in lb. per sq. in.

$P_o = 6S$ (empirical)

$S = 0.9N$

$P_o = 6 \times 0.9 \times N$

$N = \frac{40N'}{47}$ (Applies to Richville E. Sec. ZZ and Ubly N. and S. projects)

$N = \frac{40}{40.25}N'$ (Applies to Ruth N. and S. project)

N' = Number of blows req'd for 6-in. Penetration.

Weight of drop hammer = 20 lb.

Weight of penetrometer plus drop hammer = 47 lb. (Used on Richville E. and Ubly jobs only.)

(Weight = 40.25 lb. as used on Ruth job.)

Drop hammer fall distance = 34 inches

TABLE II THIRD SERIES OF TESTS

SUBGRADE BEARING VALUES IN POUNDS PER SQ. INCH
DERIVED FROM RING SHEAR TEST ($P_o = 4S$)

Project	Test Hole Number	Depth Tested in Inches	Maximum Bearing	Minimum Bearing	Average Bearing Each Level	Average Bearing For Subgrade
RICHVILLE E. SEC. 22	3-1	14-24	18.80	17.20	18.00)	12.30
	3-1	27-37	7.20	6.00	6.60)	
	3-1A	17-27	23.20	18.20	20.70)	16.15
	3-1A	29-39	12.00	11.20	11.60)	
	3-2	14-21	28.00	19.60	23.80)	16.90
	3-2	26-33	12.00	8.00	10.00)	
	3-2A	15-23	10.00	8.40	9.20)	9.50
	3-2A	27-35	11.60	8.00	9.80)	
RUTH N. & S.	3-1	13-23	22.80	10.00	16.40)	11.35
	3-1	25-35	6.60	6.00	6.30)	
	3-1A	14-24	22.40	18.40	20.40)	15.90
	3-1A	25-35	11.60	11.20	11.40)	
	3-2	13-23	10.00	10.00	10.00)	9.20
	3-2	25-35	10.00	6.80	8.40)	
	3-2A	14-24	16.00	10.40	13.20)	15.80
	3-2A	26-36	20.80	16.00	18.40)	
UHLY N. & S.	3-1	13-23	16.80	15.00	15.90)	13.85
	3-1	25-35	13.60	10.00	11.80)	
	3-1A	16-25	13.60	9.60	11.60)	10.90
	3-1A	27-37	10.40	10.00	10.20)	
	3-3	12-22	17.60	- -	17.60)	15.20
	3-3	24-34	16.00	9.60	12.80)	
	3-3A	15-25	17.20	12.00	14.60)	15.30
	3-3A	25-35	17.20	14.80	16.00)	

TABLE III **THIRD SERIES OF TESTS**

SUBGRADE BEARING VALUES
IN POUNDS PER SQUARE INCH DERIVED FROM NORTH DAKOTA CONE TESTS

Project	Test Hole Number	TEST PIT Depth in Inches to Test Point	Bearing Values; Std. N.D.Cone Method	Bearing N.D.Cone Spring Type Loading	Average Bearing at Each Level	Average Bearing for Subgrade
RICHVILLE, E. SEC. ZZ	3-1	14	753	848	801	463
	3-1	27	156	91	124	
	3-1A	17	435	341	388	273
	3-1A	29	167	148	158	
	3-2	14	437	381	409	275
	3-2	26	154	127	141	
	3-2A	15	210	236	223	184
	3-2A	27	134	154	144	
RUTH N. & S.	3-1	13	323	142	233	177
	3-1	25	113	127	120	
	3-1A	14	314	367	341	285
	3-1A	25	271	185	228	
	3-2	13	283	285	284	368
	3-2	25	700	204	452	
	3-2A	14	272	360	316	248
	3-2A	26	103	257	180	
UBLY N. & S.	3-1	13	421	456	439	314
	3-1	25	146	230	188	
	3-1A	16	254	344	299	221
	3-1A	27	125	159	142	
	3-3	12	989	681	835	498
	3-3	24	208	113	161	
	3-3A	14½	344	383	364	353
	3-3A	25	249	435	342	

TABLE IV

THIRD SERIES OF TESTS

TABULATION OF LABORATORY DATA OBTAINED FROM CORE LINER
SAMPLES TAKEN FROM SUBGRADE COINCIDENT WITH HOUSEL PENETROMETER TESTS

Project	Test Hole Number	Sample Number	Visual Classification of Soil	Depth Sampled Inches	Ring Shear Value psi.	Unconfined Compression $\frac{UC}{2}$ = psi.	Shear Correlation Unconfined Comp. Test $\frac{SUC}{4}$ = psi.	Field Density Dry Weight lb. per cu. ft.	Moisture Percent by Dry Weight	Soil Series Field Classification (Pedological)
M-46, RICHVILLE, F. SEC. 22	3-1	3-1-1	Organ. Top Soil Cl. Lo. Mix.	14-24	4.30	6.67	1.67	103.6	20.7	WISNER LOAM
	3-1	3-1-2		14-24	4.70	28.33	7.08	108.0	16.9	
	3-1	3-1-3	Sandy Cl. Loam	27-37	1.50	N.T.	- -	122.3	13.5	
	3-1	3-1-4		27-37	1.80	N.T.	- -	106.7	18.6	
	3-1A	3-1A-1	Top Soil & Clay Loam	17-27	4.55	15.00	3.75	106.7	18.6	WISNER CLAY LOAM
	3-1A	2-1A-2		17-27	5.80	18.33	4.58	114.8	14.2	
	3-1A	3-1A-3	Clay Loam	29-39	2.80	9.97	2.49	97.3	23.3	
	3-1A	3-1A-4		29-39	3.00	N.T.	- -	111.1	17.2	
	3-2	3-2-1	Organic Sa. & Lo.	14-21	4.90	N.T.	- -	104.2	15.4	WISNER
	3-2	3-2-2		14-21	7.00	N.T.	- -	83.0	21.6	
	3-2	3-2-3	Clay Loam	26-33	3.00	N.T.	- -	106.7	17.9	
	3-2	3-2-4		26-33	2.00	5.00	1.33	107.1	17.3	
	3-2A	3-2A-1	Organic Sa. Lo.	15-23	2.10	10.00	2.50	107.9	N.T.	WISNER
	3-2A	3-2A-2		15-23	2.50	N.T.	- -	96.1	23.6	
	3-2A	3-2A-3	Loam	27-35	2.00	8.33	2.08	102.3	17.8	
	3-2A	3-2A-4		27-35	2.90	8.33	2.08	108.0	16.4	

TABLE V

THIRD SERIES OF TESTS

TABULATION OF LABORATORY DATA OBTAINED FROM CORE LINER
SAMPLES TAKEN FROM SUBGRADE COINCIDENT WITH HOUSEL PENETROMETER TESTS

Project	Test Hole Number	Sample Number	Visual Classification of Soil	Depth Sampled Inches	Ring Shear Value psi.	Unconfined Compression $\frac{UC}{2}$ = psi.	Shear Correlation Unconfined Comp. Test $\frac{SUC}{4}$ = psi.	Field Density Dry Weight lb. per cu. ft.	Moisture Percent by Dry Weight	Soil Series Field Classification (Pedological)
M-51, RUTH, N. & S.	3-1	3-1-1	Peat, Orga. Lo. & Loam	13-23	5.70	N.T.	- -	119.8	13.0	CONOVER LOAM
	3-1	3-1-2		13-23	2.50	N.T.	- -	116.7	13.1	
	3-1	3-1-3	Loam	25-35	1.65	4.33	1.08	111.7	16.5	
	3-1	3-1-4		25-35	1.50	9.67	2.42	111.7	16.9	
	3-1A	3-1A-1	Sa. Lo. & Loam	14-24	5.60	11.63	2.91	107.7	17.8	CONOVER LOAM
	3-1A	3-1A-2		14-24	4.60	13.33	3.33	104.8	19.7	
	3-1A	3-1A-3	Loam, Sand Lenses	25-35	2.90	N.T.	- -	117.9	14.3	
	3-1A	3-1A-4		25-35	2.80	18.33	4.58	122.3	12.8	
	3-2	3-2-1	Organic Lo. Sand	13-23	2.50	N.T.	- -	116.3	11.2	CONOVER SANDY LOAM
	3-2	3-2-2		13-23	2.50	N.T.	- -	119.2	11.8	
	3-2	3-2-3	Loamy Sa.-Grav.	25-35	2.50	N.T.	- -	112.3	17.0	
	3-2	3-2-4		25-35	1.70	N.T.	- -	113.6	14.3	
	3-2A	3-2A-1	Pebbly Lo. Sa. & Lo.	14-24	2.60	13.33	3.33	112.3	16.5	CONOVER SANDY LOAM
	3-2A	3-2A-2		14-24	4.00	30.00	7.50	121.1	13.1	
	3-2A	3-2A-3	Loam Pebbly	26-36	4.00	33.33	8.33	124.2	12.4	
	3-2A	3-2A-4		26-36	5.20	N.T.	- -	123.6	11.3	

TABLE VI

THIRD SERIES OF TESTS

TABULATION OF LABORATORY DATA OBTAINED FROM CORE LINER SAMPLES TAKEN FROM SUBGRADE COINCIDENT WITH HOUSEL PENETROMETER TESTS

Project	Test Hole Number	Sample Number	Visual Classification of Soil	Depth Sampled Inches	Ring Shear Value psi.	Unconfined Compression UC/2 - psi.	Shear Correlation Unconfined Comp. Test S|C / F - psi.	Field Density Dry Weight lb. per cu. ft.	Moisture Percent by Dry Weight	Soil Series Field Classification (Pedological)
M-19, UBLY, N. & S.	3-1	3-1-1	Lo. to	13-23	4.20	33.00	8.33	127.6	11.1	
	3-1	3-1-2	Cl. Lo.	13-23	3.75	N.T.	- -	124.2	11.9	
	3-1	3-1-3	Lo. to Cl. Lo.	25-35	3.40	15.00	3.75	122.3	13.2	MIAMI
	3-1	3-1-4	Tr. Sa. & Silt Seams	25-35	2.50	13.33	3.33	127.3	11.0	
	3-1A	3-1A-1	Lo. to Cl. Lo.	16-25	3.40	16.67	4.17	110.4	17.4	
	3-1A	3-1A-2	Tr. Pebbles	16-25	2.40	N.T.	- -	109.8	17.4	
	3-1A	3-1A-3	Lo. to Cl. Lo.	27-37	2.60	N.T.	- -	117.9	14.0	MIAMI
	3-1A	3-1A-4	Tr. Pebbles	27-37	2.50	11.67	2.92	119.2	14.7	
	3-3	3-3-1	Organic Sa. Lo. to Lo. Sa.	12-22	4.40	N.T.	- -	112.9	15.9	
	3-3	3-3-3	Lo. Tr.	24-34	2.40	13.30	3.33	105.5	19.4	MIAMI
	3-3	3-3-4	Pebbles	24-34	4.00	N.T.	- -	113.0	16.6	
	3-3A	3-3A-1	Sa. Lo. to Lo.	15-25	4.30	21.83	5.46	111.7	16.9	
	3-3A	3-3A-2	Tr. Pebbles	15-25	3.00	N.T.	- -	121.1	12.8	
	3-3A	3-3A-3	Loam	25-35	4.30	22.00	5.50	121.1	13.0	MIAMI
	3-3A	3-3A-4	Tr. Pebbles	25-35	3.70	26.33	6.58	122.9	13.0	

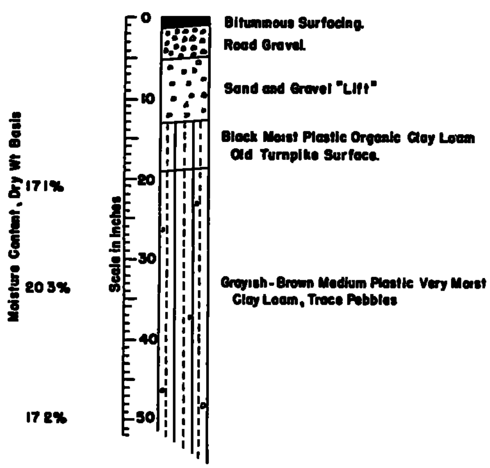


Figure 6. Non-Failure Area Soil Profile

An exaggerated scale was used to plot the frost heaving, indicated by the dotted lines on the drawing.

Another observation made during the spring testing operations of 1950 was the resilient character of the subgrades in general and especially on the Richville E. M-46 project. This condition was more obvious in the soils at the upper test level (directly beneath the road metal).

All of the spring tests recorded in this report were conducted under adverse weather conditions. While pre-test soil auger-borings showed that the subgrades had thawed out completely before any tests were run, experiences in early-spring testing in northern climates suggest that a minimum soil and air-temperature standard be considered as a prerequisite before any "sensitive" tests, such as the present standard North Dakota cone tests are conducted. Pointing up the possible mitigating influence of low, but above freezing, temperatures on soil reactions, an instance was noted in connection with the digging of Test Pit No. 3-3 on the Ubly N. and S. job. The air temperature was 45 F.; a light, wet snow had fallen in the early forenoon and the temperature the night before had gone down to near freezing. The test pit was opened to a 12-in. depth and a set of tests were run; later the hole

TABLE VII

THIRD SERIES OF TESTS

RECORD OF SELECTED MOISTURE
AND STEEL CYLINDER DENSITY TESTS

Project	Density Sample Number	Moisture Sample Number	Depth Range in Inches	Percent Moisture	Dry Density lbs. per cu. ft.
RICHVILLE	3-1-1D		14-18		109.8
	3-1-2D		27-31		108.6
		3-1-M1	48-51	15.9	
	3-1A-1D		17-21		111.1
	3-1A-2D		29-33		97.3
		3-1A-M1	48-52	17.2	
	3-2-1D		14-18		106.1
	3-2-2D		26-30		104.8
		3-2-M1	48-51	17.5	
	3-2A-1D		15-19		107.9
	3-2A-2D		27-31		106.1
RUTH	3-1-1D		13-17		96.7
	3-1-2D		25-29		111.1
	3-1A-1D		14-19		114.2
	3-1A-2D		25-29		115.4
		3-1A-M1	46-54	16.4	
		3-1A-M2	70-76	12.6	
	3-2-1D		13-17		111.7
	3-2-2D		25-29		104.8
		3-2-M1	60-66	13.6	
	3-2A-1D		14-19		116.1
	3-2A-2D		26-30		122.3
		3-2A-M1	36-40	12.9	
		3-2A-M2	46-50	13.9	
		3-2A-M3	70-74	13.5	
UHLY	3-1-1D		13-17		128.5
	3-1-2D		25-29		122.3
	3-1A-1D		16-20		109.2
	3-1A-2D		27-31		116.7
		3-1A-M1	54-58	7.3	
	3-3-1D		12-16		119.4
	3-3-2D		24-28		108.0
		3-3-M1	12-16	13.5	
		3-3-M2	24-28	19.8	
		3-3-M3	68-73	14.4	
	3-3A-1D		14-1/2 - 18-1/2		110.4
	3-3A-2D		25-29		111.1
		3-3A-M1	36-48	16.5	
		3-3A-M2	48-60	14.6	

TABLE VIII

COMPARISON OF SEASONAL SUBGRADE BEARING VALUES, FALL OF 1949 AND SPRING OF 1950

Project	Test Hole (Area) No.	Depth Range Tested Inches	Percent Moisture Dry Weight		Dry Density lb.per.cu.ft.		Bearing Values Derived from Ring Shear Tests psi.			Bearing Values Derived from North Dakota Cone Tests psi.			Bearing Values Derived from Housel Penetrometer Tests psi.		
			Fall 1949	Spring 1950	Fall	Spring	Fall	Spring	Percent Change Spring	Fall	Spring	Percent Change Spring	Fall	Spring	Percent Change Spring
M-46, RICHVILLE E SEC 22	1	14-24	18.3	18.2	106.7	107.3	12.00	18.00	+50.0	594	801	+34.9	62	75	+21.0
	1	27-37	16.7	16.1	109.9	112.5	6.60	6.60	+ 0.0	152	124	-18.4	23	23	0.0
	1A	17-27	26.9	17.1	90.2	109.8	13.80	20.70	+50.0	631	388	-38.5	60	60	0.0
	1A	29-39	21.0	20.3	105.5	101.9	15.60	11.60	-25.6	278	158	-43.2	53	41	-22.7
	2	14-21	19.6	19.0	105.5	105.2	17.40	23.80	+36.8	965	409	-57.6	66	57	-13.6
	2	26-33	17.2	17.8	107.3	106.4	16.80	10.00	-40.5	169	141	-16.6	47	41	-12.8
	2A	15-23	23.2	19.6	93.0	101.1	9.30	9.20	- 1.1	572	223	-61.0	64	35	-45.3
	2A	27-35	15.1	16.9	112.0	107.3	11.60	9.80	-15.5	207	144	-30.4	43	42	- 2.3
M-51, RUTH N & S	1	13-23	13.6	13.0	117.7	118.8	27.50	16.40	-40.5	175	233	+33.1	64	73	+14.1
	1	25-35	13.7	16.7	113.0	111.6	17.00	6.30	-63.0	186	120	-35.5	32	28	-12.5
	1A	14-24	14.6	18.4	117.7	108.6	27.50	20.40	-25.8	1133	341	-69.8	78	58	-25.7
	1A	25-35	17.5	13.6	104.8	118.5	12.60	11.40	- 9.5	122	228	+86.9	35	36	+ 2.9
	2	13-23	12.1	11.4	114.2	115.9	9.80	10.00	+ 2.0	672	284	-57.7	67	73	+ 9.0
	2	25-35	17.9	15.7	98.6	110.2	10.00	8.40	-16.0	82	452	- -	32	33	+ 3.1
	2A	14-24	12.4	14.8	123.6	116.5	33.50	13.20	-60.6	764	316	-58.7	64	42	-34.4
	2A	26-36	11.5	12.0	121.4	123.6	25.50	18.40	-27.8	344	180	-47.7	55	43	-21.8
M-19, UBLY N & S	1	13-23	10.4	11.3	131.0	127.0	19.00	15.90	-16.3	601	439	-27.0	69	62	-10.1
	1	25-35	11.4	12.1	128.5	124.0	10.40	11.80	+13.5	267	188	-29.6	41	29	-29.3
	1A	16-25	18.1	17.4	107.3	109.8	19.30	11.60	-39.9	290	299	+ 3.1	60	48	-20.0
	1A	27-37	17.4	14.3	107.7	118.2	15.70	10.20	-35.0	212	142	-33.0	39	35	-10.3
	3	12-22	9.3	15.9	121.7	116.2	36.00	17.60	-51.1	1669	835	-50.0	168	87	-48.2
	3	24-34	13.3	19.3	121.7	106.7	16.00	12.80	-20.0	207	161	-22.2	39	34	-12.8
	3A	15-25	20.9	15.5	105.8	113.7	5.60	14.60	- -	340	364	+ 7.1	60	49	-18.4
	3A	25-35	14.5	13.0	117.3	121.7	24.50	16.00	-34.7	221	342	+54.8	53	36	-32.1
THREE PROJECTS COMBINED									-21.4			-32.6			-17.0

LEGEND: (-) = Spring Loss
(+) = Spring Gain

was put down to a 24-in. depth for the next set of tests. The blacktop was 4-in. thick and the road gravel beneath was 6-in. thick resting on natural topsoil--a dark, sandy loam. When first exposed the road gravel appeared dry and crumbly and the natural soil down to 19 in. was logged as quite dry. From 19 to 28 in. it was slightly moist. The temperature of the soil in the upper part of the test pit was 42 F. and the lower part was 41 F., the air temperature remaining 45 F. In a short time, about half an hour, the side walls of the pit took on a glazed appearance and later became dripping wet. Some of this moisture probably was condensation; however, after being exposed for about an hour the road gravel that earlier had appeared dry began to ooze out from beneath the blacktop and flow down the sides of the pit. Laboratory tests later showed the soil between the 12- and 16-in. levels to contain 13.5 percent moisture and from the 24- to 28-in. levels 19.8 percent moisture. It is an assumption, but it appeared that the temperature of the soil at 41 and 42 F. immobilized the moisture which it contained until the warmer air released it. At any rate, the initial condition and structural characteristics of the exposed road gravel and underlying soil to the depth of the opened pit were radically changed.

