HIGHWAY RESEARCH BOARD

Bulletin 54

Load Capacity of Roads Affected by Frost

National Academy of Sciences—
National Research Council

publication 232

2101 Constitution Avenue, Washington 25, D. C.

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Load Capacity of Roads Affected by Frost

Presented at the
THIRTY-FIRST ANNUAL MEETING
January 1952

1952

Washington, D. C.

DEPARTMENT OF MAINTENANCE

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Report of Committee on

Load Carrying Capacity of Roads As Affected by Frost Action

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

THIS IS the fourth report covering work being done by various states on this research project. Previous reports were submitted to cover testing work performed in the years 1948, 1949, and 1950.

The objective of the project is to determine the percentage loss of strength that may occur in highways subjected to freezing and thawing action. Determining design bearing values is not a part of, or objective of, the project.

The states of Iowa, North Dakota, Ohio, and Oregon have submitted new material for this report. Minnesota completed its work last year, and Michigan, New Hampshire, and New York have discontinued their testing. Indiana and Virginia still expect to do some testing.

The North Dakota report continues to show strength loss. The Oregon work has just started, and a complete cycle of one year of tests has not been accomplished. The Ohio test was made on a road of sufficient design strength to support the test load thruout the year, without excessive deflection. The Iowa report is a continuation of and supplement to the report made on work carried on last year. The overall result continues to disclose a loss in strength due to frost action.

● THIS REPORT includes new material submitted by some of the states covering activities of the committee during 1951. For those interested in the previous work of the committee, attention is called to the three previous reports published by the Highway Research Board. The first, or 1948, report is contained in the Highway Research Board *Proceedings*, Vol. 28; while the 1949 work is published under *Research Report 10-D*, and the 1950 work is published in Highway Research Board *Bulletin 40*.

The states making significant contributions this year are Iowa, North Dakota, Ohio, and Oregon. The reports submitted by these states are included in and made a part of this report in their entirety.

Iowa - The average strength loss due to frost action is reported to be 58 percent, with variations between 84 percent and 38 percent. Correlation of plate-bearing results with instrument-testing results, one of the objectives of the committee, has so far been inconclusive. One of the interesting observations made in the Iowa report is as follows:

"Moisture and density determinations on undisturbed soil samples taken at depths of 1-ft. and 2-ft. below the surface of the subgrade failed to give accurate indications for prediction of plate bearing values to be expected."

North Dakota - The testing of subgrades with the cone-bearing device has been continued during 1951 by North Dakota. An extensive report has been submitted by this state, summarizing test results accumulated over a period of three years of testing. While individual tests show considerable variation in loss of bearing capacity during the spring of the year, the overall or average values secured over a period of three years show consistently a loss of carrying capacity during the spring of the year after the frost has left the ground, and a gradual recovery during succeeding months.

The North Dakota tests also disclose that for the past three years the highway subgrades have been suffering a general loss of carrying capacity, presumed to be due to the unusually wet seasons occurring in that state during the past three years. Tests during each succeeding year disclose that the subgrade carrying capacity in the fall is somewhat less than it was in the previous year. For instance, the grand average of all bearings secured in the fall of 1948 was 688 (cone-bearing psi.); in the fall of 1949 it was 585, and in the fall of

1950 it was 476. In addition to this general loss of carrying capacity, the subgrades suffered a still further loss of carrying capacity during the succeeding spring season.

Oregon - This state has started testing at 18 selected points with portable equipment patterned after types developed in other states under the guidance of this committee.

The results secured so far disclose increased bearing capacity following the spring thaw at one point and no change in bearing capacity at another point. Comments on this difference in behavior are offered in the body of the Oregon report, which like reports of other states is included in its entirety.

The committee is carrying on its work with increasing difficulty with each passing year. A significant development taking place as a result of the work of this committee, is the growing use of full-scale field bearing tests by the engineering departments of those states now having been provided with such test equipment under the direction of this committee. It is, therefore, becoming increasingly difficult to hold the bearing equipment for use on the testing project because of this growing demand.

With the special equipment supplied by this committee, loads are usually applied on a 12-inch diameter bearing plate. An indicative result can be secured in 20 minutes from stop to move. Such tests are known as "quickie tests" and provide revealing and relative information of significant value.

This committee has not attempted to evaluate or interpret the bearing strengths accumulated and recorded, into factors for road design. The information, however, is available to design engineers for whatever it may be worth to them. It is desired to again point out the objective of this committee, which is to investigate the percentage loss of strength of roads due to frost action. It is not the purpose of this committee to make determinations relating to bearing values that should be used in road design.

It might be well to point out again that very extensive work has been completed and reported on by Minnesota, Michigan, New York, and New Hampshire. This information is contained in previous reports published by the Highway Research Board.

IOWA

Iowa Route 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 of 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 serviceability. At each of these locations, test sites in the opposite 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 is 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, within a given section of 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 90 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 by means of the Iowa Highway Commission subgrade-resistance machine. Soil samples for laboratory tests and undisturbed soil specimens for density and moisture determinations were also obtained at various depths. Approximately 80 quickie bearing tests have been performed at the above described sites, including some parallel instrument tests.

Results of Tests - Results of 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 section of road are shown in Figure 2. Results of the detailed plate-bearing tests on the asphaltic-emulsion base north of Grand Junction are shown in Figure 3, with the corresponding quickie tests shown in Figure 4.

Although the results of each individual test are plotted on these graphs, the curves shown are those which were drawn at the conclusion of testing operations in 1950. No attempt has been made to revise those

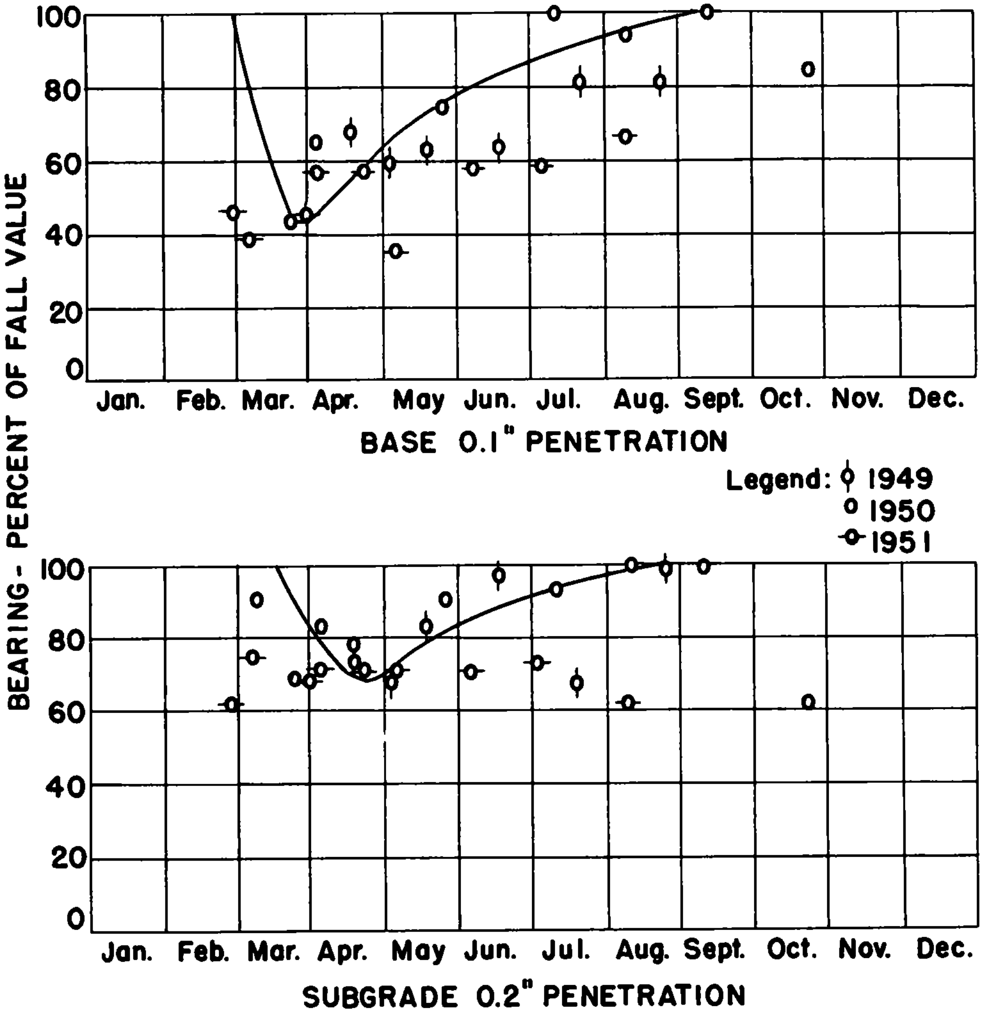

Figure 1. Soil - Aggregate Base: Iowa 144, South of Grand Junction, Plate Bearing Test, 12-in. Diam. Plate.

