SD93-03-F

SD Department of Transportation
Office of Research

Spring Restrictions: Limits and Timing

Study SD93-03
Final Report

Prepared by
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DISCLAIMER

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16. Abstract

The South Dakota Department of Transportation dveloped project SD93-03 primarily to study the effectiveness of various techniques for determining appropriate spring restriction periods. A literature review, interviews with State agencies, interviews with users, and a series of field tests were performed during this project. The results show that temperature data are an effective means to identify significant thawing periods, which signal the need to begin load restrictions. A method for measuring the degree of freezing to which a pavement is subjected, using minimum and maximum air temperatures, was developed.

The effectiveness of using speed restrictions instead of load restrictions was also studied, but no information on the benefits of speed restrictions was found. In fact, it was found that the use of speed restrictions can actually have a detrimental effect on pavements.

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EXECUTIVE SUMMARY

Each spring, thawing pavements throughout South Dakota have significantly less support capacity than at other times of the year. This project involved several activities to develop a more effective approach for determining when to begin spring restrictions, and how long they should be used. The activities performed included the following:

- **Conduct Literature Review**—A review of papers and reports dealing with the implementation of spring restrictions was conducted. Of particular interest were methods for determining the timing of restrictions and reports comparing the use of load restrictions versus speed restrictions.

- **Interview Other State Agencies**—Several State Highway Agencies were contacted to determine the methods and approaches being employed by other States. Of particular interest were the lengths that other agencies are going to keep users informed of spring restrictions, including toll-free telephone numbers and regular mailed updates of restricted routes.

- **Interview Users**—Several users were contacted within the State of South Dakota and asked for their opinions on the current spring restrictions practices used by the State. For the most part, the users were content with the current spring restriction practices, and most expressed a preference for speed restrictions rather than load restrictions, feeling that speed restrictions caused less disruption to their business.

- **Field Testing**—A series of test sites were monitored using the South Dakota Department of Transportation (SDDOT) falling weight deflectometer (FWD) and subsurface temperature devices. The FWD data provided an indication of the support capacity of the pavement both before and after the thawing process began. The subsurface temperature devices provided a clear picture of when the underlying pavement layers went from the frozen to thawed state.

Based on the results of the above efforts, several recommendations for the use of spring restrictions along thaw-susceptible pavements in the State of South Dakota were developed. They are as follows:

- **Use local temperature data**—A method of estimating the length and degree of freezing experienced by a pavement was noted during review of a Washington DOT report. Using air temperature data collected by the SCAN system, the procedure was used to determine when spring restrictions would have been implemented for that area. The starting and ending dates showed good agreement with the deflection/pavement support data and changes in subsurface temperature. The procedure can be used by each individual maintenance unit and by county highway departments within South Dakota.

A description of the procedure, along with guidelines and forms for its use has been included in the report.

- **Develop notification system for users**—Most states in the vicinity of South Dakota are currently providing an updated list of restricted routes to their users on a regular basis. The current map of routes that could be restricted is a good initial source of information, but it should be possible to set up a system for continually updating restricted routes based on the temperature data collected by the individual maintenance units. A toll-free hotline and a weekly update mailed to subscribers are two possibilities. A minimum of weekly updates should be achieved.

- **Conduct FWD testing to determine summer support levels**—A limited amount of information was available on the summer and fall support levels typical of the pavements included in the study. To better determine the duration of the spring restrictions, it is necessary to have a good idea of the deflection magnitudes typical of the summer, stable condition. The sudden increases when thawing began were easily noted, as were peak deflections when the pavements were at their weakest points. Additional data were needed to ensure that the pavements were protected until they began to exhibit higher, summer support behavior.

- **Use load restrictions instead of speed restrictions**—No information was identified during the literature review to describe any possible benefits from implementing speed restrictions. The only possible benefit—to lessen impact as trucks went over bumps—does not appear to outweigh the negatives. These negatives include the increased risk to drivers trying to pass slow-moving trucks in dangerous situations and the increased damage to smooth sections of pavement from having heavy trucks going more slowly. The current 6- and 7-ton designations are adequate reductions in load for most instances.

- **Keep restriction authority with local personnel**—Widespread use of daily temperature data will provide uniformity to the determination of load restriction timing across South Dakota. Even so, there may be instances in which pavements exhibit distress prior to restrictions based on temperature data, or pavements are no longer in danger although the temperature data indicate restrictions are still needed. In either case, local personnel familiar with the particular pavement section should retain the authority to determine whether or not restrictions are needed.

1. INTRODUCTION

The South Dakota Department of Transportation (SDDOT) developed project SD93-03 to investigate various spring restriction practices and their effectiveness. The tasks included in the project were established to ensure that the project would be completed successfully. The tasks are listed below:

- Task 1—Meet with Technical Panel to Review Project Scope and Workplan.
- Task 2—Review and Summarize Relevant Literature.
- Task 3—Interview Other States that Use Spring Restrictions.
- Task 4—Interview County Superintendents, Commercial Carriers, and Others.
- Task 5—Evaluate and Summarize Literature Regarding Load vs. Speed Restrictions.
- Task 6—Develop Procedures to Predict the Need, Start, Duration, and Type of Spring Restrictions Based on Weather Forecasts, Deflection, Temperature, and Moisture Data.
- Task 7—Submit a Final Report with Recommendations for Implementation.
- Task 8—Present Findings and Conclusions to Research Review Board.

The project consisted of several different phases for completing the objectives:

- <u>Literature Review</u>—A literature review was conducted to summarize published findings by other agencies and researchers for various approaches toward the use of spring restrictions. Of particular interest was information on the use of speed restrictions versus load restrictions by various agencies.

- <u>Agency Interviews</u>—Telephone interviews were conducted with personnel from other state highway agencies to document current practices and their effectiveness. In addition to the specific restrictions used, the information dissemination procedures and types of enforcement used by the agencies were also collected.

- <u>Local User Interviews</u>—Telephone interviews were conducted with representative users throughout the State of South Dakota. Of particular interest were user perceptions of the effectiveness of current restriction practices and recommendations from the users for effective methods of protecting thaw-weakened pavements.

- <u>Field Deflection/Temperature Data Collection Effort</u>—Nondestructive deflection testing (NDT) was performed by SDDOT personnel along four different routes near Pierre. Testing was conducted during a 3-month period over a total of 11 km (7 mi) of State routes using the SDDOT falling weight deflectometer (FWD). Two sets of subsurface temperature data were also collected for two of the routes subjected to FWD testing. The first set of temperature data was collected from the SCAN climatic data system, and the second set was collected using a roadway thermal probe (RTP) installed by SDDOT personnel.

Collection of the field data was performed to quantify changes in pavement response as the spring thaw progressed. In particular, testing was performed to identify the decrease of pavement strength during the initial stages of thawing and the increase in pavement strength as the thawing and draining of the pavement continues. By collecting temperature data concurrently with deflection data, attempts will be made to identify critical subsurface temperature changes that could be used to determine the most effective timing for the beginning and ending of spring restrictions.

Two different load levels were used during the FWD testing, to investigate the impact of different load levels during spring thaw conditions. Also of interest were the differences in response between the restricted and nonrestricted routes that were tested throughout the spring.

2. TASK 1—MEET WITH TECHNICAL PANEL TO REVIEW PROJECT SCOPE AND WORKPLAN

A meeting was held in Pierre, South Dakota, between ERES Consultants, Inc. and the South Dakota Department of Transportation on May 13, 1993. This meeting was held to kick off the project and to finalize the activities to be conducted by ERES for the successful completion of the project.

3. TASK 2—REVIEW AND SUMMARIZE LITERATURE FINDINGS

To ascertain the latest methods being employed to determine the timing, duration, and level of spring restrictions, a literature search was conducted using the University of Illinois at Urbana-Champaign library facilities. Summaries of the documents reviewed during the course of the project are contained in appendix A.

Summary of Findings

A number of researchers have used FWD devices to determine pavement support values during the development of the spring thaw period. Others have used computer simulations for the development of critical strains and layer strengths as they change throughout the thaw period. In all cases, the decrease in pavement strength (or the accompanying increase in pavement deflections) clearly shows the increased damage potential for pavements that experience thaw weakening.

Mahoney, Rutherford, and Hicks (1986) presented a compilation of agency practices for the implementation and enforcement of spring restrictions. In addition to these topics, a methodology for determining the beginning and duration of spring restrictions using a Freezing Index (FI) and Thawing Index (TI) was presented.

With the number of approaches reviewed during the literature search, it became evident that when to use spring restrictions, how long restrictions should be enforced, and what level of restriction should be applied are still fairly difficult questions for most agencies. The use of deflection devices to determine restriction timing is generally not seen as feasible, because the weakening of the thawed pavement structure can occur so quickly that an FWD cannot possibly be in position to identify initial weakened conditions along each route that needs it. The possibility of having to identify several freeze-thaw cycles during a given season further increases the amount of testing that would need to be done.

The use of devices to monitor subsurface temperatures can provide nearly instantaneous data on the thawing of the various pavement layers. However, the cost of installing and maintaining the devices, as well as the effort needed to monitor the data, makes the widespread use of these systems difficult to justify. This is especially true because most pavements susceptible to spring thaw problems are not generally high-volume routes, which would warrant instrumentation, but rather are lightly-traveled rural pavements.

One concept of interest presented in the literature involved tying the level of restriction to the time remaining until rehabilitation or reconstruction (Fernando, Luhr, and Saxena, 1987). The basic theory is that there is less of a need to protect pavements that are to be overlaid or reconstructed in the near future. By identifying which routes need to last longer and which will be repaired soon, an agency can choose to restrict only those routes truly needing protection. Fewer restricted routes means fewer problems for users during the spring thaw season.

Speed versus Load Restrictions

One of the areas emphasized by SDDOT throughout this project has been the issue of using speed restrictions, either alone or in conjunction with load restrictions, to protect thaw-weakened pavements. Speed restriction simply refers to the practice of posting lower speed limits during the spring thaw to slow down vehicles, particularly trucks and other heavy vehicles, as they travel over the restricted pavements. In cases in which speed restrictions would be the only type of restriction used, no reduced load limits would be enforced.

None of the documents reviewed for this project mentioned the use of speed restrictions as a means of protecting thaw-weakened pavements. A variety of opinions were presented as to the level of load restrictions that are most effective, how to determine appropriate load levels, and the determination of optimum timing for imposing restrictions, but none included the implementation of speed restrictions with those procedures. An article from the SDDOT (Huft) presented an argument against the use of speed restrictions, citing data collected during the AASHO road test that slower moving heavy vehicles can cause significantly more pavement damage than faster moving vehicles.

4. TASK 3—INTERVIEW OTHER STATES THAT USE SPRING RESTRICTIONS

Seven agencies were contacted as part of this project to determine the spring restriction practices being used elsewhere and the success those agencies feel they are having in protecting their thaw-weakened pavements. The following persons were contacted by telephone and asked for their opinions:

- Clayton Sullivan, Idaho Department of Transportation.
- Joe Barcomb, U.S. Forest Service, Kootenai National Forest.
- Kent Sheppard, Montana Department of Transportation.
- David Leftwich, North Dakota Department of Transportation.
- Dennis Lachowitzer, Minnesota Department of Transportation.
- Lon Kontos, Nebraska Department of Roads.
- Tom Martinelli, Wisconsin Department of Transportation.

Complete copies of the responses given by each individual can be found in appendix B. Another source of information on agency restriction practices was the "1994 Spring Load Restriction Map" produced by SDDOT, which provides not only a list of State routes that can be restricted but also the restriction practices for each of the counties within South Dakota.

Summary of Findings

Each of the state agencies contacted currently has some type of spring restriction policy intended to protect pavements susceptible to weakening during spring thaw conditions. Idaho, Minnesota, Wisconsin, North Dakota, and the U.S. Forest Service currently provide updated listings of spring restricted roads to their users throughout the spring thaw season. These listings are compiled by a central office within the agency based on reports sent in by individual districts and are distributed to a set of users who "subscribe" to the service. In Minnesota, it is estimated that approximately 10,000 users are regularly notified of changes in spring restriction status. Due to the increasing postage costs associated with the updates, Idaho is preparing to charge a nominal fee for subscribing to the service. In Nebraska, information is collected by a central office from reports submitted by each of the districts and is then disseminated to all of the districts and their enforcement personnel, but no effort is made to get this information to the users.

For each of these agencies, the initial decision to list a pavement as restricted is made by local personnel within a particular district. Modifications to a restricted road's status are also determined by local personnel, who then relay their decision to the central office for notification of users. Updated releases of spring restriction conditions vary from Idaho, which issues an updated bulletin twice each week, to Minnesota, which sends out updated bulletins only as needed (from six to eight times a season).

Each of the agencies that employs a user-notification program felt that the level of user compliance was very high. In Idaho, the bulletins are also used to provide information on why spring restrictions are needed, in an attempt to make them more palatable to the users. Nebraska does not have a user notification system in place because the Department of Roads often elects not to restrict any roads during the spring thaw, as was the case in 1993. The irregular use of restrictions does not require a system as extensive as those more northern states, which implement restrictions annually.

The Wisconsin DOT currently employs a network of SCAN sites throughout the State, similar to those located in South Dakota. One of the ways that this temperature information is used is to determine when "frozen road declarations" can be issued. These consist of notifications to users that the frozen condition of certain pavements will accommodate overloading. The process of making these declarations was started to make it easier for road salt haulers to get salt to the DOT maintenance yards during the winter by allowing them to carry larger payloads. This is also intended to reduce the cost of the salt and deicing chemicals used by the DOT each winter.

Speed versus Load Restrictions

Currently, the State of Idaho imposes speed restrictions as the first phase of its spring restriction policy. If excessive pavement damage can be avoided with only speed restrictions, then no load restrictions are applied. If damage is observed while speed restrictions are in place, then both speed and load restrictions are implemented. No information was available on how often speed restrictions alone are applied or how effective they are. The North Dakota DOT also occasionally applies speed restrictions, although not with the regularity of the Idaho DOT.

5. TASK 4—INTERVIEW COUNTY SUPERINTENDENTS, COMMERCIAL CARRIERS, AND OTHERS

To determine how users are affected by the use of spring restrictions, representative users throughout South Dakota were contacted and interviewed by telephone. Those contacted included:

- Barb Lindstrom, South Dakota Trucking Association.
- Dale Peterson, Hyman Freightways.
- Jeff Jager, Land O'Lakes Dairy, Volga.
- Ted Bultsma, Bultsma Truck Lines.

Complete responses for each of the users is given in appendix C.

The 1994 summary of South Dakota County restriction map was also used to document the restrictions each of the 66 counties used for spring, 1994.

Summary of Findings

Generally, the users who were contacted were in agreement that some type of restriction procedure was necessary to protect pavements during the spring thaw period. The South Dakota Trucking Association indicated that its members are sent copies of the routes to be restricted and the dates of the restrictions each spring, and there are generally no complaints. Complaints are most commonly received from farmers and ranchers, who traditionally have more cause to travel restricted routes during restricted times of the year. It was also mentioned that more users would have problems with the spring restrictions if they were used along major routes or were placed with no advance warning.

For the 1994 spring thaw season, 41 of the 66 counties in South Dakota implemented some sort of speed restriction during spring thaw. These restrictions ranged from 35 to 40 mph, and were imposed on either all county routes or just a select few. The counties employing speed restrictions are predominantly in the eastern half of South Dakota, although there is no obvious explanation for this phenomenon. A similar trend was reported for counties in North Dakota, with the majority of counties using speed restriction located in the eastern half of the State.

Speed versus Load Restrictions

Each of the users contacted indicated that the implementation of speed restrictions was preferable to the use of load restrictions. The consensus was that they were willing to take the extra time to drive at slower speeds rather than have routes be closed to them as a result of load restrictions. In particular, one of the contacts expressed a concern that one county was contemplating a 36,400 kg (80,000-lb) total load restriction during the spring. This is approximately 60 percent of the State legal load of 58,600 kg (129,000 lb) . Because his company runs trucks weighing in excess of 45,400 kg (100,000 lb) through that county, business would be impacted during the restricted period.

6. TASK 5—EVALUATE AND SUMMARIZE LITERATURE REGARDING LOAD VS. SPEED RESTRICTIONS

The only document reviewed for this project that discussed the use of speed restrictions was an article from the SDDOT (Huft). This article references data obtained from the AASHO road test that show the increase in pavement damage when heavy trucks travel more slowly. Other than this document, no reports reviewed mentioned the use of speed restrictions as a means of preventing excessive damage during the spring thaw.

Although there was a lack of documentation about the benefit of using speed restrictions, there are still many agencies currently using speed restrictions. None of the agencies contacted for this study was able to give a definitive reason why speed restrictions would be effective or where their use originated.

Based on the responses of the users contacted for this project, the use of speed restrictions is generally preferable to the implementation of load restrictions. The general consensus of users was that delays caused by slowing their vehicles were more acceptable than delays caused by having to reroute their vehicles to avoid roads with load restrictions.

The argument presented by Huft, along with the lack of research supporting the benefits of speed restrictions, indicates that speed restrictions should not be used in place of load restrictions when trying to prevent damage during the spring thaw. Potential safety problems also can arise when speed restrictions are used. This is especially true for situations in which slower trucks cause other drivers to become anxious and attempt passing maneuvers under dangerous conditions.

7. TASK 6—DEVELOP PROCEDURES TO PREDICT THE NEED, START, DURATION, AND TYPE OF SPRING RESTRICTIONS BASED ON WEATHER FORECASTS, DEFLECTION, TEMPERATURE, AND MOISTURE DATA

For many agencies responsible for maintaining pavements subjected to spring thaw damage, the question of how the timing of load restrictions should be determined still must be addressed. Several alternatives were investigated through this project, and the results of these efforts are presented in the following sections.

Deflection and temperature data collected during the field testing portion of the project were used for evaluating the following procedures. A complete summary of the field testing effort can be found in appendix D.

Min-Max Temperature Procedure

One promising alternative presented in a Washington DOT report (Mahoney et al., 1986) recommended the use of minimum and maximum daily air temperatures for a given location to determine the degree of freezing experienced by a pavement. The degree of freezing, along with the identification of significant warm periods, can be used to identify potentially damaging spring thaws and determine how best to implement load restrictions to reduce damage.

Agencies would simply have to record minimum and maximum daily temperatures each day starting at a point before the beginning of the freezing season (approximately November 1). The daily temperature readings are then used to calculate a daily average temperature, which is simply the mean of the minimum and maximum readings. This daily average temperature is then compared to a reference temperature of freezing (0 °C [32 °F]). If the average temperature is less than freezing, then the difference is added to the total freezing degree days for the season to calculate the freezing index. Table 1 illustrates this procedure. To use the equations and reference values presented in the WADOT report, mean daily temperatures values should be in degrees Fahrenheit.

As can be seen in table 1, the freezing season does not begin until positive freezing degree-days begin to accumulate. If negative freezing degree-days are recorded, the cumulative freezing degree-days will decrease accordingly, but the freezing index is not allowed to go below zero.

The accumulation of freezing degree-days continues throughout the winter until such a point that the thawing season begins. The thawing season begins when the daily average temperature is above -2 °C (29 °F) for a number of days in a row, resulting in a positive thawing index. Table 1 also contains data for calculating the thawing index and determining the beginning of the thawing season.

Table 1. Calculation of freezing and thawing indices.

Date	Temperature			Freezing degree-days		Thawing degree-days	
	Min.	Max.	Avg.	Daily	Cum.	Daily	Cum.
Nov. 1	32	46	39	-7	—		
Nov. 2	28	42	35	-3	—		
Nov. 3	24	39	32	0	—		
Nov. 4	20	37	28	4	4		
Nov. 5	22	36	29	3	7		
Nov. 6	20	26	23	9	16		
Nov. 7	34	48	41	-9	7		
Nov. 8	38	50	44	-12	—		
Nov. 9	32	45	38	-6	—		
Nov. 10	28	36	32	0	—		
Nov. 11	24	40	32	0	—		
Nov. 12[a]	20	36	28	4	4		
Nov. 13	18	30	24	8	12		
Nov. 14	18	29	24	8	20		
Nov. 15	16	36	26	6	26		
Nov. 16	20	28	24	8	34		
Mar. 1	14	24	19	13	1407		
Mar. 2	16	44	30	2	1409	1	1
Mar. 3	32	54	43	-11	1398	14	15
Mar. 4	16	32	24	8	1406	-5	10
Mar. 5	15	31	23	9	1415	-6	4
Mar. 6	18	28	23	9	1424	-6	—
Mar. 7[b]	26	38	32	0	1424	3	3
Mar. 8	34	53	44	-12	1412	15	18
Mar. 9	38	58	48	-16	1396	19	37
Mar. 10	39	63	51	-19	1377	22	59
Mar. 11	19	36	28	4	1381	-1	58
Mar. 12	12	38	25	7	1388	-4	54
Mar. 13	24	50	37	-5	1383	8	62
Mar. 14	32	56	44	-12	1371	15	77

[a]Beginning of freezing season, assuming that cumulative freezing degree-days (freezing index) remains greater than zero. [b] Beginning of thawing season, assuming that cumulative thawing degree-days (thawing index) remains greater than zero.

The values contained in table 1 reflect a freezing season that begins on November 12 and a thawing season that begins on March 7. The temperature data are also used to determine the start and duration of load restrictions. Based on the WADOT report, load restrictions should be applied when the thawing index reaches a value of 40 degree-days, which is on March 10 for the data in table 1.

The duration of the load restrictions can be determined several different ways in the WADOT report. The first of these is to simply take the maximum number of freezing degree-days (1,424) and insert that value into the following equation:

$$D = 25 + 0.01 \times (FDD_{max})$$

where

D = Duration for imposing spring load restrictions.
FDD_{max} = Maximum cumulative freezing degree-days observed.

For the data in table 1, the duration would then be equal to 39 days, meaning that spring load restrictions should begin on March 7 and continue for 39 days, or until April 15.

Another alternative for calculating the duration of the load restrictions presented in the WADOT report calls for calculating the thawing index needed before restrictions can be lifted. The equation is given as:

$$TI_{29} = 0.3 \times (FDD_{max})$$

where

TI_{29} = Thawing index before load restrictions are lifted.
FDD_{max} = Maximum cumulative freezing degree-days observed.

For the data in table 1, the thawing index needed to remove load restrictions would be 427 degree-days. As of March 14, the cumulative thawing index was 77 degree-days, meaning that additional monitoring of the temperature would be needed to determine when the thawing index is greater than 427 degree-days and load restrictions can be lifted.

Subsurface Temperature Monitoring

The U.S. Forest Service is currently using Roadway Thermal Probes (RTPs) in several locations in National Parks throughout the Western United States to help determine when load restrictions should begin and how long they should last. To evaluate its potential effectiveness, an RTP was purchased as part of this project and installed along the test site located on SD 1804.

The RTP consists of a series of thermistors mounted on a pipe inserted into the ground at the shoulder of the roadway. The thermistors are wired into a device that is used to monitor the temperatures at various depths below the pavement surface. The approximate depths of the thermistors used along SD 1804 were as follows:

Sensor	Depth, mm (in)
0	Air
1	0 (0)
2	76 (3)
3	229 (9)
4	381 (15)
5	533 (21)
6	686 (27)
7	838 (33)
8	1,143 (45)
9	1,524 (60)

The U.S. Forest Service currently uses RTPs to monitor subsurface temperatures weekly or bi-weekly throughout the winter. As temperatures increase, monitoring frequency is increased to better determine when the subsurface materials go from frozen to thawed conditions. The critical temperatures are commonly located in the base material, as thawing begins at the pavement surface and progresses down through the subbase and subgrade materials.

For this project, readings were taken from the RTP each time that NDT was performed along SD 1804 using the FWD. By plotting temperatures for each sensor over time, and by comparing the changes in temperature to the changes in maximum deflection (deflection measured directly under the load plate), the significant depth for freeze/thaw can be identified.

The increase in deflections corresponding to spring thaw weakening occurred between the fourth and fifth testing dates for SD 1804 (March 7 and March 10). Subsurface temperatures went from below to above freezing for sensor #3 (229 mm [9 in]) at approximately the same time. This depth represents the thawing of the top of the subgrade material, since the temperatures at sensors #4 and #5 (381 and 533 mm [15 and 21 in]) are still below freezing at this point. The poor drainage associated with the top of the layer thawing while the bottom of the layer remains frozen is most likely the cause of the increase in deflections.

One other piece of information gained from the RTP data is the time needed to thaw the entire pavement structure that was frozen over the winter. Sensor #9 (1524 mm [60 in]) showed a temperature above freezing throughout the testing, indicating that the subgrade was never frozen after February 15 (the beginning of field testing). The bottom of the frozen material would be located somewhere between sensor #8 and sensor #9 (1143 and 1524 mm [45 and 60 in]), because sensor #8 shows temperatures below freezing well into April. The sequential manner in which the RTP data show temperatures going above freezing at the different depths indicates that the thawing is working in a top-down direction. The sensor depths and the date thawing began for each is listed in table 2.

Table 2. Progression of spring thawing.

Sensor depth, mm	Date of first temperature above freezing
0	N/A
76	N/A
229	March 10
381	March 14
533	March 17
686	March 21
838	March 31
1143	April 14
1524	N/A

Note. N/A indicates that temperature data for the sensor was not indicative of thawing pavement layers.

The thawing of the top of subgrade was the critical indicator for determining when spring restrictions should begin. Using the RTP data, the restrictions would have begun after the temperature at sensor #3 (229 mm) crossed above the freezing mark (approximately March 10). Although no direction was given in the U.S. Forest Service report for determining restriction duration, one alternative is that restrictions remain in place until the entire pavement structure is thawed, allowing for more complete drainage of moisture from the top layers. For SD 1804, this would have occurred approximately April 14.

Local Discretion

The majority of States contacted for this report indicated that the responsibility for determining restrictions was left to the local personnel, generally at the district level. This type of local control was generally used to provide input to a central location within the State DOT, where it was collected and disseminated to users within the State. The major drawback to using this approach is the fact that different persons from different areas will have varying opinions as to what pavements should be restricted and at what point the restrictions should be placed and removed. This type of inconsistency can reduce the potential benefits of using spring load restrictions.

Validation of Procedures

The first two procedures described above provide guidance for determining the start and duration of load restrictions. The last method relies on local expertise to determine the best time to start and stop spring restrictions. The following section describes the steps performed to validate the applicability of the procedures using the deflection and temperature data gathered by SDDOT as part of this project.

