2. Had the effect of climate been included in the AASHO design by judiciously varying the effective asphalt layer coefficent as a function of effective modulus, a correct pavement design would have been obtained. The good agreement between the designs in the last two columns of Table 7 confirms this assertion.

These examples reaffirm the previous conclusions: namely, that the DF concept is a useful measure in assessing the relative effect of environment on pavement and that this concept could serve as a guide for personnel who allocate federal funds to projects in various parts of the country.

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Seasonal Load Limit Determined by the Criterion of Uniform Failure Rate

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ABSTRACT

Efficient performance of our highway system requires rational optimization of its use within the constraints of the adopted strategy. During the spring-thaw season in the northern part of the United States many highway agencies reduce the maximum load limits on some roads in an attempt to preserve the pavement serviceability. The selection of such a reduced load limit is not well defined now. A rational method has been developed that suggests that the load limit should be reduced in such a way to maintain a uniform rate of pavement deterioration throughout the year. The method considers various types of pavement failure such as fatigue cracking, rutting, and roughness and combines them by using the AASHO serviceability index. If the properties of the pavement materials are determined, mechanistic approaches can be used to predict the failure trend and to adjust the axle load limit to maintain the uniformity of this trend. A computer program LOADLMT has been developed in order to determine the optimum seasonal axle load limit on flexible pavements under various conditions. The use of the method was verified on a typical road under typical traffic distribution, material properties, and environmental conditions. The adoption of a seasonal load limit determined by this method indicates a large extension of the useful life of the road. The concept of this method is compared with other criteria currently used.

With the rapid aging of highway pavements, the public demand for higher levels of service, and the escalating rates for labor, equipment, and materials, highway operations should be performed according to a scientifically based procedure. A good understanding of the pavement behavior under various conditions and a rational optimization of such behavior within the constraints of the adopted strategy would result in efficient road performance.

The deterioration of pavement because of traffic and aging causes the serviceability of the road to decrease. The rate of decrease of serviceability varies depending on the amount of traffic, material properties, and environmental conditions. During

the spring-thaw season in the northern part of the United States the strength and stiffness of the subgrade soils and the unbound granular layers within the pavement section are decreased because of the increased moisture content that results from the melting ice. The loss of bearing capacity during the spring-thaw period is a recognized effect of frost action that severely impairs the performance of pavements. Under the same traffic conditions the permanent loss in pavement serviceability during a brief period in the spring may equal or exceed the loss during the rest of the year (1). One of the methods used by many highway agencies to preserve pavement serviceability on low-volume roads is to impose a low maximum load limit during the spring break-up period. The seasonal load limit is recognized by highway agencies; however, the selection process, which is the subject of this paper, is not well rationalized.

BACKGROUND

At this time the magnitude of the seasonal load limits, the dates of their imposition, and the duration of the restricted period are usually based on local experience (2). Empirical as well as mechanistic methods have been developed recently in at attempt to rationalize the criteria for a seasonal load limit. An empirical approach was introduced in NCHRP Report 76 (3) in which pavement deflection measurements were used. It was suggested that a load-limit restriction be imposed during the critical season in regions with a mean freezing index exceeding 200 degree-days and in which the average normal Dynaflect surface curvature index (SCI) measured during the previous fall exceeded 0.35 milli-in. The selection of the load-limit value is based on the assumption that the maximum safe axle load (L_s) that can be applied to a given highway during the critical period is inversely proportional to the maximum (peak) SCI measured during that period:

$$L_s = k/\text{maximum SCI} \quad (1)$$

where the constant k is equal to 6.3 and the maximum SCI is twice the normal SCI. Although this method is relatively simple and nondestructive, it does not relate the load-limit criteria directly to pavement damage. The method is also based on observations and correlations developed for specific in-service pavements that do not necessarily represent pavements in other regions. Therefore, the method is restricted to the soil types and conditions considered in the original investigation. For example, the maximum and the normal SCI values were linearly related, which may not be the case with other soil types and conditions.

Another common method used by some highway agencies is to limit the axle load based on the criterion of maintaining equal pavement surface deflection measured by a deflection-measuring device such as the Benkelman beam or the Dynaflect during the spring-thaw and summer-fall conditions. Although the method is also simple and nondestructive, it does not relate the load limit directly to pavement failures such as fatigue cracking, rutting, or roughness (slope variance). By reviewing the different factors affecting various modes of flexible pavement failure, fatigue cracking can be related to the number and magnitude of load repetitions, the horizontal strain at the bottom of the asphalt-bound layer, pavement temperature, and the fatigue properties of the asphalt-bound materials. Rutting, on the other hand, is the accumulation of permanent deformation with the increase in the number of wheel-load repetitions. Each increment of permanent deformation is a function of the deflection response, the number of previous repetitions, and the permanent deformation properties of the system. Moreover, roughness is a function of variability of the material properties and poor construction control. Therefore, the concept of controlling the load limit to obtain equal pavement surface deflections (recoverable or permanent or both) in the spring-thaw and summer-fall conditions measured by a deflection-measuring device does not necessarily produce the same rate of failure consumption.