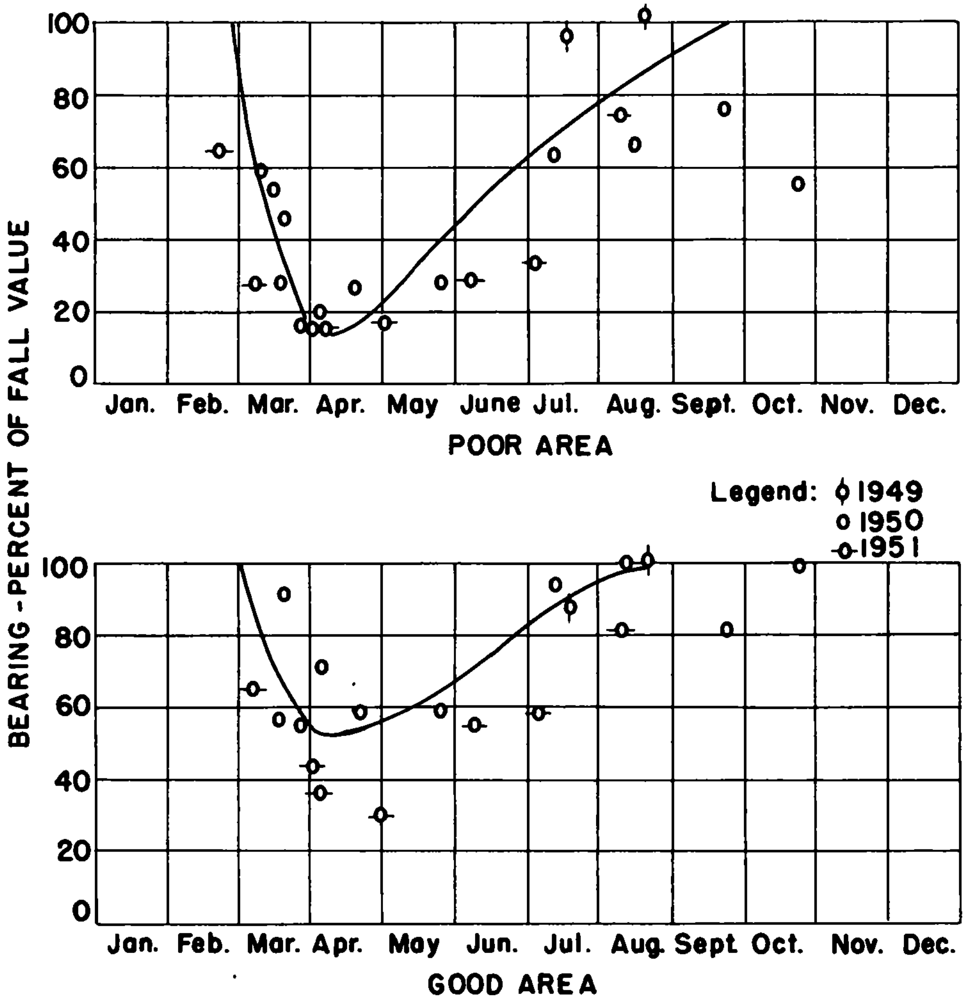

Figure 2. Soil - Aggregate Base: Iowa 144, South of Grand Junction, Quickie Bearing Test, 0.1-in. Penetration, 12-in. Diam. Plate.

curves, since the test results as plotted for 1951 show the marked influence of the unusually wet spring and summer months in retarding the recovery of bearing value lost in the most severe spring breakup in recent years. It would appear that the tests during 1952 would best serve as evidence for the establishment of the low points of the various curves rather than for the definition of the curves themselves.

The lowest bearing value for each location varied from 16 to 62 percent of the corresponding fall high value. The average of these low spring values for all test locations was 42 percent of the high fall value. These low values occurred during the later part of March or early April, and in every case the lowest value was obtained in the 1951 tests.

In examining the accompanying figures it will be noted that the curves shown for the tests on top of the base, including those for the quickie tests, are based on a deflection of 0.1-in., since the equipment available lacked capacity for obtaining 0.2-in. deflection in every test attempted.

In computing the data for plotting the test values on the figures the high fall value used for all test locations was that obtained in the fall of 1949. For the tests at 0.1-in. deflection of the plate, as mentioned above, the 1949 and the 1950 fall values are in general agreement. However, for the tests on the subgrade at 0.2-in. deflection there is some variation. Due to the necessity for using the equipment on other work in distant parts of the state it was impossible to get back to this project to obtain 1951 fall values before freezing temperatures occurred. The latest test series in mid-August, however, indicated that the recovery of bearing value had been retarded considerably by the wet weather during the spring and summer.

The plate-bearing equipment was taken to Dubuque County in November 1950, and again in April 1951, where tests were made at seven locations on the subgrade of an experimental gravel-surfaced road. At these seven test sites the April values varied from 16 to 67 percent of the corresponding values obtained the previous November, with the bearing value in April averaging 38 percent of the November value for all seven sites.

A thermocouple system for the measurement of sub-surface soil temperatures was installed below the center of the southbound traffic lane near the detailed bearing test site south of Grand Junction. This equipment was operated at short intervals through the fall, winter and spring of