Regarding the system used in identifying the test holes and data therefrom, it is recalled that the original plan of test procedure specified that sites were to be selected which included both a "failed" and an adjacent "non-failed" area. The non-failure areas are identified throughout this report by the letter A, which follows the test hole numbers.

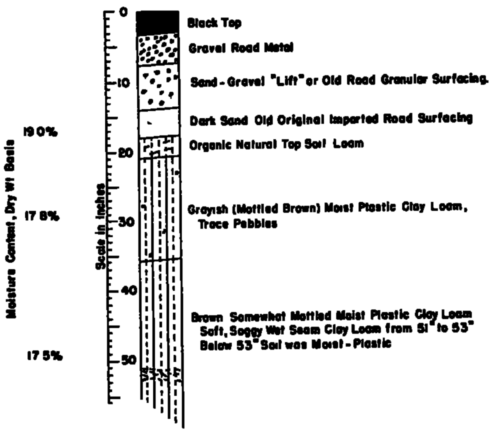


Figure 8. Failed Area Soil Profile, T. H. No 3-2

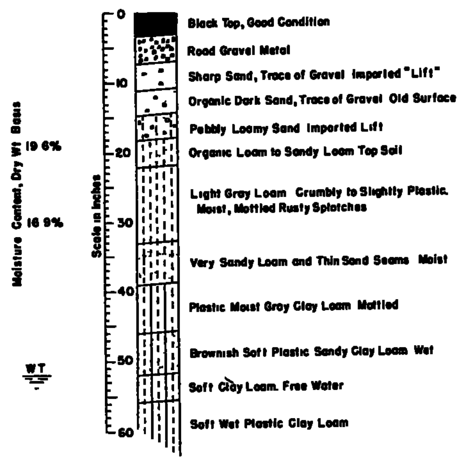


Figure 9. Non-Failure Area Soil Profile

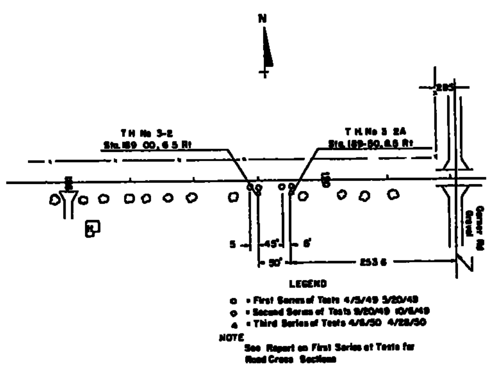


Figure 7. Map of Test Sites on M-46 Richville, E., Sec. 22

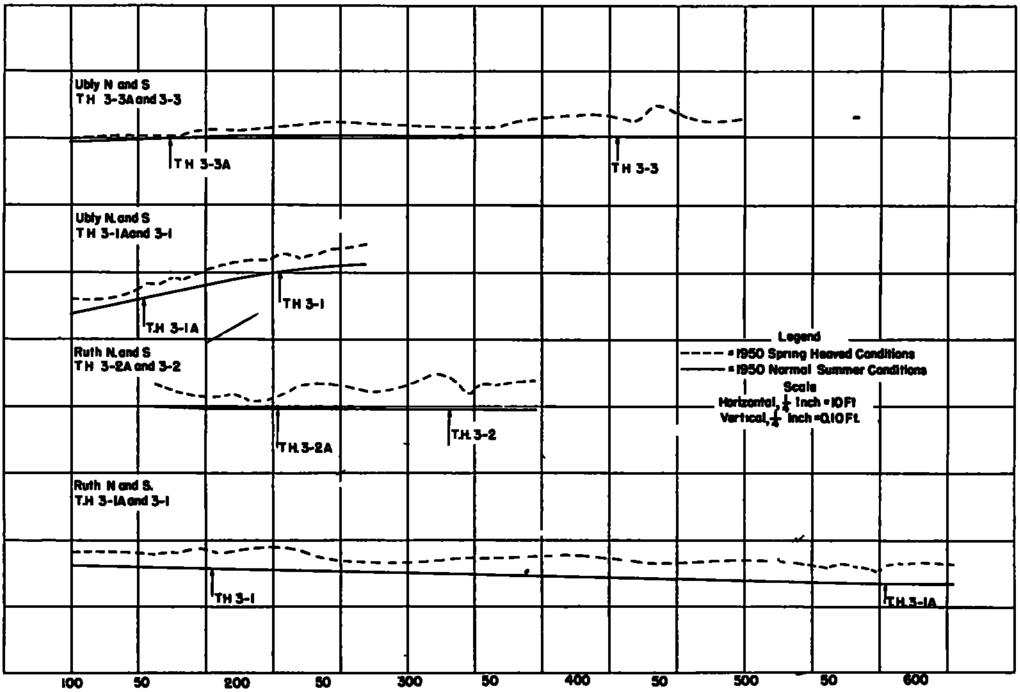


Figure 10. Comparison of Frost Heave Profiles for Third Series Michigan Tests

CONCLUSIONS

Through the medium of the indirect methods of test we can obtain a fairly reliable index of the structural capacity of any one soil texture within a foundation complex. However, when an attempt is made to comprehensively measure the passive resistance of the subgrade as a whole, certain limitations of the adopted test methods must be recognized. Irregularities and inconsistencies in the soil profile (a common occurrence in glaciated areas such as Michigan) are the major deterrents to the overall effectiveness of these methods.

When a subgrade is composed of a single soil texture or even a limited number of closely related textures and is generally free from pebbles, stones, incrustations, and water-bearing seams, an average of the bearing values of the components could be employed to reasonably calculate total carrying capacity.

However, when the subgrade is composed of several textures varying in character, thickness, and water content, it becomes difficult to properly evaluate the resultant effect of the combination when subjected to stress. Frequently, the most critical elements or conditions in a subgrade are non-conformities of a nature most difficult to analyze. Even if they could be resolved physically and mathematically, their subtle influence on the soils immediately above and below and on the subgrade as a whole could not be gauged. This is especially true in the case of relatively thin water-bearing and soft or mushy seams which respond to the pumping action of traffic.

It is the writer's opinion that unless the combined reactions of all the soils and conditions that go into the make-up of a subgrade are measured while the subgrade is stressed in a repetitive manner, the actual carrying capacity of a road, especially one recently affected by frost, remains in doubt.

MINNESOTA

As a final phase of the investigation in Minnesota, it was decided to enlarge the field of testing to cover the state as a whole. The primary objective of the 1949-1950 survey was to explore, by full-scale load testing, the loss in load-carrying capacity of roads in the spring on a statewide basis and compare the results with those secured in previous years on a limited number of projects.

Test sections were selected to include the principal soil types in the state and variable thicknesses of flexible pavements. Figure 1 shows the approximate locations of the sections of road tested. On each test section, points were selected to represent average subgrade soil conditions. The subgrade soils ranged from sand to silty clays. A minimum of three test points were located on each project. Each point was located by stationing and by point on the pavement surface.

The first cycle of plate-bearing tests was made in September and October, 1949, to represent the approximate maximum load carrying capacity. A second cycle was made in April and May, 1950, as soon as the frost had left the subgrade. The plate bearing values obtained at this time were expressed as a percentage of the previous fall

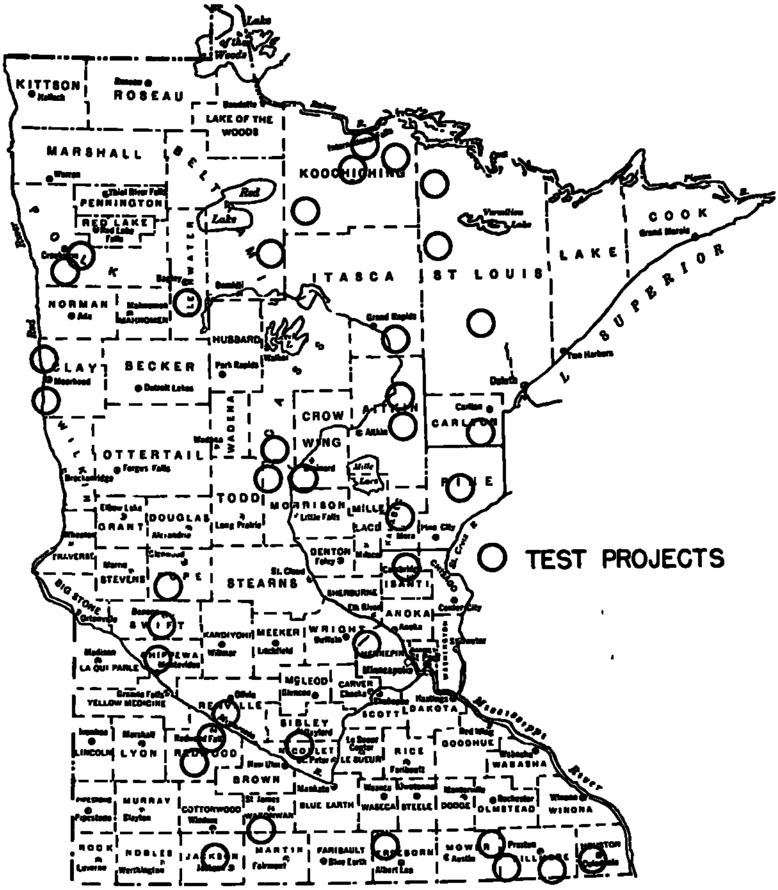


Figure 1. Test Locations in Minnesota

QUICKIE SURVEY

R S	T.H	Location	Bearing at 0 2 in Deflection - P S I Fall 1949	Spring 1950	Percent of Fall Bearing	Mat Inches	Base Inches	Percent Passing No 200 Sieve	Subgrade L L	P I
6920	53	1 7 Mi No Jct T H 169	459	235	51 2	3	6	27 8	15 5	0 3
"	"	3 6 Mi No Jct T H 169	682	336	49 3	3	5	13 8	Sl Plastic	
"	"	4 4 Mi No Jct T H 169	666	432	84 9	3	5	18 1	18 3	1 0
6921	53	0 4 Mi No Jct T H 1	230	126	54 8	3	7	79 0	57 0	34 3
"	"	1 2 Mi No Jct T H 1	210	144	68 6	3	8	72 0	42 2	21 3
"	"	2 1 Mi No Jct T H 1	147	98	66 7	2½	12	62 8	55 1	33 3
6922	53	1 2 Mi No Ash River	413	214	51 8	4	9	32 8	20 3	6 6
"	"	3 0 Mi No Ash River	293	166	56 7	3	9	74 4	30 3	13 1
"	"	4 0 Mi No Ash River	294	143	48 6	3	9	42 1	18 0	2 1
3608	53	0 2 Mi No Jct 217 at Ray	179	91	50 8	3	10	69 7	61 6	39 9
"	"	1 3 Mi No Jct 217 at Ray	174	97	55 7	2	9	61 2	58 4	36 4
"	"	6 5 Mi No Jct 217 at Ray	173	83	48 0	2½	4	52 3	31 4	17 9
"	"	7 8 Mi No Jct 217 at Ray	159	64	40 3	3	10	70 4	66 5	28 9
3613	71	0 1 Mi So Jct T H 11	160	104	65 0	2	10	33 9	26 4	10 7
"	"	1 3 Mi So Jct T H 11	130	83	63 8	2	10	67 4	43 0	26 4
"	"	3 3 Mi So Jct T H 11	139	77	55 3	2	7	68 5	35.5	20 4
"	"	5 6 Mi So Jct T H 11	117	69	59 0	3	6	80 7	58 2	32 7
3612	71	0 7 Mi So Jct T H 65	117	66	56 4	2	10	72 8	44 4	25 9
"	"	2 4 Mi So Jct T H 65	115	76	66 1	2½	10	55 7	37 1	21 5
"	"	4 3 Mi So Jct T H 65	123	72	58 5	2	11	56 3	40 2	23 0
3611	71	0 7 Mi So X Rd at Margie	220	185	84 0	2		7 3	Non-Plastic	
"	"	3 8 Mi So X Rd at Margie	97	66	68 0	2		19 0	69 6	19 9
"	"	6 9 Mi So X Rd at Margie	101	56	55 4	2		35 4	42 1	12 3
"	"	10 0 Mi So X Rd at Margie	116	90	77 6	2		47 0	55 9	10 9
3610	71	0 8 Mi So Jct T H 1	124	83	66 9	3	6	65 0	34 4	17 9
"	"	2 6 Mi So Jct T H 1	191	105	55 0	3	6	57 0	30 8	15 9
"	"	4 6 Mi So Jct T H 1	332	171	61 5	3	6	58 9	29 1	15 3
"	"	6 7 Mi So Jct T H 1	160	82	61 3			62 7	31 7	15 6
1506	92	1 1 Mi So Jct T.H 2	366	212	57 8	3	Treat	35 7	16 1	5.1
"	"	3 9 Mi So Jct T H 2	183	124	67 7	4	8	51 7	25 8	11 5
"	"	5 6 Mi So Jct T H 2	197	90	45 7	4	8	44 2	22 1	7 5
"	"	7 8 Mi So Jct T H 2	238	151	63 3	4	10	43 2	20 1	5 7
6014	102	1 3 Mi S E Jct T H 75	115	85	74 0	1½	0	84 7	51 8	30 3
"	"	3 1 Mi S E Jct T H 75	123	79	64 3	1½	0	82 1	52 4	30 3
"	"	4 3 Mi S E Jct T H 75	111	63	56 8	1½	0	78 2	41 0	23 4
"	"	8 4 Mi S E Jct T H 75	115	64	55 7	1½	0	61 3	37 1	22 6
"	"	9 5 Mi S E Jct T H 75	468	268	57 4	1½	0	7 5	Sl Plastic	
6010	75	0 1 Mi S Jct T H 102	110	62	56 3	1½	5	84.1	50 5	29 6
"	"	2 0 Mi S Jct T H 102	116	65	56 1	1	5	83 3	47 9	26 7
"	"	4 1 Mi S Jct T H 102	120	64	53 3	1½	5	76 7	59 8	21.9
"	"	6 3 Mi S Jct T H 102	83	56	67 4	1	6	80 3	41 3	25 1
"	"	8 4 Mi S Jct T H 102	128	77	60 1	3/4	7	79 0	38 5	22 1
"	"	11 7 Mi S Jct T H 102	92	64	69 6	1½	5	73 3	57 8	37 4
1407	75	0 9 Mi So Side Rd Kragnes	116	70	60 3	9		92 5	64 7	40 7
"	"	2 1 Mi So Side Rd Kragnes	79	55	69 6	9		79 1	59 6	33 8
"	"	3 1 Mi So Side Rd Kragnes	116	82	70 7	9		88 5	62 0	34 7
"	"	4 3 Mi So Side Rd Kragnes	101	71	70 6	9		88 5	63 3	37 5
1406	75	0 5 Mi So Concrete	113	71	62 7	9		86 2	50 4	27 2
"	"	1 5 Mi So Concrete	107	63	58 8	9		91 3	50 9	30 1
"	"	2 5 Mi So Concrete	122	56	45 8	4		87 4	61 6	38 4
"	"	3 5 Mi So Concrete	84	55	65 4	4		82 5	64 6	34 0
4903	10	0 7 Mi No X Rd Cushing	406	295	72 7	2½		16 0	Sl Plastic	
"	"	2 1 Mi No X Rd Cushing	593	299	50 4	2½				
"	"	5 1 Mi No X Rd Cushing	468	316	67 5	2½		20 1	15 2	3 3
1115	210	0 2 Mi E Jct T H 10	386	221	57 3	3		9 5	Sl Plastic	
"	"	2 8 Mi E Jct T H 10	220	183	83 2	6		27 7	14 8	2 1
"	"	5 2 Mi E Jct T H 10	220	119	54 1	6		20 8	Sl Plastic	
1808	218	0 4 Mi No Side Rd 8 Mi S B	290	138	47 6	5	7	31 5	16 7	2 8
"	"	2 3 Mi No Side Rd 8 Mi S B	284	147	51 8	9	6	29 6	16 7	3 7
"	"	3 9 Mi No Side Rd 8 Mi S B	238	134	56 3	6	6	19 6	Sl Plastic	
0112	65	0 5 Mi No Jct T H 210	449	274	61 0	1/2		13 5	Sl Plastic	
"	"	1 6 Mi No Jct T H 210	252	129	51 2	1/2	2½	12 6	Sl Plastic	
"	"	3 9 Mi No Jct T H 210	301	212	70 4	1/2				
0111	65	1 2 Mi So Jct T H 210	234	108	46 2	2	8	14 2	Sl Plastic	
"	"	3 3 Mi So Jct T H 210	215	99	46 0	2	10	54 1	27 7	14 2

