An Examination of Environmental Versus Load Effects on Pavements

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This paper is a summary of the results of a study undertaken to examine environmental versus load effects on pavements. Pairs of pavement sections were examined at 14 locations in five states. At each location, one section had received normal traffic and the other had never been opened. Visual condition surveys were performed on each section, and pavement condition was compared. It is concluded that traffic loadings are a much more significant cause of pavement distress than are environmental problems.

Much of the U.S. highway infrastructure has fulfilled its useful life and needs replacement or rehabilitation. High inflation rates and increased competition for tax dollars caused maintenance to be deferred on a large portion of the highway system. The Congress and state legislatures are faced with finding a funding source for maintenance, rehabilitation, and reconstruction.

To fairly allocate highway maintenance costs, it is essential to know the relative amounts of damage that result from various causes. The best-known causes of pavement damage include environment, poor materials, and traffic loads. It is often assumed that there is some base environmental- and materials-related damage to be charged equally to all users. The remaining costs are then allocated to system users according to the damage caused by each class of user.

The problem with determining the amount of damage due to each cause separately is that there are interactions between causes *(1, 2)*. For example, without precipitation rigid pavements would not pump. By the same token without loads crossing joints and cracks in the pavement during the rain there would be no pumping. Therefore pumping is caused by a combination of environment and traffic. The relationship between traffic loads and pavement damage was quantified during the AASHO Road Test, which was a comprehensive, large-scale experiment designed to determine the effects of various vehicle loads on pavement performance and on deterioration rates *(3)*.

The road test findings, published in 1962 *(4)*, show that the damaging effects of heavy axle loads are extremely large compared with damage caused by light axle loads. In spite of the evidence produced by the AASHO Road Test, there are many claims that trucks cause little or no more damage to pavements than do automobiles. These claims accompany political pressure to raise legal axle load limits without proportional increases in user fees and taxes.

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BACKGROUND

Pavement damage generally results from three factors: environmental effects, materials problems, and loads. The most important environmental effects are moisture and temperature effects. Moisture in the pavement produces several problems including surface oxidation, ice lens formation (swell), base failure, slope instability, volume changes, and stresses *(5)*. Temperature differentials cause shrinkage and expansion, and these induce stresses in pavement.

Materials or poor construction quality control, or both, can also result in accelerated pavement damage. An obvious materials problem is poor aggregate in rigid pavements. Certain aggregates can cause deterioration cracking, known as D-cracking. This distress is evidenced by hairline parallel cracks at slab corners and edges. As the cracks grow, pieces of slab work loose. Ultimately, the slab falls apart. Poor construction quality can also result in problems such as misaligned dowel bars, concrete voids under the reinforcement, and concrete mixes that are too rich or too lean. These in turn lead to premature pavement damage.

As indicated in previous reports, the primary cause of pavement damage is traffic loading generated by heavy trucks *(6)*. Some sources point to parkways (car-only roadways) such as the Baltimore-Washington Parkway and the Merrit Parkway in Connecticut as evidence that parkways wear out just as fast as highways that carry truck traffic. Studies by Hudson and Seeds *(6, 7)* looked at performance of these and other parkways to determine if they were performing properly. These studies concluded that damage to the Baltimore-Washington Parkway was primarily due to a poor choice of aggregates and not to automobile use. Damage on the Merrit Parkway was due primarily to studded snow tires, which have since been banned. These studies also concluded that properly designed parkways can be relatively thinner than Interstate highways and still meet and often exceed design lifetimes, in terms of both cumulative traffic loadings and years of expected service life.

OBJECTIVE

This study was done as a follow-on to several reports by Hudson and Hudson and Seeds that have examined the relationship between traffic, especially heavy truck traffic, and pavement damage *(5–8)*. The objective was to illustrate the relative damage due to environmental forces and materials problems compared with that caused by loads. The approach was to examine several pairs of pavement sections with similar characteristics that have been subjected to different traffic levels. Several pairs of sections in different environments were compared to examine the load-environment interaction.

The purpose of this research effort was to examine the current condition of pavements that were constructed to carry normal traffic but that have not been trafficked on a regular basis since construction. Pavements examined included primary and Interstate highway sections that were built for traffic but received little or no traffic due to legal or other delays.

