Frost Action and Load-Carrying Capacity Evaluation by Deflection Profiles

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●THIS REPORT describes the experimental use of a Benkelman beam with a Helmer recorder attached as a means of measuring the changes in load-carrying capacity of flexible pavements that occur as a result of frost action. An attempt also has been made to correlate the values of load-carrying capacity as determined by the use of the well established plate bearing test with similar load-carrying capacities as determined by the use of the Benkelman beam with the Helmer recorder attached.

About 1956 a Benkelman beam was made available to the Highway Research Board's Committee on Soils Calcium Chloride Roads. With this apparatus considerable data were collected in Alabama, Virginia, and particularly in Minnesota, on maximum deflections and residual deflections of flexible pavements under comparatively realistic loading.

During the collection of these data and later, attempts to analyze the data suggested that more information about the deflections was needed to arrive at more definite conclusions and for establishing the significance of the deflections. Also, during the collection of data in Minnesota during the spring thaw, close visual observation of the rates at which the deflections occurred with respect to the distance of the loaded wheels from the Benkelman beam probe point, and the changes of those rates of deflection with respect to the thawed condition, indicated that more information was available.

As a result, inquiries were made about constructing a device that would record the missing information. It was learned that R. A. Helmer, Research Engineer with the Oklahoma Highway Department, in cooperation with the Bureau of Public Roads, already had designed and built such an attachment for use with the basic Benkelman beam. One such device was then made available to the Committee.

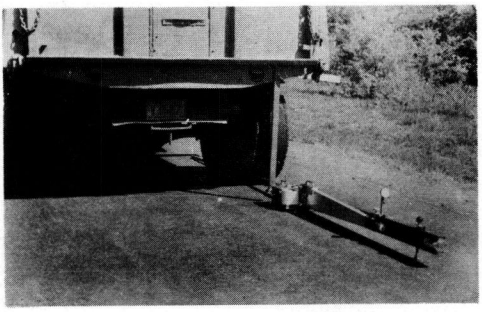

Figure 1. Benkelman beam, with Helmer recorder attached, in place for deflection determination.

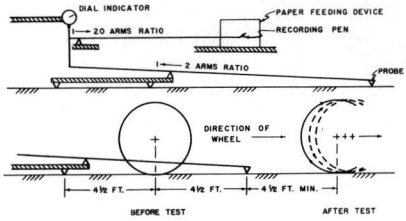

Figure 2. Schematic of Benkelman beam with Helmer recorder (upper) and position of wheel relative to beam (lower).

Figure 1 shows the complete apparatus set up ready for a determination of deflection properties of the road. The probe arm is seen projecting forward between the dual tires of the loaded truck. On the left side of the beam is seen the Helmer recorder.

Figure 2 shows the general arrangement of the arms of the Benkelman beam with a ratio such that the movement of the probe point is magnified 10 times when recorded. The position of the loading wheel is $4\frac{1}{2}$ ft back of the probe at the start of the test and moves ahead to at least $4\frac{1}{2}$ ft beyond the probe point.

Figure 3 shows a typical deflection profile of the type recorded, corresponding to the deflection of the road surface under the wheel load. It is preferred to regard the deflection profile as a virtual image of a longitudinal section through the surface of the

flexible pavement at the instant that the dual wheels straddle the probe point and the axle is directly over it.

Figure 4 illustrates three of the seven measurements made on each recorded deflection profile. These measurements are converted to inches per 1,000 lb per dual wheel. Four of the available measurements are not used at present because of their doubtful value. The three measurements illustrated include:

1. Maximum deflection, in inches.
2. Maximum initial rate of deflection, in inches per foot of pavement.
3. Maximum flection, in inches per foot.

These are discussed in further detail throughout the remainder of the paper.

With this research tool available to the committee, a considerable volume of profiles was collected intermittently in one year's time. More than 3,000 profiles were obtained in Minnesota in 24 days of actual work.

Of the data collected up to the end of 1957, less than 25 percent have been at least superficially analyzed or processed. Of the processed data, those dealing with only one test area are reported on in some detail. This test area is the one known as test area 11. Four other areas will only be referred to.

