# DEPARTMENT OF DESIGN

# Plate-Bearing Tests Used to Evaluate Minnesota Highways

PAUL G. VELZ, *Laboratory Chief*
*Division of Materials and Research, Minnesota Department of Highways*

THIS paper describes an investigation initiated as part of a survey for the long-range improvement of a group of roads tentatively designated as future 7-ton or 9-ton axle-load-capacity roads. In order to assist in the preparation of preliminary estimates of the improvements required and to make comparisons between the roads involved, the plate-bearing test was utilized to evaluate the existing road structures.

This report discusses the application of plate-bearing-test data, traffic characteristics, field work, test procedures used, adjustment of bearing values to maximum fall values, and conversion of such values to estimated spring axle-load capacities.

For this particular study, only general comparisons were required between the various sections tested and the tentative future capacities desired. It appears that the plate-bearing test has provided a reasonable basis for making these comparisons.

● IN recent years, increasing demands have been made for enlarging the network of year-round unrestricted roads on the trunk-highway system in Minnesota. These demands have developed from social and economic changes such as the consolidation of school districts, increased farm production, storage of farm products on the farm, and the general economic improvement in rural areas. These factors and others tend to increase the year-round movement of heavy commercial vehicles on the highways.

It has been general practice in Minnesota to place weight restrictions on a large mileage of bituminous roads during the spring breakup period. These restrictions range from 3 to 7 tons of axle load, with the most-general limit being 5 tons. This practice, though necessary, temporarily reduces the capacity of the trunk-highway system for approximately 2 mo. each year.

As part of the long-range program of the department of highways, consideration has been given to reinforcing a considerable mileage of these restricted roads. In order to obtain data for the preparation of preliminary estimates and to make comparisons between the roads involved, a program of full-scale plate-bearing tests was initiated.

On June 1, 1951, the sections of highways to be tested were selected on the basis of their importance in extending the network of unrestricted roads (maximum of 9-ton axle loads), or providing a minimum 7-ton axle-load spring restriction. The test sections were scattered geographically throughout the state and totaled 917 mi. in length.

This report discusses the application of plate-bearing-test data, traffic volumes on the highways tested, the field work, test procedures used, the adjustment of bearing values for seasonal variation, Minnesota's method of converting bearing values to equivalent axle-load capacities, the significance of permanent deflections measured by the plate-bearing test and how the accumulated data were prepared for the use of department engineers. Several conclusions, which seem warranted by the data, are also included.

## APPLICATION OF PLATE BEARING TEST DATA

In the original report, prepared for the use of the department, considerable emphasis was placed against the promiscuous application of bearing test data. Some of these warnings are repeated here so that the reader may have a better understanding of the significance of this work.

The plate-bearing test is relatively new in this state and the meaning of the values obtained is not clearly understood, because of the complex nature of the materials in the roadbeds. Many of the roads tested during this study have glacial drift subgrades ranging through the entire band of soil classes; subbases or bases built up from adjacent natural gravel deposits through stage construction and including local repairs or reinforcements; bituminous surfaces of variable thickness composed of road-mixed or low-type, hot plant-mixed materials and resurfacing in many areas with maintenance retreatments. Because of these conditions it was essential that a study of the roadbed materials be made at each bearing-test site.

It was also pointed out in the department report that the plate-bearing test measures the load-bearing capacity of the road structure only at the test points selected and reflects only the conditions which exist in the roadbed at the time of the test. If the selected test points are not on representative sections of a project, the bearing values will not be representative of the overall load-carrying capacity. Also, roadbed conditions (such as moisture content, density, and recovery from frost action) may vary considerably on a seasonal basis or over a longer period of time, which will affect the load-carrying capacity of the road.

These variables, along with the subsequently discussed procedures for the adjustment and conversion of bearing values and the test procedure used, should all be fully considered when applying the bearing data to a specific analysis.

It is the general opinion in Minnesota at this time that the plate-bearing test, as used in this study of existing roads, is not applicable to the design of base thickness for reinforcement, except in a general way. This test data should be thought of as another tool which may be used in conjunction with the detailed soil survey, performance experience, traffic, and other data to aid the experienced highway engineer in making a more accurate evaluation of the load-carrying capacity of a road.

### TRAFFIC CHARACTERISTICS

The factor of traffic has been included as a part of the data reported on each highway control section. A comparison of the heavier commercial traffic has been made by converting the numerical vehicle count to the equivalent number of 5,000-lb. wheel loads by the California method, as reported in the November 1941 issue of *California Highways and Public Works*.

