A STUDY OF SEASONAL VARIATION IN PAVEMENT
CONDITIONS BY MEANS OF BENKELMAN BEAM
DEFLECTION AND FROST DEPTH MEASUREMENTS

MICHIGAN
DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

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This project was initiated by a memorandum from J. W. Burge dated October 22, 1975 in which he requested that the Research Laboratory conduct a cooperative study with G. A. Premo, Soils and Materials Engineer of District 1, to evaluate the usefulness of frost depth indicators and Benkelman beam deflection measurements for determining when springtime load restrictions should be lifted from roadways in the western half of the Upper Peninsula. Development of such procedures would provide a more positive method for evaluating pavement support conditions during and immediately following critical spring thaw periods and furnish information for use in evaluating overload requests.

Frost depth indicators, as modified for use by the Department, have been used successfully on other projects and appeared to be well suited for this work.

A review of the literature resulted in a decision to use a method developed by the Minnesota Department of Highways (1) for measuring and evaluating seasonal variation in the deflection of the test areas in order to compare pavement strength during the weaker springtime thawing period with that of the stronger summer dry periods. Of particular interest was the ability of the Minnesota method to predict the springtime critical deflection value from deflection measurements made at any time during the test area's unfrozen period. The method, although empirical, was based on thousands of deflection measurements and it was hoped that the relationship developed would also be applicable to Michigan pavement conditions.

This project, begun in the spring of 1976, was supervised for the Research Laboratory by E. C. Novak, Jr., assisted by T. M. Green. Routine frost depth and Benkelman beam measurements were made by District 1 personnel under the direction of G. A. Premo.

FIELD TESTING

Seven pavements in District 1 were used in this study. From each of these, the District Soils and Materials Engineer selected a one-mile test section considered to be representative of the area with respect to pavement cross-section, subgrade, surface uniformity, and strength characteristics. Locations of the test areas are shown in Figure 1.

One frost depth indicator, of the design shown in Figure 2, was installed near the center of each test area. The indicators remained in place in the pavement, being removed as required, for reading during the frozen
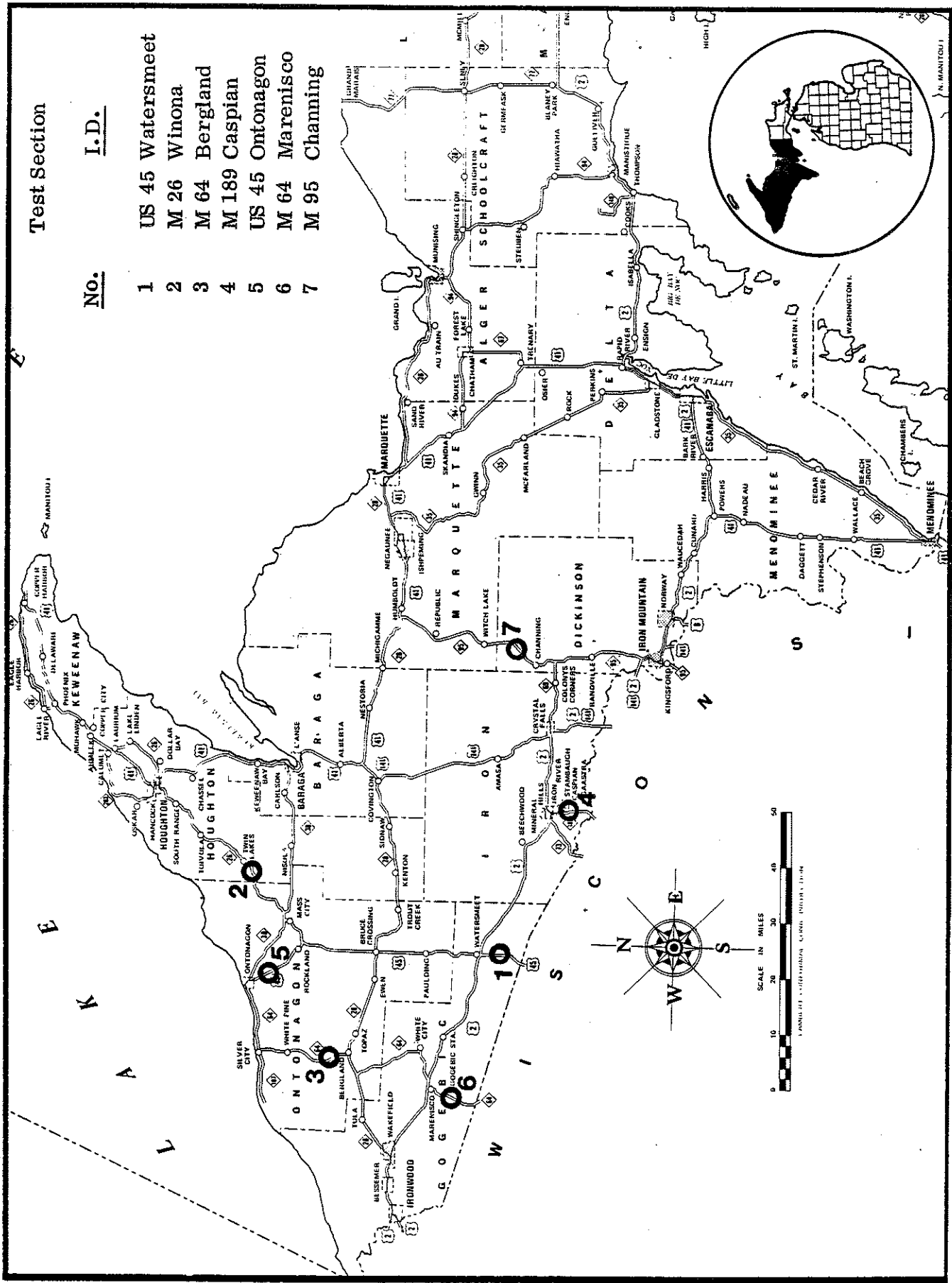
Test Section

No.	I.D.	
1	US 45	Watersmeet
2	M 26	Winona
3	M 64	Bergland
4	M 189	Caspian
5	US 45	Ontonagon
6	M 64	Marenisco
7	M 95	Channing

Figure 1. Location of test sections.