The normally constructed but untrafficked pavements were compared in each case with similar pavements that received regular highway traffic. In each case, the highway agency involved was contacted to obtain detailed design, construction, and traffic information on the sections observed. Condition surveys concentrated on distress that results from environment and load.

SCOPE

The project scope was to compare pairs of pavement sections, nearly identical in character with the exception of traffic. Ideally, pairs of sections would have identical materials, construction, age, and environmental history. To draw valid conclusions, the sections were to be part of the same pavement, with the untrafficked section having had no traffic. Observed differences in distress levels could then be related to observed differences in traffic and environment.

Because of the importance of environmental effects, sections were sought in several environmental regions that varied with respect to freezing and thawing and moisture. For this study, the six AASHTO environmental regions were adopted:

- I Wet, no freeze
- II Wet, freeze-thaw cycling
- III Wet, hard-freeze, spring thaw
- IV Dry, no freeze
- V Dry, freeze-thaw cycling
- VI Dry, hard-freeze, spring thaw

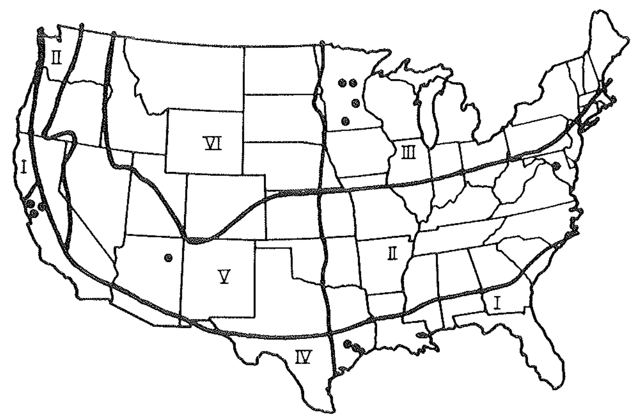
These regions are shown in Figure 1. The regions range from Region II (wet, freeze-thaw cycling) as the most environmentally destructive to Region IV (dry, no freeze) as the least destructive.

The search was concentrated in Texas for Region I, Maryland for Region II, Minnesota for Region III, California for Region IV, and Arizona for Region V.

CONDUCT OF RESEARCH

Initial contact was made with personnel from state transportation agencies in an attempt to locate study sections for comparison. Sought were stub ends, spurs, lanes, and ramps of primary or Interstate highways that were constructed but never opened to traffic. These sections were then visited and surveyed for visual condition.

Several standard terms were selected to simplify description of pavement units. A "section" is a portion of pavement that has either been trafficked or untrafficked. "Location" corresponds to a pair of sections, one trafficked, one untrafficked. In addition, as a result of the number of pavement sections, the



REGION	CHARACTERISTICS
I	Wet, No Freeze
II	Wet, Freeze-Thaw Cycling
III	Wet, Hard-Freeze, Spring Thaw
IV	Dry, No Freeze
V	Dry, Freeze-Thaw Cycling
VI	Dry, Hard Freeze, Spring Thaw

FIGURE 1 Test locations and environmental regions.

following identification system was adopted. Each location is identified by the two-letter code of the state in which it is situated, followed by a number assigned to that location. For example, the Minnesota locations are identified as MN1 through MN7. Sections are further identified by T for "trafficked" and U for "untrafficked." The untrafficked section at the seventh Minnesota location then is MN7U.

Example Location

Data from the Milaca, Minnesota, location (MN7) are presented as an example of the procedure used. MN7 is located approximately 1 mi south of Milaca (Figure 2) where US-169 changes from a four-lane divided highway to a two-lane undivided highway. MN7T is south of the point where the northbound traffic moves off the undivided AC pavement. MN7U is a stub end approximately 50 ft long (Figure 3).

Construction

MN7 is an asphalt concrete pavement built in 1972 with the following pavement structure:

- 1-in. AC hot mix,
- $1^1/_2$-in. bituminous base, and
- 6-in. aggregate base.