R S	T H	Location	Bearing at 0 2 in Deflection - P S I: Fall 1949	Spring 1950	Percent of Fall Bearing	Mat Inches	Base Inches	Subgrade: Percent Passing No 200 Sieve	L L	P I
0111	65	4 6 Mi So Jct T H 210	165	91	55 2	2	10	60 3	46 3	28 6
"	"	5 6 Mi So Jct T H 210	161	64	39 8	2	9	54 2	27 5	13 2
3104	2	10 0 Mi N W Jct T H 65	373	132	35 4			62 0	Sl Plastic	
3105	2	3 2 Mi N W Jct T H 34	459	154	35 6	5		43 6	Sl Plastic	
"	"	1 5 Mi N W Jct T H 34	285	141	49 5	2		36 6	Sl Plastic	
0901	23	13 2 Mi No X Rd Nickerson	142	101	71 1			65 9	66 7	38 1
"	"	11 5 Mi No X Rd Nickerson	138	104	75 4			89 3	60 6	37 0
"	"	5 6 Mi No X Rd Nickerson	158	94	59 5			72 0	52 4	27 6
"	"	4 8 Mi No X Rd Nickerson	271	100	36 9			50 5	32 4	15 5
5803	23	11 7 Mi No So Entrance Askov	422	257	60 9			34 7	14 2	0 9
"	"	8 4 Mi No So Entrance Askov	327	201	61 5			30 6	15 3	2 4
"	"	5 6 Mi No So Entrance Askov	340	179	52 6			25 8	Sl Plastic	
6105	29	1 4 Mi So Bridge Starbuck	247	167	67 6	3½	8	49 1	27 2	11 3
"	"	2 45 Mi So Bridge Starbuck	206	107	51 9	3½	8½	53 1	30 7	15 4
"	"	4 05 Mi So Bridge Starbuck	344	276	80 2	3	11	39 8	19 9	4 8
7607	29	2 1 Mi So End Concrete Benson	255	125	47 3	1	16	58 6	29 3	15 1
"	"	4 1 Mi So End Concrete Benson	194	111	57 2	1	15	70 7	37 9	19 7
1208	29	8 0 Mi So End Concrete Benson	152	103	67 8	1	10	78 6	27 3	6 9
1206	29	4 8 Mi So Jct T H 40	189	100	52 9	1	9	82 6	43 7	20 8
"	"	7 25 Mi So Jct T H 40	318	187	58 8	1	9	78 0	38 9	17 2
"	"	9 60 Mi So Jct T H 40	272	165	60 7	1	11	50 6	32 6	14 6
8508	71	1 15 Mi So Concrete at Olivia	206	116	56 3	3	9	56 0	46 3	21 0
"	"	7 05 Mi So Concrete at Olivia	206	51	24 8	3	9	47 5	36 4	16 7
"	"	9 05 Mi So Concrete at Olivia	275	172	62 5	3	9	78 5	44 4	22 1
6406	93	0 4 Mi No XRd 4 Mi So R Falls	149	67	45 0	2	0	72 5	38 0	15 8
"	"	1 6 Mi No XRd 4 Mi So R Falls	115	56	49 6	2	0	55 2	46 6	23 5
"	"	2 35 Mi No XRd 4 Mi So R Falls	125	69	56 2	2	0	68 6	46 9	24 3
6405	71	0 9 Mi N School 6 15 So Jct 93	151	106	70 1	1	5	62 7	49 0	23 4
"	"	2 9 Mi N School 6 15 So Jct 93	150	90	60 0	1½	4½	60 0	47 0	24 7
"	"	4 05 Mi N School 6 15 So Jct 93	137	92	67 2	1½	4½	69 5	51 1	23 1
7307	22	0 9 Mi So Concrete Gaylord	123	65	52 8	3½	0	55 6	39 1	17 2
"	"	2 5 Mi So Concrete Gaylord	89	53	59 6	3	0	63 7	38 9	16 8
"	"	3 8 Mi So Concrete Gaylord	94	15	16 0	3	0	60 2	36 3	17 9
3206	71	5 85 Mi So R R Maint Shop	91	59	64 8	2	0	40 9	32 8	14 0
"	"	7 05 Mi So R R Maint Shop	155	61	39 4	8	0	57 3	33 8	16 1
"	"	8 40 Mi So R R Maint Shop	93	62	66 6	2	0	62 2	45 5	22 1
8301	4	1 8 Mi N X Rd at Ormsby	188	147	78 1	3	9	47 7	35 1	15 9
"	"	3 15 Mi N X Rd at Ormsby	201	129	64 2	3	9	67 7	43 4	24 2
"	"	5 90 Mi N X Rd at Ormsby	155	105	67 7	3	9	53 1	33 5	16 0
2401	13	1 1 Mi So Side Rd Manchester	153	69	45 1	1	0	45 5	34 4	15 7
"	"	1 55 Mi So Side Rd Manchester	171	106	62 0	1	0	52 7	26 6	10 7
"	"	2 55 Mi So Side Rd Manchester	174	120	69 0	1	0	61 2	36 7	14 1
2803	44	0 77 Mi So Conc Spring Grove	146	82	56 2	1	0	86 8	39 6	19 0
"	"	1 65 Mi So Conc Spring Grove	139	80	57 6	1	0	87 5	39 8	20 2
"	"	2 5 Mi So Conc Spring Grove	229	165	72 1	1	0	81 1	34 6	14 5
2313	63	0 7 Mi So Conc Spring Valley	320	189	59 1	3	2	45 9	29 2	11 9
"	"	1 10 Mi So Conc Spring Valley	218	170	78 0	1½	1	56 3	38 5	19 9
2313	63	1 65 Mi So Conc Spring Valley	225	169	75 1	2	4	52 7	36 6	20 1
2316	139	1 4 Mi So Jct T H 52	238	127	53 4			89 9	35 4	12 3
"	"	2 65 Mi So Jct T H 52	195	119	61 0			88 7	36 9	15 7
"	"	3 80 Mi So Jct T H 52	180	98	54 4			86 4	39 1	18 1
5006	63	1 15 Mi No Jct T H 16	312	158	50 6			41 2	20 9	7 4
"	"	3 15 Mi No Jct T H 16	251	146	58 2			39 6	26 9	12 4
"	"	4 15 Mi No Jct T H 16	215	97	45 1			65 7	30 6	14 2
3308	65	3 9 Mi No R R X in Mora	188	60	31 9	6		70 9	26 8	9 2
"	"	8 9 Mi No R R X in Mora	188	114	60 6	3		33 4	25 4	9 5
"	"	12 2 Mi No R R X in Mora	175	32	18 3	3		57 1	22 0	4 8
3009 & 3004	65	1 9 Mi N Jct T H 95	275	160	58 2	1½	3	49 1	24 7	5 6
"	"	4 2 Mi N Jct T H 95	311	206	66 2	2½	2½	25 4	18 7	4 1
"	"	13 7 Mi N Jct T H 95	175	77	44 0	2	2	86 8	40 9	20 3
2722	55		176	86	48 9	2	6			
"	"		155	93	60 0	2				

Note All bearing values over 280 psi are estimated values obtained by extrapolation of the stress-strain curve

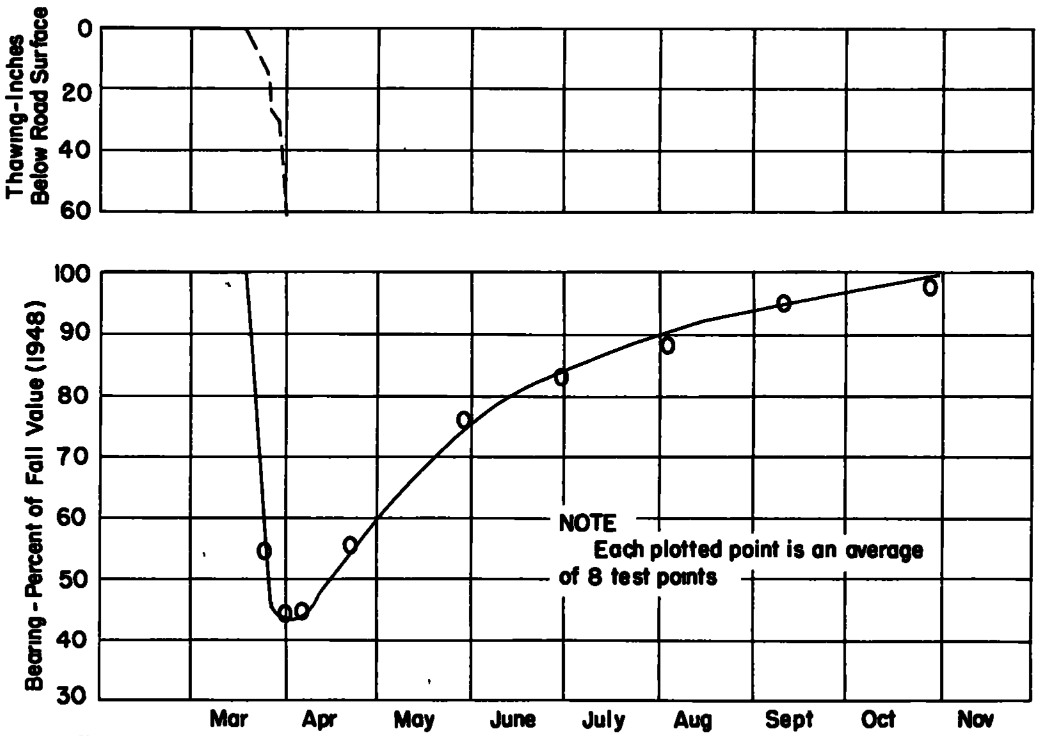


Figure 2. Minnesota Bearing Tests 1949 Loading Cycle, 12 in. Bearing Plate
Loss of Road Strength and Recovery

values in determining the loss of load-carrying capacity.

Due to flood conditions in the northern part of the state, some test sections had to be deleted. On the 38 test sections, 126 individual tests were completed for both the fall and spring bearing values. Detailed information secured is shown in Table 1. An inspection of the data will disclose that all types of soils tested so far appear to suffer from frost action; and while the grand average of all losses recorded is 42 percent, the average for each soil type, as nearly as it can be identified, seems to vary only slightly from the grand average.

Another noticeable characteristic of the test results is that thickness of base in a road structure has no appreciable effect in reducing the percentage of strength loss, even though both the fall and spring carrying capacity of the road may be considerably improved because of the base construction. This can be explained by the fact that the strength of a road structure starts with the subgrade soil, and the degree to which the subgrade soil is affected by frost action is reflected in the surface carrying capacity of the road itself.

In order to bring out the comparison between the data secured on the statewide testing program, as compared to the data accumulated from tests made at eight selected test points during the previous 3 yrs., Figures 2 and 3 are included in this report.

Figure 2 shows the average loss of load strength and recovery for the tests made in 1949, while Figure 3 shows the comparison of test results secured during the three years of 1947, 1948, and 1949. The average loss in strength was somewhat higher during these years than during 1950, but all of the information gathered in Minnesota so far indicates substantial strength losses following spring thawing and gradual recovery.

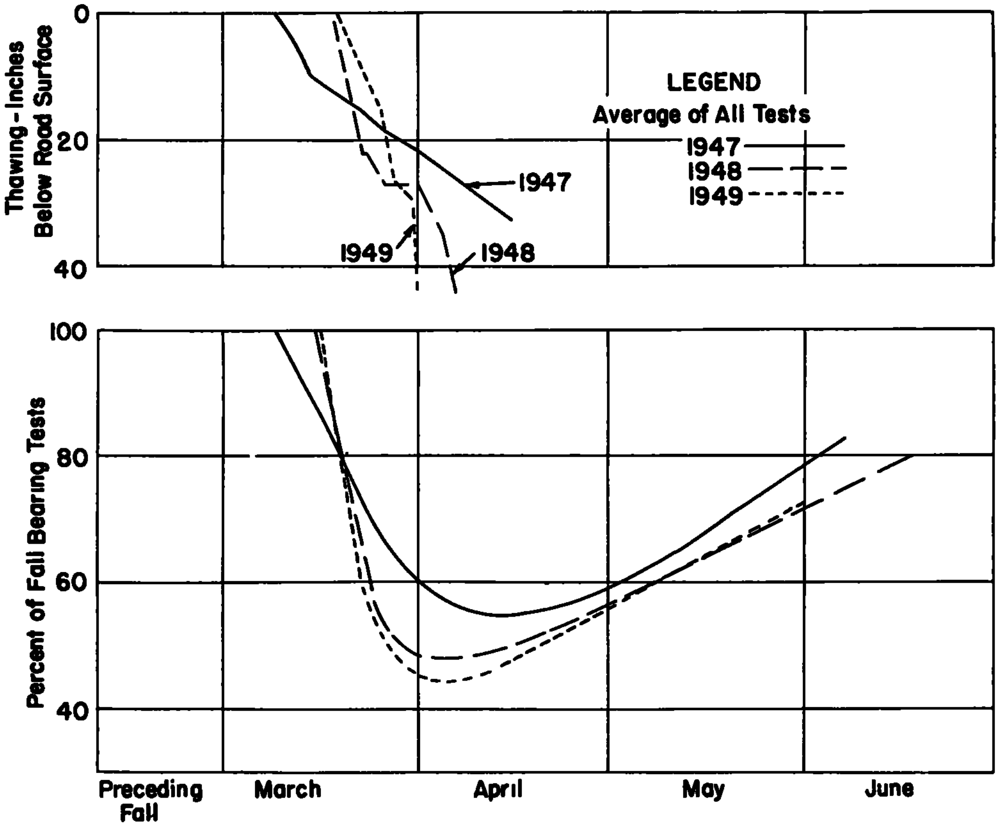


Figure 3. State of Minnesota - Dept. of Highways Comparison of Results of 1947 - 1948 and 1949 Tests

Figure 4.

NEW YORK

As a continuation of the program of field strength measurements by the use of plate-bearing tests, the Bureau of Soil Mechanics instituted a program of measurements on various roads in Rensselaer and Washington Counties. Tests were performed at the same locations, both in the fall of 1949 and in the spring of 1950.

Most of the sites at which tests were performed were in cut sections. However, a few tests were run in areas of shallow fills. The pavement at these sites represented conditions of both good and poor performance. The subgrades included soils of glacial lacustrine, glacial till, and glacial outwash origin, and soils of alluvial origin.

The loading arrangement for the plate tests consisted of an I-beam supported beneath two 5 1/2-ton trucks. These trucks were loaded with additional weight (sand and gravel) to produce a reaction under the jack position of somewhat more than 15 tons. This arrangement is similar to that used during the 1948-1949 series.

In order to permit the testing of the wide range of soil types, the tests were run on the pavement surface only, using both the 6-in. and the 12-in. diameter plates. This simplification permitted tests at 30 locations. At all locations, tests were run using the 12-in. plates, with occasional tie-in tests using the 6-in. plates. Regular and quick tests were run with both plates. The load-bearing tests were supplemented by the North Dakota cone test on the fine grained soil subgrades.

A comparison of the test results obtained (see Table 1 and Fig. 1) shows that the load bearing capacity in the spring averages from 53 to 86 percent of the fall values for all soil types tested. For lacustrine soils, the spring values are approximately 55 percent of the fall values, showing the greatest loss of strength due to frost action. The till, aluvial, and outwash soils show a lesser loss of strength, averaging 70 to 75 percent of the fall value.

Because of the large numbers of variables that may influence the bearing capacity of soils, it is impossible to say that any one factor is more responsible than any other factor. An attempt has been made to relate a number of the variables; however, only the relationship between the total thickness of pavement and the plate loading at 0.1-in. deflection for glacial lacustrine and glacial till soils seems to indicate a definite pattern. A plot of these data is given in Figure 2. No definite correlation was found between plate load values and field moisture contents, field cone bearing values, subgrade density, or characteristics

TABLE 1

SUMMARY OF SPRING LOAD BEARING VALUES REPRESENTED AS A PERCENTAGE OF THE FALL VALUES

Soil Type	12-inch Diam. Plate at Deflection of		6-inch Diam. Plate at Deflection of	
	0.10 in.	0.20 in.	0.10 in.	0.20 in.
Till Soils	65		69	79
Lacustrine Soils	53	53	56	56
Alluvial Soils	74	77	74	71
Outwash Soils	86		72	72

Note: These are average values for each soil type investigated.

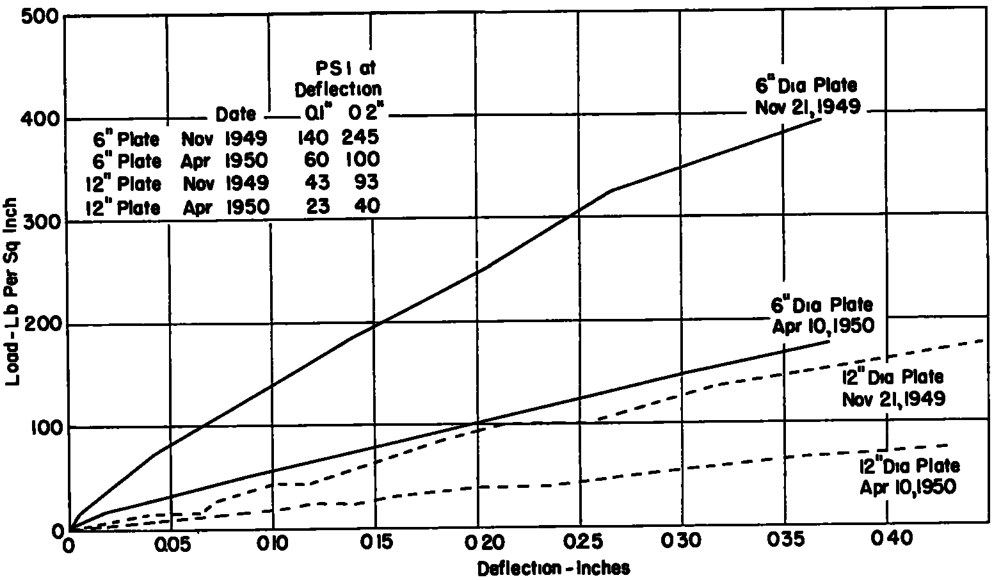


Figure 1. Pavement Load Deflection Curves C. R. 46 - East Greenbush Sta.
Soil Series - Hudson Depositional Unit - Lacustrine

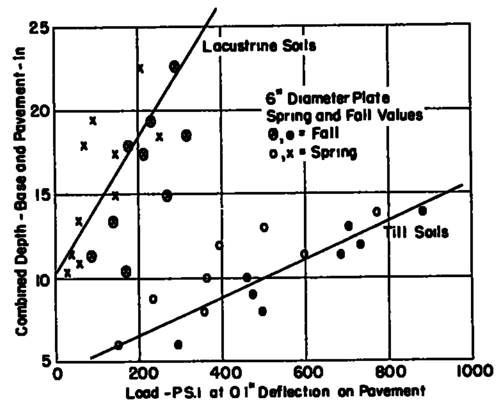


Figure 2. Load P. S. I. vs Combined Depth of Base and Pavement.

of the individual subgrade soils.

