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PAVEMENT MOISTURE ACCELERATED DISTRESS (MAD) IDENTIFICATION SYSTEM

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Final Report

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Structures and Applied Mechanics
Division
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FOREWORD

These two reports present partial results of research conducted by the University of Illinois for the Federal Highway Administration (FHWA), Office of Research, under contract DOT-FH-11-9175. The research study was part of FCP Project 5D, Structural Rehabilitation of Pavement Systems. Volume 1 describes the development of an analysis method for the engineer to identify areas where climate and subgrade soils contribute to moisture accelerated distress in pavements. Volume 2 is intended as an aid to implementation of the analysis method.

Three other reports resulting from the same study are:

(1) FHWA/RD-81/122, Structural Analysis and Design of PCC Shoulders

(2) FHWA/RD-81/077, Improving Subdrainage and Shoulders of Existing Pavements - State-of-the-Art

(3) FHWA/RD-81/078, Final Report - Improving Subdrainage and Shoulders of Existing Pavements.

Sufficient copies of the two reports are being distributed to provide a minimum of two copies to each FHWA regional office, two copies to each FHWA division office and three copies to each State highway agency. Direct distribution is being made to the division offices.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

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16. Abstract

This report is a users manual designed to provide the engineer with a rational method of examining a pavement and determining rehabilitation needs that are related to the causes of the existing distress, particularly moisture related distress. The key elements in this procedure are the MAD Index developed in Volume 1, the Pavement Condition Index (PCI) and the Moisture Distress Index (MDI). Step by step procedures are presented for calculating each parameter. Complete distress identification manuals are included for asphalt surfaced highways and jointed reinforced concrete highways with pictures and descriptions of all major distress types. Descriptions of the role moisture plays in the development of each distress type are included. A chapter is devoted to the interpretation of results with major emphasis on how the results indicate moisture distress, or the lack of it. The interpretation allows specific recommendations to be formulated by the engineer concerning the urgency of the needed rehabilitation as well as the type of rehabilitation and the need for the rehabilitation to address moisture problems in the pavement.

Volume 1 is FHWA/RD-81/079.

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Chapter 1

INTRODUCTION

The occurrence of premature distress in a pavement system should be predictable through an examination of the components of the pavement and its environment. The technology to accomplish this was presented in Volume I, A Pavement Moisture Accelerated Distress (MAD) Identification System. To be of practical importance this technology must be easily applied and understood. The results must be easily interpreted once they are obtained in order that suitable maintenance or rehabilitation may be planned.

This User's Manual will accomplish the above stated objectives and allow the investigator to systematically examine a pavement, determine its condition and the responsibility moisture played in producing that condition. The engineer will know which materials contributed to the distressed condition. This knowledge will allow for a rationally based decision to be made concerning the amount and type of work needed and how much of that should be directed towards relieving moisture problems.

Chapter 2 presents the procedure to determine the MAD Index. This index is constructed from considerations of the pavement and its interaction with moisture. The MAD Index indicates the relative potential for moisture to cause or accelerate distress. It also shows the engineer which materials are most likely responsible. The MAD Index serves as an indicator of where potential problems may be expected to develop most readily. It can be used as a design tool for new construction as well as for investigating rehabilitation needs.

Chapter 3 presents the project condition and drainage survey procedure. This procedure determines the present condition of the pavement through a comprehensive evaluation of visual distress on the pavement. The PCI is the primary quantity used to decide if work on this pavement is warranted. When the PCI is considered along with the MAD Index recommendations concerning the urgency of repair can be made.

The Moisture Distress Index (MDI) is developed from the PCI data in this chapter. The MDI is an evaluation of the existing distress to obtain an indication of the amount of distress directly attributable to moisture. The MDI provides a validation of the MAD Index prediction of areas which should develop moisture related distress. The direct comparisons between the MAD Index and the MDI will show where and why moisture distress is present. When these are considered with the PCI, maintenance and/or rehabilitation can be effectively planned for the entire project or just for areas with identified moisture problems. The nature of the moisture problems can also be addressed with specific rehabilitation procedures.

Chapter 4 presents an integrated examination of the MAD Index, the PCI, and the MDI. Combinations are presented and the implications for rehabilitation and moisture problems are discussed. This chapter will aid the engineer in interpreting the numerical values and relating their significance to a rehabilitation project to best relieve the moisture damage.

Appendices are provided for the calculations needed for the PCI and the Distress identification manuals for asphalt covered and jointed reinforced concrete pavements.

Chapter 2

MAD INDEX

The moisture accelerated distress index (MAD Index) is a ranking procedure designed to separate pavements based on their potential to exhibit drainage problems which could lead to premature deterioration of the pavement structure. The MAD Index is formed by considering the climate of the area and the properties of the pavement foundation materials. The development and importance of these considerations has been described in detail in Volume I. This manual contains step by step procedures to perform the analysis and develop the data which can be utilized to make drainage, maintenance and/or rehabilitation recommendations. This procedure can be used to examine a single roadway for a RRR project, a network of highways in a management system to note areas where the potential for damage is higher than others, or it can be used to examine new construction during the design phase. Read Vol. I. for a numerical example of the MAD Index.

Climatic Zone.

First, determine the climatic zone your pavement is located in from Figure 2-1. This will consist of a Roman numeral and a Capital letter, e.g., I-A, which will be used later in the ranking procedure. The next step is to determine if your pavement will experience a moisture surplus during the year which would accelerate the deterioration. Figure 2-2 contains the areas where seasonal moisture imbalances will exist. The value should be recorded.

Drainability of Granular Layers

The form presented in Figure 2-3 must be filled in to calculate the drainability of the granular layers. First, the pavement cross sectional properties must be recorded. These include the following which should be recorded in the appropriate spot on Figure 2-3.

1. Longitudinal Slope, g_ℓ, ft/ft
2. Transverse Slope, g_t, ft/ft
3. Thickness of Drainage Layer, H, ft
4. Width of Drainage Layer, D, ft

Sections having different cross section properties must be analyzed separately. The terminology used to differentiate each pavement section should be recorded in the appropriate block. Three calculations must be performed as indicated on Figure 2-3 for the cross sectional properties.

1. Le = effective length of drainage

$$= D\sqrt{(g_\ell/g_t)^2 + 1.0}$$

2. ge = effective slope of drainage path

$$= \sqrt{g_\ell^2 + g_t^2}$$

3. S = Slope Factor

$$S = H/(Le \cdot ge)$$

The next section which must be completed is that of the soil properties. The gradation curve and plasticity characteristics must be known. These can be obtained from construction records and tests run on core samples. Initial results can be developed from construction records but final recommendations for rehabilitation or drainage work must be based on actual core data. The information to be recorded includes:

1. Percent fines (- #200)

2. Type of fines

   a. Inert - Substantially below "A" line in Unified Classification system, PI below 1.

   b. Silty - Material plots near "A" line. PI above 1, but below "A" line.

   c. Clay - Material has high PI, it plots above the "A" line in the Unified System.

3. D_{10}, affective grain size with 10 percent of the material passing this size, mm.

4. Dry density, pcf and gm/cc.

5. Specific gravity of Solids, G_s. This may be obtained from construction records, and initial material tests, and will not vary from section to section.

These should be recorded in the appropriate blanks in Figure 2-3.

The next section to be completed on Figure 2-3 involves calculation of drainability properties of the pavement section. This section involves performing some calculations which are outlined in Figure 2-3 and may be listed as follows:

1. Assume Ws = 1.0

2. Calculate Vs = Ws/Gs

3. Calculate Vv = 1 - Vs = Ne_{max} (= B)

   Ne_{max} is the volume of water that completely fills the voids in the material.

4. From Figure 2-4 select the estimated water loss, C. Consult plasticity and grain size data for the material.

5. Calculate the specific yield.

$$Ne = (Ne_{max}) \times C/100 = (B \times C/100)$$

6. Calculate X

$$X = (Ne \cdot Le)/(H \cdot k)$$

k, the permeability may be estimated from Figure 2-5.

These data are used in Figure 2-6 to calculate drainage times and saturation levels as follows:

1. From Figure 2-7 select a time factor T for every value of U. The slope factor, S, previously calculated is used to select the proper curve.

2. Calculate the drainage time, in hours, for Column 3. (Column 2)$\cdot$X $\cdot$24 = hours

3. Specific yield, Ne, time U gives the amount of water drained during this time. Record this in Column 4.

4. Subtract Column 4 from Ne_{max} (labeled B). This is the amount of water remaining in the sample, and goes in Column 5.

5. Column 5 divided by Ne_{max} (labeled B) time 100 gives the saturation level of the sample and is recorded in Column 6.

The values of t in hours and the percent saturation should be plotted on Figure 2-8 to determine the suitability of the granular layer for drainage purposes. This classification will be either acceptable (a), marginal (m), or unacceptable (u).

If the pavement being investigated for rehabilitation has distinct portions where different granular materials are used, each section with a different granular material should be evaluated separately. Each section will receive a separate rating for granular drainability. Areas which receive similar ratings may be combined. The areas of granular drainability should be noted on a strip may of the project to show their locations.

Drainability of Subgrade.

The first step in evaluating the subgrade for potential contribution to moisture damage is to determine the type and distribution of subgrade materials present under the project. The first choice to obtain this information is the USDA County Soils Map, which will provide a very detailed picture of the soils present. Second choice would be to use soil test results taken from construction records which were used to delineate soil types for the original design.

When county soil maps are available, subgrade boundaries and types can be marked directly on a strip map of the project. The drainage class of each subgrade type can be noted from the soils map information and the Natural Drainage Index value selected from Figure 2-9. When using only soil classification data the approximate relationships in Figure 2-10 can be used to determine the Natural Drainage Index. The problem of extensive reworking of soils during grading, for example, will not produce a change in the NDI which will develop over several years once the pavement is completed. When a pavement is being investigated for rehabilitation, the intermixing will have been negated and the altered soils will have assumed the properties of the undisturbed underlying soil. Thus, the soil maps will very likely still accurately reflect the soil under the pavement. Extensive cuts or fills, greater than 4-6 feet (1.2-1.8 m) may take much longer to approach the condition of the original soil. For these localized areas, they should be examined individually and assigned an average value indicating whether the cut or fill improved the material present under the roadway and improved the position relative to the water table.

Evaluation of Pavement

When a rating for each of the parameters discussed thus far has been determined, a combined rating for the different pavement sections may be obtained from Figure 2-11. This rating (MAD Index) indicates the relative potential for moisture related damage to develop. Because any one project will be in a uniform climatic area, the main differences will exist in the granular and subgrade materials. Specific areas with the higher potential for MAD should be noted on the project strip map along with those areas having the lowest potential for MAD. These ratings can then be directly compared with the actual distress present to see if moisture is actually producing damage as predicted.

Existing drainage facilities, if present, should be noted on the project strip map. The adequacy of these facilities should be evaluated by visual inspection and discussion with personnel knowledgeable with the project. During the visual examination, other problems should be noted if they are observed. These would include improper grade lines, standing water in ditches or at shoulder edges, etc.

With these items indicated on the project strip map the engineer will know exactly where good and poor materials are located, where good and poor drainage facilities are located, and where potential moisture problems could develop. Placing all of this information on the strip map will allow the engineer to examine interactions between these factors which should relate to the amount of distress that has developed, in particular the amount of moisture related distress present on the pavement. The quantification of this distress will be presented in the following chapter.

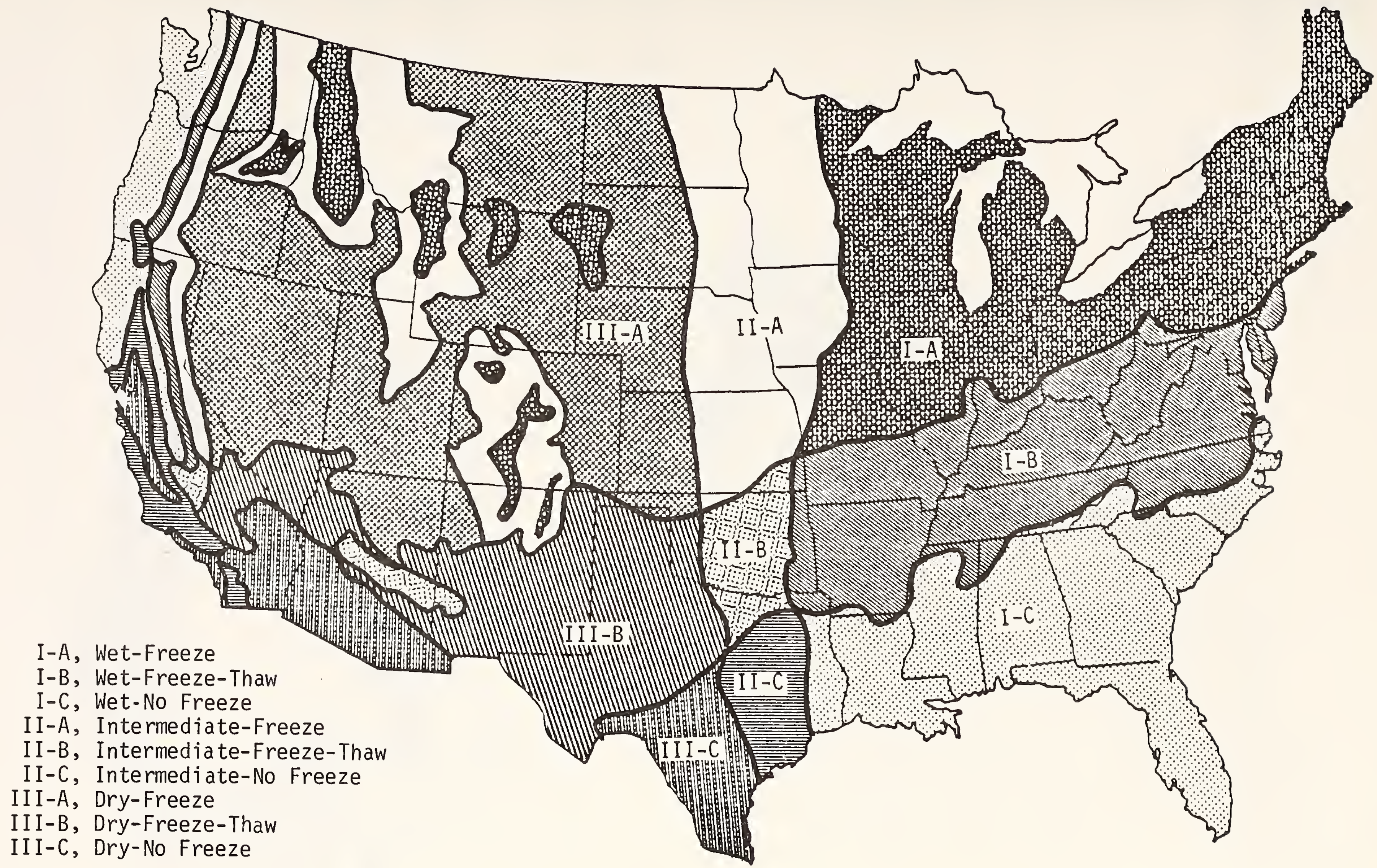


Figure 2-1. Climatic Zones for the United States.

