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16. Abstract
This summary report describes a survey of current practice as well as the guidelines developed for agencies which need load restrictions during spring thaw periods. The survey of current practice for locations in the U.S. and Canada shows that the average load reduction applied during spring thaw periods is about 44 percent. The analysis performed in the study tends to confirm that level of load restriction. Further, it was found for the assumed conditions that a minimum load restriction level (if any load reduction is needed) is about 20 percent. Load restrictions greater than 60 percent are generally not warranted for the range of cases studied. Air temperature based criteria (Thawing Index) were developed which can be used to estimate when to apply and remove load restrictions.

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A RESEARCH SUMMARY REPORT -- GUIDELINES FOR SPRING HIGHWAY USE RESTRICTIONS

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Mr. Charles Niessner of the Federal Highway Administration is gratefully acknowledged for his patience and guidance during the conduct of the study.

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STUDY SUMMARY

1. The use of load restrictions to reduce or preclude pavement damage during spring thaw periods is widely used in the U.S. and Europe. Load restrictions are primarily applied to low volume road networks.
2. Extensive examinations of load restriction related issues have been conducted in recent years in states such as Alaska, Minnesota and Washington.
3. A survey of current practice in the U.S. and Canada reveals the following:
    - (a) Load restrictions are applied mostly to pavements which have subgrades composed of moisture susceptible silts and clays.
    - (b) Load restrictions are applied mostly to aggregate and/or asphalt surfaced pavements. These pavements are usually older (about 20 years).
    - (c) The maximum legal loads are generally reduced about 40 to 50 percent for single axles and 30 to 50 percent for tandem axles.
    - (d) Judgment by field personnel is primarily used to assess where, when, how much and how long to apply load restrictions.
4. For determining where to apply load restrictions, the following factors are often considered:
    - (a) comparison of summer and spring pavement surface deflection data,
    - (b) surface thickness,
    - (c) moisture conditions,
    - (d) subgrade type, and
    - (e) local experience.

5. Use of temperature based criteria appear to be straightforward ways to determine when and for how long to apply load restrictions.

6. The average load restriction (reduction) applied by the agencies interviewed (based on seven individual state areas) is about 44 percent. Further, an analysis based on characterizing a pavement structure as a layered elastic system suggests that the <u>minimum</u> load restriction level (if any load reduction is needed) is about 20 percent. Load reductions greater than 60 percent are not justifiable for the range of cases studied. Current national practice and the analysis performed in this study suggest that for those pavements needing load restrictions, load reductions ranging from 40 to 50 percent should accommodate a wide range of pavement conditions.

7. The following recommendations are provided on where, how much, when and how long to apply load restrictions:

   (a) <u>Where to apply load restrictions</u>. If pavement surface deflections are available to an agency, spring thaw deflections greater than 45 to 50 percent of summer deflections suggest a need for load restriction. Further, considerations such as depth of freezing (generally areas with air Freezing Indices of 400°F-days or more), pavement surface thickness, moisture condition, type of subgrade, and local experience should be considered. Subgrades with Unified Soil Classifications of ML, MH, CL and CH will result in the largest pavement weakening.

   (b) <u>Amount of load reduction</u>. The <u>minimum</u> load reduction level should be 20 percent. Load reductions greater than 60 percent generally are not warranted based on potential pavement damage.

A load reduction range of 40 to 50 percent should accommodate a wide range of pavement conditions.

(c) When to apply load restrictions. Load restrictions should be applied after accumulating a Thawing Index (TI) of about 25°F-days (based on an air temperature datum of 29°F) and must be applied at a TI of about 50°F-days (again based on an air temperature datum of 29°F). Corresponding TI levels are less for thin pavements (e.g. two inches of asphalt concrete and six inches of aggregate base).

(d) When to remove load restrictions. Two approaches are recommended, both of which are based on air temperatures. The duration of the load restriction period can be directly estimated by the following relationship which is a function of Freezing Index (FI):

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

Further, the duration can be estimated by use of TI and the following relationship:

$$\text{TI} \simeq 0.3\,(\text{FI})$$

INTRODUCTION

RESEARCH OBJECTIVES

The objective of the study was to develop guidelines for local governments to use in establishing weight restrictions on county and city pavements in advance of spring breakup. To achieve this objective the following goals were accomplished as originally reported in Reference 1:

1. a literature search was conducted and the findings were summarized;
2. contacts with various highway agencies were established and in-person interviews were conducted;
3. the data from the literature search, interviews, and analysis were used to develop load restriction magnitudes and timing; and
4. guidelines were developed which can be used by local agencies to assess the need, magnitude, and time to apply and remove load restrictions.

THE PROBLEM

In areas of the United States which are subject to moderate or severe seasonal freezing, pavement structures can be susceptible to weakening during the thawing period (normally during the spring but this can occur any time during the winter months). To preclude accelerated pavement deterioration two possibilities exist:

1. apply load restrictions during the thawing (or critical) period;
2. design, construct, or otherwise modify the pavement structure to prevent or reduce the thaw weakening phenomenon.

Due to the budget constraints for many of the agencies faced with this problem, the only choice is Item (1) above.

A review of the literature reveals that few rational procedures have been used to determine the magnitude of the load restrictions, when to apply them and when to remove them. Therefore, a need exists to develop guidelines oriented toward local agencies to assist them in handling this serious problem.

Frost action in soils can cause several detrimental effects. The effect commonly addressed is that of frost heave. Less information is available on an equally serious problem, that of loss in structural capacity. This loss in strength occurs during the thaw period (usually late winter or early spring) when the moisture content increases in the pavement layers. This effect is similar to the effects due to the rise of the ground water table or infiltration of moisture through a porous pavement surfacing or shoulder. Whatever the cause, the presence of moisture levels above the amount assumed for pavement design will reduce the strength (or stiffness) of the various pavement layers. The same is true for most base and subbase materials.

The majority of currently used design methods is based on empirical studies of pavement behavior. The strength of the subgrade is usually estimated at the equilibrium conditions of moisture and density after soaking for several days (e.g., the CBR test). Empirical design methods based on the above classification procedures cannot account for adverse subgrade conditions caused by the thaw period or unusually high water tables, unless such conditions were generally prevalent when the original empirical studies, on which the methods are based, were conducted. This is because the methods are based on the average subgrade conditions exhibited by the subgrade throughout most of the pavement's life.

The damage to a pavement structure is directly related to the magnitude and frequency of the load applied. This was clearly demonstrated at the AASHO Road Test [2]. Subsequent studies of material behavior have demonstrated that the fatigue and permanent deformation characteristics of many materials depend on the magnitude and frequency of stress and strain levels induced [3]. A majority of the state DOTs use the AASHTO Interim Guide for Design of Pavement Structures [4] for designing their pavement thicknesses (or at least a portion of the AASHTO Guide). In designing a specific pavement using this method the traffic is converted to equivalent 18,000 lb. single axle loads for a given design period and for known or assumed material properties. Any lowering of material strength or increase in the number of equivalent 18,000 lb. single axle loads reduces the life of the pavement. Thus, the method of reducing loads when the strength of the pavement materials is reduced is a reasonable way to maintain the design life and general serviceability of the pavement. Hence, the need for load restrictions during critical pavement periods.