A more rational mechanistic approach was developed (2) that assumes that the flexible pavement damage is due to fatigue cracking of the asphalt-bound layer. In this method, the maximum axle load allowed during the spring-thaw period is restricted to that which produces a horizontal (critical) tensile strain at the bottom of the asphalt-bound layer equal to the strain produced by the maximum legal axle load that is allowed during the normal summer-fall period. It is further assumed that if the number of heavy axle loads does not vary seasonably, the selected criterion will result in a uniform rate of damage and fatigue life consumption throughout the year. The study suggests the use of an elastic-layer computer program to calculate the horizontal tensile strain previously mentioned. The study also estimates the saving in the remaining pavement service life if the proposed load-limit method is used with respect to the remaining life when the equal-surface-deflection method is used or when no special seasonal load limit is imposed.

Although the fatigue-based criterion for seasonal load limit discussed earlier (2) is more rational than empirical approaches, some assumptions are oversimplified and are not fully justified, as discussed in the following:

1. It was assumed that the thaw weakening affects the fatigue behavior of the pavement only. Obviously slope variance and rutting are also affected by thaw weakening. In fact, slope variance and rutting contribute to flexible pavement serviceability more than fatigue cracking (4). The fatigue-based criterion may be efficient if previous experience shows that fatigue cracking is the critical type of failure for the specific condition.
2. All axle loads were implicitly assumed to have one magnitude, which was the maximum axle load limit. No consideration was given to the actual axle load distribution, although different axle loads contribute to pavement failure.
3. Only single axle loads were considered, and no consideration was given to tandem axle loads.
4. In the calculation of the remaining fatigue life under various seasonal load limits, it was assumed that the monthly number of axles remains the same during the year even when a lower axle load limit is imposed during the spring-thaw season. In fact, when a low axle load limit is imposed, some heavy trucks select other routes, which results in reducing the number of axles on the road.
5. The study assumed linear-elastic material properties, which do not represent the true material behavior and which neglect any permanent deformation (rutting and slope variance).

It is important to impose a seasonal load limit that optimizes the use of the road and its remaining useful life on a rational basis. If too low a load limit is imposed, the pavement may last longer but the use of the road might not be efficient as far as transportation is concerned. On the other hand, a load limit equal to or close to the normal load limit may result in fast pavement deterioration. A new concept, the criterion of uniform failure rate for

TABLE 1 Material Properties for Summer-Fall and Spring-Thaw Conditions

Material Property	Summer-Fall Conditions[a]				Spring-Thaw Conditions[b]			
	Surface	Base	Subbase	Subgrade	Surface	Base	Subbase	Subgrade
Modulus (psi)	532,000	20,000	10,000	5,000	900,000	20,000	10,000	3,000
Poisson's ratio	0.35	0.40	0.40	0.45	0.35	0.40	0.40	0.45
Fatigue properties								
K_1	0.918×10^{-2}	–	–	–	0.932×10^{-5}	–	–	–
K_2	3.08	–	–	–	3.14	–	–	–
Permanent deformation properties								
μ	0.06	0.04	0.05	0.06	0.035	0.04	0.05	0.07
α	0.75	0.75	0.75	0.85	0.75	0.75	0.75	0.65

Note: For detailed testing procedure, see report on VESYS program *(5)*.
[a]Average values for June through February.
[b]Average values for March and April.

TABLE 2 Current Axle Load Distribution in the Design Lane

Single Axle		Tandem Axle	
Axle Load (kips)	No./Day	Axle Load (kips)	No./Day
22	30	36	35
20	35	34	40
18	50	32	60
16	65	30	70
14	70	28	50
12	60	26	50
10	50	24	30

Note: Current daily 18-kip EALs = 500; traffic growth rate = 3 percent per year.

a 2-month period with both summer-fall and spring-thaw conditions and to adjust the spring load limit to maintain the difference in PSI within a tolerance of 0.1. It was found that the maximum single-axle and tandem-axle loads during the spring-thaw period should be 14 and 28 kips, respectively. In this case the change in the serviceability index during the 2 months of spring thaw was 0.103, whereas the corresponding change during 2 months within the summer-fall period was 0.025, a difference of 0.078.

