Environmental effects on pavements, DIMAR

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16. Abstract
This study was completed to identify and define the interdependency relationships and corresponding interaction criteria between aging, environmental, and vehicle load effects upon and during the life cycle of highway and airport pavements and their support systems. A questionnaire was sent to numerous researchers and engineers to obtain a consensus on the definitions of pavement distress. Based on a 67 percent return it was indicated that the "Highway Pavement Distress Identification Manual," should be used for asphalt surfaced pavements and that the "Concrete Highway Distress Identification Manual for COPES" should be used for portland cement concrete pavements.

Through the use of a computerized Distress Identification and Mechanism Analysis Routine (DIMAR) program the mechanisms which are associated with distresses in flexible, rigid and composite highway and airport pavement systems were identified and tabulated. In the DIMAR program the inputs, processes, and contributing factors which related to each distress mechanism were defined and listed. The material and pavement layer properties influenced by each distress mechanism were identified and procedures for evaluating these properties were listed.

Based on the DIMAR program the potential work areas proposed under Phase II, "Analytical Model Development and Laboratory Verification," were defined and stated in a separate report.

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Pavement, Distress, Maintenance, Environmental Factors, Performance, Asphalt, Concrete, Material Properties, Testing

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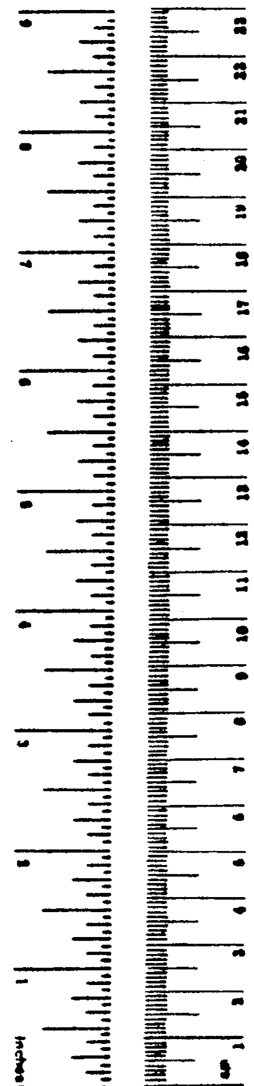
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

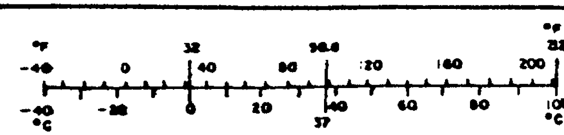
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Chapter 1

INTRODUCTION

1.1 GENERAL

In addition to large volumes of heavy traffic, pavement systems are subjected to destructive effects of weather and age which deteriorate them at a much higher rate than anticipated and accounted for in the original design. The problem is compounded with insufficient maintenance because of limited maintenance funds, restricted and hazardous working conditions, and increased user vehicle operational costs caused by traffic jams, detours, and delays; all of which reduce safety.

In the past considerable research has been conducted to develop "Premium Pavements for Zero Maintenance." A "Premium Pavement for Zero Maintenance" is defined as one designed for specific conditions which will essentially remain free of structural maintenance for 20 years and will require a minimum of maintenance for the next 10 to 20 years. The major research tasks initiated to date have been directed toward the development of new materials, new structural designs, upgrading conventional pavement designs, and toward the development of economical analysis systems.

In the AASHTO Design Procedure the effect of the environment is taken into account primarily by the use of regional factors only. The recently developed pavement analysis techniques recognize the influence of the environment upon the material properties only and include such factors as change of the elastic modulus of flexible pavements with temperature, change in support modulus of subbases with moisture content, etc.