As you will see by examining Tables 2 to 6 there was considerable variation in the field moisture content of the subgrade materials at the time of test. It is our belief that such variations could have a very large influence on the bearing value obtained. An evaluation of this factor, however, is not possible from the data we have on hand.

It may be that a comparison of the field data obtained by this series of tests with those from other areas may provide interesting correlations.

TABLE II OUTWASH

Test No	Soil Series	Location	County	Thickness Inches: Surface	Thickness Inches: Base	Type of Test	Bearing Plate Diameter–Inches	Load at Deflection PSI 0.10: Fall	0.10: Spring	0.20: Fall	0.20: Spring	% of Fall Bearing Value: 0.10	0.20	Cone Bearing Subgrade – PSI Δ	Subgrade Moisture Content Natural: Fall	Natural: Spring	Optimum #	Field Dry Density Lb/Cu Ft: Fall	Spring	% Plus No 4 (Average)	Field Dens # as % of Max Dens: Fall	Spring	Liquid Limit (Average)	Plasticity Index (Average)	
18	Copake	Melrose – Tomhannock	Renss	6"	11½"	Reg	12	160	115	—	220	72	—	— F 447 S	13 4	15 1	12 3	102 5	111 8	16	86 2	95 8	19 9	2 5	
27	Schodack	Tomhannock Reservoir Rd	"	3"	11½"	"	"	230	119	—	200	52	—	537 F 342 S	17 9	18.4	16 6	100 0	107 5	0	93.1	96 0	20 3	2 2	
25	Hoosic	"	"	3"	5"	"	"	150	203	—	—	135	—	—	6 3	5.1	10 5	—	118 0	33	—	96 4	—	NP	
47	"	So Schodack Co. Rd 52	"	6"	5½"	—	—	—	—	—	—	—	—	470 F 365 S	13.1	18.7	14.4	112.2	103.9	6	94 8	95 0	20.6	3.2	
19	Copake	Melrose – Tomhannock	Renss	6"	11½"	Reg	6"	300	240	570	385	80	68	— F 447 S	13.4	15.1	12 3	102 5	111.8	16	86 2	95 8	19 9	2.5	
28	Schodack	Tomhannock Reservoir Rd.	"	3"	11½"	"	"	580	300	960	528	52	55	537 F 342 S	17 9	18 4	16 6	100 0	107 5	0	93.1	96.0	20.3	2.2	
17	"	Melrose – Troy	"	4"	11½	Quick	"	540	535	900	875	99	97	1978 F — S	9.4	11.0	10.6	117 2	123 9	5	93.2	99 5	16 9	2.9	
26	Hoosic	Tomhannock Reservoir Rd	"	3"	5"	"	"	745	420	1160	770	56	66	—	6 3	5 1	10.5	—	118 0	33	—	96 4	—	NP	

TABLE III TILL

Test No	Soil Series	Location	County	Surface	Base	Type of Test	Bearing Plate Diameter	0.10 Fall	0.10 Spring	0.20 Fall	0.20 Spring	% 0.10	% 0.20	Cone Bearing	Natural Fall	Natural Spring	Optimum	Density Fall	Density Spring	% Plus No 4	% Max Dens Fall	% Max Dens Spring	Liquid Limit	Plasticity Index	
8	Cossyuna	Schaghticoke – Wash Co Line	Renss	3"	7"	Reg	12"	225	110	—	208	49	—	—	18 0	14.5	14 0	97 1	112 2	18	85 2	96.4	19 4	1.3	
11	"	Melrose – Troy	"	4½"	23"	"	"	—	252	—	—	—	—	—	10.3	9.1	9.7	116 0	126 0	27	91.7	100.1	—	NP	
23	"	Tomhannock Reservoir Rd	"	2"	4"	"	"	180	79	—	168	44	—	—	7.6	8 8	10 0	125 3	128 4	26	99 0	102 9	16.6	2 7	
2	Nassau	Schaghticoke – Wash Co Line	"	2"	10"	"	"	265	220	—	—	83	—	—	13 1	12 1	11.3	113 5	124.8	37	93.6	100.7	—	NP	
13	"	Melrose – Troy	"	3½"	10"	"	"	—	252	—	—	—	—	— F 379 S	8 5	11.3	10 9	133 2	115 3	29	105 5	94 2	19.5	4.4	
15	"	"	"	5"	9"	"	"	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NP	Shale
7	Mansfield	Schaghticoke – Wash Co Line	"	3"	6"	"	"	140	115	—	212	82	—	—	9 9	8 4	10 6	116 8	126.8	12	95 2	107 1	25 9	6.6	
1	Cossyuna	Schaghticoke – Wash Co. Line	Renss	2"	9½"	Reg	6"	690	600	1060	980			—	12 8	14 2	15 6	110 6	120 1	26	97.4	109.0	—	NP	
4	"	"	"	3"	7"	"	"	465	370	600	600	80	100	—	14.1	14.9	12 0	110 3	102 2	29	90 8	85 8	—	N.P.	
12	"	Melrose – Troy	"	4½	23	"	"	950	600	—	955	63	—	—	10 3	9 1	9.7	116.0	126 0	27	91 7	100 1	—	NP	
24	"	Tomhannock Reservoir Rd	"	2"	4"	"	"	300	158	570	316	53	55	—	7 6	8 8	10 0	125.3	128 4	26	99.0	102.9	16 6	2 7	
3	Nassau	Schaghticoke – Wash Co Line	"	2"	10"	"	"	740	400	—	780	54	—	—	13.1	12 1	11 3	113.5	124.8	37	93 6	100 7	—	NP	
14	"	Melrose – Troy	"	3½"	10"			710	505	1070	820	71	77	— F 379 S	8.5	11 3	10.9	133 2	115 3	30	105 5	94.2	19 5	4.4	
16	"	"	"	5"	9"	"	"	890	780	—	—	88	—	—	—	—	—	—	—	—	—	—	—	NP	Shale
5	Troy	Schaghticoke – Wash. Co Line	"	2"	6"	"	"	500	560	880	620	72	70	—	9 6	10 8	10 6	116 0	116 2	20	91.3	94.2	19 4	4.5	
6	Mansfield	"	"	3"	6"	"	"	480	240	—	450	50	—	—	9 9	8.4	10.6	116 8	126.8	12	95 2	107 1	25.9	6 6	

TABLE IV ALLUVIAL

Test No	Soil Series	Location	County	Surface	Base	Type of Test	Bearing Plate Diameter	0.10 Fall	0.10 Spring	0.20 Fall	0.20 Spring	% 0.10	% 0.20	Cone Bearing	Natural Fall	Natural Spring	Optimum	Density Fall	Density Spring	% Plus No 4	% Max Dens Fall	% Max Dens Spring	Liquid Limit	Plasticity Index
21	Saco	Melrose – Tomhannock	Renss	6"	11"	Reg	12"	115	90	—	180	61	—	—	—	11 0	—	—	—	18	—	—	—	—
29	Ondowa	River Road – Stillwater	"	6½"	16	"	"	142	97	287	190	68	66	— F 1009 S	14 7	24 2	15.8	109.5	95 7	7	97 4	89.7	22.6	3.9
31	"	"	"	3"	10"	"	"	155	146	310	274	94	88	—	14 8	18 8	13 7	114 3	109 1	5	95 0	96 6	20 6	4 6
22	Saco	Melrose Tomhannock	Renss	6"	11"	Reg	6"	255	210	640	472	82	74	—	—	11 0	—	—	—	18	—	—	—	—
30	Ondowa	River Road Stillwater	"	6½"	16"	"	"	320	212	465	317	66	68	— F 1009 S	14.7	24 2	15.8	109 5	95 7	7	97 4	89 7	22 6	3.9

\# OF STANDARD AASHO COMPACTION TEST

Δ F - Indicates Fall Values
S - Indicates Spring Values

TABLE V LACUSTRINE

Test No	Soil Series	Location	County	Thickness (Inches): Surface	Thickness (Inches): Base	Type of Test	Bearing Plate Diameter—Inches	Load at Deflection PSI, 0 10": Fall	Load at Deflection PSI, 0 10": Spring	Load at Deflection PSI, 0 20": Fall	Load at Deflection PSI, 0 20": Spring	% of Fall Bearing Value: 0 10'	% of Fall Bearing Value: 0 20"	Cone Bearing Subgrade — PSI Δ	Subgrade Moisture Content, Natural: Fall	Subgrade Moisture Content, Natural: Spring	Subgrade Moisture Content: Optimum #	Field Dry Density LB/CU FT: Fall	Field Dry Density LB/CU FT: Spring	% Plus No 4 (Average)	Field Dens # as % of Max Dens: Fall	Field Dens # as % of Max Dens: Spring	Liquid Limit (Average)	Plasticity Index (Average)
20	Hudson	Melrose - Tomhannock	Renss	5"	9'	Reg	12	140	90	265	180	64	68	—	8 0†	9 3†	9 7†	127 2†	126 7†	22†	99 1	98 6	16 9	3 0
45	Hudson	So Schodack - Co. Rd. 52	"	3"	7½'	"	12"	54	20	110	48	37	44	1163 F 405 S	17 3	18 5	15 7	107 2	107 2	0	92 9	96 1	17 2	2 3
46	"	"	"	2½"	8½"	"	"	72	22	169	53	30	31	774 F 675 S	12 0	12 0	11.7	119 1	122 2	5	95 8	100 7	15 5	0 2
38	"	E Greenbush - Co Rd 46	"	4½"	9"	"	"	43	23	93	40	53	43	218 F 100 S	30 0	28 3	26 8	92 5	93 7	0	102 2	97 3	45.5	21 9
40	"	"	"	5"	13"	"	"	58	25	115	53	43	46	147 F 130 S	28 4	26 4	27 3	93 9	95 0	0	101 7	101 5	47.6	20.4
42	"	So Schodack Co Rd 52	"	1½'	10'	"	"	40	26	98	51	65	52	366 F 180 S	25 6	28 5	22 8	95 6	88 0	0	91 7	90.5	43 1	19 3
44	Hudson	So Schodack - Co Rd 52	Renss	3"	7½"	Quick	6"	170	30	340	60	18	18	1163 F 405 S	17 3	18 5	15 7	107 2	107 2	0	92 9	96 1	17 2	2 3
76	"	"	"	-	-	Quick	"	—	55	—	127	—	—	—	12 0	12 0	—	—	—	—	—	—	—	—
39	"	E Greenbush Co Rd 46	"	4½	9"	"	"	140	60	245	100	43	41	218 F 100 S	30 0	28 6	26 8	92 5	93 7	0	102 2	97 0	45.5	22.9
41	"	"	"	5"	13"	"	"	180	68	325	130	38	40	147 F 130 S	28 4	26 4	27 3	93 9	95 0	0	101 7	101 5	47 6	20 4
43	"	So Schodack Co. Rd 52	"	1½"	10"	"	"	90	40	195	100	44	51	366 F 180 S	25 6	28 5	22 8	95 6	88 0	0	91 5	90.5	43 1	19 3
48	Vergennes	River Road	Wash.	3½"	14"	Reg	12	80	68	158	101	85	64	470 F 582 S	19 4	18 4	18 0	109 2	110 5	2	100 0	101 0	34 3	12.2
51	"	"	"	3½"	19'	"	"	106	88	215	163	83	76	1015 F 402 S	20 6	20 9	19 3	104 9	109 8	1	96 0	104 0	33 8	12 8
49	Vergennes	River Road	Wash	3½"	14"	Reg	6"	215	152	430	264	71	61	470 F 582 S	19 4	18 4	18 0	109.2	110 5	2	100 0	101 0	34 3	12 2
50	"	"	"	2½"	46"	Quick	"	290	218	495	393	75	79	—	—	37 4	—	—	—	—	—	—	35.2	15 3
52	"		"	3½"	9	"	"	290	210	520	340	72	65	1015 F 402 S	20 6	20.9	19.3	104.9	109 8	1	96 0	104.0	33 8	12 8

TABLE VI LACUSTRINE

Test No	Soil Series	Location	County	Surface	Base	Type of Test	Bearing Plate Diameter	0 10" Fall	0 10" Spring	0 20" Fall	0 20" Spring	% 0 10'	% 0 20"	Cone Bearing Δ	Natural Fall	Natural Spring	Optimum #	Dry Density Fall	Dry Density Spring	% Plus No 4	Field Dens Fall	Field Dens Spring	Liquid Limit	Plasticity Index
10	Orono	Schaghticoke Wash Co. Line	Renss	2"	9'	Reg	12	275	100	—	248	36	-	— F — S	10 2†	10 2†	10.4†	122.3†	122 2†	12	100.5	94 5	21 0	4.8
32	"	Hempstreet Park	"	4"	15½"	"	"	80	26	165	57	32	35	370 F 239 S	22 6	22 6	16.5	96.7	101 5	0	88 5	91 0	23 3	3 6
36	"	East Greenbush	"	5"	10'	"	"	80	44	170	100	55	59	572 F 195 S	14 2	20 1	16 3	116 8	106.2	2	98.5	99 0	18 5	2 9
34	"	Hempstreet Park	"	2½	16"	Quick	"	120	70	245	156	58	64	369 F 322 S	8 2	14 8	11.4	117 2	111 0	2	96 0	92.3	—	N P
33	Orono	Hempstreet Park	Renss	4"	15½'	Quick	6"	230	94	400	184	41	46	370 F 239 S	22 6	22 6	16 5	96 7	101 5	0	88 5	91 0	23.3	3.6
35	"	"	"	2½'	16"	"	"	315	255	565	438	81	78	369 F 322 S	8 2	14 8	11.4	117 2	111 0	2	96 0	92 5	—	N P
37	"	East Greenbush	"	5"	10'	"	"	280	150	490	278	54	57	572 F 195 S	14 2	20 1	16.3	116 8	106.2	2	98.5	98 9	18 5	2 9
9	"	Schaghticoke Wash Co Line	"	2"	9"	Reg	"	600	460	1020	800	77	78	— F — S	10 2†	10 2†	10 4†	122 3†	122 2†	12	100.5	94 5	21.0	4.8

\# OF STANDARD AASHO COMPACTION TEST

Δ F - Indicates Fall Values
S - Indicates Spring Values

NORTH DAKOTA

For the period covered by this report, (July 1 - Aug. 31, 1950) tests were continued on the 10 permanent test-points selected in 1948: one test point for gravel surface, one for bituminous armor coat, three for cold-laid oil-mix mats, one for hot-mix bituminous resurface, and four for asphaltic-concrete wearing surfaces.

Bearing tests were made only with the North Dakota cone device and at 3-, 9-, 15-, and 24-in. depths in the subgrade. Other data taken includes soils analysis, temperature, and subgrade density and moisture content. (Cone bearing device principally intended for use in fine-grain soils.)

From the data obtained in 1949, fall bearing values for each test point were established. These values were plotted as 100 percent on the 1950 graphs in this report. All other test values for bearing power were plotted as percentages of the fall values.

The former progress report terminated on July 1, 1949. The test data obtained after that date up to November 22, 1949, when frozen conditions suspended operations for the winter, have been added to the 1949 report graphs and included herein to complete the 1949 information. From July 1, 1949, to November 22, 1949,

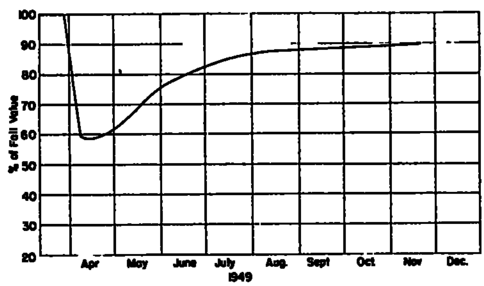


Figure 1. Average Bearings for All Tests at the 10 Test Points Bearing Tests with North Dakota Cone Device.

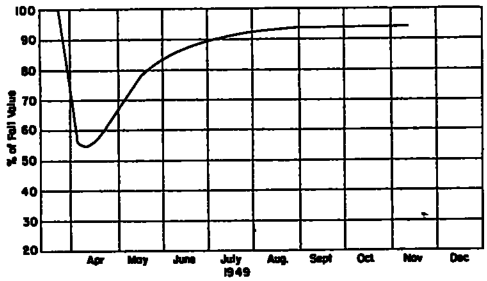


Figure 2. Average Bearing for the 10 Test Points at 3 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

48 complete tests were made. These results were plotted as continuations of the graphs contained in the progress report to July 1, 1949. Added to the work performed before July 1, the total number of tests made in 1949 was 115.

Figure 6 shows a curve representing the average bearings for all tests made in 1950 at the 10 test points, regardless of test depth. It establishes the general trend of the loss of load-carrying capacity when the subgrade is thawing, and the subsequent recovery. For 1950 it will be noted the curve shows a rapid recovery from May 10 to June 12 afterwhich a loss in bearing power occurred to July 5. Then recovery was resumed again up to the report date of August 31. This erratic procedure was not anticipated and is not definitely accounted for. However, plausible reasons are offered and the matter discussed more in detail later in this report.

Figures 2 to 5, 1949, and 7 to 10, 1950, show the average bearings for all tests at the 10 test points at the respective depths of 3, 9, 15, and 24 in. below the subgrade surface.