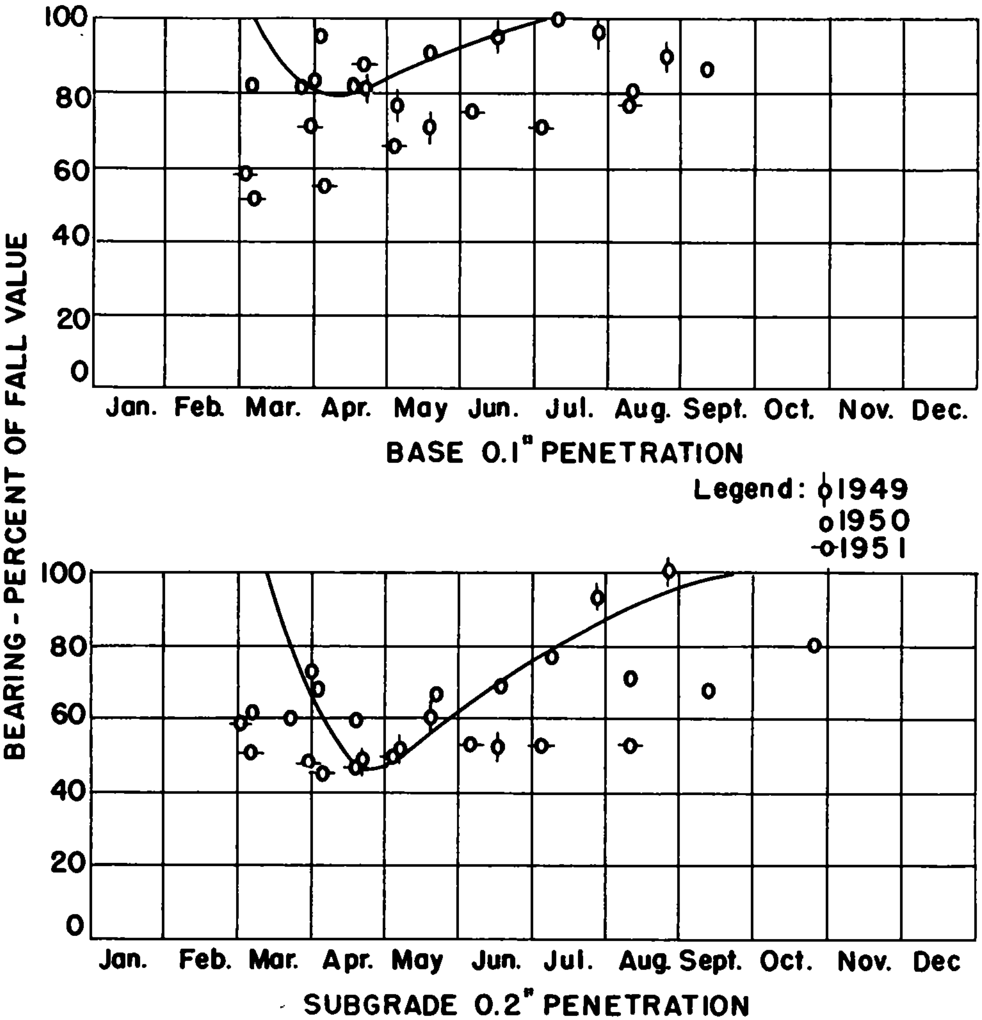

Figure 3. Emulsion Treated Base. Iowa 144, North of Grand Junction, Plate Bearing Test, 12-in. Diam. Plate.

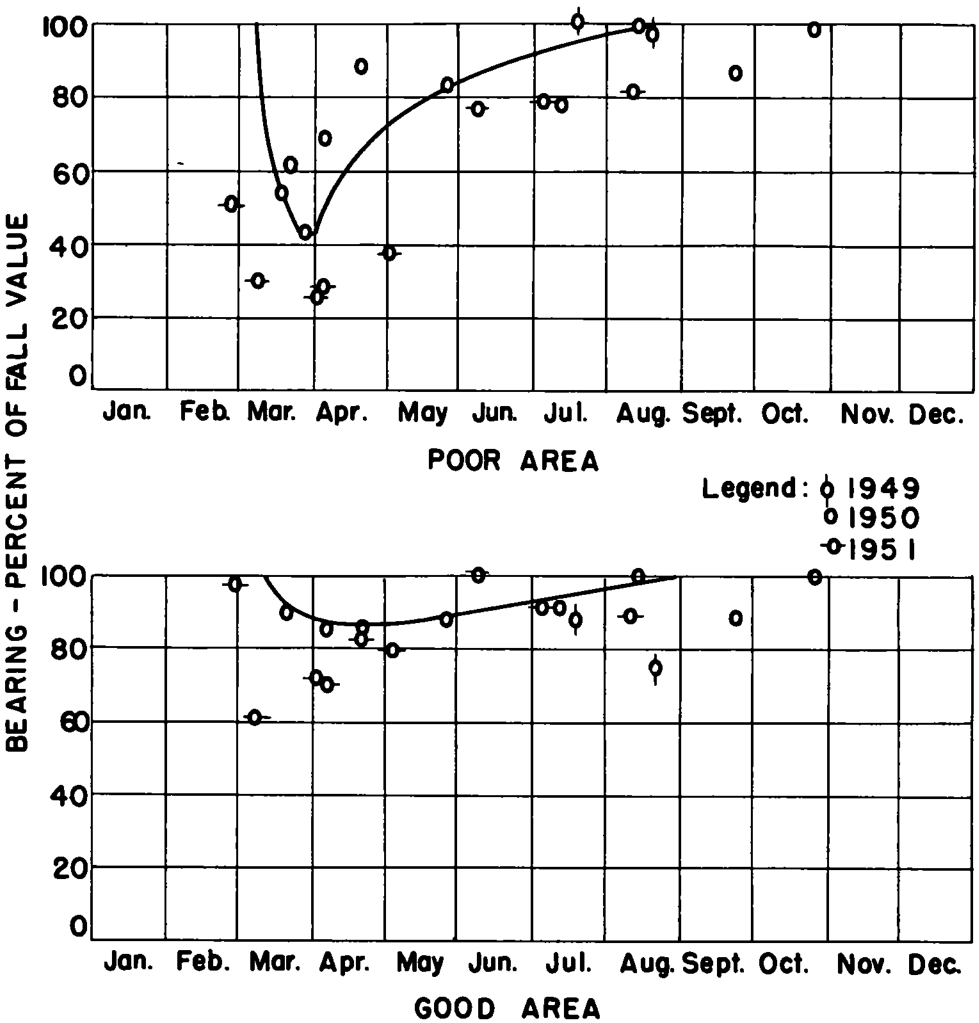

Figure 4. Emulsion Treated Base: Iowa 144, North of Grand Junction, Quickie Bearing Test, 0.1-in. Penetration 12-in. Diam. Plate.

1950-1951. The dates and the depths below the surface of the roadway at which freezing temperatures occurred during this period are shown graphically in Figure 5.

Attempts to correlate the parallel-instrument tests with plate-bearing values obtained on this project have encountered considerable difficulty. Early in the testing program it became apparent that the North Dakota cone test was not suited to this particular project since the subgrade on both sections of road contained considerable quantities of pebbles which made it difficult and often impossible to select a test site at which the influence of these pebbles was not directly reflected in the results obtained. Attempts to obtain test values conforming to the theoretical procedure became so time consuming that this portion of the program was abandoned in 1950.

A total of 44 tests were made with the Iowa Highway Commission subgrade-resistance machine. A series of 15 tests were made at each of the two detailed plate-bearing locations and a series of 7 tests was made at each of the two quickie-bearing-test locations in the poor areas. No direct correlation between plate-bearing values and the results of subgrade-resistance

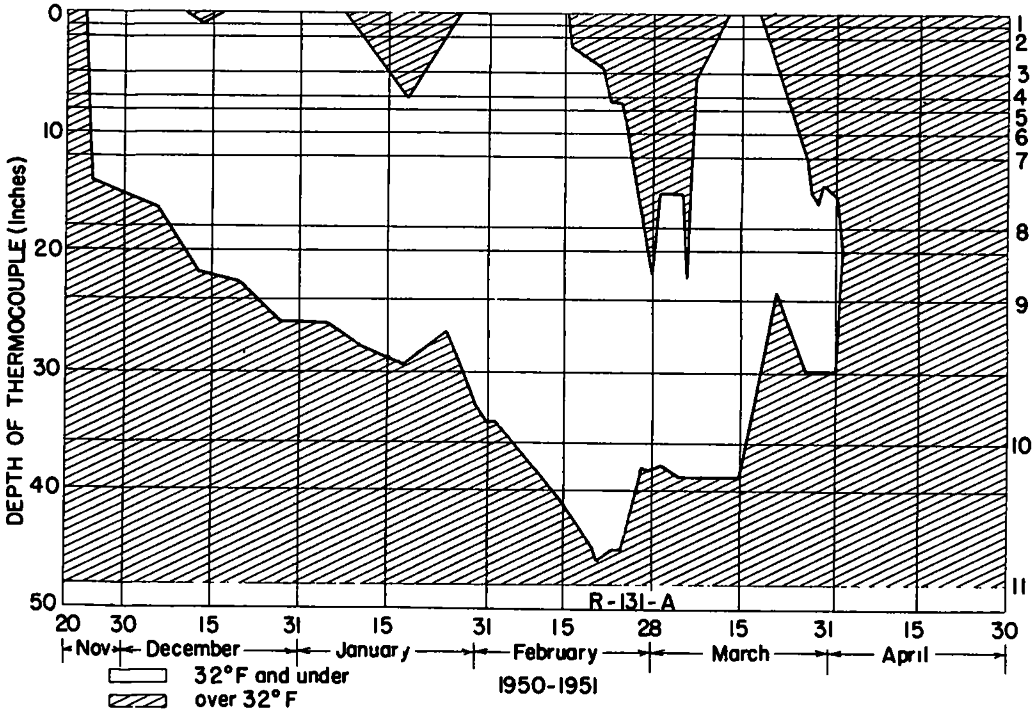

Figure 5. Temperature record (frost) as obtained by copper-constantan thermocouples and Brown Potentionmeter on Iowa, No. 144 2¼ mi. south of Grand Junction, 1950-1951.

tests has as yet been definitely established. This is not too surprising since in the plate-bearing test the loading is applied at the surface and normal to the plane of that surface, while the subgrade-resistance machine applies the load below the surface at depths of 1 to 4 ft. or more with the force in a direction parallel to the plane of the surface. Since both tests involve the direct application of load upon a known area of soil, it is felt that further analysis of the data will provide some measure of the characteristics of the soil as indicated by these test procedures. At the present writing no time has been available for a detailed analysis of the data, but it is hoped that study can be undertaken during the next few months.