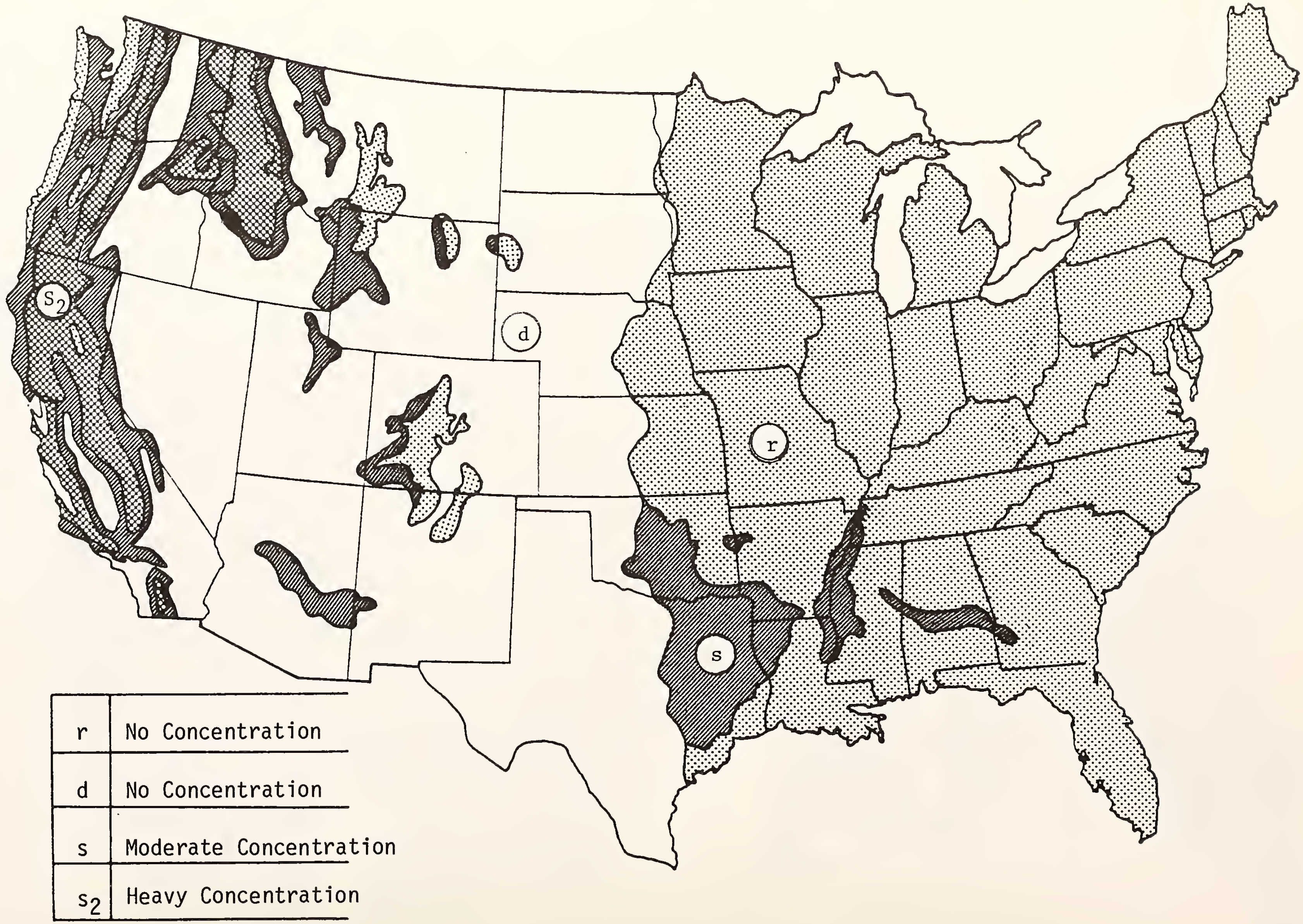


Figure 2-2. Distribution of Seasonal Moisture Variation Across the United States, after Thornthwaite.

PAVEMENT SECTION ______________________________

PERCENT FINES ____________ TYPE OF FINES ______________

D_{10} ____________ mm. DENSITY, γ_d ____________ pcf

G_S ______________________ K __________________ ft/day

H _________ ft., D __________ ft., gt ________ ft/ft., gl ________ ft/ft.

$Le = D\sqrt{(gl/gt)^2 + 1.0}$ = ____________., $ge = \sqrt{gl^2 + gt^2}$ = ____________

S = H/(Le·ge) = SLOPE FACTOR = ________________

$\gamma_d/62.5$ = $\underline{\underline{A}}$ gm/cc., V_T = 1.0 cc ∴ A = W_S = __________ gm

$V_S = W_S/G_S$; V_S = ( )/( ). = __________ cc

$V_V = 1.0 - V_S$; V_V = 1.0 − ( ) = __________ cc = Ne_{max} = $\underline{\underline{B}}$

ESTIMATED WATER LOSS (Figure 2-4) $\underline{\underline{C}}$ = __________ %

SPECIFIC YIELD, N_e = B·C/100 = ( )·( )/100 = ______________

$X = (N_e \cdot L_e^2)/(H \cdot K)$ = ______________

Figure 2-3 Form to be Filled in to Calculate Drainability

Figure 2-4 Estimated Values of Water Loss for Calculating Specific Yield, C

AMOUNT OF FINES	2.5% FINES			5% FINES			10% FINES		
TYPE OF FINES	INERT FILLER	SILT	CLAY	INERT FILLER	SILT	CLAY	INERT FILLER	SILT	CLAY
GRAVEL	70	60	40	60	40	20	40	30	10
SAND	57	50	35	50	35	15	25	18	8

* Gravel, 0% fines, 75% greater than #4: 80% water loss.

* Sand, 0% fines, well graded: 65% water loss.

* Gap graded material will follow the predominant size.

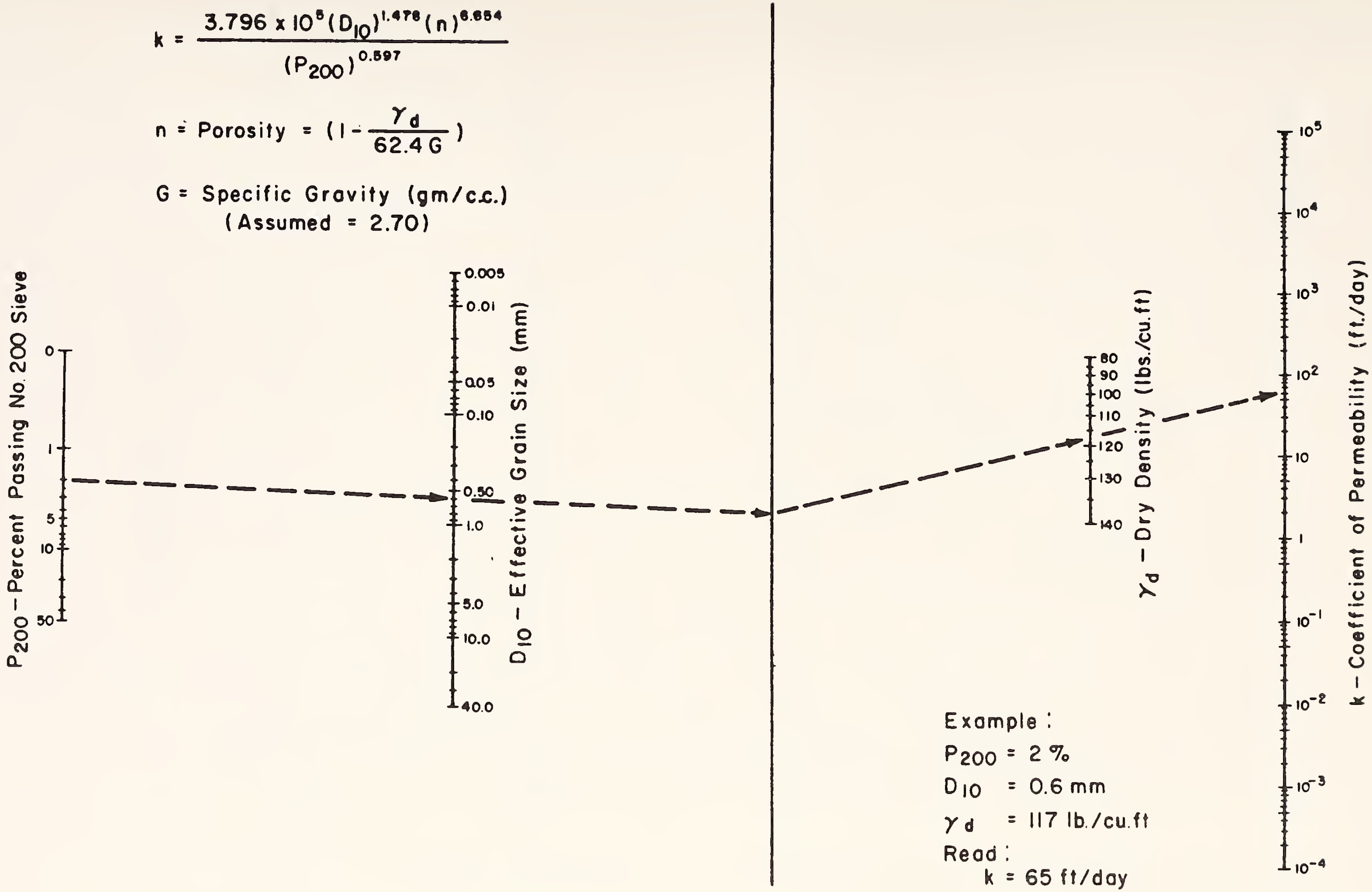


Figure 2-5 Nomographic Procedure to Estimate Permeability of Granular Materials

(1)	(2)	(3)	(4)	(5)	(6)
U	T	(2)·X·24=hrs	$N_e \cdot U$	$\underline{\underline{B}}$ - (4)	(5/$\underline{\underline{B}}$)·100
.1					
.2					
.3					
.4					
.5					
.6					
.7					
.8					
.9					

Figure 2-6 Calculation Table for Obtaining Saturation Levels and Drainage Times

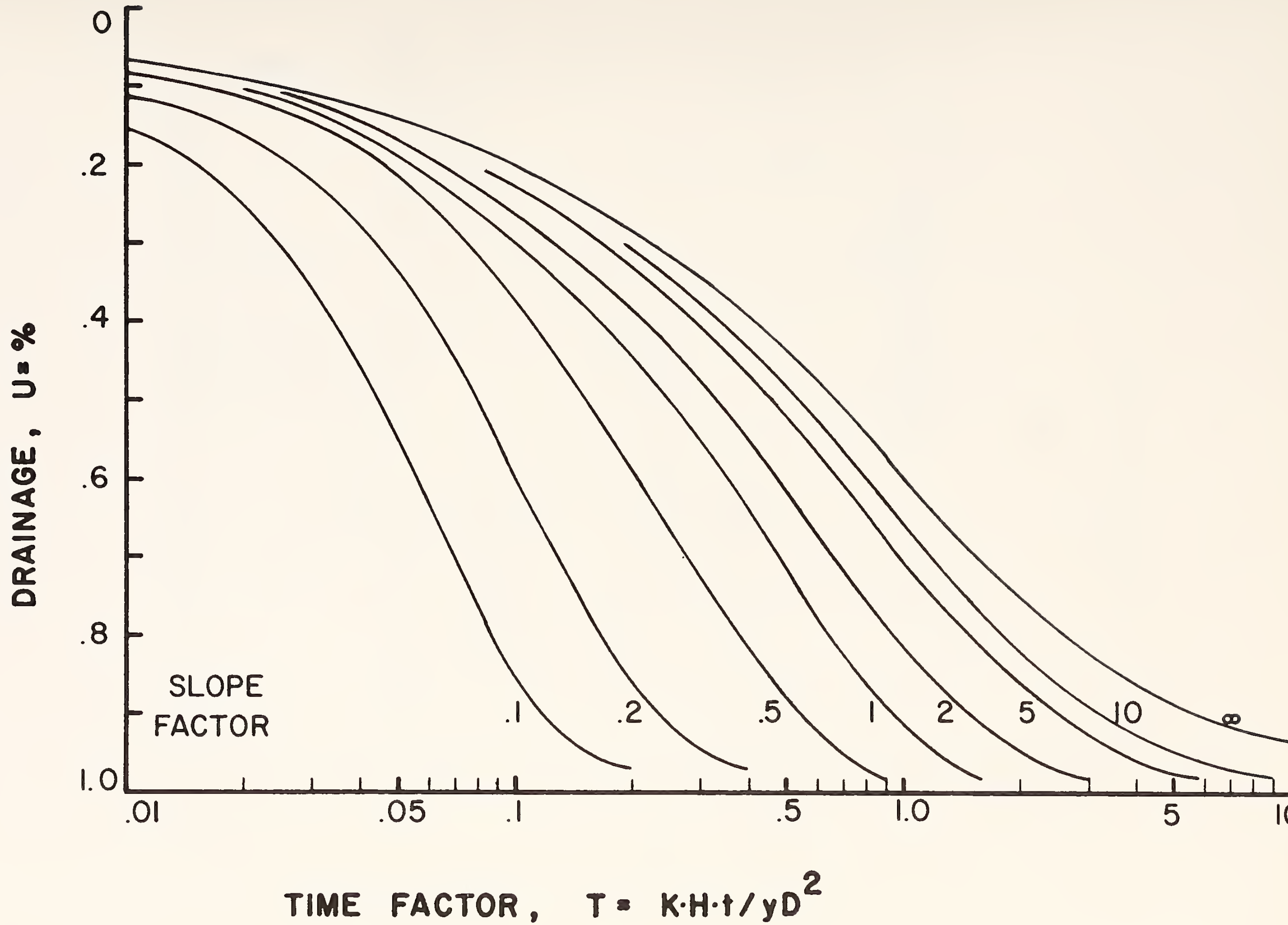


Figure 2-7 Curves for Obtaining Time Factor,T, to be used in Figure 2-5.

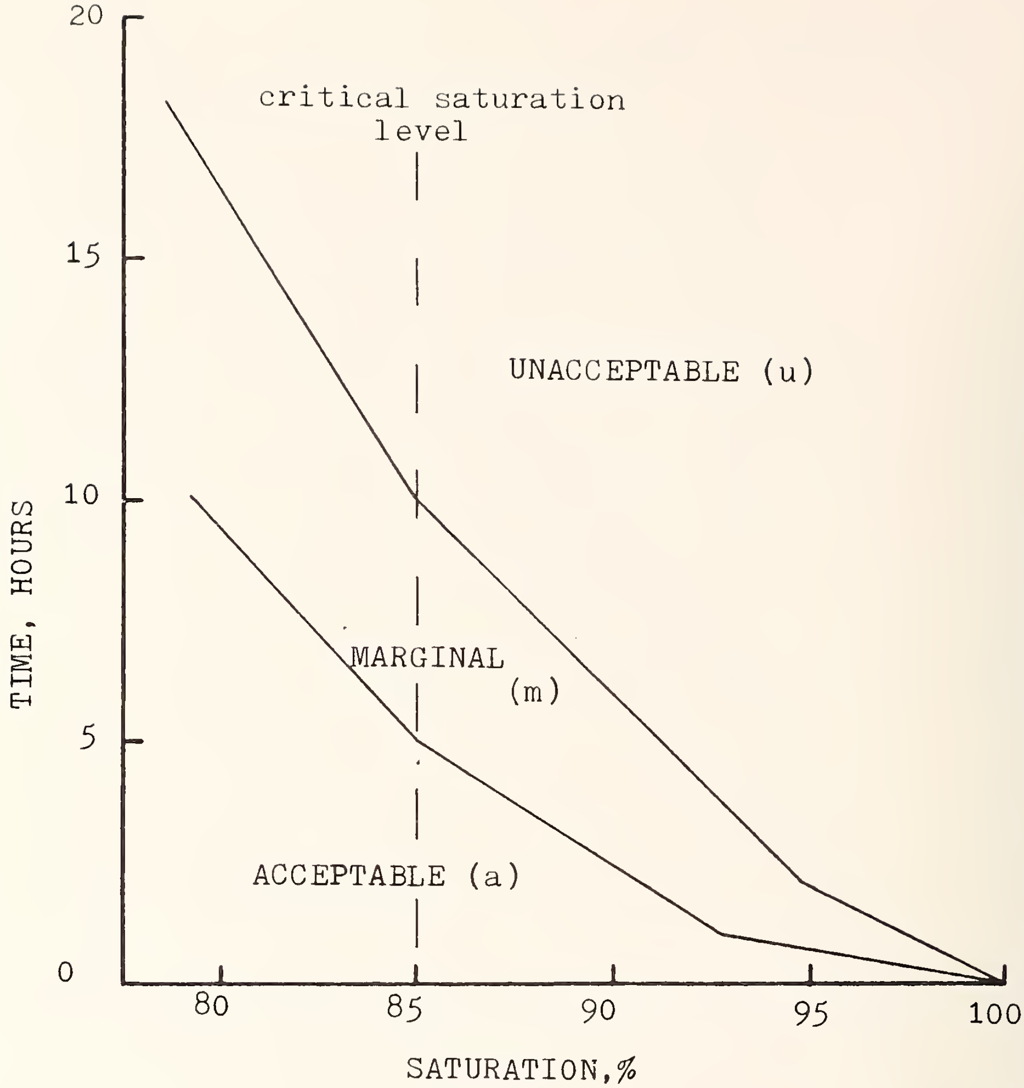


Figure 2-8 Drainability Curves for Granular Base Material.

