Development of Spring Load Restrictions for Local Roads

T. RWEBANGIRA, M. S. RUTHERFORD, J. P. MAHONEY, AND R. G. HICKS

Load restrictions to reduce or preclude pavement damage during spring thaw periods are widely used in the United States and Europe. Load restrictions are primarily applied to low-volume road networks. In recent years extensive examinations of load restriction-related issues have been conducted in states such as Alaska, Minnesota, and Washington. The development of guidelines for use in determining where to apply the load restrictions and their magnitude is reported in this paper. A survey of current practice in the United States and Canada revealed that load restrictions are applied mostly to pavements that have subgrades composed of moisture-susceptible silts and clays. It also revealed that the restrictions are mostly applied to aggregate and asphalt-surfaced pavements. The maximum legal loads are generally reduced about 40 to 50 percent for single axles and 30 to 50 percent for tandem axles during the spring thaw period. The current study recommends that load restrictions be applied whenever a pavement's spring surface deflections are greater than 45 to 50 percent of summer deflections. The extent of load restrictions suggested is a minimum of 20 percent and a maximum of 60 percent. A load reduction range of 40 to 50 percent should accommodate a wide range of pavement conditions.

In areas of the United States that are subjected 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 several times 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 budget constraints in many agencies faced with this problem, the only choice is Item 1. A review of the literature quickly reveals that few rational procedures have been used to determine the magnitude of the load restrictions. Therefore, a need exists to develop guidelines oriented toward local agencies to assist them in handling this serious problem.

The damage to a pavement structure is directly related to the magnitude and frequency of the load applied. This was clearly demonstrated by the AASHO Road Test *(1)*. 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 *(2)*. A majority of the state departments of transportation use the *AASHTO Interim Guide for Design of Pavement Structures (3)* when 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 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 loads reduces the life of the pavement. Thus, the method of load reduction in response to reduction in pavement materials strength 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 to close or open a facility is largely determined by experience and sometimes political pressures. Little definitive data exist to assist in decision making, especially for secondary and lower category highways even though these types of highways comprise the bulk of county and city highway systems. Because local governments generally have low to modest maintenance budgets, they normally cannot afford to overlay the pavements after damage during the spring thaw. Therefore, a need exists to develop criteria for the restriction of truck weights during the spring thaw.

OBJECTIVES

The objective of this paper is to report on part of the study carried out to develop guidelines for local governments to use in establishing weight restrictions on county and city pavements in advance of spring break-up *(4)*. The following is reported:

1. A summary of current practices,
2. Development of load limits, and
3. Development of guidelines that can be used by local agencies to assess the need and magnitude of load restrictions.

SUMMARY OF CURRENT PRACTICES

Summarized in this section is part of the survey of current practices dealing with load limits and typical structures on

T. Rwebangira, Department of Civil Engineering, Oregon State University, Corvallis, Oreg. 97331. Current affiliation: Department of Civil Engineering, University of Dar-es-Salaam, Tanzania. M. S. Rutherford and J. P. Mahoney, Department of Civil Engineering, University of Washington, Seattle, Wash. 98195. R. G. Hicks, Department of Civil Engineering, Oregon State University, Corvallis, Oreg. 97331.

TABLE 1 SUMMARY FROM AGENCIES INTERVIEWED

Location	Types of Pavement Failure Associated with Spring Thaw	Extent of Problem	How Are Locations for Load Restrictions Determined?
Alaska DOT	Alligator cracking, rutting, frost boils	Statewide	FWD, visual observations, measurements of thaw depth, experience
Idaho DOT	Foundation, deep base, surface	15 percent of system	Experience
Iowa DOT	Spring breakup	Low-volume roads	Selected by district engineers
Bremer County, Iowa	Pavement breakup, rutting	Up to 50 percent on aggregate-surfaced, up to 10 percent on paved	Visual observation of heaving or pumping, or both
Maine DOT	Alligator cracking	Low-volume roads statewide	Selected by district engineers
Minnesota DOT	Rutting, alligator cracking	Limited	Experience of maintenance engineer and deflection measurements with road rater and FWD
Anoka County, Minnesota	Alligator cracking, potholes	Not too extensive due to restrictions	Construction history and design, and Benkelman beam deflections
Maple Grove, Minnesota	Frost boils, alligator cracking	Citywide	Uniform load restriction policy for all streets
Wright County, Minnesota	Rutting, alligator cracking	Variable from year to year	Road rater deflections
Montana DOT	Frost boils	Statewide to minimum structure roads	Judgment of maintenance personnel
New Hampshire DOT, Division 2	Alligator cracking, rutting, frost heave	Modest	Judgment of maintenance personnel based on whether heavy hauling is occurring
North Dakota DOT	Surface break, potholes	Varies yearly depending on frost penetration	Experience
Nova Scotia DOT	Varies depending on structure and loads	Not extensive	Benkelman beam testing
Oregon DOT	Heave, cracking, pavement breakup	Central, eastern part of state	Experience and visual observation
Benton County, Oregon	Alligator cracking and breakup	All road construction types	Experience
South Dakota DOT	Potholes, edge failure, alligator cracking	Highways with thin mats typically restricted statewide	Experience
Washington State DOT	Alligator cracking, pavement breakup	Central and eastern Washington on a few low-volume roads	Judgment of maintenance personnel
Benton County, Washington	Pavement breakup, frost heave, base failure	Moderate	Observation of road conditions

