Research Report

LOAD RESTRICTION DETERMINATION STUDY

FINAL REPORT
September 1980

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16. Abstract

The project identified various highway roadways subjected to load restrictions for cataloguing on a District-wide map. An investigation of freeze-thaw events and pavement deflections was conducted in addition to collection of weather data at selected sites. "Frost Tubes" were evaluated and found to be an effective tool for measuring frost depths. Limited data was collected due to warm winters and short freeze-thaw cycles. It was concluded that load restrictions are not needed until the temperature changes to a warming period. Additional research is needed to determine when load restrictions should be removed.

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LOAD RESTRICTION DETERMINATION STUDY

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Washington State Transportation Commission

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LOAD RESTRICTION DETERMINATION STUDY

INTRODUCTION

The initial goal of this Research Project was to provide a district-wide map identifying the various highways that are subjected to load restrictions due to freezing weather. In conjunction with the cataloguing, a study was made of a relatively new device called a "Frost Tube." Frost tubes are a simply and inexpensive method for measuring the depth of frost in pavements without the necessity of digging holes or using complicated instrumentation.

This study was initiated in 1973. Concern arose originally because there did not seem to be a uniform method of determining when to impose load restrictions and when to remove them. Also there were no criteria for determining critical thawing conditions. Load restrictions were imposed on several State Highways within District No. 1 when, in the estimation of maintenance personnel charged with that responsibility, excessive damage would otherwise occur. Road closures adversely affected both individual citizens and industry which depends upon these routes for local services and transportation of marketable products.

There was considerable pressure from industry, especially in the Mt. Vernon-Anacortes area (SR 20), when load restrictions were imposed. Although no cost figures are available, imposing load restrictions adversely affects industry. Not imposing restrictions causes costly pavement damages.

Directive D-54-42(MR) effective February 26, 1974 entitled "Emergency Restrictions for Roads," sets forth current policy. This also affects roadways designed to be free from possible frost damage. Transportation Commission Resolution No. 2636 defines emergency and severe emergency conditions.

Establishment of criteria based upon research data for imposing and removing load restrictions would be of major supportive value to the Department of Transportation and of major economic value to the public.

Since 1950, Transportation Department design criteria has compensated for frost heave potential by establishing a total depth of paving using frost-free granular surfacing material. Certain roadways so designed have been subjected to load restrictions. To evaluate the validity of these closures, inter-relationships between seasonal soil moisture, thawing conditions following a freeze, and dynamic deflection tests during these periods were examined.

This study was limited to the sections of highway which were being restricted during thaw conditions. The initial objective was to develop guidelines for standardizing procedures for determination of when to impose and remove restrictions.

Sixteen highway test sites were selected for study. Pavement and soil samples from each site were obtained and analyzed. The research was conducted by District 1, under the direction of the District Materials Engineer. The program was conducted by District personnel.

The initial term of study was 9 months, starting October 1973 and ending June 1974. However, due to the lack of freezing and thawing conditions, the study was not completed until June 1979. Prior to this study there were no formal methods to determine when load restrictions were to be imposed or removed. Restrictions were imposed based on ambient temperatures, digging holes in shoulders to determine frost depths, and past experience.

This study used the following measuring techniques and equipment to obtain the required data:

- Benkleman Beam Readings--Readings taken during wet, dry, frozen, and thawing conditions.
- Soil Moisture Meter--Readings taken to determine moisture and temperature.
- Frost Tube-- Readings taken to determine frost depths.

The Benkleman Beam is one of the presently accepted standard methods for determining strength of pavement. It is a reliable, widely accepted means for obtaining deflection readings. Other types of equipment were not accessible for this study.

The soil moisture cells were buried under the frost tubes with the electrical leads running out and across the road surface through saw cuts to the road edge. Trucks and maintenance equipment often cut these leads. Also, overlaying the roadway damaged the leads. Therefore, not enough information was gathered from the soil cells to determine their usefulness or any correlation to frost tube and pavement deflection data. However, their cost is low enough to warrant further investigation of the correlation of soil temperature and moisture to frost tube and deflection readings.

Frost tubes have proved to be valuable in several ways. First, they are inexpensive and are made from common materials. Secondly, they can be installed quickly and easily. Also, untrained personnel can "read" the frost tubes without difficulty. Most importantly, the frost tubes provide a quick, easy, and accurate determination of frost depth.

FROST TUBE DISCUSSION

GENERAL

Past investigations have dealt with a variety of devices for determining frost depths in soils. Instrumental methods generally require a high initial cost, as well as costly maintenance and time-consuming measurements, and are not always precise despite large amounts of data supplied. Physical probings are destructive, difficult to obtain in compacted, frozen, or thawed subgrade material, and time-consuming.

In 1957, a new method was introduced which looked promising. A tube filed with methylene blue dye was inserted into the ground. When frozen, the dye changes color which indicates frost depths accurately to within 5 centimeters. Studies indicate that this method is as accurate as conventional instrumentation.

In its present form (shown in Figure 1), the frost tube consists of an outer polyethylene tube that is permanently installed in the soil and an inner, removable tube containing a fluorescein-saturated sand mixture. When thawed this misture is green in color, and changes to a pale pink when frozen. These color changes correspond closely with changes of frost conditions. Studies have shown this present form to be easily read by untrained persons and inexpensive to construct.