The following observations have resulted in regard to the subgrade bearing tests with the North Dakota cone device:

1. All test points show a decline in bearing strength during the

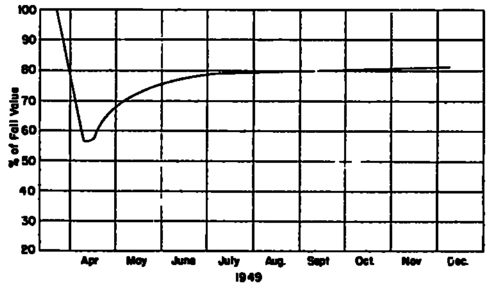


Figure 3. Average Bearing For the 10 Test Points at 9 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

spring thaw with a subsequent recovery thereafter.

2. Not all test points follow the same pattern of recovery.

3. It was noted that the average recovery in subgrade bearing strength for all tests at the 10 test points did not reach 100 percent during the 1949 season. Figure 1 shows that when field work was suspended in the fall of 1949 the average recovery had only reached 90 percent of the previous fall value. This may have been due in part to selection the previous year of fall values that were too high. Such procedure could be the result of the lack of previous data and experience to establish sounder judgement in determining reasonable fall values.

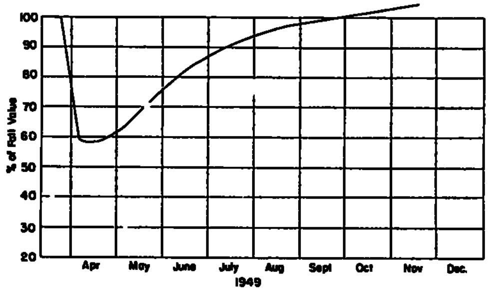


Figure 4. Average Bearings For the 10 Test Points at 15 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

Because of this probability, prior to the resumption of field work in the spring of 1950, the fall values obtained in 1949 were reviewed and adjusted to more suitably fit the average results obtained by the field tests. These adjusted fall values are shown numerically in Table 1 and may be compared with the 1948 fall values used in 1949, which are also shown in the same table.

One research party was started during April 1950. This was a later start than usual due to the abnormally cold spring which caused the frost to come out of the ground very slowly. For this reason one party could readily handle all the test points and keep up with the rate of frost recession.

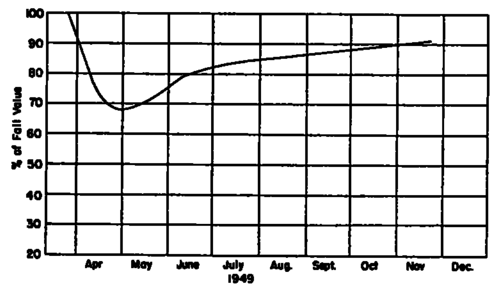


Figure 5. Average Bearings For the 10 Test Points at 24 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

The first test was made April 13 at 3 in. below the subgrade surface. The first test possible at the 24-in. depth after disappearance of frost was made April 26. There were 69 complete tests made between April 30, 1950, and August 31, 1950.

The results were plotted and are shown in this report by 1950 graphs, Figures 6 to 10. (Graphs for individual test points are not reproduced here.) As can be noted by studying the curves for all the test points and the averages for all tests at the 10 test points the results are found to be quite erratic for the 1950 season. We have been unable

TABLE 1

TABULATION OF FALL VALUES FOR 1949 AND 1950

Test Point No.	Location	1948 Fall Values For 1949 Inches 3	9	15	24	1949 Fall Values For 1950 Inches 3	9	15	24
1	US 83 Sterling South	827	398	282	239	788	378	209	224
2	N.D. 3 North of Steele	1087	309	1077	307	718	537	344	289
3	N.D. 13 East of Edgeley	1332	465	596	1352	1272	455	764	1162
4	US 52 Southeast of Sawyer	391	327	298	381	553	240	250	255
5	US 52 Southeast of Anamoose	613	417	296	266	680	340	290	266
6	US 10 West of Sterling	1880	1183	852	706	1047	536	478	542
7	US 10 East of Sterling	795	895	419	515	900	400	588	714
8	US 10 East of Menoken	807	288	1040	850	754	366	1015	357
9	US 10 West of Jamestown	1154	803	758	667	1214	856	814	660
10	US 52 Southeast of Donnybrook	1037	779	473	361	874	450	462	348

to definitely account for these variable results, but some of the causes may have resulted from the abnormal climatological conditions this season. Also, it was necessary to make personnel changes in the field party during the season. However, their work was spot checked by more experienced men to assure utmost accuracy in the field results.

Another important reason probably pertaining to erratic results is the fact that recent tests are now falling some distance farther down the road than the actual location of the original test points. This procedure is considered necessary in order that each new test will occur at an undisturbed location. In this manner some undetected changes in soil composition or presence of other unknown factors could affect the uniformity of bearing values obtained. To minimize the effect of this possibility, tests were finally made during 1950 on the opposite side of the centerline than formerly and as near the original location as possible. However, this procedure has not appeared to improve or affect the uniformity of results to any appreciable extent up to the time of this report.

The month of April was the coldest April since records began for this state. Unusually heavy snow covered the ground during the first half of

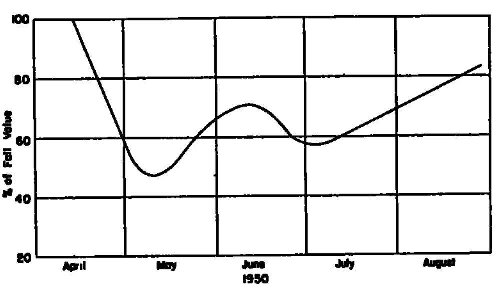


Figure 6. Average Bearings For All Tests at the 10 Test Points Bearing Tests with North Dakota Cone Device.

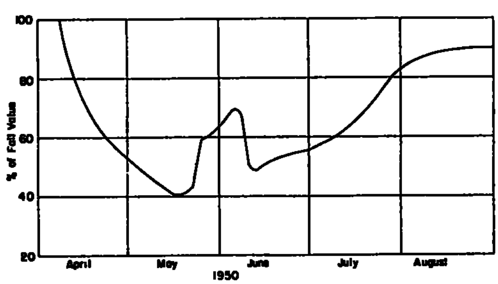


Figure 7. Average Bearing for the 10 Test Points at 3 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

the month. Consequently, the thaw period was retarded and not much testing could be accomplished in April.

The outstanding feature of May weather was its continuation of one of the most backward seasons ever experienced in North Dakota. A new record of snowfall was established for the month. The Weather Bureau records show an average snowfall for the state of 8.8 in. which was more than twice the previous all-time high of 4.0 in. set in 1905 for May. This compares with a normal snowfall of 1/2 in. for the month of May. This condition no doubt largely accounts for the low average subgrade bearing around May 10, which equals 47 percent of the previous fall value for the avera◦e of all test points. In comparison, the spring value average in 1949 for all 10 test points was 58 percent of the previous fall value.

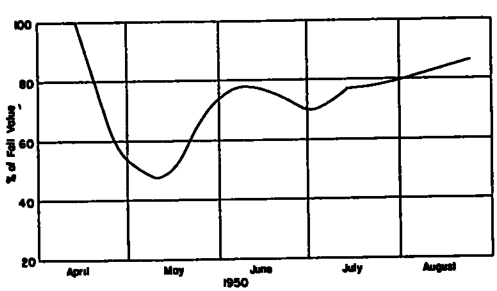


Figure 8. Average Bearing For 10 Test Points at 3 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

June was a warm and dry month, and during this period the subgrade at all the test points showed partial recovery. On June 24 and 25 rain was general throughout the state. This moisture seemed to affect the subgrade considerably as the average bearings dropped substantially thereafter.

July was a comparatively dry month but not unusually hot. However, the subgrade bearings gener-

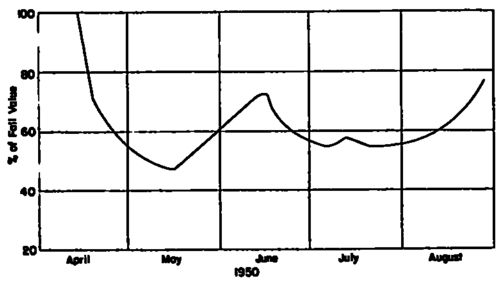


Figure 9. Average Bearing for 10 Test Points at 15 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

ally improved and the recovery of subgrade bearing power resumed during that month.

August weather was similar to that of July and subgrade bearings continued to improve.

In conclusion, the 1950 variable results appear somewhat disappointing as more uniform results were anticipated. The results reported are those actually obtained without discounting or culling the extreme values. For utmost accuracy, tests were often repeated as many as four times before a single reading was finally accepted and recorded as representative of the conditions at the time of the test.

After plotting the results on the curve sheets the variations are graphically apparent. The curves shown are the actual averages for

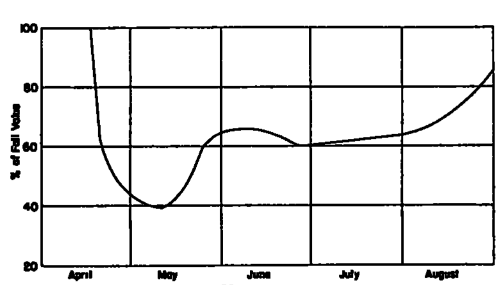


Figure 10. Average Bearings for 10 Test Points at 24 in. Below Subgrade Surface Bearing Tests with North Dakota Cone Device.

the bearings shown and plotted. For this reason the curves are not as uniform as might be the case. No doubt more uniformity in the curves could be obtained by studying the general trends of the data and then by redrawing curves representative of those trends from which extreme values have been culled or discounted. This point is casually mentioned for consideration in case such procedure appears practical.

Without question, however, the 1950 work re-established the 1949 result that a large loss of subgrade bearing power, amounting to approximately 50 percent of the previous fall value, occurs during the spring thaw period. It is sincerely hoped that as the research work progresses, more skill in testing will be developed and that additional valuable and reliable information pertaining to the project will be compiled for use by this state and the committee.

OHIO

The plate-bearing tests in Ohio were made on a road selected as typical of modern, heavy-duty, flexible pavements on US 36, Mileage Station 22.62, Delaware County and the pavement section included: 4 in. hot-mixed bituminous concrete; 8 in. waterbound macadam; 10 1/2 in. classified embankment material.

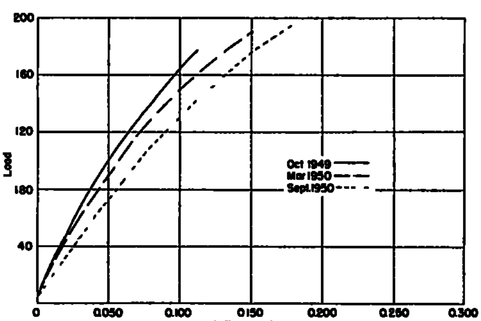


Figure 1, Average Tests on Surface.

The plate bearing tests were made in accordance with the procedure outlined by the committee, using a 12-in. plate. The charts show the average load-deflection curves obtained on each layer of pavement in three series of tests made on the dates shown. There was little difference between the fall and spring tests and consequently a percentage load-season curve based on loads at 0.2 in. was not attempted. The 1949-1950 winter in this area was very mild, and it is doubtful if frost penetration ever extended to the top of the subbase and rarely to the depth of the top of the macadam.

The average temperatures recorded at the time tests were made were:

Item	Average Temperatures Oct.'49	Mar.'50	Sept.'50
Air	52 F	63 F.	80 F.
Bituminous Concrete	56	48	76
Macadam	58	54	74
Subbase	60	49	75
Subgrade	62	48	72

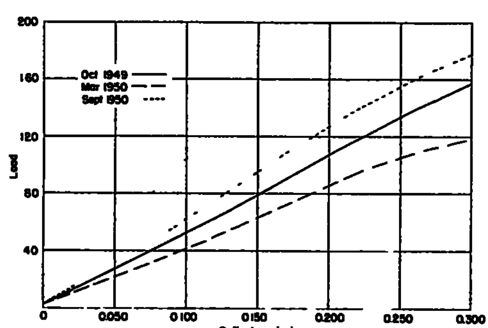


Figure 2, Average Tests on Macadam.

Tests made in this same location with the North Dakota cone bearing equipment were inadequate and no results are reported. The subgrade contained considerable granular material. Limitations on the amount of subgrade that can be exposed for testing on a completed pavement result in an insufficient number of readings to obtain a comparison.

The subgrade soil consists of H.R.B. Class A-6 (6) having a liquid limit of approximately 28 and a plasticity index of approximately 12. The Standard A.A.S.H.O. compaction was 96.6 percent.

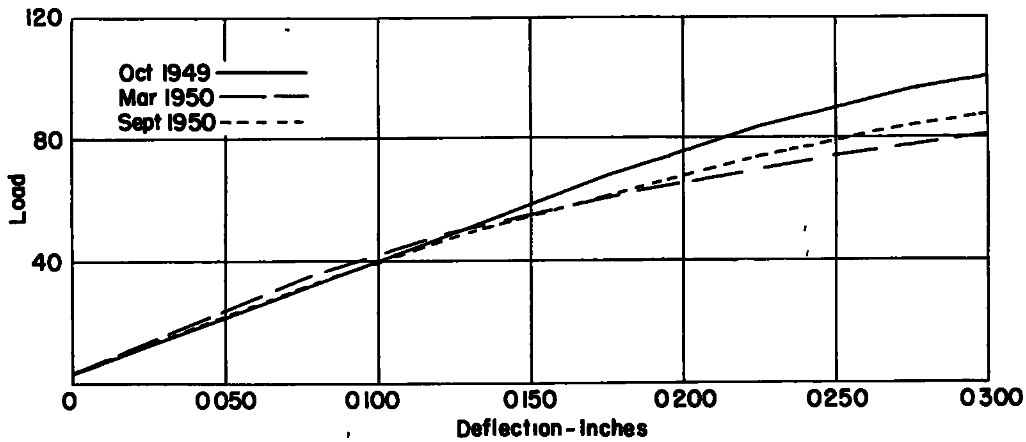


Figure 3. Average Tests on Subbase.

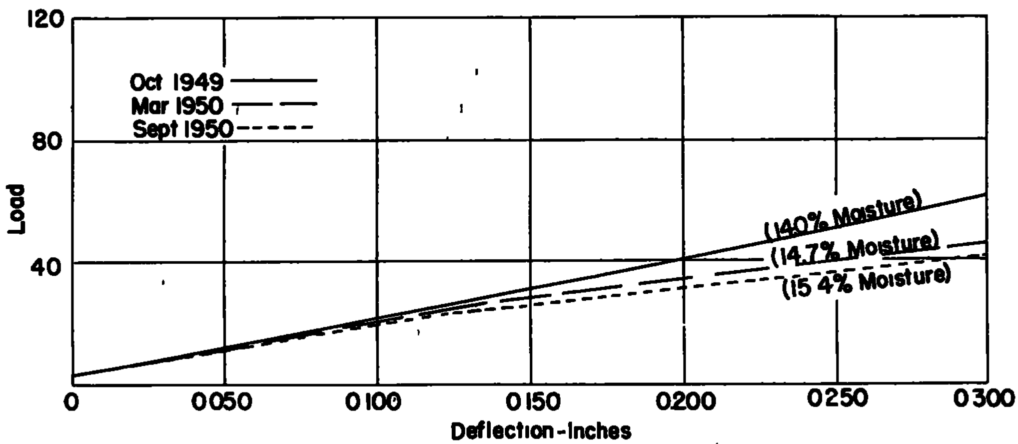


Figure 4. Average Tests on Subgrade.

THE EFFECT OF TEMPERATURE ON THE BEARING VALUE OF FROZEN SOILS

Miles S. Kersten, *Associate Professor of Civil Engineering, University of Minnesota*
and
Allen E. Cox, *Construction Engineer, Groves, Lundin, and Cox*

Many problems must be considered in the construction of buildings, roads, runways, and other structures in regions of permafrost. One plan followed in such areas is an attempt to retain the foundation soil in a frozen condition, with the idea that if such is accomplished, the frozen soil will remain firm and of high bearing value. This practice suggested the subject of this research--Is all frozen soil of approximately equal bearing value, and do the bearing characteristics vary any with changes in temperature?

Muller, in his collection of information on permafrost(1),has shown that the properties of ice are dependent upon temperature, as well as upon such other properties as orientation of ice crystals. Both the compressive strength and the shearing strength of ice increase for a decrease in temperature. Muller also citesdata concerning the strength of frozen soils. In general the properties of frozen soils follow the same trend as ice for changes in temperature. The effect of soil texture and moisture content are not very clear.

In the investigation reported herein, tests were made on four soils of widely varying textures, viz., sand, sandy loam, silt loam, and clay. Each soil was tested over a range of varying moisture contents and densities. A simple penetration bearing test was made and test temperatures were varied from about 10 F. to above 32 F.

SOILS TESTED

Four soils were tested: Soil P-4602, Fairbanks Silt Loam, a gray soil from the permafrost research area of the Corps of Engineers at Fairbanks, Alaska; Soil P-4604, Lowell Sand, a material furnished by the Corps of Engineers, New England Division, is a cohesionless, siliceous sand from a glacial outwash deposit at South Lowell, Massachusetts; Soil P-4713, Ramsey Sandy Loam, a local soil from Ramsey County, Minnesota; and Soil U-4701, Gumbo Clay, a local soil from near Wolverton, Minnesota. The characteristics of the soils are shown in Table 1.

BEARING TEST

The bearing test consisted essentially of placing soil at a known density and moisture content in a cylinder with a thermocouple, freezing the sample with a vertical steel rod at the top, and finally applying a load to the steel rod while recording load, penetration and temperature. The test was arbitrarily made similar to the California bearing-ratio test in that speed of penetration and points of penetration at which loads were read were the same for both tests.

Figure 1 shows a cross-section of the test cylinder. Eleven molds were in use.

Soil was mixed to the desired moisture content and compacted into all 11 molds at the desired density.