Local and state highway agencies have a wide variety of practices for imposing weight restrictions in advance of the "spring thaw." Truck weight enforcement programs adopted by the various agencies vary widely in terms of the weight limits applied, the forms the restrictions take and their implementation. The decision of closing or opening a facility is largely determined by experience and sometimes political pressure. There is very little definitive data to help in decision making, especially for secondary and lower category highways, even though these types of highways form the bulk of county and city highway systems. Local governments generally have low to modest maintenance budgets and normally cannot afford to overlay the pavements after damage during the spring thaw. Therefore, a need exists for criteria to use for determining truck weight restrictions during the spring thaw.

The problem of pavement related frost effects can be separated and summarized into two separate but related processes:

1. frost heaving resulting from the accumulation of ice in the pavement layers (primarily base and subgrade) during the freezing period, and

2. weakening of the pavement structure when thawing temperatures occur (weakening is mainly due to excessive moisture from melting ice and/or surface infiltration).

The conditions necessary for frost heave to occur include

1. subfreezing temperatures,
2. water, and
3. frost susceptible soil (mainly silts and silty soils).

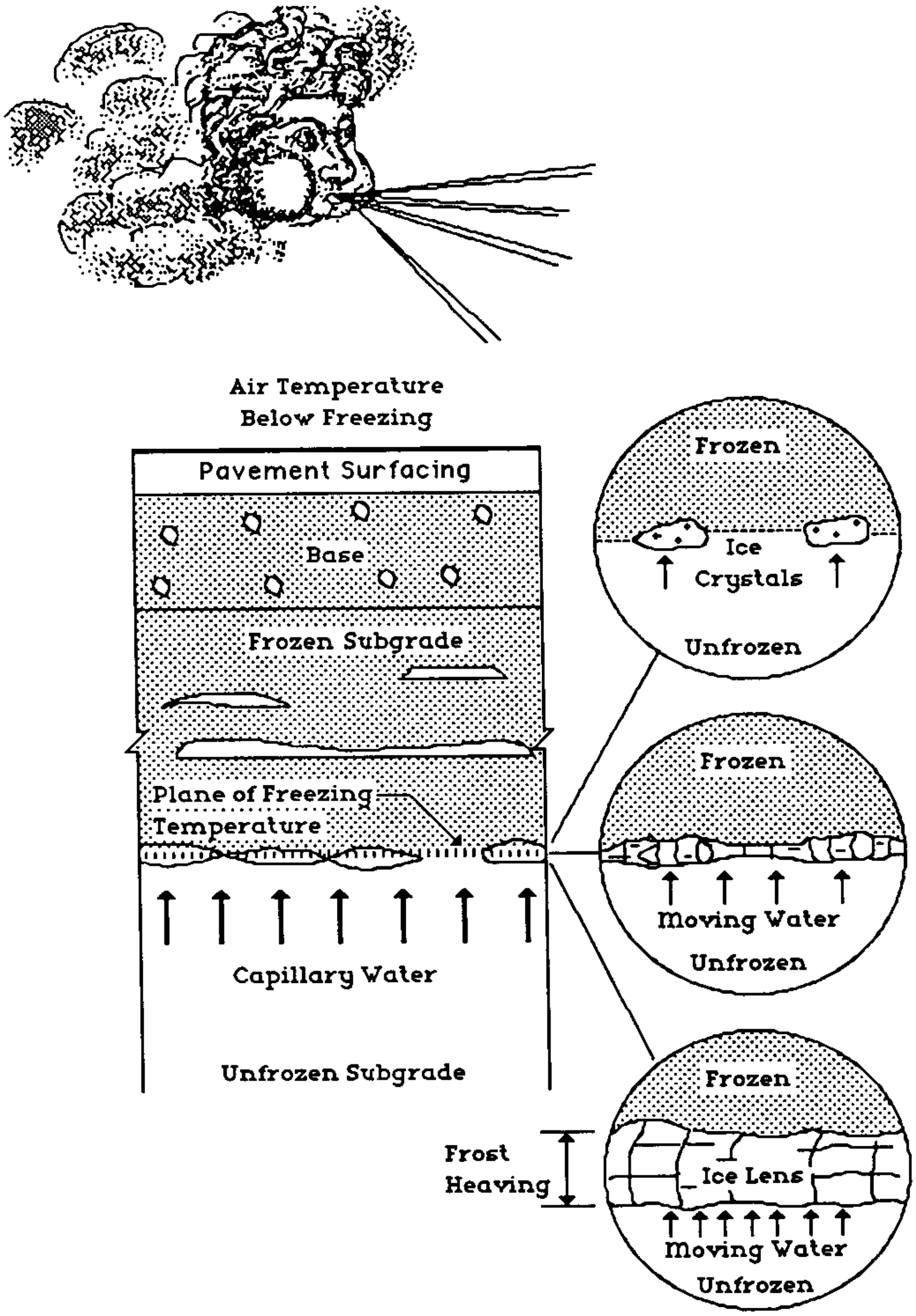
Remove any of the above conditions and pavement related frost effects will be eliminated or at least minimized.

Heaving

Frost heaving of soil is caused by crystallization of ice within the larger soil voids and a subsequent extension to form continuous ice lenses, layers, veins, or other ice masses. An ice lens grows in thickness in the direction of heat transfer until the water supply is depleted or until freezing conditions no longer support further ice crystallization. Ice segregation occurs primarily in soils containing fine particles (i.e., "a frost susceptible soil"). Clean sands and gravels are non-frost susceptible. Frost susceptible soils are mainly silts and clays. Figure 1 illustrates the formation of ice lenses in a frost susceptible soil.

In general, it is difficult to totally eliminate heave; thus, the objective is to reduce its magnitude and make it more uniform. An occasional problem for many pavement sections is differential heave, which is likely to occur at locations such as

1. abrupt transitions from cuts to fills with ground water close to the surface,
2. where subgrades change from clean sands and/or gravels to silty frost susceptible materials,
3. where excavation exposes water-bearing strata, and



Water in large void space freezes into ice crystals along plane of freezing temperature.

Ice crystals attract water from adjacent voids, which freezes on contact and forms larger crystals.

Crystals continue to grow and join, forming ice lens. Vertical pressure exerted by ice lens heaves surface.