The original VESYS computer program (5) was further used to investigate the trend of pavement failure with and without the seasonal load limit. The trends of the failure components--fatigue cracking index, rut depth, and slope variance--in the two cases are shown in Figures 4, 5, and 6. On the other hand, the trends of the serviceability index in the two cases are shown in Figure 7. It is noted that the trends of the individual pavement failure types are not uniform under the seasonal load limit condition. However, the trend of serviceability index under this condition is uniform, as shown in Figure 7. Also, if the terminal serviceability index is 2, the pavement is expected to reach the end of its useful life after 3.3 years without the seasonal load limit, whereas it is expected to last for 7 years with the seasonal load limit.

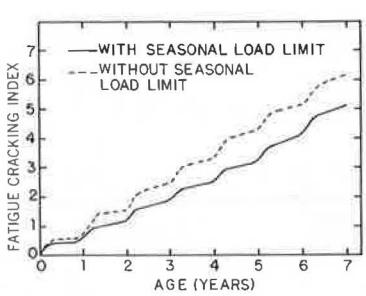

FIGURE 4 Fatigue cracking index versus age with and without seasonal load limit.

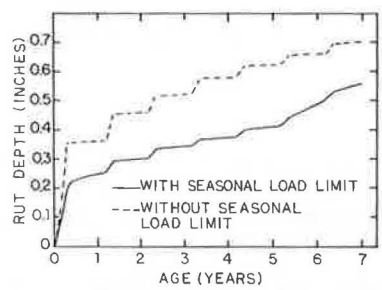

FIGURE 5 Rut depth versus age with and without seasonal load limit.

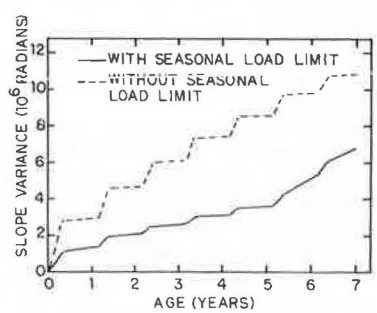

FIGURE 6 Slope variance versus age with and without seasonal load limit.

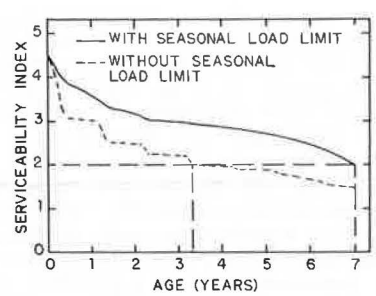

FIGURE 7 Serviceability index versus age with and without seasonal load limit.

In this example a comparison was made between the criterion of uniform failure rate and the equal deflection and the fatigue-based criteria by using the VESYS computer program. The results indicate that if the equal deflection criterion is used, a seasonal single-axle load limit of 18 kips should be imposed. On the other hand, if the fatigue-based criterion is used, no special seasonal load limit should be imposed because the horizontal tensile strains at the bottom of the asphalt-bound layer under the assumed properties for the spring-thaw and summer-fall conditions are close. Obviously this comparison is applicable for this example only. In general the criterion of uniform failure rate should provide more conservative seasonal load limits than those obtained by the fatigue-based criterion because the former considers various types of pavement failure and not just fatigue cracking.

CONCLUSION

Because of the weakening process in the pavement structure during the spring-thaw period it is necessary to impose a low load limit during that period for many secondary roads in the United States. A rational method of selecting this load limit is discussed and compared with other empirical and mechanistic methods. In this method the load limit should be reduced in such a way to maintain a uniform rate of pavement failure throughout the year. Various pavement failure types should be considered, such as fatigue cracking, rutting, and roughness. If the properties of the pavement materials under the summer-fall and spring-thaw conditions are determined, mechanistic techniques can be used to predict the failure trend and to adjust the axle load limit to maintain the uniformity of the pavement failure rate. In this study the computer program LOADLMT has been developed by modifying the FHWA computer program VESYS-3-A in order to determine the optimum seasonal axle load limit. The use of the method was verified by determining the seasonal load limit for a typical road under typical traffic distribution, material properties, and environmental conditions. The adoption of the seasonal load limit by using this method indicates a large extension of the useful life of the pavement. The results were compared with those obtained with other criteria. It is believed that the results obtained from this method would be more accurate than those from other methods. Although the proposed method is sophisticated, its use is justified in view of the escalating rate of highway maintenance.

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