FWD Testing

FWD testing conducted on the five test sections included in this study indicated a sudden increase in deflections for all test sections during the first week of March. The magnitude of the deflection increase varied depending on whether or not the section was restricted, with the two nonrestricted routes experiencing significantly less increase in deflections.

For two of the test sites, SD 26 and SD 47, data were available from previous FWD testing efforts performed in August 1992, October 1992, and April 1993. Using data from these three dates, comparisons were made between the deflections obtained during spring 1994 and the previous spring and summer deflections. Figures 1 through 7 show the deflections obtained at each sensor from February 15 to May 12, 1994, along SD 26. Also shown on these figures are the mean deflections from the previous testing in 1992 and 1993.

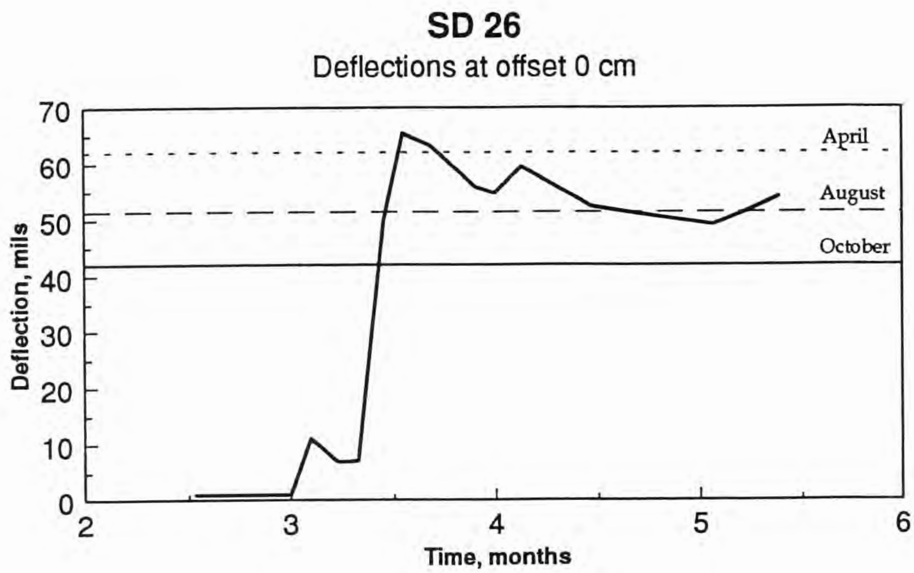

Figure 1. Maximum deflections over time (0 offset)—SD 26.

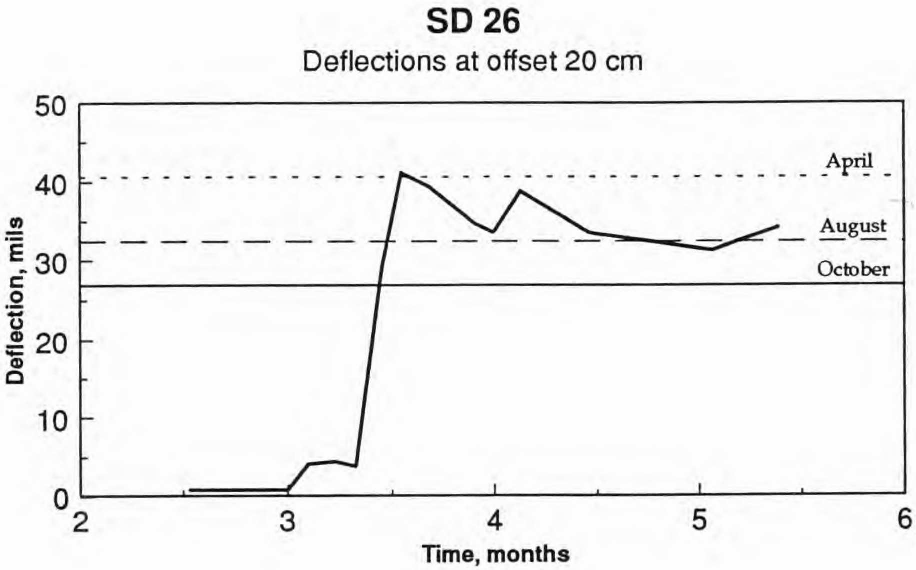

Figure 2. Deflections over time (200 mm offset)—SD 26.

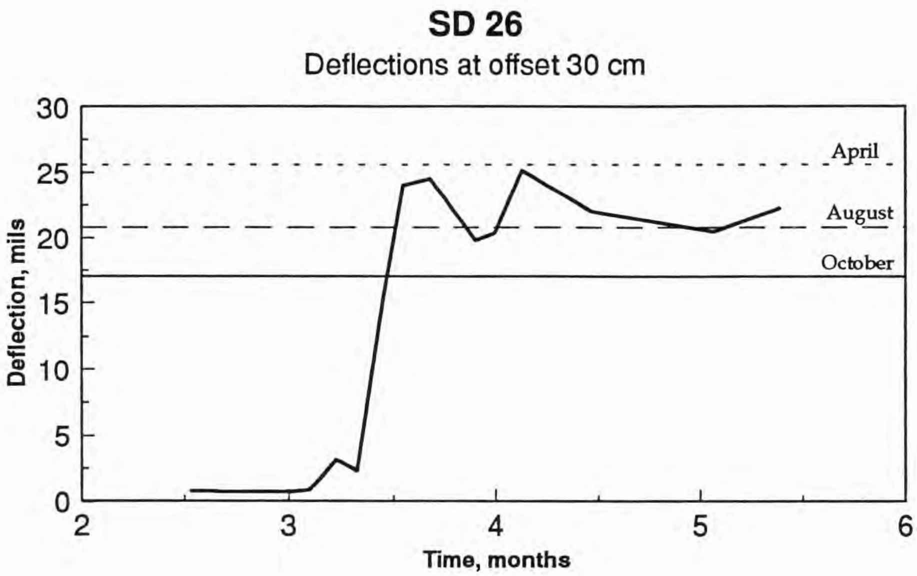

Figure 3. Deflections over time (300 mm offset)—SD 26.

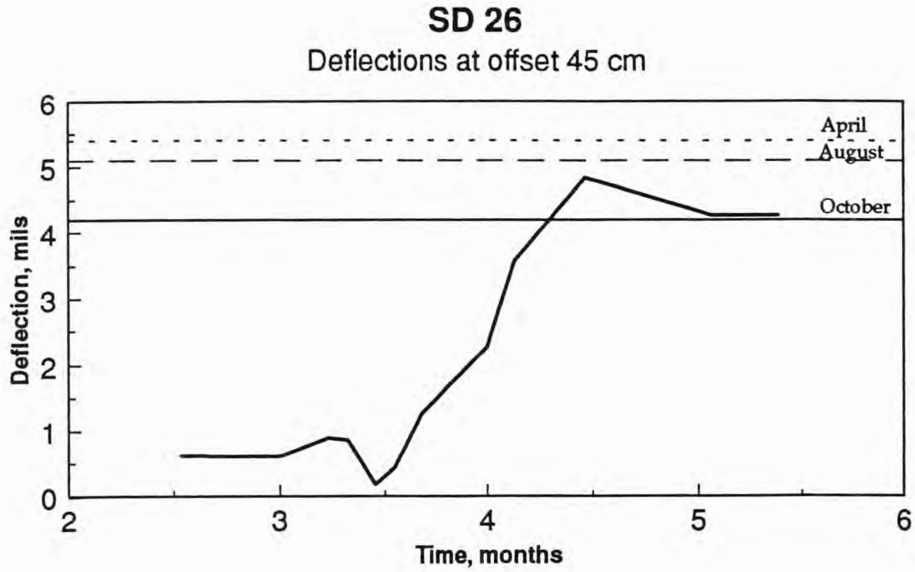

Figure 4. Deflections over time (450 mm offset)—SD 26.

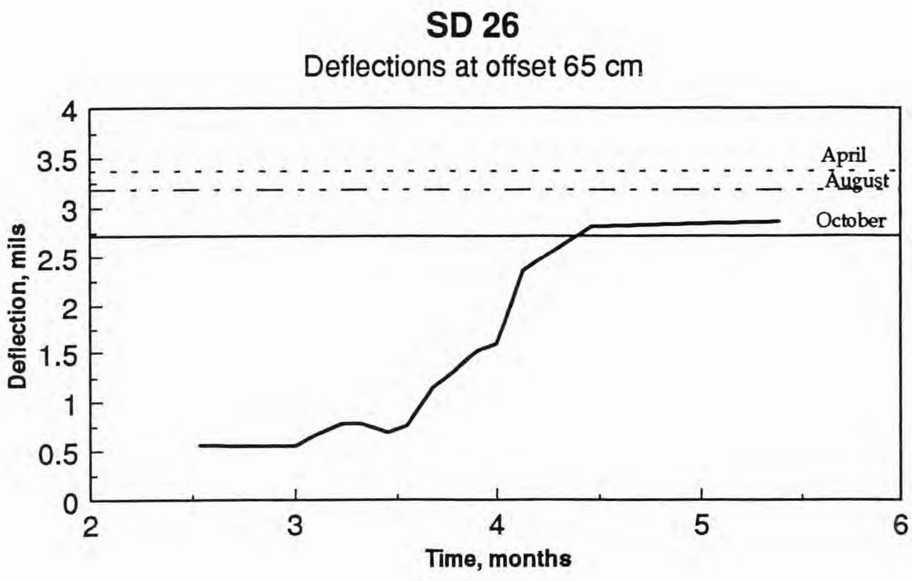

Figure 5. Deflections over time (650 mm offset)—SD 26.

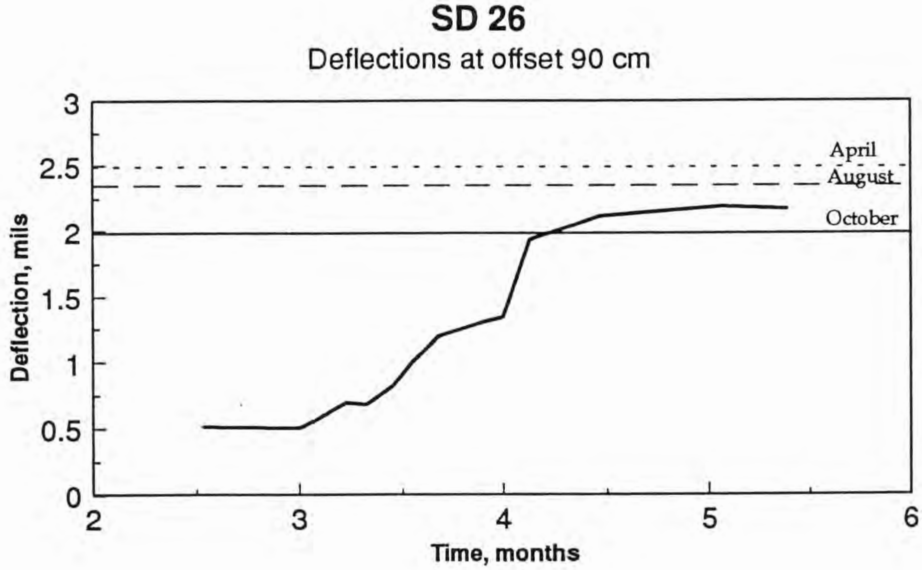

Figure 6. Deflections over time (900 mm offset)—SD 26.

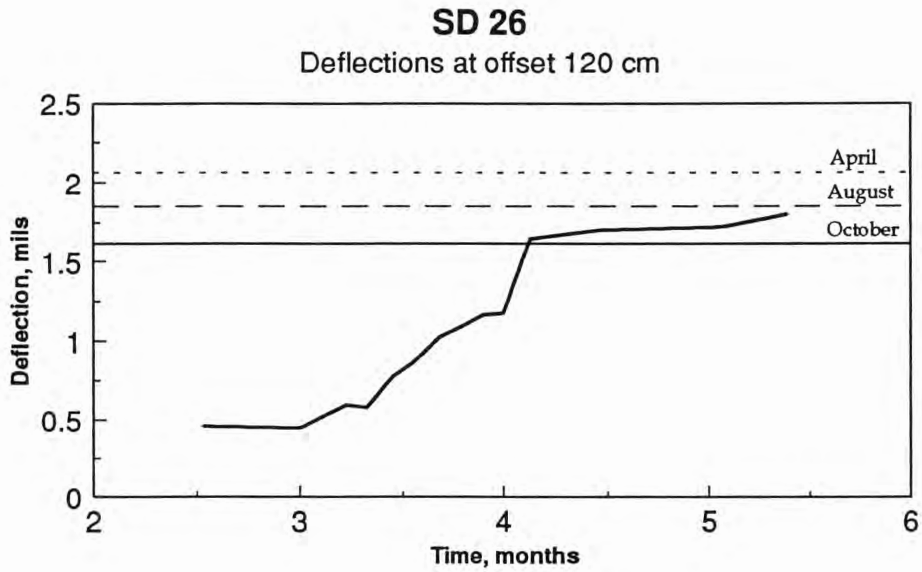

Figure 7. Deflections over time (1200 mm offset)—SD 26.

These figures indicate an increase in deflection for each sensor throughout the spring 1994 testing, with the sharpness of the increase diminishing as the sensor offset increases. For the first four sensors (offsets of 450 mm and less), deflections increase, reach a peak, and then begin to decrease. Although the decrease in deflections is not as significant as initially expected, each sensor reaches a level comparable to or less than the August 1992 deflections by the first week in May.

For the three outer sensors (650, 900, and 1200 mm), the increase in deflections does not appear to peak prior to the May 12 test date, although the change in deflections has flattened substantially at this point. For all three sensors, the magnitude of the deflections is less than the August 1992 values, indicating that the summer levels have been essentially reached.

Because the three inner sensors (0, 200, and 300 mm) show the most dramatic increase and decrease in deflections, it is recommended that they be used to determine when the pavement is thawed enough to remove the load restrictions. Based on the comparison of deflections to the summer values, restrictions should be continued until the latter half of April, when the deflection magnitudes approximate the summer values obtained previously.

The data collected for the other two restricted routes, SD 47 and SD 1804, exhibited similar trends in their deflections over time. The one exception noted was that the test site along SD 1804 experienced more of a peak for the outer sensors than the other two sites. Figures 8 through 21 illustrate the deflections collected over time for these two restricted sites for each sensor.

SCAN Temperature Data

To test the effectiveness of the WADOT procedure for determining the start of spring restrictions, air temperature data were obtained from the SCAN site installed along US 83 south of Pierre, South Dakota. From the data available, minimum and maximum temperatures were obtained from January through April 1994. This information was used to calculate freezing and thawing indices according to the WADOT procedure. Table 3 contains the daily temperatures, indices, and notes on the beginning and duration of the spring load restrictions for the US 83 test site.

As table 3 indicates, the WADOT procedure would have the freezing season beginning on December 19 and continuing through March 1, with the thawing season beginning on March 2. The cumulative freezing index would be calculated at 1,219 degree-days. The beginning of load restrictions would be March 4, based on a thawing index of 40 degree-days. Depending on which procedure is used to determine the duration of the restrictions, they would be in place until April 6 or April 8.

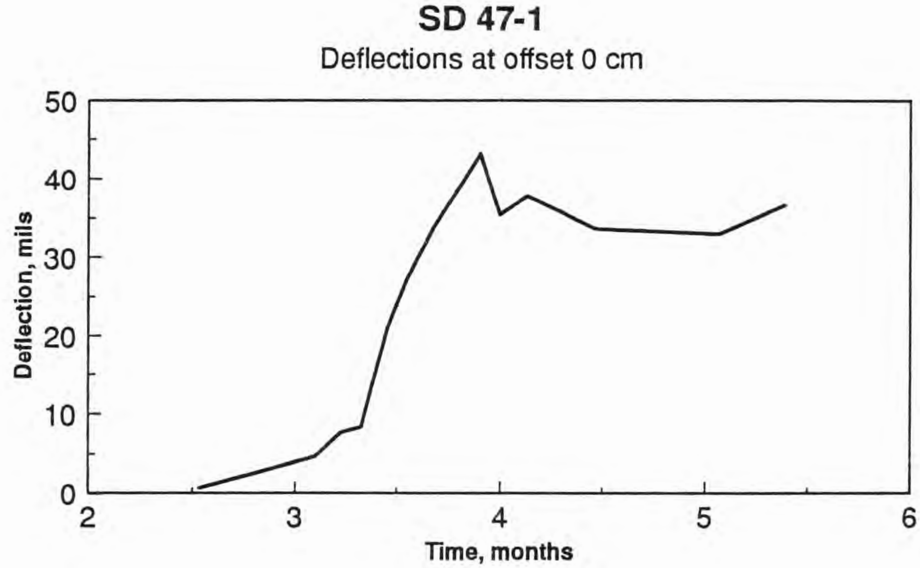

Figure 8. Maximum deflections over time (0 mm offset)—SD 47.

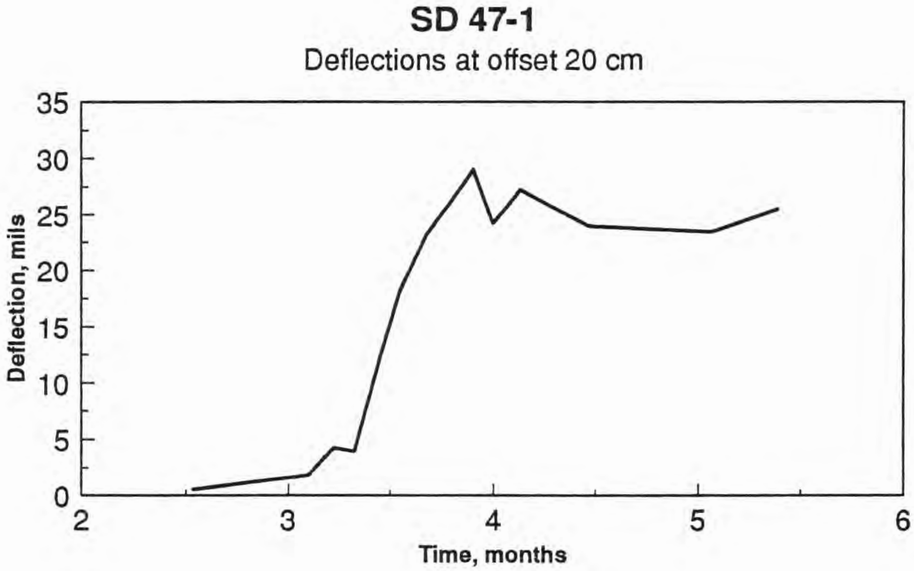

Figure 9. Deflections over time (200 mm offset)—SD 47.

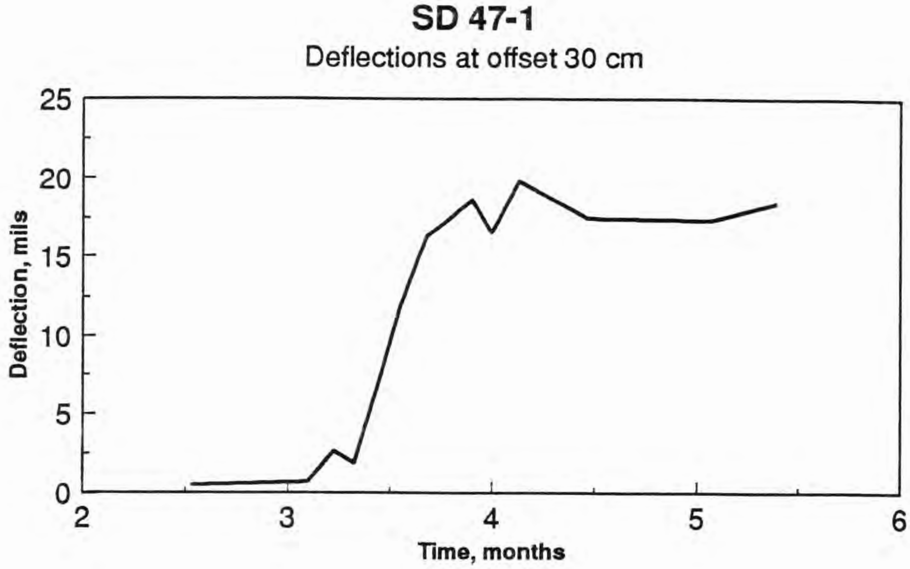

Figure 10. Deflections over time (300 mm offset)—SD 47.

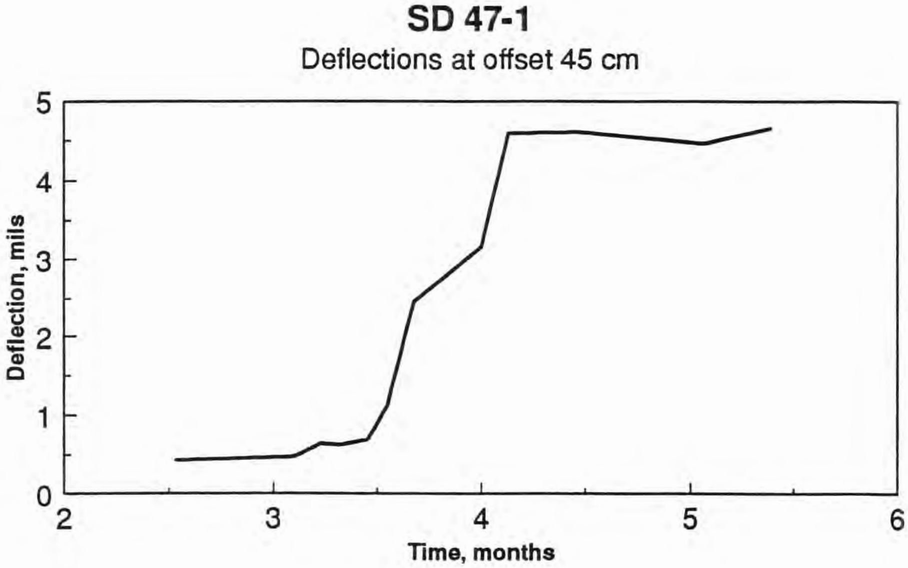

Figure 11. Deflections over time (450 mm offset)—SD 47.

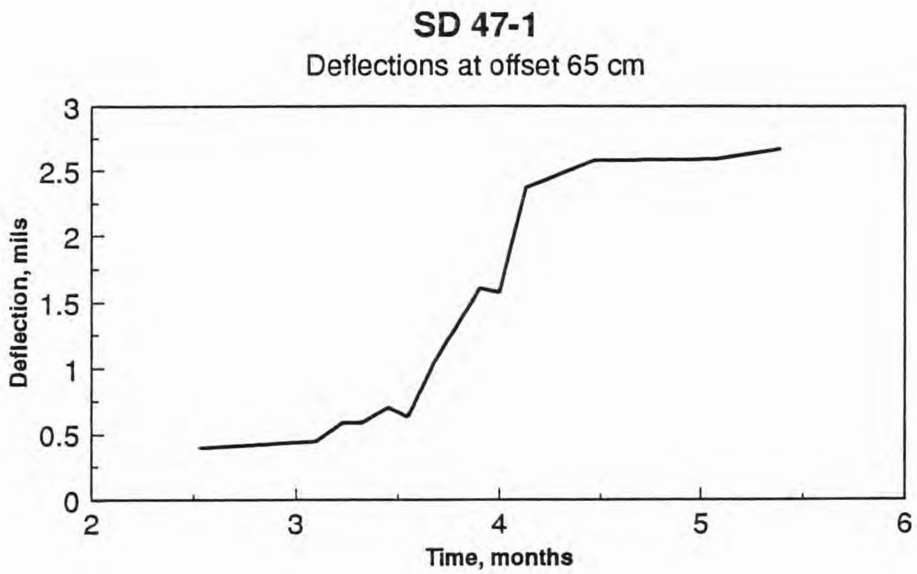

Figure 12. Deflections over time (650 mm offset)—SD 47.

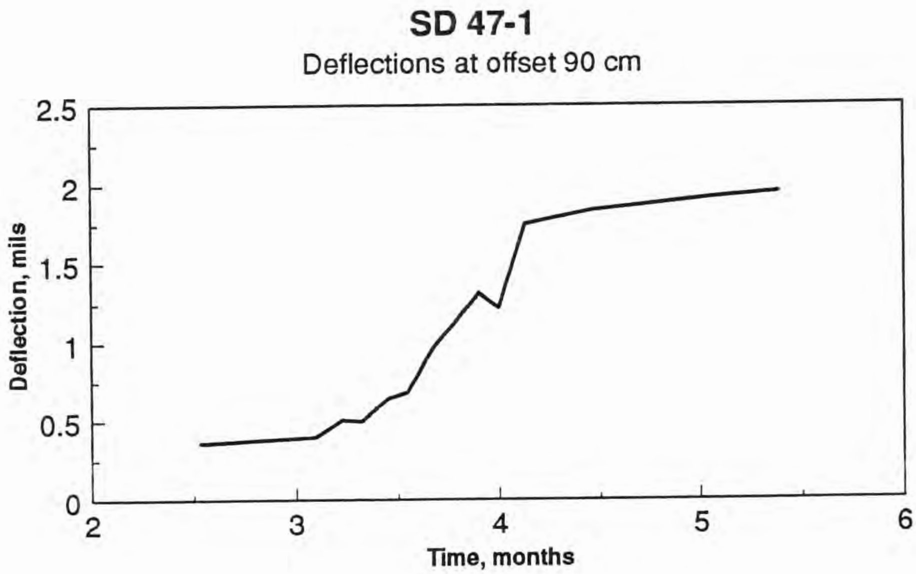

Figure 13. Deflections over time (900 mm offset)—SD 47.