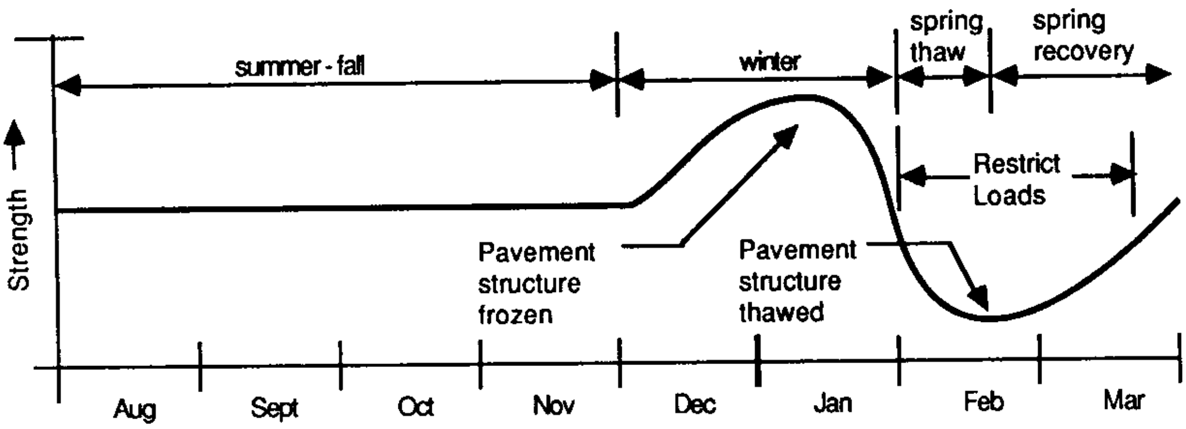
Figure 1. Formation of Ice Lenses in a Pavement Structure.

4. culverts, which frequently result in abrupt differential heaving due to different backfill material or compaction and the fact that open buried pipes change the thermal conditions (i.e., remove heat from the surrounding soils resulting in more frozen soil -- analogous to an air conditioning duct).

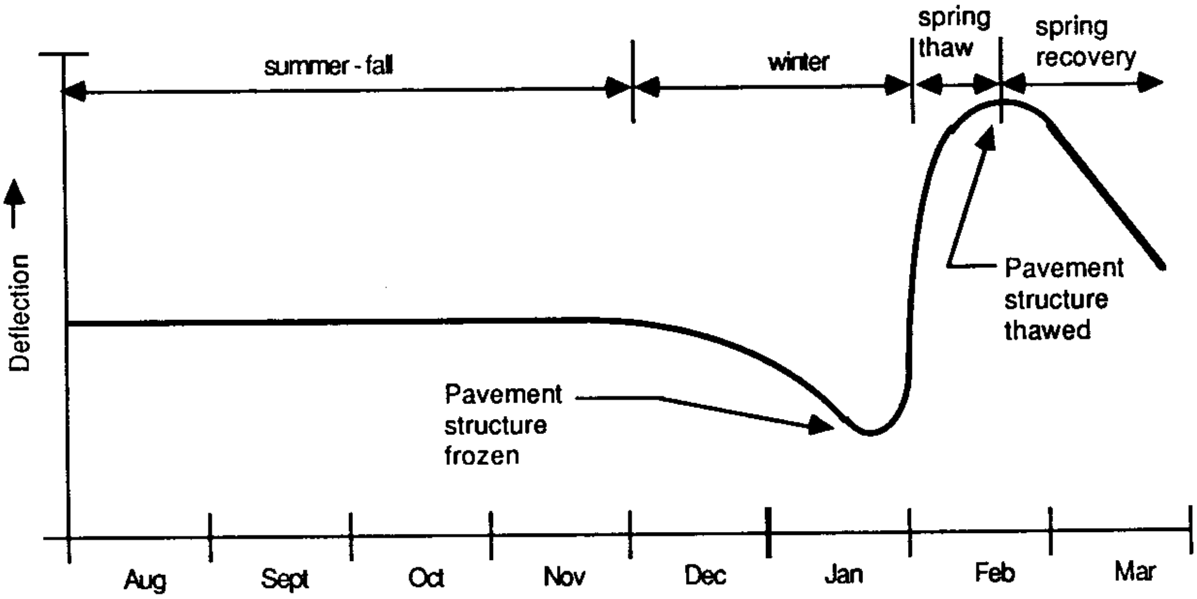
Thawing

Pavement thawing can proceed from the top downward, from the bottom upward, or both. How this occurs depends mainly on the pavement surface temperature. During a sudden spring thaw, melting will occur almost entirely from the surface downward. This type of thawing leads to extremely poor drainage conditions. The frozen soil beneath the thawed layer can trap the water released by the melting ice lenses so that lateral and surface drainage are the only paths the water can take.

Loss of pavement strength (or load capacity) during the spring thaw period (or other thawing periods occurring during the winter months) is one of the most serious problems associated with frost action. The usual pattern of pavement seasonal strength variation includes a significant increase from "normal" summer-fall conditions during the winter months when the pavement structure (including at least part of the subgrade) is frozen. Thawing can produce a rapid decrease in pavement strength below the summer-fall conditions followed by a gradual recovery over a period of weeks or months. Figure 2 illustrates this process of strength variation by use of pavement surface deflections (higher deflections represent a weaker pavement structure).



(a) Pavement Strength



(b) Pavement Deflections

Figure 2. Pavement Seasonal Changes.

SURVEY OF CURRENT PRACTICE

INTRODUCTION

This section summarizes the results of contacts and visits with selected agencies throughout the U.S. and Canada. The purpose of the contacts was to assess the following:

1. types of pavement failures associated with spring thaw,
2. types of facilities requiring weight restriction during the spring thaw period,
3. the intended purpose of weight restriction and how such policies were developed and implemented,
4. cost benefit analysis of weight limit enforcement on a specific facility (if available data existed), and
5. legal aspects of truck load restrictions.

To collect the needed information, three survey techniques were used which included an initial information request mailed to all state DOTs and most Canadian provinces (which generally experience cold winter weather), interviews with selected agencies and detailed follow-up requests to additional selected agencies.

RESULTS OF INTERVIEWS AND FOLLOW-UP REQUESTS

Personal interviews were conducted in five states with a total of twelve agencies. Follow-up questionnaires were obtained from six states and one Canadian province. Each agency was asked questions dealing with the following:

1. development of load restrictions,
2. types of highways receiving load restrictions,
3. design information for roads receiving load restrictions,

4. criteria for imposing load restrictions, and
5. enforcement methods.

Responses to each of the above topic areas are summarized below.

Development of Guidelines

Specific questions dealing with the types of pavement failure associated with spring thaw, the extent of the problems, and the procedures used for determining locations for load restrictions were asked of all agencies (state, county, and city). The results indicate the following:

1. The predominant types of pavement failure included alligator cracking, rutting, frost boils, and potholes.
2. The extent of the problem varied from very little to agency-wide, and predominantly on low volume roads.
3. The locations for load restrictions were based on past experience and/or surface deflection. For some of the smaller agencies, the restrictions were placed on all roads.