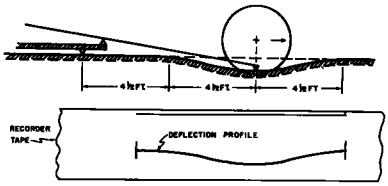

Figure 3. Recorded profile (lower) is virtual image of longitudinal section through flexible pavement with dual wheels astride the probe point (upper).

Test area 11, involved in this report, is on a secondary road which is a part of Minnesota Trunk Highway 97 and is located about 30 miles northeast of the Minneapolis-St. Paul area. This test area was selected for this report because it has shown considerable distress as a result of frost action.

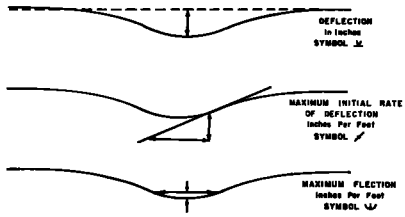

Figure 4. Measurements obtained from deflection profiles.

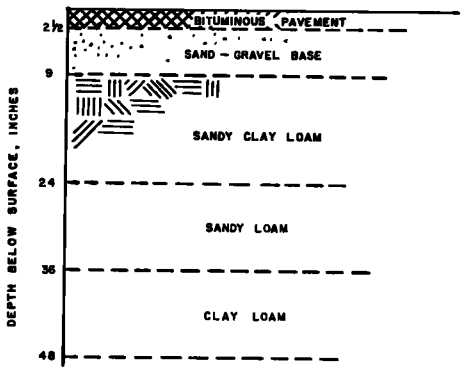

Figure 5. Soil profile at test area No. 11.

Figure 5 shows the soil profile typical of test area 11, on which the flexible pavement is 11½ in. in total thickness. The soils here are somewhat more plastic than at the other test points on this road.

Figure 6 shows the appearance of recovery trends of the four measurements when expressed in absolute units (that is, inches per kip per dual wheel for the three deflection profile measurements;) pounds per square inch, or tons per axle, for the plate bearing values.

It may be noted that the magnitude of the plate bearing values is increasing as recovery occurs, whereas for the deflection profile values their magnitude is decreasing as recovery occurs. The position of the several curves or the magnitude of their values in relation to each other should not be regarded as having any special significance.

Data from both the plate bearing test and the deflection profiles were put on an equivalent basis when trying to compare the trends in strength recovery from frost action. The plate bearing value obtained at any given time was expressed as a percentage of the autumn value, which is taken as 100 percent. For example, a spring value of 100 psi