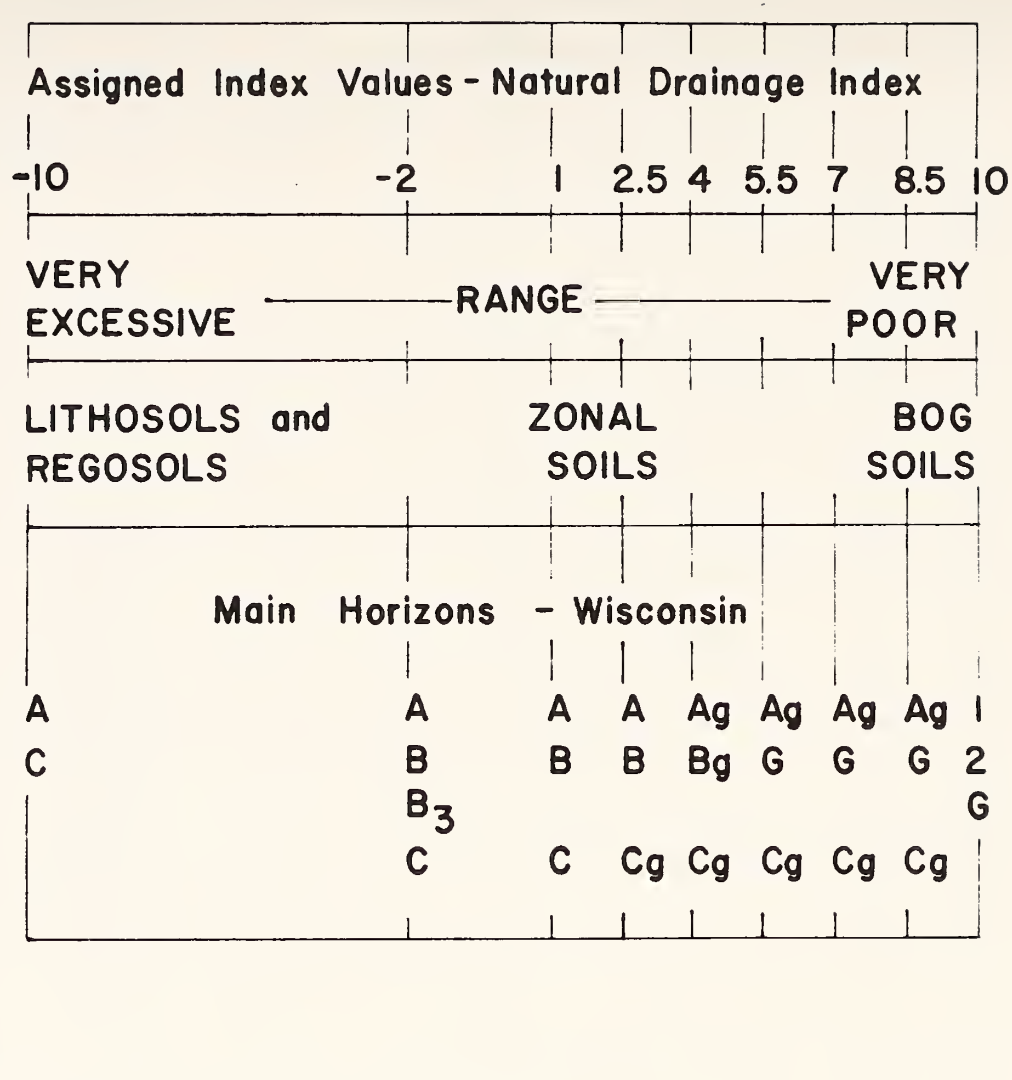


Figure 2-9 Natural Drainage Index Relationships

AASHTO Class. \ Position in Topography.	Top of Hills	Sides of Hills	Depressions
A-1 A-3	K	K	K
A-2-4 A-2-5	K	K	J
A-2-6 A-2-7	K	K	J
A-4	K	J	J
A-5	J	J	i
A-6	J	i	i
A-7-5 A-7-6	i	i	i

A group index above 20 will alter the NDI rating, K → J, J → i.

A group index below 5 will alter the NDI rating, i → J, J → K.

Figure 2-10. Approximate Relationships for Obtaining the Natural Drainage Index from Soil Classification Data.

Key to combination codes (e.g. III Cak): Moisture Region (III) – Temperature Region (C) – Granular Material acceptability (a) – Subgrade Drainability (k)

MAD Index	Damage Potential	Combinations
100	NEGLIGIBLE	
99		
98		
97		
96		
95		
94		
93		
92		III Cak
91		
90		
89		III Cmk
88		
87		
86		
85		III Caj, III Bak
84	LOW	
83		
82		III Bmk
81		
80		
79		
78		III Caj, III Cmj, III Baj, III Cuk, III Aak
77		
76		
75		III Amk
74		II Cak
73		
72		
71		III Cuk, III Bmj, III Aaj, III Buk, II Cmk
70		III Cmi, III Bai
69	NORMAL	
68		
67		II Caj, II Bak
66		
65		
64		III Buk, III Amj, III Auk, II Bmk
63		III Cui, III Bmi, III Aai
62		
61		
60		II Cmj, II Baj, II Cuk, II Auk
59		II Cai
58		
57		III Auk, II Amk
56		III Bui, III Ami
55		
54	MODERATE	I Cak
53		II Cmi, II Bai, II Cuk, II Bmj, II Auj, II Buk
52		
51		I Cmk
50		
49		III Aui
48		
47		I Caj, I Bak
46		II Buk, II Amj, II Auk
45		II Cui, II Bmi, II Aui
44		I Bmk
43		
42		
41		
40		I Cmj, I Bai, I Cuk, I Aak
39		II Auk, I Cai
38		II Bui, II Ami
37		I Amk
36		
35		
34	HIGH	
33		I Cuj, I Bmj, I Aaj, I Buk
32		I Cmi, I Bai
31		II Aui
30		
29		
28		
27		
26		I Buj, I Amj, I Auk
25		I Cui, I Bmi, I Aai
24		
23		
22		
21		
20		
19		I Aui
18		I Bui, I Ami
17		
16		
15		
14	EXCESSIVE	
13		
12		
11		I Aui
10		
9		
8		
7		
6		
5		
4		
3		
2		
1		
0		

Figure 2-11. Ranking of Material Combinations, The MAD Index

Chapter 3

PROJECT CONDITION AND DRAINAGE SURVEY

A project survey should be conducted to determine (1) an overall assessment of pavement condition, (2) the relative influence that moisture has had on the present condition, (3) information of specific drainage related items, and (4) the general type of maintenance or rehabilitation needed, if any. The project survey is conducted in the following manner.

Survey Crew

A 2-4 person survey crew is organized that has thoroughly familiarized themselves with the distress identification manual. A distress manual for highspeed highways is provided in the appendix. Another manual for city streets is available.[1] Approximately 20 distress types were identified for asphalt surfaced pavements and for jointed reinforced pavements. With field training, the distress types and severity levels can be consistently identified and measured in the field. Only generally available equipment is needed to measure the distress: hand odometer, small ruler, string line, or straight edge (approximately 10 ft (3 m) long), mid-to full-sized automobile, traffic control signs (if needed), and safety items, and joint faultmeter (or means to measure joint faulting).

Highspeed Lane Pass

The crew drives over the entire project in each traffic lane at the speed limit. During these passes the general condition along the project is observed, and any swells or depressions recorded. If the project exhibits

[1] Shahin, M. Y., and S. D. Kohn, "Development of a Pavement Condition Rating Procedure for Roads, Streets, and Parking Lots", Vol. II: Distress Identification Manual", Technical Report M-268, Construction Engineering Research Laboratory, U. S. Army Corps of Engineers, July 1979.

generally uniform condition, then there is no need to divide it up into separate lengths for evaluation purposes. If, however, a certain portion or portions exhibit significantly different condition, it may be desirable to evaluate each portion separately.

Slow Shoulder Pass

The crew then begins a slow speed (normally walking) pass along the entire project. Distress information may be recorded in two ways depending on the purpose of the survey:

(1) The project has been programmed for rehabilitation and a detailed survey of the entire project is needed to assist in preparation of contract documents. In this case the crew must walk the entire length and record all distress occurence using appropriate data sheets. One method that can speed up this work is to obtain aerial photographs at a scale of say 50 ft = 1 in (15m = 25mm). The various distress types and severity can be written on the large prints. The results of this survey can then be used not only for determining the extent of moisture damage, but also to prepare contract documents. (e.g. stations where patching is required). The distress must be recorded so that it can be related to stationing along the project.

(2) The project has not been programmed for rehabilitation, but is being evaluated for possible existing moisture damage. In this situation a sampling procedure can be utilized. A detailed survey of approximately 10 percent

of the project will provide sufficient information.

A length of approximately 0.1 mile (.16 km) randomly selected within each mile of pavement must be surveyed and all distress recorded within this section. Data are recorded separately for each lane and each shoulder.

The distress identification manual should be carefully followed as to identification of types, level of severity, and how to measure.

The crew should also take photographs of specific conditions observed during the survey. Photos will be extremely helpful in communicating pavement condition to management as well as for future reference.

Drainage Survey

At the time the low speed lane pass is conducted, the visual examination of the existing drainage should also be performed. This survey is done to record items in each section of the project being examined which could have a detrimental effect with water present. Items which should be noted include the following:

1. Lane/Shoulder joint integrity.
2. Type of drainage system present, if any.
3. Free flowing condition of outlets.

   (may be done following a rain or with water truck if results are questioned)
4. Maintenance of proper ditch line.
5. Standing water.

   (in the ditch, in depressions at pavement or shoulder's outer edge)
6. Growths of vegetation requiring large quantities of water next to the pavement. (willow trees, cat tails, etc.)

These items should be noted whenever they occur and included for future evaluation of the project. They are important when considered with the other parameters such as the MAD Index, PCI, and the moisture condition index, to be discussed.

Compilation of Data

The distress data should be compiled and summarized into a form that can be readily used for evaluation of moisture damage. The distress data is used for determining the amount of existing damage caused or accelerated by moisture, and to compute a Pavement Condition Index (PCI).*

The distress data for each approximately 0.1 lane mile (0.16 km) section surveyed are tabulated on the data sheet in Figures 3-1 and 3-2 for asphalt surfaced and Figures 3-3 and 3-4 for jointed reinforced concrete pavements. The shoulder distress data can also be recorded on a similar sheet. Figures 3-1 and 3-3 show some example data recorded. The units of the data are specified in the distress manual.

The distress data are then used to determine deduct values and compute the PCI. The individual deduct values represent the relative significance of the specific distress type, severity, and amount (or density) on the structural and/or operational condition of the pavement. The PCI represents the overall rating of the pavement as to its structural integrity and operational condition. Extensive research on the development of the PCI is available in References 1 and 2.

First, the density of each type and severity is computed. Distress measured by length or area is divided by the total area of the approximate 0.1 mile long (0.16 km) land (or shoulder) and multiplied by 100. Distress

---

* Note: The PCI was first developed for airfield pavements by the U.S. Air Force in 1975. It was then extended to roads and streets for the U.S. Army in 1977. It has been implemented and is used daily in pavement maintenance and rehabilitation decisions.

measured by counting the number of distresses must be converted into number per mile. Next, the deduct values are determined from the appropriate graph given in the Appendix for high speed highways (or Reference 1 for city streets). The total deduct value is calculated and the corrected deduct value (CDV) determined from the appropriate graph. The number of deduct values greater than 5 points (or q) is used in the correction curve. Finally, the PCI is calculated as:

$$PCI = 100 - CDV.$$

The extent of all distress that is caused or accelerated by moisture can be calculated using the data from Figure 3-1 and 3-3 . The types of distress and specific severity levels that are believed to be caused by, or that contribute to moisture damage must be identified. For example, this could be Nos. 1M and 5 from Figure 3-1. The distress manual contains a brief paragraph on how each distress is accelerated by moisture. Once this is done, the percentage of moisture related distress is calculated as follows:

$$\text{Moisture Distress Index} = \frac{\text{Sum of Deduct Values of Moisture Related Distress and Severity}}{\text{Sum of All Deduct Values from Section}} \times 100$$

This percentage is termed the Moisture Distress Index (MDI). The overall mean project MDI can be computed by averaging the value for each section surveyed. The MDI for the pavement section in Figure 3-1 is computed as:

$$\frac{35 + 19}{113} \times 100 = 48 \text{ percent.}$$

Thus, approximately one half of all existing distress is caused or accelerated by moisture.

A description of the way in which each distress type is caused or accelerated by moisture is given in the distress manual in the Appendix. Based on the type of distress measured in the field, the percentage of deduct values attributed to moisture effects, and the overall PCI, the engineer can obtain a good idea of the impact of moisture on the pavement's performance.

ASPHALT SURFACED HIGHWAY PAVEMENT

Distress Summary and PCI Calculation Sheet

Highway Designation I-55 Station 1024+00 to 1029+28

Survey Date 6/15/80 Mile Post 113.6 to 113.7

Survey Crew MD/SC/SH Length ft Width 12 ft

OUTER TRUCK LANE

Asphalt Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Corrugation
5. Depression
6. Joint Reflection Cracking(PCC slab)
7. Lane/Shoulder Dropoff-Heave
8. Lane/Shoulder Separation
9. Longitudinal and Transverse Cracking
10. Patch Deterioration
11. Polished Aggregate
12. Potholes
13. Pumping/Water Bleeding
14. Raveling/Weathering
15. Rutting
16. Slippage Cracking
17. Swell

Existing Distress Summary

Distress No.		1	5	9	15									
		2x50L	12x20 M	12M	3x528 L									
		3x75L		12M										
		2x25M		12M	3x528 L									
		2x200L		12M										
		2x35M												
		3x50M												
Totals	L	725	0	0	3168									
	M	270	240	48										
	H	0	0	0										

PCI Calculation

Distress Type	Severity	Density	Deduct Value
1	L	11	24
1	M	4	35
5	M	4	19
9	M	0.8	16
15	L	50%	19
Total Deduct Value		q=5	113
Corrected Deduct Value(CDV)			34

PCI = 100 - CDV = 66

Figure 3-1. Example Data Summary Sheet for Asphalt Surfaced Highway Pavements for Calculating PCI

ASPHALT SURFACED HIGHWAY PAVEMENT

Distress Summary and PCI Calculation Sheet

Highway Designation ________ Station ________ to ________

Survey Date ________ Mile Post ________ to ________

Survey Crew ________ Length ________ Width ________

Asphalt Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Corrugation
5. Depression
6. Joint Reflection Cracking(PCC slab)
7. Lane/Shoulder Dropoff-Heave
8. Lane/Shoulder Separation
9. Longitudinal and Transverse Cracking
10. Patch Deterioration
11. Polished Aggregate
12. Potholes
13. Pumping/Water Bleeding
14. Raveling/Weathering
15. Rutting
16. Slippage Cracking
17. Swell

Existing Distress Summary

Distress No.												
Totals L												
Totals M												
Totals H												

PCI Calculation

Distress Type	Severity	Density	Deduct Value
Total Deduct Value			
Corrected Deduct Value(CDV)			

PCI = 100 - CDV = ________

Figure 3-2. Blank Data Summary Sheet for Asphalt Surfaced Highway Pavements for Calculating PCI

JOINTED CONCRETE SURFACED HIGHWAY PAVEMENT

Distress Summary and PCI Calculation Sheet

Highway Designation US66 Station 590+00 to 596+00

Survey Date 7/13/80 Mile Post 274.1 to 274.0

Survey Crew MD/MH/SC Length 600 ft Width 12 ft

Slab Length = 50 ft. N. B. Lane

Jointed Concrete Distress Types

1. Blowup
2. Corner Break
3. Depression
4. Durability "D" Cracking
5. Faulting-Trans. Joints
6. Joint Load Trans. System Det.
7. Joint Seal Damage
8. Lane/Shoulder Dropoff-Heave
9. Lane/Shoulder Joint Separation
10. Longitudinal Cracks
11. Longitudinal Jt. Faulting
12. Patch Deterioration
13. Patch Adjacent Slab Det.
14. Popouts
15. Pumping & Water Bleeding
16. Reactive Aggregate
17. Scaling, Map Cracking
18. Spalling of Joints
19. Spalling of Corners
20. Swell
21. Trans. & Long. Cracks