Highways Receiving Load Restrictions

This topic was concerned with defining the types of highways receiving load restrictions. Specifically, the following questions were asked:

1. What highway functional classes receive load restrictions?
2. What are typical values for average daily traffic (ADT) and percent of trucks for these highways?
3. What soil types are found beneath these highways?
4. What surface types receive load restrictions?
5. What are typical cross sections for the roadways receiving load restrictions?

The responses to these questions generally indicate the following:

1. Load restrictions by state agencies were applied to both primary and secondary roads but mostly secondary. Few states applied them to Interstate facilities. Local agencies generally applied load restrictions to all types of facilities.
2. Of those states responding, load restrictions were generally applied to roads with ADT less than 2500 and 10 percent trucks or less. Local city and county agencies applied restrictions to roads with ADTs up to 30,000 and up to 10 percent trucks.
3. Primarily, load restrictions were applied to pavements which had moisture susceptible silt or clay subgrades. If the agencies had granular subgrades, load restrictions were not usually required.
4. Load restrictions (if used) were normally applied to aggregate and/or asphalt surfaced roads. Most portland cement concrete pavements reportedly had adequate structure to withstand the critical thaw period.
5. The pavement cross sections to which load restrictions were applied generally ranged as follows:

	Range	Normal
Asphalt surface, inches	1.5 - 5	2 - 4
Aggregate base, inches	4 - 18	6 - 12

Thicker pavements apparently have sufficient strength to overcome the thaw weakening period.

Design Information for Roads Receiving Load Restrictions

This topic dealt with design questions such as:

1. Is frost protection considered in thickness design?
2. Are load restrictions used in lieu of full frost protection?

3. What is the age of pavements receiving load restrictions?
4. What are the typical drainage conditions of pavements receiving load restrictions?

Responses to these questions indicate

1. Some of the state agencies surveyed designed pavements for partial frost protection while others did not consider frost protection in design at all. Most local agencies did not consider frost protection in their design procedure.
2. Several of the agencies interviewed used load restrictions in lieu of designing for full frost protection.
3. A variety of thickness design procedures were used to determine layer thickness. The most common was the AASHTO method. Others included the Hveem method, experience and/or precedent.
4. The age of pavements receiving load restrictions tended to be 10 to 20 years or older. In some cases they tended to be farm-to-market kinds of roads constructed just after World War II.
5. Drainage conditions for pavements receiving load restrictions varied from poor to good. There appeared to be little relation between surface drainage and the need for load restrictions.

Load Restriction Criteria

This question dealt with

1. the current load limits (normal vs. spring),
2. methods used to establish load limits,
3. the basis for initiating and/or removing load restrictions, and
4. whether deflection measuring equipment have been used to establish load restrictions.

The significant findings resulting from this question include

1. For most agencies normal load limits were 18,000 to 20,000 lbs on a single axle and 34,000 lbs on tandem axles.
2. Spring load restrictions generally ranged from 10,000 to 14,000 lbs for single axles and 18,000 to 28,000 lbs for tandem axles.
3. Percentage reductions were 30 to 50 percent for single axles and 18 to 47 percent for tandem axles.
4. Most load limits had been established from experience. A few agencies such as the Alaska, Minnesota, and Washington DOTs had conducted extensive studies.
5. The basis for starting a load restriction varied from experience (presence of water coming through cracks/joints or pumping) to the use of deflection measurements. By far the majority of the agencies relied on the judgment (or experience) of field personnel.
6. Load restrictions were removed based on the judgment of field personnel, deflection measurements, or when sufficient political pressure mounted. Most agencies, however, relied on judgment or past experience.
7. Only three of the agencies interviewed used deflection measurements to establish load limits.

Enforcement Methods

The next topic dealt with enforcement methods for spring load restrictions. Specifically, it requested information to questions such as

1. how load restrictions are enforced,
2. how vehicle operators are notified,
3. are overweight permits available,

4. what enforcement methods are used, and
5. are fines levied, and if so, what are they?

In general, the following impressions were noted:

1. Both fixed and portable weigh scales were used. Some agencies relied only on patrols.
2. Methods used to notify vehicle operators of the load restrictions included
    (a) newspapers and news releases,
    (b) road signs,
    (c) detour and embargo maps,
    (d) radio and television.
3. Most of the agencies used overweight permits. Some agencies had exceptions to the load limits (e.g., school buses and/or emergency situations).
4. Enforcement methods used included patrol (by police) or weighing trucks (all or a selective sample).
5. Fines were levied by almost all agencies. The fine was normally assessed as a cost per 1000 lb.

Legal Aspects

The last topic dealt with legal aspects of load restrictions. Specifically, the requested information related to

1. the availability of local regulations addressing load restrictions,
2. enforcement problems with the use of load restrictions, and
3. legal problems associated with load restrictions.

The significant findings are discussed below:

1. All agencies had regulations allowing them to initiate and enforce load restrictions.

2. The major problems with enforcement included
   (a) lack of personnel to adequately enforce the load restriction,
   (b) political pressure to allow truck operations, and
   (c) evasive tactics of truckers.
3. Most agencies had not experienced legal action as a result of enforcing load limits.

EVALUATION OF SURVEY RESULTS

The survey of agencies with load restrictions provided significant information in several areas including

1. types of load restrictions currently used,
2. basis for load limits,
3. criteria used to initiate and remove load restrictions,
4. unique capabilities of local agencies, and
5. requirements and problems associated with enforcement.

Each of these issues are discussed in the following sections.

Types of Load Restrictions

Most agencies interviewed restricted loads on a per axle basis. Limits differed between single and tandem axles, but not with tire size (conventional vs. flotational). The load reductions were a maximum of 60 percent for single axles and 60 percent for tandem axles.

Basis for Load Limits

Current limits were established primarily on the basis of prior experience. Only a few state DOTs reported that they used research studies to establish or verify their load limits. There appears to be a definite need to develop a more rational approach for establishing load limits.

Criteria Used to Initiate and Remove Load Limits

Most agencies surveyed indicated that they initiated limits based on judgment. This could range from evidence of water at the surface (indicating a saturated base) or signs of cracking (which is too late). Other agencies simply relied on an established date. Few agencies used deflection or weather data to establish a starting date for load limits. Clearly, there is a need for an improved method of establishing this date.

Removal of load limits was also generally based on experience. Use of deflection measurements could greatly aid in this process and should be encouraged.

Capabilities of Local Agencies to Measure Deflections

Most local agencies did not have the equipment or personnel to measure surface deflections. Unless this changes, it would be impractical to recommend use of deflections to establish the initiation and removal of the load limits.

Personnel used to establish these critical periods were often from the maintenance department and would have to be trained in the use and interpretation of deflection data.

Requirements and Problems with Enforcement

Enforcement was usually accomplished by the county sheriff or city police. Special training was not usually required to enforce load limits.