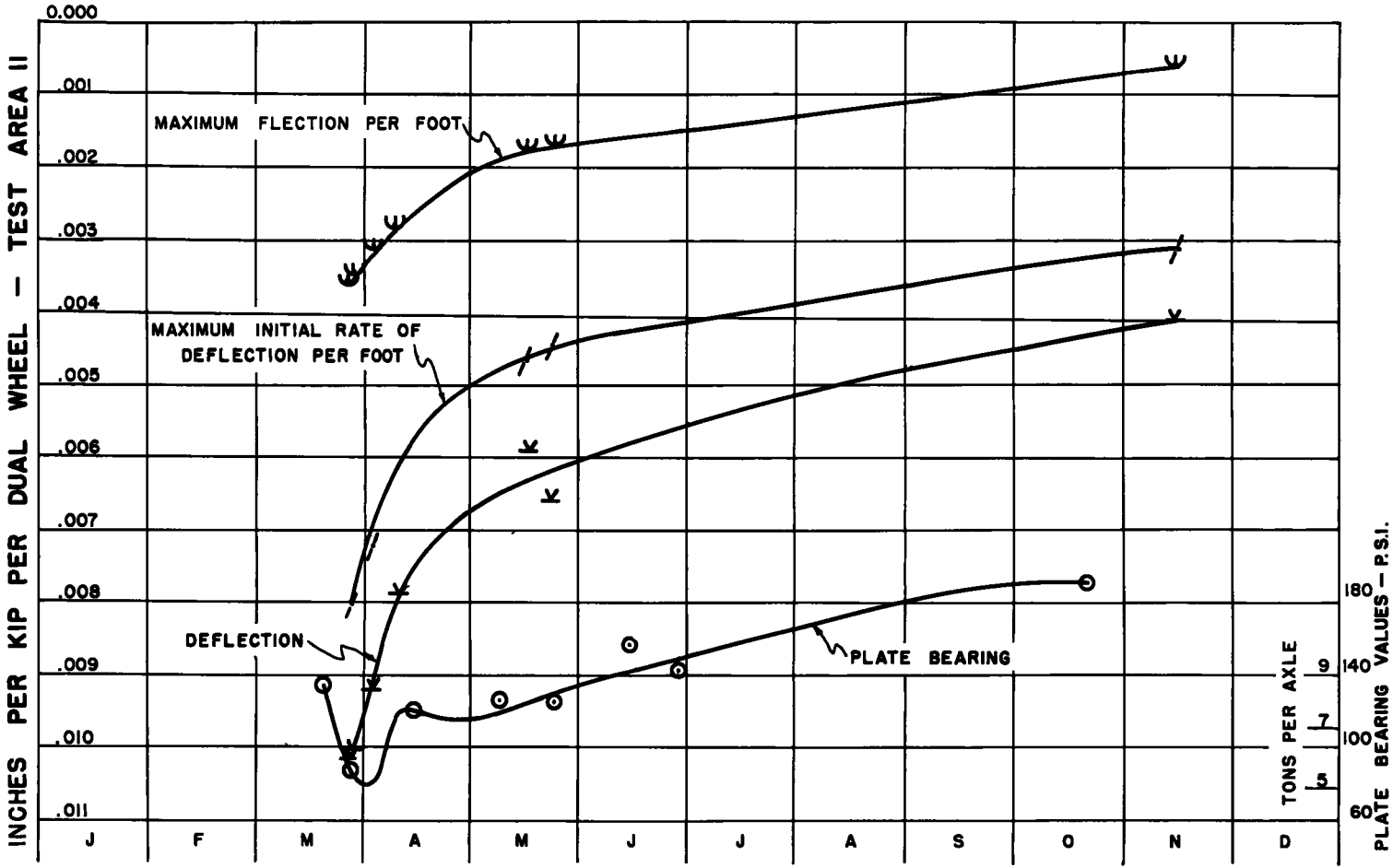

Figure 6. Recovery trends in absolute values, test area 11.