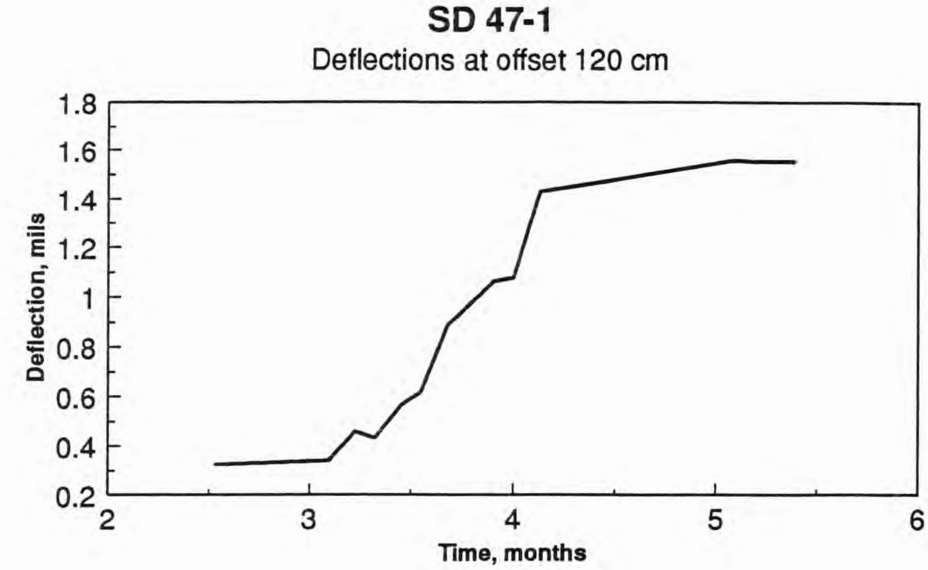

Figure 14. Deflections over time (1200 mm offset)—SD 47.

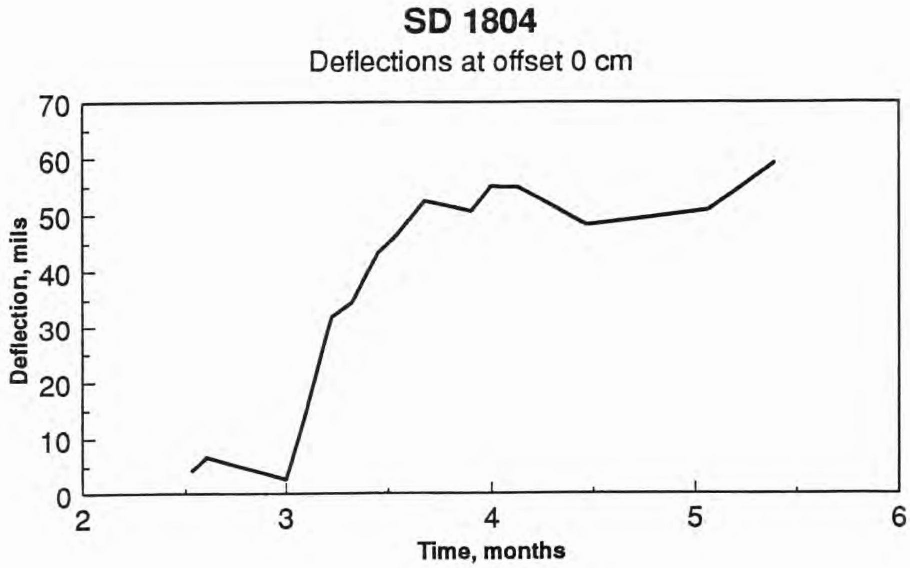

Figure 15. Maximum deflections over time (0 mm offset)—SD 1804.

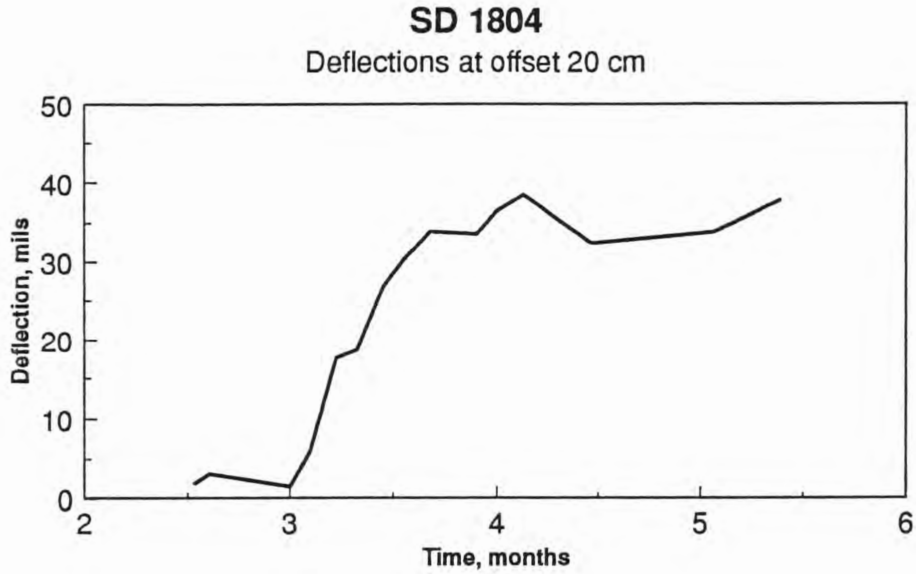

Figure 16. Deflections over time (200 mm offset)—SD 1804.

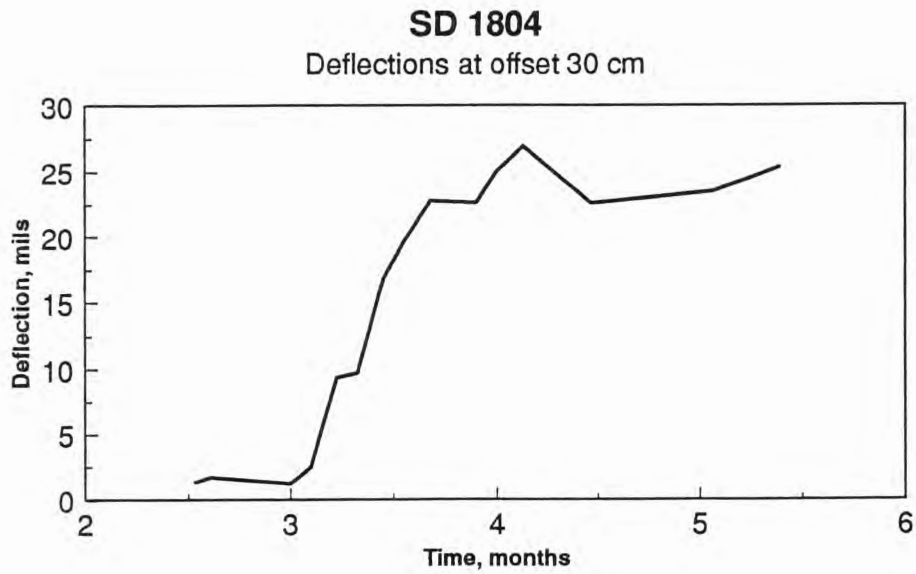

Figure 17. Deflections over time (300 mm offset)—SD 1804.

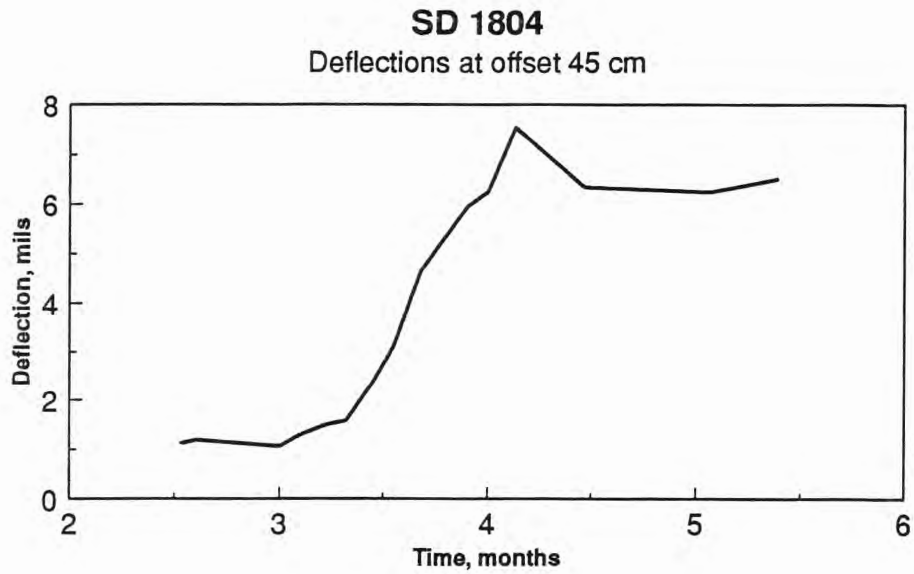

Figure 18. Deflections over time (450 mm offset)—SD 1804.

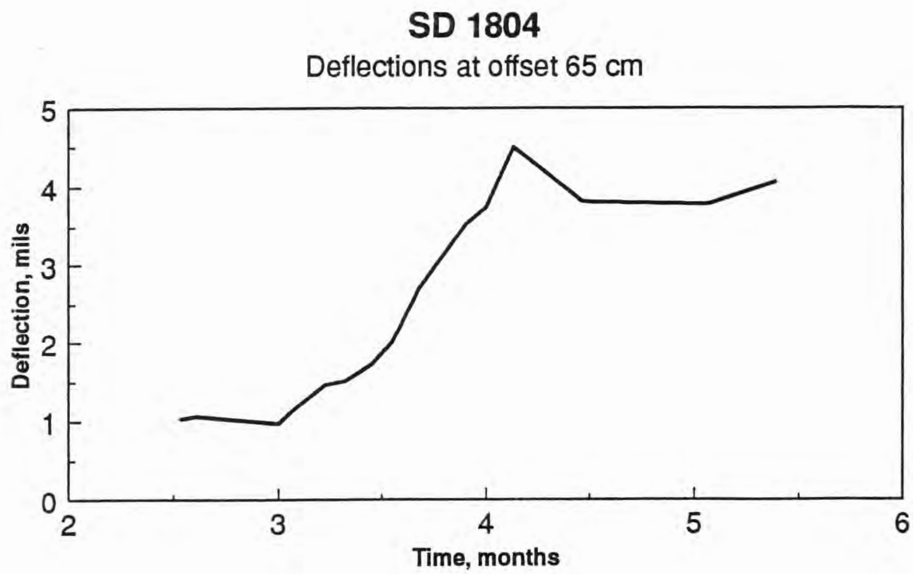

Figure 19. Deflections over time (650 mm offset)—SD 1804.

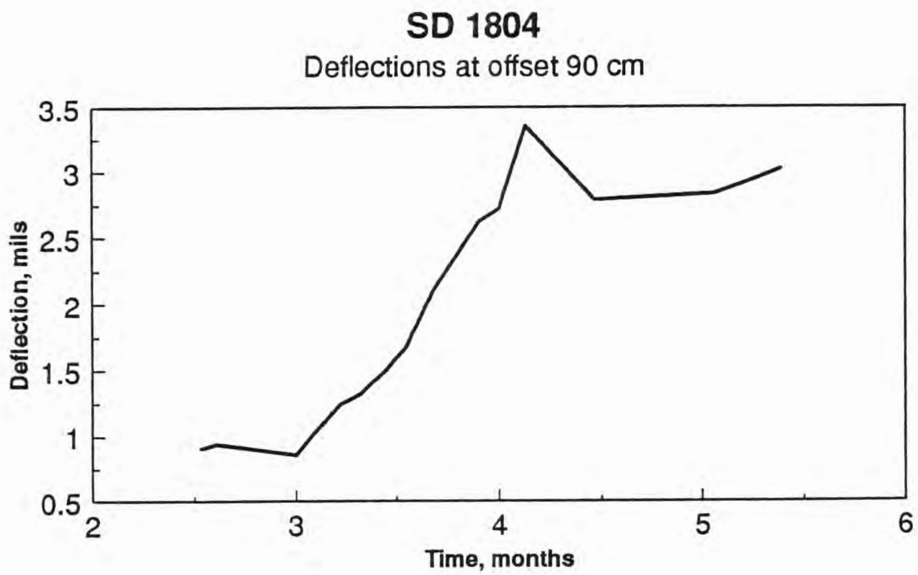

Figure 20. Deflections over time (900 mm offset)—SD 1804.

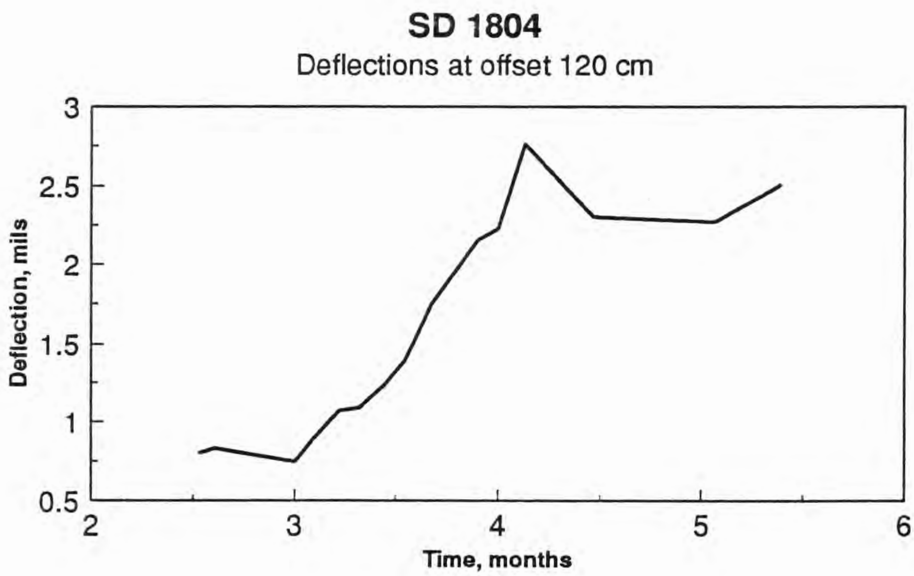

Figure 21. Deflections over time (1200 mm offset)—SD 1804.

Table 3. US 83 freezing and thawing indices.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Dec. 1	52	33	42					
Dec. 2	53	24	38					
Dec. 3	51	24	38					
Dec. 4	50	32	41					
Dec. 5	48	34	41					
Dec. 6	42	30	36					
Dec. 7	45	24	34					
Dec. 8	47	22	34					
Dec. 9	48	23	35					
Dec. 10	46	24	35					
Dec. 11	44	29	37					
Dec. 12	42	26	34					
Dec. 13	40	19	30	2	2			
Dec. 14	35	27	31	1	3			
Dec. 15	38	23	30	2	5			
Dec. 16	44	28	36	-4	1			
Dec. 17	42	29	35	-3	—			
Dec. 18	40	26	33					
Dec. 19	35	20	27	5	5			Begin freezing season
Dec. 20	27	22	24	8	13			
Dec. 21	28	20	24	8	21			
Dec. 22	31	18	24	8	28			
Dec. 23	34	24	29	3	31			
Dec. 24	32	20	26	6	37			
Dec. 25	32	22	27	5	42			
Dec. 26	35	22	29	3	45			
Dec. 27	33	18	26	7	52			
Dec. 28	30	15	23	10	61			
Dec. 29	27	17	22	10	72			
Dec. 30	29	20	25	8	80			
Dec. 31	28	18	23	9	89			

Note. Data for December created for example. Data is not from SCAN temperature data for US 83 SCAN installation.

Table 3. US 83 freezing and thawing indices (cont.).

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Jan. 1	29	17	23	9	97			
Jan. 2	25	-2	12	21	117			
Jan. 3	42	0	21	11	128			
Jan. 4	25	14	20	13	141			
Jan. 5	12	0	6	26	167			
Jan. 6	0	-10	-5	37	204			
Jan. 7	8	-12	-2	34	238			
Jan. 8	14	0	7	25	263			
Jan. 9	31	2	17	16	278			
Jan. 10	23	4	14	19	297			
Jan. 11	33	2	18	15	311			
Jan. 12	33	18	26	7	318			
Jan. 13	35	0	18	15	332			
Jan. 14	2	-4	-1	33	365			
Jan. 15	16	-10	3	29	394			
Jan. 16	23	-5	9	23	417			
Jan. 17	1	-18	-9	41	458			
Jan. 18	0	-18	-9	41	499			
Jan. 19	4	-10	-3	35	534			
Jan. 20	27	-10	9	24	557			
Jan. 21	43	18	31	2	559	2	2	
Jan. 22	47	14	31	2	560	2	4	
Jan. 23	47	27	37	-5	555	8	12	
Jan. 24	27	12	20	13	568	-10	2	
Jan. 25	13	8	11	22	589	-19	—	
Jan. 26	18	13	16	17	606			
Jan. 27	18	12	15	17	623			
Jan. 28	28	2	15	17	640			
Jan. 29	7	-4	2	31	670			
Jan. 30	8	-8	0	32	702			
Jan. 31	17	9	13	19	721			

Table 3. US 83 freezing and thawing indices, continued.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Feb. 1	18	-2	8	24	745			
Feb. 2	27	2	15	18	763			
Feb. 3	18	-2	8	24	787			
Feb. 4	28	0	14	18	805			
Feb. 5	37	6	22	11	815			
Feb. 6	25	-8	9	24	839			
Feb. 7	-8	-13	-11	43	881			
Feb. 8	-11	-24	-18	50	931			
Feb. 9	12	-29	-9	41	971			
Feb. 10	28	6	17	15	986			
Feb. 11	26	11	19	14	1000			
Feb. 12	26	6	16	16	1016			
Feb. 13	40	18	29	3	1019	0	0	
Feb. 14	42	24	33	-1	1018	4	4	
Feb. 15	40	22	31	1	1019	2	6	
Feb. 16	40	28	34	-2	1017	5	11	
Feb. 17	45	20	33	-1	1016	4	15	
Feb. 18	52	34	43	-11	1005	14	29	
Feb. 19	36	12	24	8	1013	-5	24	
Feb. 20	16	6	11	21	1034	-18	6	
Feb. 21	10	2	6	26	1060	-23	—	
Feb. 22	7	1	4	28	1088			
Feb. 23	20	1	11	22	1110			
Feb. 24	12	-3	5	28	1137			
Feb. 25	6	-3	2	31	1168			
Feb. 26	16	0	8	24	1192			
Feb. 27	28	12	20	12	1204			
Feb. 28	24	14	19	13	1217			

Table 3. US 83 freezing and thawing indices, continued.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Mar. 1	44	16	30	2	1219			End of freezing season
Mar. 2	54	32	43	-11		14	14	Begin thawing season
Mar. 3	58	38	48	-16		19	33	
Mar. 4	63	39	51			22	55	Begin restrictions (TI>40)
Mar. 5	53	34	44			15	70	
Mar. 6	Data not available for this date							
Mar. 7	36	19	28			-2	68	
Mar. 8	38	12	25			-4	64	
Mar. 9	42	15	29			-1	63	
Mar. 10	40	22	31			2	65	
Mar. 11	52	25	39			10	75	
Mar. 12	52	22	37			8	83	
Mar. 13	62	30	46			17	100	
Mar. 14	59	30	45			16	116	
Mar. 15	52	24	38			9	125	
Mar. 16	57	26	42			13	138	
Mar. 17	59	40	50			21	159	
Mar. 18	63	31	47			18	177	
Mar. 19	77	41	59			30	207	
Mar. 20	52	35	44			15	222	
Mar. 21	67	29	48			19	241	
Mar. 22	57	34	46			17	258	
Mar. 23	38	18	28			-1	257	
Mar. 24	38	14	26			-3	254	
Mar. 25	42	18	30			1	255	
Mar. 26	45	22	34			5	260	
Mar. 27	34	20	27			-2	258	
Mar. 28	42	18	30			1	259	
Mar. 29	36	22	29			0	259	
Mar. 30	58	16	37			8	267	
Mar. 31	58	26	42			13	280	

Table 3. US 83 freezing and thawing indices, continued.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Apr. 1	72	33	53			24	304	
Apr. 2	43	28	36			7	311	
Apr. 3	67	22	45			16	327	
Apr. 4	54	25	40			11	338	
Apr. 5	42	16	29			0	338	
Apr. 6	59	23	41			12	350	End restrictions [D= 25+.01(1219)=37 days]
Apr. 7	62	29	46			17	367	
Apr. 8	57	34	46			17	384	End restrictions [TI= .3(1219)=366 deg-days]
Apr. 9	57	27	42			13	397	
Apr. 10	52	26	39			10	407	
Apr. 11	53	29	41			12	419	
Apr. 12	62	33	48			19	438	
Apr. 13	64	29	47			18	456	
Apr. 14	55	36	46			17	473	
Apr. 15	60	33	47			18	491	
Apr. 16	75	40	58			29	520	
Apr. 17	82	42	62			33	553	
Apr. 18	83	52	68			39	592	
Apr. 19	60	42	51			22	614	
Apr. 20	77	42	60			31	645	
Apr. 21	66	37	52			23	668	
Apr. 22	74	43	59			30	698	
Apr. 23	81	57	69			40	738	
Apr. 24	71	51	51			32	770	
Apr. 25	50	37	44			15	785	
Apr. 26	37	29	33			4	789	
Apr. 27	40	24	32			3	792	
Apr. 28	33	29	31			2	794	

8. RECOMMENDATIONS

For this project, there were several basic methods evaluated that could be used for determining the start and duration of spring load restrictions: WADOT daily temperature procedure, U.S. Forest Service RTP subsurface temperature monitoring, FWD deflection testing, and agency discretion. Each of these is discussed in the following section.

WADOT Daily Temperature Method

The WADOT method provides a simple means to estimate the degree of freeze experienced during the winter, and takes this into account when estimating the duration for spring restrictions. The colder the winter and the larger the freezing index, the more thawing will be required to completely thaw the frozen pavement layers. One other positive aspect of this procedure is that the data needed for calculating the indices are readily available in the form of daily minimum and maximum temperatures.

One potential problem with this procedure is the fact that there may be more applicable thawing index values and duration equations than those presented in the WADOT report. Continued monitoring and additional correlation between the indices and pavement deflection will be needed to refine the process for locations within South Dakota.

U.S. Forest Service RTP Monitoring

The RTP subsurface monitoring system provides a good tool for following the progress of the thaw during the spring season. Whether the pavement is thawing from the top down or from the bottom up will determine how severe the spring weakening will be, with top-down thawing being more severe because of the impeded drainage situation discussed previously.

One problem with the RTP system is the fact that measurements must be taken at the site itself, requiring extra labor and vehicle time. The data from the device are also dependent on the continued survival of the thermistors, such that when thermistors break down, the data will not be as complete. The system developed by the U.S. Forest Service to notify users based on the RTP data has many benefits and has been adopted into the final recommended procedure.

Even though the cost of the RTPs is less than $500, the cost of installing and maintaining a wide spread network of RTPs to provide data on thawing pavements is probably not justified.

FWD Deflection Monitoring

The ability of FWD testing to identify the beginning of the spring thaw has been demonstrated through this project. For each of the five test sections, the dramatic increases in deflection have clearly shown the changes taking place in the pavement as the materials go from a frozen to a thawed state.

The largest drawback to widespread use of the FWD for determining when spring restrictions should begin is the cost associated with testing the number of locations that would be necessary. For this project, the SDDOT FWD tested 7 miles of pavement twice a week for several weeks to identify the beginning of the thaw. Given the number of miles of load restricted routes in South Dakota, the feasibility of having an FWD device available in every location as it begins to thaw is very unlikely. The ability of counties within South Dakota to use an FWD for monitoring thawing pavement is even more unlikely.

Local Discretion

The history of a roadway and how it has behaved during previous thawing seasons is known best by agency personnel familiar with the pavement. In most cases, this will be a State maintenance crew within a district, or a county maintenance crew responsible for maintaining a restricted route. This type of local experience can be very beneficial in determining when load restrictions should be used and when they are not needed.

The greatest drawback to having the decision making process at the local level is that there may be many different ideas about when loads should be restricted. Roads that may be restricted in one area may not be in another, and these discrepancies can lead to uneven use of restrictions, and may reduce the benefits of applying restrictions.

Summary

Based on the tasks performed during this project, a method for objectively determining when spring restrictions should be implemented and how long they should last has been created. This procedure uses portions of each of the methods described above, and is intended to be used by local crews from SDDOT, as well as by counties within South Dakota. The procedure is contained in the next chapter, and it was created so that it may serve as a stand-alone document for distribution by the SDDOT.

9. PROCEDURE FOR DETERMINING START AND DURATION OF SPRING LOAD RESTRICTIONS IN SOUTH DAKOTA

Introduction

To provide a uniform method for determining the start and duration of spring load restrictions within South Dakota, the following procedure has been developed. The procedure requires the collection of temperature data in the field by agency personnel for calculation of freezing and thawing indices. These indices are then used to determine when routes should be restricted within a specified area. Also included in this procedure are guidelines for notifying users of restricted route status throughout the spring thaw season.

The procedure is intended to be used by each maintenance unit within the SDDOT. The procedure can also be used by county maintenance agencies if sufficient data are available.

Temperature Data

At each SDDOT maintenance unit, minimum and maximum daily temperatures will be collected beginning November 1 of each year. Temperature data collection will continue through April 30 of the following spring, or until the end of spring load restrictions has been determined. Temperature values should be collected in degrees Fahrenheit. Tables are provided at the end of this document for recording the minimum and maximum temperatures for each day throughout the specified period.

The daily minimum and maximum temperatures will be used to calculate the daily average temperature. The daily average temperature will be calculated using the following equation:

$$\text{Avg.} = (\text{Min.} + \text{Max.})/2$$

All average daily values should be rounded down (i.e., 39.5 rounds to 39, -8.5 rounds to -9). All three values—minimum, maximum, and average—should be entered into the appropriate spot on the temperature recording sheets.

Freezing Index

Beginning with the first day having an average temperature less than or equal to 0 °C (32 °F), a freezing degree-day value will be calculated. The freezing degree-day value is simply:

$$F_{deg\text{-}day} = 32 - (\text{daily average temperature, °F})$$

The freezing degree-day values will be accumulated each day to calculate the overall freezing index for the location.

Once positive freezing degree-days begin to accumulate (average daily temperatures below freezing), it is possible to have negative freezing degree-days (average daily temperatures above freezing). For example, if the freezing index is 36 degree-days after several cold days, and if several warm days are then recorded (38, 46, 40, and 44 °F), the freezing index after the fourth warm day would be -2 degree-days. In situations such as this, the freezing index would be set to zero, and no freezing degree-days will be accumulated until the average daily temperatures fall below freezing again.

The day after which the freezing index remains greater than zero for the rest of the winter is designated as the beginning of the freezing season. The largest value recorded for the freezing index will correspond to the end of the freezing season and will be used to calculate the duration of spring load restrictions.