Generally, the roads tested do not carry a large volume of traffic. The most heavily traveled section, on Trunk Highway 10 east of Detroit Lakes, had a 1950 daily average of 2,071 vehicles, of which 369 were commercial vehicles. This section had a computed equivalent wheel load (EWL) of 785,000 per year. The remainder of the test sections ranged from an EWL of 229,000 to 48,000, or from 30 percent to 6 percent of the heaviest traveled section.

The above figures indicate that traffic volume was not the only factor considered in the selection of the test sections. These highways serve large areas of rural Minnesota and, in many cases, provide the only available con tact with the more-improved and heavier-traveled highways.

### FIELD WORK

In order to accomplish this rather-extensive program in one season, it was necessary to establish a schedule which would allow the longest testing period prior to freeze-up. Testing was begun on June 18, 1951, in the southern part of the state, where the roads had recovered somewhat from the spring breakup. The schedule provided for progressing northward through the western portion of the state so that the most northerly sections were tested in the middle of the summer. Then testing progressed southerly into the central and south-central portions to take advantage of the later fall in these areas. Testing was completed on September 27, somewhat earlier than expected. This was fortunate in that it allowed for retesting a number of the southerly sections which had been tested in the spring and early summer. Retesting was completed on October 25, 1951.

A general-surface-condition survey was made on each section of highway. Based on this survey, test points were selected on representative good and poor areas at intervals of approximately 1 mi. This was not considered as the most desirable frequency, but it was assumed that this would be the maximum amount of testing that could be done if the entire mileage was to be covered before freeze-up. The road condition at each test point was classified as good, retreated, or failed. Alligator cracking or displacement was considered as failure. Local resurfacing, spot sealing, or patching was designated as re-treated and evidence of weakness when the degree of failure was not evident.

Insofar as possible, the above preliminary work was accomplished prior to the arrival of the three-man testing crew on a section. This permitted them to concentrate on the testing work and increased the overall efficiency of the field work. All plate-bearing tests were made with a 12-in.-diameter plate on top of the bituminous surface using a "Quickie" type procedure. The details of this procedure and of the testing equipment are presented later in this report.

jack assembly and fine sand was used, in the least amount necessary, to provide uniform bearing under the plate.

2. A seating load of 2 psi. was applied, after which the initial or zero reading on the deflection gauge was recorded.

3. Loads were then applied as rapidly as possible in uniform increments of 14 psi. Following the application of each increment, the load was maintained until the rate of increasing deflection became less than 0.004 in. per min., at which time the total deflection was read from the Ames dial. This procedures was continued until the total deflection equaled or exceeded 0.2 in., or the loading capacity of the equipment was reached.

4. Immediately after the last deflection reading was made, the load was released, the

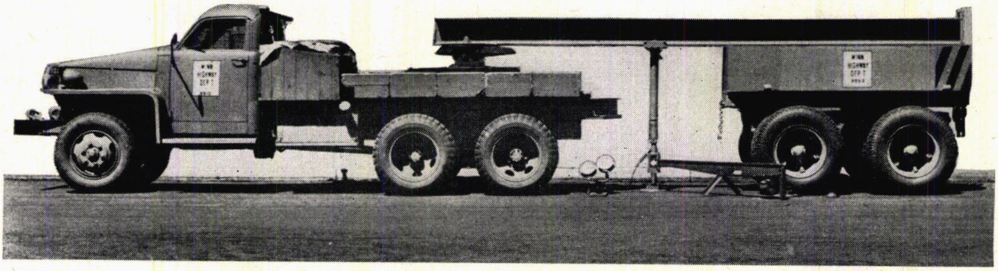

**Figure 1. Minnesota's truck-trailer equipment for making plate-bearing tests.**

plate reseated by 2 psi. load and the permanent deflection measured.

The testing crew also took borings to a depth of 3 ft. below the surface of the road at each test point. The thickness and quality of the mat, base and subbase were determined; the subgrade soils were classified texturally; and observations made as to the moisture conditions.

### "QUICKIE" TEST PROCEDURE AND EQUIPMENT

As previously stated, the 12-in. plate and a "Quickie" test procedure were used on this work. The reasons for these selections were three-fold: first, tests could be made rapidly; second, most of the previous Minnesota tests had been made by this method; and third, the method of converting bearing values to axle loads had been correlated, to a large degree, with data obtained by this test procedure.