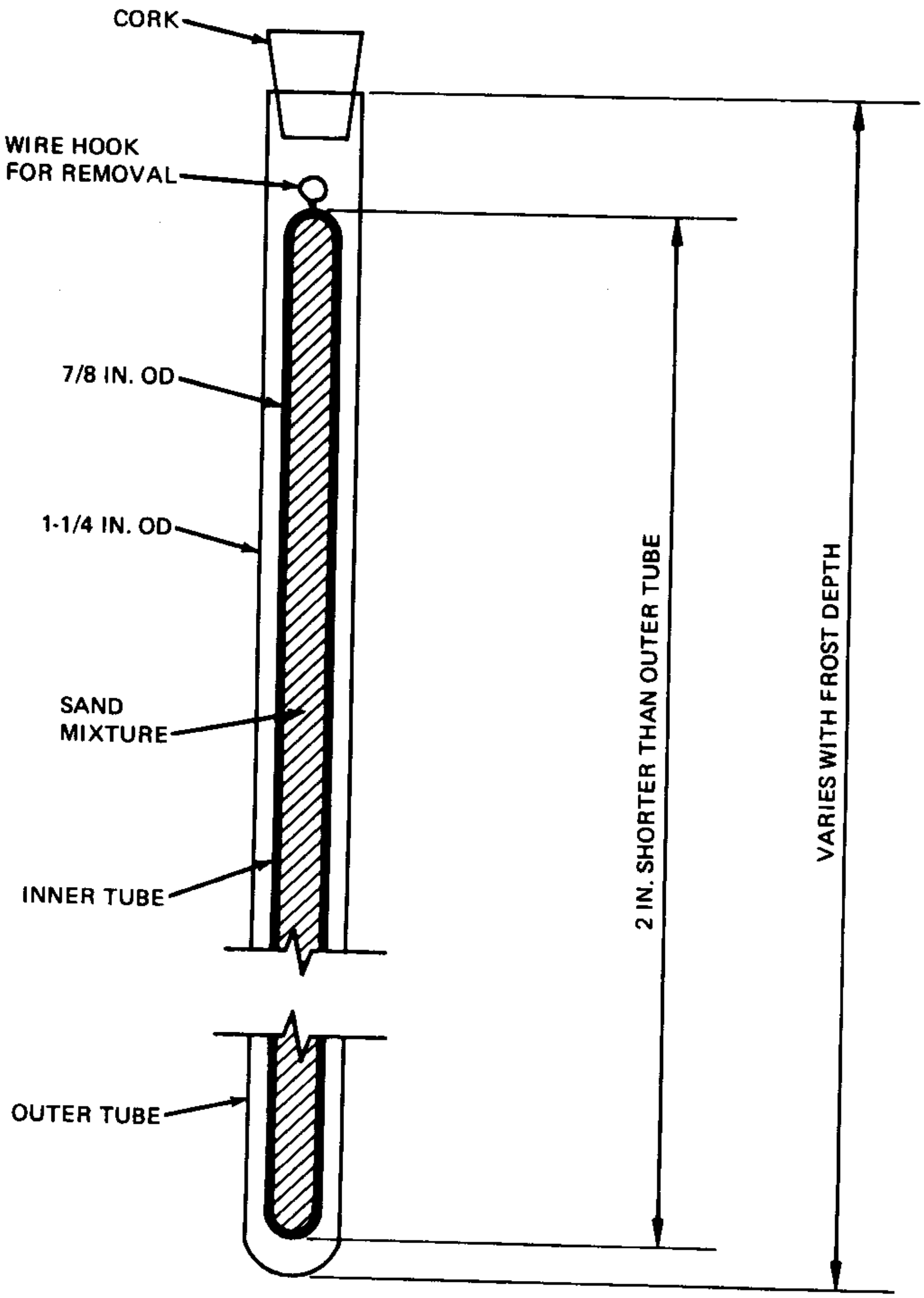


Figure 1. Typical Frost Tube

INSTALLATION

Frost tubes were installed with the use of a core drilling machine and a 2½-inch auger. A 4-inch core was first cut through the asphalt roadway (in no case were frost tubes installed in concrete paving). A 2½-inch diameter auger was then attached and a 2-foot deep hole was augered through the surfacing and into the subgrade. After the hole was cleaned as well as possible, the frost tube unit was placed into the hole and carefully backfilled with pea gravel or dry sand. A typical installation is shown in Figure 2.

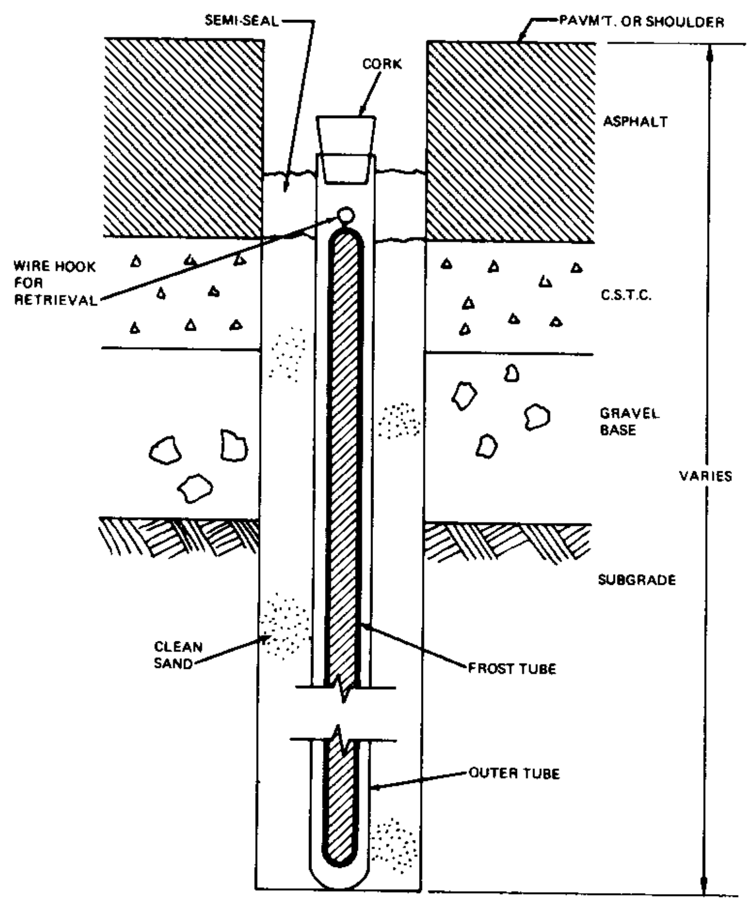


Figure 2. Frost Tube Installation

Frost tubes that were installed in asphalt roadway were left approximately 2 inches below the pavement. Those installed in the shoulder were 2 to 4 inches below the surface and covered with a 2-inch diameter plastic cap for protection.

Another method of installation was with the use of a portable penetrometer (Figure 3). It was necessary in one instance to install a frost tube in a shoulder area during a period of heavy frost. Cold weather had frozen the ground to a depth of 15 inches. With the use of a portable penetrometer, it was possible to drive a 2-inch diameter shaft into the ground, remove the shaft, and place the frost tube. This was found to be an excellent and quick method of installation.

Frost tube installation sites were located at sections of highway where frost restrictions had previously been imposed during winter freezing conditions. At first, the frost tubes were placed in the middle of the outside lane in an easily accessible location. Later, some frost tubes were installed in the shoulder area to facilitate ease of reading.