Traffic

Traffic, including 7 percent trucks, is as follows:

Year	*ADT*
1984	2,425
1982	2,150
1980	2,025
1978	2,038
1976	1,843

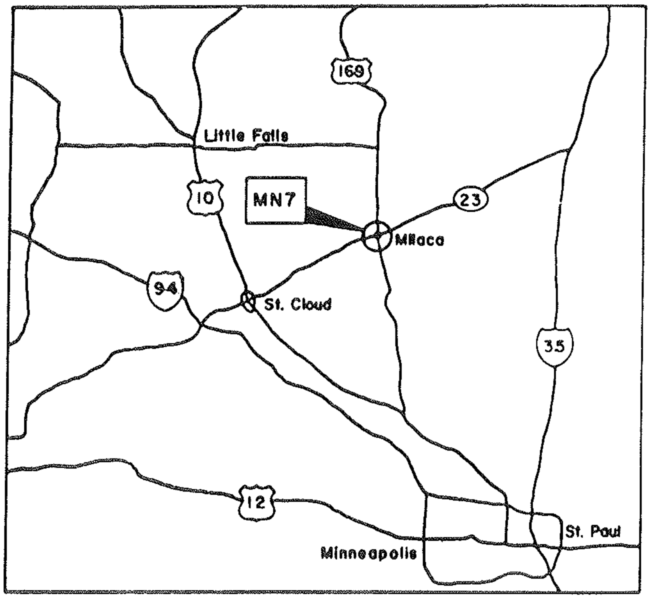


FIGURE 2 Milaca, Minnesota, location.

Environment

MN7 is located in Environmental Region III (wet, freeze).

Distress

MN7T is cracked into 10- to 15-ft blocks with all cracks spalled 1/2 to 1 in. The wheelpaths are slightly alligator cracked and have ruts 1/8 to 1/4 in. deep. The area between the wheelpaths is slightly raveled. The cracks on MN7U are not spalled and are 25 to 30 percent as dense as those on MN7T.

Observations

There is a clear difference in cracking severity for this section. The cause of the cracking and severity of the distress between MN7T and MN7U demonstrates that, although this distress is environmentally caused, it is accentuated by traffic.

Results

As the study progressed, 14 suitable pairs of pavements were located. A complete data set was collected for 11 of these and is given in Table 1. Although some data (traffic and construction) were unobtainable for three sections (located in Arizona and California), visual condition survey data on these sections are given in Table 2.

Two trends are apparent in the data:

- For each pair of sections, the diversity, extent, and distress are greater for trafficked sections than for untrafficked sections.
- The effect of environment is not constant across different environmental regions.

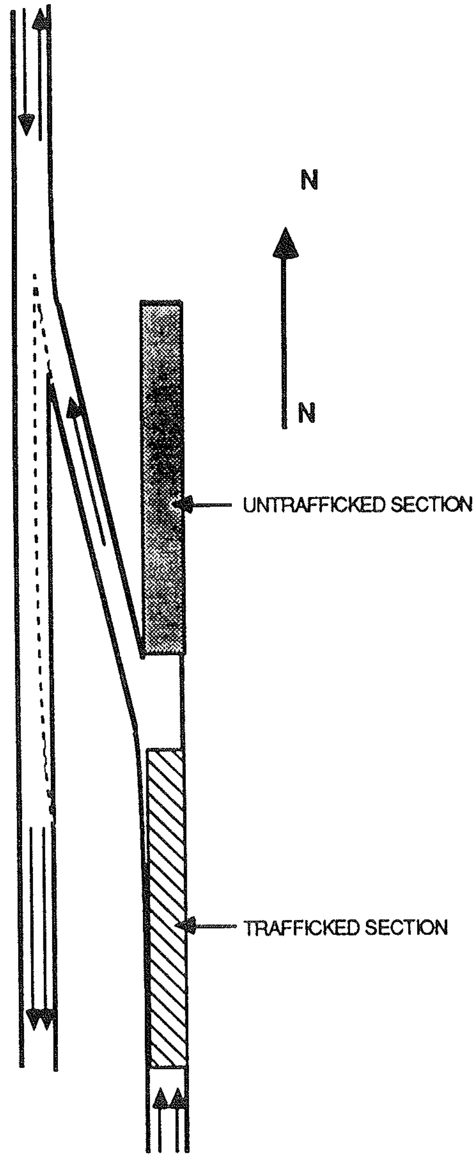


FIGURE 3 Detail of Milaca location.