Thawing Index

As daily average temperatures begin to move above -2 °C (29 °F) in the spring, the thawing degree-days will be calculated. The thawing degree days are calculated as:

$$T_{deg\text{-}day} = (\text{daily average temperature, °F}) - 29$$

The thawing degree-day values will be accumulated each day to calculate the overall thawing index for the location.

Once positive thawing degree-days begin to accumulate (average daily temperatures above -2 ° [29 °F]), it is possible to have negative thawing degree-days (average temperatures below 2 ° [29 °F]). For example, if the thawing index is 28 degree-days after several warm days, and if several cold days are then recorded (24, 20, 22, 23, and 25 °F), the thawing index after the fifth cold day would be -3 degree-days. In situations such as this, the thawing index would be set to zero, and no thawing degree-days will be accumulated until the average daily temperatures rise above -2°C (29 °F) again. Accumulation of the freezing index continues at the same time as thawing index is being accumulated, until the beginning of the thawing season is identified.

The day after which the thawing index remains greater than zero for the rest of the spring is designated as the beginning of the thawing season. As with the freezing season, the beginning of the thawing season will not be known until the index becomes positive for an extended period of time.

Load Restrictions—Begin

The beginning of spring load restrictions will correspond to a thawing index greater than 40 degree-days. Restrictions should begin as soon as possible after the 40 degree-days have been accumulated.

If negative thawing degree-days reduce the thawing index to less than 0, load restrictions will be lifted until the thawing index is once again greater than 40 degree-days. As discussed previously, the thawing index will be set to zero, and no additional negative thawing degree-days will be accumulated. The thawing index will begin to accumulate only when positive thawing degree-days are calculated.

To take into consideration the various moisture zones present in the State of South Dakota, different levels of the thawing index may be used to trigger the start of load restrictions. The values for each of the moisture zones are:

Zone 1	Wet	35 degree-days
Zone 2	Moderate	40 degree-days
Zone 3	Dry	50 degree-days

The three zones are shown in figure 22.

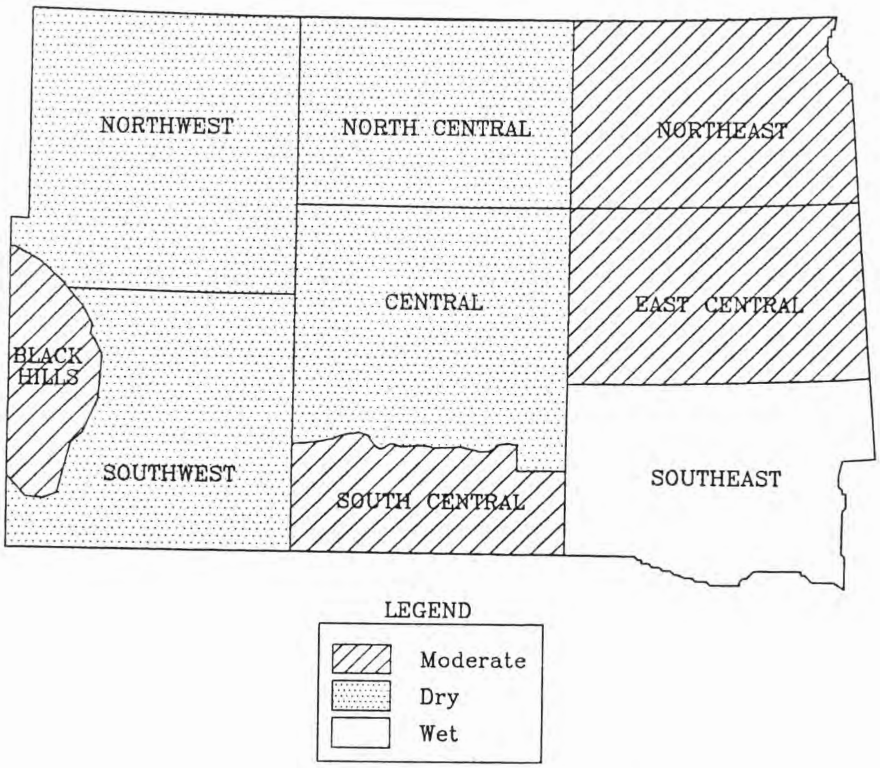

Figure 22. Moisture zones in South Dakota.
(From *Climatic Atlas of the United States*, National Oceanic and Atmospheric Administration, 1972)

Load Restrictions—Duration

There are two possible alternatives for determining the duration of load restrictions using the maximum freezing index value calculated for a particular winter. The first procedure calls for simply taking a percentage of the maximum freezing index as the minimum thawing index required to remove load restrictions. Again, to take into account the various moisture zones in South Dakota, variable percentages may be used for each of the three moisture zones shown in figure 22.

Zone 1	Wet	40 percent
Zone 2	Moderate	30 percent
Zone 3	Dry	25 percent

For example, a maximum freezing index of 1,500 degree-days in zone 2 would result in load restrictions in place until a thawing index of 450 degree-days had been achieved. The same freezing index in zone 1 would require 600 degree-days to remove the load restrictions.

The second alternative for determining the duration of load restrictions is to calculate the number of days that restrictions must be in place in order to remove load restrictions. The calculation for the duration is:

$$\text{Duration} = 25 + 0.01(\text{Max. Freezing Index})$$

For example, if the freezing index is 1,500 degree-days, the duration of load restrictions would be 40 days.

Because the first approach takes into account the degree of thawing taking place as well as the degree of freezing which took place, it is recommended as more effective in determining the necessary duration of load restrictions.

Local Knowledge

In some instances, the familiarity of local personnel with a particular route may indicate that restrictions are necessary when the temperature method says they are not (or vice versa). Any observations by local personnel that restrictions are being inaccurately determined for a particular route using the temperature method should be reported to the central office, along with recommendations for actions to be taken. This information will be considered when compiling restriction updates.

Data Reporting

From November 1 through the end of the freezing season, the only information that needs to be submitted to the central office is the monthly summary sheets with the daily temperatures and freezing index data filled in. Copies of the sheets should be sent to the central office by the 5th of the following month. Any comments should be entered in the appropriate column when needed.

As the thawing season approaches, notice should be sent to the central office each time a positive thawing index is maintained for 3 consecutive days. The information to be submitted should include:

- Dates of the 3 consecutive thawing days.
- Thawing index value after the third day.
- Five-day forecast for the location.
- Any observations from the route that might indicate that restrictions are needed (pumping, crack development, excessive rutting, etc.).
- Recommendation as to whether or not restrictions will be needed.

This information should be sent to the central office by Thursday afternoon to be included in the restriction update to be sent out that Friday.

When the thawing index goes above the appropriate value for the moisture zone, the central office should be notified, and plans should be made for posting the route as restricted.

Restricted Route Updates

On or before February 1 of each year, the SDDOT should prepare and distribute copies of the map showing state routes that are eligible for consideration as load restricted routes during that spring thaw period. A brief summary of how the restrictions are being determined should also be included, along with a description of the increase in damage possible when thaw-weakened pavements are overloaded and an estimate of the amount of money SDDOT spends each year repairing roads damaged by truck traffic during the spring thaw.

Once spring thaw necessitates the restriction of routes, weekly updates on the status of restricted routes throughout the State will be sent out each Friday. If no changes are received in the central office by Thursday, no notice will be sent out on Friday, and the last update will remain in effect. Information on restricted routes to be included in the updates should include:

- Route designation.
- County (or city if applicable).
- Date restriction will take effect.
- Type of load restriction to be enforced (6- or 7-ton designation).
- Indication that load restrictions are being lifted (if applicable).
- Contact person for alternative route information.

The final notice sent out by the central office will inform users that there are no longer any load restrictions in place along state routes in South Dakota.

Information concerning the status of restricted county routes can also be sent to the central office for inclusion in the restriction update. The same information listed above will be necessary for county routes to be included.

If interest in the restriction update becomes too large, and postage costs become excessive, a program should be initiated to have interested users pay for subscriptions to the update to offset the postage costs.

November daily temperature recording sheet.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Nov. 1								
Nov. 2								
Nov. 3								
Nov. 4								
Nov. 5								
Nov. 6								
Nov. 7								
Nov. 8								
Nov. 9								
Nov. 10								
Nov. 11								
Nov. 12								
Nov. 13								
Nov. 14								
Nov. 15								
Nov. 16								
Nov. 17								
Nov. 18								
Nov. 19								
Nov. 20								
Nov. 21								
Nov. 22								
Nov. 23								
Nov. 24								
Nov. 25								
Nov. 26								
Nov. 27								
Nov. 28								
Nov. 29								
Nov. 30								

December daily temperature recording sheet.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Dec. 1								
Dec. 2								
Dec. 3								
Dec. 4								
Dec. 5								
Dec. 6								
Dec. 7								
Dec. 8								
Dec. 9								
Dec. 10								
Dec. 11								
Dec. 12								
Dec. 13								
Dec. 14								
Dec. 15								
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Dec. 20								
Dec. 21								
Dec. 22								
Dec. 23								
Dec. 24								
Dec. 25								
Dec. 26								
Dec. 27								
Dec. 28								
Dec. 29								
Dec. 30								
Dec. 31								

January daily temperature recording sheet.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Jan. 1								
Jan. 2								
Jan. 3								
Jan. 4								
Jan. 5								
Jan. 6								
Jan. 7								
Jan. 8								
Jan. 9								
Jan. 10								
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Jan. 27								
Jan. 28								
Jan. 29								
Jan. 30								
Jan. 31								

February daily temperature recording sheet.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Feb. 1								
Feb. 2								
Feb. 3								
Feb. 4								
Feb. 5								
Feb. 6								
Feb. 7								
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Feb. 25								
Feb. 26								
Feb. 27								
Feb. 28								
Feb. 29								

March daily temperature recording sheet.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Mar. 1								
Mar. 2								
Mar. 3								
Mar. 4								
Mar. 5								
Mar. 6								
Mar. 7								
Mar. 8								
Mar. 9								
Mar. 10								
Mar. 11								
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Mar. 25								
Mar. 26								
Mar. 27								
Mar. 28								
Mar. 29								
Mar. 30								
Mar. 31								

April daily temperature recording sheet.

Date	Daily temperatures, °F			Freezing Index, degree-days		Thawing Index, degree-days		Comments
	Max.	Min.	Avg.	Daily	Cum.	Daily	Cum.	
Apr. 1								
Apr. 2								
Apr. 3								
Apr. 4								
Apr. 5								
Apr. 6								
Apr. 7								
Apr. 8								
Apr. 9								
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Apr. 29								
Apr. 30								

APPENDIX A

LITERATURE REVIEW

Allen, H. S., and D. L. Bullock, "Evaluation of Deflection Data as Criteria for the Posting and Removal of Spring Load Limits," Transportation Research Record 1106, 1987, pp. 140-145.

A study conducted by the Minnesota Department of Transportation found it infeasible to use falling weight deflectometers (FWD) to determine the beginning of spring restrictions because the thawing of the pavement occurred too rapidly to allow for warning of commercial carriers based on FWD data alone. The deflection data were acquired using Dynatest Model 8000 FWDs, with the emphasis being on the average D1 (center of load) and D7 (furthest from center) sensor readings. Deflection basin areas were also calculated, as were the tensile strain at the bottom of the bituminous layer (adjusted to 70 °F [21 °C]) and the subgrade modulus values.

Overall, 14 test sites were included in the study, with between 2 and 8 in (51 and 203 mm) of asphalt surface (average 4.5 in [115 mm]) and between 0 and 30 in (762 mm) of gravel base (average 10.6 in [270 mm]). The subgrade conditions ranged from sandy loam/peat mixtures to clay to plastic materials.

Observations included the following:

- The D1 and D7 deflections showed the same trend of increasing in the spring and gradually decreasing during the rest of the year, though the trend was more pronounced in the D1 deflections.

- Weakening was observed after rain during fall testing.

- Calculated values of tensile strain in the asphalt layer (corrected to a standard temperature) generally peaked before the D1 deflections reached their peak.

- Rapid strength loss was observed as the spring thaw commenced, with maximum deflections occurring when the thaw depth reached between 38 and 48 in (0.97 and 1.22 m).

Because of the relatively long period needed for recovery of the pavement strength, the FWD approach can be used to determine when to end spring restrictions. One recommendation would be a period of 3 weeks after maximum pavement deflection is obtained. When the 3 week dates were calculated for the test sections and were compared to the actual dates that the load restrictions were removed, the deflection dates averaged 9 days earlier than the actual dates that restrictions were lifted. Three of the test sections showed deflection dates later than the actual dates (between 4 and 15 days), with the remaining test sections showing deflection dates between 3 and 33 days earlier than the actual dates.

This report did not address the issue of imposing speed restrictions, only spring axle weight limits.

Allen, W., R. Berg, and S. Bigl, "Prediction of Damage to Flexible Pavements in Seasonal Frost Areas,", Transportation Research Record 1286, 1990 pp. 234-247.

Research at the U.S. Army Cold Region Research and Engineering Laboratory is developing a mechanistic pavement design model using five computer programs to compute soil and pavement moisture and temperature (FROST1), resilient modulus and Poisson's ratio (TRANSFORM), pavement stresses and strains under load (JULEA and NELAPAV), and cumulative damage (CUMDAM). The model was calibrated for six soil types and was used to predict cumulative damage at test sections in Springfield, Missouri and Rochester, Minnesota.

Two pavement sections were tested using a repeated-load plate bearing (RPB) device. The responses from these two pavements were used to calibrate the mechanistic model for the different combinations of materials, subgrade types, and layer thicknesses present. For the two layer systems, all five cumulative damage equations resulted in cumulative damage going from 0 to 1 in a single spring that period, with the vertical strain models having slightly steeper slopes than the horizontal strain models.

For the three- and four-layer systems, the FAA vertical strain model still predicted cumulative damage going from 0 to 1 in a single spring thaw period, though the slope was not as severe as in the two-layer system. Two of the horizontal strain models, Witczak and Army Corps of Engineers, also had damage going from 0 to 1 in one spring thaw, but at a significantly slower rate than either the two-layer system or the FAA model. Both Asphalt Institute equations (horizontal and vertical strain) showed damage less than 1 for the three- and four-layer systems, with the horizontal strain model having approximately three times the damage after 1 year that was calculated using the vertical strain model.

One of the conclusions reached by the researchers was that the linear elastic solution that had been used was not as effective as a nonlinear solution would be. This was felt to be especially true during periods of thawing as were encountered during the field testing for the project.

This report did not address the issue of imposing speed restrictions for thaw-weakened pavements.

Barcomb, J., "Use of Thermistors for Spring Road Management," Transportation Research Record 1252, 1989, pp. 12-20.

The United States Forest Service implemented a series of thermistor sensors along roads in the Kootenai National Forest in northwestern Montana to monitor the underlying temperatures during the spring thaw period. The thermistor sensors cost between $250 and $450 to install, and have lasted about 3 years in the ground. The thermistor strings consist of sensors placed in the asphalt surface, just below the asphalt mat, 6, 12, 18 and 24 in below the pavement surface, and every 12 in below that. One thermistor is also placed in a shaded spot to record ambient air temperatures.

In order to record the temperature data, a hand-held electric thermometer is plugged into each of the individual thermistor wires, and the readings are recorded by hand. Readings are done every week or two until temperatures begin to approach the thawing point (32 °F). In this report, the critical temperature has been determined to be 31.7 °F for the particular soil conditions encountered in the Kootenai National Forest. Figure A-1 shows the temperature readings over a 5-month period from one thermistor arrangement.

Another important aspect of the program implemented in the Kootenai National Forest is a procedure for notifying the local users (predominantly logging companies) of restriction conditions prior to the actual enforcement of the load restrictions. Working with the local users, having them see the advantages of restricting loads, and being able to quickly lift restrictions during refreeze conditions has promoted cooperation between the Forest Service and the local users regarding the restrictions. For example, one stretch of road that has had thermistor strings installed has seen yearly maintenance costs drop as much as 70 percent, from a yearly average of $3,300/mile to $970/mile.

The report also advises correlation between thermistor readings and deflection measurement to determine the relationship between the pavement strength and depth of thaw. Also recommended is the initial installation of extra sensors (at $10 each) and allowing for failed sensors rather than putting in a minimal number of sensors and having to replace whole strings as a result of single thermistor failures (at a cost of approximately $300 per installation).

The thermistor monitoring system has one drawback in that no criteria have been established for the lifting of spring restrictions. The procedure for lifting restrictions that was reported included visual evaluation of moisture in ditches and in pavement cracks.

This report did not address the issue of imposing speed restrictions, but did acknowledge that other agencies may not be able to totally close down a road as the Forest Service can.

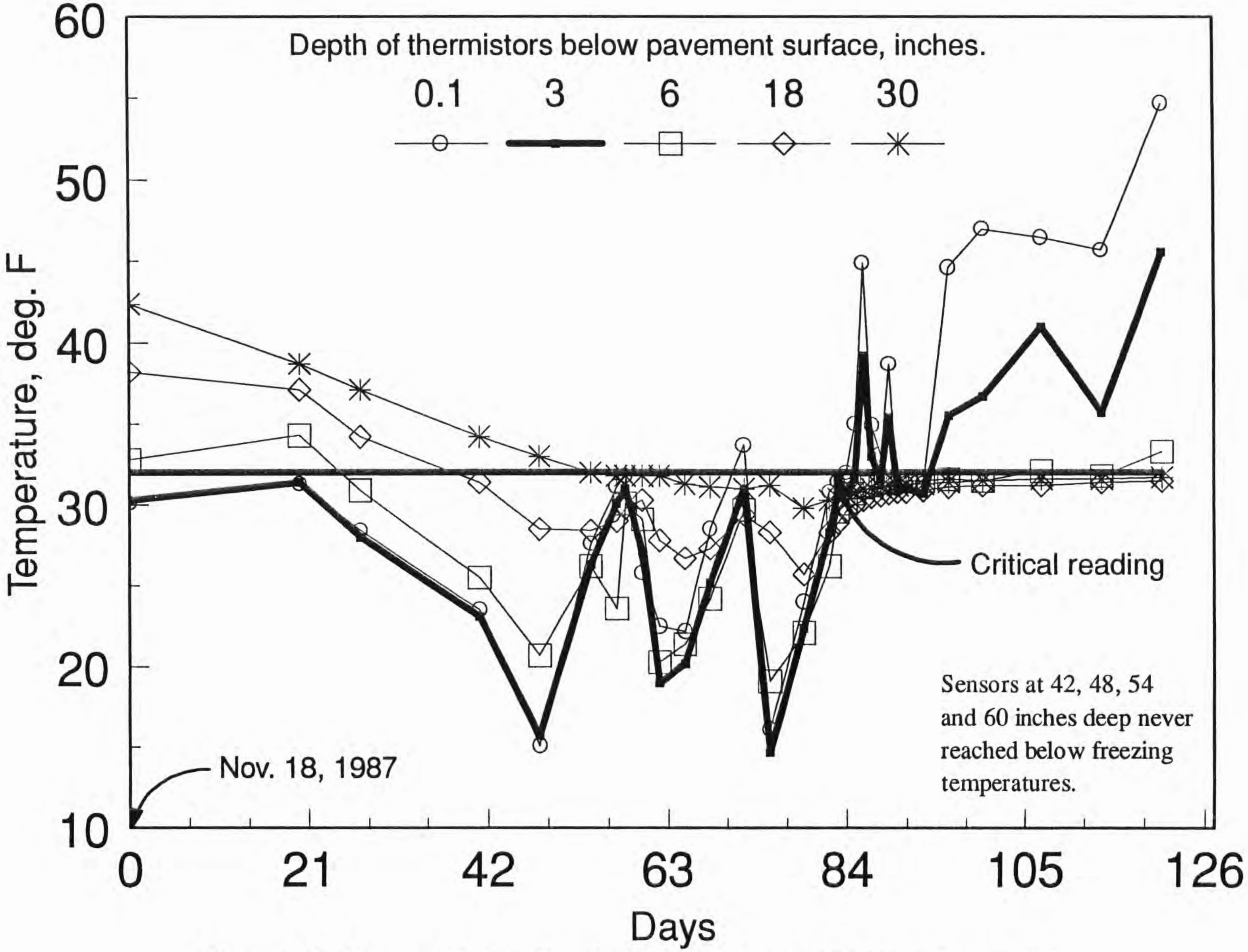

Figure A-1. Example of subsurface temperatures recorded by thermistor probe.

Fernando, E. G., D. R. Luhr, and H. N. Saxena, "The Development of a Procedure for Analyzing Load Limits on Low-Volume Roads," Transportation Research Record, 1987, pp. 145-156.

In developing a procedure for determining load restrictions for the Commonwealth of Pennsylvania, single, tandem, and triple axle configurations at a series of load levels were analyzed. Field data from the falling weight deflectometer (FWD) and RoadRater, along with theoretical deflection basins from the BISAR multi-layer linear elastic program developed by Shell Laboratories, were used in the analysis. Regression equations were developed based on the AASHO Road Test equation for performance, using the FWD and RoadRater data from Pennsylvania rather than the Benkelman Beam data originally obtained at the AASHO Road Test. The equations developed for the Pennsylvania data calculate vertical compressive strain of subgrade as a function of measured deflections and layer thicknesses. This subgrade strain value can then be used to calculate allowable loads for different subgrade strengths as determined by the FWD or RoadRater during the spring thaw.

One other strategy proposed in this report is the use of load limits that increase with the age of the pavement. This procedure requires the determination of a plot showing posted load limit versus time before next rehabilitation, as shown in figure A-2. The theory behind this procedure is that the sooner a pavement will be rehabilitated, the less it needs spring restrictions to protect it.

This report did not address the issue of speed restrictions for thaw-weakened pavements.

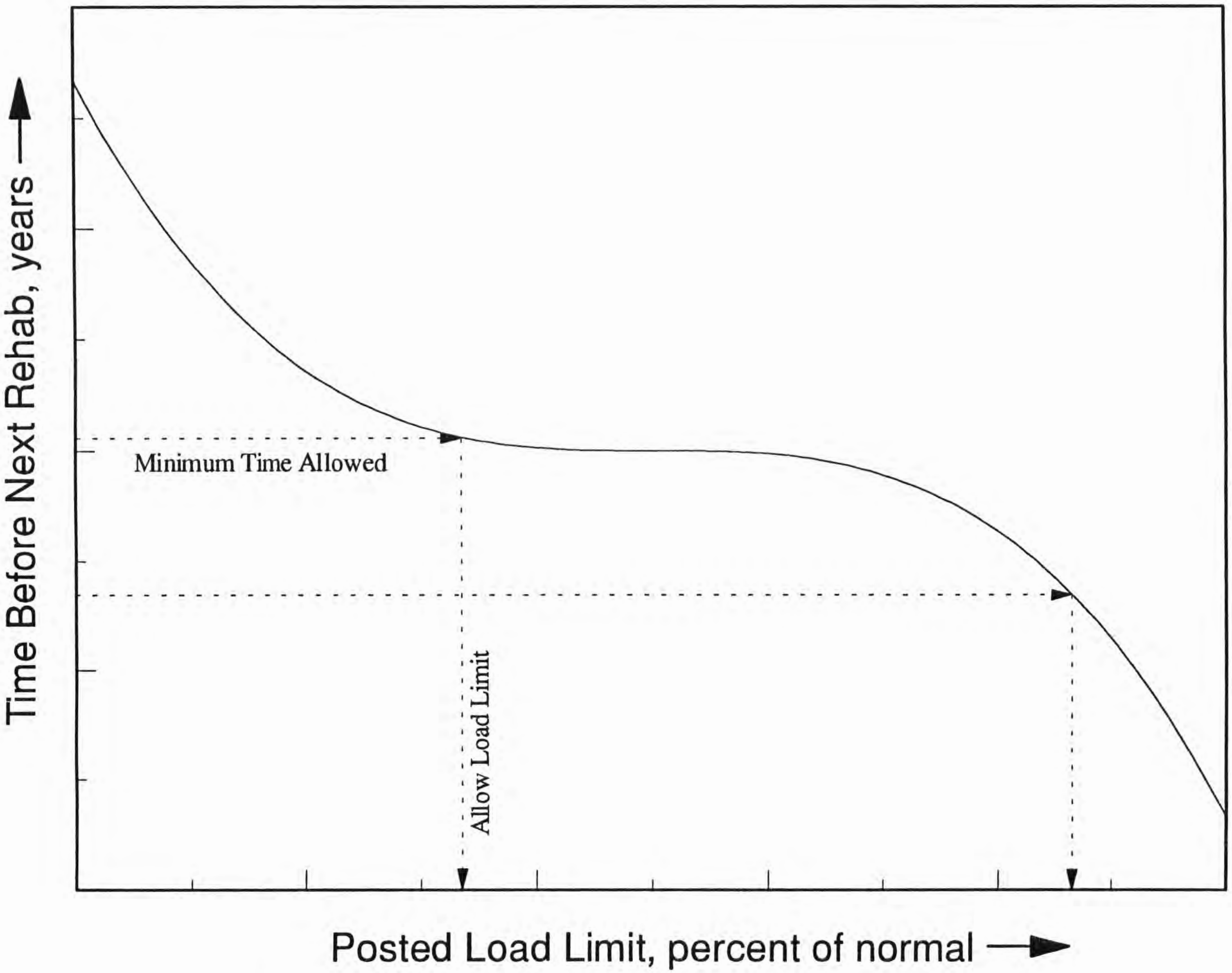

Figure A-2. Example of posted load limit versus time to rehabilitation.

Huft, David, "Spring Speed Restrictions—Do They Really Work," South Dakota Department of Transportation, Date ????.

Mr. Huft presents data from the AASHO road test showing the increases in deflection and pavement damage associated with having heavy trucks travel more slowly over pavements. The increase in pavement damage when a truck is slowed from 50 mph to 25 mph is approximately 250 percent. The only method recommended for protecting pavements weakened by spring thaw is to impose load restrictions during the period when the underlying pavement layers are thawing.

Janoo, V. C., and R. L. Berg, "Thaw Weakening of Pavement Structures in Seasonal Frost Areas," Transportation Research Record 1286, 1990, pp. 217-233.