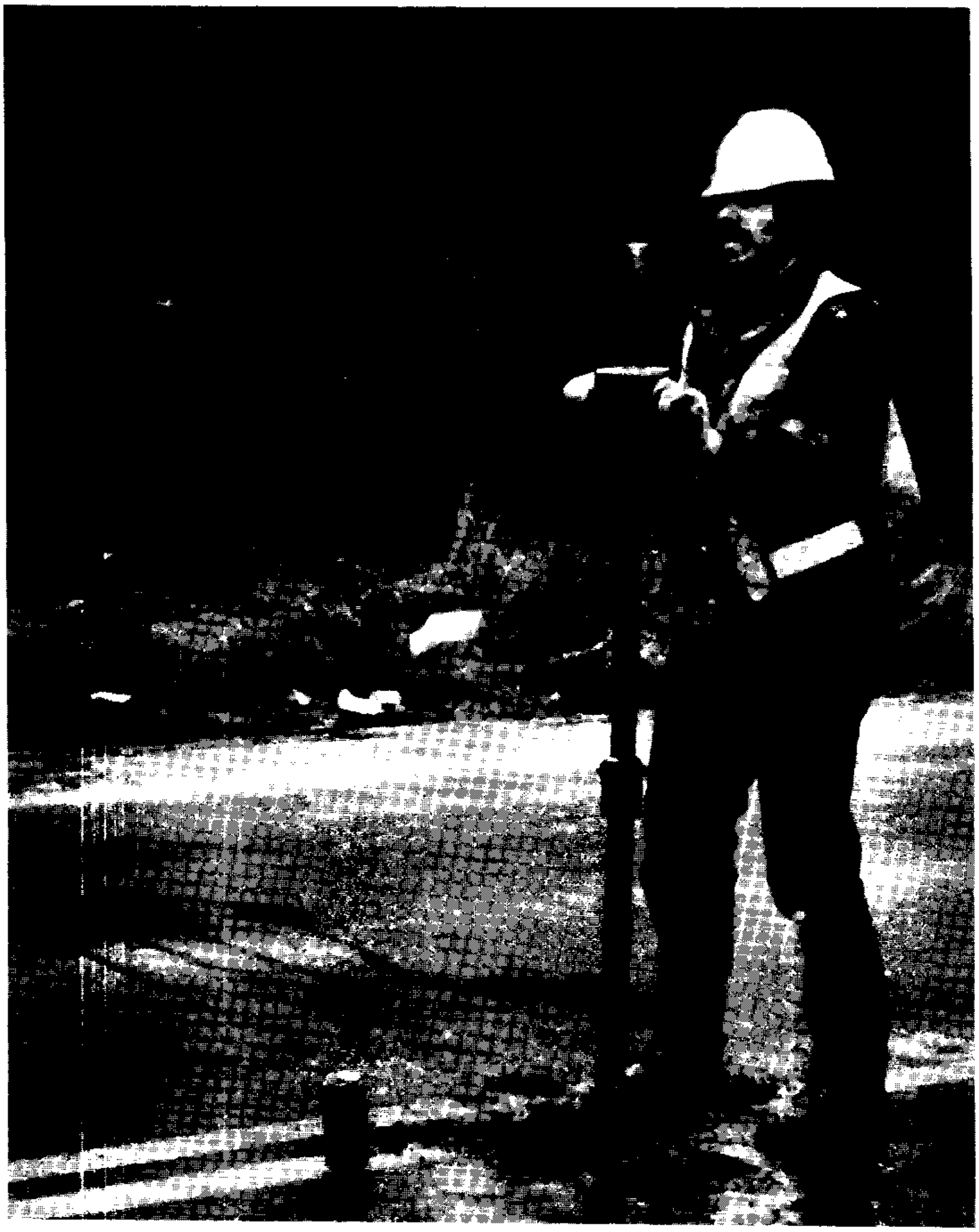


Figure 3. Portable Pentrometer

Identifying a location is important as maintenance repairs and overlays may cause the loss of some frost tubes. The use of mile posts as shown in Figure 4, or reference stakes set on the back side of the adjacent ditch were found to be the best means of identifying the location of the frost tubes.

Figure 4. Frost Tube Reference Point and Drilling Operation

OPERATION

Reading the frost tube is a simple operation that easily can be handled by one person. It consists of removing the cork, inserting the wire hook to engage the wire loop of the inner unit, and then removing the unit. If there has been a period of sustained freezing, the frozen section of the sealed unit will be light pink, while the unfrozen section will be pale green or yellow. (Experience indicates the frozen section will be light pink as opposed to previously published reports stating a color change from green to pale yellow).

Depending on the depth of the frost and stage of freeze-thaw condition at which the frost tube is read, there can be one of four situations (see Figure 5):

(1) Entire frost tube is pale green - indicates no freezing

(2) Entire frost tube is light pink - indicates freezing to full depth of tube

(3) Top portion of frost tube is pink and bottom is pale green - indicates top portion is frozen and bottom portion is thawed

(4) Frost tube has combination of pale green, pink, then green again - indicates a thawing condition where a portion of the ground at the top and bottom are thawed while the middle portion is frozen.

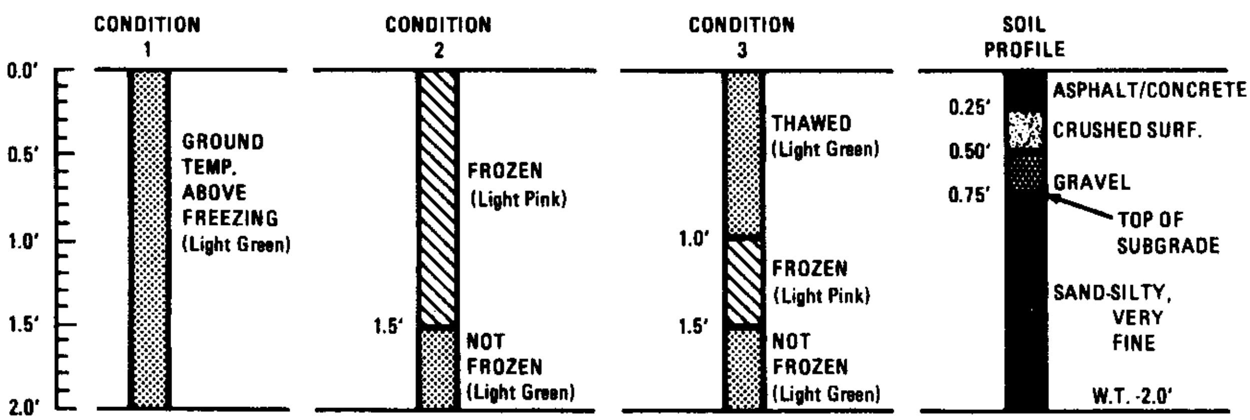


Figure 5. Example of Frost Tube Reading

It is advisable when reading the frost tubes to record the date, ambient air temperature, depth to the pink area, and depth to the bottom of the pink area. If readings are made daily when there is a predicted warming trend, recording the ambient air temperature and frost depths will allow a reasonably accurate prediction as to when the pavement strength is approaching the point where heavy loads could cause roadway damage. (Instructions for reading the frost tubes and a sample form for recording needed data are shown as Appendix Exhibit A and B of this report.)

All frost tubes were installed in secondary highways which carry a relatively low volume of traffic, allowing one person to read the frost tube. When there is considerable traffic, additional personnel should be present to monitor and control traffic.