Moisture and density determinations on undisturbed soil samples taken at depths of 1 and 2 ft. below the surface of the subgrade failed to give accurate indications for prediction of plate-bearing values to be expected.

NORTH DAKOTA

The current report covers the period from January 1 to July 31, 1951. It also includes comparisons of the average results obtained in 1949, 1950, and 1951. Results in 1951 are based upon fall values established in the fall of 1950. The report shows the loss in subgrade bearing power during the 1951 spring thawing period and the recovery thereafter up to the report date of July 31.

During 1951 tests were continued on the permanent test points selected in 1948: (1) one test point for a gravel-surface section; (2) one for bituminous armor coat; (3) three for cold-laid oil-mix mats; (4) one for hot-mix asphaltic-concrete resurface; and (5) four for asphaltic-concrete pavements.

Subgrade bearing tests were made with the North Dakota cone device at depths of 3, 9, 15, and 24 in. below the subgrade surface at each test point. From the data obtained in 1950, the fall bearing value was established for each test point. These values are plotted as 100 percent on the 1951 graphs in this report. All other 1951 test results for subgrade bearing power are plotted as percentages of the 1950 fall values.

Last year the field tests were suspended November 22, 1950, due to frozen subgrade conditions. Field tests were resumed April 3, 1951, at the beginning of the spring thawing period. Due to the manpower shortage, only one field party was engaged in the testing work this season. This party devoted its full time to the project during the critical spring thawing period. Then as the summer season developed and subgrade recoveries occurred, the testing work was gradually reduced, due to other necessary work commitments. However, sufficient testing was done to obtain the required data.

For the most part, North Dakota experienced another cool spring and summer season in 1951. It was somewhat similar to the abnormal weather in 1950, although generally not quite as abnormal. All the frost this season was not reported to be completely out of the ground until the latter part of May.

A study of the graphs in the current report indicates some erratic subgrade performances as reflected by the test results. In general, however, the performance was more uniform than in 1950. The data shown on the individual graphs will be found self explanatory. Therefore, discussion will be confined largely to the average results shown.

As the subject implies, the purpose of this project is to determine the loss in subgrade bearing power as affected by frost action. It is difficult, however, to compile and submit such a report without including some additional closely related facts regarding flexible-pavement design and performance.

The curve in Figure 6 represents a summary of all bearing tests made in 1951 up to July 31. It shows the average results obtained for all ten test points. This curve clearly depicts the annual spring loss in subgrade bearing power and the subsequent recovery. The greatest average loss occurred around May 3, which is about three weeks ahead of the final date when all the frost was reported to be out of all the subgrades.

It will be noted the minimum average subgrade strength for all test points in 1951 is 76 percent of the 1950 fall value. For the years of 1949 and 1950 this figure was 59 percent and 47 percent respectively of the previous fall value. It might be assumed from this data that the loss in subgrade strength during the spring of 1951 was less than that for the two previous test years. However, a further analysis of the actual bearings obtained indicates this assumption is false.

Due to the wet, abnormally cool season in 1950, the recovery of subgrade strengths was retarded which caused the 1950 fall values to be established at lower figures than in former years. For this reason the percentage of loss in subgrade strength during the spring of 1951 would be correspondingly less than in former years.

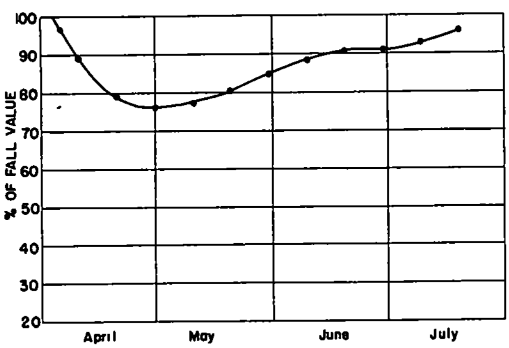

Figure 6. Average bearing for all tests at the 10 test points; bearing tests with North Dakota cone device.

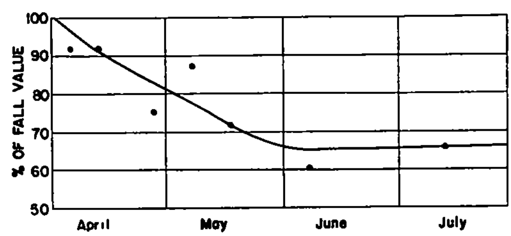

Figure 7. Test Point 1 bearing tests with North Dakota cone device; 1939 construction. Single bituminous armor coat, 4-in. stabilized gravel roadbed.

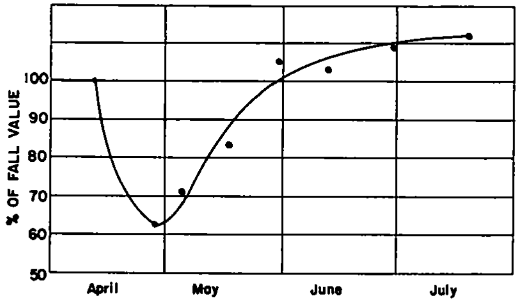

Figure 8. Test Point 2, original construction 1930; latest regravel 1947. Gravel surface bearing tests with North Dakota cone device.

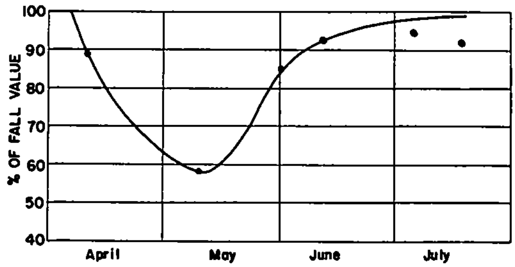

Figure 9. Test Point 3, 1948 construction; 2½-in. asphaltic concrete surface; 2-in. stabilized base; 5 in. pit-run base. Bearing tests with North Dakota cone device.

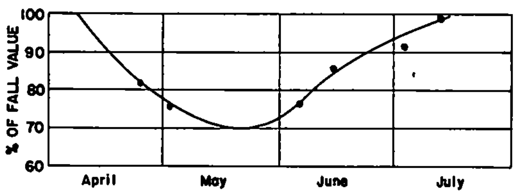

Figure 10. Test Point 4, 1948 construction; 2½-in. asphaltic-concrete surface, 2-in. stabilized base; 5 in. pit-run base. Bearing tests with North Dakota cone device.

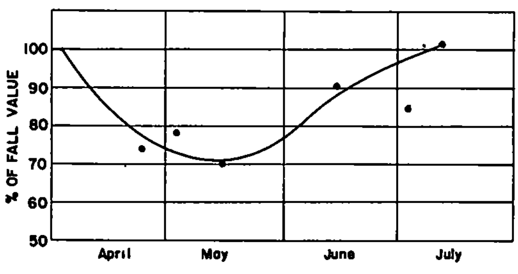

Figure 11. Test Point 5, 1948 resurface with 2½ in. of asphaltic concrete on 4-in. stabilized-gravel base with bituminous armor coat.