Existing Distress Summary

Distress No.		5 →		18 →		12		21		8				
		.12	.19	L	M	1L		1M		Mean = 0.6 ins.				
		.25	.19	M	H	1L		1M						
		.21	.22	M	L	1L		2M						
		.18		M										
		.35		L										
		.17		L										
		.20		M										
		.22		L										
		.12		M										
Totals	L				5	3								
	M	Mean	=.20		6			4						
	H		ins		1									

PCI Calculation

Distress Type	Severity	Density	Deduct Value
5	Mean = 0	.20	42
18	L	44	31
	M	53	57
	H	9	39
12	L	26	24
21	M	35	1
8	M	0.6 ins	10
Total Deduct Value		q = 6	204
Corrected Deduct Value (CDV)			60

PCI = 100 - CDV = 40

Figure 3-3. Example Data Summary Sheet for Jointed Reinforced Concrete Highway Pavements for Calculating PCI

JOINTED CONCRETE SURFACED HIGHWAY PAVEMENT

Distress Summary and PCI Calculation Sheet

Highway Designation ________ Station ________ to ____________

Survey Date ______________ Mile Post ________ to ____________

Survey Crew ______________ Length ________ Width __________

Jointed Concrete Distress Types

1. Blowup
2. Corner Break
3. Depression
4. Durability "D" Cracking
5. Faulting-Trans. Joints
6. Joint Load Trans. System Det.
7. Joint Seal Damage
8. Lane/Shoulder Dropoff-Heave
9. Lane/Shoulder Joint Separation
10. Longitudinal Cracks
11. Longitudinal Jt. Faulting
12. Patch Deterioration
13. Patch Adjacent Slab Det.
14. Popouts
15. Pumping & Water Bleeding
16. Reactive Aggregate
17. Scaling, Map Cracking
18. Spalling of Joints
19. Spalling of Corners
20. Swell
21. Trans. & Long. Cracks

Existing Distress Summary

Distress No.													
Totals L													
Totals M													
Totals H													

PCI Calculation

Distress Type	Severity	Density	Deduct Value
Total Deduct Value			
Corrected Deduct Value(CDV)			

PCI = 100 - CDV = ________

Figure 3-4. Blank Data Summary Sheet for Jointed Reinforced Concrete Highway Pavements for Calculating PCI

Chapter 4

FORMULATING RECOMMENDATIONS

Three distinct evaluation parameters have been obtained at this point. These are as follows:

1. Moisture Accelerated Distress (MAD) Index
2. Pavement Condition Index (PCI)
3. Moisture Distress Index (MDI)

Each of these values provide needed information that must be considered in combination with the others to allow specific recommendations concerning the urgency and type of maintenance and/or rehabilitation. The MAD Index gives an evaluation of the pavement concerning the potential for moisture related damage to occur based on material properties and climatic factors. The moisture distress index (MDI) represents the proportion of all distress present on the pavement that is directly attributable to moisture. These two parameters provide data for recommendations concerning the need for moisture related preventive maintenance or rehabilitation activities. The pavement condition index (PCI) represents the overall judgement of experienced engineers as to the pavement's existing structural integrity and surface operational condition. It indicates the general urgency for performing any needed maintenance or rehabilitation.

MAD Index

The MAD Index is composed of factors representing the climate, granular layers, and the subgrade. Descriptions of the various levels for the MAD Index are given in Figure 4-1. The breakdown by individual components is given in Figure 4-2. Each individual component of the MAD Index will have an influence on the rehabilitation decision. Brief descriptions are given in Figure 4-3 through 4-7 describing the factors which are important in moisture related distress.

For any one climatic zone, the materials could still be moisture susceptible and produce distress even with low moisture present (Region II and III). Figure 4-8 contains general recommendations which may be written as follows:

- Acceptable granular layer with:
  - Excellent subgrade: No problems
  - Acceptable subgrade: Watch water table fluctuations. If this section is a cut the table may be near the pavement.
  - Poor subgrade: Subgrade may act as source of water for granular layers. If water table is high, drains should be considered to control the subsurface water and not the flow through the granular layer.
- Marginal granular layer with:
  - Excellent subgrade: Subgrade will assist drainage of granular layer to great extent, producing acceptable performance.
  - Acceptable subgrade: For this combination edge drainage may be very effective in maintaining good drainage. The subgrade offers no assistance but does not hinder performance either.

- Poor subgrade: Edge drainage is a must for this combination. The subgrade actually decreases the level of performance in the granular layer. Drainage is critical to remove the moisture provided by the subgrade.

- Unacceptable granular layer with:
  - Excellent subgrade: Edge drains are of little or no use with a granular layer of this makeup. The subgrade provides the only beneficial drainage. Every attempt should be made to keep water from penetrating the surface layer.
  - Acceptable subgrade: Again, drainage will add little benefit. In this combination the subgrade is not considered to assist the granular layer.
  - Poor subgrade: There is very little hope for this combination to be improved through drainage.

The Moisture Distress Index (MDI)

The MAD Index, with its various components merely estimates the <u>potential</u> for moisture related distress to occur. The MDI provides an indication of the extent moisture related distress has actually developed in the pavement. Brief descriptions of the MDI are given in Figure 4-9.

The MDI can be used to evaluate an entire project or portions of a project to determine the actual amount of moisture related distress present. On a project evaluation, an MDI above 50 indicates that a majority of the existing distress is caused or accelerated by excess moisture.

Examining every area having an MDI >50 is recommended when the MAD Index values are variable, since localized rehabilitation may be used. When this is done, the following relationships should be noted.

1. Low MAD Index and high MDI: Moisture damage is present where it is predicted. Depending on materials, rehabilitation should be directed toward moisture removal.

2. High MAD Index and low MDI: Moisture damage is not present and it is not supposed to be present.

3. Low MAD Index and Low MDI: This combination indicates moisture susceptible materials, but no moisture related distress has yet developed. The visual examination of drainage must be considered here to determine what outside influences, differing from other projects or areas within the project, contributed to the reduced amount of moisture related distress.

4. High MAD Index and High MDI: The MAD Index predicts a low potential for moisture problems while there is a high amount of moisture related distress present. This combination is the most difficult to explain. The visual examination may provide information about possible differences which may be accelerating the distress in this project. Samples may be required to determine if the materials placed were the same as that specified for construction.

The MAD Index and the MDI provide information necessary to make specific recommendations concerning the necessity for drainage and the likelihood of success given the materials present. This comparison also clearly shows areas where more extensive methods of rehabilitation (recycling, etc.) may be required. Descriptions of some typical distress types and moisture influence are given in Figure 4-10 and Figure 4-11. These should be consulted, along with the distress types in the Appendix.

The Pavement Condition Index (PCI)

The urgency of the rehabilitation must come from examination of the PCI which indicates the overall condition. If the PCI is high then preventive maintenance may be all that is required. If the MDI indicates most of the distress is moisture related, and the MAD Index indicates a high potential for moisture damage to occur, strong considerations should be given to placing drainage depending on the age of the pavement. A young pavement would have more investment to be saved than an older pavement that should have already returned its investment in proportion to its age.

receive higher consideration than an older pavement. A younger pavement will

A low PCI indicates large amounts of distress and implies that rehabilitation should be planned. The time frame depends on the value of the PCI and the usage of the highway. General recommendations are given in Figure 4-12. If the MDI and MAD Index show moisture to be a problem, then drains should be considered if the materials are suited, or reworking and even new materials should be considered if the materials present are unsatisfactory. Again, the age of the pavement will indicate the extent of the rehabilitation technique.

Strict guidelines cannot be formulated recommending specific maintenance or rehabilitation techniques for all of the possible combinations. The required evaluation parameters, MAD Index, PCI, and MDI, can be obtained without completely understanding the information used in their development. These three evaluation parameters provide the needed information to make a decision. The discussions in this manual and Volume I, Chapter 4 must be studied, however, to make a rational decision. It is felt that the procedures developed in Volumes I and II will make that decision easier and more consistent.

MAD Index	
Negligible: (85-100)	This pavement would not show any moisture-related problems during its lifetime - Drainage not needed.
Low: (70-85)	This pavement contains a combination of properties that make it moisture insensitive, but climatic influences and maintenance must be carefully watched to maintain the good performance.
Normal: (55-70)	This pavement is composed of average materials exposed to average situations. Moisture damage is likely unless adequate drainage and maintenance are kept at a high level.
Moderate: (35-55)	Lower quality materials and a slightly inferior climate will produce large amounts of moisture damage unless extensive care is given to drainage considerations and routine maintenance.
High: (15-35)	Even with adequate drainage moisture damage will appear due to variability in materials. Without drainage there would be excessive moisture damage.
Excessive: (0-15)	The combination of climate and materials precludes any effectiveness of drainage in reducing moisture damage. Severe problems will develop, excessive maintenance should be planned for.

Figure 4-1 Potential for Moisture Accelerated Problems in a Pavement, as Indicated by the MAD Index

Key to each combination code (e.g. "III Cak"): Moisture Region, Temperature Region, Granular Material acceptability, Subgrade Drainability

MAD Index	Damage Potential	Combinations
100	NEGLIGIBLE	
99		
98		
97		
96		
95		
94		
93		
92		III Cak
91		
90		
89		III Cmk
88		
87		
86		
85		III Caj, III Bak
84	LOW	
83		
82		III Bmk
81		
80		
79		
78		III Caj, III Cmj, III Baj, III Cuk, III Aak
77		
76		
75		III Amk
74		II Cak
73		
72		
71		III Cuk, III Bmj, III Aaj, III Buk, II Cmk
70		III Cmi, III Bai
69	NORMAL	
68		
67		II Caj, II Bak
66		
65		
64		III Buk, III Amj, III Auk, II Bmk
63		III Cui, III Bmi, III Aai
62		
61		
60		II Cmj, II Baj, II Cuk, II Auk
59		II Cai
58		
57		III Auk, II Amk
56		III Bui, III Ami
55		
54	MODERATE	I Cak
53		II Cmi, II Bai, II Cuk, II Bmj, II Auj, II Buk
52		
51		I Cmk
50		
49		III Aui
48		
47		I Caj, I Bak
46		II Buk, II Amj, II Auk
45		II Cui, II Bmi, II Aui
44		I Bmk
43		
42		
41		
40		I Cmj, I Bai, I Cuk, I Aak
39		II Auk, I Cai
38		II Bui, II Ami
37		I Amk
36		
35		
34	HIGH	
33		I Cuj, I Bmj, I Aaj, I Buk
32		I Cmi, I Bai
31		II Aui
30		
29		
28		
27		
26		I Buj, I Amj, I Auk
25		I Cui, I Bmi, I Aai
24		
23		
22		
21		
20		
19		I Aui
18		I Bui, I Ami
17		
16		
15		
14	EXCESSIVE	
13		
12		
11		I Aui
10		
9		
8		
7		
6		
5		
4		
3		
2		
1		
0		

Figure 4-2. Ranking of Material Combinations, The MAD Index

Region	Description
A	This region experiences long winters with the temperature below freezing for extended periods. The potential for a slowly advancing freezing front into the subgrade is extremely high. Frost damage is to be expected accompanied with other low temperature problems.
B	This region experiences winters with more fluctuation of the temperatures about the freezing point. Freeze-thaw cycling into the base course is to be expected. Some Thermal Fatigue problems could be expected, with hot summers being a problem in the West due to radiation.
C	This region is characterized by relatively mild winters (compared to A or B) and damage may range from minimal thermal fatigue in the North to high temperature stability problems in the south.

Figure 4-3 Regional Temperature Descriptions

Region	Description
I	Due to the climatic influences the subgrade will remain wet for the majority of the year and very little moisture variation will occur. Performance relationships indicate that the region will maintain a moisture level that will produce low load related performance.
II	The state of moisture in the subgrade will vary during the year, but the average moisture condition is very much drier than Region I. Region II produces a moisture state that produces load related performance in a transitional portion between good and poor. Seasonal concentration of moisture will be important in determining which level of performance would be present.
III	In Region III the annual moisture state is dry. The load related performance is good for all materials. Seasonal concentrations of moisture will be responsible for producing slightly lower performance in one area than another where the moisture is not concentrated in one time period.

Figure 4-4 Regional Moisture Descriptions

Concentration Index	Description
r & d	In these areas there is little or no water surplus in any season and the performance will be as indicated by the Regional description.
S	In these areas there will be a moderate concentration of moisture during the winter months and slightly decreased performance during the winter may account for moderate performance differences between other areas that do not have this uneven input.
S_2	In these areas there will be a large concentration of moisture during the winter months. In these areas, accelerated deterioration due to moisture will occur as compared to areas without this concentration. Moisture damage should be similar to regions having higher annual moisture.

Figure 4-5 Seasonal Moisture Concentration

Acceptable:	(a):	Will readily pass water to the down slope. Free draining. Load Related granular moisture performance will be excellent and will not be influenced by the subgrade.
Marginal:	(m):	May let load related moisture damage accumulate in the granular layer. Drainage is an absolute necessity for this material. The moisture related performance may be improved by the subgrade.
Unsatisfactory:	(u):	Granular layer will absorb moisture and remain above the critical saturation level even with drainage. Moisture damage will be excessive in the granular layer and the subgrade cannot alter it. (See Figure 4-8)

Figure 4-6 Performance of Granular Layer Defined by the Quality Level, Representing Best Situation Attainable.

i - poorly drained, depressional soil with high water table.

NDI < -2

j - moderately drained, larger texture, situated higher in the topographic relationship, with a greater depth to the water table.

-2 < NDI < 2

k - excessively drained, highest in the topography with the water table at a great depth where it does not interact with the pavement.

NDI > 2

Figure 4-7 Subgrade Classification

GRANULAR CLASSIFICATION / SUBGRADE SOIL NDI	ACCEPTABLE	MARGINAL	UNACCEPTABLE
< -2	All materials are free draining, excellent performance. Provide positive outlet, recommended.	Subgrade assists drainage of granular layers. Positive outlet is critical to performance.	Maintain surface integrity. Draining granular layer will provide marginal benefits at best.
< -2, < 2	Good granular layer drainage. Subgrade may be a problem. Provide positive outlet for granular layer.	Drainage may be beneficial, in these materials, in upgrading performance.	Drainage Recommendations not beneficial except to remove subsurface water.
> 2	Removal of subsurface water is required. Must provide positive outlet for granular layers.	Drainage of surface filtration and subsurface water must be done.	Do not try to drain surface infiltration. Maintaining surface integrity is critical. Rework materials.

Figure 4-8 Summary of Material Combinations and Resulting Problems

$100 > \text{MDI} > 75$: A large majority of distress is moisture related. This project is highly sensitive to moisture over its entire length.

$75 > \text{MDI} > 50$: Over one-half the distress present is related to moisture. A majority of the project is highly moisture susceptible.

$25 < \text{MDI} < 50$: Moisture is playing some role in deterioration of this project.

$\text{MDI} < 25$: Moisture is only playing a minor role in the deterioration of this project.