FROST TUBE CONSTRUCTION

Following is a list of materials used in the manufacture of frost tubes, including the 1978 costs at the time of purchase:

MATERIAL	AMOUNT	1978 COSTS
Fluorescein Dye RC2250-1	1 lb.	$ 18.20
1¼-inch Polyethylene Pipe	25 ft.	10.54
7/8-inch Polyethylene Pipe	100 ft.	11.91
ATTAWA Sand	100 lb.	15.55
Corks	100/bag	10.00
Material costs for twelve 2-foot tubes		$ 66.20

Material costs per tube	$ 5.51
Labor per tube	11.42
Total cost per tube	$ 16.93

Additional installation costs for labor and equipment include transportation, traffic diversion, flagging or coning, core drilling, and other miscellaneous equipment.

The frost tube unit (see Figure 1) consists of an outer polyethylene tube that is permanently installed in the soil and an inner, removable sealed tube containing a fluorescein-saturated sand mixture.

The inner tube, which is 7/8-inch polyethylene, is cut to length and one end is sealed with a hot iron or other appropriate tool. The length of the frost tube should not be less than the depth of frost to be measured. The tube is then filled with water and 0.1% solution of fluorescein dye. A clean sand is then slowly poured into the dye. The tube should be continuously tapped to eliminate any trapped air. The process can be reversed as long as a homogenous mixture of dye and sand is obtained in the tube.

A wire hook is embedded in the top end of ttube to facilitate removal for readings. It is then sealed. The larger outer tube, made of 1¼-inch polyethylene, is cut approximately two inches longer than the inner tube so that a cork may be used to seal the unit. The bottom end of the outer tube is also sealed.

Polyethylene tubing usually comes in a circular or coiled roll. The coiling action tends to give a set curve to the tubing. When installing the frost tube it is sometimes necessary to warm the tubing. This allows the tubing to be easily straightened and facilitates installation. With the cork in place, the unit is completely sealed and ready for installation.

TEST AREAS

SITE SELECTION CRITERIA

Thirteen test site locations (see Figure 6 and Table 1) were originally set up in 1974 for recording and checking.* Each test site was cored for pavement thickness and checked for surfacing depths. Construction contracts were checked to verify pavement and surfacing depths. A frost tube was placed in the middle of an outside lane, with a soil cell at the bottom of the frost tube. Frost tubes were to record frost depths and the soil cells record temperature.

Recording of information began in January 1975. Frost tubes were checked and read and the temperature recorded. Benkleman Beam readings were taken at each test site during dry and wet conditions for control purposes.

*Three additional test sites were established in 1978.