Present design models recognize and account for the warp and curl of rigid pavements caused by moisture and temperature gradients through the slab thickness by merely adding the environmental effects algebraically to the corresponding effects caused by vehicle loads. They fail to account for the change in subbase support of the vehicle loads caused by the warp and curl of the rigid slab. Very little attention has been devoted to the study of the interdependence and the interaction relationships between environmental and vehicle load as they effect pavement performance. For example, the progressive reduction and eventual loss of subbase support of vehicle loads due to dynamic pumping action beneath rigid slabs is generally omitted in present design technology. Similarly, in the present design of flexible pavements, the aging effects and the rate and frequency of vehicle load applications are usually neglected, as is the interaction phenomenon between rutting and cracking. Analysis of past pavement studies indicate that research directed to identifying the interdependency, interactions, and relationships that exist between aging, environmental, and vehicle load effects upon and during the life cycle of the pavement system is needed.

1.2 OBJECTIVES

The general objective of this report is to identify and define all interdependency relationships and corresponding interaction criteria between aging, environmental, and vehicle load effects upon and during the life cycle of highway and airport pavements and their support systems as defined in Phase I "Identification and Definition of Contributing Factors."

The specific objectives which were accomplished are as follows:

1. To gain a consensus on the definitions of pavement distress used by highway, pavement and or transportation engineers.

2. Identify and tabulate the mechanisms which are associated with distresses in flexible, rigid, and composite pavements.
3. Define and list the inputs, processes, and contributing factors which relate to the distress mechanisms.
4. Identify the material and pavement layer properties influenced by each distress mechanism and the procedure for evaluating these properties.
5. Develop a systematic and efficient procedure for documentation of the pavement distress information.

Chapter 2

DISTRESS DEFINITIONS

2.1 GENERAL

In this study it was felt important to gain a consensus on the definitions of pavement distress used by highway, pavement, and/or transportation engineers. It is observed that many states and agencies have their own definitions of pavement distress and distress manifestations. These definitions are generally tailored to the needs and idiosyncrasies of a particular state or region.

2.2 DISTRESS DEFINITIONS

The first step taken during this study was to select a standard to identify and define distresses associated with pavement systems. The standard selected was the "Highway Pavement Distress Identification Manual"(1). This manual was produced under two contracts. The asphalt pavement portion was done under FHWA contract and the portland cement concrete pavement section was done under NCHRP Project 1-19. The manual provides standardized identification of distress types associated with four types of conventional pavements: jointed plain concrete, jointed reinforced concrete, continuously reinforced concrete, asphalt surfaced with granular or stabilized base and asphalt overlays over portland cement concrete. Each distress type is described in the manual along with its primary mechanism, levels of severity, and measurement criteria.

2.3 TEST OF STANDARD

In order to test the standard a questionnaire shown in Appendix A was sent to thirty researchers and fifteen state highway department engineers to ascertain whether they agreed with the distress types identified and defined in the "Highway Pavement Distress Identification Manual." The researchers and state highway department engineers were selected as those who are eminently qualified based on their experience, interests, and contributions in pavement design, highway materials, and pavement rehabilitation.

Certainly it is impossible to include all qualified and renown individuals in such an effort. However, it is believed that the views expressed by those responding in this survey are typical of the majority of qualified personnel in this area.

Complete responses were received from twenty of those canvassed and at least a partial response was received from an additional ten. Thus a response was recorded from 67 percent of those questioned which was considered successful.

2.4 QUESTIONNAIRE RESULTS

The general response from those canvassed was that they agreed in principal with the "Highway Pavement Distress Identification Manual." The comments included in Appendix A are the only significant alterations or additions suggested by these responding to the questionnaire.

A number of those responding suggested alternate manuals to <u>supplement</u> the "Highway Pavement Distress Identification Manual." These manuals are:

1. "Manual for Pavement Condition Rating Surveys," State of Washington, DOT.
2. "Development of Pavement Condition Rating Procedures for Roads, Streets and Parking Lots - Vol. II - Distress Identification Manual," <u>Technical Report M-268</u>, CERL, July, 1979.

3. "Cracking in Continuously Reinforced Concrete Pavements," Kentucky DOT, October, 1977.

4. "The D-Cracking Phenomenon: A Case Study for Pavement Rehabilitation," Kentucky DOT, April, 1976.

5. "Guidelines for Flexible Pavement Failure Investigation," Research Report 214-16, TTI, August, 1980.