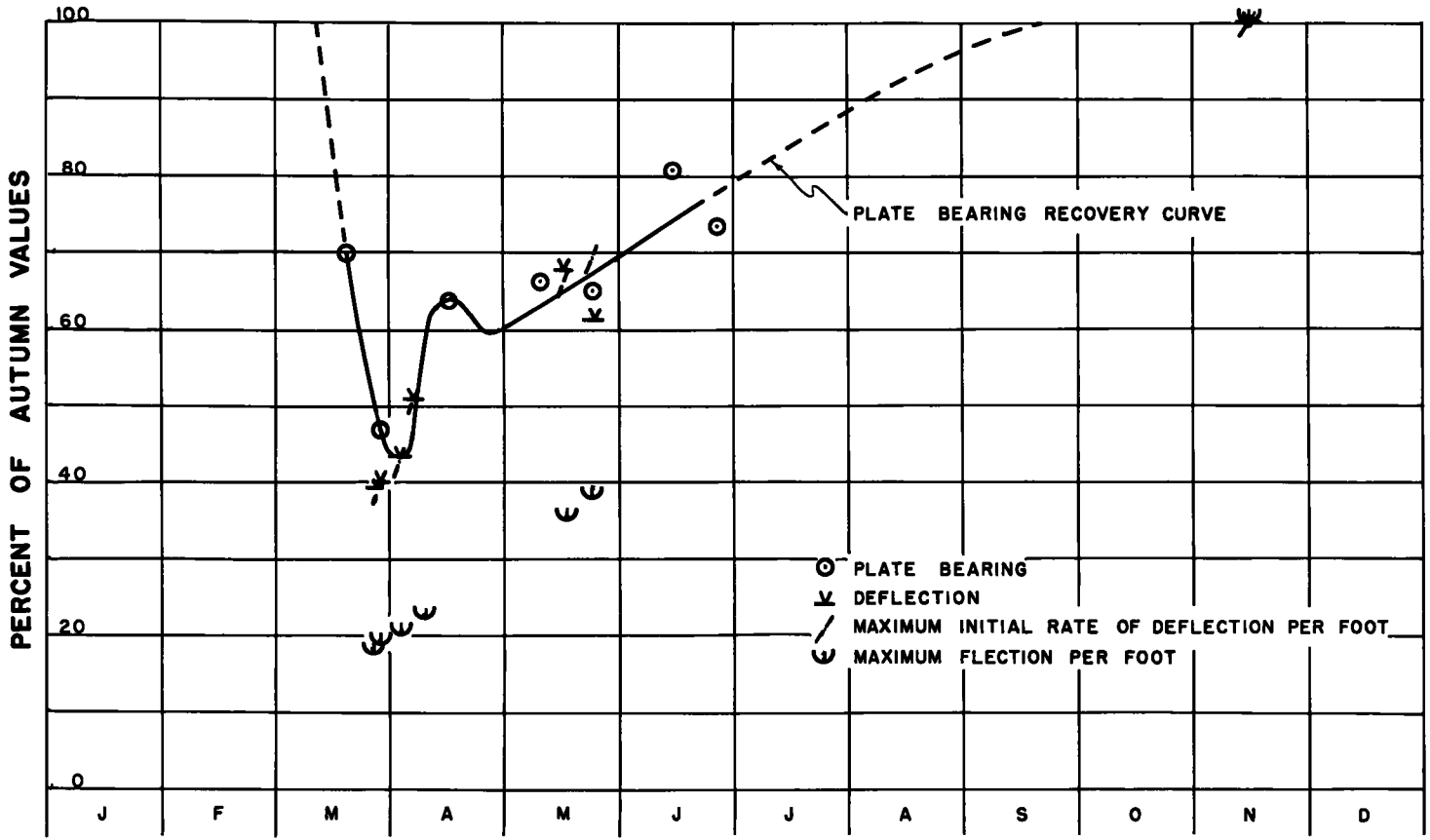

Figure 7. Relative plate bearing and inverse profile values, test area 11.