The major problem to be overcome with enforcement is to develop a proper data base to resist political pressures to waive the limits. If the amount of damage done to the roads during the critical spring period and the associated cost of early wear-out could be shown, the political problems of load limits could be minimized. The development of a visual aids package to assist local officials in this effort would be of great value. Such a package has been developed as part of this study.

LOAD RESTRICTION GUIDELINES

INTRODUCTION

Based on the literature review, survey of current practice, and analysis conducted in the study, the following guidelines will be presented in this section:

1. where to apply load restrictions,
2. the magnitude of the load restrictions, and
3. when to apply and remove load restrictions.

The guidelines are general in scope and not intended to be "absolute," since the nature of the problem is site specific.

GUIDELINES FOR WHERE TO APPLY LOAD RESTRICTIONS

An examination of the study analyses shows that pavement sections which have surface deflections 45 to 50 percent higher during the spring thaw than summer values are candidates for load restriction. Clearly, this is not an absolute criterion for selecting pavement sections to receive load restrictions. Site specific conditions could significantly alter the deflection increase threshold. For example, a relatively "thin" or "weak" pavement section may have relatively high summer deflections. Thus spring thaw deflections may need to increase much less than the threshold level of 45 to 50 percent to necessitate load reductions. Surface deflection increases of less than 45 percent result in load reductions of about 25 to 30 percent or less.

Other criteria which should be considered in selecting pavements for load restrictions include

1. surface thickness,
2. pavements on fine-grained subgrades, and
3. local experience relating to observed moisture and pavement distress.

If the surface thickness of a pavement is about two inches or less and in an area where the FI is greater than 400°F-days (i.e., a modest depth of freezing), then this suggests that load restrictions should be considered. Figure 3 is provided to illustrate how the depth of freeze increases with increasing FI for a relatively thin pavement structure. In general, the depth of freeze increases as a function of the FI.

Pavements on fine-grained subgrades such as silts and clays (Unified Soil classifications ML, MH, CL and CH) are candidates for load restrictions. Again, the depth of ground freezing is important.

The observed site specific drainage is significant in assessing the need for load restrictions. Items such as poor drainage from side ditches, available ground water, high winter precipitation, and snow removal policies should be considered. For example, pavement in cold but dry locations probably will not need any type of restriction.

Another criterion to use for selecting load restriction locations involves observation of pavement distress such as fatigue (alligator) cracking and rutting. If these distress types primarily occur during the spring thaw, load restrictions are needed if options such as strengthening the overall pavement structure are not possible (or appropriate).

Overall, local experience relating to the conditions associated with the performance an individual agency's road network is important. Clearly, various nondestructive pavement response measures such as surface deflection can help define the potential pavement weakening during the thaw period; however, the experience of agency personnel should be used to the fullest extent.

GUIDELINES FOR LOAD RESTRICTION MAGNITUDE

The load reductions used by the agencies interviewed ranged from about 20 to 60 percent. The average load reduction for seven locations (grouped state areas) was approximately 44 percent (standard deviation of about 8 percent). This suggests that

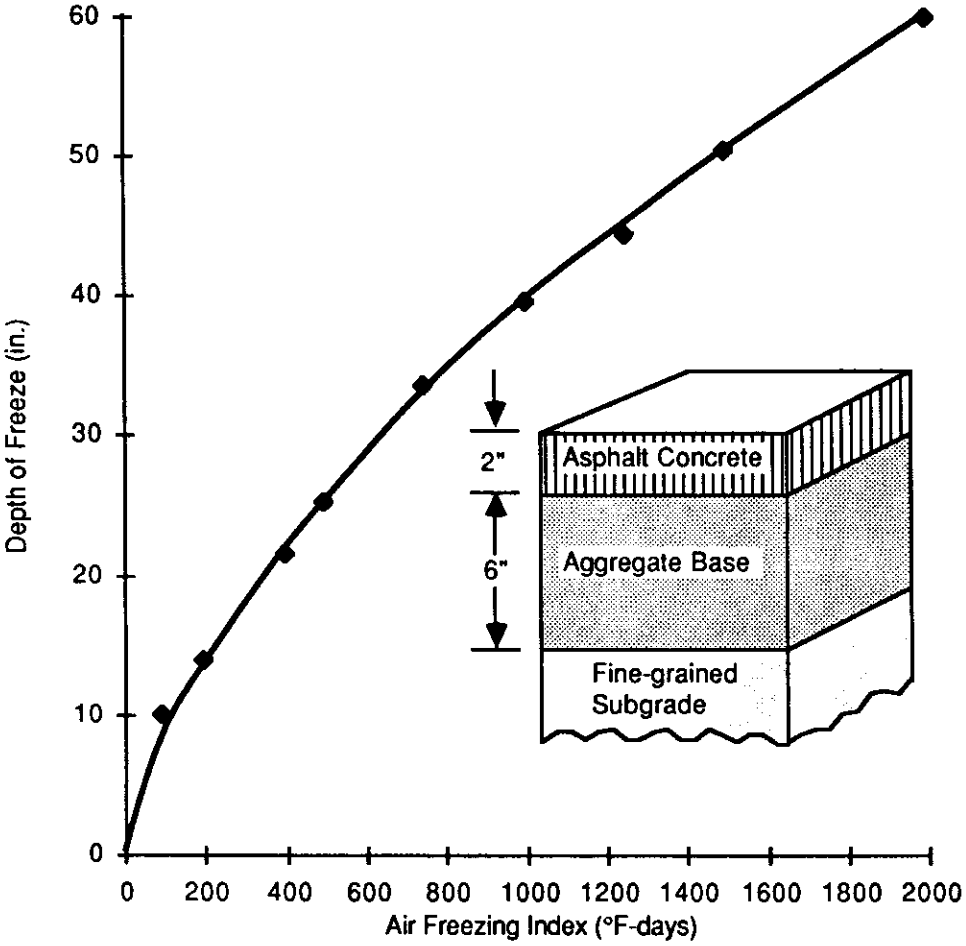


Figure 3. Depth of Freeze vs. Air Freezing Index for a Thin Pavement Structure on a Fine-grained Subgrade.

reducing the load on individual axles (or tires) by about 40 to 50 percent reduces the associated pavement response to levels that preclude or reduce the resulting pavement distress to acceptable levels.

The study analysis results show that as the load reduction percentage is increased the associated pavement life is increased (as one would expect). The following potential pavement life increases result as a function of load reduction (starting with a load reduction of 20 percent):

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

Thus, if the 44 percent load reduction level is used (average of the seven grouped state areas previously noted), this results in a potential improvement in pavement life of about 90 percent. The basic (and very conservative) assumption is that all the pavement damage (hence load reduction benefit) occurs during the thaw weakened period. For some pavements, this may actually occur but generally is not the case for most.