TABLE 1

	Textural Class		Mechanical Analysis						Modified	
Soil No.	U.S. Bur. of Chem. & Soils	Corps of Engrs	Gravel Over 2.00 *	Sand 0.05 to 2.00	Silt 0.05 to 0.005	Clay Under 0.005	Liquid Limit	Plasticity Index	Opt. Moist.	Max. Den
P-4604	Med. Sand	SW	0.0	100.0	0.0	0.0	--	N P.	12.2	119.0
P-4713	Sandy Loam	CL	0.4	53.6	27.5	18.5	24.6	9.3	9.0	127.5
P-4602	Silt Loam	ML	0.0	7.6	80 9	11.5	34.0	N.P.	15.5	110.0
U-4701	Clay	CH	0.0	9.2	37.5	53.3	77.0	53.5	19.8	107.1

*Size in millimeters

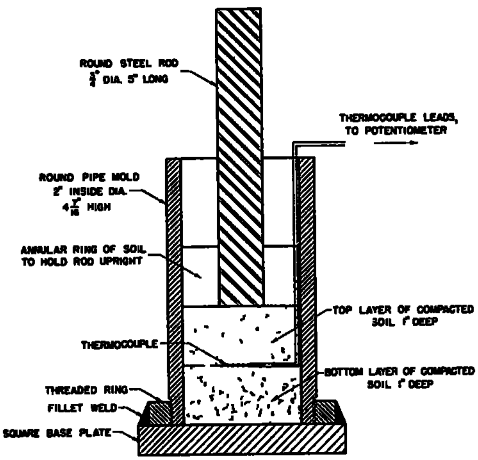


Figure 1. Cross-Section of Test Cylinder with Sample in Place

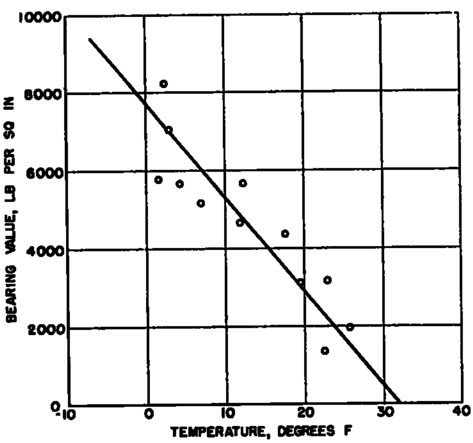


Figure 2. Bearing Value - Temperature Curve for Ice

They were placed in a cold-room at approximately -10F. for about 24 hours.

The bearing test was made in a hydraulic testing machine at a head speed of 0.05 in. per min. A cylinder was taken from the cold-room and the thermocouple leads attached to a potentiometer. Upon contact of the head with the 3/4 in. rod, an Ames dial was read to determine penetrations. Loads were read at 0.025, 0.050. 0.075, 0.1. 0.2, 0.3, 0.4, and 0.5 in. penetrations and temperatures at about the same intervals. Many of the tests were run to only a 0.2 in. penetration.

One cylinder was surrounded with granulated cork in the cold-room before being tested. This gave the lowest temperature test. Subsequent cylinders were permitted to warm up in the laboratory air before being tested. Attempts were made to have the temperatures at the time of test vary from below 0 F up to 32 F for seven or eight tests, and to have the other three or four tests made at temperatures above 32 F.

The test result selected for expression of the bearing value was the unit load at a penetration of 0.1 in. This selection was arbitrary, and no particular significance should be attached to the exact numerical values which result. A maximum unit load was usually obtained at either the 0.1 or 0.2 in. penetration. For comparative purposes the bearing value as defined above appears to be reasonable.

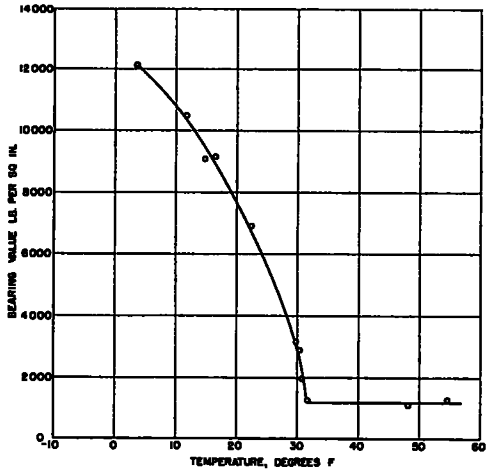


Figure 3. Bearing Value - Temperature Curve Sand, Test No. 4
Dry Density 109.8 lb. per cu. ft.
Moist. Cont. 9.0 Percent

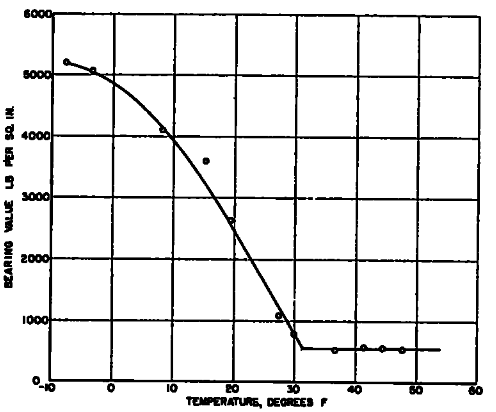


Figure 4. Bearing Value - Temperature Curve Sandy Loam, Test No. 2
Dry Density 116.3 lb. per cu. ft.
Moist. Cont. 9.6 Pe-cent

The temperature read at the time of 0.1 in. penetration was used to correlate the bearing values with temperature.

From five to eight moisture-density conditions were tested for the four soils. It was attempted to select these so that both the effects of moisture variations at a constant dry density and density variations at a constant moisture content could be ascertained.

Special tests were also made to determine the variation of temperatures in the test specimen and the bearing values for ice.

BEARING STRENGTH OF ICE

Bearing tests made on ice gave more irregular results than tests on frozen soils. (See Fig. 2.) A straight line plot through zero strength at 32 F seems reasonable. This curve is of interest for purposes of comparison with the strength of frozen soils.

BEARING STRENGTH OF SOILS

The series of bearing-value tests on the four soils gives a qualitative indication of the effects of temperature, texture, moisture content, and density. Typical test results for one series of tests on each soil are shown in Figures 3 to 6, inclusive. In any one of these series the soils were all at approximately the same density and moisture content, the only variable being the temperature at the time of the bearing test. For each of the soils

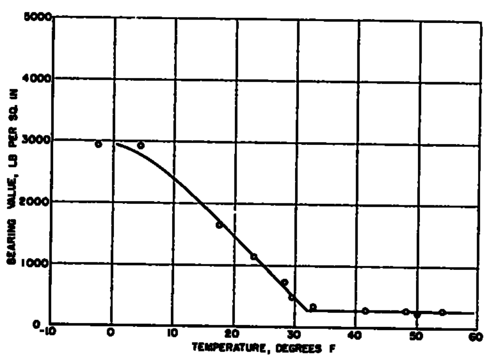


Figure 5. Bearing Value - Temperature Curve Silt Loam, Test No. 4
Dry Density 93.5 lb. per cu. ft.
Moist. Cont. 17.0 Percent

the results of tests made above freezing were about the same, and the curve is shown as a horizontal line for this temperature range. The tests on the frozen soil, however, show a wide variation, depending upon the temperature. Bearing values at 0 F, for example, are as much as 10 times those just below freezing. The increase in bearing strength with decrease in temperature is approximately a straight-line relationship with some decrease in the rate of increase-of-strength at lower temperatures.

Nearly all series of tests gave curves similar to those of Figures 3 to 6. The curves for all series of tests on each soil are plotted in Figures 7 to 10, inclusive. In Figure 7, for example, the five series of tests on the sand soil are shown. The individual test points are not shown. A study of these curves, together with the moisture contents and densities, gives an indication of the effect of the variables under consideration.

The point at which the strength curves for the temperature ranges above and below freezing intersect is of interest. For the sand (Fig.7), this is, in general, between 31 and 32 F, for the sandy loam (Fig.8), somewhat variable but on the average about 31F; for the silt loam (Fig.9), 31 to 32 F; but for the clay (Fig.10), several of the points are below 30 F, and the average is about 29 F. This value for the clay may be the result of a depressed freezing-point for a fine-grained soil, as has been discussed by Bouyoucos, Wintermeyer, and others. From appearance the clay seemed to be frozen up to a temperature of 32 F, but curves such as those of Figures 6 or 10 indicate that no gain in strength results from freezing until a temperature of less than 28 to 30 F is reached.

The effect of the dry density of a frozen soil on its bearing value may be illustrated by a study of the strength curves for the sand, Figure 7. Test series 2 and 4 are at about the same moisture content (9.34 and 9.00 percent) but widely different densities (94.7 and 109.8 lbs per cu ft). The high-density soil has a much greater strength (Curve 4) than the low-density soil (Curve 2). Similar relationships can be noted on Figures 8, 9, and 10. On Figure 8, three series of tests on the sandy loam at 9-plus percent moisture content and at 116.3, 120.9, and 125.2 lbs-per-cu-ft. densities show, in general, an increasing strength.

The effect of a variation in moisture content with an approximately uniform dry density can be studied in a similar manner. For

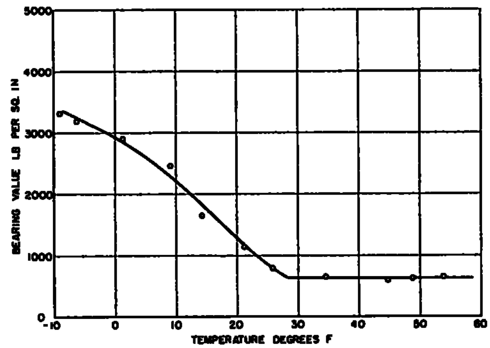


Figure 6. Bearing Value - Temperature Curve Clay Test No. 8 Dry Density 101.9 lb. per cu. ft. Moist. Cont. 20.2 Percent

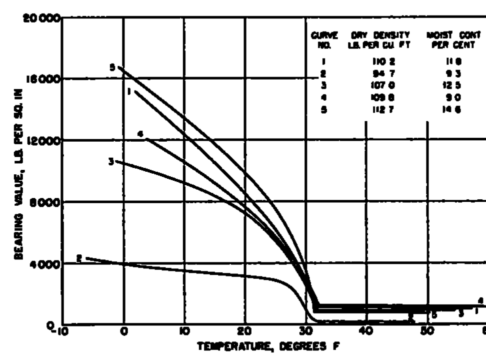


Figure 7. Summary of Bearing Value-Temperature Curves Sand

example, on the sand soil, Figure 7, test series 4, 1, and 5 are within 3 lbs. per. cu. ft. of the same density with moisture contents of 9.00, 11.78, and 14.55 percent. In the frozen range, the bearing strength shows an increase with this increase in moisture. The silt-loam soil (Fig. 9) shows a similar increase for test series 5, 3, and 1, which have moisture contents of 9.88, 16.55, and 22.62 percent for a density of about 101 lb. per. cu. ft. The sandy loam and clay soils do not show such distinct increases.

The bearing value of frozen soil is apparently also dependent upon the texture of a soil. (See Fig. 11.) The bearing-value temperature curves for each soil at the moisture-density test condition closest to the modified optimum moisture content and maximum density have been plotted together with the curve for ice as shown in Figure 2. It will be noted that the order of soils from lowest to highest strength is clay, silt loam, sandy loam, and sand. This is the order which might be expected according to the normal bearing characteristics of these soils. The strength of the frozen clay is appreciably less than that of the ice; that of the silt loam and sandy loam is approximately the same as ice; and that of the sand is two or more times greater than ice. The strength of the sand in the unfrozen state is low because of the lack of any appreciable surcharge in the bearing test as run.

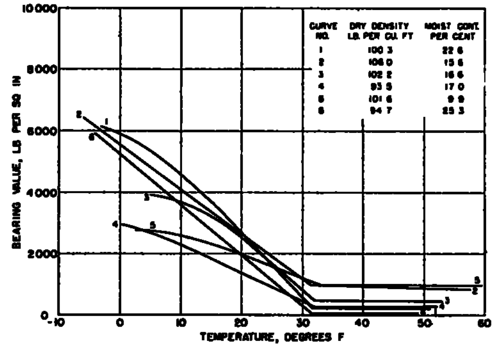


Figure 9. Summary of Bearing Value-Temperature Curves Silt Loam

VARIATION OF TEMPERATURE WITHIN SPECIMEN

It is realized that in the test method followed the temperature of the soil was changing as the penetration test was in progress and that the temperature was not uniform throughout the soil specimen. For tests made at low temperatures (0 F, plus or minus), the temperature, as measured at the center of the soil specimen, might change as much as 5 to 10 degrees during the

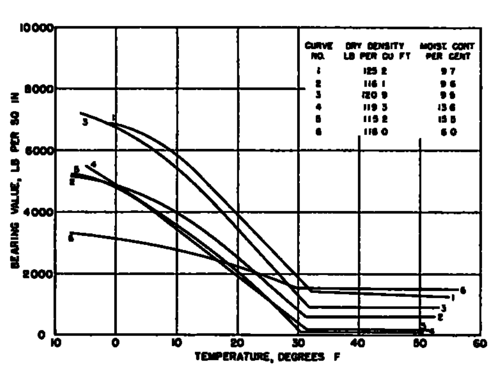


Figure 8. Summary of Bearing Value-Temperature Curves Sandy Loam

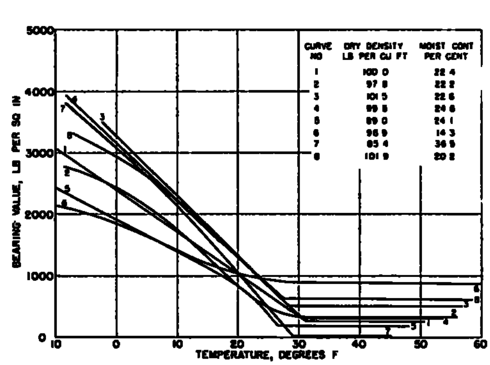


Figure 10 Summary of Bearing Value-Temperature Curves Clay

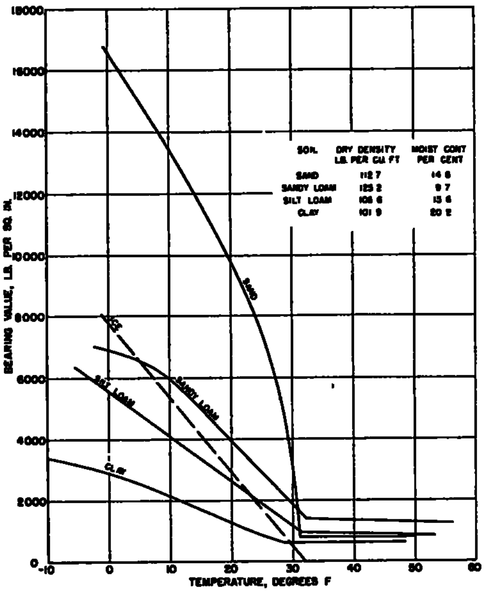


Figure 11. Bearing Value - Temperature Curves
Soil Approximately at Modified Optimum Moisture Content and Maximum Density

attainment of 0.1 in. penetration. For tests just below the freezing point the rate of temperature change was much slower.

Some special tests were made with five or six thermocouples placed in the specimen at various depths. Thermocouples in actual contact with the base plate or the 3/4-in. rod gave higher temperatures than those not in contact with the metal; the difference was in the nature of 10 degrees. Thermocouples within the soil and more than 1/8 in. from the metal bottom or plunger showed variations in the neighborhood of 5 degrees. Such tests suggest that the exact temperatures given in the various graphs should be considered only as approximate. The depth of soil beneath the plunger, which controls the penetration, is not known. Whatever this depth might be there would be some temperature variation within it; exact determination of an average would be difficult. The qualitative nature of the graphs is still held to be essentially correct. More exact temperature control and measurement might result in a shifting of such curves as shown in Figures 3 to 10 to the right or left, but their general form would not change.

SUMMARY AND CONCLUSIONS

An arbitrary test procedure has been developed and tests on four different soils at a wide range of moisture contents and densities have been made at temperatures from about 0 F to above 32 F. The test was a penetration type similar in character to the California bearing-ratio test but using much smaller equipment.

The soils tested cover a wide textural range, viz., sand, sandy loam, silt loam, and clay. The following conclusions seem warranted:

1. The test procedure was sufficient to portray the effects of differences in density, moisture content, soil texture and temperature on stability. The numerical values of the bearing value are for comparative purposes only and are not considered directly applicable to other conditions.
2. The bearing power of frozen soils varies markedly with their temperature. The bearing value increases as the temperature decreases below approximately 32 F. The strength at 0 F may be several times that at 30 F.
3. The bearing power of a frozen soil at a given moisture content and temperature increases with an increase in density.
4. The bearing power of a frozen soil at a given temperature and dry density increases, in general, with an increase in moisture content. For thawed soils an increase in moisture content results in a decrease in bearing value.

5. The bearing power of frozen soils may vary considerably according to their texture. The order of strengths of the four frozen soils tested in this program from least to greatest was clay, silt loam, sandy loam, and sand. The bearing strength of ice as compared to the soils was greater than the clay, about the same as the silt loam and sandy loam, and less than the sand.

ACKNOWLEDGMENT

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The authors gratefully acknowledge the help given by Prof. Frank B. Rowley and Prof. C. E. Lund of the Engineering Experiment Station.