Testing of four flexible pavement test sections at the U.S. Army Cold Region Research and Engineering Laboratory included the use of in-pavement thermocouples, electrical resistance gauges, and a Dynatest 8000 FWD. Each of the test sections was subjected to five freeze-thaw cycles, with only data from the first two cycles presented in the paper. Plots of resistance and temperature show distinct jumps or drops in resistance as the temperature of the pore water in the pavement goes from just above to just below freezing or from just below to just above freezing, respectively. The differences in pavement strength noted in the report are for only the first two of five freeze-thaw cycles so that thermal effects and not traffic were the sole cause for differences.

Deflection testing was carried out at two different load levels: 40 kN, which represents currently allowable loading, and 50 kN, which represents illegal tire pressures. This deflection testing over time showed a steady increase in total basin area as the pavement thawed for both the first and second cycles, reflecting lower strengths for the pavement sections. Impulse Stiffness Modulus (ISM) and Subgrade Strength Index (SSI) were calculated and plotted with time as well. The ISM decreased rapidly and leveled off during the second thaw cycle, while the SSI tended to increase with time through both thaw cycles. In the case of the CH subgrade, the modulus values decreased by a factor of between 2 and 2.2 after being subjected to freeze-thaw conditions.

The comparisons of thaw depth to total deflection basin area showed good correlations for pavement depths in the subgrade layer. Relationships are also observed in the base layer of the test sections, but with a distinctly different slope than the area-thaw depth relationships in the subgrade layer. The relationship in the subgrade layer shows a much quicker increase in deflection basin areas with increasing thaw depths than for the base layer.

The report did not discuss the possible effects of lowering speeds (increasing deflection testing load pulse) for the thaw-weakened pavements.

Mahoney, J. P., M. S. Rutherford, and R. G. Hicks, *Research Summary Report—Guidelines for Spring Highway Use Restrictions,* Washington State Transportation Center and the University of Washington, 1986.

This report contains several recommendations on the use of spring restrictions based on surface deflection measurements, air temperature (Freezing Index), type of subgrade, pavement cross-section, and moisture conditions. The report recommend the use of load restrictions where spring deflections are at least 45 to 50 percent greater than summer deflections.

This report also contained a summary of questionnaires and interviews with state, county, and city agencies on the subject of spring restrictions. The responses received indicated:

- The majority of spring restrictions placed by states are on roads of 2,500 ADT and 10 percent trucks or less, while local agencies imposed restrictions on roads with ADT up to 30,000 and 10 percent trucks.
- Most agencies did not consider frost protection when designing pavements.
- Load restrictions were usually imposed by local personnel based on judgement and past experience. Very few agencies used deflection measurements in their decisions.
- Notification of load limits included newspapers, road signs, and detour and embargo maps.
- Enforcement of load limits was done with fixed and portable scales.
- Enforcement of load limits was most often hindered by lack of personnel, political pressure, and evasive drivers.

Given the different mechanisms for freezing temperatures to weaken pavement, either heaving or thawing, the most damaging in many instances is where thawing of frozen pavement layers begins at the pavement surface and works its way down through the pavement. This creates a "bathtub" situation in which melted water is kept from draining by the frozen layers below. The high moisture content causes weakening of the pavements, resulting in more damage from traffic loadings.

A Freezing Index (FI) of 400 °F-days (based on 29 °F) is presented as one alternative for determining when restrictions are necessary with pavement surface thicknesses less than 2 in. Load restrictions are recommended as 20 to 60 percent reduction of load, with 40 to 50 percent reduction being applicable to many types of pavements.

The beginning of load restrictions is recommended after an accumulation of a Thawing Index (TI) of 25 °F-days (based on 29 °F-days), or 10 °F-days for thin pavement sections. The duration of restrictions is recommended based on an equation using the FI value:

$$\text{Duration (days)} = 25 + 0.01(\text{FI})$$

Nazarian, S., K. H. Stokoe II, and R. C. Briggs, "Nondestructively Delineating Changes in Modulus Profiles of Secondary Roads," Transportation Research Record 1136, 1987, pp. 96-107.

In order to determine the properties of a pavement structure, several types of devices are possible. One of these devices is the Spectral-Analysis-of-Surface-Waves (SASW) method which was used on two sections of low-volume roads in Texas. The SASW method is a type of seismic testing used to determine shear wave velocity and elastic Young's modulus profiles. Field testing of local roads in Texas was conducted to determine modulus values of the pavement layers using accelerometers and geophones to measure surface waves at distances less than 4 ft and more than 4 ft, respectively.

Testing was done before and after rain to give dry and wet results for the subgrade, and was performed at two sites: one in good condition and the other showing deterioration. After-rain results showed approximately a 20 to 30 percent decrease in modulus values within the subgrade, with little difference between the before and after conditions for the surface and base layers. The change in subgrade modulus values was less for site 1 (good condition) than for site 2 (deteriorated condition).

Testing with a falling weight deflectometer (FWD) at both sites after rain showed similar trends in the subgrade response at both sites. The subgrade modulus values calculated from FWD testing showed lower values for site 2 (deteriorated condition) than for site 1 (good condition), which is in agreement with the relative subgrade modulus values determined by the SASW equipment.

The majority of the observed softening of the overall pavement system was due to the weakening of the subgrade materials, as opposed to the asphalt or base materials. This was observed after heavy rains for a clayey subgrade, as opposed to during a thawing period of a frozen pavement structure.

Rutherford, M. S., "Pavement Response and Load Restrictions on Spring Thaw-weakened Flexible Pavements," Transportation Research Record 1252, 1989, pp. 1-11.

The use of spring load restrictions requires information on the time to impose restrictions and what magnitude of load restrictions should be used to protect the pavement without overprotecting it. A method for determining these two things was to be determined beyond simply visually examining the pavement and relying on the judgement and experience of the local agency personnel.

The ELSYM5 layered elastic pavement analysis program was used to calculate stress and strain conditions for various stages of thaw in several different pavement cross-sections. These stages were summer, base thaw, subgrade thaw to 4 in, and total thaw. Using the calculated stresses and strains, along with assumed modulus values for the different layers, allowable loads were calculated using a single tire, single axle configuration. Significantly different results were obtained for the 2- and 4-in (51 and 101 mm) thick asphalt surface layers, suggesting that this is a factor to be considered. The most critical period for this analysis was at a point where only the top 4 in (101 mm) of subgrade had thawed and the remainder was frozen.

A second series of simulations was performed using dual tires on both single and tandem axles on the 4 in (101 mm) thaw condition, to assess the damage from these load configurations. Single tire, single axle loads were found to be more critical in terms of both tensile strain at the bottom of the asphalt surface and vertical strain in the top of the subgrade, which were the two critical conditions used to evaluate the pavement systems.

Deflections are not a reliable indicator of when the critical conditions are reached for a thaw-weakened pavement. This is because critical deflections (maximum recorded during spring thaw periods) are not reached until after critical values of both the tensile strain at the bottom of the asphalt layer and compressive strain at the top of the subgrade are reached.

The results of this particular study indicate that load restrictions of up to 100 percent may be needed to protect pavement integrity during spring thaw, compared to the 50 to 80 percent of maximum loads that are currently being enforced throughout the U.S. and Canada. These results are based on maintaining performance levels that exist during summer conditions. Most of the discrepancy between what is needed to maintain summer performance and what is being done in practice is explained by the fact that many agencies are simply trying to slow the rate of deterioration, rather than maintain the integrity of the pavement structure at summer levels.

This report does not consider imposing speed restrictions for thaw-weakened pavements.

Rutherford, M., "Evaluation of Variables Affecting Flexible Pavement Thawing for Timing Spring Load Restrictions," Transportation Research Record 1286, 1990, pp. 248-258

Four flexible pavement structures were evaluated to determine the effects of different factors on the thawing process. The pavement structures consisted of 2- and 4-in thick asphalt concrete surface layers, 6- and 12-in thick base layers, and fine- and coarse-grained subgrade materials. Also included in this analysis were the consideration of ground surface effects (radiation, convection, inclination) and latent heat effects caused by the phase change of water as it freezes and thaws. Climatic variables included air temperature (quantified by freezing index [FI]), shortwave radiation, longwave radiation, and convection (expressed in terms of pavement surface and air temperature, and average wind speed).

A model was developed for predicting the location of the thawing plane, and a sensitivity analysis was conducted to determine the effects of different latitude, cloud cover, wind speed, location-specific temperature functions, and variations in subgrade thermal properties. For early thawing (late February and early March), the latitude had the most effect in differences in pavement surface and air temperatures. For late thawing (late March and early April), wind speed had the most impact on the differences between pavement surface and air temperatures. Thin pavement sections were found to thaw in anywhere from 1 to 4 days, while thicker pavements were found to thaw in 4 to 9 days. Overall, the subgrade type had the greatest impact on the duration of thawing.

Information on temperature differences between pavement surface and air temperatures suggests that thawing can begin well before air temperatures reach 32 °F (0 °C). The difference between pavement surface and air temperatures was also shown to increase, meaning that any attempts to determine thawing from air temperatures would require a changing critical temperature during the spring. For example, if there is a 2 °F difference between pavement surface and air temperature in February, then the critical air temperature would be 30 °F. However, by late March the difference could be as high as 12 °F, resulting in a critical air temperature of 22 °F.

The duration of thawing should not be assumed to be the critical period. Once thawing is completed, drainage of the excess moisture from the pavement section must continue for summer/fall strength levels to be attained.

Stubstad, R. N., and B. Connor, ***Prediction of Damage Potential on Alaskan Highways During Spring Thaw Using the Falling Weight Deflectometer,*** **State of Alaska, Department of Transportation, August 1982.**

The use of load restrictions in the State of Alaska was estimated to cost the trucking industry approximately $100,000 per day (in 1980 dollars). The effective timing of these restrictions must therefore protect the roadway as well as limit the increases in trucking costs. Criteria evaluated for determining critical pavement conditions include the tensile strain at the bottom of the asphalt layer, vertical strain at the top of the subgrade, and vertical strain at the top of the base material.

The State of Alaska began using a Dynatest FWD in 1982 to collect deflection information that could be used to determine thaw depth and potential for damage due to traffic loadings. The FWD was set up to approximate a 9,000-lb wheel load at 82 psi, which was thought to be reasonable for the trucks using Alaskan highways at the time.

As a result of relatively low deflections at large offsets, the Chevron N-layer computer program was used to determine what the effects of different thaw depths would be on different pavement types. After accumulating over 350 runs of different pavement types and thaw depths, a solution table was constructed, which could be used to compare the FWD results obtained in the field and provide a better idea of what the actual conditions in the pavement structures were. A computer program (FROST) was created to compare the FWD field data and the solutions generated by the Chevron program.

The resulting procedure is able to determine thaw depth to within 1 ft for shallow depths and within 2 ft for greater depths. Also determined by the FROST program are the adjusted center deflections if no frost was present (adjusted to 70 °F). These values are most reliable for AC thicknesses less than 3 in. The last value determined by the FROST program was the "Damage Indicator," which is basically the strain value for the top of the granular base layer. This is believed to be the most critical of the failure measurements.

One of the results of this study was that the frozen nature of the pavement caused misleading deflection measurements to be observed. The example provided in the report shows how FWD testing over time shows an increase in center deflection, but that both the adjusted center deflection and vertical strain at the top of the base are at their most critical when the actual center deflection is the lowest. Waiting for peak deflections to impose load restrictions would have resulted in significant damage based on the other criteria evaluated.

The State of Alaska hoped to use the adjusted center deflections as the criteria for imposing and lifting load restrictions, to address concerns that load restrictions based on peak deflection were being imposed too late. There was also the hope that short stretches of weakened pavement could be identified for structural rehabilitation in order to avoid the use of load restrictions altogether.

Preventing Potholes with Spring Use Restrictions, **Special Bulletin Series 9, South Dakota Transportation Technology Transfer Service.**

This special bulletin is based on results obtained during a study at the Washington State Transportation Center. Observations on the causes of the problem and potential solutions are listed. One of the points made is that "maintenance agencies often know where to apply restrictions, but not how much to restrict or when to apply and remove the restrictions."

The following table is provided to indicate how much protection is attained from different load restrictions:

Load Reduction (%)	Life Increase (%)
20	62
30	78
40	88
50	95

South Dakota law allows spring restrictions as early as February 15 and as late as April 30, depending on weather and road conditions. Recommended calculations for determining when to impose spring restrictions and what duration should be used are the same as those presented in the report by Mahoney et al.

No mention is made in the bulletin of the use of speed restrictions for thaw-weakened pavements.

APPENDIX B

SUMMARY OF AGENCY INTERVIEW RESPONSES

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Clayton Sullivan Date: January 12, 1994
Organization: Idaho Department of Transportation

Background of contact person

Mr. Sullivan has been with the Idaho Department of Transportation for 33 years, serving as the State Maintenance Engineer for the past 7 years.

Do you feel that spring restrictions help pavements to last longer?

Yes, spring restrictions help pavements that have outlived their useful life, are not adequately ballasted, need upgrading, or have less than adequate drainage. In Idaho, these pavements would generally be older sections along the secondary road network. Spring restrictions are not effective for sections of the trunk highway network that are in need of repair.

Are you aware of speed restrictions being used in your area?

Yes. Idaho DOT will first post speed restrictions (30 or 35 mph) along sections that are susceptible to spring breakup. If damage is still observed with the speed restrictions, then weight restrictions will be posted.

What will it take to convince users of the need for spring restrictions?

Idaho DOT sends out information releases through the media prior to the spring thaw period explaining why spring restrictions are needed, with drawings illustrating how pavements break up, how frost lenses develop and cause problems, and so on. This system seems to work well for Idaho DOT.

What type of enforcement is used for spring restrictions?

Idaho DOT is responsible for enforcing weight restrictions, while the local sheriff and State Police are responsible for enforcing speed restrictions. The DOT uses roving scale setups in areas where local DOT forces believe there is a consistent disregard for the weight restrictions.

What types of things should be avoided when using spring restrictions?

Spring restrictions should not be slapped on with no advance notice to the public. Weight restrictions should not be used unless speed restrictions have been tried and proven ineffective. Spring restrictions should not be used as a means of protecting trunk line pavements that are in need of rehabilitation.

How much is currently spent in your area repairing pavements damaged during spring thaw?

Idaho DOT has no record of spring thaw repairs in its maintenance management system, but it would probably be a substantial amount of money. There are also extreme cases which occur (not on an annual basis) where large sections of pavement need to be repaired as a result of the spring breakup.

Do you think significant savings can be seen from implementing spring restrictions?

Yes. Positively.

How do you determine when to start and when to stop spring restrictions?

Currently, a very crude system is used in which the local DOT personnel, such as the District Maintenance Engineer will make a subjective decision based on the presence of pumping, historical knowledge, experience, common sense, moisture amounts, and other factors to determine when to begin speed restrictions. The start of weight restrictions is determined in basically the same fashion. Restrictions are left in place until the thaw is finished, or until a cold spell refreezes the pavement, providing adequate support. In that case, speed restrictions will be started again when the thaw begins to weaken pavements.

Other comments:

Idaho DOT puts out a bulletin to subscribers of their "spring restrictions service," giving a couple of days' notice of impending restrictions. District personnel submit sections that they will be posting two days before, so that the subscribers can be notified and make necessary adjustments. Currently, the bulletin is sent out twice weekly, with most of the subscribers being trucking firms and timber companies. While the service has been free of charge previously, Idaho DOT will be charging a small fee in the future to offset mailing costs.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Joe Barcomb Date: January 12, 1994
Organization: U.S. Forest Service, Kootenai National Forest

Background of contact person

Mr. Barcomb authored a paper for *Transportation Research Record 1252* (1989) on the use of thermistor probes to monitor depth of thaw during the spring as a means of determining when to implement spring load restrictions. He is currently working on a project with the Montana DOT to collect NDT data to correlate to the thermistor temperature information.

Do you feel that spring restrictions help pavements to last longer?

Yes. For example, one pavement which was originally designed for a 10-year service life has been protected with spring restrictions and is entering its 11th year of service with minimal maintenance having been performed.

Are you aware of speed restrictions being used in your area?

The U.S. Forest Service does not use speed restrictions. Local counties in the vicinity of the Kootenai National Forest do use them.

What will it take to convince users of the need for spring restrictions?

Kootenai National Forest is still using the notification system documented in the TRR report for notifying the local users of impending spring restrictions.

What type of enforcement is used for spring restrictions?

The U.S. Forest Service has the authority to shut down a roadway (place a 10-ton limit) if spring restrictions are not adhered to, providing a very effective means of enforcement.

How much is currently spent in your area repairing pavements damaged during spring thaw?

There isn't any information on how much money is spent repairing thaw-damaged pavements, but there is between a 40 and 60 percent reduction for maintaining a road where spring restrictions are implemented soon enough, versus a pavement where restrictions are used too late or not at all.

Do you think significant savings can be seen from implementing spring restrictions?

(See previous response.)

How do you determine when to start and when to stop spring restrictions?

Spring restrictions are imposed when the thermistors record temperatures nearing the critical temperature for the area (determined to be 31.7 °F). When to stop restrictions is one topic being studied as part of the NDT project with Montana DOT.

Other comments:

No new reports have been made on the use of the thermistor probes, though Gordon Hanek (one of the authors of the original paper in *TRR 1089*) is currently working with CRREL to collect additional data. The NDT project with Montana DOT is looking at the rate of strength recovery once the pavement has experienced the spring thaw. Testing to date has included a set of baseline readings in October 1992, spring readings in April, May, and June 1993, and another set of baseline readings in August 1993. Testing this spring with the RoadRater should occur earlier than last year, when a hard freeze hit the area in late February and one of the logging companies covered the roadway with sawdust to inhibit thawing. The entire study is expected to last between 3 to 5 years. The U.S. Forest Service is no longer manufacturing its own thermistor strings, but is having them produced by a company in Oregon. Cost for purchase and placement of a probe is approximately $500, with nine pavement sensors and one air sensor being included. Only the Forest Service and one local county in Montana are currently using the probes to determine when spring restrictions should begin.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Kent Sheppard Date: January 13, 1994
Organization: Montana DOT

Background of contact person

Mr. Sheppard is currently working with the U.S. Forest Service to perform the NDT testing for spring restricted roads in the Kootenai National Forest. He is also testing Montana State routes for the same type of research.

Other comments:

The NDT testing of spring-restricted roads in the Kootenai National Forest is being conducted using a RoadRater deflection device. Testing is performed every 440 ft along the roadway. A single force level is used to test during frozen or thawed periods (winter or summer/fall). During the actual thaw, the testing is conducted at 15 different load levels at 100-lb increments. The data collected are then used to develop deflection versus load plots for various stages of the thawing process. One goal is to be able to tie percent changes in test load to percent changes in wheel loads that result in critical increases in deflection. He cited a previous U.S. Forest Service report published in the early 1970s, which arrived at a value of 2 mils as the critical increase during spring thawing. For analysis of the Montana DOT project, the center deflections and the backcalculated resilient modulus values are the values that will be used.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: David Leftwich Date: January 14, 1994
Organization: North Dakota DOT Secondary Roads

Background of contact person

Mr. Leftwich is with the Secondary Roads Division of the North Dakota Department of Transportation.

Do you feel that spring restrictions help pavements to last longer?

Yes.

Are you aware of speed restrictions being used in your area?

The North Dakota DOT uses predominantly weight restrictions, but will occasionally use speed restrictions. The counties in North Dakota also use speed restrictions, with a similar distribution to the counties in South Dakota: most of the eastern counties use speed restrictions, most of the western counties do not.

What will it take to convince users of the need for spring restrictions?

Most users in North Dakota comply with the restrictions, though there are occasional complaints about the placement of restrictions too early.

Do you think significant savings can be seen from implementing spring restrictions?

Yes.

How do you determine when to start and when to stop spring restrictions?

Restrictions are first determined by the local District maintenance personnel, who make recommendations for restrictions to the Maintenance Central Office. The Central Office then puts together a weekly update of the roads which are affected by spring restrictions. The local maintenance personnel also determine the end of restrictions. The decisions to start/stop restrictions are based on a combination of visual surveys, weather forecasts, and experience with the roadways.

Other comments:

In general, the spring restrictions in North Dakota begin in March in the southwestern corner of the State and in April in the northeastern corner. The roads are classified by the legal limit during the restrictions (1, A, AA, etc.) with 1 being an 80,000 lb total load rather than the 105,500 lb total load limit, which is normally the legal limit.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Dennis Lachowitzer Date: January 14, 1994
Organization: Minnesota Department of Transportation

Background of contact person

Do you feel that spring restrictions help pavements to last longer?

Yes.

Are you aware of speed restrictions being used in your area?

Minnesota DOT does not use speed restrictions along their state routes.

What will it take to convince users of the need for spring restrictions?

There are approximately 10,000 names on the mailing list for the spring restrictions bulletin, all of whom are at least interested in knowing what roads will be restricted.

What type of enforcement is used for spring restrictions?

State Police use portable scales to check axle weights, or they can have trucks travel up to 5 miles from their original route to permanent scales if they suspect an overloaded vehicle.

What types of things should be avoided when using spring restrictions?

Minnesota DOT tries to keep the users informed as to the status of the roads so that the level of compliance will be higher.

Do you think significant savings can be seen from implementing spring restrictions?

Yes, if restrictions are applied properly.

How do you determine when to start and when to stop spring restrictions?

The Central Maintenance Office sends out a map of the different State routes and restriction zones in the State of Minnesota, along with a bulletin explaining how the spring restrictions will work. As individual Area Maintenance Supervisors determine that their pavements need to be restricted, the information is submitted to the Central Office, and updated bulletins are sent out with the new restriction information. The DOT also maintains a telephone taped message that contains the same information as the bulletins. The series of bulletins will continue until all of the restrictions have been lifted, resulting in approximately 6 - 8 bulletins being sent out every season.

The counties in Minnesota automatically restrict from a 9-ton axle limit to a 5-ton limit between March 20 and May 15 every year. Additional restrictions are made by the individual counties as needed.

Other comments:

The Minnesota DOT also uses a RoadRater device to determine the maximum allowable load certain pavements should be restricted for. The information from the RoadRater is provided to the Area Maintenance Supervisor, who may or may not use it in the decision to restrict a road.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Lon Kontos Date: January 19, 1994
Organization: Nebraska Department of Roads

Background of contact person

Mr. Kontos is the Permit Manager for the Nebraska Department of Roads.

Do you feel that spring restrictions help pavements to last longer?

Yes, when there is a need.

Are you aware of speed restrictions being used in your area?

No.

What type of enforcement is used for spring restrictions?

Carrier Enforcement, which is a division of the State Patrol, is responsible for enforcing restrictions when they are used. Normally they would set up portable scales in the area of a restricted pavement when necessary.

How much is currently spent in your area repairing pavements damaged during spring thaw?

It depends on the year, and the particular pavement section.

Do you think significant savings can be seen from implementing spring restrictions?

For some pavements, but not the majority.

How do you determine when to start and when to stop spring restrictions?

Each of the eight Districts in the Nebraska DOR is responsible for determining which roads are to be restricted on an as-needed basis. The decision to end restrictions is also up to the individual Districts.

Other comments:

When a District designates a road to be restricted, the information is relayed to the other seven districts and to Carrier Enforcement. No effort is made to get this information to the users, unless someone were to call and request the information. The Nebraska DOR Central Permits Office is responsible for issuing permits to "over-dimensional" vehicles. These permits allow the carriers to travel over a designated route, which the DOR sets to avoid restricted roads, construction areas, etc. During the spring of 1993, no roads were restricted in the State of Nebraska.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Tom Martinelli Date: January 20, 1994
Organization: Wisconsin Department of Transportation

Background of contact person

Mr. Martinelli is a Regional Maintenance Engineer in the Central Maintenance Office for the Wisconsin Department of Transportation.

Do you feel that spring restrictions help pavements to last longer?

Yes. Wisconsin DOT has two different types of restrictions: Class 2 roads and posted roads. Class 2 roads are defined as roads that are not Class 1, and are subject to no overloaded vehicles (greater than 80,000 lb) during the period of spring restrictions. Posted routes are actually designated as allowing some load less than the legal limit during spring restrictions. Both Class 2 and posted designations are determined by the District Maintenance Engineers, who send the information to the Central Office.

What will it take to convince users of the need for spring restrictions?

Most users in Wisconsin are convinced of the need for restrictions.

What type of enforcement is used for spring restrictions?

The Wisconsin State Patrol is responsible for enforcing both the Class 2 and posted sections of pavement. In some instances, they will also be called in by counties that are having a problem with overloads along county routes.

How do you determine when to start and when to stop spring restrictions?

Restrictions along Class 2 routes begin at the same time for all designated routes, generally in early March. Restrictions are generally lifted in two stages, first for the southern half of the state, and then for the northern half, approximately 1 or 2 weeks apart. Posted route restrictions are started and ended based on the discretion of the local district personnel.

Other comments:

A map showing the Class 2 routes is put together and sent out to users prior to the start of spring restrictions. Distribution of the map, and any subsequent bulletins, is handled by the Permits Office. Updates on the posted routes is included in the information sent out by the Permits Office. Wisconsin DOT also uses subsurface temperature data from their SCAN installations (about 30 throughout the State) to determine when restrictions should begin. The temperature data are simply checked for when the temperatures begin to rise above the freezing point. SCAN data are also used to determine a "frozen road declaration" in the winter. This declaration designates certain routes as allowing overloads for carriers of deicing salts and chemicals, pulp products, or materials used in the winter maintenance of the roads. This allows those carriers to not pay for overload permits, which in turn lowers the cost of hauling materials used by the State during winter. Wisconsin DOT also has some frost tubes that are monitored to determine the timing of restrictions, though their locations are not widespread throughout the State.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Theodore V. Eggebraaten Date: November 24, 1993
Organization: Brookings County, South Dakota

Background of contact person

Mr. Eggebraaten is the County Highway Superintendent for Brookings County, and has served in that capacity for the past 5 years. Prior to that, Mr. Eggebraaten spent 9 years working for a private contractor and 15 years working for the DOT.

Do you feel that spring restrictions help pavements to last longer?

Yes. I feel that if we can reduce the loads in the spring it greatly helps our roads. Blotter roads are the ones that really need the reductions. Also roads that do not have the thickness to allow proper or legal loads under adverse conditions.

Are you aware of speed restrictions being used in your area?

The speed restrictions are not going to work unless you use both the speed and weight reductions together.

What will it take to convince users of the need for spring restrictions?

Strict enforcement of the load limits and the raising of taxes if our roads continue to get abused by overloads.

What type of enforcement is used for spring restrictions?