6. "Concrete Highway Distress Identification Manual for COPES - Part III," Appendix to Interim Report, NCHRP Project 1-19, November, 1979.

2.5 STUDY CONCLUSION

It is the conclusion of this study that the "Highway Pavement Distress Identification Manual" should be used for asphalt surfaced pavements and that the "Concrete Highway Distress Identification Manual for COPES," should be used for portland cement concrete pavements. The "Concrete Highway Distress Identification Manual for COPES" is simply a revised treatment of the material for portland cement concrete pavements in the original "Highway Pavement Distress Identification Manual."

Chapter 3

DISTRESS IDENTIFICATION AND MECHANISM ANALYSIS ROUTINE (DIMAR)

3.1 GENERAL

The identification and tabulation of the mechanisms associated with distress in flexible, rigid, and composite pavements were obtained from References 1 through 36. References 1 through 8 were considered to be the major sources of information based on the distress survey. The distresses surveyed were considered to be representative of those found in the various climatic regions of the United States.

Early in the study it became apparent that a systematic and efficient procedure would be necessary to document and disseminate the vast quantity of interactive information being gathered in this study. For this reason the computerized Distress Identification and Mechanism Analysis Routine (DIMAR) was developed.

3.2 DIMAR

Appendices B through F show all portions of the DIMAR program.

Appendix B provides a listing of the DIMAR computer program. This program is written in "basic" language and stored on disc for use in a CDC CYBER 175 computer. The program can be easily updated or expanded with little disruption to the user. The program can also be easily and quickly accessed from a remote terminal.

Appendix C provides an explanation of DIMAR and definitions of terms. Appendices D through F provide listings of the highway and airport pavement distresses stored in the DIMAR program. The distresses have been identified for plain and reinforced jointed concrete pavements, continuously reinforced concrete pavements, and flexible pavements.

In DIMAR one or more mechanisms have been identified for each distress. Each mechanism consists of a combination of inputs, processes, and contributing factors which results in a distress response as shown in the flow diagram in Appendix C. The mechanism processes, which are listed and defined in Appendix C, consist of the following:

1. PS - Structural
2. PP - Particulate
3. PD - Dynamical
4. PC - Chemical
5. PM - Moisture
6. PT - Thermal

The mechanism inputs which are also listed and defined in Appendix C include the following:

1. IL - Load
2. IM - Moisture
3. IT - Temperature
4. IC - Chemical

The factors contributing to a distress mechanism include:

1. CM - Material Properties
2. CD - Design, Construction, and Maintenance
3. CG - Geometry of Pavement.

In the listing the prefixes P, I, and C indicate processes, inputs, and contributing factors respectively. In DIMAR the processes, inputs, and contributing factors may act interactively or separately. Interactive processes for a distress are shown in DIMAR as PM+PC+PT for example. Processes which are of equal importance but act separately are shown for example as PM/PT. In DIMAR the distress is related to either the properties of a specific pavement material (M) or to the properties of the entire pavement structure (S).

The output from the various distresses are shown in Appendices D, E, and F. For each distress mechanism the processes and pavement materials and/or layers affected are listed. This is followed by a listing of inputs and contributing factors which influence the distress mechanism. The material and pavement system properties are then listed along with procedures for evaluating the properties associated with a distress mechanism. As an option, secondary distresses which may result from a primary distress can also be specified by the DIMAR program.

The DIMAR program is a flexible, efficient, and easily used program for evaluating pavement distress mechanisms and it has the advantage of being expanded to account for other distress factors as they become evident.

Chapter 4

SUMMARY AND CONCLUSIONS

4.1 SUMMARY

This phase was completed to identify and define the interdependency relationships and corresponding interaction criteria between aging, environmental, and vehicle load effects upon and during the life cycle of highway and airport pavements and their support systems. A questionnaire was sent to numerous researchers and engineers to obtain a consensus on the definitions of pavement distress. Based on a 67 percent return it was indicated that the "Highway Pavement Distress Identification Manual", should be used for asphalt surfaced pavements and that the "Concrete Highway Distress Identification Manual for COPES" should be used for portland cement concrete pavements.