which they are applied. The survey results are from contacts and visits with selected agencies throughout the United States and Canada. The relevant questions on load limits were

1. Types of facilities requiring weight restriction during the spring thaw period,
2. Types of pavement failures associated with spring thaw,
3. The magnitude of weight restriction and how such policies were developed.

To collect the needed information, three survey techniques were used: the initial information request, interviews, and follow-up requests. The response by the agencies contacted is given in Table 1.

Highways Receiving Load Restrictions

This question was concerned with defining the types of highways receiving load restrictions. The responses indicate the following:

1. Load restrictions by state agencies were applied to both primary and secondary roads, but mostly secondary. Few states have applied them to Interstate highways. Local agencies generally applied load restrictions to all types of facilities.
2. Of those states responding, load restrictions were generally applied to roads with average daily traffic (ADT) less than 2,500 and 10 percent trucks or less. Local, city, and county agencies applied restrictions to roads with ADT levels up to 30,000 and up to 10 percent trucks.
3. Primarily, load restrictions were applied to pavements that 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- 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, in.	$1^1/_2$ to 5	2 to 4
Aggregate base, in.	4 to 18	6 to 12

Thicker pavements apparently have sufficient strength to withstand the effects of the thaw-weakening period.

Design Information for Roads Receiving Load Restrictions

This question addresses design information such as whether frost penetration is considered in thickness design, the age of the pavement, and typical drainage conditions. The results indicate

1. Some of the state agencies surveyed design pavements for partial frost protection whereas 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 used load restrictions in lieu of designing for full frost protection.
3. A variety of design procedures were used to determine layer thickness. The most common was the AASHTO method. Others included the Hveem method, experience, or precedent.
4. Pavements receiving load restrictions tended to be 10 to 20 years old or older. In some cases they tended to be farm-to-market types of roads constructed 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.

Magnitude of Load Restriction

This question addressed the current load limits and how they were determined. The significant findings include the following:

1. For most agencies normal load limits were 18,000 to 20,000 lb on a single axle and 34,000 lb on tandem axles.
2. Spring load restrictions generally ranged from 10,000 to 14,000 lb for single axles and 18,000 to 28,000 lb 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. Only a few states, such as Alaska *(5)*, Minnesota *(6)*, and Washington *(7)*, had conducted extensive studies.
5. Only three of the agencies used deflection measurements to establish load limits.

The summary of current practices clearly shows the types of pavement structures that are subjected to spring load restrictions. It also shows the types of failure associated with spring thaw, as well as the magnitude of normal and spring load limits. Using the information from current practice, an attempt is made in the following sections to develop a rational procedure for spring load limits.

DEVELOPMENT OF LOAD LIMITS

The development of the procedure used to establish guidelines on the magnitude of spring load restrictions is presented in this section. The procedure is based on pavement structural analysis using a layered elastic program and typical pavement structures.

Analytical Procedure

Layered elastic theory has been widely applied to analyze pavement response to load. Several analysis programs exist for mainframe and microcomputers; the program selected for this study was ELSYM5 *(8)*. This program was developed at the University of California, Berkeley, and can be used to analyze up to 10 identical loads in a 5-layer system. It computes stresses, strains, and displacements at specified points and assumes the material behavior is linear elastic.

It has been widely recognized that base course and subgrade materials (both coarse and fine) exhibit nonlinear elastic behavior. Because test cases used in the study are hypothetical, representing a range of structural conditions that might be found anywhere in the frost areas of the United States, it was not possible to identify any meaningful nonlinear relationships. In addition, in reviewing data from previous frost studies performed for the Washington State Department of Transportation *(7)*, it was found that the behavior of the materials was not highly nonlinear in the ranges of stresses studied. Therefore, it is believed that a linear elastic analysis was capable of providing adequate results.