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STATE OR PROVINCE	METHOD USED			SIGNS TO PROTECT PAINT		POLICE PATROL WET PAINT	PERSONS CROSSING ARRESTED	REFLECTORIZED PAINT				LENGTH OF DASHES FT	LENGTH OF GAP FT	WIDTH OF LINE	LBS BEADS PER GAL	COST BEADS PER GAL	SAVING/MILE FOR DASHED LINE
	PREMIX	BEADS ON PAINT	OTHER	SPACING	TYPE OF SIGNS			DRYING TIME MIN	TROUBLE W/GUN	VISIBILITY BEFORE WEAR	WEARING QUALITIES						
ALABAMA		YES		80' APART	2 X4"X8" BLOCKS	NO'	NO	35 - 45	NONE	GOOD	AVERAGE	15	25	4"	6		62.5%
ARIZONA	YES	YES		75 - 100'	FLAGS	NO	NO			GOOD	GOOD	15	25	4"	5-6	1.35-1.62	62.5%
ARKANSAS		YES		100'	BLOCKS & SIGNS	YES	AT TIMES	60	MINOR	GOOD	AVERAGE	20	40	4"	5-6		66.7%
CALIFORNIA		YES	EXPER	200-300'	INVERTED V SIGNS	NO	AT TIMES	10 - 20	MINOR	GOOD	GOOD	9	15	4"	6	0.98	62.5%
COLORADO	YES	YES		500'-1000'	SIGNS	AT TIMES	AT TIMES	60	MINOR	GOOD	GOOD	15	25	4"	5-6	0.85	62.5%
CONNECTICUT	YES			100'	RED FLAGS	NO	NO	20 - 45	MINOR	GOOD	GOOD	15	25	4"	5	1.04	62.5%
DELAWARE		YES		45	INVERTED "U"-SHAPED MARKERS	ON REQUEST	YES	30	NONE	GOOD	GOOD	15	30	4"	6	0.84	66.7%
FLORIDA	YES	YES	OVERLAY	25'	Z-BARS (RUBBER)	NO	NO	60		GOOD	AVERAGE	15	25	4	6		62.5%
GEORGIA		YES		50	4"X4"X12" BLOCKS	YES	AT TIMES	40 - 60	MINOR	AVERAGE	GOOD	20	20	4"	6		50%
IDAHO		YES			3-SIDED BLOCKS "KEEP OFF"	NO	NO	15 - 20	MINOR	AVERAGE	AV - POOR	20	30	4	5¼	1.15	60%
ILLINOIS		YES		200'	18"X10" TENTS "WET PAINT"	NO	NO	20 - 30	MINOR	GOOD	VARIABLE	NOT	USED	5"	6	1.20	NOT USED
INDIANA		YES		50	FLAGS	AT TIMES	NO	10 - 20	NONE	GOOD	GOOD	NOT	USED		6		NOT USED
IOWA		YES			NONE	NO	AT TIMES	30 - 60				15	30	3"	4	0.64	66.7%
KANSAS		YES			NONE	YES	NO	15		GOOD	AVERAGE	15	35	4"	6	0.90	70%
KENTUCKY	YES	YES		15'-25'	PYRAMIDS, FLAGS	NO	NO	30	NONE	GOOD	AVERAGE	15	25	4"	6	1.20	62.5%
LOUISIANA		YES		200'	14"X20" SIGNS	NO	NO	40	CLOGS	GOOD	POOR	15	25	4"	6	0.81	62.5%
MAINE	YES	YES		FLAGS AT START OF LINE		YES	NO	30	NONE	GOOD	GOOD	15	25	4"	6	0.90	62.5%
MARYLAND		YES		1000'	TRIPOD SIGNS	YES	YES	60	NONE	AVERAGE	GOOD	30	30	4"	6	0.75	50%
MASSACHUSETTS		YES			Z - GUARDS	NO	WARNED	45	MINOR	GOOD	GOOD	15	25	4"	6		62.5%
MICHIGAN		YES		50	INVERTED TIN V-8"X7½" HIGH	YES	NO	20 - 30	NONE	AVERAGE	AVERAGE	20	30	4"	6	0.83	60%
MINNESOTA	YES			150	FLAGS	NO	NO	30 - 60	MINOR	GOOD	GOOD	10	40	4"	4½		80%
MISSISSIPPI		YES		40 - 200'	FLAGS	AT TIMES		30	NONE	GOOD	GOOD	15	25	4"	5	0.75	62.5%
MISSOURI		YES		75 - 100	2 X 6 BLOCK	YES		20 - 30	NONE	GOOD	AVERAGE	9	18	4"	5	0.95	66.7%
MONTANA	YES			150	RUBBER CONES	YES	YES	20	CLOGS	AVERAGE	AVERAGE	20	30	3"-4"			60%
NEBRASKA	YES				FLAGS ON STAFF	NO	NO	45		GOOD	GOOD	15	25	4	4-6	1.00	62.5%
NEVADA			EXPER									15	25	4"			62.5%
NEW HAMPSHIRE		YES		50' - 100'	FLAGS	AT TIMES	AT TIMES	45	MINOR	GOOD	GOOD	15	25	4"	6		62.5%
NEW JERSEY		YES		50	BLOCKS & FLAGS	NO	NO	30	MINOR	GOOD	GOOD	70	70	4"	6	0.90	50%
NEW MEXICO	YES				SIGNS	NO	NO	30 - 45	NONE	AVERAGE	GOOD	15	25	4"	4¼		62.5%
NEW YORK	YES	YES		200	BLOCKS	YES	WARNED	20	NONE	GOOD	AVERAGE	15	25	4	5	0.70	62.5%
NORTH CAROLINA	YES	YES				NO	NO	20	NONE	AVERAGE	POOR	15	25	4"	4½	0.68	62.5%
NORTH DAKOTA	YES			500	SIGNS	NO		30	NONE	GOOD	AVERAGE	20	40	4"			66.7%
OHIO	YES	YES			Z - GUARDS & PLASTIC PYRAMIDS	YES	YES	30 - 60	MINOR	GOOD	GOOD			4"	4	0.55	
OKLAHOMA	YES	YES	-	20	BLOCK & RED CLOTH	YES	YES	15	NONE	AVERAGE	AVERAGE	20	40	4"	5	1.00	66.7%
OREGON	YES	YES		50 - 100'	SIGNS	NO	NO	10	NONE	GOOD	GOOD	15	25	3" & 4"	6	1.20	62.5%
PENNSYLVANIA		YES		50'	FLAGS	YES	YES	50	MINOR	GOOD	GOOD	15	25	4"	6		62.5%
RHODE ISLAND	YES	YES		75	METAL SIGNS	SOME	YES	20 - 60	NONE	AVERAGE	GOOD	16	32	6"	6	1.20	66.7%
SOUTH CAROLINA		YES		100	BLOCKS	NO	NO	20	NONE			65	65	4"	6	0.66	50%
SOUTH DAKOTA	YES				SIGNS & FLAGMEN	AT TIMES	WARNED	20	MINOR	AVERAGE	AVERAGE			4"			
TENNESSEE	YES			25	FLAGS & CONES	NO	NO	45	NONE	AVERAGE	GOOD			4½"	4		
TEXAS		YES	EXPER PREMIX		RED FLAGS	NO	NO	30	NONE	AVERAGE	AVERAGE	20	40	4"	6		66.7%
UTAH	YES	YES		200	RED FLAGS	NO	NO	15 - 20	MINOR	GOOD	AVERAGE	15	25	4"	6	1.02	62.5%
VERMONT	YES	YES		50 - 100	LINE GUARDS	NO	NO	20	MINOR	GOOD	GOOD	15	35	5"			70%
VIRGINIA	YES	YES		60 - 1500	SIGNS & GUARDS	AT TIMES	AT TIMES	60 - 120	MINOR	AVERAGE		60	60	4"	6	0.82	50%
WEST VIRGINIA		YES		20 - 60	LINE GUARDS	NO	NO	60 - 120		AVERAGE	AVERAGE	20	20	4'	6	1.80	50%
WASHINGTON	YES	YES	OVERLAY		SIGNS & CONES	YES	YES	10 - 30	NONE	GOOD	GOOD	15	25	4"	6	1.05	62.5%
WISCONSIN	YES	YES		300	FLAGS & BLOCKS	NO	RARELY	30 - 60	FREQUENT	GOOD	GOOD	15	35	4"	6	0.95	70%
WYOMING		YES		1300'	TENTS & CONES	NO	NO	10	FREQUENT	GOOD	AVERAGE	15	25	4"	5	0.80	62.5%
HAWAII	PART	PART		40 - 60	RUBBER CONES	NO	NO	20 - 45	MINOR	AVERAGE	GOOD	6	9	4"	6½	1.62	60%
BRITISH COLUMBIA		YES		35'	FLAGS ON STAND	NO	YES	30	MINOR	GOOD	AVERAGE	15	25	4"	7	3.25	62.5%
MANITOBA		YES		40'	RED BLOCKS	NO	NO	20	MINOR	GOOD	GOOD	12	38	4½"	7		75%
NOVA SCOTIA		YES		40	BLOCKS & FLAGS	YES	WARNED	30	MINOR	GOOD	AVERAGE	10-20	20-100	4"	7	2.24	67%-83%
ONTARIO	YES	YES		20	BLOCKS & FLAGS	NO	NO	30	NONE	AVERAGE	GOOD	10	20	5"	6-7		66.7%
NEW BRUNSWICK		YES			SIGN EACH 4 MILES	AT TIMES	AT TIMES	30	MINOR	GOOD	GOOD	10	50	4"	7	2.45	83%

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STATE OR PROVINCE	PLAIN WHITE PAINT						ASPHALT PAINT						REFLECTORIZED WHITE						REFLECTORIZED YELLOW					
	MANUFACTURER	COST/GAL	GAL /MI	COST/MI	LABOR/MI	TOTAL/MI	MANUFACTURER	COST/GAL	GAL /MI	COST/MI	LABOR/MI	TOTAL/MI	MANUFACTURER	COST/GAL	GAL /MI	COST/MI	LABOR/MI	TOTAL/MI	MANUFACTURER	COST/GAL	GAL /MI.	COST/MI	LABOR/MI	TOTAL/MI.
ALABAMA	H	1.50	6 75	10 12	6 75	16 87													H	2 60	6 75	17.55	8 51	26 06
ARIZONA		2 75												3 95										
ARKANSAS	J	3 00	7	21 00	12 00	33 00							J	4 50	15	67 50	12 50	80 00	J	4 50	15	67 50	12 50	80 00
CALIFORNIA	K	1 80	6	10 80	10 00	20 80							K	2 78	6	16 56	10 00	26 56						
COLORADO	L	1 65	7	11 55	19 70	31 25							J	3 22	19	61 18	19 70	80 88	YY	3 53	19	67 07	19 70	86 77
CONNECTICUT													X	3 08	8 3	25 54	4 49	30 03						
DELAWARE													J	3 80	9 2	35 00	38 00	73 00						
FLORIDA																								
GEORGIA	BOUGHT ON BID	1 95	12-14	24 00	7 00	31 00							BOUGHT ON BID	2 98	12-14				BOUGHT ON BID	4 15	12-14			
IDAHO	M & N	1 60	8-7½	12 38	19 54	31 92																		
ILLINOIS		1 60	20	32 00	7 00	39 00		0 40	20	8 00	7 00	15 00								3 50	20	70 00	10 00	80 00
INDIANA													J	4 10	16	65 60		APPROX 139 00	J	4 45	16	71 20		APPROX 150 00
IOWA		1 60	6½				IOWA HWY SPEC	0 39	14			8 04	BOUGHT ON BID	2 44	6 5			15 69	BOUGHT ON BID	2 94	6			
KANSAS													X X	2 70	7 85	21 20	6 67	27 87						
KENTUCKY	P	1 49	9 6	14 30	2 13	16 43							Y	3 98	15	59 70	8 00	67 70		3 39	15			
LOUISIANA	H	1 55	18	27 90	7 99	35 89														2 99	18	53 82	7 99	61 81
MAINE		1 45	12-14											3 50	16					3 50	16			
MARYLAND		1 19	23										X	1 94	23	43 62	6 38	50 00						
MASSACHUSETTS													J	3 15	10									
MICHIGAN		1 51	15				H H	0 38	10	3 80	8 00	11 80	X	2 34	15	35 07	8 00	43 07		2 45	15			
MINNESOTA	Q	1 58	15	23 70				0 42	15					3 28	15				Y Y	3 81	15	57 15		
MISSISSIPPI	BOUGHT ON BID	1 50	7 5	11 25	7 65	18 90		0 45																
MISSOURI		1 59	20				BOUGHT ON BID	0 31	16	4 96	3 00	7 96		2 40	21				BOUGHT ON BID	2 60	21	54 60	16 38	70 98
MONTANA													P&SS	2 35	12	28 20	8 00	36 20						
NEBRASKA	P	1 35	14	18 90	5 85	24 75	X	0 46	14	6 44	5 85	12 29							P	2 10	13	27 30	5 85	33 15
NEVADA	N	1 90	6	11 40	12 72	24 12																		
NEW HAMPSHIRE	R	1 56	10	15 60	15 13	30 73							J	3 04	15	45 60	16 58	62 18	J	3 06	15	45 90	16 58	62 48
NEW JERSEY	BOUGHT ON BID	1 48	17	25 16	38 20	63 36							BOUGHT ON BID	2 34	17	39 78	25 74	65 52						
NEW MEXICO	M	2 20	10	22 00	11 29	33 29							Y Y	3 95	6	23 70	11 50	35 20	Y Y	3 95	15	59 25	11 50	70 75
NEW YORK	S	1 45	6 2	9 00	3 60	12 60							J	3 90	6 2	24 18	3 27	27 45						
NORTH CAROLINA	PRISON	2 00	11	22 00									PRISON	2 15	15	32 25								
NORTH DAKOTA		1 36	7	9 52	6 38	15 90																		
OHIO	T&ZZ	1 27	12	15 24	18 95	34 19							T	2 00	15	30 00	18 95	48 95	T & Z	2 20	15	33 00	18 95	51 95
OKLAHOMA							J J	0 17	70	11 90	23 10	35 00	Y Y	3 90	17	66 30	62 70	129 00	Y Y	3 90	17	66 30	62 70	129 00
OREGON	U	1 70	10	17 00	15 66	32 66													J	3 60	10	36 00	24 00	60 00
PENNSYLVANIA		1 80	10 5	18 90	9 10	28 00								2 19	13	28 47	29 53	58 00						
RHODE ISLAND	BOUGHT ON BID	2 30	18	41 40	10 60	52 00							Y Y	3 65	20	73 00	6 00	79 00						
SOUTH CAROLINA																								
SOUTH DAKOTA																								
TENNESSEE							PRISON	1 00	14	14 00	29 00	43 00	J&YY	3 95	14	55 30	29 00	84 30	J&YY	4 00	14	56 00	29 00	85 00
TEXAS													J	3 38	17 50	59 15	49 97	109 12						
UTAH	M-UU	1 38	14	19 32	4 45	23 77																		
VERMONT	R	1 40	11	15 40	9 39	24 79																		
VIRGINIA	V	1 63	14	22 82	10 06	32 88							V	2 47	16	39 52	11 23	50 75						
WEST VIRGINIA		1 55	9 84			24 92							J	4 38	13 45			66 99						
WASHINGTON	YELLOW PAINT BOUGHT ON BID	1 35	15	23 30	9 11	32 41													BOUGHT ON BID	2 83	13	36 80	9 11	45 91
WISCONSIN		1 75	10					36	7					2 90	13					3 10	13			
WYOMING	YELLOW PAINT W	1 99	6	11 94	4 88	16 82													W	2 79	6	16 74	4 88	21 62
HAWAII	VARIOUS	2 75	15	41 25	13 42	54 67							VARIOUS	4 10	16	65 60	19 62	85 22						
BRITISH COLUMBIA		4 50	15										J	8 05	5	40 25	14 75	55 00						
MANITOBA													J	6 32	16	101 12	42 40	143 54						
NOVA SCOTIA													J	5 75	13 2	75 90	33 66	109 56						
ONTARIO		2 70	10	27 00	19 60	46 60								5 74	10	57 40	19 60	77 00						
NEW BRUNSWICK													J	5 95	10	59 50	25 50	85 00						