Through the use of a computerized Distress Identification and Mechanism Analysis Routine (DIMAR) program the mechanisms which are associated with distresses in flexible, rigid and composite highway and airport pavement systems were identified and tabulated. In the DIMAR program the inputs, processes, and contributing factors which related to each distress mechanism were defined and listed. The material and pavement layer properties influenced by each distress mechanism were identified and procedures for evaluating these properties were listed.

4.2 CONCLUSION

From this study the following conclusions are presented:

1. The "Highway Pavement Distress Identification Manual" and the "Concrete Highway Distress Identification Manual for COPES" are recommended as guidelines for pavement distress identification.
2. The computerized DIMAR program provides a systematic and efficient procedure for documentation of pavement distress information.
3. The DIMAR program provides for easy access to large amounts of pavement distress information by multiple users.
4. The DIMAR program can be easily up-dated or expanded as more pavement distress information becomes available.

4.3 RECOMMENDATIONS

Based on this research the following recommendations are made

1. Encourage implementation of the computerized DIMAR program for use by State and Federal transportation agencies.
2. Expansion of the DIMAR program to quantitatively account for the occurrences of distress mechanisms related to aging, environmental, and vehicle load effects.

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APPENDIX A

DISTRESS QUESTIONNAIRE AND COMMENTS

This questionnaire is keyed to the Table of Contents of FHWA Manual FHWA-RD-79-66, "Highway Pavement Distress Identification Manual".

Please check the appropriate general statement below and return with the questionnaire.

_____ Due to time constraints I am unable to assist you in this survey.

_____ I agree in principle with the general definitions of the FHWA Pavement Distress Identification Manual, but haven't the time to individually evaluate the distress categories.

_____ I agree in principle with the general definitions and approach of the FHWA Manual Pavement Distress Identification Manual. However, I have reservations about certain aspects which I have noted in the questionnaire.

Distress Type	Description Agree	Description Disagree	Severity Level Agree	Severity Level Disagree	Method of Measurement Agree	Method of Measurement Disagree	Remarks
ASPHALT SURFACED							
Alligator or Fatigue Cracking	___	___	___	___	___	___	
Bleeding	___	___	___	___	___	___	
Block Cracking	___	___	___	___	___	___	
Corrugation	___	___	___	___	___	___	
Depression	___	___	___	___	___	___	
Joint Reflection Cracking from PCC Slab	___	___	___	___	___	___	
Lane/Shoulder Dropoff or Heave	___	___	___	___	___	___	
Lane/Shoulder Separation	___	___	___	___	___	___	
Longitudinal and Transverse Cracking (Non-PCC Slab Joint Reflective)	___	___	___	___	___	___	
Patch Deterioration	___	___	___	___	___	___	
Polished Aggregate	___	___	___	___	___	___	
Potholes	___	___	___	___	___	___	
Pumping and Water Bleeding	___	___	___	___	___	___	
Raveling and Weathering	___	___	___	___	___	___	
Rutting	___	___	___	___	___	___	
Slippage Cracking	___	___	___	___	___	___	
Swell	___	___	___	___	___	___	

Distress Type	Description Agree	Description Disagree	Severity Level Agree	Severity Level Disagree	Method of Measurement Agree	Method of Measurement Disagree	Remarks
JOINTED PLAIN CONCRETE							
Blow-up	___	___	___	___	___	___	
Corner Break	___	___	___	___	___	___	
Depression	___	___	___	___	___	___	
Durability ("D") Cracking	___	___	___	___	___	___	
Faulting of Transverse Joints and Cracks	___	___	___	___	___	___	
Joint Load Transfer System Associated Deterioration	___	___	___	___	___	___	
Joint Seal Damage of Transverse Joints	___	___	___	___	___	___	
Lane/Shoulder Dropoff or Heave	___	___	___	___	___	___	
Lane/Shoulder Joint Separation	___	___	___	___	___	___	
Longitudinal Cracks	___	___	___	___	___	___	
Longitudinal Joint Faulting	___	___	___	___	___	___	
Patch Deterioration	___	___	___	___	___	___	
Patch Adjacent Slab Deterioration	___	___	___	___	___	___	
Popouts	___	___	___	___	___	___	
Pumping and Water Bleeding	___	___	___	___	___	___	
Reactive Aggregate Durability Distress	___	___	___	___	___	___	
Scaling, Map Cracking and Crazing	___	___	___	___	___	___	
Spalling	___	___	___	___	___	___	
Swell	___	___	___	___	___	___	
Transverse and Diagonal Cracks	___	___	___	___	___	___	