Structure Cross Section

The structure cross sections used in the study were selected to represent as near as possible the types of road construction and subgrade materials present in the geographic region and jurisdictions of interest. Therefore, the data obtained in the interviews were weighted heavily in the selection of the structure cross-section cases.

Surface courses were assumed to be either asphalt concrete (AC) or bituminous surface treatment (BST) with thicknesses ranging from 2 to 4 in. The base course was assumed to be unstabilized aggregate varying from 6 to 12 in. thick. No subbases were considered. Subgrades of both coarse and fine materials were investigated. The specific cases analyzed are given in Table 2.

Material Properties

Several different cases of environmental conditions occur in a pavement structure annually that have an effect on the pavement structure's stiffness properties and therefore, its response. If it is desirable to restrict loads during spring when overall structural stiffness is reduced so that the strains and deflections experienced are comparable to those during the full-strength summer case, then the stiffness properties of the summer case and various stages of spring thawing need to be modeled.

For the reference condition, a range of resilient properties was selected to represent the surface course, base course, and subgrade. The analysis performed assumed that for the condition of a base course underlain by a weaker material, the base course resilient modulus was a function of the underlying material. The following relationship was used:

$$Mr_{base} = 1.5\ Mr_{subgrade}$$

This type of relationship originally used by Heukelom and Klomp *(9)* has been subsequently used by the Shell Oil Company *(10)* and by the Asphalt Institute *(11)* in their respective pavement design methods. The commonly used range for the modular ratio is about 1.0 to 4.0 (for this study a value of 1.5 was selected, which is in the lower end of the range).

TABLE 2 SUMMER PAVEMENT STRUCTURE

Type	Material	Thickness (in.)	Resilient Modulus (psi)
Surface	BST or ACP	2	300,000
	ACP	4	300,000
Base	Gravel	6	Base M_R = 1.5 Subgrade M_R
		12	
Subgrade	Fine-grained	212	7,500
	Coarse-grained	212	40,000

A range of subgrade resilient moduli was selected from results of field and laboratory data and is given in Tables 3 through 5. The values represent typical moduli for soils ranging from silty-clay to gravel *(7, 11, 12)* for the different cases of thawing condition analyzed. Because the asphalt concrete and bituminous surface treatment resilient moduli are highly dependent on temperature, the modulus value selected for the summer case was 300,000 psi and was based on a reference temperature of 75°F *(10)*. Using the same reference data *(10)*, the surface course resilient modulus during the spring thaw (temperature of 40°F) was found to be 1,200,000 psi.

During the early thawing period, the base course resilient modulus can be reduced substantially due to moisture conditions and undrained loading. The base course assumed during this period was either 25 or 50 percent of the reference (summer) condition. This decision was based in part on work reported by Lary et al. *(7)* and Shook et al. *(11)*. The cases that were analyzed during thawing included the following:

1. Thaw to the bottom of the base course,
2. Thaw 4 in. into the subgrade, and
3. Thawing complete.

When thawing occurred in the subgrade, the $Mr_{subgrade}$ was assumed to be 5 to 50 percent of the reference (summer) condition (Tables 3 and 5). Where the subgrade material was frozen, the resilient modulus was assumed to be 50,000 psi.

Loading Cases

Currently, most jurisdictions, whether national, state, or local, restrict loads on classes of roads according to axle loads. Based on information obtained in the interviews and a review of current practice throughout the United States, a maximum single axle load of 20,000 lb and a tandem axle load of 34,000 lb were selected as reference load levels.

Because the ELSYM5 program models the wheel loads with a circular configuration, it was decided that the loading was most accurately represented by selecting the maximum load and corresponding tire pressure recommended by the Tire and Rim Association for a particular tire size *(13)*. Load reductions were modeled by maintaining the contact pressure (tire pressure) and reducing the load, thereby reducing the contact area.

The loading cases evaluated included the following tires: single axle-single tire (16.5-22.5), single axle-dual tires (10-22.5), and tandem axle-dual tires (10-22.5). The loads and pressures for each of these cases are given in Table 6. All loading cases were analyzed for 20 and 100 percent of the maximum load to obtain load-deflection and load-strain plots.