Clearly, the needed level of load reduction is not as simple as the preceding numbers suggest. For example, many thin or generally weak pavement structures need high levels of load reduction during the spring thaw period to prevent significant pavement damage (i.e., small or even modest levels of load reduction will not preclude significant pavement damage).

If load restrictions are to be used, it appears that a minimum load reduction of 20 percent is needed. Load reductions greater than 60 percent appear to be excessive (given the assumptions used in the analysis). Further, general national practice is to use load reductions ranging from 40 to 50 percent. The analysis performed in this study tends to confirm this range of load reduction.

GUIDELINES FOR WHEN TO APPLY LOAD RESTRICTIONS

A primary activity of the study was to develop guidelines on when to apply and remove load restrictions (assuming that load restrictions are needed). These guidelines are based on easy to obtain air temperature data from local weather stations or site specific high-low recording thermometers. As pointed out earlier, most agencies do not have the capability to use deflection measuring equipment during the start of the critical period to assess when to apply load restrictions.

Thermal analyses performed in the study resulted in two possible times for applying load restrictions. Both were based on a Thawing Index (TI) calculated by use of a 29°F datum (not the normally used 32°F) and are a function of total pavement thickness.

Pavement Structure	BST/Asphalt Concrete Thickness (inches)	Base Course Thickness (inches)	Thawing Index (°F-days) Should Level	Thawing Index (°F-days) Must Level
■ Thin	2 inches or less	6 inches or less	10	40
■ Thick	Greater than 2 inches	Greater than 6 inches	25	50

Should Level

The "should" load restriction application time occurs after accumulating a TI = 10°F-days for thin pavements and 25°F-days for thick pavements following the start of the thawing period. This is used to estimate thaw to the bottom of the base course.

Must Level

The "must" load restriction application time occurs after accumulating a TI = 40°F-days for thin pavements and 50°F-days for thick pavements following the start of the thawing period. This is used to estimate thaw to approximately four inches below the bottom of the base course.

Discussion

The above criteria are best suited for use during the "normal" start of the spring thaw period (generally late February to April). A different condition exists for mid-winter thawing cases. First, the sun angle is lower for a mid-winter thaw than used in the analysis, suggesting a higher base temperature (such as 31°F) for calculating TI. Second, for most areas, the percent cloud cover is higher during mid-winter.

The temperature based TI criteria are best applied to fine-grained soils. The analysis performed in the study showed more consistent results for this soil type than coarse-grained.

GUIDELINES FOR DURATION OF LOAD RESTRICTIONS

Based on the literature review, interviews, and the structural and thermal analyses, the duration of the load restriction period should approximate the time required to achieve complete thawing.

Two different approaches were developed in the study to predict the duration of load restrictions, both of which were based on regression equations with the Freezing Index (FI) as the independent variable.

The first equation was developed for fine-grained subgrade cases (which tend to be the most critical) and can be used to estimate the load restriction duration as a function of FI. This equation is

$$\text{Duration (days)} = 22.62 + 0.011\,(\text{FI})$$

where

Duration = duration for complete thaw based on a start date when the air temperature is 29°F or above (days),

FI = freezing index (°F-days)

An approximate solution to the above equation is

$$\text{Duration} \simeq 25 + 0.01\,(\text{FI})$$

The two above equations are based on fine-grained soils at a moisture content of 15 percent and a range of FI from 400 to 2000 °F-days. Predicted durations outside of this data range may result in poor estimates. Further, for locations with relatively low FI (400 to 500 °F-days), the predicted durations are probably conservative (i.e., longer than actual).

Another approach to use in estimating the time required for complete thawing to occur (hence duration of load restrictions) is based on a TI criterion. The TI (again based on a 29°F air temperature datum) is estimated from a regression equation which has the independent variable of FI. The resulting equations have higher correlation coefficients than those for estimating duration as a function of FI. The equation selected for potential use (based on fine-grain cases and 15 percent moisture content) is

$$\text{TI} = 4.154 + 0.259\,(\text{FI})$$

An approximate solution is

$$\text{TI} \simeq 0.3\,(\text{FI})$$

An example of how to calculate FI and TI for a "typical" pavement and location is shown in Appendix A.

The above criteria for duration of load restrictions results in a restriction period of slightly less than four weeks and 6.5 weeks for areas with FIs of 400 and 2,000°F-days, respectively.

REFERENCES

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3. Monismith, C.L. and D.B. McLean, "Technology of Thick Lift Construction - Structural Design Considerations," Proceedings, Association of Asphalt Paving Technologists, Cleveland, Ohio, 1972.

4. ________________, "AASHTO Interim Guide for Design of Pavement Structures - 1972," American Association of State Highway and Transportation Officials, Washington, D.C., 1981.

APPENDIX A
EXAMPLE OF DATA COLLECTION AND ESTIMATION OF START AND DURATION FOR IMPOSING LOAD RESTRICTIONS

Location: Mansfield, Washington (central Washington state)

Pavement section typically restricted during spring thawing

2 inches bituminous surfacing

6 inches granular base

Silty subgrade

High and low daily temperatures are collected through the freezing and thawing period to calculate freezing index, based on 32°, and thawing index based on 29°F (Figure A-1).

CALCULATING THE FREEZING INDEX

The freezing index is a measure of the magnitude and duration of the temperature differential during the freezing period. The freezing index is calculated using the following equation:

$$FI = \Sigma(32 - \overline{T})$$

where:

$\overline{T}$ = $1/2\,(T_H + T_L)$ in °F,

T_H = maximum daily temperature (°F), and

T_L = minimum daily temperature (°F).

The temperature data collected for Mansfield to identify the freezing period and the freezing index are shown in Figure A-1.

STEPS:

1. When $\overline{T}$ becomes less than or equal to 32°F for several days, the freezing season begins. The freezing season for 1985 begins on November 9.

2. The average daily temperature is equal to

   $\overline{T}$ = 1/2(column 3 + column 4)

   On November 13, for example:

   $\overline{T} = 1/2(35 + 7) = \underline{21°F}$

3. The freezing degree-days per day (column 6) is equal to

   Daily FI = 32 - $\bar{T}$ (from column 5)

   For November 13, for example:

   Daily FI = (32 - 21) = <u>11°F-days</u>

4. The freezing index is the accumulation of daily freezing degree days from the start of freezing

   FI = Σ (32 - $\bar{T}$) from the start of freezing

   For November 13, for example:

   FI = (3 + 7 + 9 + 8 +11) = 38°F-days

5. The end of the freezing season is near for pavements when the average daily air temperatures (column 5) in spring go above 29°F for several days causing thawing of the pavement to begin. The thawing season for Mansfield during 1986 begins on February 24 (refer to Figure A-1). The freezing index for the entire freezing season from November 9 to February 23 is

   FI = Σ (32 - $\bar{T}$)

   FI = (3 + 7 + 9 + 8 + ... + 24 (February 21) + 18 (February 22) + 10 (February 23))

   FI = <u>1375°F-days</u>

   A review of the temperature data in Figure A-1 shows that four thawing periods occurred during January and February. Three of these periods were followed by freezing periods thus canceling any cumulative thawing effects (approximately) and reducing the cumulative freezing effects as well.