Distress Type	Description		Severity Level		Method of Measurement		Remarks
	Agree	Disagree	Agree	Disagree	Agree	Disagree	
JOINTED REINFORCED CONCRETE							
Blow-up	___	___	___	___	___	___	
Corner Break	___	___	___	___	___	___	
Depression	___	___	___	___	___	___	
Durability ("D") Cracking	___	___	___	___	___	___	
Faulting of Transverse Joints and Cracks	___	___	___	___	___	___	
Joint Load Transfer System Associated Deterioration	___	___	___	___	___	___	
Joint Seal Damage of Transverse Joints	___	___	___	___	___	___	
Lane/Shoulder Dropoff or Heave	___	___	___	___	___	___	
Lane/Shoulder Joint Separation	___	___	___	___	___	___	
Longitudinal Cracks	___	___	___	___	___	___	
Longitudinal Joint Faulting	___	___	___	___	___	___	
Patch Deterioration	___	___	___	___	___	___	
Patch Adjacent Slab Deterioration	___	___	___	___	___	___	
Popouts	___	___	___	___	___	___	
Pumping and Water Bleeding	___	___	___	___	___	___	
Reactive Aggregate Durability Distress	___	___	___	___	___	___	
Scaling, Map Cracking and Crazing	___	___	___	___	___	___	
Spalling	___	___	___	___	___	___	
Swell	___	___	___	___	___	___	
Transverse and Diagonal Cracks	___	___	___	___	___	___	

Distress Type	Description		Severity Level		Method of Measurement		Remarks
	Agree	Disagree	Agree	Disagree	Agree	Disagree	
CONTINUOUSLY REINFORCED CONCRETE							
Asphalt Patch Deterioration	___	___	___	___	___	___	
Blow-up	___	___	___	___	___	___	
Concrete Patch Deterioration	___	___	___	___	___	___	
Construction Joint Distress	___	___	___	___	___	___	
Depression	___	___	___	___	___	___	
Durability ("D") Cracking	___	___	___	___	___	___	
Edge Punchout	___	___	___	___	___	___	
Lane/Shoulder Dropoff or Heave	___	___	___	___	___	___	
Lane/Shoulder Joint Separation	___	___	___	___	___	___	
Localized Distress	___	___	___	___	___	___	
Longitudinal Cracking	___	___	___	___	___	___	
Longitudinal Joint Faulting	___	___	___	___	___	___	
Patch Adjacent Slab Deterioration	___	___	___	___	___	___	
Popouts	___	___	___	___	___	___	
Pumping and Water Bleeding	___	___	___	___	___	___	
Reactive Aggregate Distress	___	___	___	___	___	___	
Scaling, Map Cracking and Crazing	___	___	___	___	___	___	
Spalling	___	___	___	___	___	___	
Swell	___	___	___	___	___	___	
Transverse Cracking	___	___	___	___	___	___	

REVIEW COMMENTS

Asphalt Surfaced

Fatigue Cracking

1. Combine definitions of longitudinal and alligator cracking under fatigue cracking. Delineate longitudinal and alligator cracking as severity level of fatigue cracking.

2. Length of roadway or percentage of roadway should be included in presentation of fatigue cracking data. Another alternative is percentage of wheel pattern containing alligator cracking.

3. Some cracking attributed to block cracking in the manual is actually fatigue cracking (longitudinal). The longitudinal cracks that appear parallel to the centerline are load induced due to the tensile stresses induced in the surface adjacent to the wheel path. These cracks progress downward.