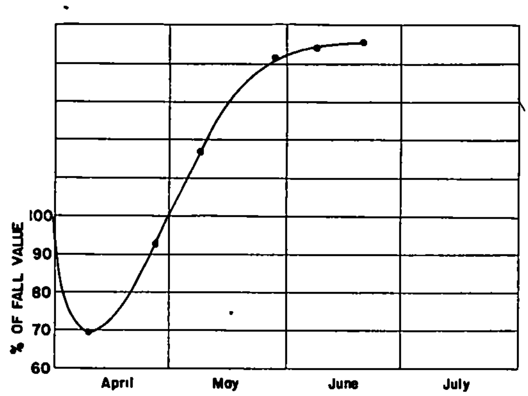

Figure 12. Test Point 6, 1947 construction: 2½ in. bituminous mat (cold laid), 5-in. stabilized base not closed to traffic during construction.

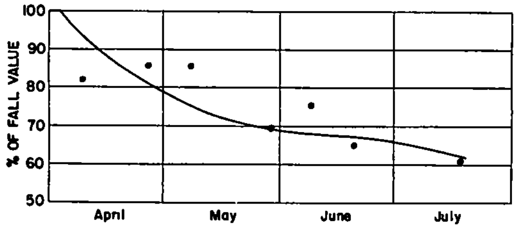

Figure 13. Test Point 7, 1947 construction· 2½ in. bituminous mat (cold laid), 5-in. stabilized base closed to traffic during construction.

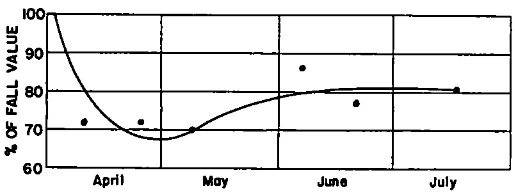

Figure 14. Test Point 8, 1947 construction: 2½-in. asphaltic concrete surface, 2-in. stabilized base, 5-in. pit-run base. Base and mat of original project about 1.3 ft. below current subgrade surface.

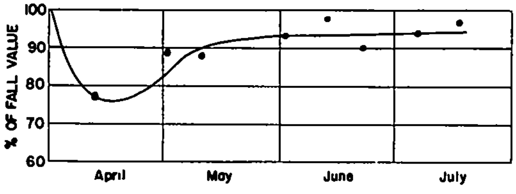

Figure 15. Test Point 9, 1942 to 1945 construction: 2½-in. bituminous mat (cold laid), 6-in. stabilized base (trench section).

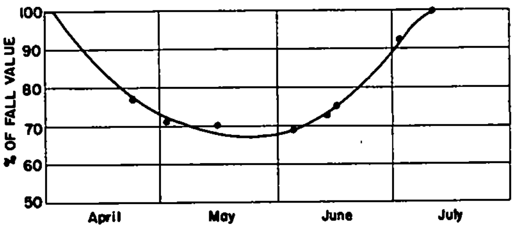

Figure 16. Test Point 10, 1948 construction: 2¼-in. asphaltic-concrete surface, 2-in. stabilized base, 5-in. pit-run base.

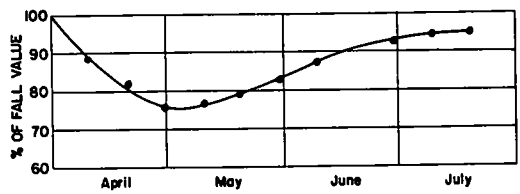

Figure 17. Average bearing for the 10 test points at the 3-in. depth below subgrade surface.

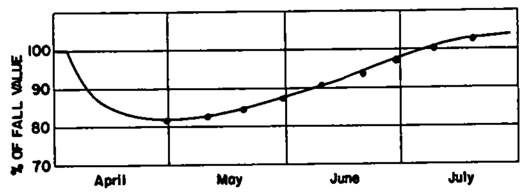

Figure 18. Average bearing for the 10 test points at the 9-in. depth below subgrade surface.

Therefore, comparisons of numerical results of the bearing tests rather than by percentage methods are considered to be more reliable for establishing an accurate basis of comparison between the results obtained during the three test years. Table 1 shows the tabulation of the numerical fall values for all test depths for all test points for the years of 1948, 1949, and 1950.

For a graphic comparison of average test results obtained in 1949, 1950, and 1951, three curves are superimposed in Figure 21. It will be noted that higher average subgrade bearings were obtained in 1949, with the lowest average spring value being 59 percent of the previous average fall value of 688 psi. The year of 1949 had a normal, dry, warm summer season. For some unexplained reason the average subgrade strength in the fall of 1949 was 585 psi. or only 85 percent of the 1948 fall value.

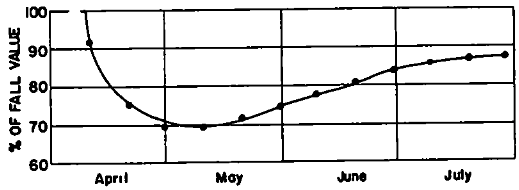

Figure 19. Average bearing for the 10 test points at the 15-in. depth below subgrade surface.

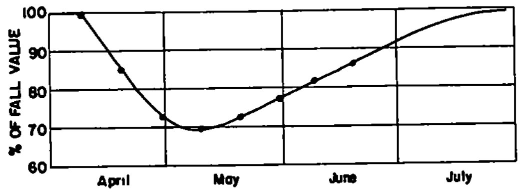

Figure 20. Average bearing for the 10 test points at the 24-in. depth below subgrade surface.

The year 1951 was abnormally wet and cool. Lower subgrade bearings were obtained than in 1949. Test results were erratic as indicated by the 1950 average curve in Figure 21. It will be noted also that the average fall value for 1950 did not recover to the 1949 average fall value. The 1950 fall value was 476 psi. This result is 81 percent of the 1949 fall value of 585 psi. instead of approximately 100 percent of it which result could normally be expected. Because of this lack of recovery in subgrade strength which occurred for the second year in succession, the subgrades entered the 1951 season with lower strengths than in former years.

In 1951, subgrade performance was somewhat more uniform than in 1950. In general, higher subgrade bearings were obtained than in 1950. Although results vary considerably at individual test points, it can be stated that by the progress report date of July 31, 1951, indications were that the 1951 average fall value would exceed that of 1950. As previously stated, a consistent drop in subgrade bearing values had occurred in both the falls of 1949 and 1950. Had not this two year trend begun to reverse itself this season, as now appears to be the case pending completion of subgrade tests this fall, the average

TABLE 1

Tabulation of Fall Values for 1949, 1950, 1951

Test point	Location	1948 Fall Values For 1949				1949 Fall Values For 1950				1950 Fall Values For 1951			
		3"	9"	15"	24"	3"	9"	15"	24"	3"	9"	15"	24"
No.													
1	US 83 Sterling South	827	398	282	239	788	378	209	224	495	375	405	445
2	ND 3 North of Steele	1087	309	1077	307	718	537	344	289	735	400	335	225
3	ND 13 East of Edgeley	1332	465	596	1352	1272	455	764	1162	770	500	575	895
4	US 52 Southeast of Sawyer	391	327	298	381	553	240	250	255	400	255	206	212
5	US 52 Southeast of Anamoose	613	417	296	266	680	340	290	266	550	334	237	208
6	US 10 West of Sterling	1880	1183	852	706	1047	536	478	542	915	430	365	455
7	US 10 East of Sterling	795	895	419	515	900	400	588	714	815	490	300	625
8	US 10 East of Menoken	807	288	1040	850	754	366	1015	357	775	435	480	360
9	US 10 West of Jamestown	1154	803	758	667	1214	856	814	660	1275	800	550	410
10	US 52 Southeast of Donnybrook	1037	779	473	361	874	450	462	348	475	200	190	165
	Average Fall Value for the 4 depths at the ten test points.	688.05				584.7				476.7			