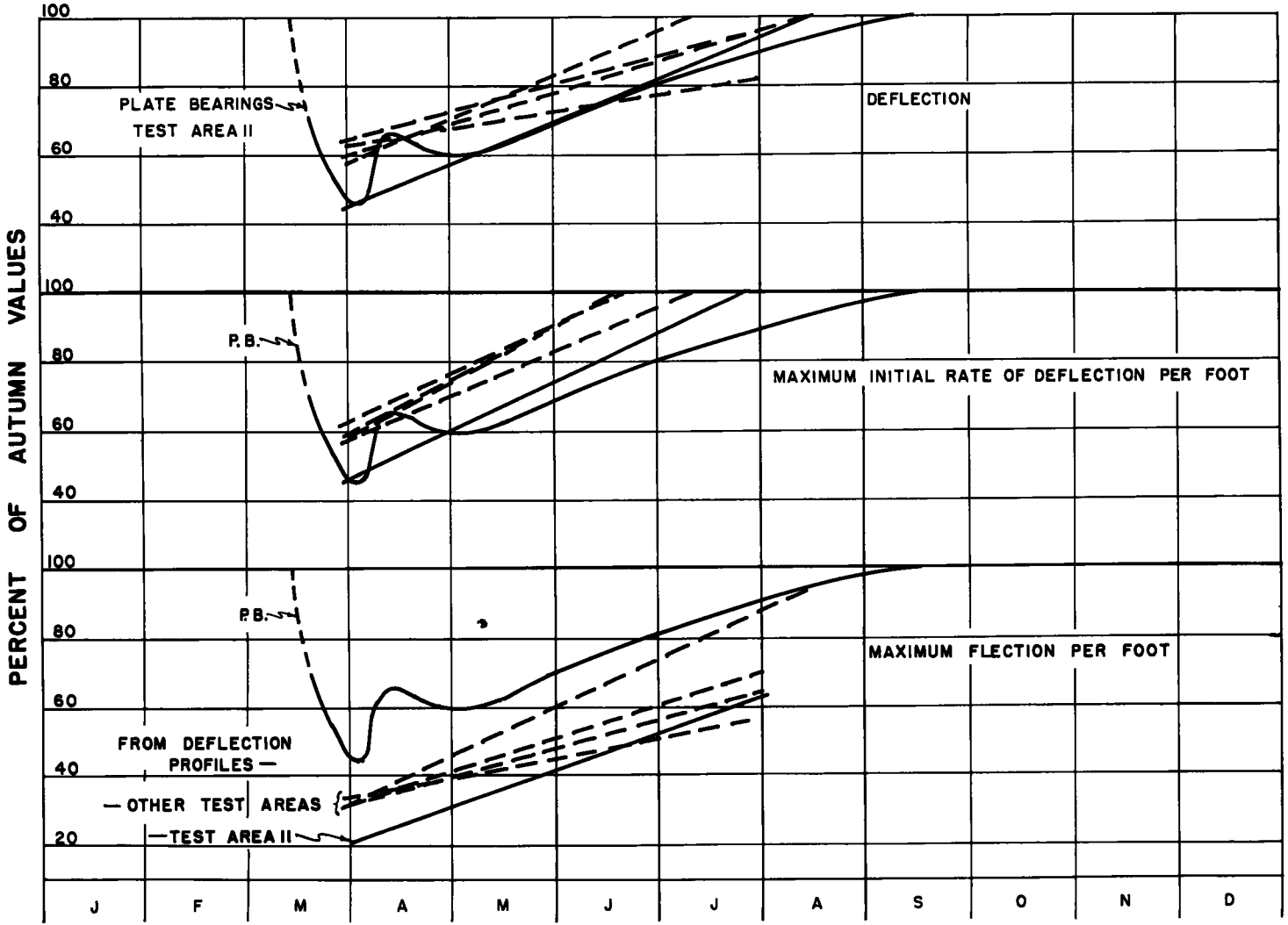

Figure 8. Recovery trends—from plate bearing values and inverse profile values.