4. Some disagreements exist between what is identified in the manual as low severity alligator cracking, (Figure 2.3*) and tensile cracking due to lateral flow.

5. Some disagreement exists on what causes shoulder cracking in Figure 2.6. It could also be water seepage at the pavement-shoulder joint and subsequent freezing resulting in the shoulder being raised. Melting action then produces tension cracking.

Bleeding

1. An alternate definition was submitted which probably better reflects the consensus of those questioned: Bleeding is a film of bituminous material on the pavement surface which can create a slippery condition when wet. A pavement with advanced bleeding will have a shiney, almost glass-like surface

*See Highway Pavement Distress Identification Manual, FHWA-RD-79-66.

which can become sticky at elevated temperatures. Bleeding is caused by excessive asphalt or extremely low air voids in the asphalt concrete. Seal coats or surface treatments will exhibit similar conditions if there is an excessive loss of surface aggregate. Since the bleeding process is not reversible, the accumulation of bituminous material will tend to increase with time and traffic.

Low severity-bleeding can be observed in isolated locations and is not considered excessive to the degree that a slippery condition can occur when the pavement is wet.

Medium severity-bleeding can be observed over most of the area with only isolated areas (less than 10 percent of area) considered excessive and slippery when wet.

High severity-bleeding can be observed over most of the area and would be potentially dangerous when wet.

Block Cracking

1. Shrinkage cracks in soil-cement could reflect to the surface causing what appears to be block cracking.

2. Too many subcategories of severity; confusing in the field. Researchers recommend something like the following:

Low - cracks are sealed or unsealed with an average width of 1/8 inch or less.

Medium - unsealed cracks have an average width of approximately 1/4 inch or less.

High - unsealed cracks have an average width of 1/4 inch or more.

Corrugation

1. Corrugation should perhaps more accurately be defined as a series of closely spaced ridges and valleys occurring at relatively close spacing, usually less than 5 feet, along the pavement. The ridges are perpendicular to the direction of traffic. Corrugation manifests itself in the asphalt layers and is usually associated with unstable asphalt concrete or severe stresses; actually due to deceleration or acceleration of traffic.

Low severity-corrugation has a minor effect on riding quality.

Medium severity-corrugation will significantly reduce the level of riding quality and should be corrected.

High severity-corrugation will significantly reduce the level of riding quality and could influence the ability to control the vehicle during rainy periods.

2. The extent of corrugation should be measured in square feet.

3. Evaluate corrugations visually by observing vehicles driving over distressed areas in a passenger vehicle.

Joint Cracking from PCC Slab

1. Reflection cracking can occur at any previous discontinuity in PCC slab and should not be limited to joints.

2. Estimate lineal feet of dominant level of severity. It is too slow to identify the amount of each level of severity.

Raveling

1. The definition should also address aggregates which are subject to freeze-thaw popout and aggregates subject to stripping.

2. The definition should reflect that insufficient asphalt or the wrong grade of asphalt are reasons for raveling.

Shoving

1. A definition accompanied by pictures should be included for 'shoving.' One cause at traffic signals is the longitudinal flow caused by braking action of heavier vehicles - particularly during periods of warm weather.

Swell

1. The definition of swell should be limited to swell caused by soil movements. Thus, Figure 2.77 should be included under "blow-up" and not swell.

Jointed Plain Concrete Distress

1. In the definition of 'blow-up', generally there is insufficient initial width in the joints to provide for expansion. Subsequent infiltration is an additional aggravation, not the primary cause. Further down in the definition, "...Blow-ups are accelerated due to a spalling away of the slab at the bottom creating reduced joint contact area"--(Add) "And increased unit stresses which subsequently exceed the compressive strength of the concrete". The last sentence of the published definition is exactly backwards. "D"-cracking does not cause spalling. "D"-cracks are compressive shear failures, and spalling is simply the removal by traffic of failed concrete. Thus, the degree of potential blow-ups increases with increasing evidence of 1. "D"-cracks, and 2. subsequent spalling.