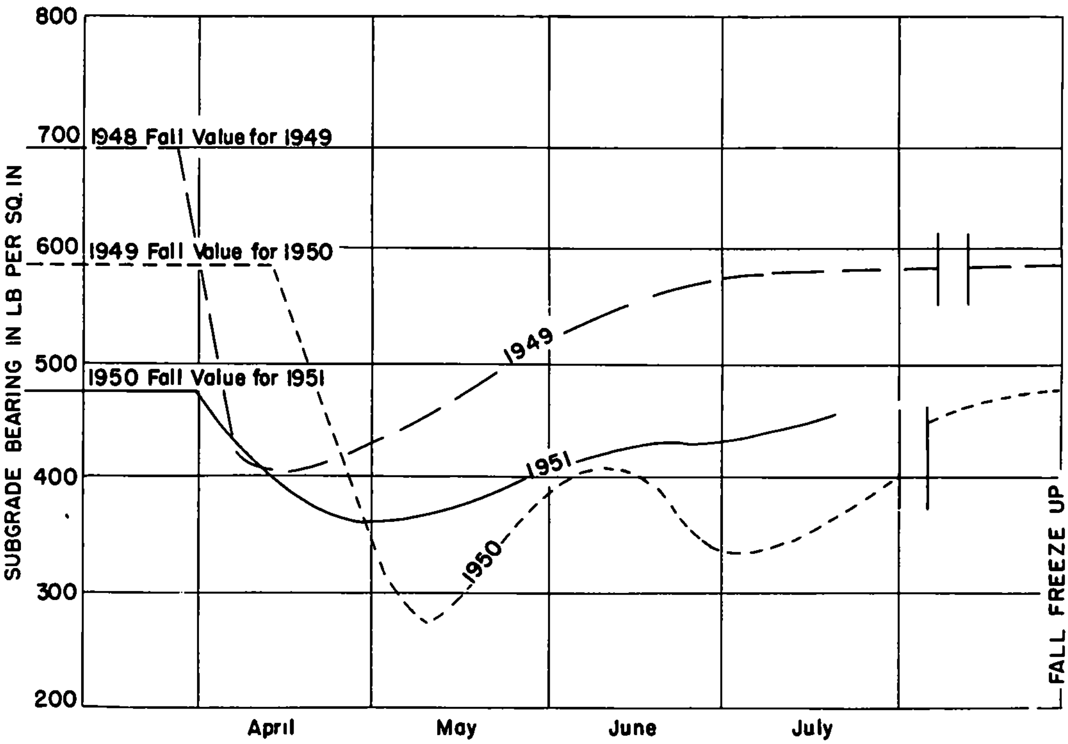

Figure 21. Average bearing for all tests at 10 test points for 1949, 1950, and 1951.

bearing strength of the subgrades undergoing test observations would have reached a minimum value incompatible with the flexible-pavement design practice utilized in this state.

Load limits are used during the annual spring thawing period to protect and preserve the highway system until the subgrades have recovered sufficiently to again carry the legal loads satisfactorily. Due to the low bearings and slow subgrade recoveries that occurred the past two years, some individual test results have been so near the critical North Dakota flexible-pavement design limit that no factor of safety existed. The continuation of such a condition for any length of time obviously would result in an accelerated rate of deterioration of the highway system.

SUMMARY

The 1951 results clearly reconfirm the large loss in subgrade bearing power which occurs during the spring thawing period.

A three-year accumulation of subgrade tests is now available for analysis. It is being studied to determine if any useful hidden information is present. While this data is incomplete and test work is still in progress, the available information is proving valuable to our department.

On the basis of the three-year study, it is apparent that atmospheric weather conditions greatly affect subgrade strengths in the northern climates where severe freezing-and-thawing cycles occur. Subgrade moisture content is also closely related to subgrade strength and performance. However, the extent of this relationship has not been able to be scientifically determined or correlated.

For accurate comparisons between bearing strengths in different years, it is recommended the comparisons be made on the basis of actual cone bearing values in pounds per square inch, rather than by the percentage method of fall values.

It is hoped that future tests and subgrade performance will continue to become more uniform, so definite design and performance information can be obtained from the results.

It is also hoped that a practical method can be established for determining the calendar dates for the start and end of the critical spring thawing period during which time load limits must be applied.

OHIO

Supplementing the report of November 15, 1950, the chart (Fig. 22) has been brought up-to-date by including the plate bearing-test results obtained in February and September 1951 on the surface at the Delaware County test site. As previously reported, the pavement section at this test site is: 4-in. hot-mixed bituminous concrete, 8-in. waterbound macadam, and 10½ in. of classified embankment material.

It may be noted from the chart that the test results which were obtained in February 1951 are average by comparison to previous tests and consequently do not show a loss in strength even though these tests were made at a time when some other pavements (of less thickness) were showing considerable breakup from thaw and load.

The tests in September 1951 are lower than any of the previous tests on the surface of this pavement. It is felt that, in this series of surface tests, the variation in temperature of the 4-in. asphaltic-concrete surface course could be more responsible for the variation in results than any action due to frost.

OREGON

The Oregon test apparatus, was completed in January 1951. Tests were started on 18 test points in central Oregon early in February, following the only severe weather of a generally mild winter. Tests were continued at intervals of about two weeks through the spring, and a set of midsummer readings were taken in July. All tests to date have been by the quickie method as recommended in Highway Research Board *Research Report 10-D*. Results vary from no apparent reduction in load-carrying capacity to readings as low as 20 percent of highest readings thus far observed. Tests on these points, with moisture determination added, will be continued.

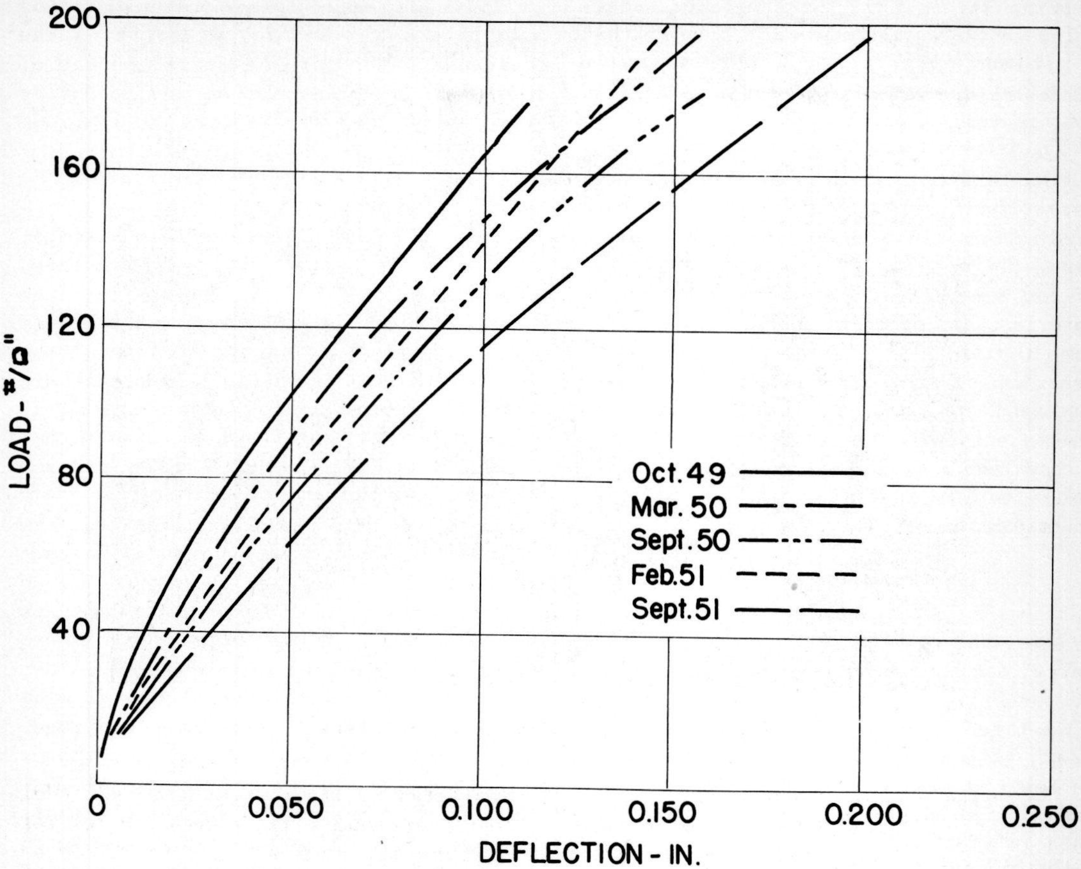

Figure 22. Average tests on surface, 12-in.-diameter plate.