Parameters Calculated

When a pavement fatigue analysis is performed, two strain parameters are used. These parameters are the tensile strain at the bottom of the surface course (ε_t) and the vertical strain at the top of the subgrade (ε_{vs}). Another parameter typically considered as well is the maximum pavement surface deflection (δ). In addition to these widely used damage indicators, some researchers *(7, 14)* have found that the vertical strain at the top of the base course (ε_{vb}) was also an indicator of distress due to a weakened condition. As a result, for this study, all of these parameters were considered potential indicators of excessive load. Therefore, an increase in any one of these parameters above the reference level (summer condition) constituted a required reduction in the load level sufficient to maintain them at levels comparable to the reference (or summer) conditions. The locations of these parameters are shown in Figure 1.

Once the deflections and strains were calculated, the determination of the spring load that caused the same damage as the maximum legal allowable load during the summer could be computed. This can be illustrated using a plot such as the one shown in Figure 2. The plot was constructed as follows:

1. Plot δ, ε_t, ε_{vb}, and ε_{vs} for two loads used in the spring analysis (hence spring thaw material properties), and load-deflection and load-strain lines were drawn through these points. The load levels used in the analysis were 20 and 100 percent of the legal maximum. This was done for different structural profiles and material combinations.
2. Enter the plot on the vertical axis with the summer deflection or any summer strain value.
3. Draw a horizontal line to intersect the appropriate load-deflection or load-strain value.
4. At the intersection, a vertical line is drawn to intersect the horizontal or tire-load axis.
5. The values at the intersection with the tire-load axis are the tire loads that would result in the same deflection or strains

TABLE 3 SPRING THAW PAVEMENT (COMPLETE THAW)

Type	Material	Thickness (in.)	Resilient Modulus (psi)
Surface	BST or ACP	2	1,200,000
	ACP	4	
Base	Gravel	6	Base M_R = 1.5 Subgrade M_R
		12	
Subgrade	Fine-grained	-	15, 20, 25% of Summer Subgrade M_R
	Coarse-grained	-	25, 30, 50% of Summer Subgrade M_R

TABLE 4 SPRING THAW PAVEMENT STRUCTURE (THAW TO BOTTOM OF BASE)

Type	Material		Thickness (in.)	Resilient Modulus (psi)
Surface	BST or ACP		2	1,200,000
	ACP		4	1,200,000
Base	Gravel		6	25, 50% of Summer Base M_R
			12	
Subgrade	Frozen		Depth of freeze minus surface, base, and thawed subgrade	50,000
	Unfrozen	Fine-grained	212	7,500
		Coarse-grained	212	40,000

TABLE 5 SPRING THAW PAVEMENT STRUCTURE (THAW TO 4 IN. BELOW BASE)

Type	Material	Thickness (in.)	Resilient Modulus (psi)
Subgrade	BST or ACP	2	1,200,000
	ACP	4	1,200,000
Base	Gravel	6	Base M_R = 1.5 Subgrade M_R
		12	
Subgrade	Thawed fine-grained	4	5, 15% of Summer Subgrade M_R
	Thawed coarse-grained	4	25, 50% of Summer Subgrade M_R
	Frozen fine-grained and coarse-grained	Depth of freeze minus surface, base, and thawed subgrade	50,000

TABLE 6 LOADING CASES

Case	Size (Nominal)	Tire Pressure (psi)	Tire Load (lbs)
Single Axle (Max. Load = 20,000 lb)			
a) Single Tires	16.5-22.5	90	9900
b) Dual Tires	10-22.5	100	5000
Tandem Axle (Max. Load = 34,000 lb Axle Spacing = 48 in.)			
a) Dual Tires	10-22.5	100	4250

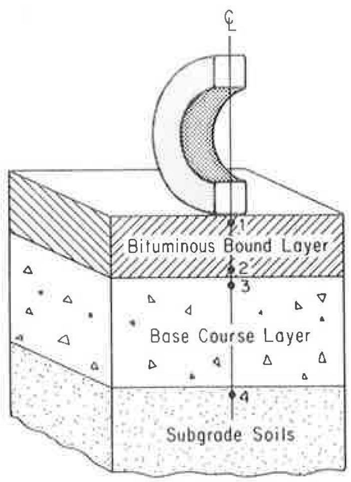

FIGURE 1 Pavement response locations used in evaluating load restrictions.

as obtained during the summer under the maximum allowable loading.

From these values, the percentage reduction in summer load required to maintain the same strains and deflections was computed.