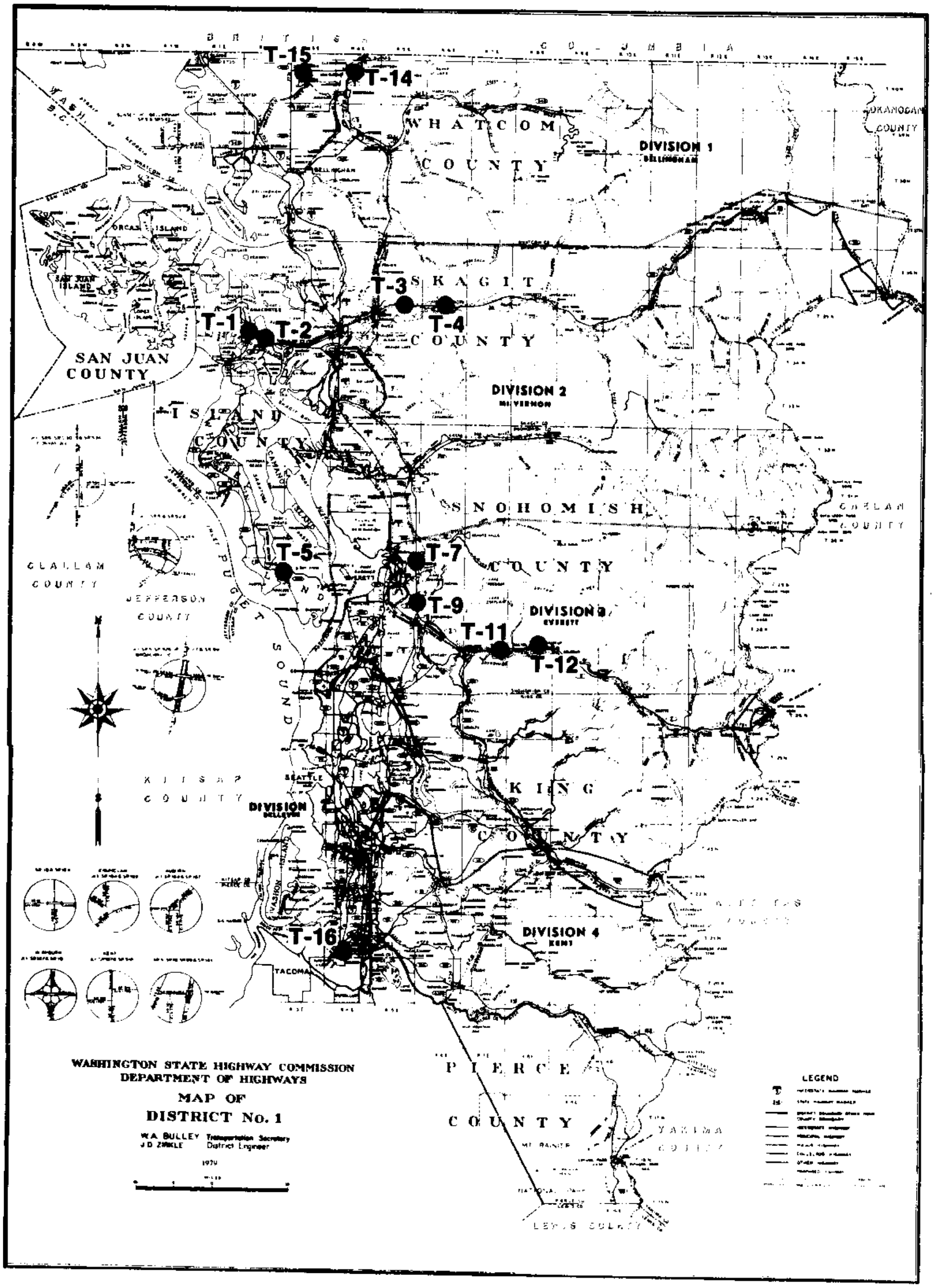


Figure 6. District No. 1 Test Section Locations

Table 1. Test Section Characteristics

CONTRACT NUMBER	DATE	PAVING INFORMATION	
<u>TEST SECTION NO. 1 (SR20)</u>			
5434	Jan. 1957	Rdwy Borrow	12"
5859	May 1958	C.T.B.	6"
		A.C.P. Cl. B. base	1-1/2"
		Cl. B. wearing	1-1/2"
8048	Jun. 1966	A.C.P. Cl. B. overlay	1-7/8"
<u>TEST SECTION NO. 2 (SR20)</u>			
6787	Aug. 1961	Selected Matrl.	13-1/2"
7165	Mar. 1963	C.S.T.C.	1-7/8"
		C.T.B.	6"
		A.C.P. Cl. B. base	1-7/8"
		Cl. B. wearing	1-1/4"
(unknown)		Overlay	1-1/4"
<u>TEST SECTION NO. 3 (SR20)</u>			
6529	Aug. 1960	Rdwy Borrow	5"
6829	Oct. 1961	C.S.T.C.	2"
		C.T.B	6"
		A.C.P. Cl. B. base	1-1/2"
		Cl. B. wearing	1-1/2"
(unknown)		A.C.P.	4-1/4"
<u>TEST SECTION NO. 4 (SR20)</u>			
7894	Nov. 1965	Subgrade	
8227	May 1967	Grave Base Cl. A.	4-3/4"
		E.S.T.C.	1-7/8"
		A.C.P. Cl. E.	4-1/4"
		Cl. B.	2-3/8"
		Cl. B.	1-7/8"
(unknown)		Overlay	1-7/8"
<u>TEST SECTION NO. 5 (SR525)</u>			
7037	July 1962	Special Sand Borrow	4"
		Rdwy Borrow	6-1/2 - 14-1/2"
		C.S.T.C.	3"
		A.C.P. Cl. B.	1-1/4 - 2-3/4"
		Cl. B.	1-1/4"
<u>TEST SECTION NO. 6 (SR9)</u>			
5492	Apr. 1957	Subgrade	
5897	June 1958	Rdwy Borrow	7"
		C.S.T.C.	2-1/2"
		A.C.P. Cl. B.	1-1/4 - 2-3/4"
		Cl. B.	1-1/4"

Table 1. Test Section Characteristics (Continued)

CONTRACT NUMBER	DATE	PAVING INFORMATION		
TEST SECTION NO. 7 (SR9)				
5297	July 1956	Rdwy Borrow		7-1/2"
5786	Mar. 1958	C.S.T.C.		2-1/2"
		A.C.P. Cl. B.	1-1/4 -	2-3/4"
		Cl. B.		1-1/4"
TEST SECTION NO. 8 (SR204)				
4937	May 1955	Rdwy Borrow		7-1/2"
		C.S.T.C		2"
		Light Bitum Surf. Tr. Meth. A		
5575		A.C.P. Cl. B.		1-1/2"
		Cl. B.		1"
TEST SECTION NO. 9 (SR9)				
3999	June 1951	Rdwy Borrow		6"
		C.S.T.C.		2"
		B.S.T. Type F		2-1/2"
7200	Apr. 1963	A.C.P. Cl. D.		1/2"
TEST SECTION NO. 10 (SR2)				
3386	Mar. 1948	Rdwy Borrow		11"
		C.S.T.C.		1-1/2"
3675	Aug. 1949	B.S.T. Type F		2-1/2"
(unknown)		Overlay		2-3/8"
TEST SECTION NO. 11 (SR2)				
3798	May 1950	Rdwy Borrow		4-1/2"
4065	Aug. 1951	C.S.T.C.		2"
		B.S.T. Type F		3"
(unknown)		Overlays		8-1/4"
TEST SECTION NO. 12 (SR2)				
4116	Dec. 1951	Rdwy Borrow		3-1/2"
		C.S.T.C.		2"
		B.S.T. Type F		3"
(unknown)		Overlay		3"
TEST SECTION NO. 13 (SR522)				
6881	Jan. 1962	Sp. Sand Borrow		3"
		Rdwy Borrow		4"
(unknown)		C.S.T.C.		3-1/2"
(unknown)		A.C.P.		4-3/4"

Table 1. Test Section Characteristics (Continued)

CONTRACT NUMBER	DATE	PAVING INFORMATION	
TEST SECTION NO. 14 (SR9)			
Unknown		Sand	14-3/8"
Unknown		Silt	17-3/8"
Unknown		C.S.T.C	3-5/8"
Unknown		Road Mix	1-5/8"
Unknown		A.C.P.	4-7/8"
TEST SECTION NO. 15 (SR546)			
Unknown		Sand	12"
Unknown		Silt	14"
Unknown		C.S.T.C.	2-1/2"
Unknown		Road Mix	1-3/4"
Unknown		A.C.P.	6"
TEST SECTION NO. 16 (SR161)			
Unknown		Gravel	6"
Unknown		Grav. Borrow	9"
Unknown		C.S.T.C.	2-3/8"
Unknown		A.C.P.	7-1/8"

ANALYSIS

A review of the available test data was made to determine which data could be used in the analysis. This review resulted in selecting Test Sections 1, 2, 3, 4, 14, 15, and 16 for further study. These sections all had deflection data collected during 1979 along with detectable amounts of frost in the pavement base, subbase or subgrade layers.

Table 2 is a summary of the available data for these seven sections. The principal elements in the table include the date of data collection, the corresponding depth of frost, associated air and/or pavement surface temperatures, and a summary of Benkelman Beam rebound deflection data. The deflection data was obtained for essentially consecutive days in January and for one day in June. For the six sections which had deflection data collected in this manner, the deflections obtained in June are higher than any of the measurements obtained in January. This is of specific interest since the depth of frost measurements indicates that the underlying pavement layers were undergoing thaw conditions in January--presumably a critical situation which would produce "high" deflections. Since the stiffness of asphalt concrete mixtures changes with temperature, the modulus of the asphalt concrete in June should be significantly lower than the corresponding modulus in January. Additionally, Test Sections 1 through 4 have asphalt concrete thicknesses ranging from a low of 4.4 inches (TS#2) up to 10.4 inches (TS#4). Thus, it is reasonable to assume that a substantial portion of the load-carrying capability of these pavements is derived from the asphalt concrete layers. In view of these pavement cross sections (Test Sectons 1 through 4), it is not unreasonable that the higher pavement deflections occurred in June as opposed to January.