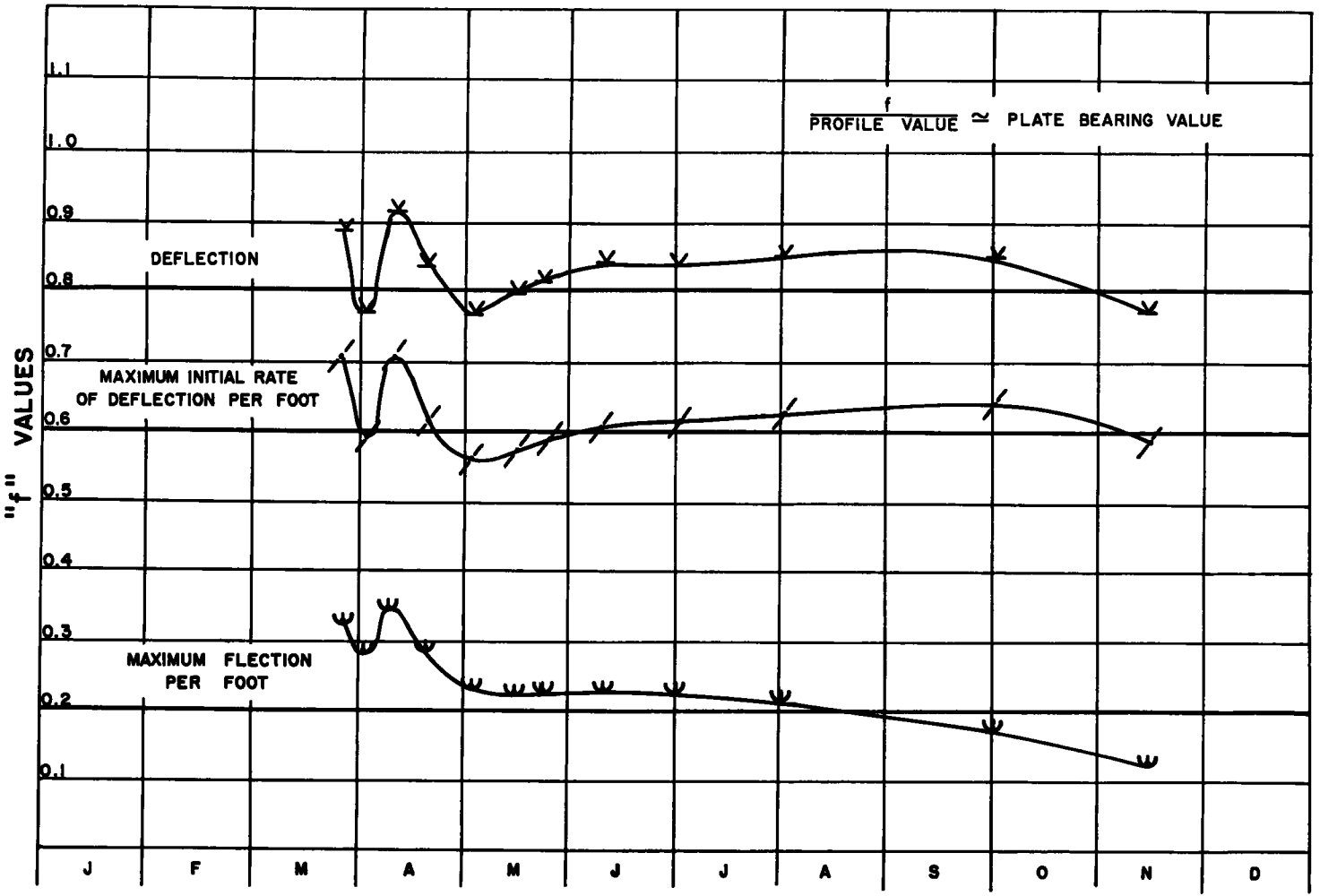

Figure 9. f—values for correlating profile values with plate bearings—test area 11.