The following is a brief description of the "Quickie" test procedure:

1. The bearing plate was centered under the

5. The deflection readings were plotted against the corresponding unit loads in pounds per square inch and a curve drawn through the plotted points. From the curve, the unit load required to produce a 0.2-in. deflection was taken as the bearing value.

6. Where the capacity of the equipment was not adequate to produce a 0.2-in. deflection, an approximation of the bearing value was obtained by extrapolation of the load-deflection curve. These values are not considered very reliable.

The Minnesota plate-bearing equipment consists of a truck-trailer unit capable of providing a maximum reaction of 31,000 lb. The unit was designed to have axle loads not in excess of 4 tons so that it could be operated on restricted roads during the spring. Figure 1 shows the equipment in testing position.

Load was applied to the bearing plate by a 20-ton hydraulic jack activated by a hand pump. The pressure gauges were calibrated and load increments were converted into pressure gauge readings for the convenience of the operator. By using a hollow, rectangular steel block between the jack and the bearing plate, it was possible to measure deflections with a single Ames dial. Figure 2 is a closer view of this portion of the equipment. With this equipment, it was possible for one man to make the bearing tests.

SEASONAL ADJUSTMENT OF BEARING VALUES

It has been established that the supporting power of roads in Minnesota varies from a minimum in the spring to a maximum in the fall. The recovery curve apparently changes somewhat from year to year; but, in general, it can be assumed that the minimum spring bearing value will be approximately 50 percent of the maximum fall value. On that basis, bearing values measured in the fall can be converted to estimated spring values by multiplying by 50 percent with an acceptable degree of accuracy. However, if bearing values are to be measured throughout the period from late spring to fall, the values must be adjusted to either maximum or minimum conditions before they can be used as comparative data. In this investigation, all such bearing values were adjusted to maximum fall values by applying factors (obtained from a predetermined recovery curve) which vary according to the time of year at which the bearing tests were made. The Division of Materials and Research has established recovery curves for the years 1947, 1948, and 1949 in connection with the investigation of "Loss of Load-Carrying Capacity Due to Frost Action." The 1949 curve, shown in Figure 3, was selected because it covered the complete seasonal range from the fall of 1948 to the fall of 1949. The factors used for adjusting bearing values to maximum fall values are shown in Table 1.

Bearing values measured during the periods shown in Table 1 were multiplied by the corresponding factors to obtain the adjusted fall values. By making this adjustment, it was possible to compare the various roads tested regardless of the time at which the tests were made.

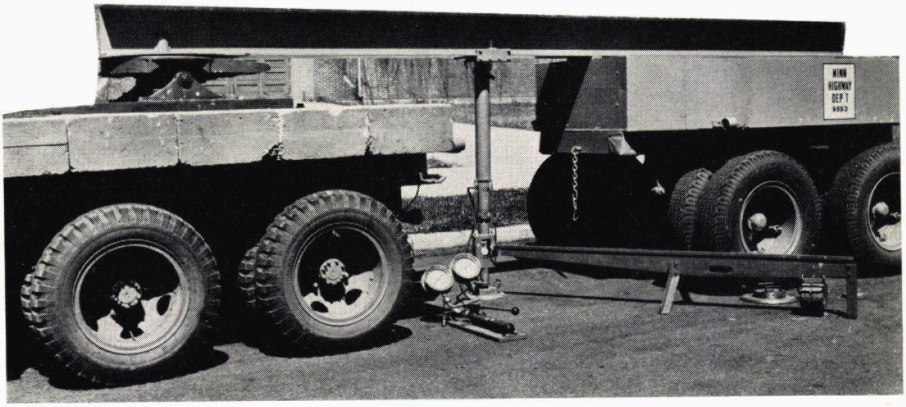


**Figure 2. Closeup of plate and jack assembly.**

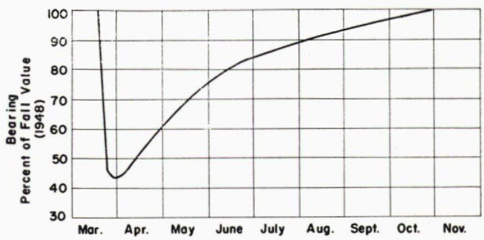


**Figure 3. The 1949 recovery curve showing the seasonal variation of bearing values in Minnesota.**

The retesting which was done between October 1 and October 25 provided a check on the adjusted fall values determined from the recovery curve as described above. One-hundred test points were retested which originally were tested during three seasonal periods between June 15 and July 31. It was found that the retest values averaged 5.4 percent above the adjusted values. Table 2 shows a more complete analysis of these data. It will be seen that the largest variation was nine percent, occurring in the period between July 1 and July 15. Based on the data in Table 2, it seems logical to conclude that the recovery curve may be used for the adjustment of bearing values with an acceptable degree of accuracy. It appears that tests made later in the summer can be adjusted with greater accuracy.