Table 2. Field Data Summary for Selected Test Sections

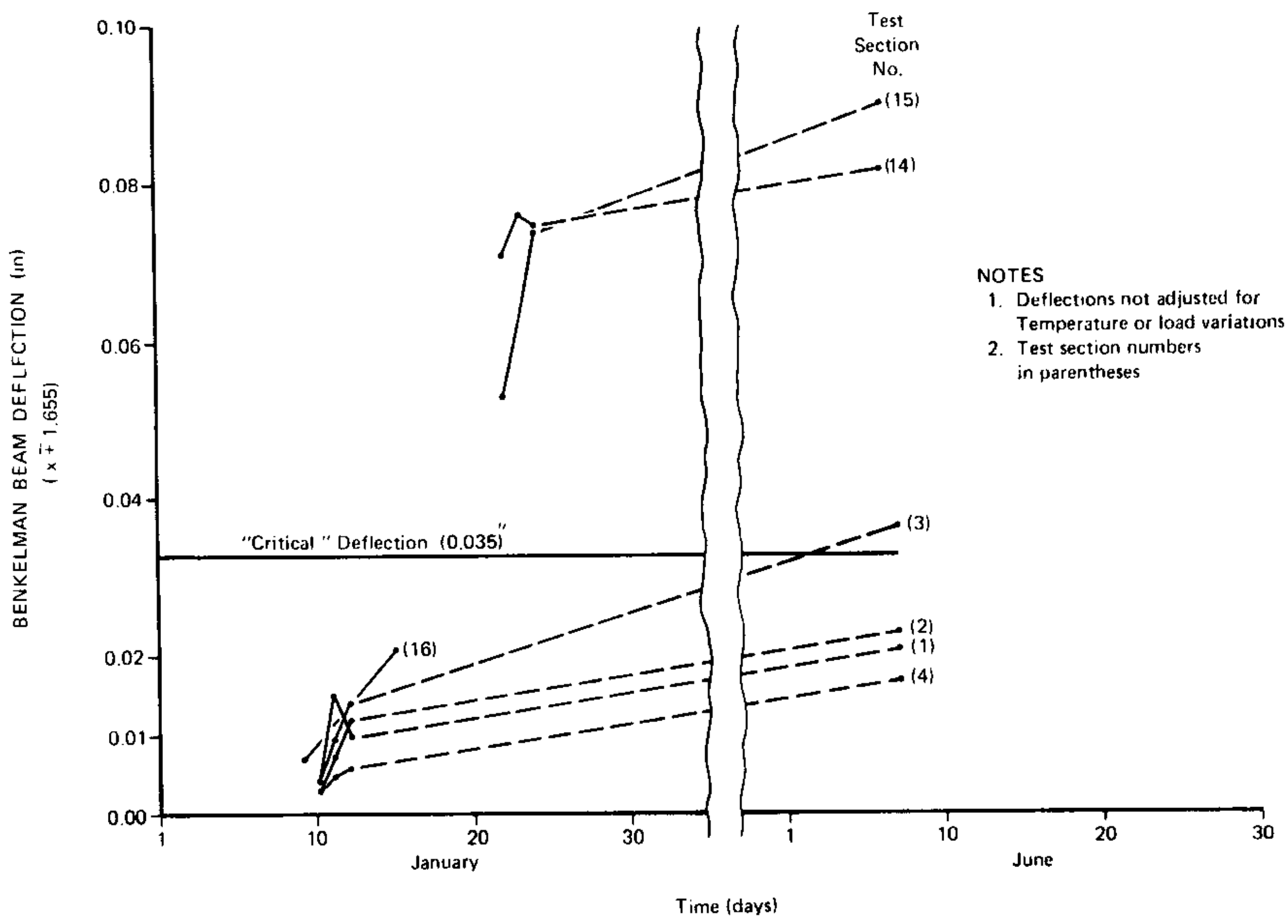
Test Section No.	Date	Depth of Frost (in.)	Temperature (°F) Air	Pavement	Benkelman Beam Deflections Mean (in.)	Std Dev (in.)	Coef of Var (%)	n	Axle Load (lbs)
1	1/10/79	10	38	-	0.003	0.000	10.7	6	18,000
	1/11/79	0	38	38	0.014	0.001	6.0	6	18,000
	1/12/79	0	40	38	0.008	0.001	9.2	6	18,000
	6/07/79	0	60	-	0.018	0.002	10.9	6	20,000
2	1/10/79	13	-	38	0.003	0.000	0.0	6	18,000
	1/11/79	6	-	38	0.006	0.001	9.2	6	18,000
	1/12/79	5	40	38	0.010	0.002	17.0	6	18,000
	6/07/79	0	60	-	0.018	0.003	14.9	6	20,000
3	1/10/79	14	38	-	0.004	0.000	5.1	6	18,000
	1/11/79	11	38	-	0.009	0.001	8.2	6	18,000
	1/12/79	8	40	38	0.012	0.001	9.2	6	18,000
	6/07/79	0	65	-	0.031	0.004	13.0	6	20,000
4	1/10/79	Frozen pin	38	-	0.003	0.000	0.0	6	18,000
	1/11/79	"	38	38	0.005	0.000	5.8	6	18,000
	1/12/79	"	40	38	0.005	0.000	8.9	6	18,000
	6/07/79	0	60	-	0.015	0.001	6.7	6	20,000
14	1/22/79	6	34	-	0.047	0.015	30.9	12	19,850
	1/23/79	3	33	-	0.051	0.016	30.4	12	19,850
	1/24/79	0	34	-	0.047	0.017	36.0	12	19,850
	6/06/79	0	-	-	0.064	0.011	16.7	12	18,000
15	1/22/79	3	33	-	0.040	0.008	20.4	12	19,850
	1/23/79	3	-	-	0.044	0.011	25.5	12	19,850
	1/24/79	-	34	-	0.044	0.018	42.2	12	19,850
	6/06/79	0	-	-	0.063	0.016	25.0	12	18,000
16	1/09/79	18	-	32	0.005	0.001	19.1	26	18,000
	1/15/79	0		38	0.014	0.004	30.5	26	18,000

Table 3 was prepared to show how the variability of the deflection measurements can be further considered. The mean standard deviation and mean plus 1.65 x standard deviation are shown. This last term (x + 1.65s) is a way to obtain an overall deflection value which only five percent of all such deflection measurements would exceed, i.e., if numerous Benkelman Beam measurements were obtained at any given test section on a specific date. It is expected that this value (x + 1.65s) would be exceeded only five percent of the time (or 5 out of 100 samples). These values were plotted for the deflection measurements shown in both Figures 7 and 8.