Sensitivity Analysis

A sensitivity analysis was carried out to test how the magnitude of load reduction varied with some variation in the input parameters. To do this, the pavement surface modular ratio ($M_r$spring/$M_r$summer) was first varied from 1.25 to 3.75. The second item varied was the magnitude of the subgrade strength reduction during the spring thaw. Finally, the percentage reduction in resilient modulus was varied from 70, 80, and 85 percent for fine-grained soils, and 50, 70, and 75 percent for coarse-grained soils. The results of the sensitivity analysis *(4)* indicated that

1. Load reduction during spring thaw is more sensitive to changes in subgrade than pavement surface modulus.
2. The subgrade strength reduction of 75 percent for fine-grained soils resulted in a reasonable value for spring load reductions when compared to current practice. The corresponding value for coarse-grained soils was found to be 50 percent.

Structural Analysis Results

Typical results of the structural analysis are given in Table 7. The thawing cases include complete thaw, partial thaw to the bottom of the base course, and partial thaw 4 in. into the subgrade (i.e., 4 in. below the bottom of the base). Typical results of load reduction for various pavement structural sections for the complete thaw case are given in Table 7. The load reduction is also shown for various axle and tire configurations, and the results in Table 7 are for a single axle and both single- and dual-tire configurations. Load reduction results are given for both fine- and coarse-grained subgrade soils. The results in Table 7 are for a coarse-grained subgrade. Only one case is shown here; for complete results please refer to *Guidelines for Spring Highway Use Restrictions (4).*

DISCUSSION OF RESULTS

Magnitude of Load Reduction

The magnitudes of load restriction vary with both pavement structure and load response parameter (deflection and strain) (Table 7). The calculated load reductions (for those cases that require a reduction) ranged from a low of 1 percent to a high of 69 percent *(4)*. For all cases, the surface deflection and vertical subgrade strain provided the most consistent load-reduction values (for the assumed conditions). The tensile strain (bottom of surface course) and vertical strain at the top of the subgrade criteria resulted in the largest reductions in load. An average load reduction of 34 percent results for the complete thaw and partial subgrade thaw cases for fine and coarse-grained soils for the subgrade vertical strain criterion (includes both 2- and 4-in.-thick surface courses) *(4)*. For the same conditions, but for 2-in.-thick surface courses only, the average load reduction increases to 45 percent. The corresponding value for 4-in.-thick surface courses is 21 percent. An average load reduction of 39

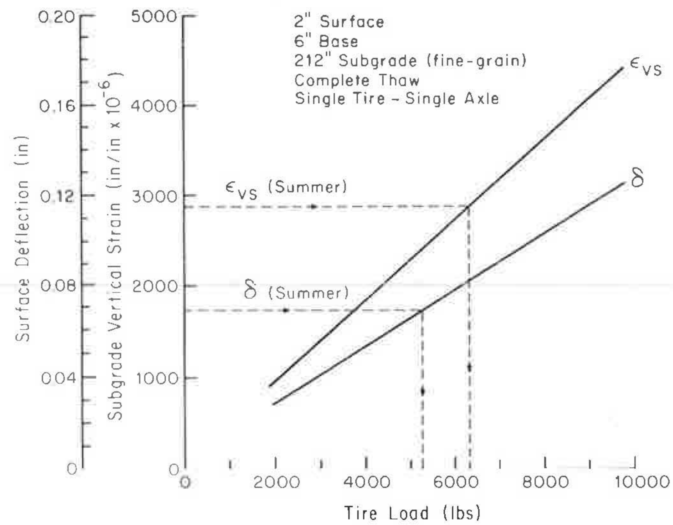

FIGURE 2 Graphical illustration of the determination of allowable load during spring thaw period.

percent results for the complete thaw and partial subgrade thaw cases for fine-grained soil and both thickness levels of surface course (based on the subgrade vertical strain criterion as before). For the same conditions but for 2- and 4-in.-thick surface courses, the average load reductions are 52 and 25 percent, respectively.

Thus, for fine-grained soils (which are the types of soils that generally necessitate the need for load restrictions), a load reduction of about 50 percent is needed for thin-surfaced bituminous pavements. The benefit of thicker surface courses (or stabilized pavement layers in general) is illustrated for the 4-in.-thick surface course. For the fine-grained subgrade case, a load reduction of about 25 percent is needed (or one-half the load reduction amount needed for the 2-in.-thick surface course).

It should also be noted that there are no significant differences in reductions for single and dual tires *(4)*. For both fine- and coarse-grained soils in the complete thaw case, the dual-tire configuration results in slightly higher reductions than the single tire. The dual-tandem configuration results in about the same range of load reductions; although the deflections and strain levels are lower than the single and dual-tire single-axle cases. The maximum strain values for the dual-tandem configuration generally occurred between the dual tires.