TUBE LIST

TUBE I.D.	SIZE		MATERIAL
	O.D.	I.D.	
LINER	1"	7/8"	POLYCARBONATE
INDICATOR	5/8"	1/2"	POLYCARBONATE
INSERT	7/16"	1/4"	TYGON

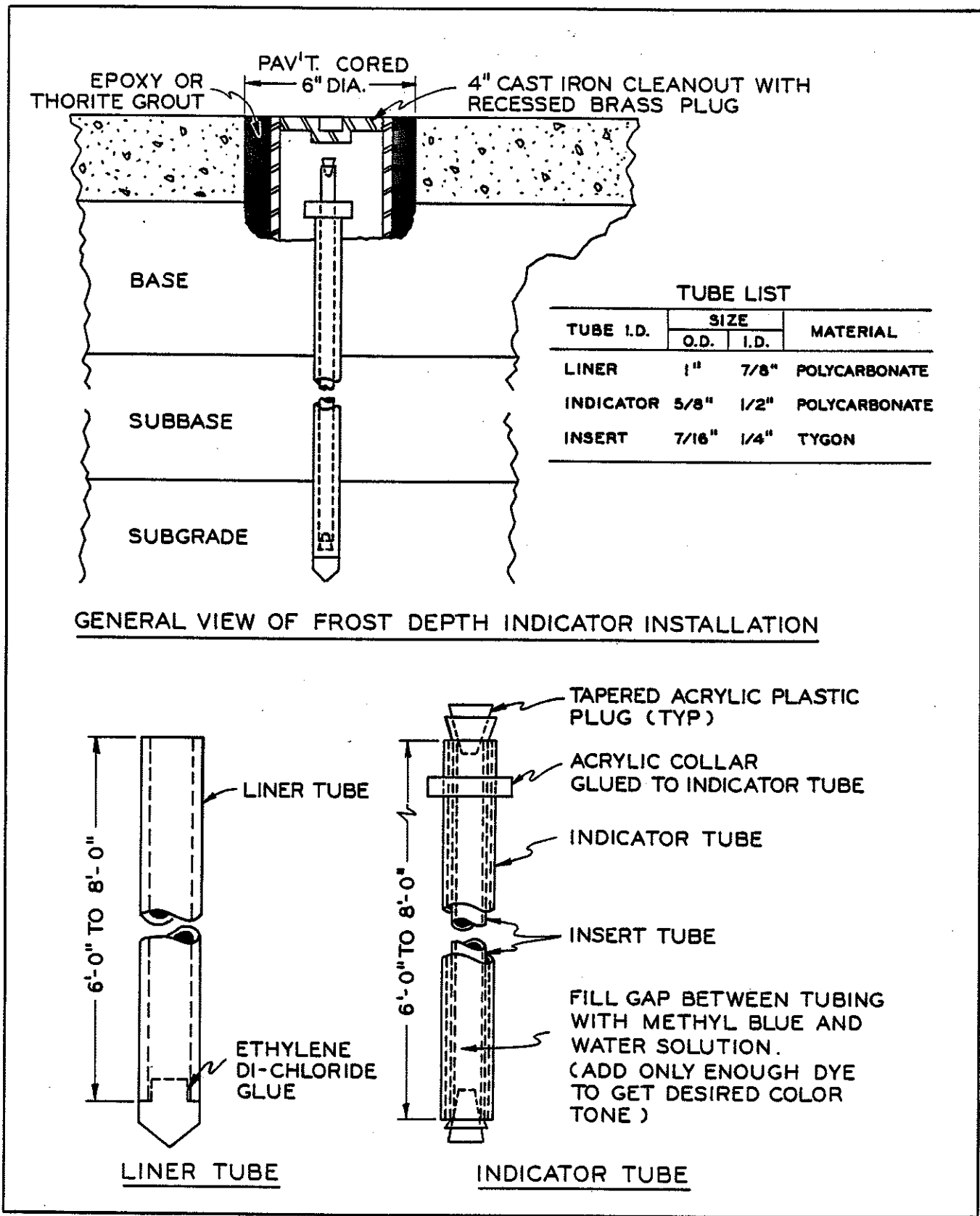GENERAL VIEW OF FROST DEPTH INDICATOR INSTALLATION

Figure 2. Details of the frost depth indicators used for this study.

and thawing periods. Figure 3 shows a typical reading of the indicator in which the frozen area of the pavement and subgrade is shown by a distinct color change of the methyl blue solution in the calibrated indicator tube. Frost depth measurements were made not only for the purpose of monitoring frozen profiles during springtime freezing and thawing periods but also to show when the pavement layers were no longer frozen—a requirement when using the Minnesota method to predict springtime deflection values from later, unfrozen deflection measurements.

Benkelman beam deflection measurements of the test areas were obtained following procedures suggested by Minnesota (Fig. 4). Ten measurements, located at approximately 500-ft intervals, were made for each mile-long test area. The average of these 10 readings (plus two standard deviations, to compensate for areas weaker than the average) represented the deflection value used for the particular test site. Measurements were begun during the spring and continued periodically until fall and were resumed the following spring.

The pavement cross-section for each test area was determined by coring through the bituminous surface and recording the thickness of each layer. Samples of the base, subbase, and subgrade were saved for laboratory identification tests and drainability analysis. Each mile-long test section was represented by the average of layer thicknesses measured at the ends and center of the section.

Temperatures were measured within, at the surface of, and 4 ft above the bituminous surface course for the area at the time of testing. Supplemental temperature and precipitation information were obtained from the Weather Bureau data collection station nearest to each test section.

Testing was confined primarily to 1976 and the early spring of 1977. Pressure of other work forced discontinuance of systematic testing after this time.