TABLE 1
FACTORS FOR ADJUSTING BEARING VALUES TO MAXIMUM FALL VALUES

| Period in Which Tests Were Made | Avg. % of Fall Value | Adjustment Factor |
|---|---|---|
| June 1 to June 15 | 78.0 | 1.282 |
| June 16 to June 30 | 82.5 | 1.212 |
| July 1 to July 15 | 86.0 | 1.163 |
| July 16 to July 31 | 88.0 | 1.136 |
| August 1 to August 31 | 92.5 | 1.081 |
| September 1 to September 30 | 96.0 | 1.042 |
| October 1 to October 31 | 100.0 | 1.000 |

TABLE 2
COMPARISON BETWEEN ADJUSTED AND ACTUAL FALL BEARING VALUES

| Period in Which Original Tests Were Made | No. of Points Retested in the Fall | Avg. Ratio of Fall to Original Values | Factor from the Recovery Curve | Avg. % Variation in Bearing Values |
|---|---|---|---|---|
| June 15 to 30 | 34 | 1.279 | 1.212 | 6.7 |
| July 1 to 15 | 48 | 1.253 | 1.163 | 9.0 |
| July 16 to 31 | 18 | 1.141 | 1.136 | 0.5 |

## AXLE LOAD EQUIVALENTS

The Minnesota method of converting bearing values into load-carrying capacity expressed as tons of axle load is strictly empirical and based on observations and tests on Minnesota roads. The general practice has been to make this conversion on the basis of spring conditions to indicate the minimum supporting power of the road. Since the most serious damage occurs during the spring, despite load restrictions, it has often been possible to correlate the estimated capacity of a road with its performance, especially when the estimated capacity was not in close agreement with the load restriction in force. To date, this conversion method has been found to be reasonably adequate and consistent with the performance of Minnesota highways.

The details of this method are relatively simple and were first proposed several years ago. It had been observed on a number of bituminous-surfaced roads that where permanent displacement had occurred in the wheel tracks in excess of ⅛ in. considerable failure was evident. Since it was not feasible to determine a correlation between excessive displacement in the road and the permanent deflection caused by a bearing test, it was decided to approach this problem on the basis of the unit load required to cause a given deflection when using a given plate-bearing-test procedure. The 12-in.-diameter bearing plate was selected because its area is approximately the same as the contact area of a truck tire under the maximum legal axle load of 9 tons, or a 9,000-lb. wheel load. To add a slight safety factor and to compensate for some overloading, a 10,000-lb. load was used in the subsequent determination.

The unit load on a 12-in. plate supporting 10,000 lb. total load is 88 psi. Thus, it was assumed that the road surface should not deflect more than ⅛ in. under a 12-in. plate loaded to 88 psi. if the road was to support 9-ton axle loads. In effect, this assumption declares that, if a road had this much resistance to deflection during the spring breakup period, it would support an undetermined volume of traffic without load restrictions No attempt was made to estimate or indicate this undetermined volume of traffic; but rather, it was hoped that through broad application of this method it would be possible to make such an estimate in the future.

It was not considered desirable to measure bearing values at ⅛-in. deflection, but rather at 0.2-in. deflection. Therefore, it was necessary to determine a bearing value at 0.2-in. deflection which would be equivalent to 88 psi. at ⅛ in. This was accomplished by proportion, which assumes that the load-deflection curve is a straight line, and resulted in a bearing value of 140 psi. It was recognized that the load-deflection curves obtained by plate-bearing tests are most generally convex and only rarely approach a straight line in this range of deflections. Therefore, if a bearing value of 140 psi. was obtained during a test, it was most probable that the unit load at ⅛ in. of deflection would be somewhat greater than 88 psi. This has the effect of adding a slight safety factor. Consequently the bearing value of 140 psi. at 0.2-in. deflection was assigned to represent a supporting capacity of a 9-ton axle load. Axle loadings for bearing values other than 140 psi. were determined by straight proportion.