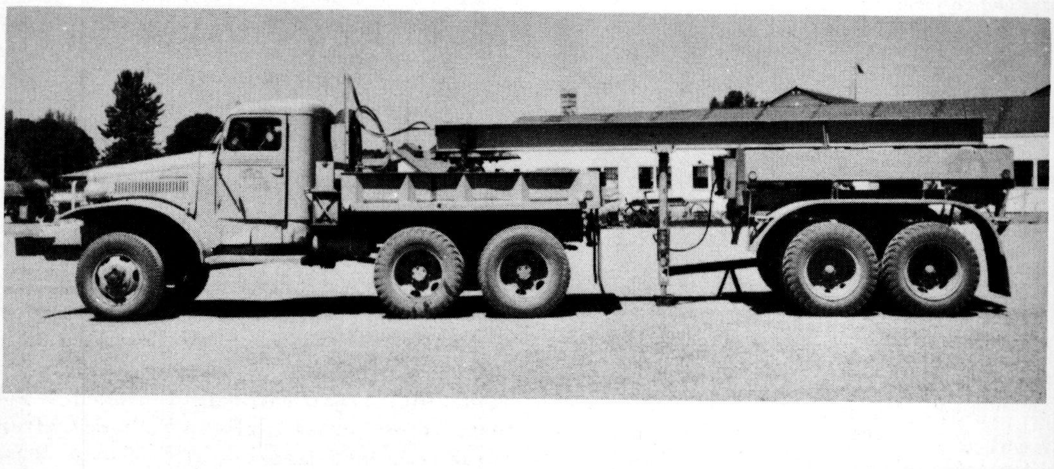

Figure 23. Truck in testing position.

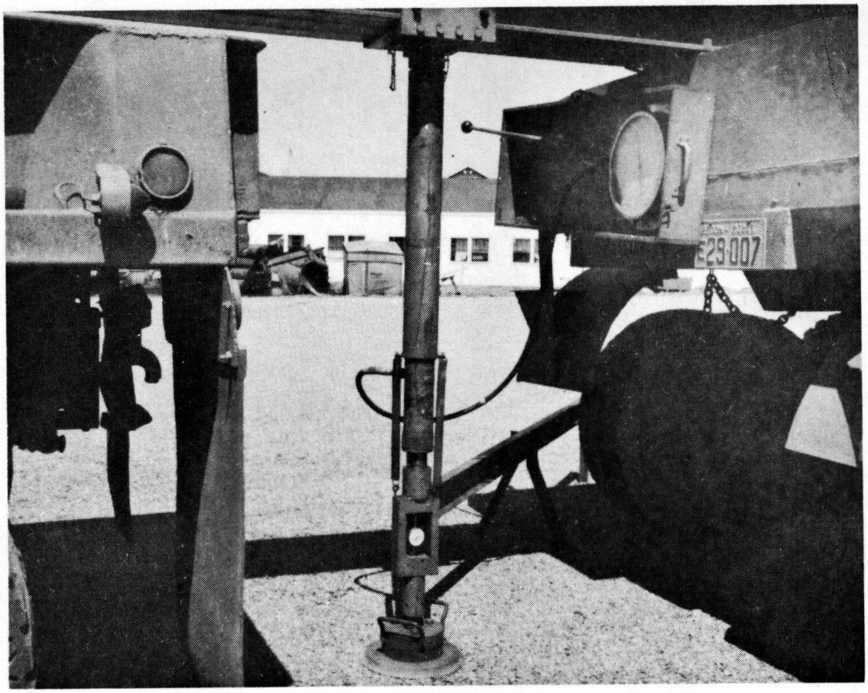

Figure 24. Close-up of loading apparatus.

The test apparatus (Figs. 23, 24) was built up on a 2½-ton 6-by-6 truck and logging trailer following the Minnesota plans with minor exceptions. Both the truck and trailer have steel beds loaded with punchings. To prevent overloading the pin connection of the fifth wheel, outriggers were arranged to transfer the truck load directly from the truck bed to the beam while testing. Several 14-in., 7,500-psi. gages were on hand from a previous project. One of these was used instead of the two gages and valve employed by Minnesota. The long sweep of the gage hand gives suitable accuracy at all ranges. After considerable operation of the apparatus, it was decided to mount the gage and pump on the front of the trailer. This allows the ram and pump to remain connected while making short moves between test points. For longer trips over the Cascades, etc., the hose is disconnected, the pump and ram are covered and the ram is removed from the ram post. This system saves time and has proved generally satisfactory. The quickie tests are conducted by a test operator and a truck driver. A flagman is employed when necessitated by traffic conditions. Additional personnel will be required for soil moisture measurement. To minimize the effect of heat-softened asphaltic surfaces, summer readings are taken between 4:30 and 10:30 a.m.

Tests in the vicinity of Salem, while interesting from other standpoints, would not come within the scope of the committee project since severe freezing is the exception rather than the rule. Test points were selected in central Oregon because it is the most convenient to Salem of the areas subject to severe winters and because it affords a variety of soil, base and surface types.

A total of 18 points were selected to cover all normal types of construction usually employed in this state and a wide variety of soil types (Fig. 25). Highways with lava-cinder base both with rock and cinder-oil treatment were included. The tests were started early in February after the only severe freezing of the year, during the last week in January. The tests to date may thus be assumed to follow the recovery phase of the annual cycle. Since