Consequence of Maintaining Loads

An evaluation of the consequences of maintaining the maximum summer loads during the spring was performed. This was done by examining criteria generally accepted as indicators of pavement distress. These are the maximum tensile strain at the bottom of the bituminous-bound layer (fatigue cracking) and the vertical strain at the top of the subgrade (rutting). The Asphalt Institute criteria *(11)*, have been used to determine the number of load applications to failure for any given strain. The results are given in Table 8 for prediction of loads to failure for complete thaw. Other conditions evaluated included thaw to bottom of base and thaw 4-in. below the bottom of the base. The data in Table 8 show the summer and spring strain values and the corresponding loads to failure, they also show the percentage change in pavement life (number of loads to failure) between summer and spring cases. This is shown for several pavement structural sections and for both fine- and coarse-grained subgrade soil. The remaining cases can be found in *Guidelines for Spring Highway Use Restrictions (4)*.

The predicted loads to failure for the load cases evaluated are relatively low for the fine-grained subgrade cases (both summer and spring conditions). This is due in part to the cross sections selected for evaluation but primarily the material properties (the principal material property being resilient modulus). The negative percent change in the loads to failure (summer to spring) is consistently high for the 2-in.-thick surface course cases. For the 4-in.-thick surface course, occasionally the spring condition (with the higher stiffness surface course) results in a positive change in the estimated loads to failure (e.g., longer pavement life).

DEVELOPMENT OF IMPROVED GUIDELINES

Guidelines for Where to Apply Load Restrictions

The procedure to establish load restrictions was based on the assumption that pavement response (deflection and strain) during the spring thaw should be limited to those estimated for summer conditions. The way to achieve equal pavement response is to reduce allowable axle loads (or individual tire loads). Further, many agencies have the capability to measure pavement surface deflections with equipment such as the Benkelman beam, Dynaflect, or the Falling Weight Deflectometer (FWD). Thus for both the fine- and coarse-grained subgrade cases, the percent increase in surface deflection was calculated for summer to complete spring thaw for both single-tire–single-axle and dual-tire–single-axle conditions. These deflection increases were matched with the associated load reduction percentages; a summary is given in Table 9 and plotted in Figure 3. The data in Table 9 show the increase in surface

TABLE 7 PERCENT LOAD REDUCTION FOR COMPLETE THAW—COARSE-GRAINED SOILS—SINGLE AXLE, 50 PERCENT REDUCTION IN SUBGRADE RESILIENT MODULUS

Pavement Structural Section		Load Reduction (Percent)							
		Single Tire (a) – Pavement Response Criteria				Dual Tire (b) – Pavement Response Criteria			
Surface Thickness (in.)	Base Thickness (in.)	Pavement Surface Maximum Deflection	Bituminous Tensile Strain	Base Vertical Strain	Subgrade Vertical Strain	Pavement Surface Maximum Deflection	Bituminous Tensile Strain	Base Vertical Strain	Subgrade Vertical Strain
2	6	32	60	37	30	43	8	1	26
	12	33	61	38	39	34	5	1	40
4	6	10	NR	NR	NR	11	NR	NR	23
	12	11	NR	NR	19	12	NR	NR	26

Notes: (a) Single tire: Tire size: 16.5 - 22.5 Maximum legal tire load: 9,900 lb. Tire pressure: 90 psi
(b) Dual tires: Tire size: 10 - 22.5 Maximum legal load per tire: 5,000 lb Tire pressure: 100 psi
(c) NR = No Reduction

TABLE 8 CHANGE IN PAVEMENT LIFE, SINGLE TIRE, SINGLE AXLE, TENSILE STRAIN BOTTOM OF BITUMINOUS BOUND LAYER, COMPLETE THAW

Pavement Structural Section		Fine-Grained Soil					Coarse-Grained Soil				
		Summer		Spring[a]		Percent	Summer		Spring[a]		Percent
Surface Thickness (in.)	Base Thickness (in.)	Strain (in./in. $\times 10^{-6}$)	Loads to Failure	Strain (in./in. $\times 10^{-6}$)	Loads to Failure	Change Loads to Failure	Strain (in./in. $\times 10^{-6}$)	Loads to Failure	Strain (in./in. $\times 10^{-6}$)	Loads to Failure	Change Loads to Failure
2	6	950	10,800	902	3,900	−64	190	2.1×10^6	312	128,600	−94
	12	899	12,900	870	4,400	−66	182	2.5×10^6	296	152,900	−94
4	6	655	36,670	372	72,100	+97	243	956,100	193	624,600	−34
	12	629	41,800	365	76,700	+84	232	1.1×10^6	186	705,900	−37

NOTES: Equation for estimating number of loads to cause up to 10 percent cracking in the wheelpath: $\log N_f = 15.947 - 3.291 \log (\varepsilon_t/10^{-6}) - 0.854 \log (M_R/10^3)$. Single tire, single axle: Load = 9,900 lb; tire pressure = 90 psi.