A summary of the steps involved in converting a measured bearing value into an estimated spring axle-load capacity is as follows:

1. Adjustment of the bearing value to maximum fall conditions by applying the recovery factor corresponding to the date on which the test was made.
2. Divide the adjusted fall value by two to obtain the estimated minimum spring bearing value. This compensates for the 50 percent loss in supporting power attributed to frost action.
3. Divide the estimated minimum spring bearing value by 140 and multiply by 9 to obtain the estimated spring capacity expressed in tons axle load. It is often more convenient to omit Step 2 and convert the maximum fall value directly to spring axle-load capacity. This is very simply done by dividing the fall value by 280 and multiplying by 9

## PERMANENT DEFLECTIONS NOT SIGNIFICANT

In reviewing the approximately 1,000 plate-bearing tests made during this study, it was impossible to determine a relationship between the permanent deflections measured as part of the bearing test and any other data obtained. Many of the permanent deflection values were nearly identical for a great variety of bearing values and roadbed conditions. This confirmed earlier conclusions regarding permanent deflections.

## PRESENTATION OF DATA

The accumulated data were presented in graphical form to bring together the various elements of the study so they could be readily compared with each other. A graph was prepared for each highway control section for easy reference and these were grouped according to the test sections. A brief discussion of the data for each test section preceded the group of graphs. Typical graphs from a test section on Trunk Highway 2 are shown in Figures 4 and 5.

Before discussing the items of interest in these graphs, it may be well to clarify a few items as follows:

1. The bearing values, actual and adjusted, were plotted to the same scale to clearly indicate the magnitude of the adjustment.
2. The scale, Estimated Spring Axle Load in Tons, was arranged so that the values in tons correspond to the equivalent fall bearing values; that is, 9 tons of axle load corresponds to a bearing value of 280 psi. Therefore, the plotted fall bearing values may be automatically converted to spring axle-load capacity by referring to this scale. Bearing values other than fall values cannot be used with this scale.
3. The dashed line, labeled "restriction," indicates the axle load to which the road was restricted during the spring breakup period in 1951. In the figures shown, the restriction was 5 tons of axle load.

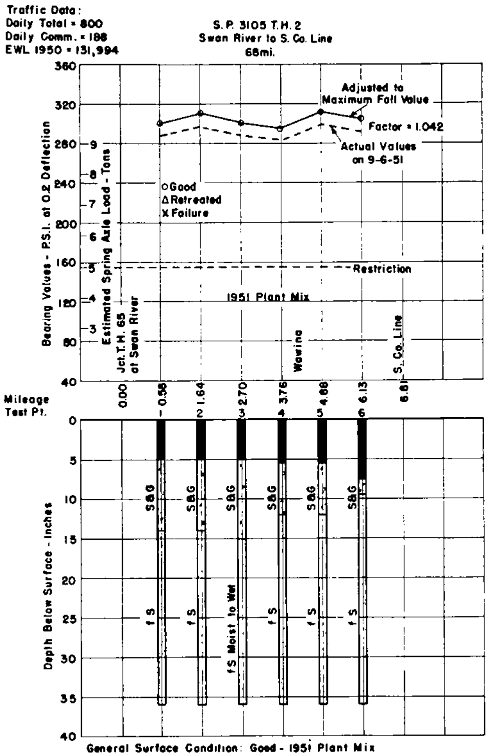


**Figure 4. A typical high-bearing road with uniform bearing values and roadbed materials.**

The section of road represented in Figure 4 was constructed through a fine-sand-outwash area interspersed with peat swamps. The fine sand provided a good, uniform subgrade over