Figure 4-9. Explanation of MDI Levels

Figure 4-10 DISTRESS MANIFESTATIONS FOR FLEXIBLE PAVEMENTS

TYPE	DISTRESS MANIFESTATION	MOISTURE PROBLEM	CLIMATIC PROBLEM	MATERIAL PROBLEM	LOAD ASSOCIATED	STRUCTURAL DEFECT BEGINS IN ASPHALT	BASE	SUBGRADE
SURFACE DEFECT	ABRASION	NO	NO	AGGREGATE	NO	YES	NO	NO
	BLEEDING	NO	ACCENTUATED BY HIGH TEMP	BITUMEN	NO	YES	NO	NO
	STRIPPING	YES	YES	BOTH	YES	YES	NO	NO
	RAVELLING	NO	NO	AGGREGATE	SLIGHTLY	YES	NO	NO
	WEATHERING	NO	HUMIDITY AND LIGHT-DRIED BITUMEN	BITUMEN	NO	YES	NO	NO
SURFACE DEFORMATION	BUMP OR DISTORTION	EXCESS MOISTURE	FROST HEAVE	STRENGTH-MOISTURE	YES	NO	YES	YES
	CORRUGATION OR RIPPLING	SLIGHT	CLIMATIC & SUCTION RELATIONS	UNSTABLE MIX	YES	YES	YES	YES
	SHOVING	NO		UNSTABLE MIX LOSS OF BOND	YES	YES	NO	NO
	RUTTING	EXCESS IN GRANULAR LAYERS	SUCTION & MATERIAL	COMPACTION PROPERTIES	YES	YES	YES	YES
	WAVES	EXCESS	SUCTION & MATERIALS	EXP. CLAY FROST. SUSC.	NO	NOT INITIALLY	NO	YES
	DEPRESSION	EXCESS	SUCTION & MATERIALS	SETTLEMENT, FILL MATERIAL	YES	NO	NO	YES
	POTHOLES	EXCESS	FROST HEAVE	STRENGTH-MOISTURE	YES	NO	YES	YES
CRACKING	LONGITUDINAL	YES	SPRING-THAW STRENGTH LOSS		YES	FAULTY CONSTRUCTION	YES	YES
	ALLIGATOR	YES DRAINAGE		POSSIBLE MIX PROBLEMS	YES	YES MIX	YES	YES
	TRANSVERSE	YES	LOW-TEMP., F-T CYCLES	THERMAL PROPERTIES	NO	YES, TEMP. SUSCEPTIBLE	YES	YES
	SHRINKAGE	YES	SUCTION, MOISTURE LOSS	MOISTURE SENSITIVE	NO	YES, HARDENING	YES	YES
	SLIPPAGE	YES	NO	LOSS OF BOND	YES	YES-BOND	NO	NO

Figure 4-11 DISTRESS MANIFESTATIONS FOR RIGID PAVEMENTS

TYPE	DISTRESS MANIFESTATION	MOISTURE PROBLEM	CLIMATIC PROBLEM	MATERIAL PROBLEM	LOAD ASSOCIATED	STRUCTURAL DEFECT BEGINS IN SURFACE	BASE	SUBGRADE
SURFACE DEFECTS	SPALLING	POSSIBLE	NO	CHEMICAL INFLUENCE	NO	YES - FINISHING	NO	NO
	SCALING	YES	F-T CYCLING		NO	YES	NO	NO
	D-CRACKING	YES	F-T CYCLING	AGGREGATE	NO	YES	NO	NO
	CRAZING	NO	NO	RICH MORTAR	NO	YES - WEAK SURFACE	NO	NO
SURFACE DEFORMATION	BLOW-UP	NO	TEMPERATURE	THERMAL PROPERTIES	NO	YES	NO	NO
	PUMPING	YES	MOISTURE	FINES IN BASE MOISTURE SENSITIVE	YES	NO	YES	YES
	FAULTING	YES	MOISTURE-SUCTION	SETTLEMENT DEFORMATION	YES	NO	YES	YES
	CURLING	POSSIBLE	MOISTURE AND TEMP.		NO	YES	NO	NO
CRACKING	CORNER	YES	YES	FOLLOWS PUMPING	YES	NO	YES	YES
	DIAGONAL TRANSVERSE LONGITUDINAL	YES	POSSIBLE	CRACKING FOLLOWS MOISTURE BUILDUP	YES	NO	YES	YES
	PUNCH OUT	YES	YES	DEFORMATION FOLLOWING CRACKING	YES	NO	YES	YES
	JOINT	PRODUCES DAMAGE LATER	POSSIBLE	PROPER FILLER AND CLEAN JOINTS	NO	JOINT	NO	NO

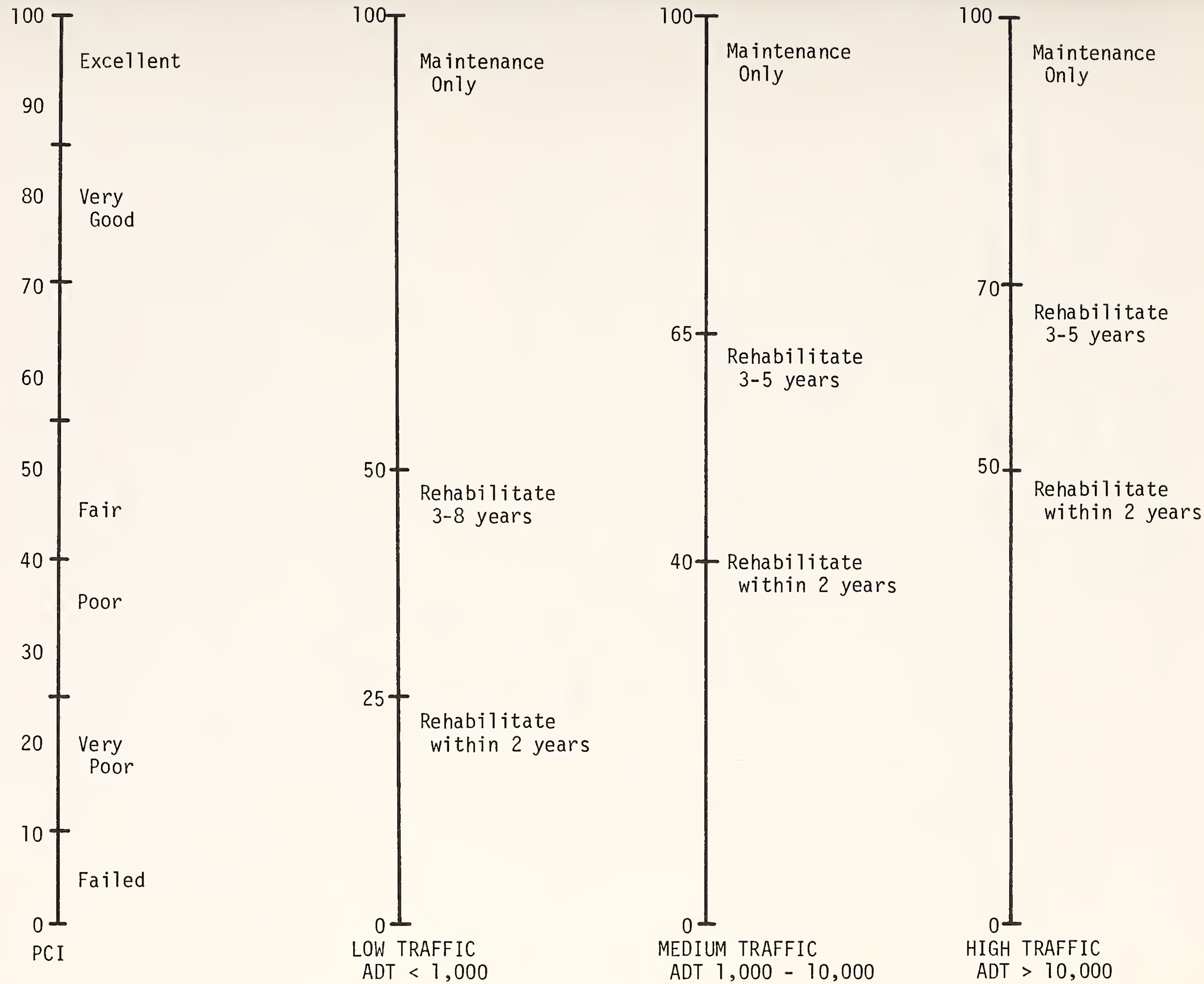


Figure 4-12 Rehabilitation and Maintenance Needs

APPENDIX A

DEVELOPMENT OF DEDUCT VALUE CURVES AND CORRECTED DEDUCT VALUE CURVES

Deduct value curves are included for asphalt surfaced pavements (eg. both flexible and asphalt overlays over jointed concrete pavements), and jointed reinforced concrete pavements. These curves were developed by a five member project staff experienced in pavement evaluation and rating. The deduct values were computed from the following relationship:

Deduct Value = 100 - Mean Pavement Condition Rating.

The rating scale shown below was used by the raters:

Scale	Structural & Operational Condition
100 - 86	Excellent
85 - 71	Very Good
70 - 56	Good
55 - 41	Fair
40 - 26	Poor
25 - 0	Very Poor

The individual curves were developed by assuming a given pavement condition having a single distress at a given level of severity. The group of experienced engineers would then give the pavement a rating according to how they independently felt the distress affected the pavement's structural and operational condition. The distress definitions were followed carefully in rating the impact of the distress. The mean group rating would then be computed and the average deduct value determined. The deduct value points were plotted on graphs over a range of distress occurrence and a smooth curve fitted through the data points.

After all of the individual deduct value curves were developed, the corrected deduct value curves were derived. These curves are used when an existing pavement has two or more different distress types or levels of severity, which is normally the case. They "adjust" or correct the total deduct value obtained by summing the deduct values from all distresses and levels of severity, to a value that represents 100 minus the mean group rating for such a pavement. This correction is necessary because the overall impact of more than one distress type on pavement condition is not a linear sum of deduct values.

Each member of the rating group rated pavement sections having a variety of distress conditions, and the mean group rating was computed for each pavement section. The corrected deduct value (CDV) was computed for a given pavement as:

$$CDV = 100 - \text{Mean Group Rating.}$$

The total deduct value for the same pavement was then determined by summing all deduct values corresponding to each distress/severity level. A plot shown in Figure A1 was developed for different numbers of distress/level of severity (shown here for $q = 2$ and $q = 8$) and smooth curves fitted through the data. The parameter "q" is the number of deduct values greater than five (5) points. The final set of curves are shown in Figure A2.

The deduct value curves included herein were developed by a group of experienced engineers. However, the curves should be considered as tentative, and in need of field validation by the highway agency utilizing them. Individual agencies should validate these curves and adjust them as needed to more closely fit their localized pavement conditions. This can be accomplished by first appointing an experienced group of design, maintenance, and construction engineers to review the distress definitions, and then check each individual deduct value curve. The correction curves should then be verified utilizing actual field sections maintained by the agency.

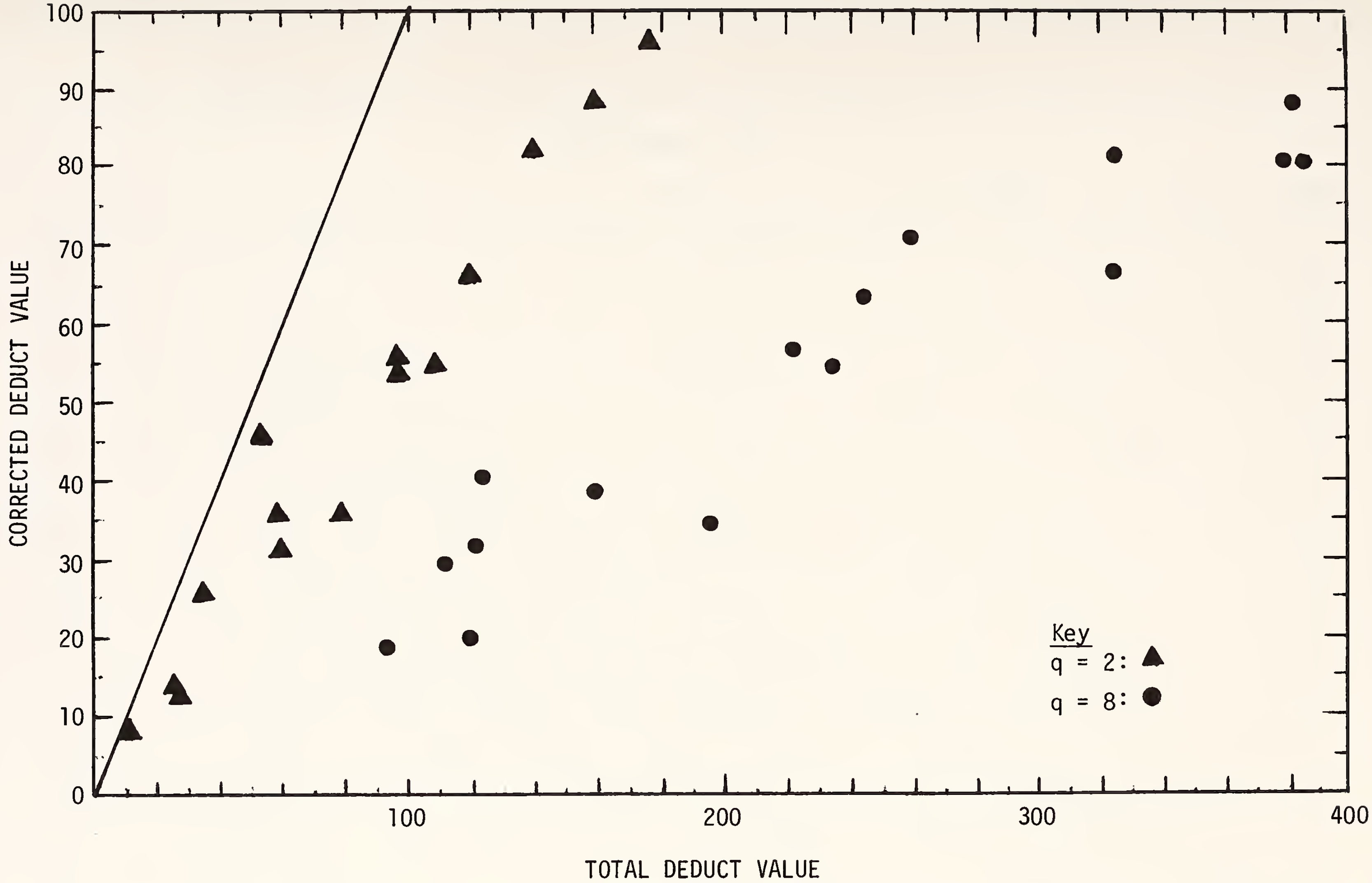


Figure A1. Illustration of the development of the corrected deduct curves. (Note: Each point represents a pavement section. The corrected deduct value equals 100 - mean group rating. The total deduct value is the same of all individual values for each distress/severity level. q = number of deduct values greater than 5 points).

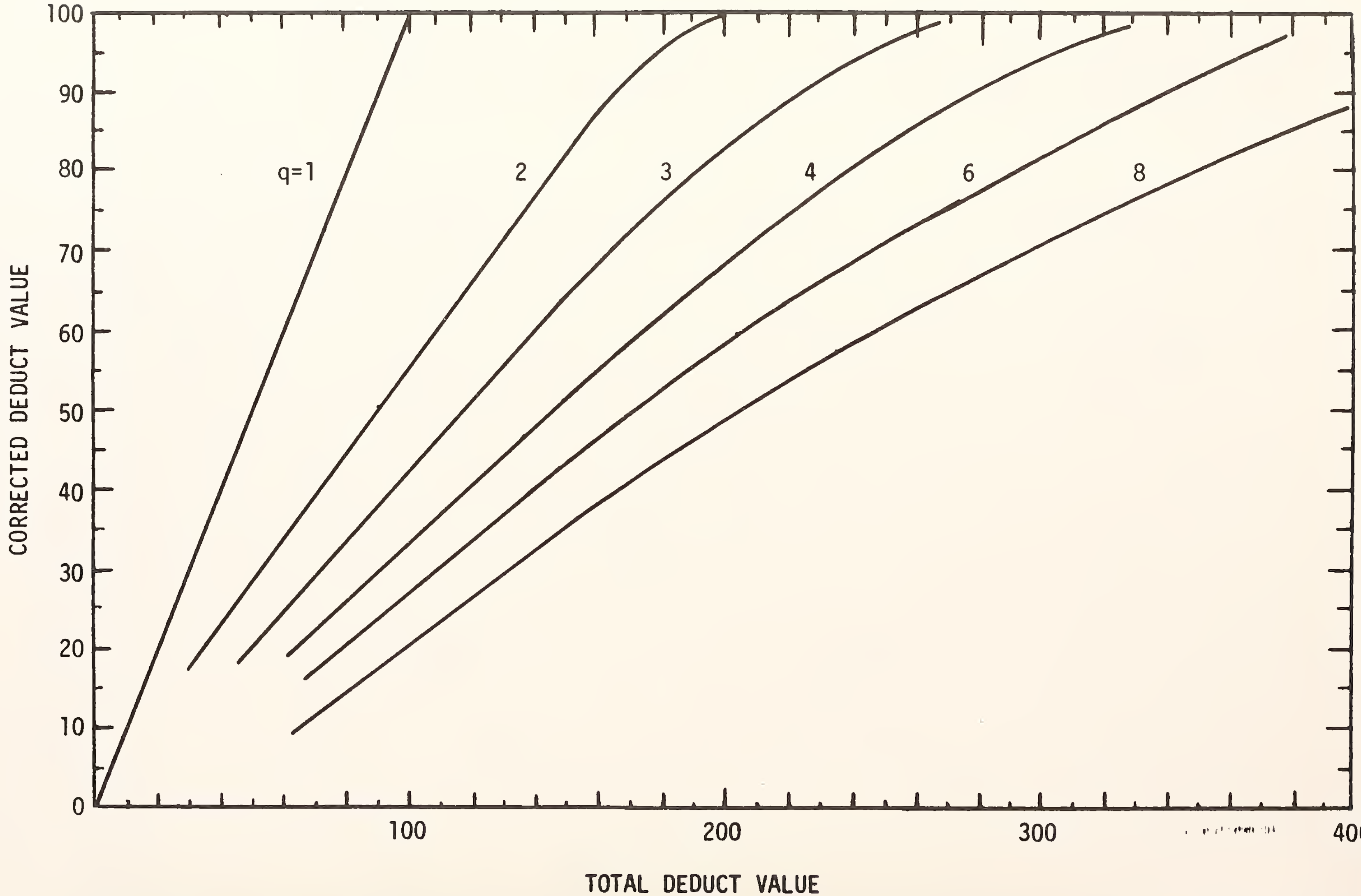


Figure A2. Corrected deduct value curves used when more than one distress type/severity level exists.