[a]Spring case for complete thaw: (a) Fine-grained: 75 percent reduction in subgrade resilient modulus; (b) Coarse-grained: 50 percent reduction in subgrade resilient modulus.

TABLE 9 SURFACE DEFLECTION INCREASES (FROM SUMMER TO COMPLETE THAW CASE) AND ASSOCIATED LOAD REDUCTIONS

Pavement Structural Section		Single Tire – Single Axle		Dual Tires – Single Axle	
Surface Thickness (in.)	Base Thickness (in.)	Surface Deflection Increase (a) (Percent)	Load Reduction (b) (Percent)	Surface Deflection Increase (a) (Percent)	Load Reduction (b) (Percent)
Fine-grained Subgrade					
2	6	76	43	98	49
2	12	80	44	100	50
4	6	22	18	43	23
4	12	25	20	47	26
Coarse-grained Subgrade					
2	6	44	30	67	26
2	12	45	39	68	40
4	6	10	—	29	23
4	12	11	19	31	26

Notes: (a) Increase in pavement surface deflection from summer to complete spring thaw
(b) Load reductions from Tables 4.6 and 4.7 for the subgrade vertical strain response criterion

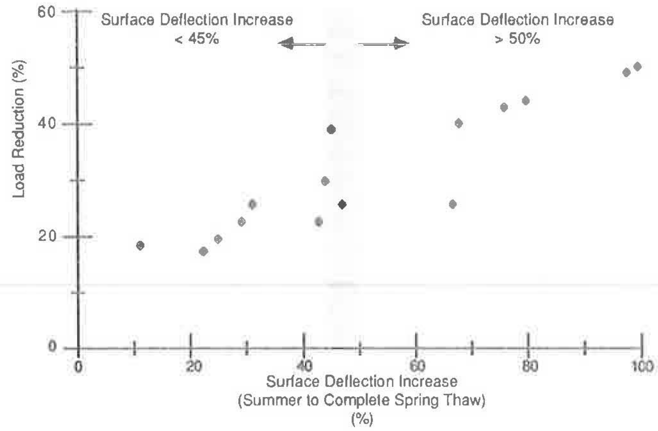

FIGURE 3 Development of surface deflection for locating pavements requiring load restrictions.

deflection corresponding to the complete thaw case. The data also show the load reduction necessary to maintain the deflections at their summer values. The results are given for the various pavement structures, subgrade types, and single- and dual-tire configurations.

An examination of Figure 3 reveals that pavement sections that have surface deflections 45 to 50 percent higher during the spring thaw than in summer are candidates for load restrictions. 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, which is in agreement with the work by Connor *(15)*.

Other criteria that 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.

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. Poor drainage from side ditches, available groundwater, 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 restrictions.

Another criterion to use for selecting locations for load restrictions 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 of 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 possible.

Guidelines for Load-Restriction Magnitude

The load reductions used by the agencies contacted range from about 20 to 60 percent. An average load reduction for seven locations (individual state areas) is approximately 44 percent (standard deviation of about 8 percent) *(4)*. This suggests that 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.

To further examine the amount of load reduction needed, Figure 4 was developed. This is a plot of load reduction (percent) versus the increase in pavement life due to the application of load restrictions (percent). The load reduction percentages were obtained from tables similar to Table 7 (for the vertical strain at the top of the subgrade cases only). The increase in pavement life was obtained from tables similar to Table 8. To determine the increase in pavement life from these tables, the negative change in pavement life (based on the rutting failure criterion) is eliminated as a result of load reductions, thus increasing the potential pavement life. All three tire-axle configurations were used. This curve contains data points for both the 2- and 4-in.-thick surface courses and both fine- and coarse-grained subgrades for the rutting failure criterion (a wide range of conditions). Undoubtedly, different failure criteria would tend to shift the curve.

The results given in Figure 4 show that as the load reduction percentage is increased the associated pavement life is increased (as expected). An increasing slope is noted for load reductions greater than about 20 percent. 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 states 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) can occur during the thaw-weakened period. For some pavements, this may actually occur but generally would not be the case for most. What this curve allows is for an agency to select the amount of benefit desired and restrict loads accordingly.

Clearly, the needed level of load reduction is not as simple as an examination of Figure 4 suggests. 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).