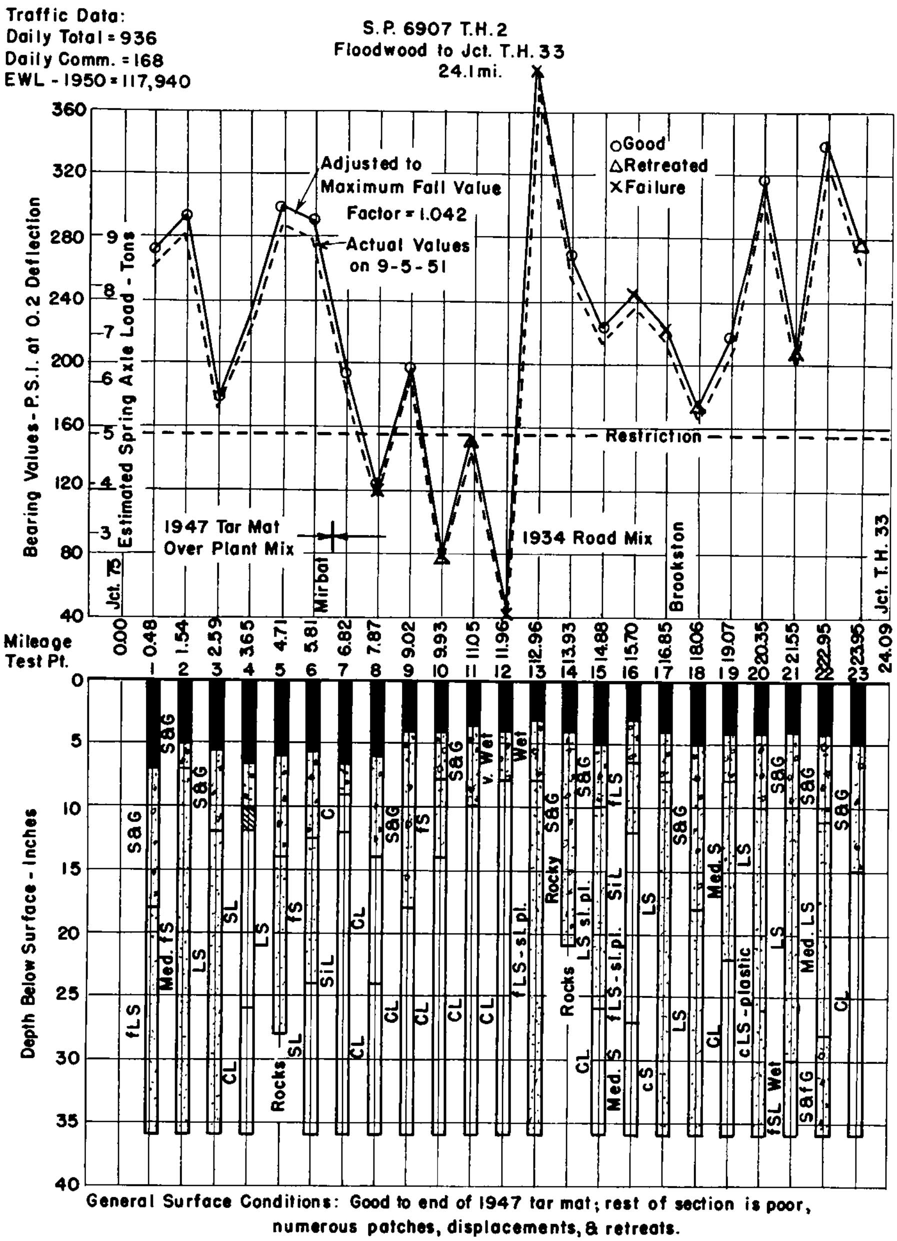


**Figure 5. Typical results obtained on a poor section with variable roadbed materials.**

the entire section. The thickness of sand-gravel base ranged from 6 in. to 10 in. with test point six showing only 2 in. although the mat is indicated as being thicker at this point. A slight excess of moisture was found in the subgrade at Point 3. In 1951 a 1½-in. hot plant-mixed surface was placed over the 1939 plant-mixed surface prior to making the bearing tests. The bearing values were uniformly high and, along with the other data, indicated that this section of Trunk Highway 2 was capable of supporting unrestricted traffic.

Figure 5 shows the data obtained on a poorer section of Trunk Highway 2 to the east of S.P.3105, but in the same test section. This road was constructed through a terminal moraine area containing a variety of soils. The soil variations showed up in the subgrade to a marked degree and were responsible for a great deal of the variation in the bearing values. Between Point 7 and the end of the section, only a token (4- to 5-in.) base course and a road-mixed surface were placed in 1934. Since that time, a great deal of maintenance was required to perpetuate this section as a bituminous-surfaced road. It was doubtful whether any of the 1934 mat remained uncovered in 1951. In 1952 this section was reinforced with gravel base and surfaced with a hot, plant-mixed, bituminous surface. The bearing values, borings, and road performance on this section all indicated the need for extensive reinforcement if this section was to support unrestricted traffic. It was interesting to note the high bearing values obtained at failed areas such as Points 13, 16, and 17. This was encountered on other projects and emphasized that high bearing values did not guarantee a completely sound road structure. However, by comparing the data at these points with those at Points 8, 10, and 12, it was evident that the higher bearing values did indicate a greater potential strength. It was data such as these that prompted the warnings against the promiscuous application of bearing test values as mentioned earlier in this report.