Asphalt Surfaced Deduct Value Curves

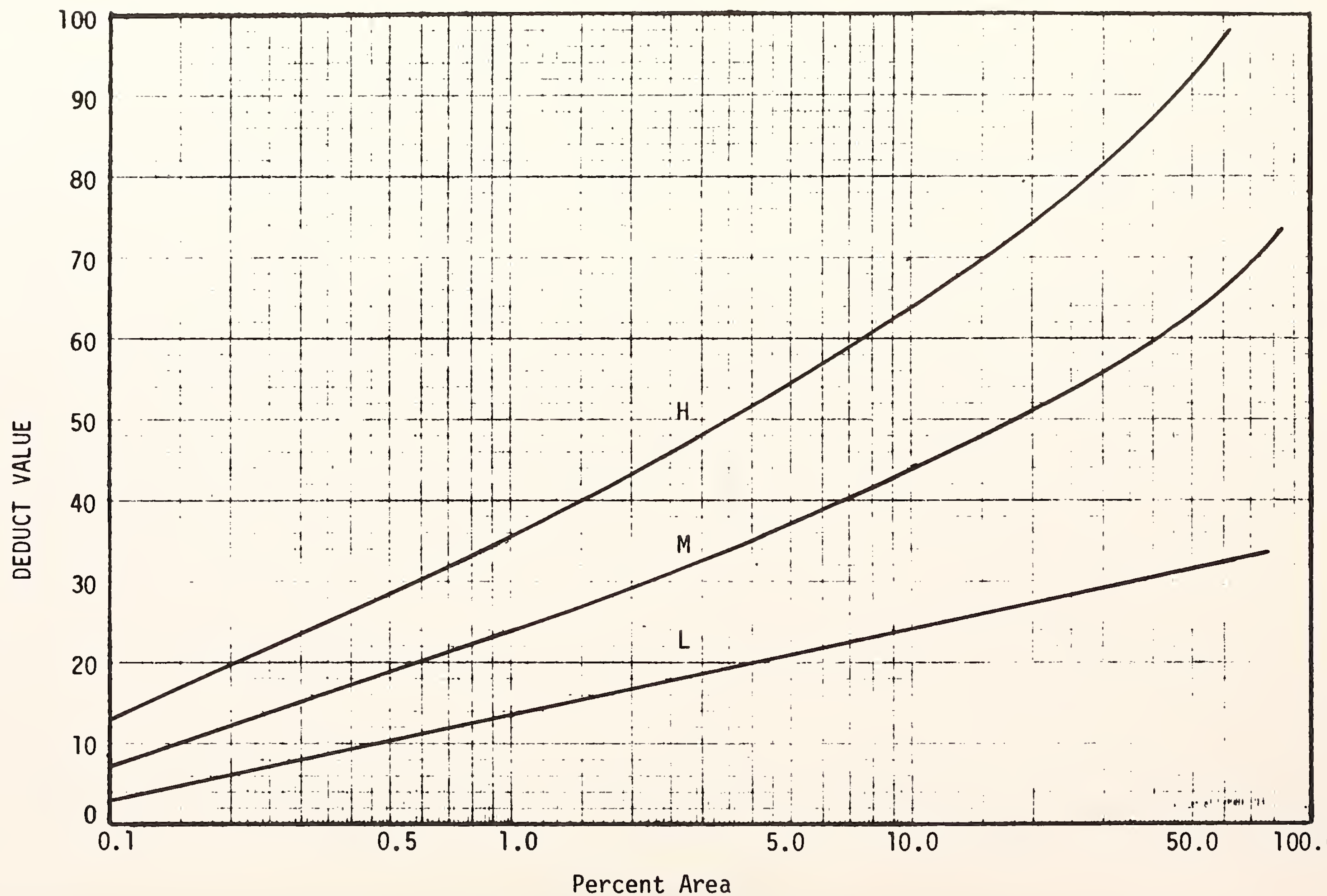


Figure A3. Alligator or Fatigue Cracking.

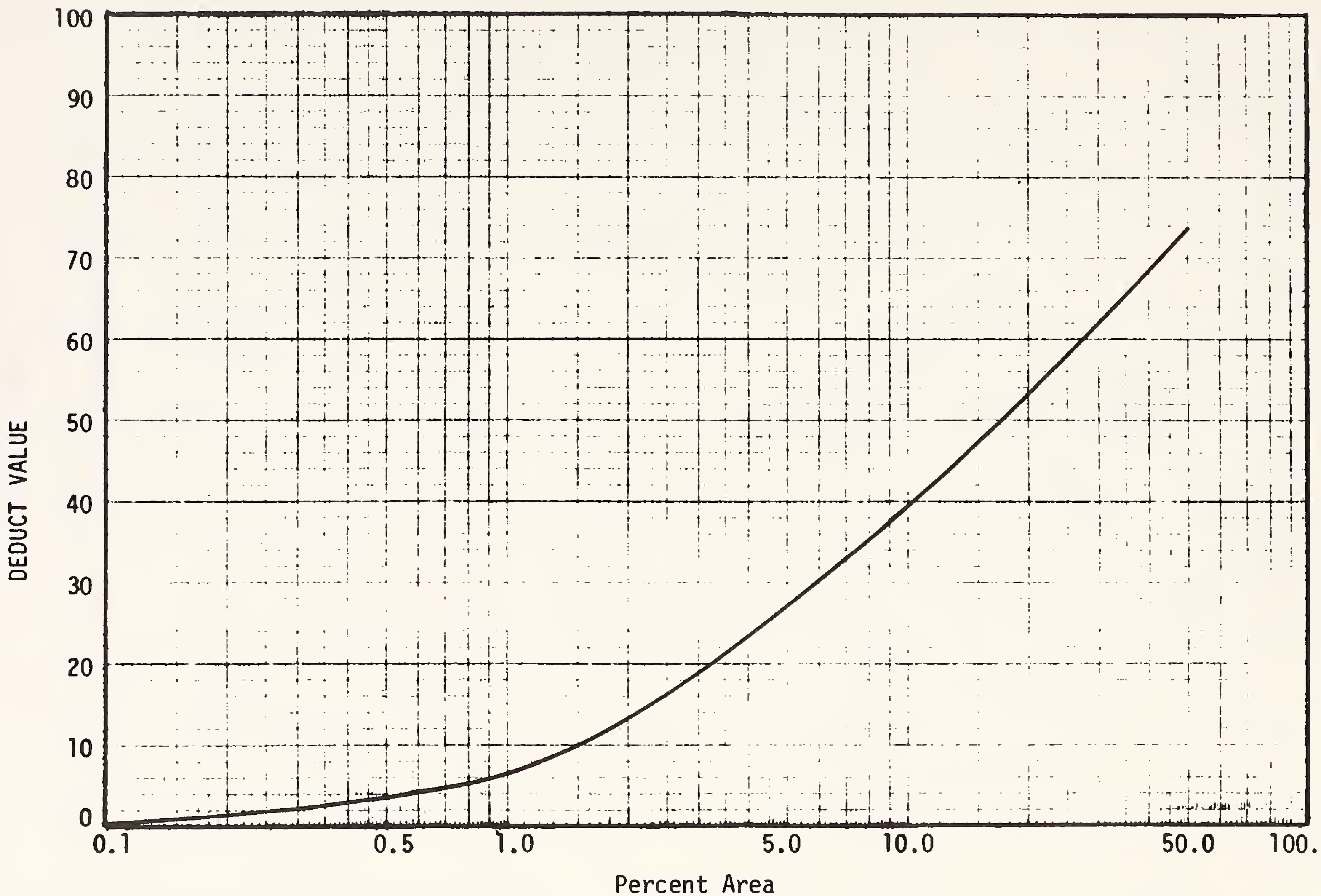


Figure A4. Bleeding.

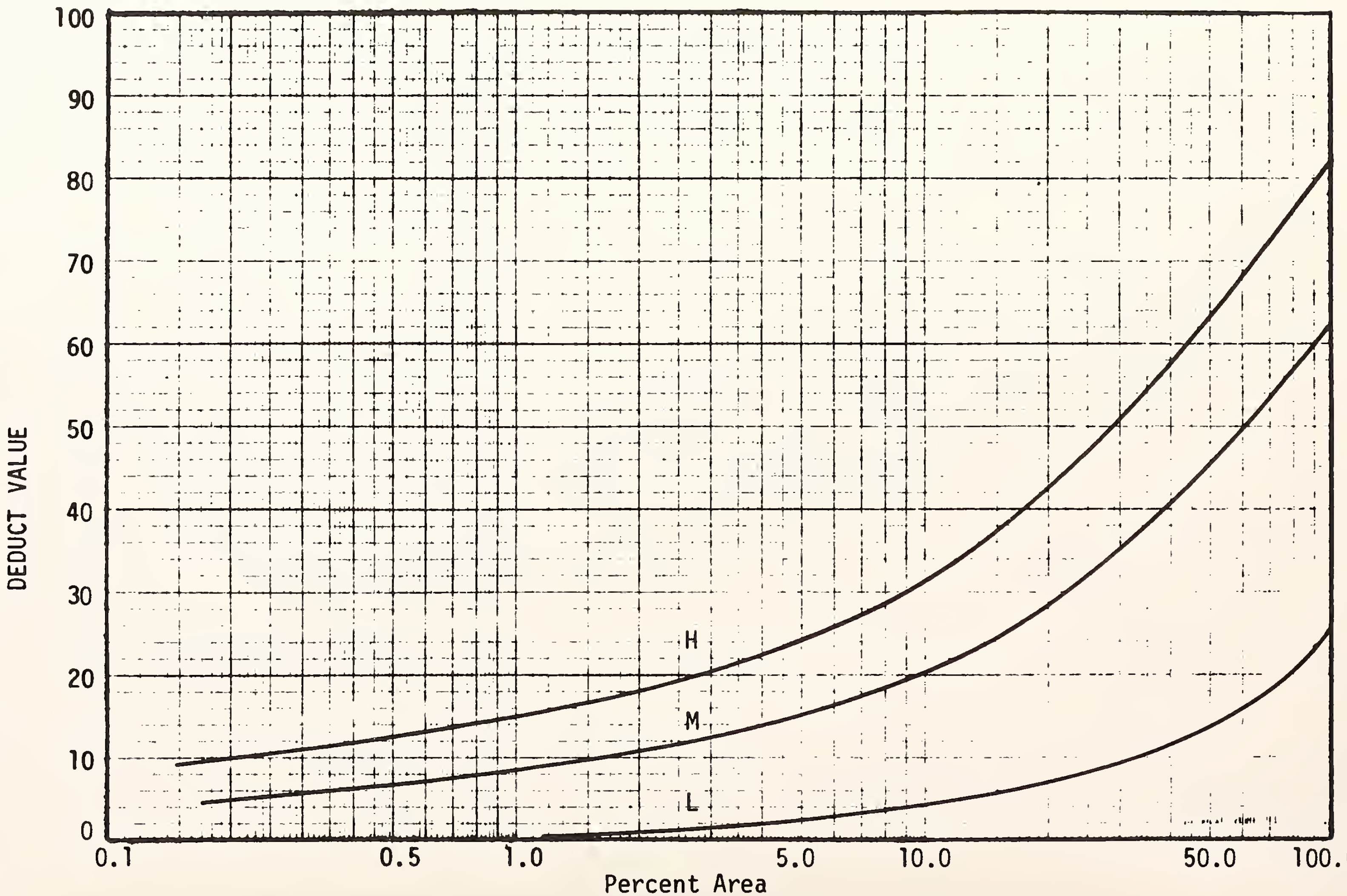


Figure A5. Block Cracking.

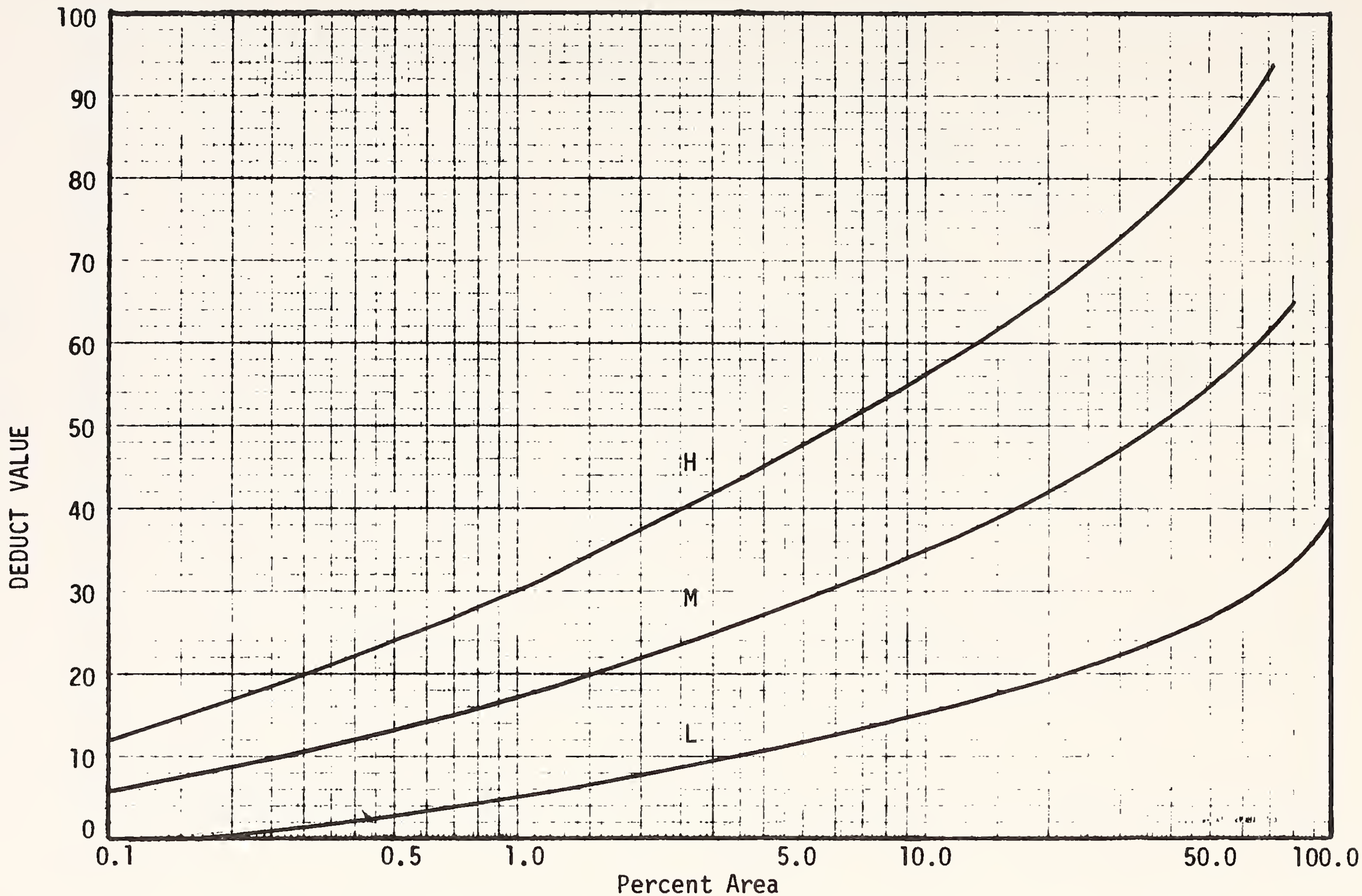


Figure A6. Corrugation.