Figure 3. Use of the frost depth indicator.
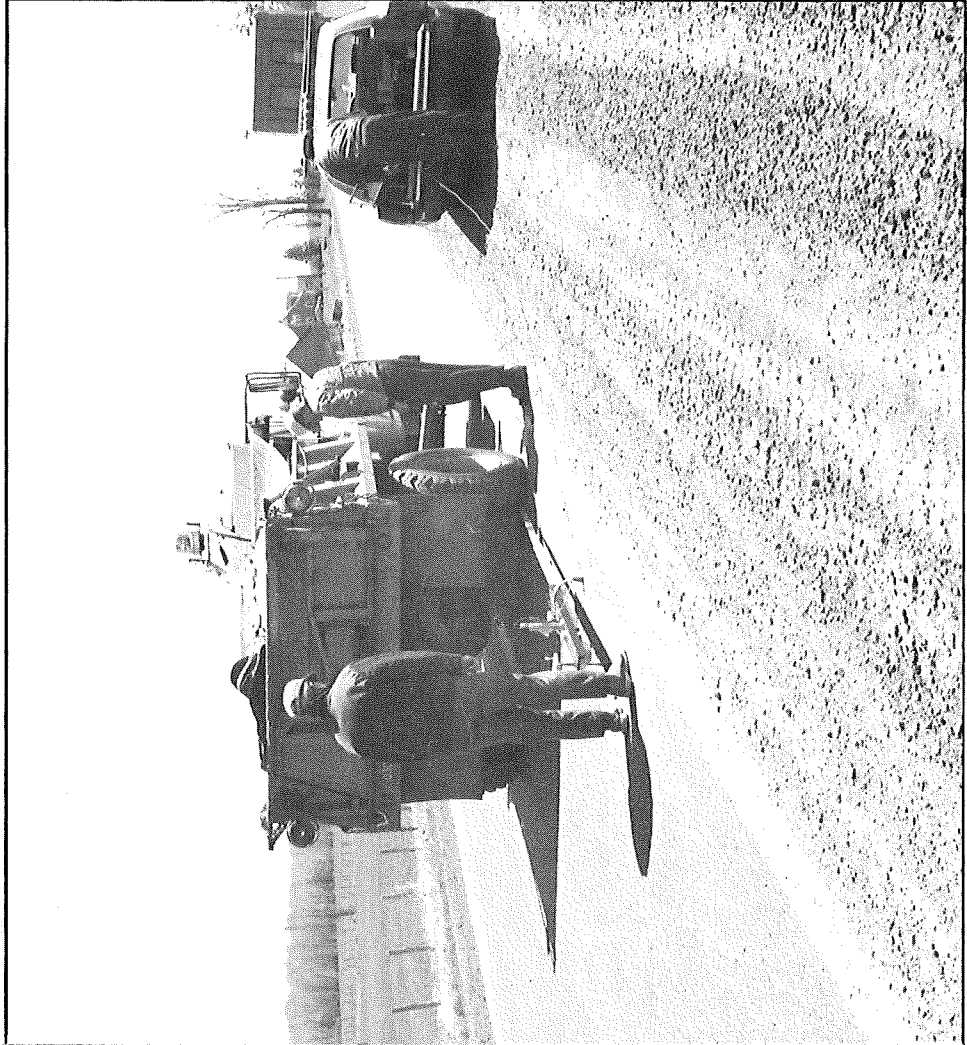
Figure 4. Benkelman beam deflection measurements.

TABLE 1
PROPERTIES OF THE TEST SECTION LAYERS

Test Section	Bituminous Concrete Surface, in.	Base				Subbase					Subgrade		
		Type	Permeability, k, ft/day	Drained % Saturation	$\frac{k}{N_e}$	Type	Permeability, k, ft/day	Drained % Saturation	$\frac{k}{N_e}$	T_{50} Drainage Time, days	Type	Soil Support	Drainage
US 45 Watersmeet	5	12-in. gravel 5.2% -200	0.3	85.0	10	20.0-in. sand 8.8% -200	1.4	81.3	34	10	clay 23.3% -200	4	Poor
M 26 Winona	3.8	6-in. gravel 9.2% -200	<0.1	100.0	Does Not Apply	17.3-in. sand 4.1% -200	6.7	69.0	101	>10	sand 1.7% -200	6	Good
M 64 Bergland	3.0	7.8-in. gravel 10.3% -200	0.2	89.8	8	37.3-in. sand 14% -200	<0.1	100.0	--	--	loam 38.2% -200	4	Poor
M 189 Caspian	3.0	13-in. gravel 5.7% -200	0.7	93.7	13	14.0-in. sand --	1.3	93.3	33	10	sand 21.9% -200	6	Good
US 45 Ontonagon	2.8	8.3-in. gravel 7.9% -200	<0.1	100.0	Does Not Apply	27.0-in. mine rock --	>100.0	<50.0	--	<10	clay --	2	Poor
M 64 Marenisco	3.0	7.7-in. gravel 5.1% -200	0.5	82.5	7	23.0-in. sand 11% -200	5.2	74.3	37	10	loam 12.9% -200	4	Poor
M 95 Channing	4.7	9.0-in. gravel 4.9% -200	<0.1	100.0	Does Not Apply	31.0-in. sand 14.5% -200	0.5	80.6	4	<10	loam 14.9% -200	4	Poor

NOTE: Good drainage -- $k/N_e > 33$

Poor drainage -- $k/N_e < 8$

TEST RESULTS

Properties of the pavement layers of the seven test sections are summarized in Table 1. Drainage characteristics included in this table were obtained by laboratory test methods described in previous Research Laboratory work (2, 3). Precipitation data for the test areas are summarized in Table 2.

TABLE 2
SUMMARY OF PRECIPITATION DATA FROM WEATHER BUREAU STATIONS LOCATED CLOSEST TO EACH TEST SECTION

Location	Precipitation, in. (Departure from Normal)							
	1976					1977		1978
	March	April	May	June	September	March	April	March
US 45 Watersmeet	3.1 (+1.5)	2.1 (−0.3)	3.1 (−0.6)	2.7 (−1.6)	0.6 (−2.7)	3.5 (+1.9)	3.9 (+1.5)	0.4 (−1.2)
M 26 Winona	3.1 (+1.6)	0.9 (−1.4)	1.4 (−1.9)	2.7 (−0.9)	1.1 (−2.0)	4.0 (+2.5)	2.6 (+0.2)	1.1 (−0.4)
M 64 Bergland	4.8 (+2.6)	1.1 (−1.8)	1.7 (−2.1)	3.1 (−1.0)	2.7 (−2.2)	4.7 (+2.4)	4.5 (+1.6)	0.7 (−1.5)
M 189 Caspian	3.1 (+1.5)	2.1 (−0.3)	3.1 (−0.6)	2.7 (−1.6)	0.6 (−2.7)	3.5 (+1.9)	3.9 (+1.5)	0.4 (−1.2)
US 45 Ontonagon	3.1 (+1.6)	0.9 (−1.4)	1.4 (−1.9)	2.7 (−0.9)	1.1 (−2.0)	4.0 (+2.5)	2.6 (+0.2)	1.1 (−0.4)
M 64 Marenisco	4.5 (+2.5)	1.1 (−1.5)	1.9 (−2.0)	6.1 (+1.7)	1.1 (−2.0)	2.9 (+0.9)	2.8 (+0.2)	0.8 (−1.2)
M 95 Channing	3.1 (+1.4)	2.2 (−0.1)	4.0 (−0.7)	2.8 (−1.2)	0.8 (−2.6)	3.6 (+1.9)	3.9 (+1.6)	0.7 (−1.0)