ESTIMATING THE TIME TO PLACE LOAD RESTRICTIONS

The pavement consists of 2 inches of asphalt concrete on 6 inches of aggregate base. This would be classified as a <u>thin</u> pavement. The "should" level for placing load restrictions for thin pavements is

TI_{29} should restrict = 10°F-days

The thawing season starts on February 24.

TI_{29} = 9 (February 24) + 14 (February 25)

= 23°F-days

The load restrictions <u>should</u> be placed by February 26.

TI must restrict = 40°F-days

The "must" level for restricting a thin pavement is

$$TI_{29} = 9 \text{ (February 24)} + 14 \text{ (February 25)} + 11 \text{ (February 26)} + 7 \text{ (February 27)}$$

$$= 41^\circ\text{F-days}$$

The load restrictions must be placed by February 28.

The earlier thaw period (January 31 to February 7) could have been used to start load restrictions. However, this would have been somewhat premature being as this period was followed by more freezing weather. As with any criterion, judgment must be used. For this location (Mansfield, Washington), the normal thaw period starts during the last week of February or the first week of March.

ESTIMATING THE DURATION FOR LOAD RESTRICTIONS

The duration may be estimated in days or in thawing degree-days. It is preferable to estimate the duration of the thawing period using the thawing index based on 29°F.

To estimate the number of thawing degree days required for the restricted period the exact equation is:

$$TI_{29} = 4.154 + 0.259 \text{ (FI)}$$

$$TI_{29} = 4.154 + 0.259 \text{ (1375}^\circ\text{F-days)}$$

$$= 360^\circ\text{F-days}$$

On March 28, the TI_{29} (column 9) is 347°F-days

On March 29, the TI_{29} is 368°F-days

Therefore, the load restrictions should be removed by March 30.

The simpler approximate equation for the thawing degree-days required for the restricted period which may be used in place of the above equation is:

$$TI_{29} = 0.3 \text{ (FI)}$$

$$TI_{29} = 0.3 \text{ (1375}^\circ\text{F-days)}$$

$$= 412^\circ\text{F-days}$$

On March 31, the TI_{29} is equal to 412°F-days. Therefore, the load restrictions should be removed by April 1. Alternatively, the duration of the thawing period may be estimated in days.

The exact equation for estimating duration in days is

$$D = 22.62 + 0.011\,(FI)$$

For this freezing season in Mansfield,

$$FI = 1375^{\circ}\text{F-days}$$

$$D = 22.62 + 0.011\,(1375^{\circ}\text{F-days})$$

$$= \underline{38\text{ days}}\text{ from the start of thawing (February 24)} = \underline{\text{April 2}}$$

A simpler approximate equation for estimating duration in days which may be used instead of the preceding equation is

$$D = 25 + 0.01\,(FI)$$

$$D = 25 + 0.01\,(1375^{\circ}\text{F-days})$$

$$= 25 \quad + \ 14$$

$$= \underline{39\text{ days}} = \underline{\text{April 3}}$$

Day	Month/ Year	Measured Daily Air Temperature (° F)		Average Daily Air Temperature, (°F)	Daily Freezing Index = Avg. Daily Temp. - 32° F. (see note) (° F - days)	Sum of Daily Freezing Index (°F-days)	Daily Thawing Index = Avg. Daily Temp. - 29° F. (see note) (° F - days)	Sum of Daily Thawing Index (°F-days)
		High	Low	$\left(\frac{\text{High + Low}}{2}\right)$				
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	Nov., '85	43	24	34				
2	" "	51	29	40				
3	" "	55	26	40				
4	" "	60	35	48				
5	" "	50	30	40				
6	" "	50	30	40				
7	" "	54	25	40				
8	" "	50	18	34				
9	" "	45	13	29	3	3		
10	" "	40	10	25	7	10		
11	" "	35	11	23	9	19		
12	" "	40	8	24	8	27		
13	" "	35	7	21	11	38		
14	" "	33	4	18	14	52		
15	" "	30	4	17	15	67		
16	" "	32	7	20	12	79		
17	" "	26	5	16	16	95		
18	" "	35	10	22	10	105		
19	" "	20	-6	7	25	130		
20	" "	16	-6	5	27	157		
21	" "	14	-4	5	27	184		
22	" "	14	0	7	25	209		
23	" "	12	-8	2	30	239		
24	" "	11	-8	2	30	269		
25	" "	10	-12	-1	33	302		
26	" "	10	-8	1	31	333		
27	" "	16	-8	4	28	361		
28	" "	13	-8	2	30	391		
29	" "	11	-8	2	30	421		
30	" "	27	-8	10	22	443		

Note: Calculate Daily Freezing Index starting at the beginning of the freezing season and accumulate throughout the normal freezing period. The air temperature datum for Freezing Index is 32°F and 29°F for Thawing Index. The Thawing Index period for much of the U.S. will start in late February to April.

Figure A-1. Worksheet for Bituminous Surfaced Pavements.

Day	Month/ Year	Measured Daily Air Temperature (° F)		Average Daily Air Temperature, (°F)	Daily Freezing Index = Avg. Daily Temp. - 32° F. (see note) (° F - days)	Sum of Daily Freezing Index (°F-days)	Daily Thawing Index = Avg. Daily Temp. - 29° F. (see note) (° F - days)	Sum of Daily Thawing Index (°F-days)
		High	Low	$\left(\frac{\text{High + Low}}{2}\right)$				
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	Dec., '85	17	-8	4	28	471		
2	" "	8	-8	0	32	503		
3	" "	18	2	10	22	525		
4	" "	24	8	16	16	541		
5	" "	34	12	23	9	550		
6	" "	34	12	23	9	559		
7	" "	34	16	25	7	566		
8	" "	34	14	24	8	574		
9	" "	34	20	27	5	579		
10	" "	26	12	19	13	592		
11	" "	20	2	11	21	613		
12	" "	22	12	17	15	628		
13	" "	26	-4	11	21	649		
14	" "	23	-3	10	22	671		
15	" "	22	-2	10	22	693		
16	" "	20	-3	8	24	717		
17	" "	20	2	11	21	738		
18	" "	30	2	16	16	754		
19	" "	25	10	18	14	768		
20	" "	28	18	23	9	777		
21	" "	26	18	22	10	787		
22	" "	24	14	19	13	800		
23	" "	24	18	21	11	811		
24	" "	22	16	19	13	824		
25	" "	22	14	18	14	838		
26	" "	21	12	16	16	854		
27	" "	21	14	18	14	868		
28	" "	18	14	16	16	884		
29	" "	20	12	16	16	900		
30	" "	20	12	16	16	916		
31	" "	20	10	15	17	933		

Note: Calculate Daily Freezing Index starting at the beginning of the freezing season and accumulate throughout the normal freezing period. The air temperature datum for Freezing Index is 32°F and 29°F for Thawing Index. The Thawing Index period for much of the U.S. will start in late February to April.