Help from the State Highway Patrol with scales, and our own County Sheriff's Department to help monitor our systems.

What types of things should be avoided when using spring restrictions?

No notification of the restrictions in local papers and highway superintendents being relaxed in who they let go and where they can go on the system.

How much is currently spent in your area repairing pavements damaged during spring thaw?

Possibly $100,000, but it depends on the previous winter.

Do you think significant savings can be seen from implementing spring restrictions?

I believe with strict enforcement, along with help from the community, we can reduce many problems in this area.

How do you determine when to start and when to stop spring restrictions?

I usually go by the "bleeding" in the cracks. When we see the first signs, we put up the restriction signs and contact the State DOT to find out their intentions of placing signs.

Other comments:

I am a firm believer that speed will not help if you continue to let the people haul legal load during this period. Design is a big factor in this also. If you have a design that has some thickness to allow legal loads then it might be OK, but most of the county systems do not have a design to allow an open policy on their roads in the spring. I firmly believe that weight reduction is the only way to go and to enforce it to the max. When to put the restrictions is the hardest part, because you normally have damage before you put up your limit signs, when you are using the visual evaluation prior to sign placement.

APPENDIX C

SUMMARY OF USER INTERVIEW RESPONSES

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Barb Lindstrom Date: January 13, 1994
Organization: South Dakota Trucking Association

Background of contact person

Barb Lindstrom is the Administrative Assistant to Mr. Van Johnson, President of the SD Trucking Association, who was unavailable at the time of the call.

Do you feel that spring restrictions help pavements to last longer?

Yes, as do most of the members of the Association.

Are you aware of speed restrictions being used in your area?

I am unaware of speed restrictions in the State of South Dakota.

What will it take to convince users of the need for spring restrictions?

Most members of the South Dakota Trucking Association agree that spring restrictions are needed. One exception would be farmers/ranchers who have more cause to travel the lower volume roads at the critical times of the year. In most cases it is the same roads being restricted each year, so most carriers can anticipate the spots to avoid.

What type of enforcement is used for spring restrictions?

Current enforcement by the State Police with portable scales seems to be enough.

What types of things should be avoided when using spring restrictions?

Restrictions should not be placed on major highways, nor should they be placed with no advance warning.

Do you think significant savings can be seen from implementing spring restrictions?

While the Association does not have actual figures, there should not be any reason why spring restrictions wouldn't reduce the cost to maintain roads.

How do you determine when to start and when to stop spring restrictions?

The South Dakota Trucking Association has no input into how the spring restrictions are placed, when they begin, or how long they last.

Other comments:

The Trucking Association provides its members with information as to which routes will be restricted and the dates of restrictions. This information is sent out by the South Dakota DOT each spring. The Trucking Association generally hears no complaints from its members about the use of spring restrictions, with the exception of the farmers and ranchers.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Dale Peterson Date: January 14, 1994
Organization: Hyman Freightways

Background of contact person

Mr. Peterson is with Hyman Freightways, and deals with a lot of shipping between Aberdeen and North Dakota, which involves the use of spring restricted pavements.

Do you feel that spring restrictions help pavements to last longer?

Yes, there is a need for them.

Are you aware of speed restrictions being used in your area?

Yes, and the speed restrictions are preferable to the weight restrictions.

What will it take to convince users of the need for spring restrictions?

I am convinced that the restrictions are necessary.

What types of things should be avoided when using spring restrictions?

The use of weight restrictions have more of a negative effect on his business than the speed restrictions, though he admits that there are some roads which do need to have weight restrictions imposed.

Other comments:

Restrictions are needed in some cases to protect the roads, and our drivers adhere to speed restrictions when they are used. More use of weight restrictions would cause more problems for our business.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Jeff Jager Date: January 14, 1994
Organization: Land O'Lakes Dairy, Volga

Background of contact person

Mr. Jager is the dispatcher at the Land O'Lakes facility in Volga. He estimates that Land O'Lakes has between 75 and 100 trucks on the road in South Dakota at any one time, some weighing in excess of 100,000 lbs.

Do you feel that spring restrictions help pavements to last longer?

Yes.

Are you aware of speed restrictions being used in your area?

The counties use the speed restrictions on their roads.

What will it take to convince users of the need for spring restrictions?

The use of spring speed restrictions seems warranted in most cases, but weight restrictions are not always necessary.

What type of enforcement is used for spring restrictions?

There is little problem conforming to the current system of restrictions.

What types of things should be avoided when using spring restrictions?

I am concerned about a county that is contemplating a spring restriction of 80,000 lbs total load. Since South Dakota allows up to 129,000 lbs, and some of our trucks exceed 100,000 lbs total load, the use of that type of restriction would cause problems for us.

Other comments:

Overall, the current system is something that our operation can adhere to, while the possibility of counties imposing 80,000 total load restrictions is an idea that I oppose.

QUESTIONNAIRE FOR SDDOT SPRING RESTRICTIONS PROJECT

Contact Name: Ted Bultsma Date: January 18, 1994
Organization: Bultsma Truck Lines

Background of contact person

Mr. Bultsma is the former president of the South Dakota Trucking Association, and has operated a trucking company in South Dakota for over 30 years.

Do you feel that spring restrictions help pavements to last longer?

Yes, in some instances. There seems to be less of a need for embargoes along the State routes than there has been in previous years, possibly due to the fact that the pavements have stronger sections, which can withstand the thawing effects.

Are you aware of speed restrictions being used in your area?

Yes, though the State does not use them as extensively as in the past. The speed restrictions are more preferable from a trucker's standpoint in that you can still haul a full load, even if it takes longer to get from one point to another.

What will it take to convince users of the need for spring restrictions?

Speed restrictions are necessary in some cases.

How do you determine when to start and when to stop spring restrictions?

The current method used by South Dakota DOT is to use embargoes from March 1 to May 1, or some equivalent time period, with specific routes being designated as 6- and 7-ton routes.

Other comments:

While there are fewer embargoes along South Dakota highways than in the past, there does not seem to be any more breakup than there used to be. Overall, the current methods used by the State are acceptable, especially when compared to how things have been done throughout the 30 years I have been in the trucking business. I am also interested in the use of "district designated" restrictions, where each maintenance district is responsible for designating when certain roads are to be restricted and when the restrictions can be lifted. This type of procedure would allow for more flexibility relative to the local conditions, which are not the same from one end of the State to the other.

APPENDIX D

FIELD TESTING EFFORT

SUMMARY OF FIELD TESTING EFFORTS

In order to determine the responses of pavements subjected to climatic changes during spring thaw, a program of FWD testing and temperature gathering was undertaken as part of this project. This section details the data collection effort and the information that was collected. It was anticipated that the FWD testing program would identify the changes in pavement strength as they occurred during the spring thaw. By matching the changes in pavement strength to the changes in subsurface temperature, it was anticipated that critical temperature depths could be identified that would identify the beginning and ending times when load restrictions would be needed.

FWD Testing

All FWD testing performed as part of this project was done by SDDOT personnel. A total of 11 km (7 mi) along five test sites was tested over a period from February 15 to June 2, 1994. The test site locations were as follows:

Test Site	Route	Location
1	Hwy 47	Northbound MRM 152-154
2	Hwy 26	Eastbound MRM 231-233
3	Hwy 47	Northbound MRM 131.75-132.25
4	Hwy 1804	Southbound MRM 273-275
5	U.S. 83	Northbound MRM 106-106.5

Test sites 1, 2, and 4 are routes that were posted as 5,400 kg (6-ton) routes for spring 1994. Test site 3 was included as a control to determine what differences could be observed between a restricted and nonrestricted portion of the same route. Test site 5 was also a nonrestricted route, but was included in the study because it is currently monitored as part of the SCAN network in South Dakota. This allowed for the collection of very extensive subsurface and air temperature data for comparison with the deflection data. Figure D-1 illustrates the different cross-sections reported for each of the five test sites.

The test sites were arranged in such a way that a complete circuit of all five test sites could be performed by the FWD operator in a single day. Tests were performed on the following dates:

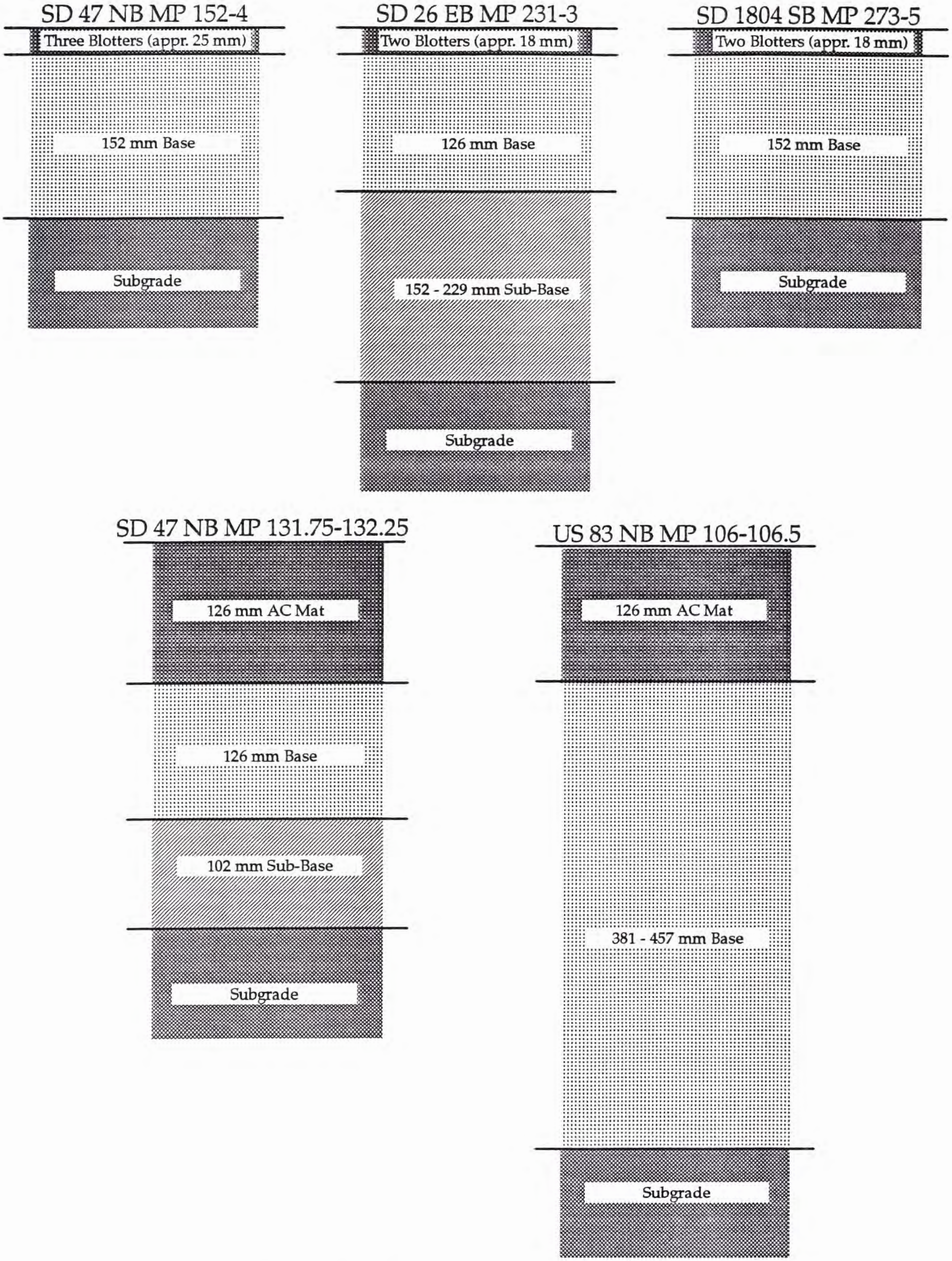

Figure D-1. Cross-sections for all test sites.

February 15	March 28
February 28	March 31
March 3	April 4
March 7	April 14
March 10	May 2
March 14	May 12
March 17	June 2
March 21	

Testing was performed at two nominal load levels, 3,410 and 4,540 kg (7,500 and 10,000 lb). For data presentation purposes, deflections have been corrected to the corresponding load level to allow for a more accurate comparison. The formula used for this correction for the lower load level is

$$D_{corrected} = D_{actual} \times (P_{corrected}/P_{actual})$$

where

$D_{corrected}$ = Corrected deflection for corresponding corrected load level
D_{actual} = Actual deflection recorded in the field
$P_{corrected}$ = Corrected load level, either 3,410 or 4,540 kg (7,500 or 10,000 lb)
P_{actual} = Actual load recorded in the field

This relationship assumes a linear relationship between load and deformation, which is a reasonable assumption for relatively small variations in load, as was the case for this project.

Figures D-2 through D-6 illustrate the average maximum recorded deflections for each of the five test sites at the 3,410 kg (7,500-lb) load level. These deflections were collected using the sensor in located at the center of the load plate. Also shown in figures D-2 through D-6 are the lines representing ±1 standard deviation about the mean maximum deflection. The space between these two lines provides an indication of the variability present for each of the mean values shown.

As figures D-2 through D-6 indicate, the magnitude of the maximum deflection (recorded directly under the load plate) is very low for all test sites until approximately March 1. The increase in deflections can be divided into two categories: restricted (test sites 1, 2, and 4) and nonrestricted (test sites 3 and 5) routes. For the two nonrestricted routes, the maximum deflections increase to approximately 0.64 mm (25 mils) over a period of about 3 to 4 weeks. For the three restricted routes, the maximum deflections increase to between 1.0 and 1.5 mm (40 and 60 mils) over the same period, with test site 2 experiencing the most severe increase in mean deflections. Figures D-7 through D-16 show typical deflection basins for each test site before and after thawing had begun.

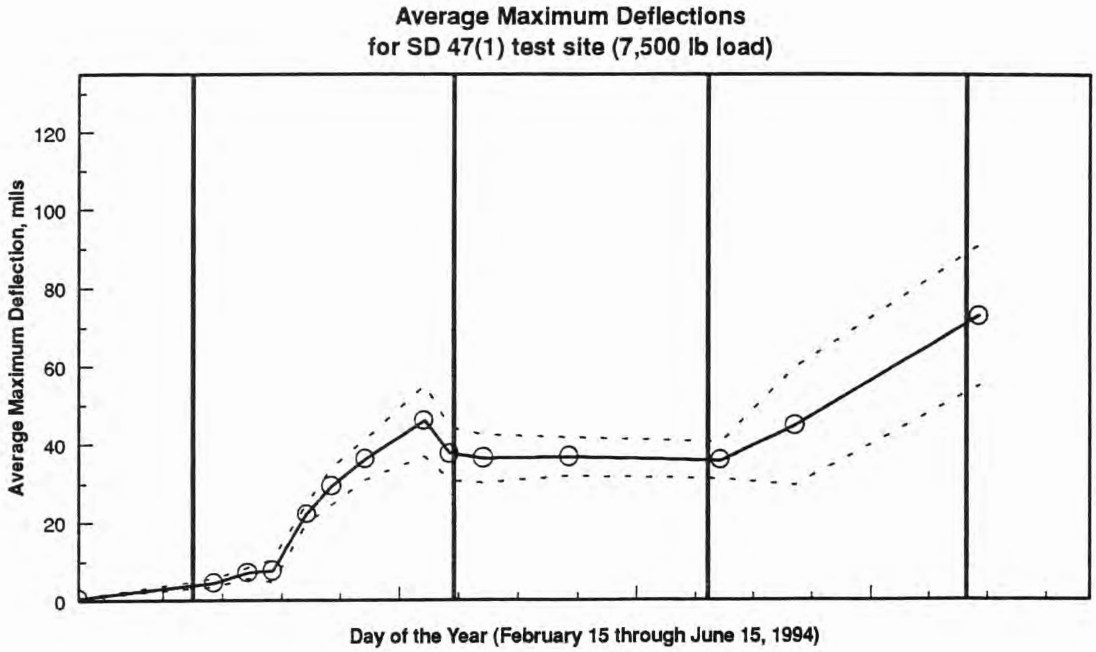

Figure D-2. Summary of average maximum deflections for test site 1.

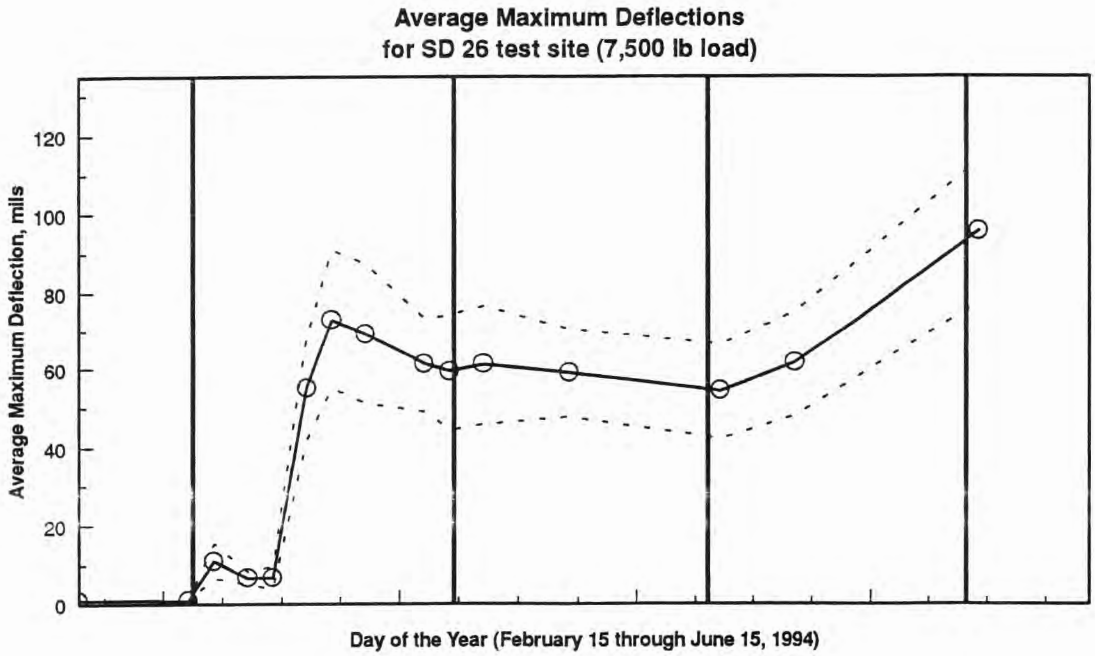

Figure D-3. Summary of average maximum deflections for test site 2.

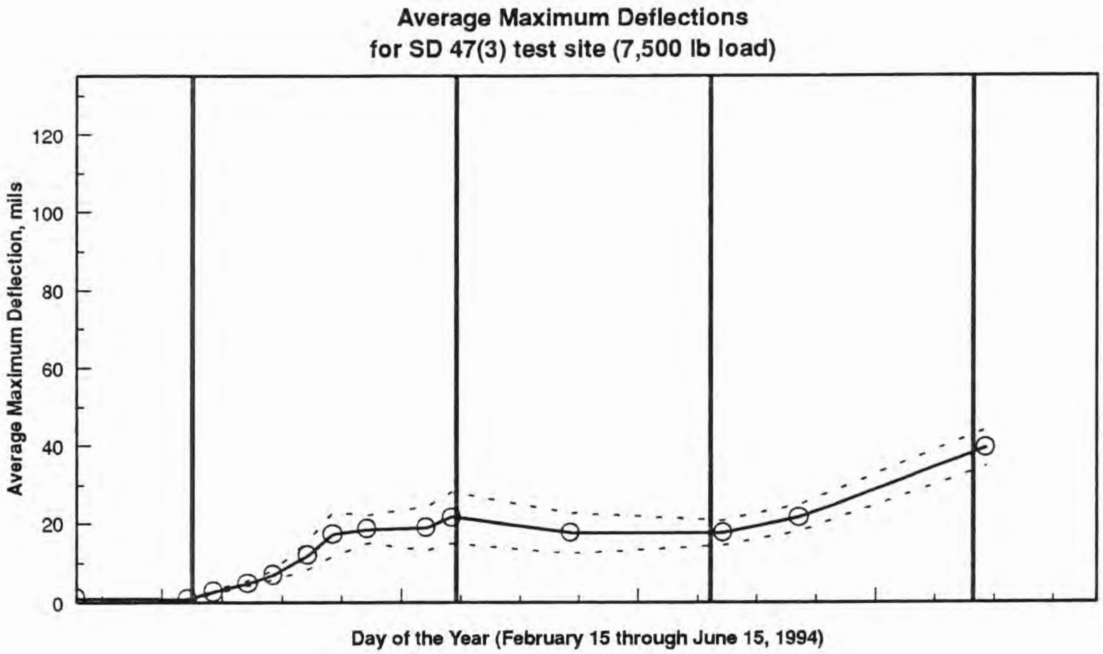

Figure D-4. Summary of average maximum deflections for test site 3.

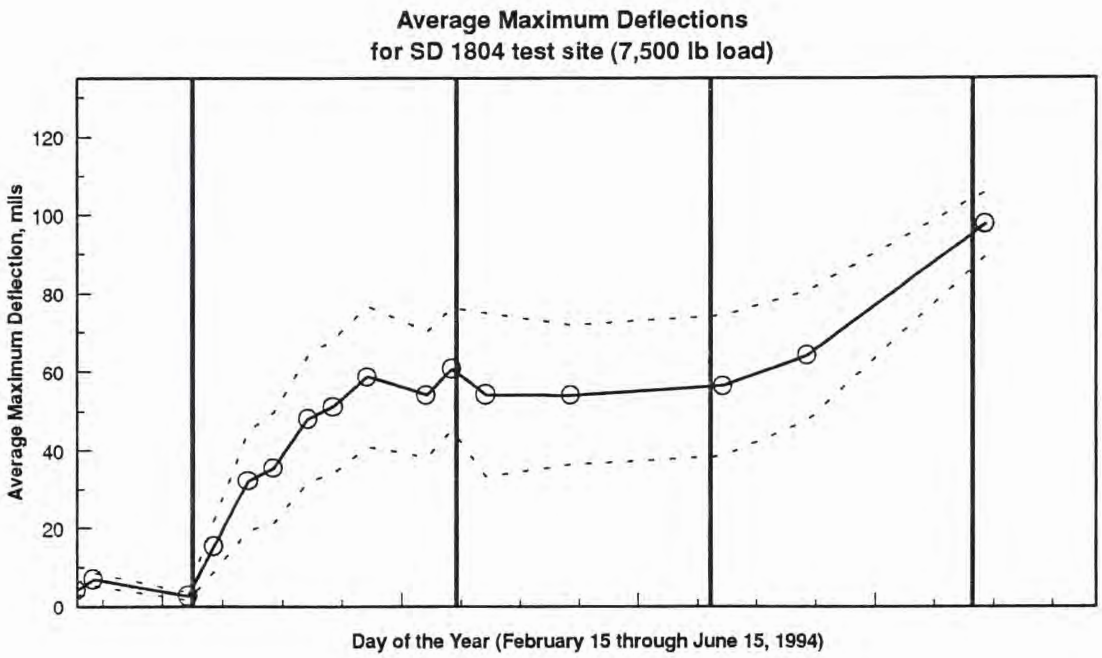

Figure D-5. Summary of average maximum deflections for test site 4.

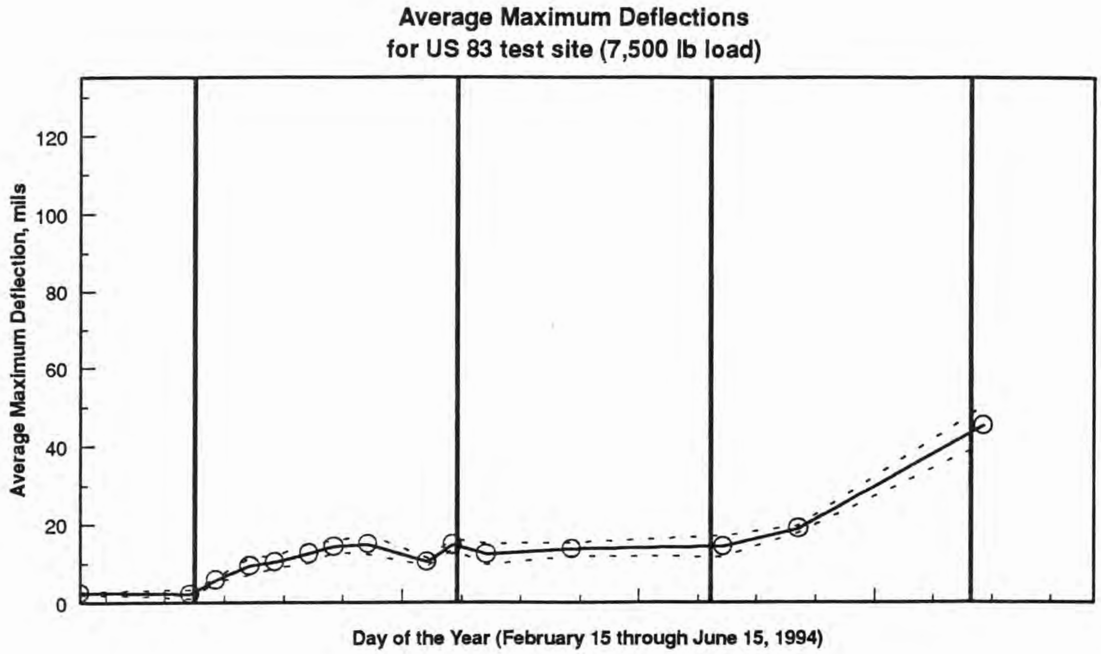

Figure D-6. Summary of average maximum deflections for test site 5.