STATE OR PROVINCE	WHERE STRIPING EQUIP WAS OBTAINED	DATE ACQUIRED	TIME USED	WEIGHT	COST	VEHICLES NEC FOR OPERATION TYPE & SIZE	OVERALL WIDTH	PUSHED, TRAILED SELF-PROPELLED	NO PAINT TANKS	GALLONS CAPACITY	HOW PAINT IS LOADED INTO TANKS	PRESSURE OR FLOW NOZZLES
ALABAMA	PURCHASED STRIPER A	NOV 1949	APPROX 1 YR		$10,318	PAINT TRUCK–2 PICK-UP TRUCKS	7'-4"	SELF-PROPELLED	3	60	5 GAL CONTAINERS	PRESSURE
ARIZONA	PURCHASED STRIPER B	1940	APPROX 10 YRS					SELF-PROPELLED	1	12	PAIL	PRESSURE
ARKANSAS	PURCHASED STRIPER B	FEB 1950	APPROX 1 YR		6,496	1 5 TON TRUCK–1 PICK-UP TRUCK	7'-0"	TRAILED	3	1-250 2- 60	HAND PUMP	PRESSURE
CALIFORNIA	BUILT IN STATE SHOP	1948	2 YRS	1,600 LBS	6,000	2 TON TRUCK- 1 TON TRUCK	5'-7"	PUSHED	4	2- 80 2- 30	PUMPED FROM MIXING TANK	PRESSURE
COLORADO	BUILT IN STATE SHOP	1948	2 YRS	1,000	12,500	PAINT TRUCK, PICK-UP, PANEL TRUCK	6'-0"	PUSHED	4	60	PAIL	PRESSURE
CONNECTICUT	BUILT IN STATE SHOP	1949	1 YR	18,000	12,000	1 LINE PAINTER –(2) 3 TON TRUCKS	5'-4"	SELF-PROPELLED	1	1-375	PUMPS	PRESSURE
DELAWARE	PURCHASED STRIPER C	JUNE 1947	3 YRS	800	830	1 5 TON TRUCK	2'-11"	SELF-PROPELLED	1	12	PAIL	PRESSURE
FLORIDA	PURCHASED STRIPER B	1935	15 YRS			1 5 TON TRUCK		SELF-PROPELLED	2	55	PUMPS	PRESSURE
GEORGIA	BUILT IN STATE SHOP	1948	2 YRS	5000	5,000	1 5 TON TRUCK 1 TON TRUCK		SELF-PROPELLED	2	1-100 1-150	AIR PUMP	PRESSURE
IDAHO	BUILT IN STATE SHOP	1946	4 YRS	1,900	1,800	1 5 TON TRUCK PICK-UP, STA WAGON, PAINT CART		PUSHED	3	2- 60 1- 40	AIR PUMP	PRESSURE
ILLINOIS	PURCHASED STRIPER E&G	1941	9 YRS	6000	5 000	STRIPER 3 PICK-UPS MATERIAL TRUCK	4'-0"	SELF-PROPELLED	2	1- 70 1-250	AIR PUMP	PRESSURE
INDIANA	PURCHASED STRIPER D	1934	16 YRS	4,500	3,245	DODGE TRUCK W/WHITE CENTER LINER	4 -2"	SELF-PROPELLED	1	150	PAIL	PRESSURE
IOWA	BUILT IN STATE SHOP	1948	2 YRS	10,000	5 800	(2) 2-TON TRUCKS 1 PICK-UP TRUCK	8'-0"	SELF-PROPELLED	3	3-60	PUMP	FLOW
KANSAS	BUILT IN STATE SHOP	1939-49-50	1-11 YRS	750	3 000	1 5 TON TRUCK – 1 SUPPLY TRUCK	4 –8"	PUSHED	2	80	PUMP	PRESSURE
KENTUCKY	PURCHASED STRIPER B	NOV 1947	3 YRS	12,000	5,500	1 5 TON TRUCK	8'-0"	SELF-PROPELLED	3	1-120 2- 60	PUMP	FLOW
LOUISIANA	PURCHASED STRIPER B	APRIL 1946	4 YRS	6,600	5,650	(2) 1 5 TON TRUCKS, 2 PICK-UP TRUCKS	7 - 4"	TRAILED	4	60	PAIL	PRESSURE
MAINE	PURCHASED STRIPER A	MAY 1949	1 YR	10,000	9,000	(1) 1 TON TENDER	8 –0"	SELF-PROPELLED	3	60	PAIL	PRESSURE
MARYLAND	BUILT IN STATE SHOP	1935	15 YRS	14 000	3.750	3 TON TRUCK	8 –0"	SELF-PROPELLED	2	1-450 1-250	PRESSURE	PRESSURE
MASSACHUSETTS	PURCHASED STRIPER B	1945	5 YRS	500	850	1 MATERIAL TRUCK	3 –0"	SELF-PROPELLED	1	12	PAIL	PRESSURE
MICHIGAN	BUILT IN STATE SHOP	1947–1950	1-3 YRS	15,000	7,500	1 GMC -350 SERIES	7'-0"	SELF-PROPELLED	3	60	PUMP	PRESSURE
MINNESOTA	PURCHASED STRIPER E	1948	2 YRS	12 000	9,500	2 5 TON TRUCK, PICK-UP TRUCK	7'-6"	SELF-PROPELLED	3	60	PAIL	PRESSURE
MISSISSIPPI	PURCHASED STRIPER B	VARIOUS	SEVERAL	400	750	1- STRIPER & MATERIAL TRUCK	3'-0"	SELF-PROPELLED	1	12	PAIL	PRESSURE
MISSOURI	BUILT IN STATE SHOP	1949	1 YR	800	700	PICK-UP TRUCK & 1 5 TON TRUCK	STD	SELF-PROPELLED	1	65	PUMP	FLOW
MONTANA	PURCHASED STRIPER A	AUG 1950	4 MOS	175	2 439	3 TON PLATFORM TRUCK	9'-6"	TRAILED	2	60	PAIL	PRESSURE
NEBRASKA	BUILT IN STATE SHOP	MAY 1950	6 MOS		1,500	1 HEAVY TRUCK, PICK-UP, 1 PANEL	STD	PUSHED	4	60	HAND PUMP	PRESSURE
NEVADA	BUILT IN STATE SHOP	1948	2 YRS	6,000	11 000	2 TON TRUCK, STRIPER, 1 PICK-UP	7'-6"	PUSHED	3	50	PAIL	PRESSURE
NEW HAMPSHIRE	PURCHASED STRIPER B	1949	1 YR	4,000	7 800	(1) 2-TON TRUCK 1 PICK-UP TRUCK	8'-0"	TRAILED	3	60	PAIL	PRESSURE
NEW JERSEY	PURCHASED STRIPER B	1948	2 YRS	600	800	15 TON TRUCK PICK-UP TRUCK	3 - 0"	SELF-PROPELLED	1	12	PAIL	PRESSURE
NEW MEXICO	PURCHASED STRIPER A	1946	4 YRS		3,085	PICK-UP, 2 TON DELIVERY, 2 TON STRIPER 1 5 TON STOR	8 - 0"	TRAILED	4	60	PAIL	PRESSURE
NEW YORK	BUILT IN STATE SHOP	1938	12 YRS		1 600	PUSHMOBILE 18' 2 5 TON STAKE TRUCK	7'- 6"	PUSHED	2	60	PAIL	PRESSURE
NORTH CAROLINA	PURCHASED STRIPERS A & B	1947–1949	1-3 YRS	VARIABLE	1,-5 000	TWO TRUCKS	STD	SELF-PROPELLED	2	10 & 35	PAIL	PRESSURE
NORTH DAKOTA	BUILT IN STATE SHOP	1936	14 YRS		4 000		4 - 0"	TRAILED	1	100	HAND PUMP	FLOW
OHIO	PURCHASED STRIPER B	1949	1 YR	22,000	16 000	1 STRIPER, (2) 1 5 TON TRUCKS	8'- 0"	SELF-PROPELLED	1	700	PUMP	PRESSURE
OKLAHOMA	PURCHASED STRIPER F	OCT 1947	3 YRS		4 275	(2) 15 TON, (1) 75 TON TRUCKS	6 - 0"	SELF-PROPELLED	3	60	PAIL	PRESSURE
OREGON	BUILT IN STATE SHOP	1940	10 YRS	250	600	TRUCK & STRIPER 22 LONG	4 - 0"	PUSHED	2	60	CENTRIFUGAL PUMP	PRESSURE
PENNSYLVANIA	PURCHASED STRIPER B	1950	6 MOS	18, 000	7,500	TWO-TON TRUCKS	8' - 0"	SELF-PROPELLED	2	60	HAND OR PUMP	PRESSURE
RHODE ISLAND	PURCHASED STRIPER B	1941	9 YRS		800	(2) 1 5 TON TRUCKS		SELF-PROPELLED	1	12	PAIL	PRESSURE
SOUTH CAROLINA	BUILT IN STATE SHOP	1935	15 YRS		2,000	PICK-UP TRUCK	4 - 6"	SELF-PROPELLED	1	45	PAIL	PRESSURE
SOUTH DAKOTA	PURCHASED STRIPER A	NOV 1947	2 YRS		2 290	(2) 15 TON TRUCKS	8'- 0"	TRAILED	2	150	PAIL	PRESSURE
TENNESSEE	PURCHASED STRIPER A	1948	2 YRS	4 500	4 500		4 - 0"	SELF-PROPELLED	2	30	PAIL	PRESSURE
TEXAS	PURCHASED STRIPER B	1947	3 YRS		767	1 STRIPER, 1 SERVICE TRUCK	2 - 8"	SELF-PROPELLED	1	12	PAIL	PRESSURE
UTAH	PURCHASED STRIPER B	JUNE 1950	6 MOS	14,8 60	15,524	(1) 2 TON STRIPER & 2 PICK-UP TRUCKS	7'- 6"	SELF-PROPELLED	3	1-250 2- 75	PUMP	PRESSURE
VERMONT	PURCHASED STRIPER B	1946-1947	3-4 YRS		1 650	15 TON TRUCK & 1 PICK-UP TRUCK	9'- 0"	TRAILED	1	60	PAIL	PRESSURE
VIRGINIA	PURCHASED STRIPER B	1946	2 YRS	10,050	5,500	(1) 5 TON TRUCK	7'- 6"	SELF-PROPELLED	3	60	POWER PUMPS	PRESSURE
W VIRGINIA	PURCHASED STRIPER B	1940-1949	1-10 YRS	6,500	8-10,000	25 TON FLAT BED TRUCKS	7'- 6"	SELF-PROPELLED	2	60	PAIL	PRESSURE
WASHINGTON	BUILT IN STATE SHOP	1940-1949	1-10 YRS		6-11 000	(1) 4 TON TRUCK EQUIPPED	7 - 0"	SELF-PROPELLED	2	1-100 1-400	PUMP	PRESSURE
WISCONSIN	PURCHASED STRIPER E	1946-1949	1- 4 YRS	8-15 000	5,000	1 5 TON TRUCK	7' - 0"	SELF-PROPELLED	3	55	AIR PUMP	PRESSURE
WYOMING	PURCHASED STRIPER B	1946	4 YRS	4 000	5 000	1 5 TON TRUCK & 2 PICK-UP TRUCKS	6'- 0"	TRAILED	3	300	PAIL	PRESSURE
HAWAII	PURCHASED STRIPER B	1950	8 MOS		950	1 PICK-UP TRUCK		SELF-PROPELLED	1	12	PAIL	PRESSURE
BRITISH COLUMBIA	PURCHASED STRIPER B	1948	2 YRS		16 000	STRIPER & PICK-UP TRUCK	STD	SELF-PROPELLED	2	150*	PUMPS	PRESSURE
MANITOBA	MARKINGS PLACED BY CONTRACTOR							TRAILED	2	1- 180* 1- 200	PUMPS	PRESSURE
NOVA SCOTIA	MARKINGS PLACED BY CONTRACTOR							SELF-PROPELLED	2	202*	PUMPS	PRESSURE
ONTARIO	PURCHASED STRIPER B	1947	3 YRS	2 000	1 600	3 TON TANDEM & 2 TON STAKE BODY	8"	TRAILED	1	375*	PUMPS	PRESSURE
NEW BRUNSWICK	BUILT IN HIGHWAY SHOP	MAR 1950	6 MOS	14,000	16 500	(1) 3 TON TRUCK	7"	SELF-PROPELLED	2	1- 200* 1- 250*	PUMPS	PRESSURE
					TOTAL $280 000 AVG 5 600							

* IMPERIAL GALLON

PREPARED BY COMMITTEE ON ROADWAY PAVEMENT MARKINGS.
HIGHWAY RESEARCH BOARD, NATIONAL RESEARCH COUNCIL JANUARY 1951

STATE OR PROVINCE	PERSONNEL ONE UNIT	PRELIM MARKING	COST OF PRELIM. MARKINGS/MI. CENTER LINE	BARRIER LINE	POLICE ESCORT	OTHER ESCORT	GAPS LEFT IN LINES X-STREETS	X-ROADS	MARKING SPEED MPH	AVG MPD MARKED	ADD COST/MILE USING 2 COLORS	SAVING/MILE ONE COLOR	NO TRIPS TO PAINT TWO-LANE HIGHWAY	FREQUENCY OF PAINTING PLAIN	REFLECTORIZED
ALABAMA	7	YES	$8 00		NO	CAR AHEAD	YES	NO	8	30			1	2 YRS	18 MOS
ARIZONA		YES			NO	SIGNS AHEAD	YES	YES							
ARKANSAS	4-5	YES	$7 35	$10 25	YES	SIGNS AHEAD	YES	NO	8	12-20	NONE		2	12-18 MOS	12-18 MOS
CALIFORNIA	3	YES	$18 00	NO EXTRA	NO	SIGNS AHEAD	YES	YES	6	20	NONE		1	1 YR	2 YRS
COLORADO	5	YES			YES		NO	NO	10	30	$510		1	6-12 MOS	1 YR
CONNECTICUT	7	NO			NO	SIREN & FLASHER	YES	YES	8-10	25	NOT USED		1	NOT USED	1 YR
DELAWARE	1	YES			NO	SIGNS	NO	YES	8	5-10			3	4-6 MOS.	6-12 MOS
FLORIDA	5	YES			NO	SIGNS	YES	NO	15	40			1	1-3 YRS	1-3 YRS
GEORGIA	10	YES	$5 00	$5 00	YES		YES	YES	8-10	25-40			1	1 YR	1 YR
IDAHO	8	YES			NO	FLAGMAN	YES	NO	6-10	TO 50			1	1-2 YRS	
ILLINOIS	4-5	NO			YES		YES	NO	5-10	25		$45 00	1	1 YR	1 YR
INDIANA	2	YES			NO	FLAGMAN SIGNS	YES	YES	20	15-30			1	NOT USED	1 YR
IOWA	7	YES			YES			NO	10-15	50-60			2	1-2 YRS	1-2 YRS
KANSAS	4	YES			YES		NO	NO	8-13	25-40		SLIGHT	1		6-24 MOS
KENTUCKY	3	NO			NO	TRUCK AHEAD	YES	YES	15-20	75-100	NEGLIGIBLE		1	1 YR	VARIABLE
LOUISIANA	10	YES	$2 50	$5 40	YES	FOLLOW & LEAD TRUCK	YES	YES	5	11	$11 34	$11 34	1	1 YR	1 YR
MAINE	4	NO			YES	FLASHERS	YES	NO	10-12	40-50		NONE	1	1 YR	18 MOS
MARYLAND	2	YES	$2 50	$1 25	YES		YES	YES	12	20	$9 30	$9 30	1	8-12 MOS	
MASSACHUSETTS	6	YES			NO	SIGNS	YES	YES	2	5			3	NOT USED	1 YR
MICHIGAN	6	YES		$0 70	YES		MAJOR	MAJOR	5	25-30	$1 65		1		1 YR
MINNESOTA	6	NO			NO	TRUCK AHEAD	YES	YES	12	75-100	NONE	NONE	1	1-2 YRS	1-2 YRS
MISSISSIPPI	4	NO			NO	SIGNS, FLAGS	YES	NO	3	8				18 MOS	18 MOS
MISSOURI	2	YES			YES		YES	NO	8-12	15-30			1-2	1 YR	1 YR
MONTANA	3	YES	$0 75	$1 00	YES		NO	NO	10	40	NONE	NONE	1	1 YR	1 YR
NEBRASKA	11	YES	$1 00		NO	FLAGMEN	NO	NO	12-16	40			1	1 YR	1 YR
NEVADA	5	YES	$35 00	NO EXTRA	NO	FOLLOW & LEAD TRUCK	YES	YES	5-6	30-35			1	6-12 MOS	
NEW HAMPSHIRE	4	25%			YES	SIGNS & FLAGS	YES	YES	7-12	9-20			1	12-18 MOS	15 MOS
NEW JERSEY	5-6	YES	SLIGHT		NO	SIGNS & FLAGS	YES	YES	3	20	NOT USED		1	6-12 MOS.	6-12 MOS
NEW MEXICO	6	YES	$2 50	$15 00	YES	SIREN & FLASHER	YES	YES	5-12	35	NONE		1	6-12 MOS	2 YRS
NEW YORK	5	YES	$2 00	$2 00	YES	SIREN & FLASHER	YES	YES	10	35	NOT USED		1	6 MOS	1 YR
NORTH CAROLINA	3-9	YES			NO	TRUCK AHEAD	YES	YES	3-10	10				1 YR	1 YR
NORTH DAKOTA	2	YES			NO	FLAGMEN	YES	NO	6	50			1	1 YR	2 YRS
OHIO	2	YES	$2 75	NO EXTRA	YES	SIREN & FLASHER	YES	YES	7-10	25-70	NONE		1	1 YR	1 YR
OKLAHOMA	2	YES	$2 65	$2 85	YES			NO	4	25	NEGLIGIBLE	NEGLIGIBLE	1	NOT USED	1 YR
OREGON	8	NO			NO	SIGNS	YES	NO	10	20-25			1	YR	1 YR
PENNSYLVANIA	3	YES			YES		YES	YES	6-8	30-40			1	VARIES	VARIES
RHODE ISLAND	4	YES			NO	SIGNS	YES	YES	5	8-10				6 MOS	1 YR
SOUTH CAROLINA	2	SOME		NOT USED	NO	SIGNS	YES		6	40				NOT USED	1-2 YRS
SOUTH DAKOTA	7	YES			YES		NO	NO	4	36			1	2 YRS	
TENNESSEE	1	YES	$6 30	$6 30	NO	SIGNS	YES	NO	6	7			1	6 MOS	1 YR
TEXAS	1	YES	$1 50	$1 00	NO	SIGNS	YES	NO	3-5	30					VARIES
UTAH	7	YES	$6 00	$7 00	NO	FLAGMAN	YES	YES	8-14	30-50	$0 25	$0 25	1	1 YR	18 MOS
VERMONT	5	NO			NO	FLAGMAN	NO	NO	5	25			1	1 YR	
VIRGINIA	2	YES	$5 60	NO EXTRA	YES	ADVANCE TRUCK	YES	MAJOR	4-7	15-30		$2 00	1	1 YR	1 YR
W VIRGINIA	2	YES	$5 48		NO	GUARDS & SIGNS	YES	YES	8-10	20-25			1	6 MOS	
WASHINGTON	2	YES			NO	FLAGMEN	YES	YES	8-10	20-25			1	6-12 MOS	6-12 MOS
WISCONSIN	2	NO		$0 30	NO	ADVANCE TRUCK	YES	MAJOR	10	15-60			1	1 YR	1 YR
WYOMING	5	NO				ADVANCE TRUCK	YES	YES	6-8	35-40			1	1 YR	1 YR
HAWAII	4	YES	$28 50		NO	MEN WORKING SIGNS	YES	YES	4	6-7			2	6 MOS	9 MOS
BRITISH COLUMBIA	4	YES	$10 00	$5 00	YES		YES	NO	6	20			2	NOT USED	6-12 MOS
MANITOBA	4	SOME			NO	SIGNS & FLAGMEN	YES	MAJOR	3-5	10-40			1		1-2 YRS
NOVA SCOTIA	6	YES			YES		YES	YES	6-8	22			1		1-2 YRS
ONTARIO	5-6	YES	$5 28	$5 28	SOME	FLAGMAN	YES	YES	5	20			1	1 YR	1 YR
NEW PRUNSWICK	6	NO			AT TIMES			YES	5	25			1		2 YRS

NATIONAL RESEARCH COUNCIL

The National Academy of Sciences is a private organization of eminent American Scientists, chartered under a special act of Congress in 1863 to "investigate, examine, experiment, and report on any subject of science or art." The Academy maintains the National Research Council as its operating agency.

The Council, organized with the cooperation of the scientific and technical societies of America, enjoys the voluntary services of more than 2600 scientists making up over 400 standing committees, boards, and panels in all fields of the natural sciences; its membership includes representatives of business and industry. The Council provides advisory and administrative services for research, and attempts to stimulate and coordinate research effort.

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The National Research Council operates through eight divisions covering fundamental and applied natural sciences, as well as matters of international relations in scientific research. The Division of Engineering and Industrial Research is concerned with the stimulation and correlation of research in a wide variety of fields in engineering and the applied sciences.

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HIGHWAY RESEARCH BOARD

The Highway Research Board is organized under the auspices of the Division of Engineering and Industrial Research of the National Research Council. Its purpose is to provide a national clearing house for highway research activities and information. The membership consists of 42 technical, educational, industrial, and governmental organizations of national scope. Associates of the Board are firms, corporations, and individuals who are interested in highway research and who desire to further its work.

The purposes of the Board are: "To encourage research and to provide a national clearing house and correlation service for research activities and information on highway administration and technology, by means of: (1) a forum for presentation and discussion of research papers and reports; (2) committees to suggest and plan research work and to correlate and evaluate results; (3) dissemination of useful information and (4) liaison and coöperative services."