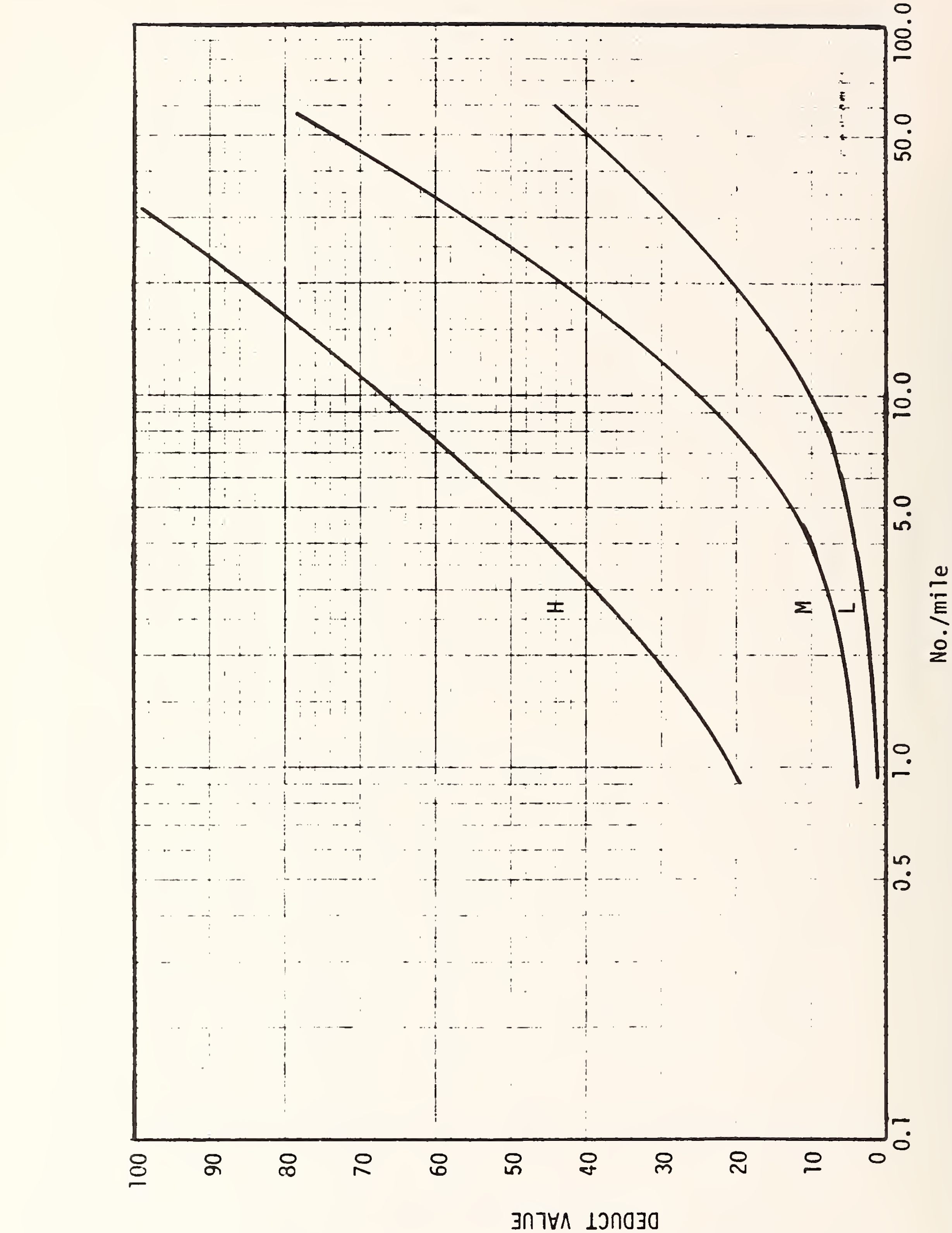


Figure A7. Depression.

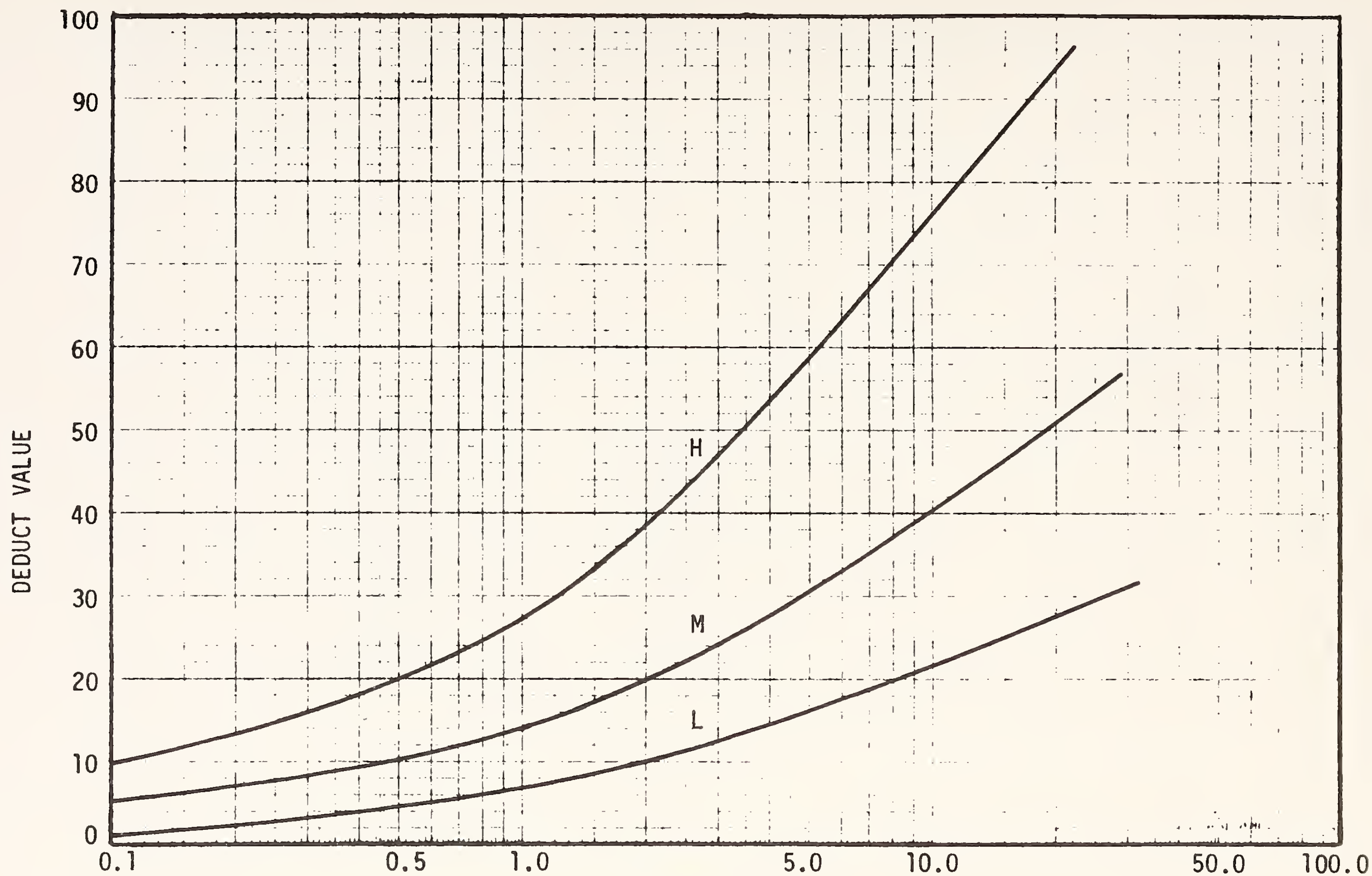


Figure A8. Joint reflection cracking from PCC slab.

Figure A9. Lane/shoulder dropoff-Heave.

L 10 deduct points
M 25 deduct points
H 59 deduct points

Figure A10. Lane/shoulder separation.

L 6 deduct points
M 14 deduct points
H 26 deduct points

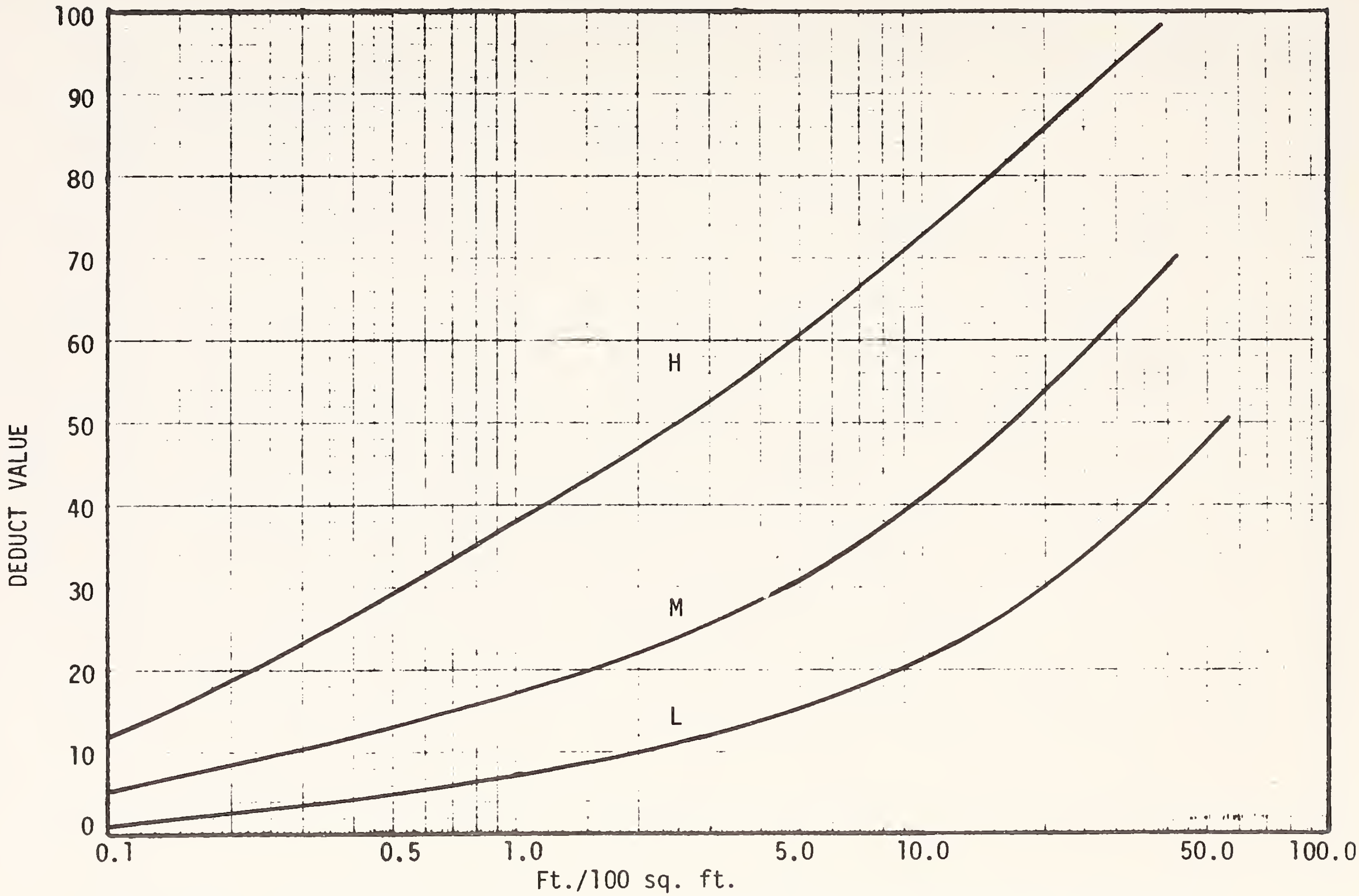


Figure A11. Longitudinal and transverse cracking (Non-PCC slab joint reflective)

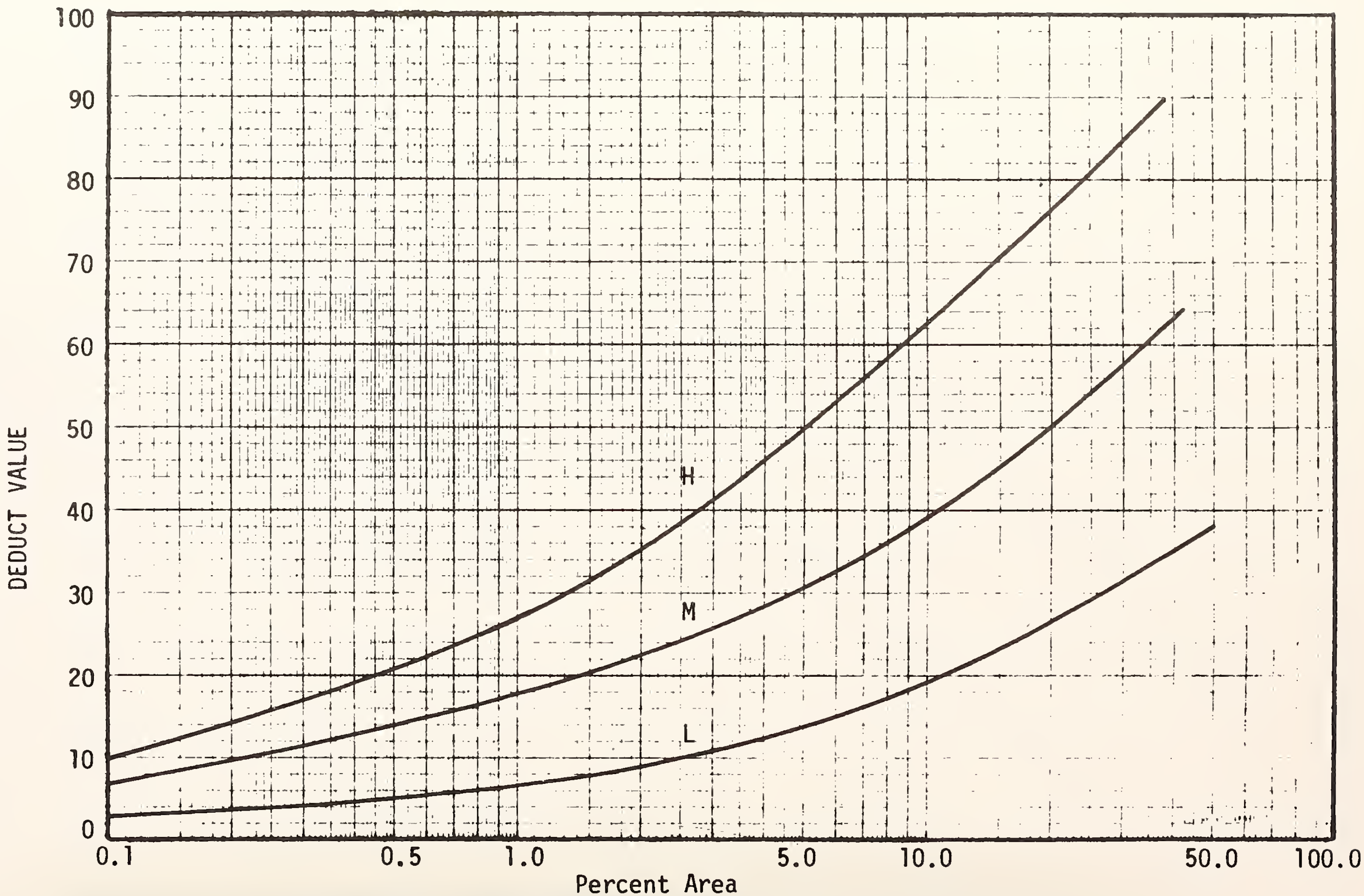


Figure A12. Patch deterioration.