Effect of Traffic

For every pair of sections examined there was significantly more distress with respect to type, extent, and severity on the trafficked than on the untrafficked section.

Effect of Environment

Environmental forces caused distress in the untrafficked sections. In all but a few of these sections there was distress, although it was universally less than distress on the comparable trafficked section.

DISCUSSION OF FINDINGS

The information collected here is from a series of case studies that were examined to compare pavement damage. In each case, one pavement section was subjected to environmental forces only while a companion section was subjected to the combined effects of traffic loads and environmental forces.

TABLE 1 COMPLETE INFORMATION ON LOCATIONS

STATE	ROUTE	CITY	ENVIRONMENTAL REGION	T-TRAFFICKED U-UNTRAFFICKED	PAVEMENT STRUCTURE: PAVEMENT TYPE	PAVEMENT STRUCTURE: SURFACE THICK INCHES	AGE (YEARS)	TRAFFIC: ADT	TRAFFIC: % TRUCKS	RIGID: FAULTING	RIGID: D CRACKING SLIGHT	RIGID: D CRACKING MODER	RIGID: PATCH & POTHOLES	RIGID: PUNCHOUTS	RIGID: TRANS CRACKS < 1/4"	RIGID: TRANS CRACKS 1/4"-1/2"	RIGID: SCALING/ABRASION	RIGID: SEALANT DAMAGE	RIGID: CORNER CRACKS	RIGID: SPALLING < 1/2"	RIGID: SPALLING > 1/2"	RIGID: POLISHED AGGREG	FLEXIBLE: CRACKING SLIGHT	FLEXIBLE: CRACKING MODER	FLEXIBLE: BLEEDING	FLEXIBLE: RUTTING	FLEXIBLE: RAVELLING	FLEXIBLE: FATIGUE CRACKING
MD	I-95	WASHINGTON, DC	II	T	CRCP	8/9	15	30K	17		X		X	X	N		X			X								
				U	CRCP	8/9	15	0	0									X										
TX	U S 290	CYPRESS	I	T	JCP	10	20	18K	10			X	X		X			X		X		X						
				U	JCP	10	20	0	0						X													
	SH 146	SEABROOK	I	T	JCP	10	15	16 6K	6		X				X		X	X										
				U	JCP	10	15	0	0								X											
MN	I -94	ST. PAUL (WESTBOUND)	III	T	JCP	10	14	47 4K	6	X		X	X			X	X	X			X							
				U	JCP	10	14	0	0						X						X							
		ST. PAUL (EASTBOUND)	III	T	JCP	10	14	47 4K	6				X		X		X				X							
				U	JCP	10	14	0	0											X								
	I-35 W	MINNEAPOLIS	III	T	JCP	10	10	37 4K	5 6				X															
				U	JCP	10	10	0	0									X										
	U S 280	MINNEAPOLIS	III	T	JCP	9	14	15K	8 8	X			X					X	X		X							
				U	JCP	9	14	0	0						X			X		X								
	SH 60	ST. JAMES	III	T	JCP	9	8	2 4K	16									X	X	X								
				U	JCP	9	8	0	0											X								
	U S 10	RANDALL	III	T	AC	3	7	2K	10												X			X			X	
				U	AC	3	7	0	0														X					
	U S 169	MILACA	III	T	AC	3	14	2 4K	7												X			X		X	X	X
				U	AC	3	14	0	0											X								
CA	SR 17	SUMMIT	IV	T	AC	5	15	51K	6 2				X											X		X	X	X
				U	AC	5	15	0	0																			