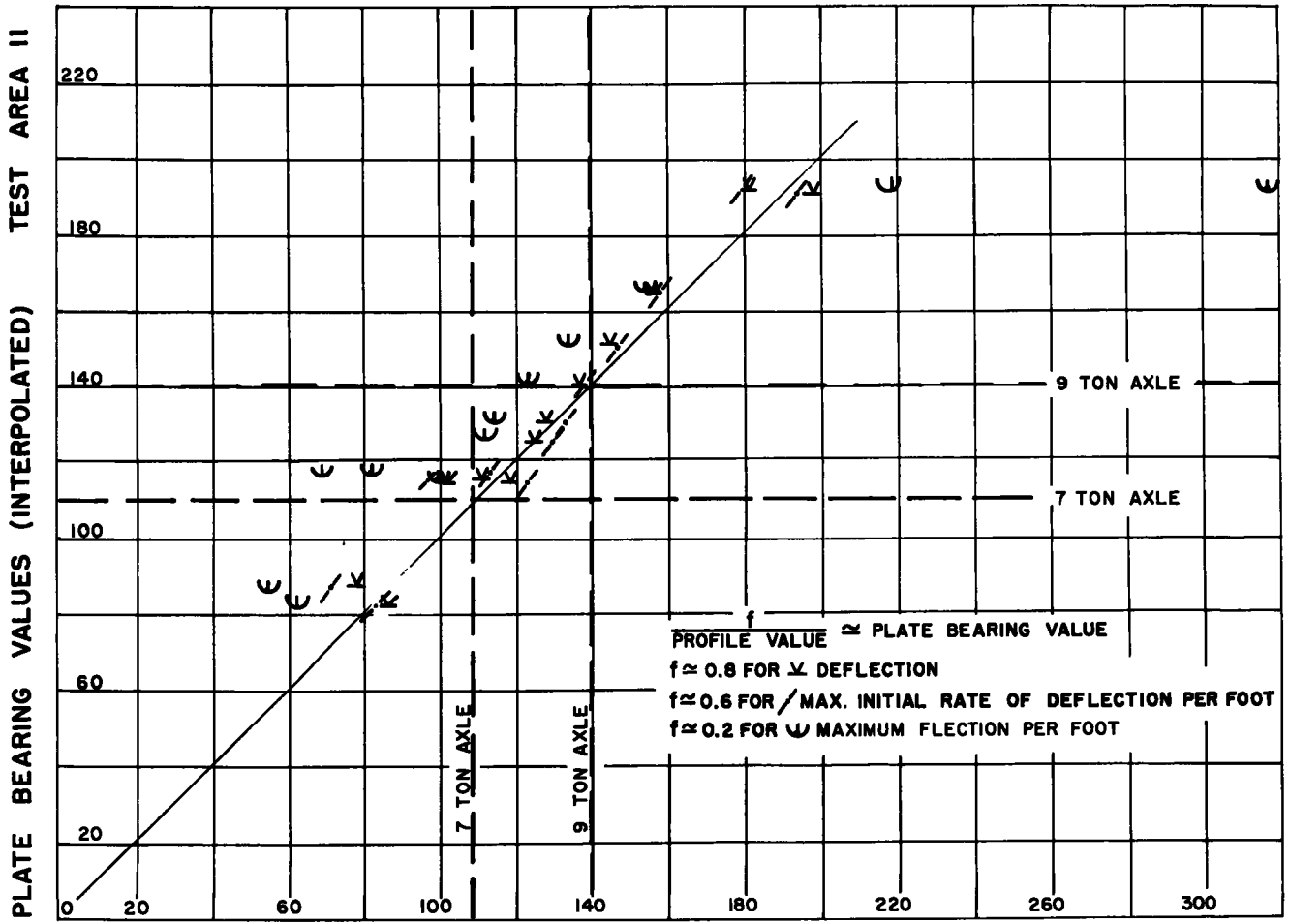

Figure 10. Estimates of plate bearing values from profile values (interpolated).

divided by the autumn value of 200 psi gives a relative bearing value of 50 percent.

The deflection profile values vary inversely as to magnitude in comparison with the plate bearing values; that is, high deflections in the spring and low in the autumn as against low bearing values in the spring and high in the autumn. Therefore, for the profile measurements the relative values are computed from the inverse of the profile values. (For example, an autumn deflection of 0.005 in. per kip per dual wheel divided by the spring deflection of 0.010 in. per kip per dual wheel gives a relative value of 50 percent, similar to that obtained from the plate bearing values.)

A. From Plate Bearing test:

$$\frac{(9)\ (\text{Plate Bearing Value})}{140} = \text{Tons/axle}$$

B. From Deflections by Benkelman Beam:

$$\frac{(0.05)\ (\text{Weight on rear axle in tons})}{\text{Total deflection in inches}} = \text{Tons/axle}$$

Figure 11. Computation of load-carrying capacity from test data.

Figure 7 shows the plate bearing recovery curve for test area 11, along with the three series of measured values obtained from the deflection profiles, all expressed as percentages of the values determined in the autumn. There appears to be reasonable agreement among the recovery trends from frost action. Separated from the other three trends is the plot of the maximum flections per foot of flexible pavement. Unless the flection values obtained in the autumn of 1957 are not reliable, it might be assumed that a measure of the maximum flection per foot of the flexible pavement might be a most critical measure of the loss of bearing caused by frost action.