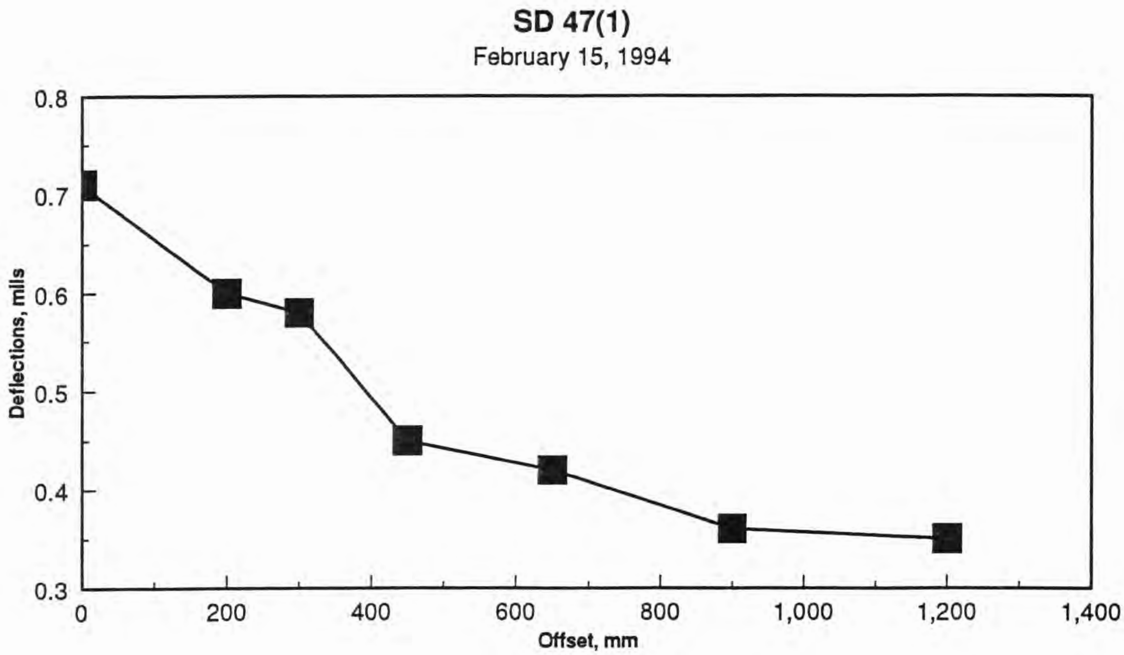

Figure D-7. Test site 1 deflection basin-frozen.

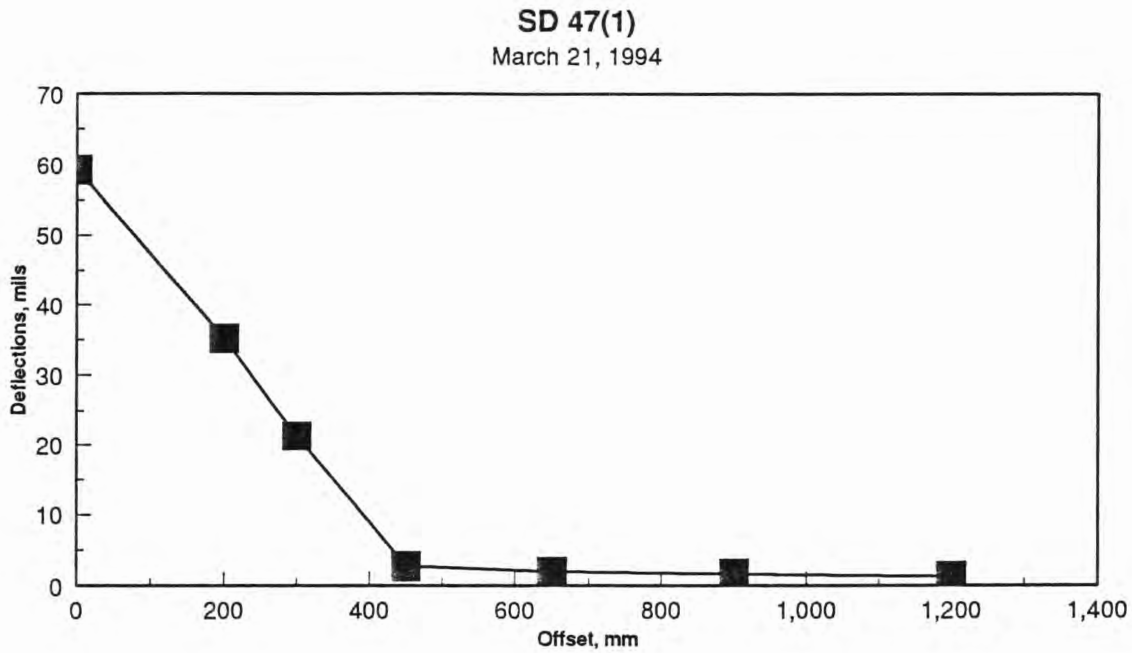

Figure D-8. Test site 1 deflection basin-thawed.

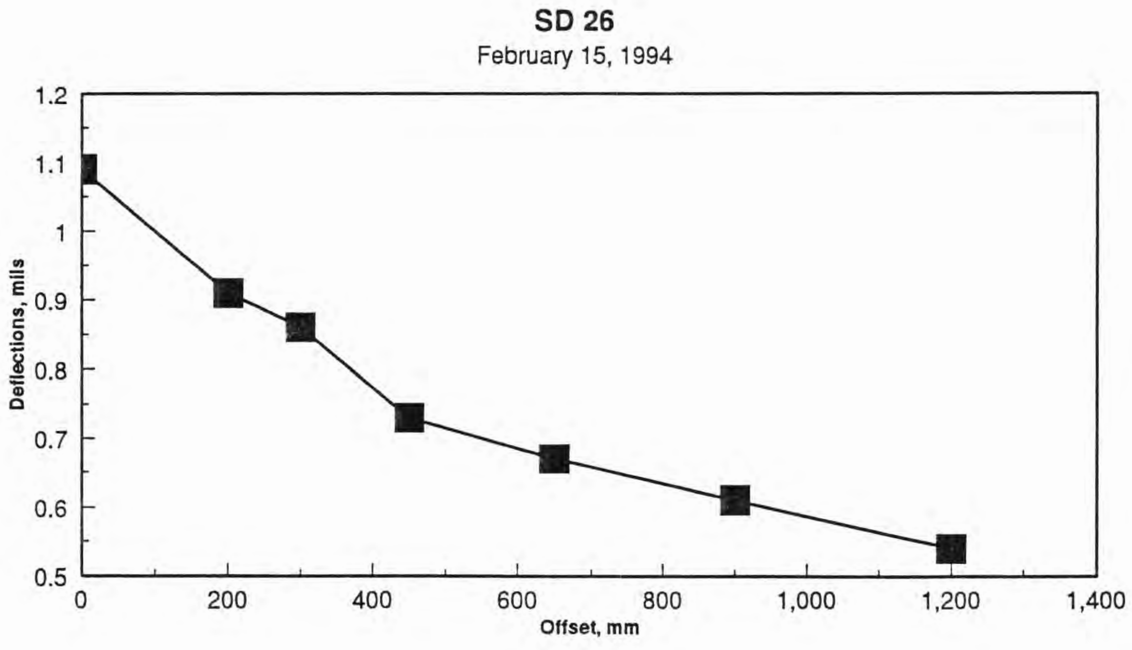

Figure D-9. Test site 2 deflection basin-frozen.

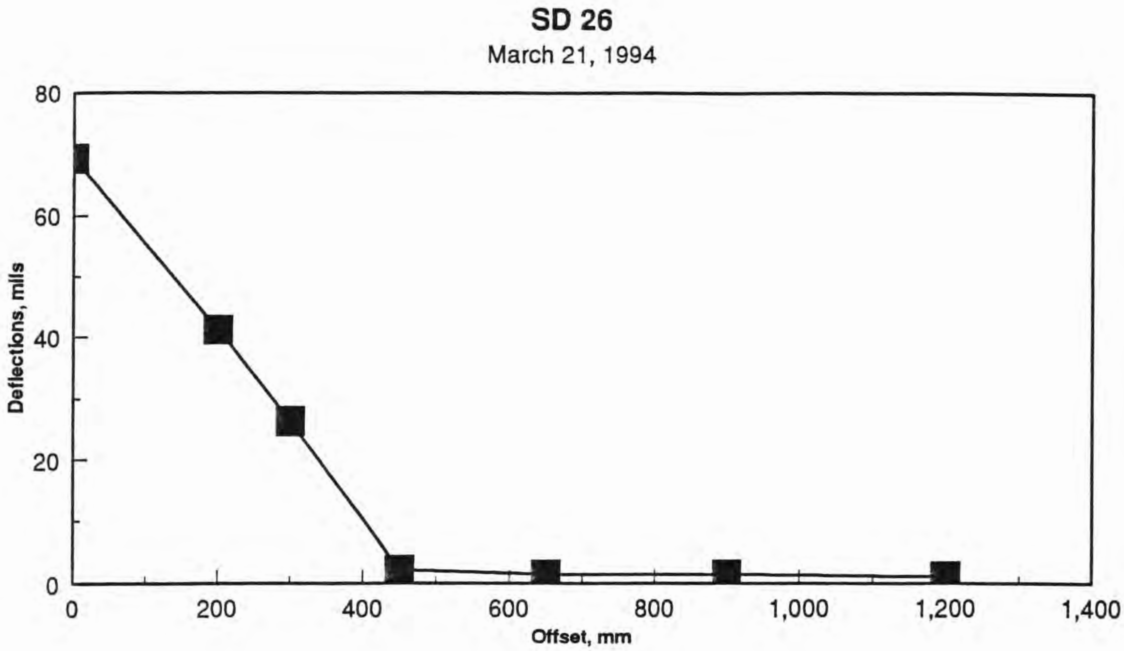

Figure D-10. Test site 2 deflection basin-thawed.

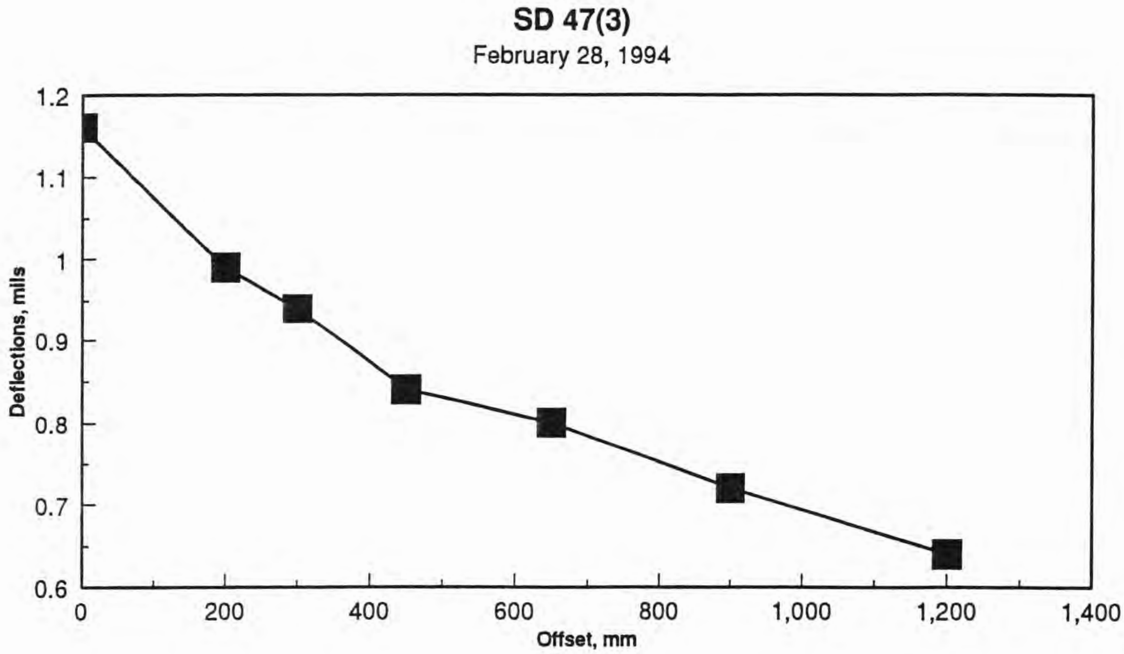

Figure D-11. Test site 3 deflection basin-frozen.

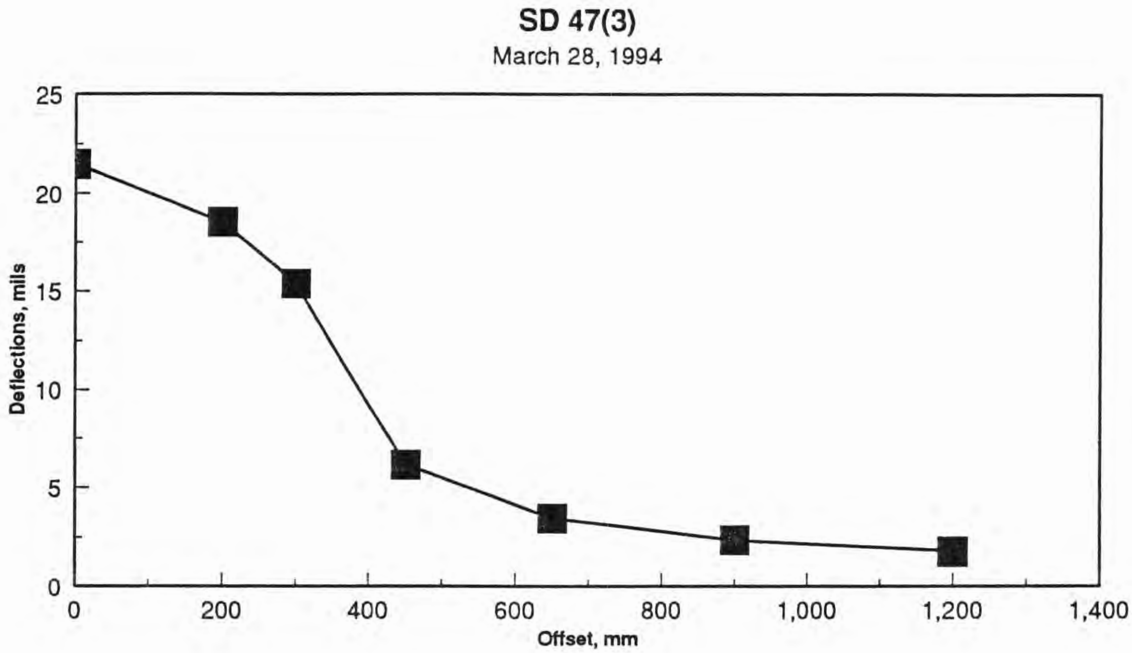

Figure D-12. Test site 3 deflection basin-thawed.

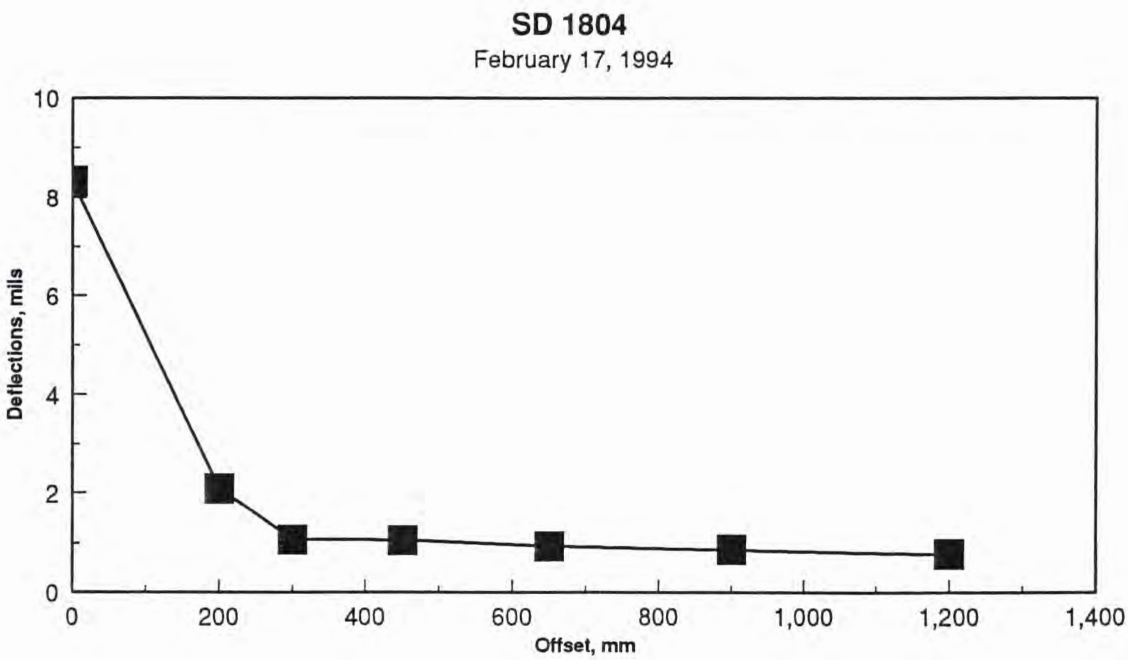

Figure D-13. Test site 4 deflection basin-frozen.

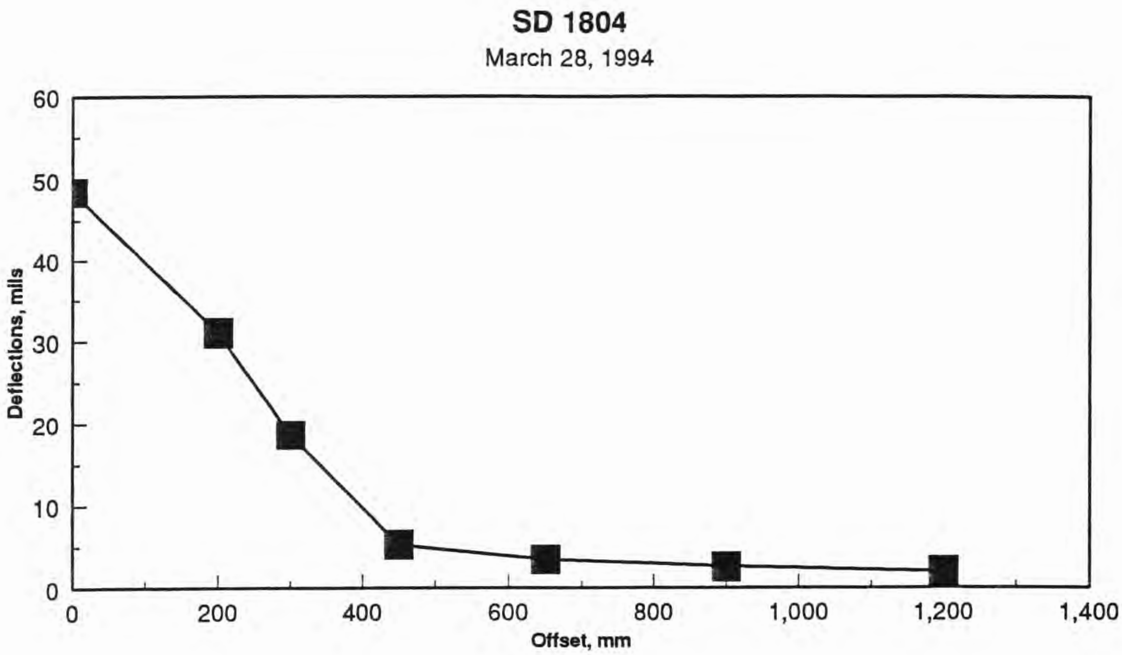

Figure D-14. Test site 4 deflection basin-thawed.

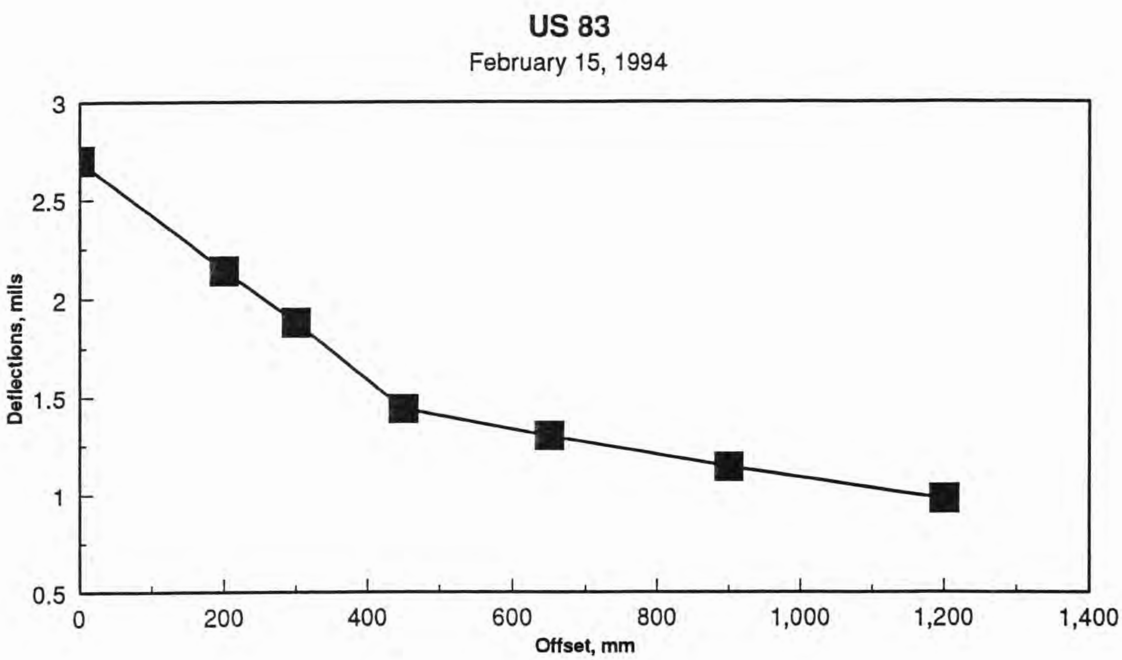

Figure D-15. Test site 5 deflection basin-frozen.

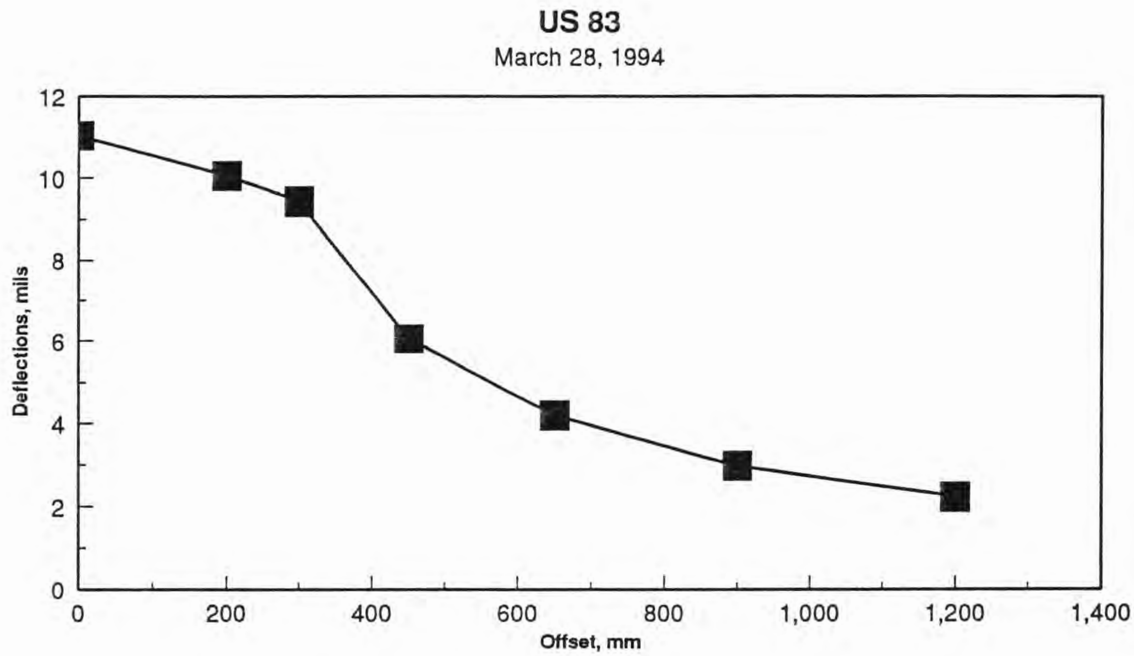

Figure D-16. Test site 5 deflection basin—thawed.

One other note concerning the maximum deflections over time: the variability along the test sites generally increases with increases in the magnitude of the mean maximum deflection. This increase in variability indicates that there is a wider range of pavement support conditions along a section of pavement. This makes it more difficult to effectively protect the entire length of pavement without overcompensating for areas that still have adequate support.

Temperature Data Collection

Two of the five test sites included in this study were used to provide information on the subsurface temperatures over the duration of the field testing. Two different methods were used for this process: the SCAN weather data collection system (test site 5—U.S. 83) and the Roadway Thermal Probe (RTP) (test site 4—Hwy 1804).

The SCAN data collection system consists of a network of sensors located throughout the State which provide a constant readout of the climatic conditions at a particular site. In addition to monitoring air temperature, pavement surface temperature, subsurface temperatures, moisture conditions, and wind speeds, a complete history of each data element is also maintained. Accessing the SCAN system simply requires a computer with modem capabilities and the ability to capture the output to an ASCII computer file. For this project, the SCAN location along U.S. 83 was used to obtain an extensive record of the air and pavement subsurface temperatures from January 1 through May 15, 1994. Figure D-17 shows the subsurface temperature at a depth of 430 mm (17 in) for the U.S. 83 location over the course of the field testing. In addition to the 430 mm (17-in) depth, temperatures at 152 and 305 mm (6 and 12 in) were also collected.