Table 3. Statistical Summary of Deflection Data

Test Section No.	Date	Benkelman Beam Deflections (in.) x	s	x + 1.65s
1	1/10/79	0.00300	0.00032	0.004
	1/11/79	0.01367	0.00082	0.015
	1/12/79	0.00825	0.00076	0.010
	6/07/79	0.01783	0.00194	0.021
2	1/10/79	0.00300	0.0	0.003
	1/11/79	0.00567	0.00052	0.007
	1/12/79	0.01000	0.00170	0.013
	6/07/79	0.01833	0.00273	0.023
3	1/10/79	0.00392	0.00020	0.004
	1/11/79	0.00917	0.00075	0.010
	1/12/79	0.01200	0.00110	0.014
	6/07/79	0.03067	0.00398	0.037
4	1/10/79	0.00300	0.0	0.003
	1/11/79	0.00475	0.00027	0.005
	1/12/79	0.00500	0.00045	0.006
	6/07/79	0.01533	0.00103	0.017
14	1/22/79	0.04730	0.01470	0.071
	1/23/79	0.05108	0.01554	0.076
	1/24/79	0.04690	0.01689	0.075
	6/06/79	0.06425	0.01076	0.082
15	1/22/79	0.03967	0.00808	0.053
	1/23/79	0.04408	0.01124	0.063
	1/24/79	0.04375	0.01847	0.074
	6/06/79	0.06342	0.01585	0.090
16	1/09/79	0.00507	0.00097	0.007
	1/15/79	0.01373	0.00479	0.021

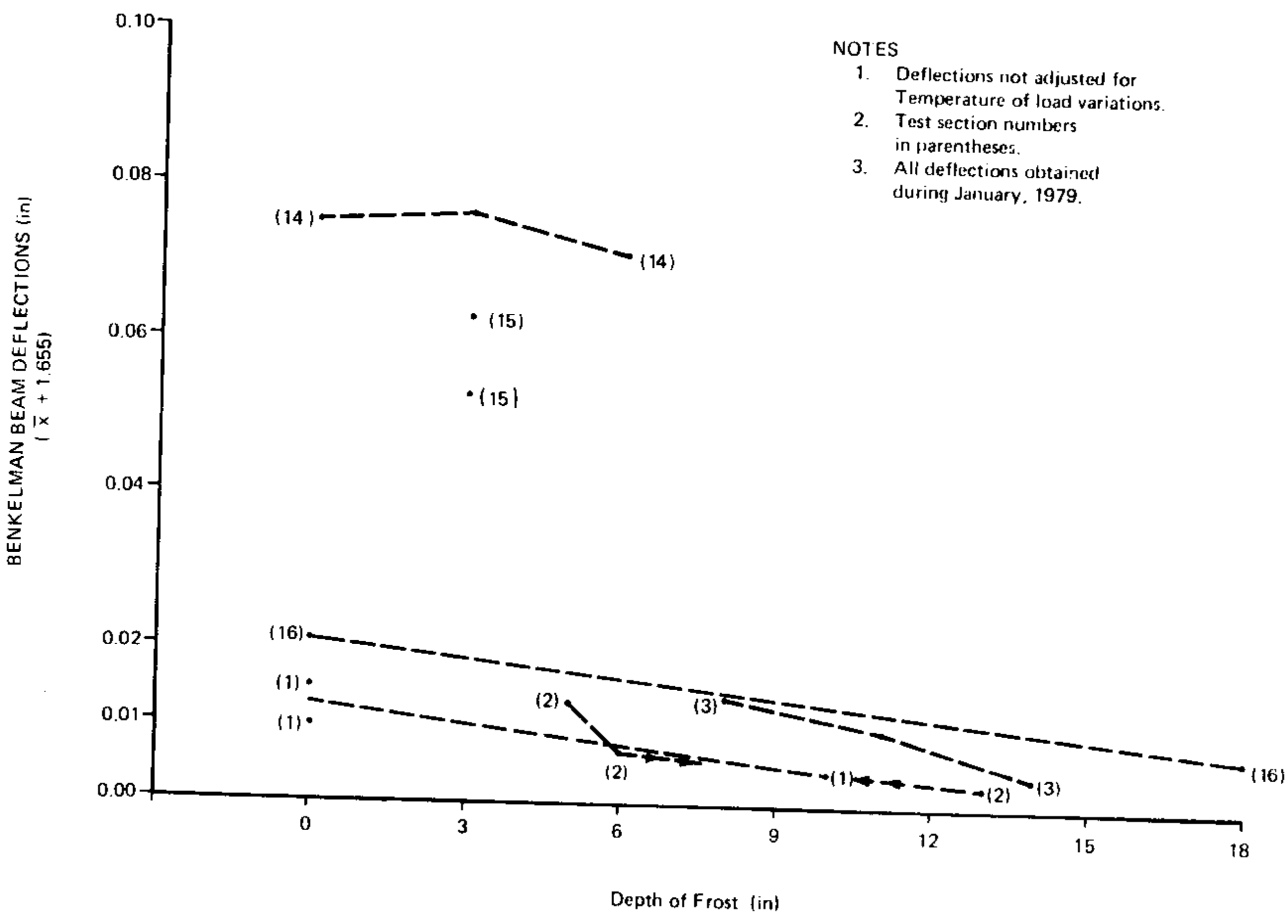
Figure 7 graphically shows the higher pavement deflections which occurred during the June measurements. The dotted lines shown in this figure are provided only to demonstrate that the June deflections are higher than those obtained in January and do not imply that a linear relationship exists between the January and June measurements. Previous research efforts[3] have suggested that pavement deflections exceeding about 0.035 to 0.050 inch are "critical" in that deflections above this value result in accelerated pavement fatigue. This 0.035-inch value is plotted in Figure 7 (appropriate for spring thaw conditions). Only Test Sections 14 and 15 exceed this value consistently. Thus, it would appear that the majority of the selected test sections do not exhibit unacceptably high deflections during any season of the year, but the available data was obtained for a very limited time period (three days in January and one day in June), thereby eliminating a firm conclusion as to the maximum deflections these sections may experience.



DEFLECTION VS TIME FOR SELECTED TEST SECTIONS

Figure 7.

In Figure 8, plots of deflection vs. depth of frost were made. Only the data for January 1979 were used. In general, for the selected test sections, the majority of the sections experience an increase in deflection with a reduction in frost depth as thawing occurs. This is as one would normally expect. Although the slopes of these lines vary, an overall trend appears. The slope is the change (increase) in deflection with the change (reduction) in frost depth (units: inches per inch). This value ranges from a low of 0.0006 in./in. to a high of 0.0060 in./in.--a difference of a factor of 10. Notably, this difference occurred for the same test section. These slopes were calculated for between sampling dates for each section (Table 4).



DEFELECTION VS DEPTH OF FROST FOR SELECTED TEST SECTIONS
(January 1979 Data)

Figure 8.

Table 4. Slopes of Deflection vs. Depth of Frost Relationships

Test Section No.	Slope Increase in deflection per inch of thaw
1	0.0008
2	0.0006
	0.0060
3	0.0013
	0.0020
14	0.0017
16	0.0008
Mean (x)	0.0019
Std Dev (s)	0.0019
Coeff of Var (VR)	100%

The average for these slopes is about equal to the corresponding standard deviation (0.0019 inch), thus indicating the high variability in this data. The possible significance of these slopes becomes apparent if we combine a rounded-off average slope of, say, 0.0020 in./in. with a known frost depth as measured with a frost tube. By multiplying the slope (or expected increase in pavement deflection with decrease in frost depth) by the measured frost depth, we can roughly estimate the expected increase in pavement deflection due to a thaw of the underlying pavement layers. Further, if we know the initial pavement deflection in the frozen state, the addition of these two values results in an estimate of the total pavement deflection which can be expected after all layers have thawed. If this total value exceed some appropriate deflection criteria (say 0.035 inch), then the need for load restrictions can be anticipated. It cannot be emphasized enough that this simplified approach is based on <u>little</u> data and does not directly consider many significant variables, such as subgrade soils, overall drainage conditions (surface and sub-surface), overall pavement structure, etc. Additionally, the increase in deflection may be significantly higher in the months of February or March with corresponding different relationships. The approach is an attempt to use the available data which has been collected on the research project to date. Future analysis of the currently available or future data should provide for development of improved relationships.