N - NORMAL TRANSVERSE CRACKING FOR CRCP

TABLE 2 LOCATIONS WITH INCOMPLETE INFORMATION

State	Route	City	Environmental Region	T-Trafficked U-Untrafficked	Pavement Structure: Pavement Type	Rigid: Faulting	D Cracking: Slight	D Cracking: Moder.	Patch & Potholes	Punchouts	Trans Cracks: < 1/4"	Trans Cracks: 1/4" to 1/2"	Scaling	Sealant Damage	Corner Cracks	Spalling: < 1/2"	Spalling: > 1/2"	Polished Aggreg.	Cracking: Slight	Cracking: Moder.	Flexible: Bleeding	Rutting	Ravelling	Fatigue Cracking
CA	I 280	SAN JOSE	IV	T	JCP						X					X								
				U	JCP											X								
	I 380	SAN FRANCISCO	IV	T	JCP	X					X													
				U	JCP																			
AZ	I-40	HOLBROOK	V	T	AC																X	X	X	X
				U	AC																			

The case study locations were situated in four of the severest environmental regions used to classify areas of the United States (Figure 1). Although these 14 case studies do not represent all possible combinations of traffic, pavement strength, and environmental conditions, they do represent a good cross section of pavements in the United States. The significant factor is that in every case the section subjected to the combination of traffic and environment suffered greater damage than did the section subjected to environment alone. In most cases, the difference was rather dramatically greater when traffic was added.

As previously pointed out, the observed difference was probably not due to traffic alone. In some cases it is due to the interaction between traffic and environment. For example, the environment can induce a temperature crack that is aggravated and intensified by traffic repeatedly passing over it. In some of the cases, the same type of distress was observed on both sections, but the severity of the distress was much greater on the trafficked than on the untrafficked section. In these cases, the distress was of the type that is usually environmentally induced and then load enhanced. In the case of thermal cracking, for example, not only was the spalling of the cracks more severe under traffic but the density of the cracks in the section was also more severe.

At some of the observed sections, there was considerable distress of a given type in the trafficked section but no such distress in the untrafficked section. In such cases, it is probable that traffic was the initiating cause of the damage, because it occurred only in the trafficked sections. It is probable that the environment then enhanced or increased the effect of the load-induced damage.

Examination of the data shows differences between levels of severity of distress in the regions where freezing was a factor. In both freeze-thaw-cycling and hard-freeze regions, the difference in the levels of severity of distress was greater than in the no-freeze region. In other words, in both freeze-related regions where environmental distress is expected to be greater, the difference in distress between trafficked and untrafficked sections is greater than in the milder region. This suggests again that the interaction of load with the environment has a severe effect. Location MN7 at Milaca, Minnesota, clearly illustrates this interaction. Similar results are observable for differences in distress between wet and dry areas, as evidenced by location TX1 at Cypress, Texas.

An example of the phenomenon with respect to wet and dry areas is the previously cited pavement pumping problem. Clearly pumping and related damage is induced by loads in the presence of water, but such interaction is also more prevalent in wet areas than in dry areas. Thus the effect of loads is not only more severe than the effect of environment but the effect of load is compounded more severely in harsh environments than in mild environments.

SUMMARY

The objective of this study was to examine the relative amount of damage caused by environmental forces versus that caused by loads. Fourteen similar pairs of pavement sections were examined. Each pair consisted of a pavement section that had received traffic and a similar one that had not. To strengthen possible conclusions from the data, the sections selected were generally of identical construction and age. Untrafficked pavements were sections that had never been opened to traffic for various reasons. The trafficked sections consisted of adjacent pavement subjected to normal traffic. Sections were examined in Arizona, California, Maryland, Minnesota, and Texas to give wide coverage of environmental variables.

For all 14 case study pairs the damage on trafficked sections is more severe than the damage on untrafficked sections. In addition, the total damage with traffic loading was generally greater in harsh environments than in mild environments. Therefore, although quantitative conclusions cannot be drawn, these data support the conclusion that the damaging effect of traffic is generally more severe than the effect of environment alone and that the damaging effect of traffic is proportionally greater in harsh environments than it is in mild environments.

There remains the important need to collect more adequate data on pavement performance to quantify relationships and develop mathematical models. These models will, in turn, define the relative effects of load and environment and their interaction on pavement damage and ultimately pavement performance. Although the Strategic Highway Research Program proposes to undertake such a study, the results will be 5 to 10

years or longer in coming. Until such results are available, it is essential that the findings of small studies such as this one be used to help assess realistic relationships for defining the effects of damage and using these relationships in the difficult task of allocating pavement costs.

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