## CONCLUSIONS

Several conclusions appear to be warranted as a result of this investigation as follows:

1. Bearing values measured during late spring and summer may be adjusted to maximum fall or minimum spring conditions with a reasonable degree of accuracy by the use of a predetermined recovery curve.
2. The proposed method of converting bearing values into tons of axle-load capacity appears to be adequate and consistent with the performance of Minnesota highways.
3. Permanent deflections, measured as part of the plate-bearing test, do not appear to be significant.
4. It is recognized in Minnesota that the plate-bearing test is only another tool, which may be used in conjunction with the detailed soil survey and other data, to aid the experienced highway engineer in making a more accurate evaluation of the load-carrying capacity of roads. For this particular study, only general comparisons were required between the supporting power of the roads and the tentative future capacities desired. The plate-bearing test has provided this comparison on a large mileage of roads in one season.

Another testing program has been conducted during 1952 covering an additional 400 mi. of highways. This work followed the pattern of the 1951 work described in this report except that test points were spaced closer together in order to obtain more data on each section tested.

## REFERENCES

1. C. L. Motl, "Load Carrying Capacity of Roads as Affected by Frost Action." Highway Research Board *Research Report No. 10-D*, 1950.
2. Fred J. Grumm, "Designing Foundation Courses for Highway Pavements and Surfaces." California Highways and Public Works—November 1941.

## DISCUSSION

W. H. Campen, *Manager, Omaha Testing Laboratories*—As an advocate of the use of circular steel plates for the design and evaluation of streets, roads and airport pavements, this writer is pleased to know that Minnesota has adopted the use of plates to measure the load-carrying capacity of its highways. This procedure when correlated with the actual wheel loads using the highways should establish the much-desired relationship between plate-bearing value and allowable wheel load. It is hoped that Minnesota continues the work and publishes more data.

The procedure is most valuable also for the reason that it evaluates the deleterious effect of frost action.

Raymond C. Herner, *Chief, Airport Division, CAA Technical Development and Evaluation Center*—As an old-time advocate of plate-bearing tests for design and evaluation of pavements, the writer wishes to commend Minnesota for its program of pavement evaluation, and to congratulate Velz on a very fine presentation of this work. It is hoped that this paper will encourage further studies along this line There have been criticisms as to the high cost of plate-bearing tests, but apparently the Minnesota State Highway Department has worked out a schedule and procedure which reduces the unit cost of such tests to a comparatively low figure.

The method of correcting the test results for monthly variations in pavement stability is very interesting. It should be emphasized, perhaps, that these variations apply to the entire pavement structure, and that the differences would be much greater if only the subgrade were being considered. This leads to the question as to whether the same correction factors could be applied to very thick and very thin pavement sections. Although this is not a matter of immediate concern in the Minnesota investigations, it is a point which would have to be considered in the general application of such correction factors to plate-bearing tests.

P. G. Velz, *Closure*—Herner's and Campen's remarks are very encouraging, although it is realized that we are confronted by a number of problems which should be investigated before the plate-bearing-test data are given more significance. Minnesota has spent considerable time and effort experimenting with plate-bearing tests and the evaluation program described in this paper was the first attempt to apply our knowledge to a large-scale program.

The accurate adjustment of bearing values for seasonal variation is a complicated problem in itself because of the variations in climate from year to year and between the northern and southern areas of the state as well as variations in the road structures. We are quite certain that the recovery curve of the subgrade would be different than that based on surface tests. Therefore, Herner's question relative to applying the same correction factor to thick and thin pavement sections is well-founded. However, when pavement structures vary a great deal from test point to test point, both as to thickness and quality, a single factor appears to be adequate for general evaluation purposes.

The relationship between plate-bearing values and actual wheel loads, as mentioned by Campen, will probably remain undefined for some time to come because of the difficulty of obtaining adequate traffic data on the numerous roads tested and for other reasons. However, it is hoped that evidence can be obtained which will further justify the criteria used to convert bearing values into tons of axle load for average Minnesota traffic and road conditions.