A demonstration of the above procedure is as follows:

a) Initial frozen pavement deflection = 0.005 inch

b) Depth of frost (measured with frost tube) = 10 inches

c) Expected increase in deflection due to thaw of frost = (0.0020 in./in.) (10 inches) = 0.020 inch

d) Total expected pavement deflection after thawing = 0.005 inch + 0.020 inch = 0.025 inch

e) Required action: None--because the expected total pavement deflection does not exceed the criteria maximum of 0.035 inch.

It should be noted that the expected increase in deflection due to frost (item (c) above) could range from a minimum of 0.006 inch to a maximum of 0.060 inch based on the data collected; although a value calculated with the average slope as shown in (c) is the most probable.

It should also be noted that it would be necessary to take deflection readings on each highway to obtain a predetermined slope for use with this method.

CONCLUSIONS

1. Load restrictions need not be placed until the temperature changes to a warming period.

2. Load restrictions should be applied when a warming trend occurs and the frost tubes show a thawing condition. It is essential that the frost tubes be observed at least twice a day during the warming period. Additional readings may be necessary until the pavement increases in strength.

3. The analysis as discussed indicates a method to determine possible frost damage based on very limited data. However, it is reasonable to assume that with considerably more controlled data, an easier and more simplified technique for determining when to apply and remove load restrictions could be obtained.

RECOMMENDATIONS

1. Additional studies should be carried out in eastern Washington where a longer and more even thawing period may be expected.

2. Only study a few, closely spaced sites so that multiple readings may be taken during critical periods.

3. Designate specific personnel, equipment, and funds for any future study to ensure a more organized and effective program.

4. Future studies should first utilize available work reported by numerous agencies in the U.S. and worldwide in guiding the overall design and conduct of the research.

5. If additional frost studies are conducted east of the Cascades, some of the selected test sections should have the potential for undesirably large deflections during thawing conditions.

6. Emphasis should be placed on the actual stresses and/or strains experienced by pavements as opposed to exclusive use of deflection measurements.

7. It would be advantageous to use thermocouples to measure actual in-site pavement layer temperatures along with measurement of frost depths with frost tubes. This system would permit a more careful evaluation of the reliability of frost tube measurements.

REFERENCES

1. Soiltest Inc., "MC-300A Soil Moisture Meter and Cells Instruction Manual," Bulletin C172-64, (Evanston, IL 1970).

2. Brown, J., and Rickard, W., 1971. The performance of a frost-tube for the determination of soil freezing and thawing depths. Soil Science 113: 149-154.

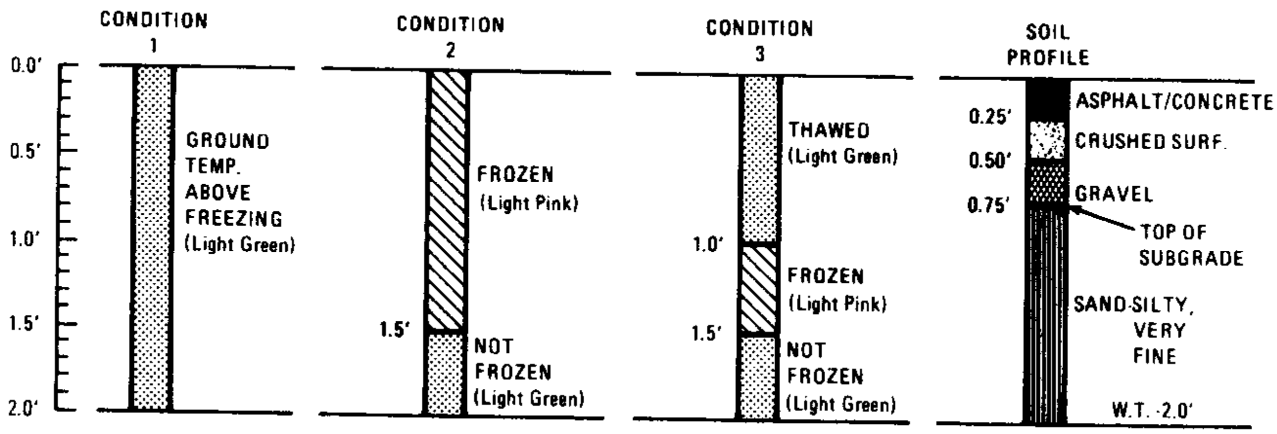
3. Huculak, N.A., "Evaluation of Pavements to Determine Maintenance Requirements," Highway Research Record No. 129, Highway Research Board, 1966.

APPENDIX

FROST TUBE EXAMPLE AND INSTRUCTIONS

EXHIBIT A

FROST TUBE EXAMPLE AND INSTRUCTIONS



A roadway with a history of frost damage.
Inadequate surfacing and paving depths to prevent frost heave.
Frost susceptible subgrade soil.
Water table near the surface and subgrade soils are saturated.

CONDITION #1

Normal - Ground temperature above 32° F.
Entire tube is light green in color.

CONDITION #2

Roadway is frozen to a depth of 1.5', in this example the maximum depth of frost penetration.
Top 1.5' of the "Frost Tube" is orange, bottom 0.5' did not freeze so remains light green.

CONDITION #3

Thawing conditions prevail. The roadway has thawed to a depth of 1.0" ("Frost Tube" color is light green), frozen from 1.0' to 1.5' ("Frost Tube" color is orange) and not frozen from 1.5' to 2.0 ("Frost Tube" color is light green).

REMARKS:

From the soil profile it would appear that load restrictions should be in force by or before the time that thawing has reached a depth of 0.75'. Determination as to when to lift load restrictions must be based upon past history and future observations. It is requested that a complete record be kept on each "Frost Tube" on the attached form. Please submit a copy at the end of each month during the period of November through March, to the District Materials Engineer for evaluation.

TEST SECTION ____________ EXHIBIT B

SENSOR NO. ____________________

LOCATION: ____________ **SR** ____________ **MP** ____________

REMARKS: ________________________________

PHOTO NO. ____________________

TIE: ________________________________

DATE	AMBIENT AIR TEMP.	ROADWAY TEMP.	SOIL MOIST CELL RESISTANCE	FROST TUBE FROST DEPTH	REMARKS