Figure 5 shows the seasonal deflection values for all test sections during 1976 and the spring of 1977. These values clearly show the higher deflection during spring following the thawing of the foundation and the recovery during the summer. It should be noted that several of the sites were not frozen when measurements were begun in 1976, but were frozen during the earlier measurements in 1977.

Figure 6 shows the deflection as related to the location of frost within the foundation and compares these values with the highest spring and the lowest summer deflections. These show that deflections were low when the foundation was frozen from the surface down to several feet—as would be expected. There was no consistent relationship, however, between deflection values and the distance of the top of the frost below the surface, nor to the total depth of the frost layer.
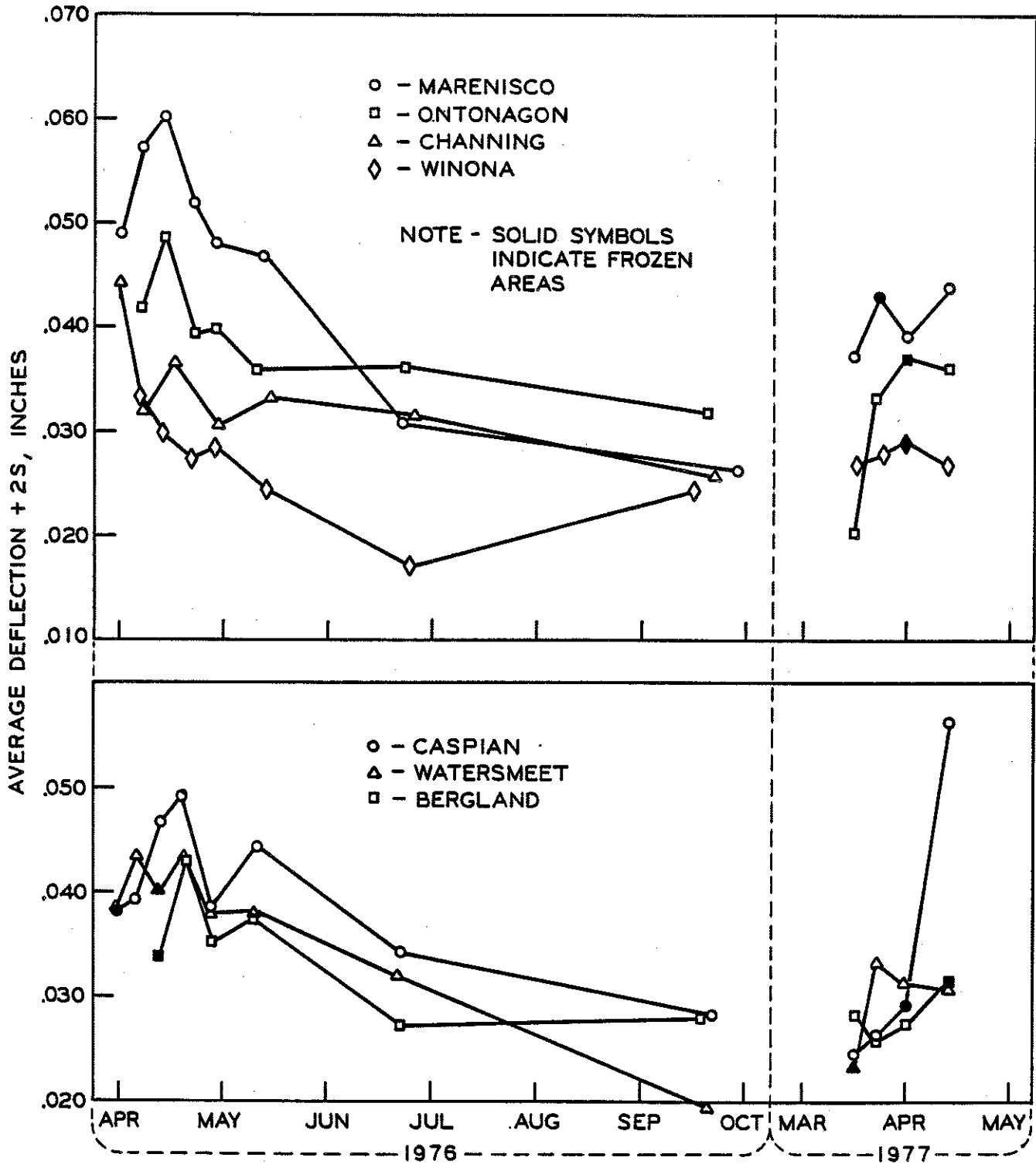
Figure 5. Seasonal variation in measured deflections of the test sections.
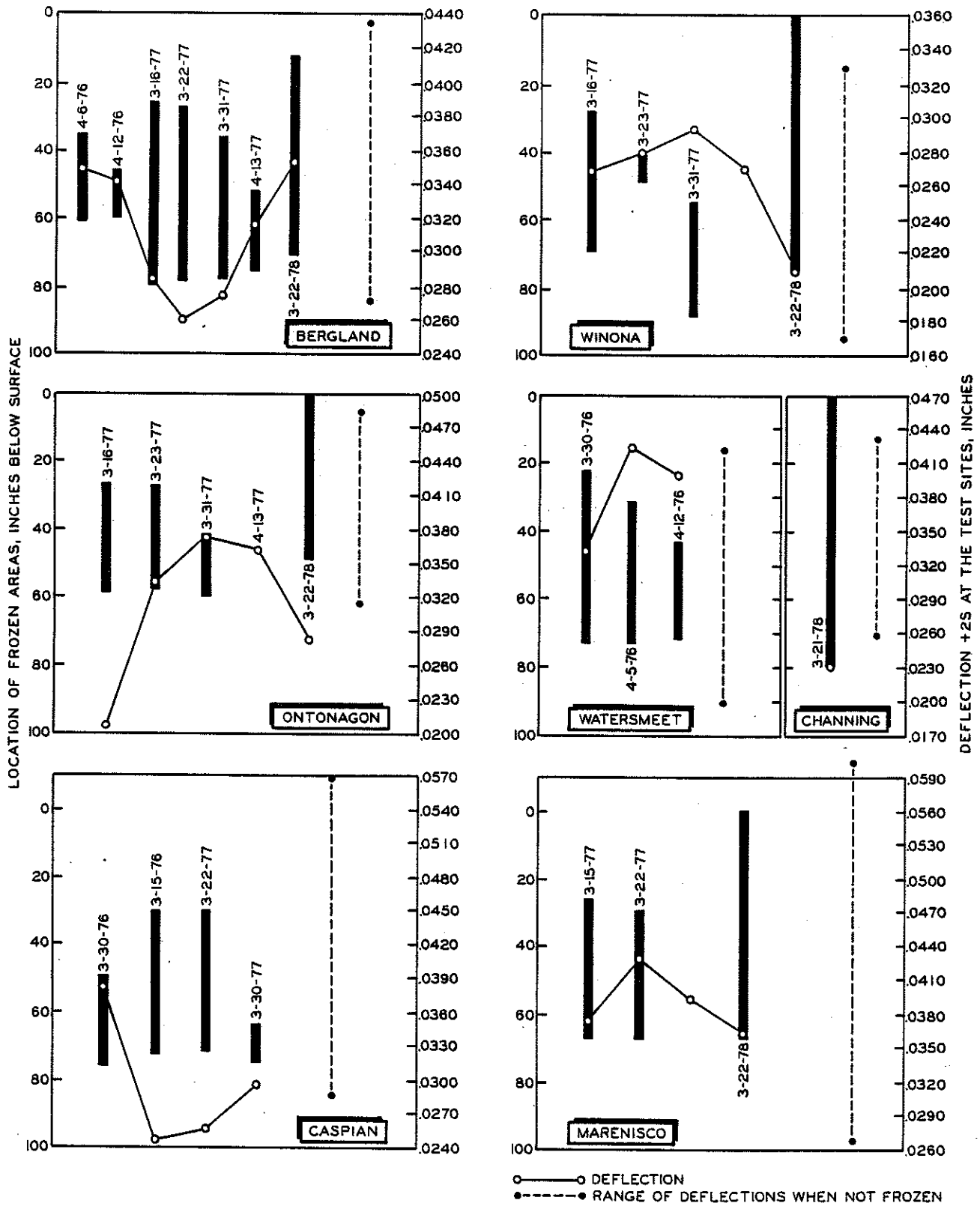
Figure 6. Relationships between frozen profile and deflection for the test sections.
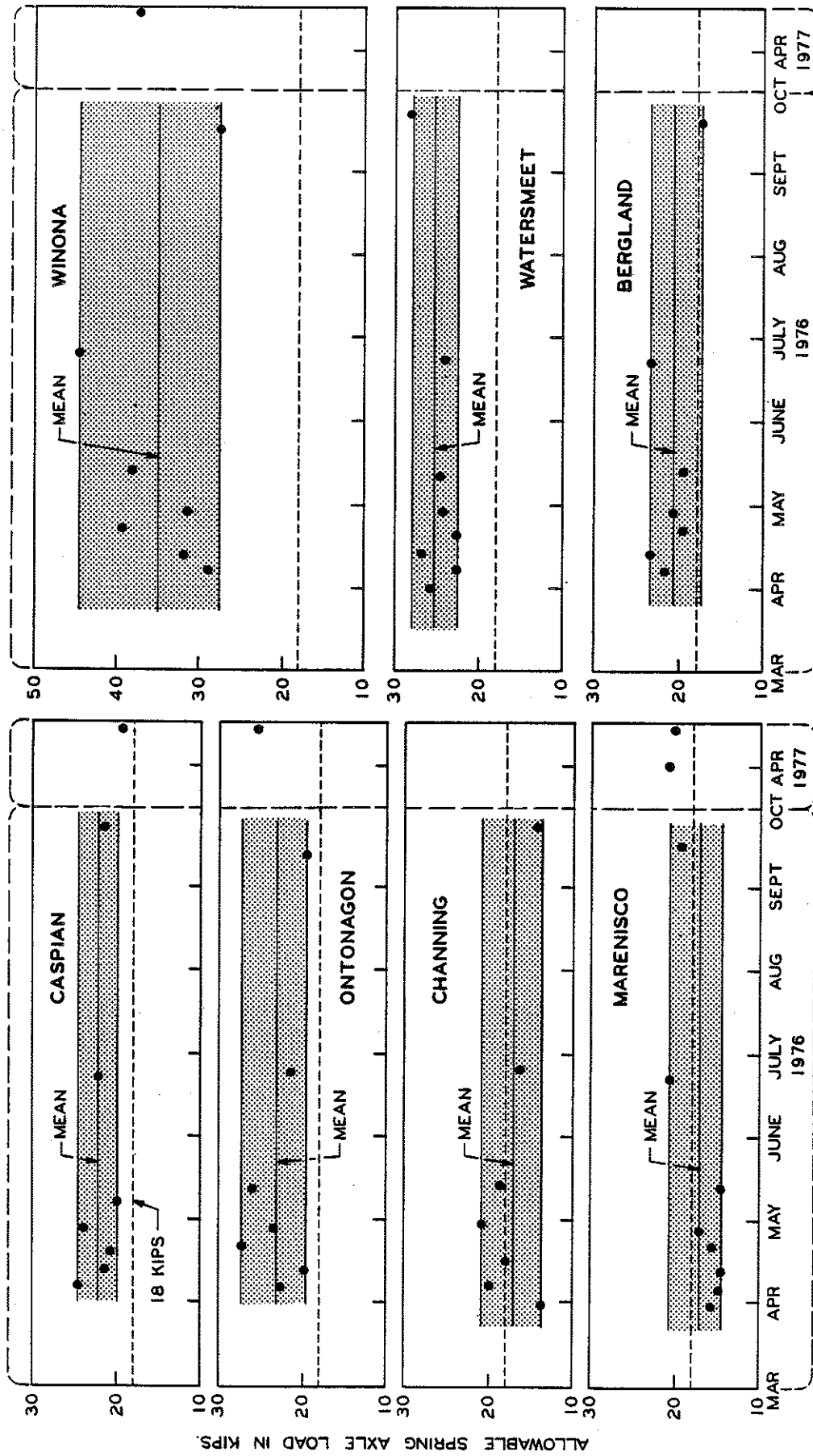
Figure 7. Allowable springtime loads as predicted by the Minnesota method from deflections measured at the time indicated (shown for 1976 data).