To further assist agencies, Figure 5 was developed. This figure is a plot of the load reduction required to maintain equivalent summer rutting levels (similar to Figure 4) versus reduction in remaining life due to spring thawing. Figure 5 was developed for the same tire-axle cases and the rutting failure criterion as used in Figure 4. The differences in remaining life between the actually applied and required load reductions were based on the relative values of the equivalent summer vertical subgrade strain (which results in the required load reduction) and that strain resulting from the actually applied load reduction. The family of curves shown are for various levels of actually applied load reduction (0 to 50 percent).

For example, if a pavement section actually needed (or required) a 40 percent load reduction to prevent pavement damage from exceeding that accumulated during the summer but only a 30 percent load reduction was actually applied, then the reduction in remaining life would be about 40 percent. Again, if the required load reduction is 40 percent but only a 20 percent load reduction was applied, then the reduction in remaining life would be slightly more than 60 percent.

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 would appear to be excessive (given the assumptions used in the preceding 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.

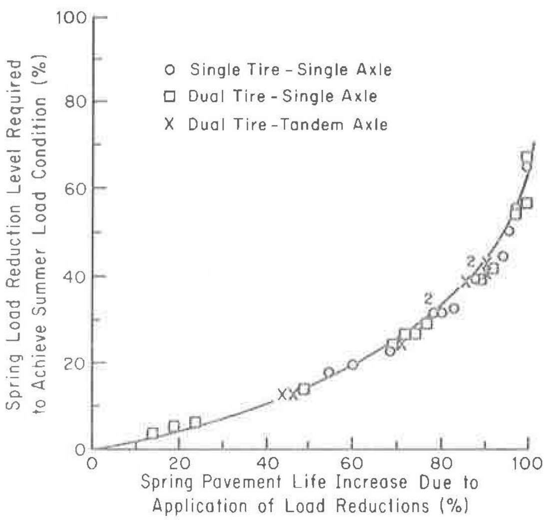

FIGURE 4 Load limit percentages from measured maximum spring deflections and known or assumed acceptable summer deflection levels.

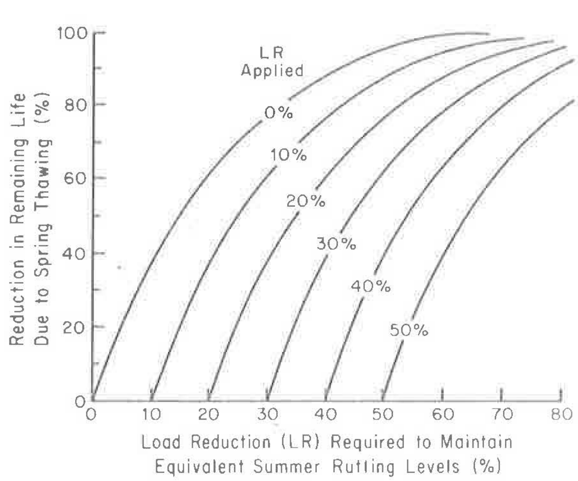

FIGURE 5 Increase in pavement life due to application of load reductions.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of this study indicate the following conclusions are warranted:

1. Surveys conducted in this study reveal the following:

- Load restrictions are applied mostly to pavements that have subgrades composed of moisture-susceptible silts and clays.
- Load restrictions are applied mostly to aggregate or asphalt-surfaced pavements, or both types. These pavements are usually older (about 20 years).
- The maximum legal loads are generally reduced from about 40 to 50 percent for single axles and 30 to 50 percent for tandem axles.
- Judgment by field personnel is primarily used to assess where, when, how much, and how long to apply load restrictions.

2. In the determination of where to apply load restrictions, the following is often considered:

- Comparison of summer and spring pavement surface deflection data,
- Surface thickness,
- Moisture conditions,
- Subgrade type, and
- Local experience.

3. The average load restriction 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 a minimum load restriction level (if any load reduction is needed) is 20 percent. Load reductions greater than 60 percent are not justifiable for the wide range of cases studied. Current national practice and the analysis performed in this study suggest that for those pavements that need restrictions, load

reductions ranging from 40 to 50 percent should accommodate a wide range of pavement conditions.

Recommendations

The following recommendations have been developed on the basis of the study findings:

1. Where to apply load restrictions: If pavement surface deflections are available to an agency, spring thaw deflections that are 45 to 50 percent greater than corresponding summer deflections suggest a need for load restriction. Further, considerations such as 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.
2. Load restriction magnitudes can be based on guidance provided in Figures 4 and 5. A minimum 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.

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