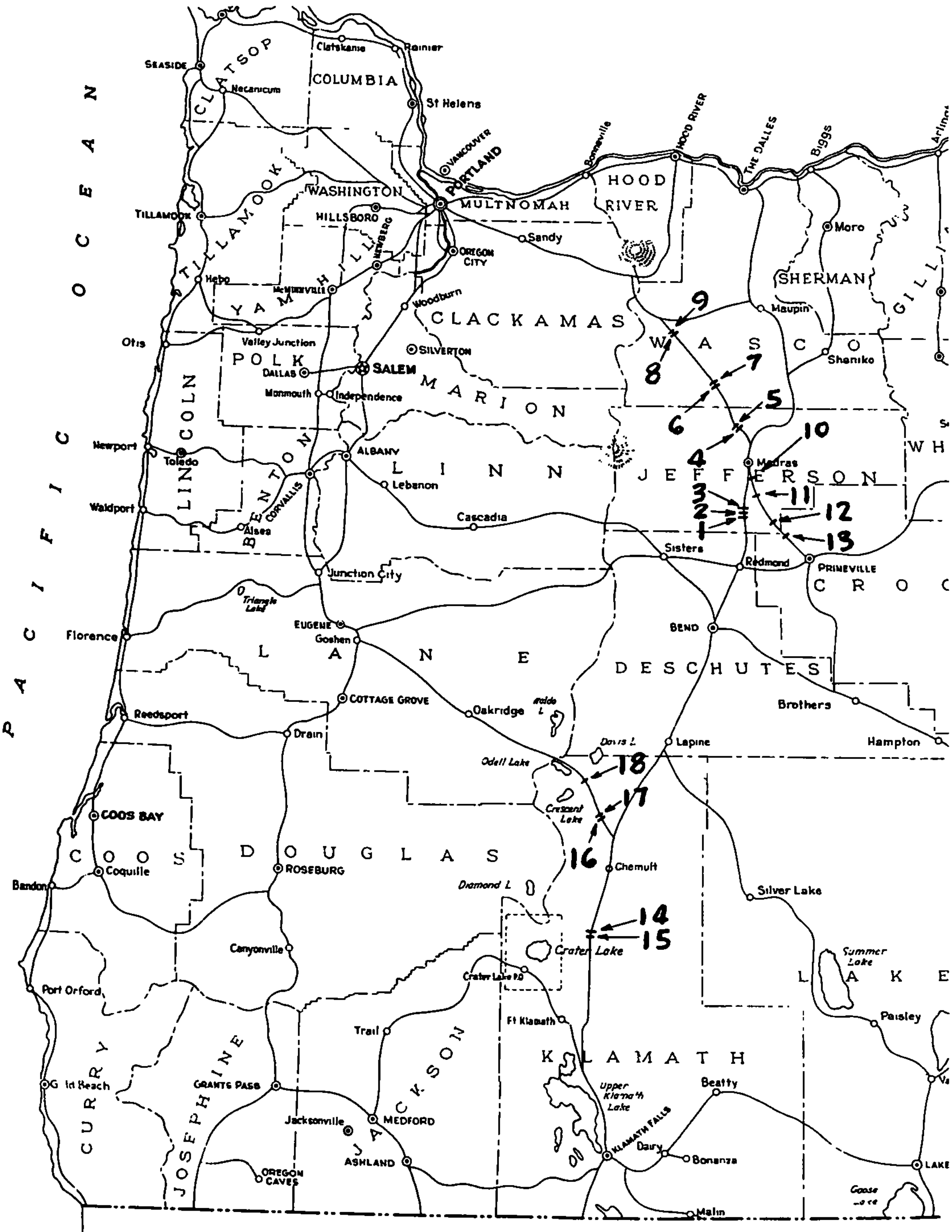

Figure 25. Location of Test Points.

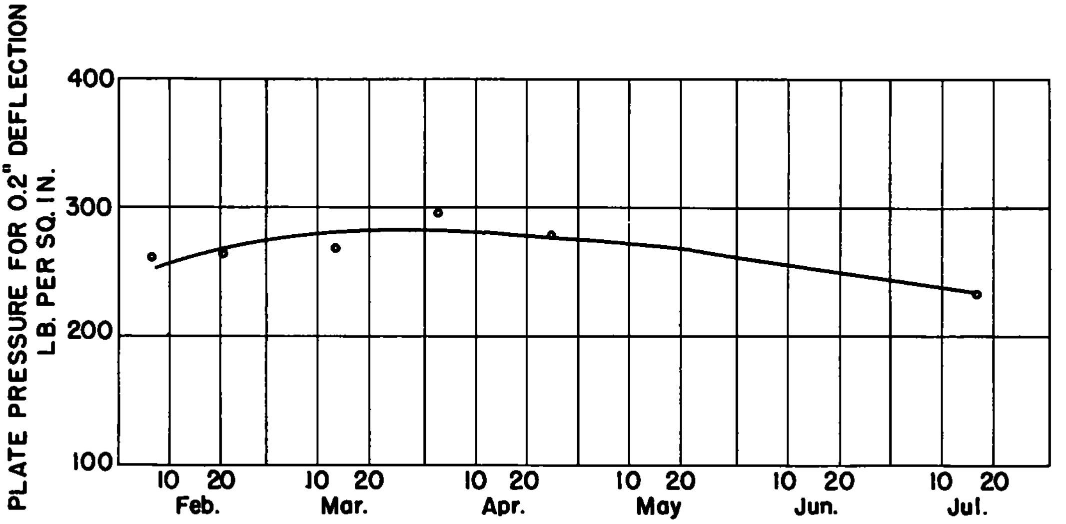

Figure 26. Test Point 3.

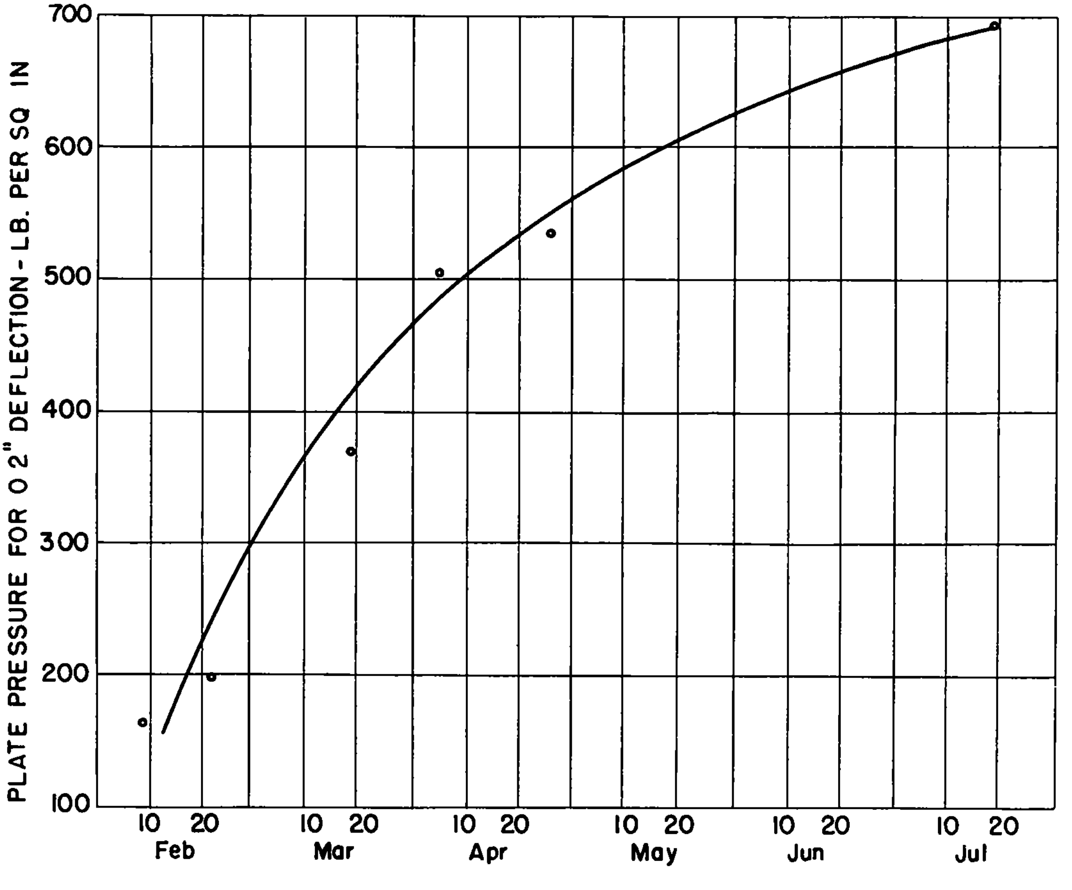

Figure 27. Test Point 15.

it is impossible to determine whether or not maximums have been reached, curves and calculations based on percentage of maximum bearing value cannot be submitted. However, two curves based on pounds per square inch for 0.2 in. of deflection are included (Figs. 26, 27). The highway at Point 3 consists of a 6-in. keyed-rock base and 3 in. bituminous macadam with crushed-rock aggregate on Type A4 soil. This point shows practically no variation since commencement of the tests. There is a possibility that the lower July reading might be related to irrigation in the immediate vicinity. Point 15 has 7 in. of cinders for a base and 1¼ in. of oil-mat treatment with cinder aggregate on Type A-4 soil. Here, the low during the thaw was only 20 percent of the July reading. Both sections have served satisfactorily on a main truck route without load restriction.

Tests will be continued through the remainder of the year and thereafter if results warrant further expenditure. The original plans called for converting 6 of the 18 points to detailed study points by installing thermocouples and moisture cells. Reports from other organizations using various moisture cells have been so unfavorable that the cells have not been purchased. A drive tube sampler will be used to obtain soil samples for moisture determination. If this does not prove satisfactory, samples will be obtained by digging under the edge of the surfacing.

Plans are being made for the use of the equipment for taking bearing tests on subgrades during construction. The State Board of Aeronautics is considering the use of our equipment for evaluation of airport bases and subgrades.

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