Based on data shown in Figures 5 and 6, the Winona test area showed the least difference in deflection between spring thaw and dry conditions. The Marenisco site showed the greatest change in strength. However, there appears to be no consistent correlation between differences in deflections for the test sites and the engineering properties summarized in Table 1.

Figure 7 shows data developed directly from the Minnesota method in which allowable spring axle loads can be computed from deflection measurements made at any time during the year when the pavement is not frozen. For example, a deflection measurement obtained in August can be converted to a design springtime deflection which would have been obtained had the measurement been made during the most critical springtime condition. This value in turn can be converted to an allowable spring axle load. The basic steps in this method, described in Ref. (1), include:

1) Correction of measured deflection to an 80 F equivalent,

2) Conversion of this value to the design spring deflection (deflection caused by the same test load during critical spring period) by means of a given deflection ratio,

3) Determination of allowable spring deflection from a given table based on surface thickness and traffic level of the test site,

4) Computation of allowable spring single axle load from the single axle load used in the test, using a ratio of allowable spring deflection to the design spring deflection. This is the value used to set load restrictions.

Figure 7 shows the mean and range of allowable single axle loads based on the deflection values obtained at various times of the year for the seven test sites. Considering the fact that Minnesota data were compiled from a large mass of data in which best fit values were used, some variation of specific testing is to be expected. Originally, for this study, it was planned to conduct field measurements over at least a three-year period in order to help compensate for such variation. Further testing of the method should be of value.

With the exception of the Marenisco and possibly the Channing test sites, all test areas showed an ability to carry 18 kip single axle loading during the 1976 spring thaw period and some could carry much higher. During the spring of 1977, however, Marenisco was also able to carry more than 18 kip single axle loading as was predicted by the preceding fall measurements. This is a further indication that more lengthy testing would have been desirable, in order to determine yearly variations of the method.
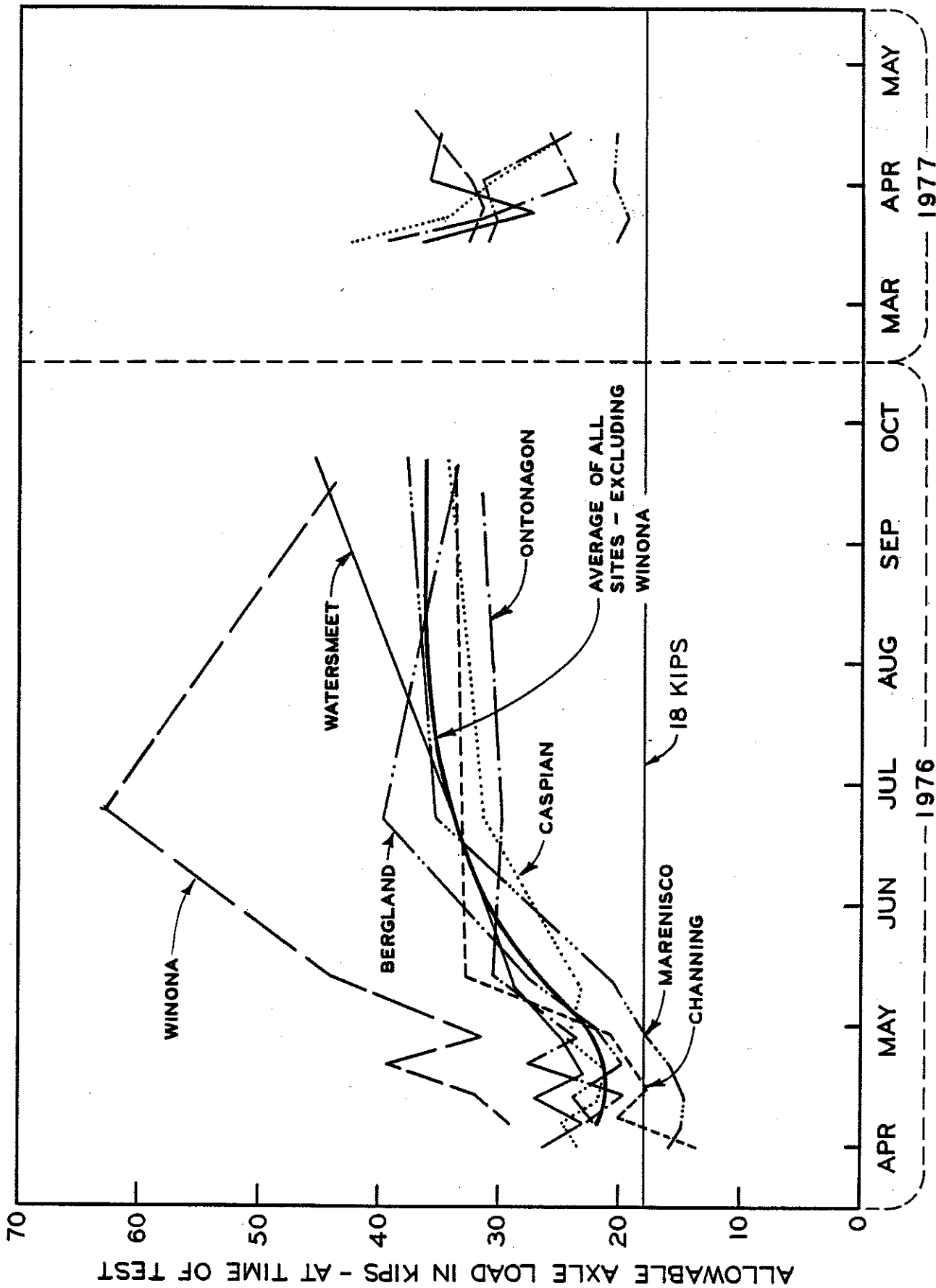
Figure 8. Seasonal allowable axle loads based on present design deflection (not converted to springtime values).