Figure A-1. Worksheet for Bituminous Surfaced Pavements (cont.).

Day	Month/ Year	Measured Daily Air Temperature (° F)		Average Daily Air Temperature, (°F)	Daily Freezing Index = Avg. Daily Temp. - 32° F. (see note) (° F - days)	Sum of Daily Freezing Index (°F-days)	Daily Thawing Index = Avg. Daily Temp. - 29° F. (see note) (° F - days)	Sum of Daily Thawing Index (°F-days)
		High	Low	$\left(\frac{\text{High + Low}}{2}\right)$				
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	Jan., '86	27	5	16	16	949		
2	" "	34	0	17	15	964		
3	" "	26	6	16	16	980		
4	" "	28	9	18	14	994		
5	" "	28	9	18	14	1008		
6	" "	30	12	21	11	1019		
7	" "	26	8	17	15	1034		
8	" "	30	10	20	12	1046		
9	" "	40	16	28	4	1050		
10	" "	37	28	32	0	1050	3	3
11	" "	39	20	30	2	1052	1	4
12	" "	34	16	25	7	1059	-4	0
13	" "	32	10	21	11	1070		
14	" "	18	18	18	14	1084		
15	" "	26	14	20	12	1096		
16	" "	27	20	24	8	1104		
17	" "	36	26	31	1	1105	2	2
18	" "	46	30	38	-6	1099	9	11
19	" "	40	30	35	-3	1096	6	17
20	" "	40	21	30	2	1098	1	18
21	" "	40	21	30	2	1100	1	19
22	" "	40	12	26	6	1106	-3	16
23	" "	34	22	28	4	1110	-1	15
24	" "	41	20	30	2	1112	1	16
25	" "	32	6	19	13	1125	-10	6
26	" "	26	6	16	16	1141	-13	--
27	" "	28	16	22	10	1151		
28	" "	31	24	28	4	1155		
29	" "	30	20	25	7	1162		
30	" "	34	24	29	3	1165	0	0
31	" "	38	30	34	-2	1163	5	5

Note: Calculate Daily Freezing Index starting at the beginning of the freezing season and accumulate throughout the normal freezing period. The air temperature datum for Freezing Index is 32°F and 29°F for Thawing Index. The Thawing Index period for much of the U.S. will start in late February to April.

Figure A-1. Worksheet for Bituminous Surfaced Pavements (cont.).

Day	Month/ Year	Measured Daily Air Temperature (° F)		Average Daily Air Temperature, (°F)	Daily Freezing Index = Avg. Daily Temp. - 32° F. (see note) (° F - days)	Sum of Daily Freezing Index (°F-days)	Daily Thawing Index = Avg. Daily Temp. - 29° F. (see note) (° F - days)	Sum of Daily Thawing Index (°F-days)
		High	Low	$\left(\frac{\text{High + Low}}{2}\right)$				
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	Feb., '86	36	32	34	-2	1161	5	10
2	" "	40	26	33	-1	1160	4	14
3	" "	34	30	32	0	1160	3	17
4	" "	38	30	34	-2	1158	5	22
5	" "	37	27	32	0	1158	3	25
6	" "	36	25	30	2	1160	1	26
7	" "	40	18	29	3	1163	0	26
8	" "	32	10	21	11	1174	-8	18
9	" "	32	20	26	6	1180	-3	15
10	" "	28	16	22	10	1190	-7	8
11	" "	30	14	22	10	1200	-7	1
12	" "	32	15	24	8	1208	-5	--
13	" "	32	7	20	12	1220		
14	" "	29	11	20	12	1232		
15	" "	30	15	22	10	1242		
16	" "	29	12	20	12	1254		
17	" "	30	11	20	12	1266		
18	" "	29	15	22	10	1276		
19	" "	30	-8	11	21	1297		
20	" "	23	-10	6	26	1323		
21	" "	21	-6	8	24	1347		
22	" "	28	0	14	18	1365		
23	" "	34	10	22	10	1375		
24	" "	45	32	38	--	--	9	9
25	" "	48	38	43			14	23
26	" "	48	32	40			11	34
27	" "	48	24	36			7	41
28	" "	48	26	37			8	49

Note: Calculate Daily Freezing Index starting at the beginning of the freezing season and accumulate throughout the normal freezing period. The air temperature datum for Freezing Index is 32°F and 29°F for Thawing Index. The Thawing Index period for much of the U.S. will start in late February to April.

Figure A-1. Worksheet for Bituminous Surfaced Pavements (cont.).

Day	Month/ Year	Measured Daily Air Temperature (° F)		Average Daily Air Temperature, (°F)	Daily Freezing Index = Avg. Daily Temp. - 32° F. (see note) (° F - days)	Sum of Daily Freezing Index (°F-days)	Daily Thawing Index = Avg. Daily Temp. - 29° F. (see note) (° F - days)	Sum of Daily Thawing Index (°F-days)
		High	Low	$\left(\frac{High + Low}{2}\right)$				
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	Mar., '86	43	25	34			5	54
2	" "	48	22	35			6	60
3	" "	40	20	30			1	61
4	" "	46	24	35			6	67
5	" "	47	21	34			5	72
6	" "	46	24	35			6	78
7	" "	47	29	38			9	87
8	" "	49	30	40			11	98
9	" "	50	30	40			11	109
10	" "	52	31	42			13	122
11	" "	40	33	36			7	129
12	" "	52	32	42			13	142
13	" "	52	25	38			9	151
14	" "	45	20	32			3	154
15	" "	53	26	40			11	165
16	" "	53	26	40			11	176
17	" "	54	26	40			11	187
18	" "	54	32	43			14	201
19	" "	56	31	44			15	216
20	" "	57	32	44			15	231
21	" "	62	35	48			19	250
22	" "	50	32	41			12	262
23	" "	47	34	40			11	273
24	" "	54	30	42			13	286
25	" "	50	30	40			11	297
26	" "	52	34	43			14	311
27	" "	52	36	44			15	326
28	" "	58	42	50			21	347
29	" "	58	41	50			21	368
30	" "	59	40	50			21	389
31	" "	60	43	52			23	412

Note: Calculate Daily Freezing Index starting at the beginning of the freezing season and accumulate throughout the normal freezing period. The air temperature datum for Freezing Index is 32°F and 29°F for Thawing Index. The Thawing Index period for much of the U.S. will start in late February to April.

Figure A-1. Worksheet for Bituminous Surfaced Pavements (cont.).