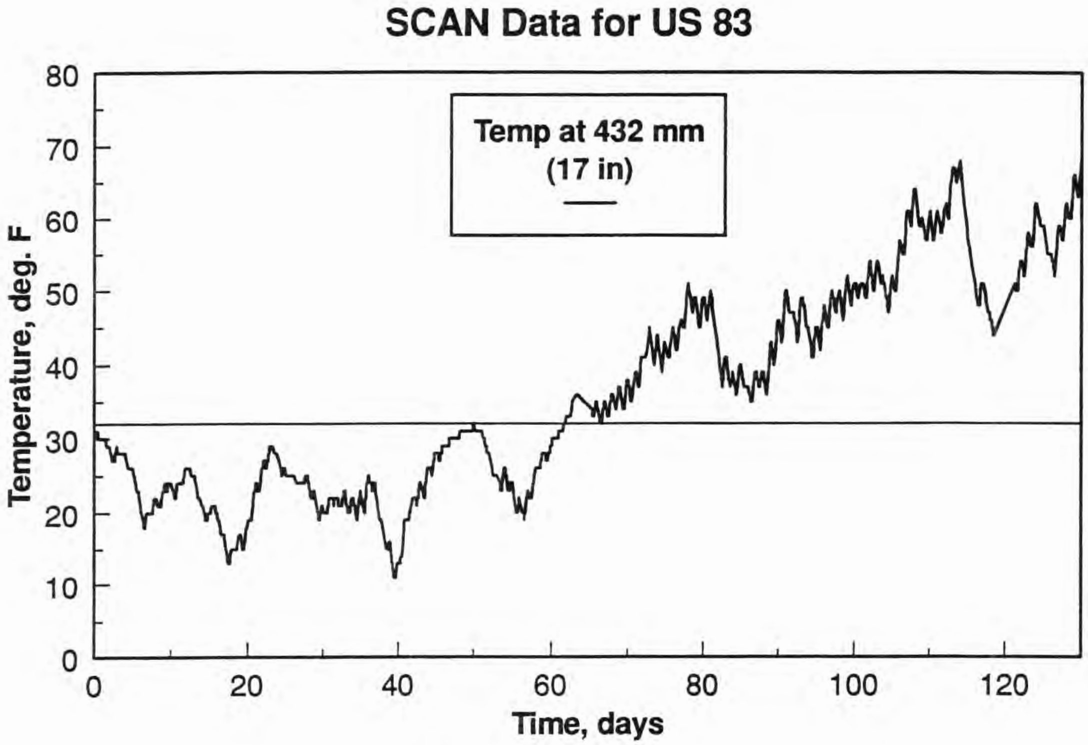

Figure D-17. SCAN subsurface temperature over time.

The second method used for collecting subsurface temperature data was using an RTP. This device consists of a series of thermistors mounted on a piece of tubing, which is placed into a bore hole at the edge of the pavement. The RTP was used by the SDDOT personnel to measure the subsurface temperatures at the time of FWD testing. While the RTP did not provide the same quantity of data points collected by the SCAN system, it did provide an effective means of monitoring the changes in subsurface temperature over time. The purchase cost of the RTP was approximately $425, which included the probe, a readout device, and shipping from the manufacturer. Installation of the device was performed by SDDOT personnel. Figures D-18 through D-27 show the changes in subsurface and air temperatures recorded by SDDOT personnel using the RTP.

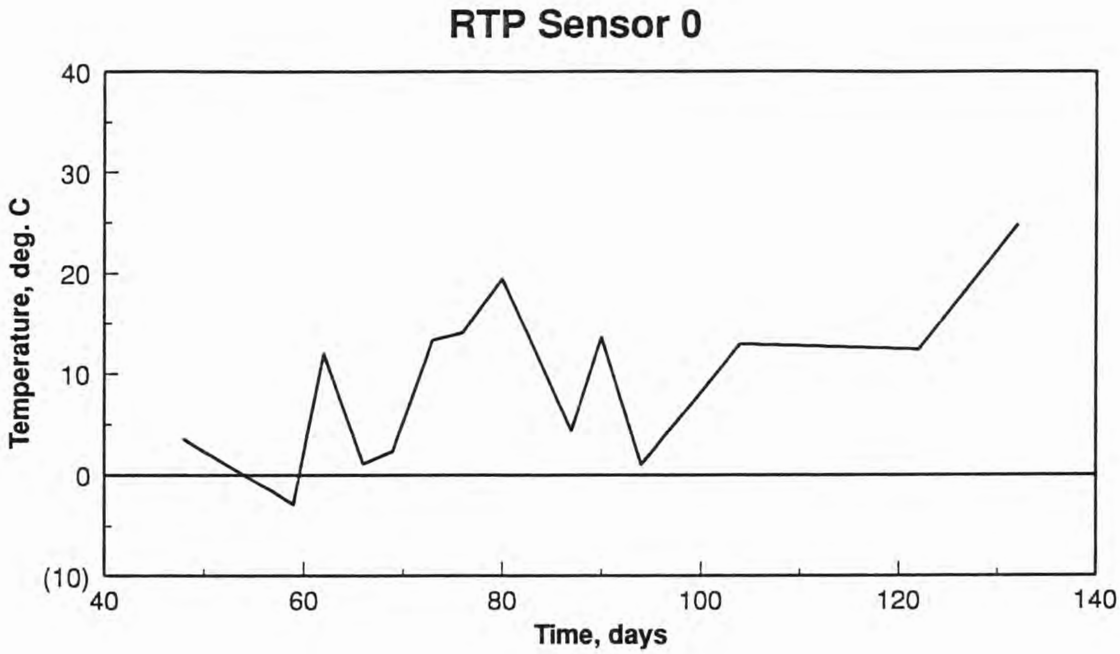

Figure D-18. RTP temperature for sensor 0 (air).

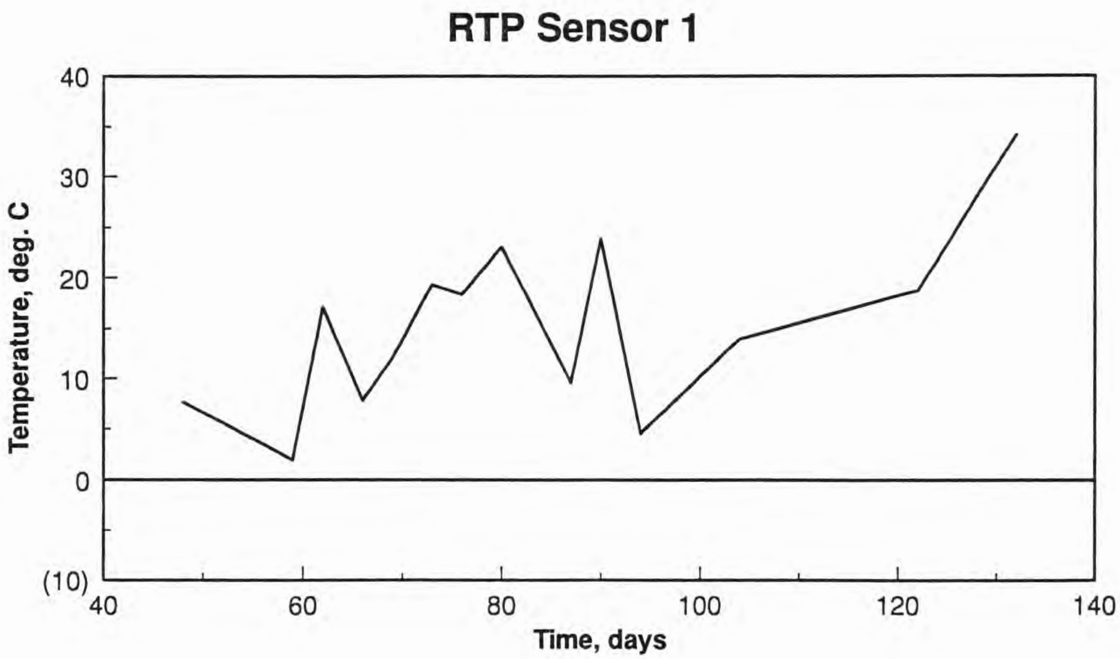

Figure D-19. RTP temperature for sensor 1 (pavement surface).

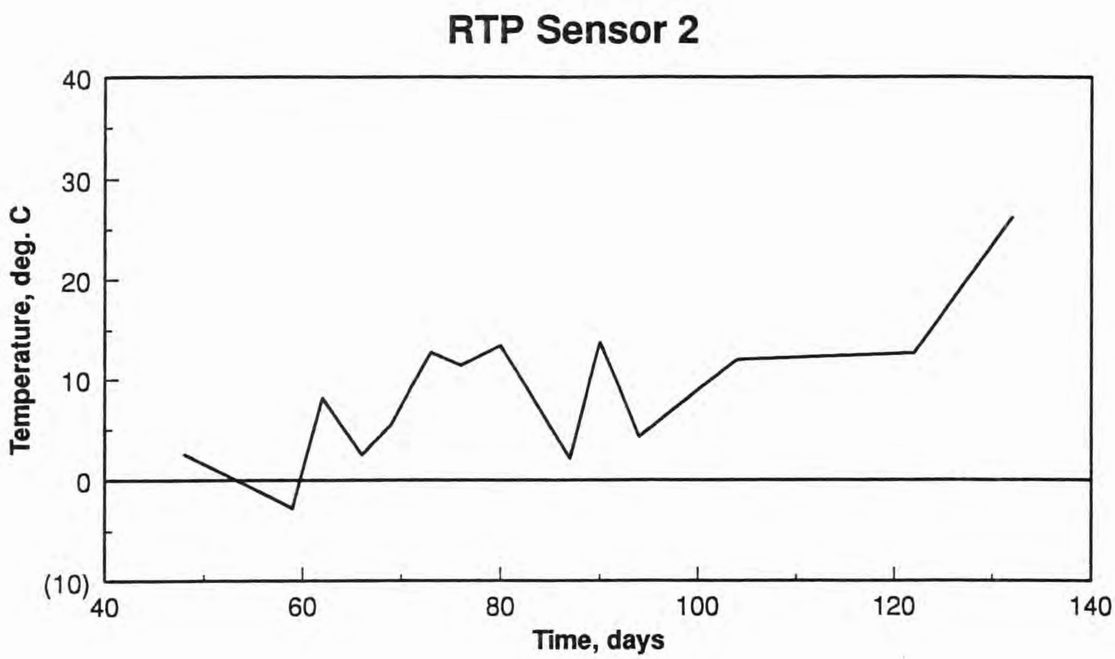

Figure D-20. RTP temperature for sensor 2 (76 mm).

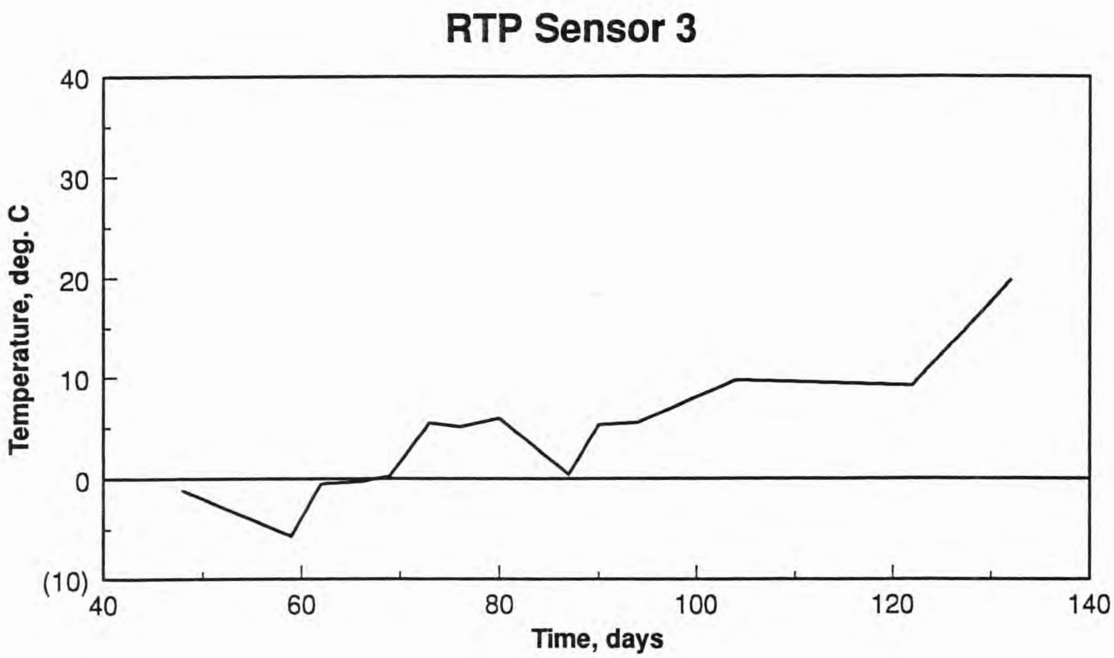

Figure D-19. RTP temperature for sensor 1 (pavement surface).

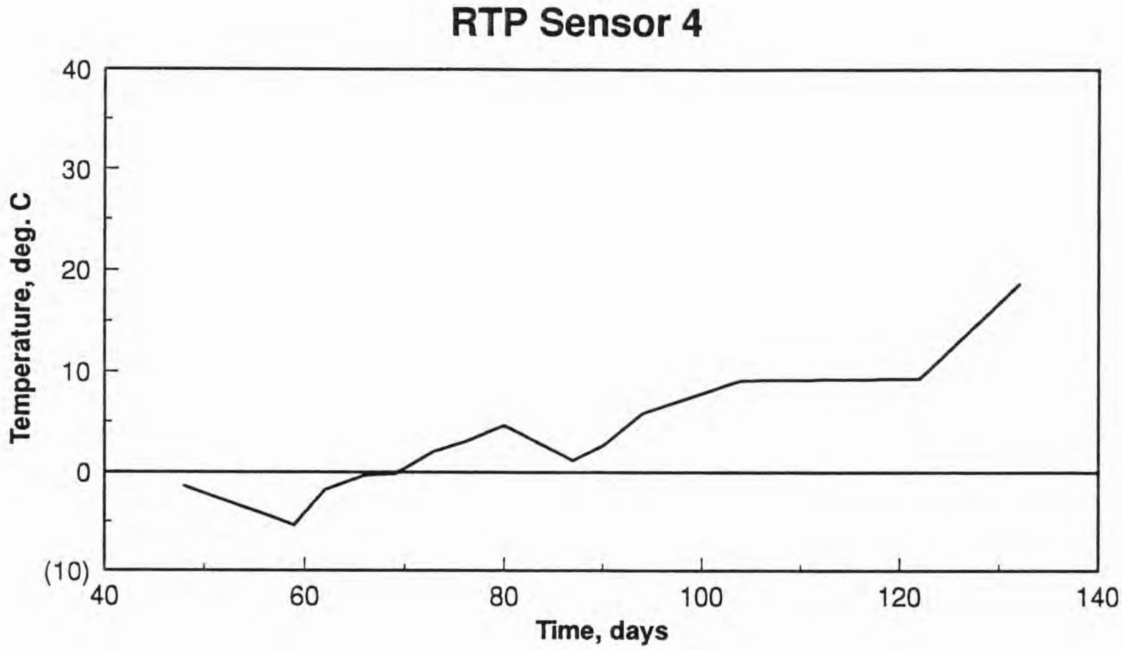

Figure D-22. RTP temperature for sensor 4 (381 mm).

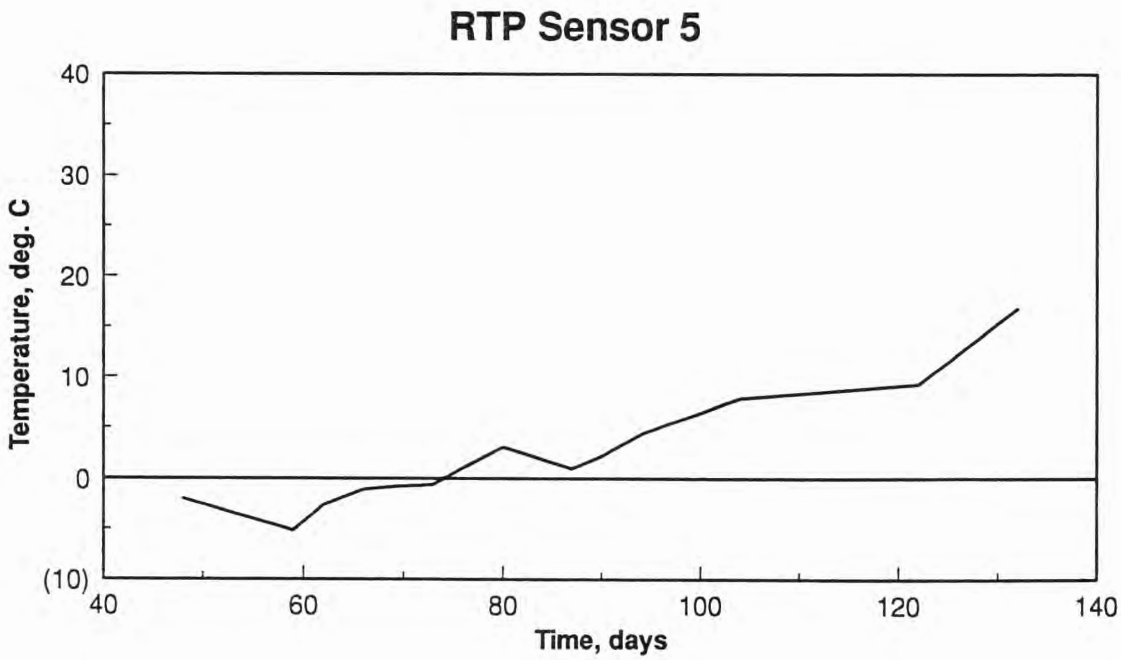

Figure D-23. RTP temperature for sensor 5 (533 mm).

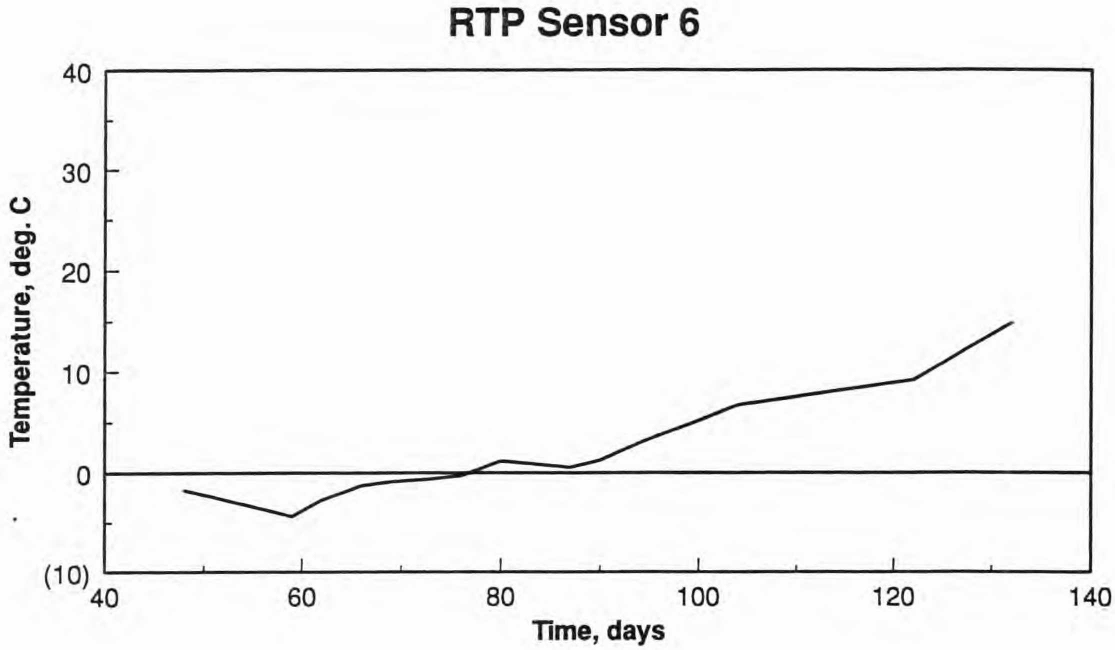

Figure D-24. RTP temperature for sensor 6 (686 mm).

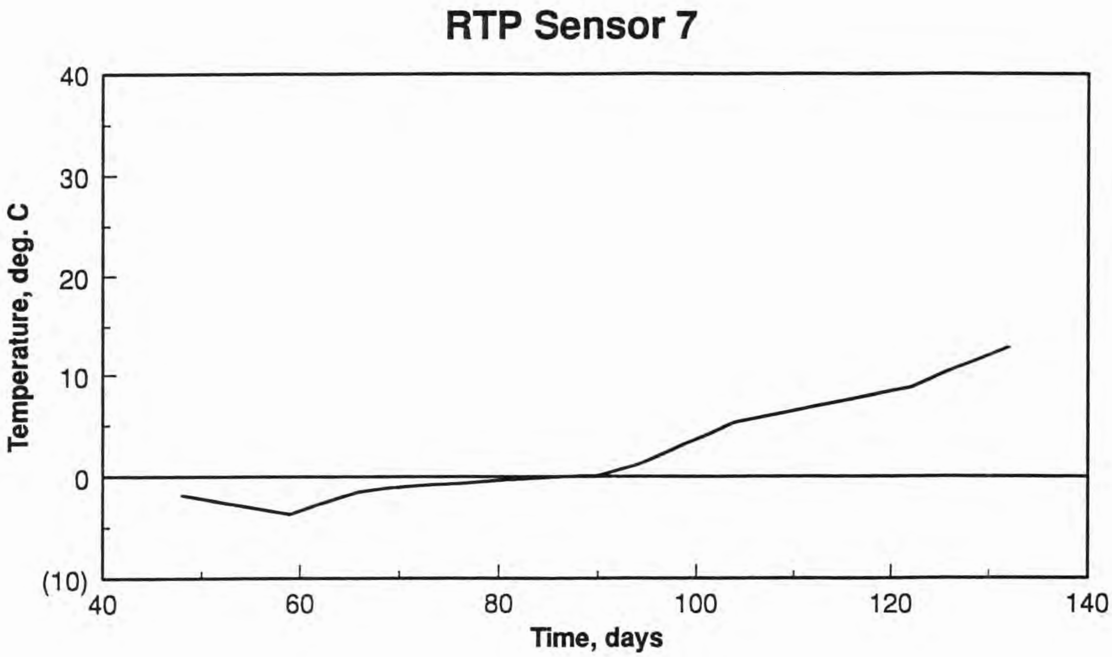

Figure D-25. RTP temperature for sensor 7 (838 mm).

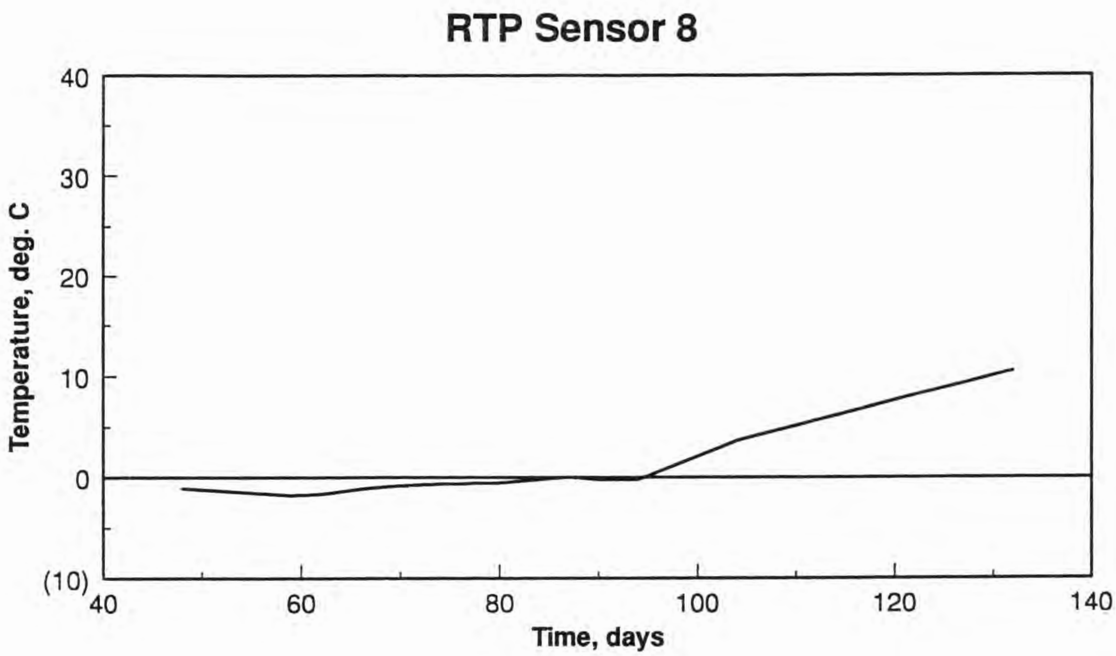

Figure D-26. RTP temperature for sensor 8 (1143 mm).

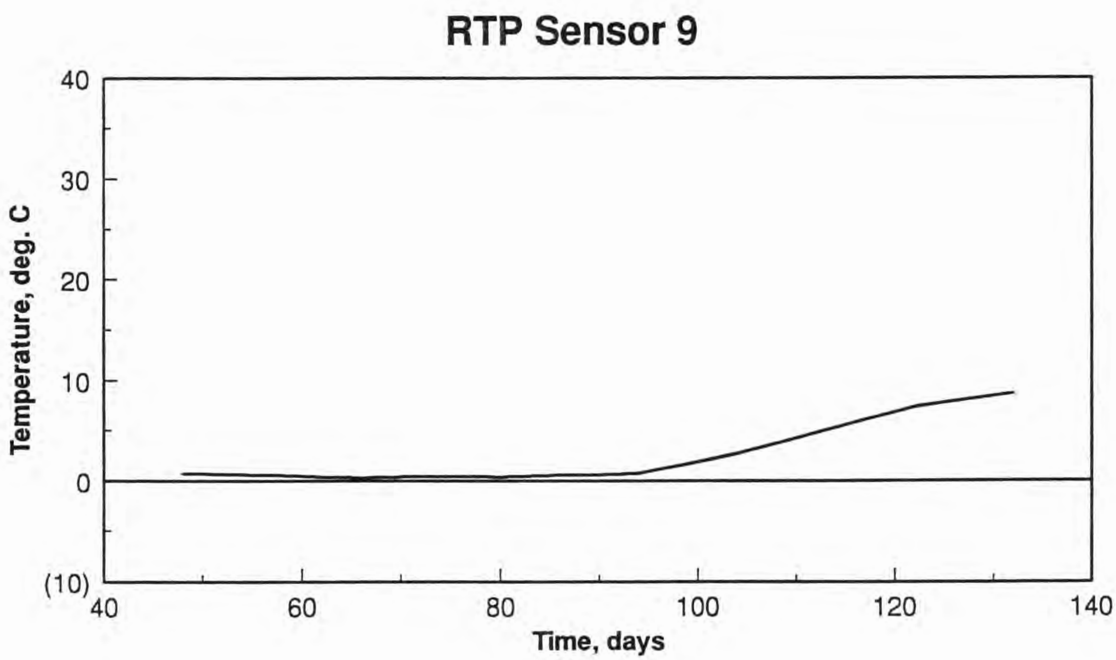

Figure D-27. RTP temperature for sensor 9 (1524 mm).