Figure 8 shows the seasonal variation in the allowable axle load for the test areas as obtained from the Benkelman beam deflection measurements. These data show the increase in support value after springtime thawing to a level equal, approximately, to the frozen support values obtained during the following early spring (1977). The increase in strength varies with the different pavements—due to their construction characteristics, particularly drainability—but in all cases strength increase had begun by May 1 and continued until about the middle of June. The Marenisco and Channing sites were the only two showing a need for springtime load restrictions but their recovery was equal to the average gained by the other sites. The Winona site showed an ability to support significantly higher loading than did the other sites which fell into a general coverage pattern as shown by the average curve in Figure 8. Other than good drainability of its subbase and subgrade the physical properties included in Table 1 show no reason for the significant difference nor, from Table 2, is there any indication of a specific lack of rainfall at the Winona site.

DISCUSSION

The Minnesota method is based on extensive and thorough testing of pavement conditions in Minnesota, the performance of which were measured by criteria developed from the AASHO Road Test. The method is based on the volume of commercial traffic and maximum pavement deflection with the assumption that the expected pavement life will be 20 years, at the end of which time its Present Serviceability Index would be no less than 2.5. The method establishes a maximum allowable spring axle load, based on a combination of environmental and load induced forms of failure. Recommended allowable deflections were developed from results obtained from various sources, including the AASHO Road Test. The relationship between load and deflection for any pavement section is assumed to be a straight line relationship (but this may not always be true) which allows computation of expected deflection for any load, once a deflection for a specific load has been established. However, the allowable deflections used were established on the basis of experience not yet obtained in Michigan. Also, because of variations in drainage characteristics, layer thickness, strengths of pavement layers, and embankment classifications at a test site, the universal application of the method might be subject to question. This would be particularly true if stabilized bases were used. Whether the Minnesota method is strictly applicable to Michigan pavement conditions cannot be established at this time. However, the method was designed to provide conservative allowable load values (1) and its use on this project, as well as on other work in Michigan (4), has established its usefulness for measuring relative load carrying values for different pavements and for measuring seasonal variations of individual pavements.
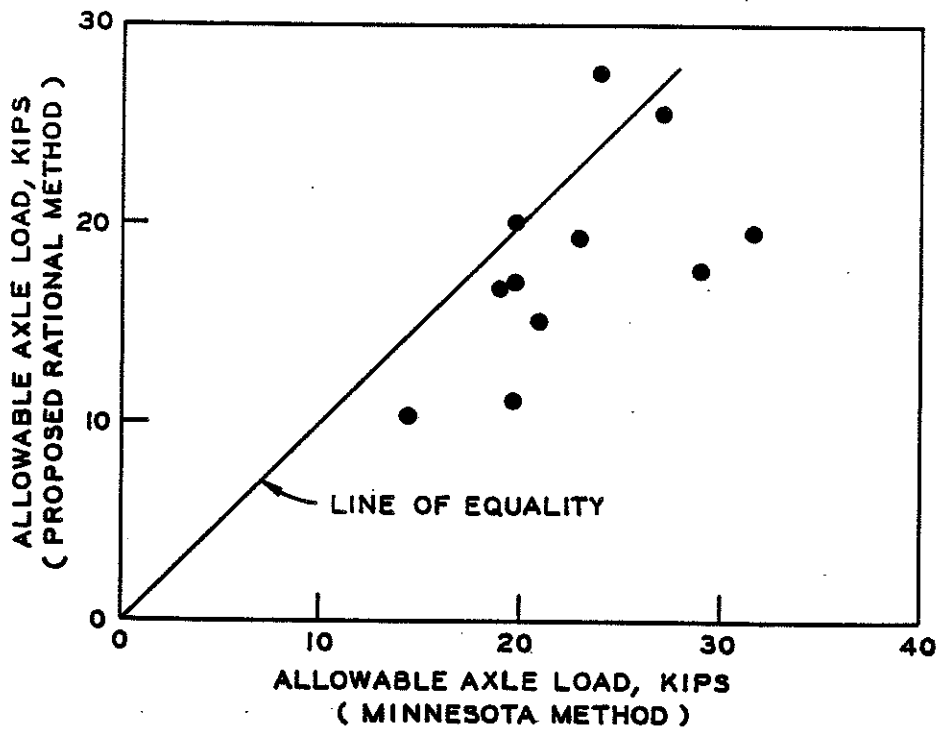
Figure 9. Relationship between springtime allowable axle loads by two methods of test.
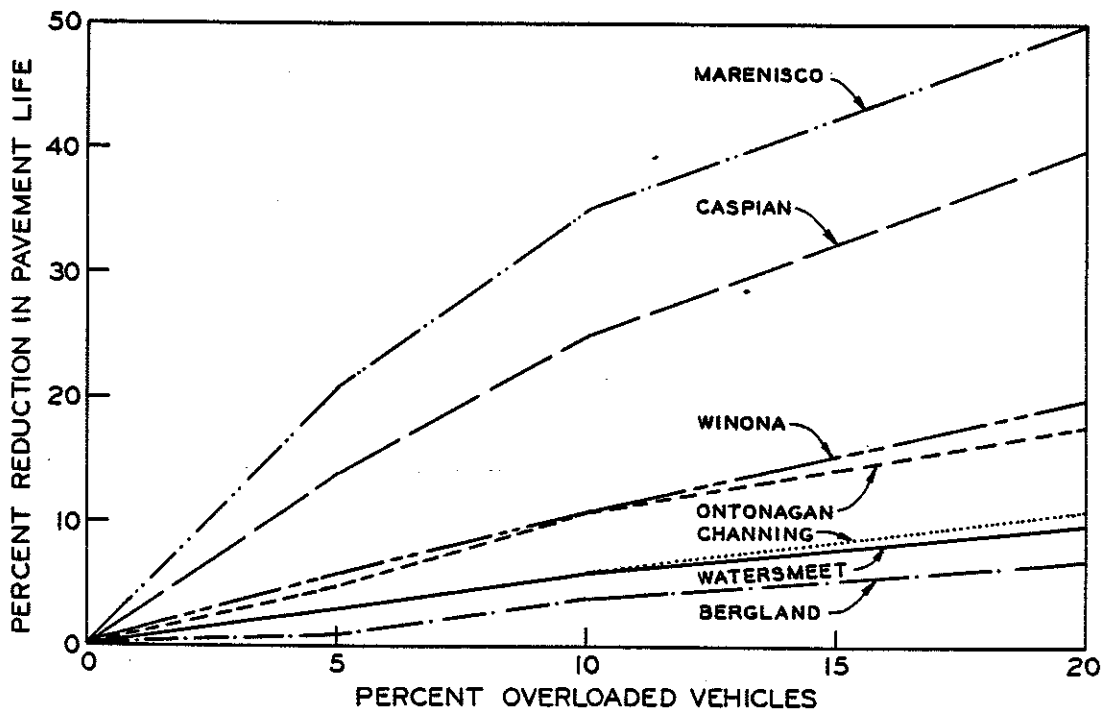