2. Durability ("D") cracking: "D"-cracking caused by freeze-thaw expansive pressures or "...reactive aggregates..." are very minor causes. Reference is made to Kentucky Research Report 445 "The D-Cracking Phenomenon: A Case Study for Pavement Rehabilitation". The entire "D"-cracking phenomenon is strickly a function of excessive compressive stresses caused by large temperature differential over an annual period. Figures 1 through 36 of

Report 445 are the most appropriate for your inspection. Aggregates subject to "freeze-thaw" or "reactive problems" may well be primarily destroyed by temperature-induced compressive stresses which may be excessively high for those aggregates, but below critical stresses for good quality aggregates. Thus, the differential temperature change between winter and summer conditions may be the primary cause and the winter freezing conditions just "complete" the deterioration.

The above comments on "D"-cracking apply to the definition found in the "Jointed Reinforced Concrete Distress" and "Continuously Reinforced Concrete Distress" sections also.

3. Spalling (transverse and longitudinal joint-crack): The third sentence should be revised to read, "Spalling usually results from 1) temperature expansion stresses at the joint, 2) lack of insufficient number of expansion joints, 3) infiltration of incompressible materials and subsequent expansion or traffic loading, 4) prior disintegration of the concrete, 5) weak concrete at the joint caused by excessive differential temperature stresses or over-working during placement combined with traffic, or 6) a poorly designed or constructed load transfer device."

4. Figure 3.37 also shows "D"-cracking at the intersection of the transverse and longitudinal joint and should be noted in the caption.

5. Spalling (Corner): The last sentence of the description is incorrect because "D"-cracking is not a cause but a result of some action. A suggested replacement might be, "corner spalling can be caused by excessive shearing or compressive forces arising from freeze-thaw, temperature, load, or other factors and has an appearance similar to a "D"-crack."

6. Transverse and diagonal cracks: An additional cause is a nonfunctioning joint assembly (misalignment, frozen, etc.).

Continuously Reinforced Concrete Distress

1. In addition to earlier comments about the definition of "D"-cracking, freeze-thaw expansive pressures are not involved in continuously reinforced concrete. (See Kentucky Research Report 480).

2. Figures 5.15 and 5.16 are not "D"-cracking. (See Report 480).

3. Transverse cracking: The first sentence of the description should read, "Transverse cracking of continuously reinforced slabs is a normal occurrence and is to be considered a distress." Also, load transfer cannot be obtained through aggregate interlock because the steel yields, thus relieving the aggregate-to-aggregate friction. Aggregate interlock can only occur prior to yielding of the steel, thus can only be involved for an extremely short period in the life of the pavement.

4. Figure 5.7: Where is the deterioration except for the small spall at the left joint? Kentucky consider this to be a good patch. Thus, some additional description needs to be added to the caption, or the wrong photograph was used here.

5. Figure 5.14 appears to be severe rather than medium.

6. Figures 5.13, 5.15, and 5.16 are not "D"-cracking. They are temperature cracks and the mechanism is explained in Kentucky Report 480.

7. Figure 5.37 is a poor photograph. What appears in this particular photograph may be spalling if associated with a crack. Is there a better photograph available?

8. In the section on joints, the manual does not include the separation of the longitudinal construction joint. Kentucky has experienced several occurrences of this type of failure, one of which is shown in Figure 11 of Kentucky Report 480. The separation usually occurs on long curves and is the result of a greater length of pavement in the lane that is on the outside of the curve. Thus, it is hypothesized that expansion stresses due to temperature

and/or expansive aggregates become greater and the curve "Bows" horizontally outward.

Jointed Reinforced Concrete Distress

1. Earlier comments made for blow-up, depressions, "D"-cracking, faulting, pumping, and spalling (both definitions) apply to this section and to continuously reinforced concrete distress.

2. Figure 4.15: Deterioration shown in photograph has the same appearance as a result of compression failure at the joint.

3. The following should be added to the caption for Figure 4.45, "Medium Severity Spalling--Caused by Pure Horizontal Compression Forces."

APPENDIX B

DIMAR COMPUTER PROGRAM