Figure 8 shows that the other four test areas demonstrated characteristics similar to test area 11. It shows the relationship between the recovery trends of the test areas,

C. From maximum initial rate of deflection, by Benkelman Beam.

$$\frac{(0.037)\ (\text{Weight on rear axle in tons})}{\text{Max. initial rate of deflection in inches per foot of pavement}} = \text{Tons/axle}$$

D. From maximum flection, by Benkelman Beam:

$$\frac{(0.013)\ (\text{Weight on rear axle in tons})}{\text{Maximum flection in inches per foot of pavement}} = \text{Tons/axle}$$

Figure 12. Computation of load-carrying capacity from test data.

as reflected by the three measurements obtained from the profiles, and the plate bearing values indicated by the smoothed curve. It will be seen that test area 11 generally stands out by itself in comparison with the other four test areas. It will be noted, also, that in the plot of maximum flections per foot, all test areas indicate greater loss of bearing values than is shown by the plate bearing curve.

An attempt was made to find if a simple relationship exists between the plate bearing values and the absolute values from the deflection profiles. From each of the deflection profile recovery curves shown in absolute values in an earlier figure, several values were selected and multiplied by the corresponding plate bearing values in pounds per square inch; the resulting f-factors are shown in Figure 9. If there were a consistent relationship the f-values should fall on a straight line. Because this is not true, an estimate was made of reasonably safe f-values that could be used for the purpose of

estimating plate bearing values from the measured profile values. These are indicated by straight lines to the values 0.8, 0.6, and 0.2, for the profile measurements being correlated.

Figure 10 shows the correlation between values from the plate bearing test and the estimated plate bearings as computed from the deflection profile measurements, using the factors indicated. Although the correlation is not perfect, the general results are encouraging.

If a high order of correlation is not considered necessary, the Benkelman beam with the Helmer recorder is capable of making rapid on-the-spot road checks to assist the engineer in estimating reasonable load-carrying capacities in tons per axle.

Figure 11 shows two simple formulas for computing load-carrying capacities or axle ratings from different types of test data. The first is from the plate bearing test as used in Minnesota with loads applied through a 12-in. circular plate. The formula is strictly empirical, but over a period of years it has been found to show a reasonably good correlation with performance of flexible pavements.

The second formula shows the computation of axle rating from maximum deflections determined by the Benkelman beam.

The two formulas of Figure 12 are also simple methods for computing load-carrying capacities from the other two measurement profiles obtained from the beam deflection profiles.

From the data obtained at test area 11 critical values of deflection and flection have been determined, as follows:

Item	Approximate Critical Value (in.)
Total deflection	0.084
Maximum initial rate of deflection—per foot of flexible pavement	0.070
Maximum flection—per foot of flexible pavement	0.028

These values are related to the maximum legal spring season axle loading of 7 tons, which may be assumed to have caused the damage to the flexible pavement in the test area. Thus, the maximum deflection of about 0.012 in. per 1,000 lb per dual wheel, which was associated with observed alligator cracking, is equivalent to the value of 0.084 in. given. Similarly, values were established for maximum initial rates of deflection and for maximum flections.

These values cannot be assumed to be applicable to other traffic loadings and volumes, pavement design, and other variable factors, but are presented to illustrate a possible application of the deflections in establishing critical load limits.

CONCLUSIONS

The Benkelman beam with Helmer recorder attached is a practical and convenient instrument to use for rapid evaluation of the load-carrying capacity of flexible pavements, even though the correlation with the well-established plate bearing test is not of the highest order.

The recorded profile should be considered as a virtual image of a longitudinal section through the road surface between the dual wheels at the instant that they straddle and are over the probe point.

The measurements of the maximum deflection and maximum initial rates of deflection describe recovery trends from frost action that are similar to those obtained by use of the plate bearing test, but the maximum flection recovery trend indicates that it is a more critical measurement of the effect of frost action upon load-carrying capacity.

With research in particular areas that are showing distress, the following should be determined:

1. Critical limits for the maximum flection per foot of flexible pavement that the pavement can take at temperatures near or below freezing.

2. Similar critical limits for the maximum total deflection and maximum initial rates of deflection.

From an empirical approach to the problem, it appears that reasonably approximate constants can be determined for use in converting deflection of flexible pavement measurements into reasonable estimates of plate bearing values and, further, into ratings of roads in tons per axle.