Figure 10. Effect of overload traffic—during springtime—on pavement life (rational method after E. C. Novak, Jr.).

In favor of the more general applicability of the method are the data plotted in Figure 8. Although the materials and engineering properties of the test sections are different (Table 1) and they were constructed at different times, the plots of seasonal allowable axle loads for six of the seven sites all fall within a relatively narrow band around an average curve. This would indicate that pavement variables do not appreciably affect the Minnesota method results for pavements of the same design life (20 years). Additional testing in other geographical locations of Michigan should be useful for evaluating, more fully, the general applicability of the Minnesota method for predicting the load carrying capacity of Michigan pavements.

Although the Minnesota method can be used to obtain the maximum allowable springtime axle load, from which some idea of overload allowance can be made, there is no provision in the method for actually measuring the detrimental effects of overloads or for establishing the number of permissible overloads of a given magnitude for a particular pavement. An attempt to provide such information is included as part of an overall pavement design and evaluation method developed by E. C. Novak, Jr. of the Research Laboratory—which will be the subject of a future research report (5).

Figure 9 shows the relationship between springtime allowable axle loading derived by this method (rational method) and the Minnesota method for the test areas in their weakest springtime state. Although the values obtained by the two methods are not equal there is a definite relationship between the two. Comparisons at other seasons, however, yielded no usable correlation.

Figure 10 shows the effects that overloads (applied during the weakest condition of the pavements) would have on the life of the test areas when 0, 5, 10, and 20 percent of the total 18-kip single axle loads permitted on the pavement were replaced by the same number of 25-kip single axle loads. Data for these curves were derived from the rational method of evaluation and show the percentage that the estimated life of a pavement would be reduced by the overload. According to these data the Marenisco and Caspian sites would be most affected by overloads. Although the theoretical methods used in the rational derivation of these data cannot be related directly to the empirical results obtained by the Minnesota method, it should be noted that the Marenisco and Caspian sites also showed the greatest springtime deflection by the Benkelman beam tests—the use of which was common to both methods—indicating that increased damage due to higher axle loads is greatest for the weaker pavements.

CONCLUSIONS

Based on the testing of seven sites in Michigan's Upper Peninsula over an approximately one-year period, the following conclusions were reached concerning the applicability of frost depth indicators and deflection measurements to the determination of seasonal variations in pavement load carrying capacity.

1) Michigan's frost depth indicators are functional and show a profile of the frozen condition of pavement layers before and during springtime thawing periods.

2) The test methods used were sensitive to seasonal variations in pavement strength. Increase in pavement deflections during and after springtime thaw and decreased deflections during summer were successfully monitored by deflection measurements.

3) Strength increase of pavements began by May 1 at all sites and full strength was regained between June 1 and 15.

4) The Minnesota method was generally successful in predicting spring allowable loads from deflections measured at any time of the year when the pavement structure was not frozen.

5) The Minnesota test method indicated that, with the exception of the Marenisco and Channing sites, all of the test areas can support at least 18,000-kip single axle design loads during springtime conditions, with some able to support a considerable overload.

6) A longer period of time (at least three years as originally proposed) should be spent on this evaluation in order to compare any yearly changes that might affect results. Also, more frequent measurements should be made throughout late spring and summer.

7) The sampling method used for the Benkelman beam measurements, as developed by Minnesota, is excellent and suitable for other Benkelman beam testing programs.

8) The Minnesota method offers a relatively simple procedure for measuring seasonal variations in pavement load supporting ability. Although developed for pavement conditions (design, construction, and use) in Minnesota, the method may be more generally applicable. In this study

seasonal allowable axle loads, developed by the Minnesota method, did not vary greatly for six of the seven sites tested although the pavements were constructed at different times and of different materials and cross-sections.

9) Rational methods for evaluating pavement performance (also using Benkelman beam deflection measurements) have been developed recently in the Research Laboratory and offer promise of providing more detailed and accurate information in many areas of pavement study. One such method permits the prediction of the effects of overloads on the life of a pavement and was used for such purpose in this study.

REFERENCES

1. "Flexible Pavement Evaluation with the Benkelman Beam, Summary Report," Minnesota Department of Highways, Investigation No. 603, 1968.

2. Novak, E. C., Jr., "A Method of Determining Subbase Drainability," Michigan Department of Transportation, Research Report R-805, April 1972.

3. Novak, E. C., Jr., "Development and Evaluation of a Field Drainability Test Method," Michigan Department of Transportation, Research Report R-1001, June 1976.

4. Hsia, F. T., "Comparison Study on the Performance of Bituminous Stabilized Bases (M 66 and M 20)," Michigan Department of Transportation, Research Report R-1046, February 1977.

5. Novak, E. C., Jr., "A Rational Method for Determining the Load Carrying Capacity of Flexible Pavements," Unpublished data prepared at the Research Laboratory, Michigan Department of Transportation.