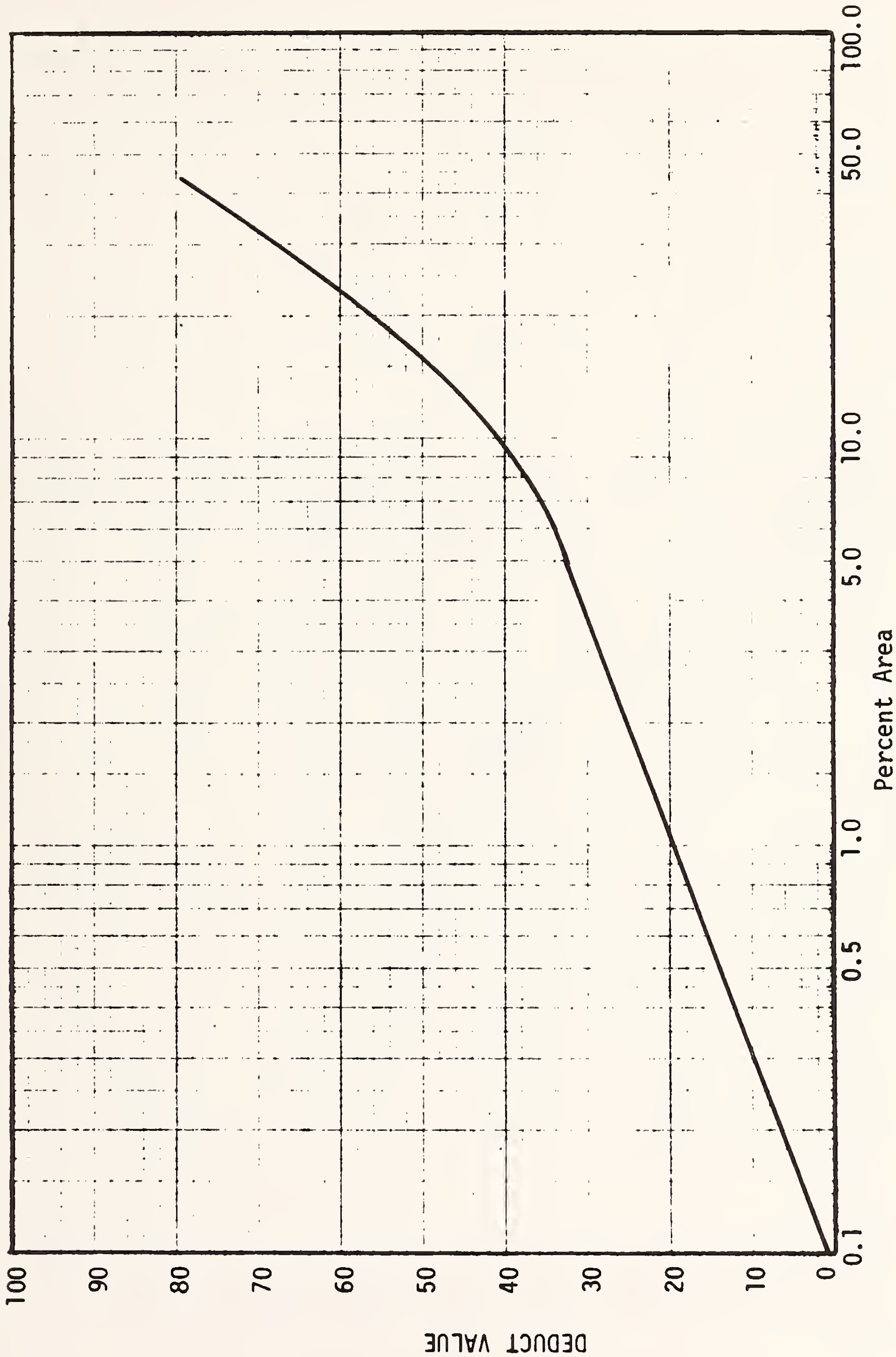


Figure A13. Polished aggregate.

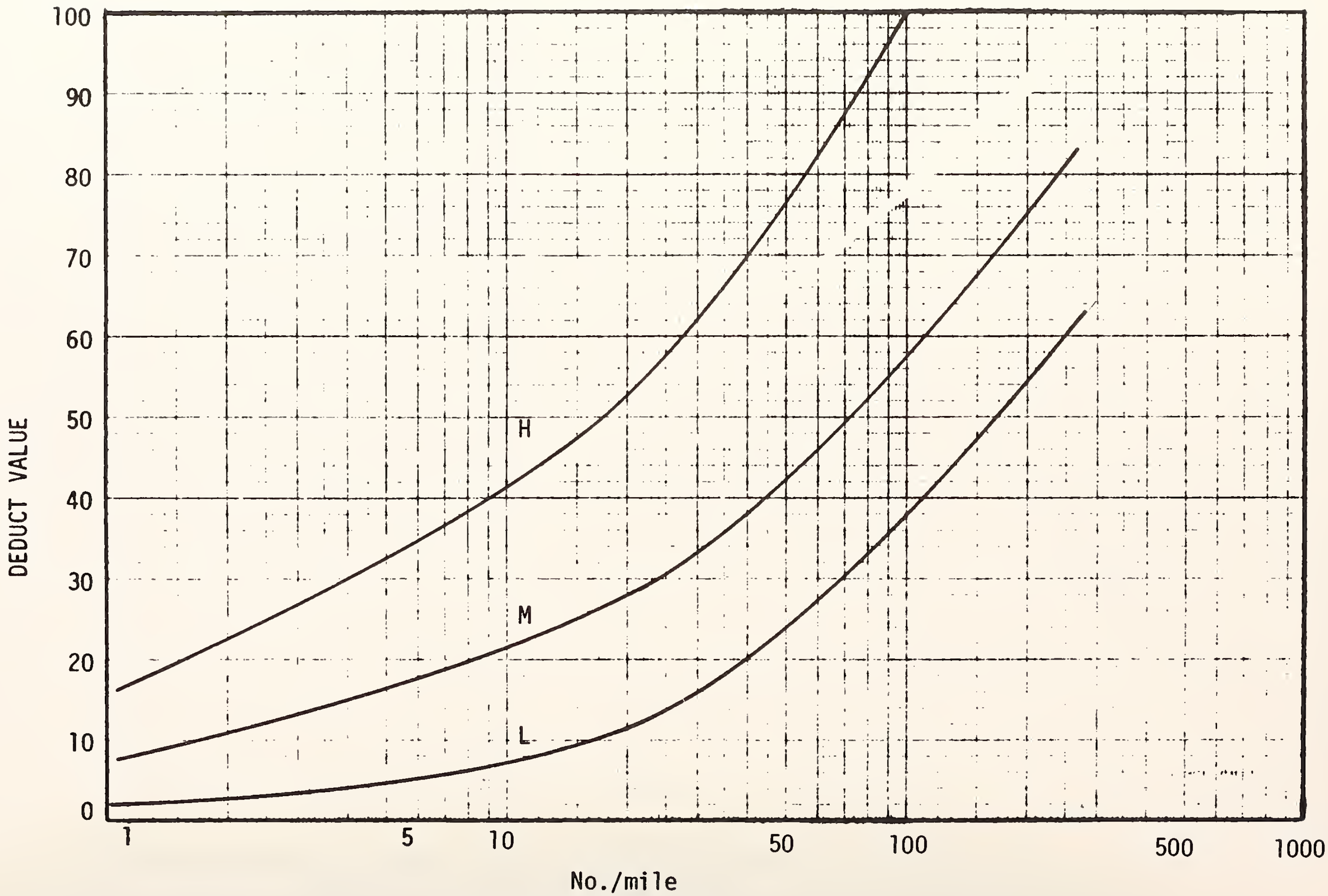


Figure A14. Potholes.

Figure A15. Pumping and water bleeding.

L 11 deduct points
M 31 deduct points
H 53 deduct points

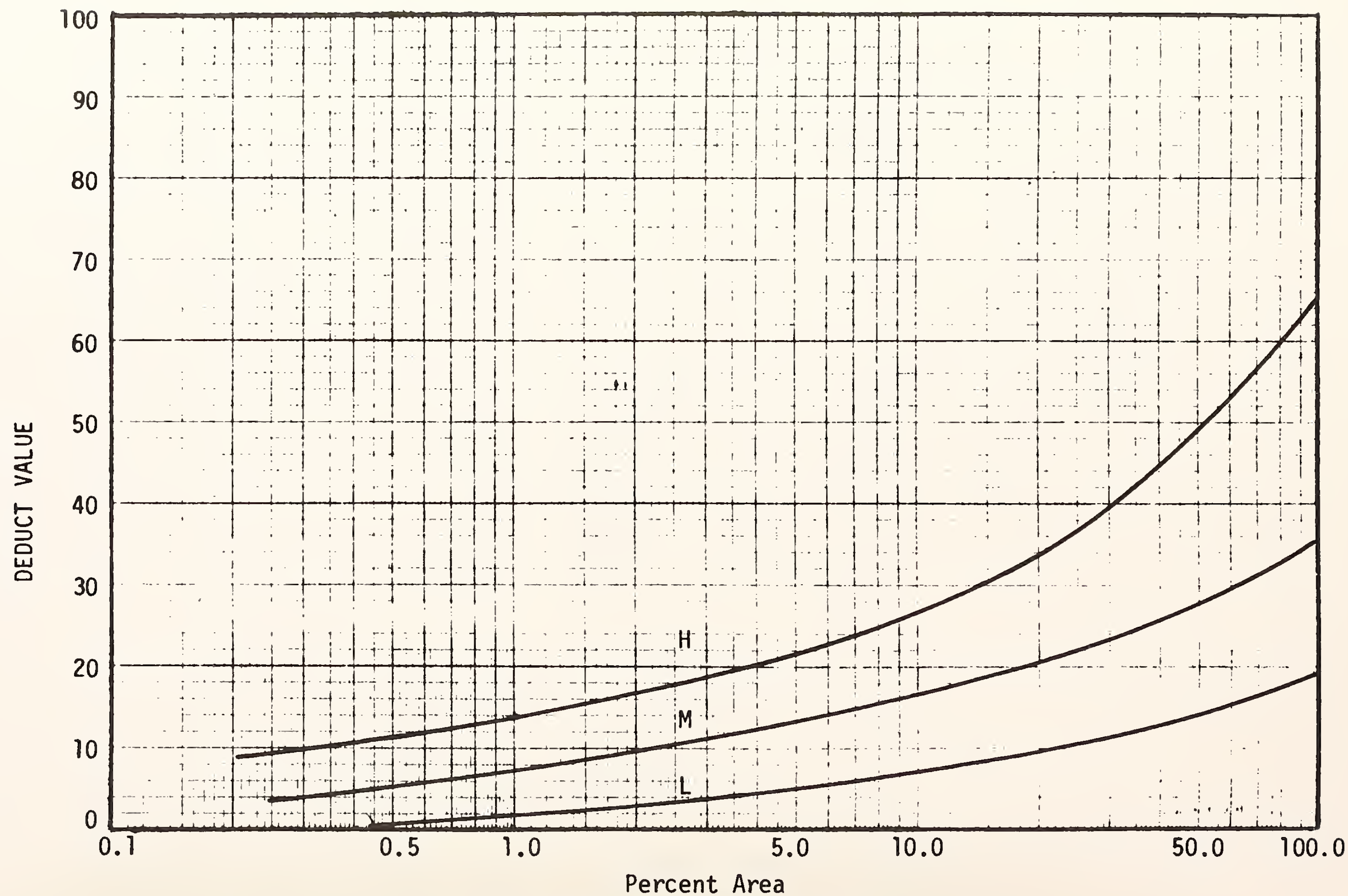


Figure A16. Raveling and weathering.

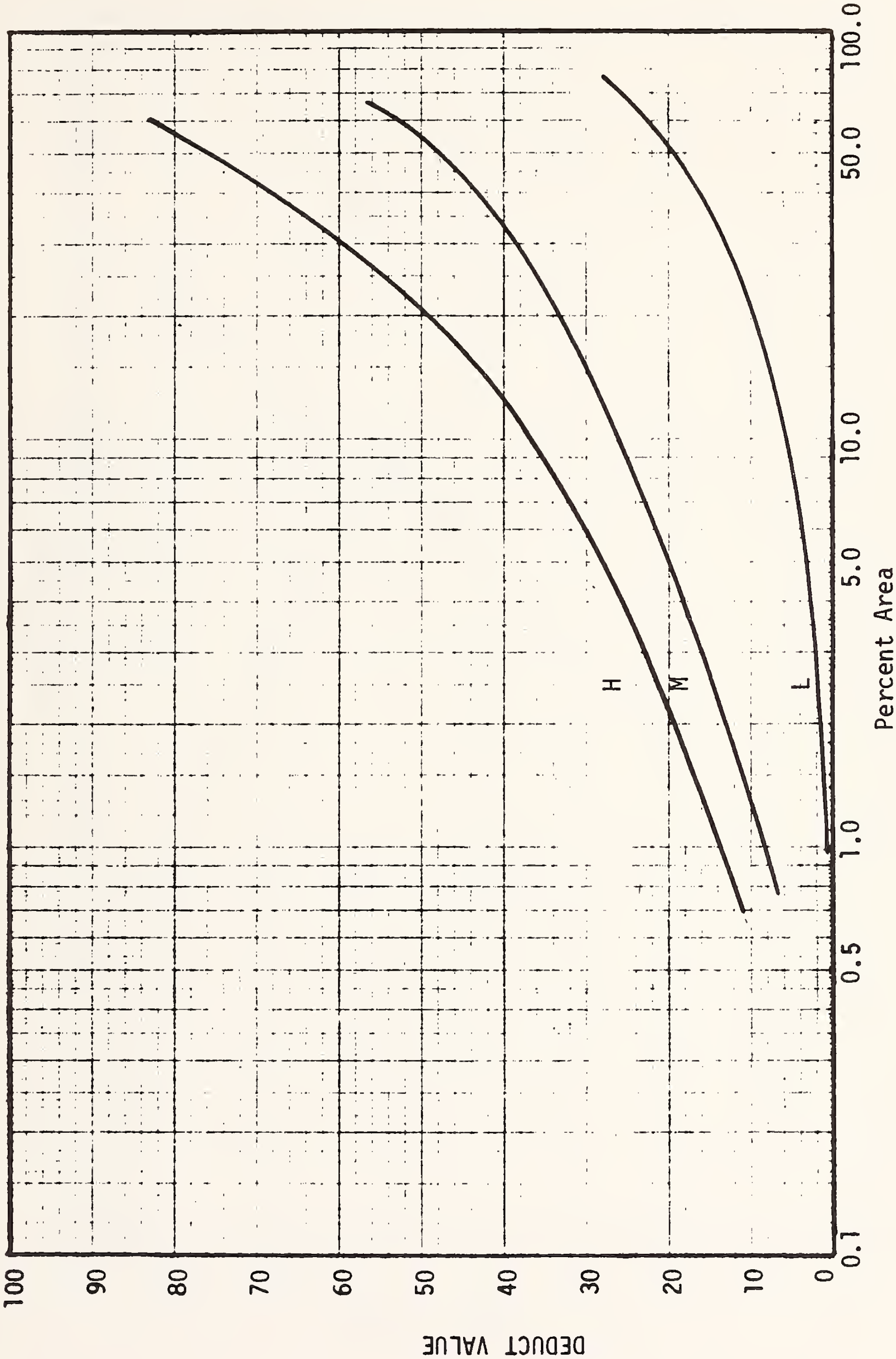


Figure A17. Rutting.

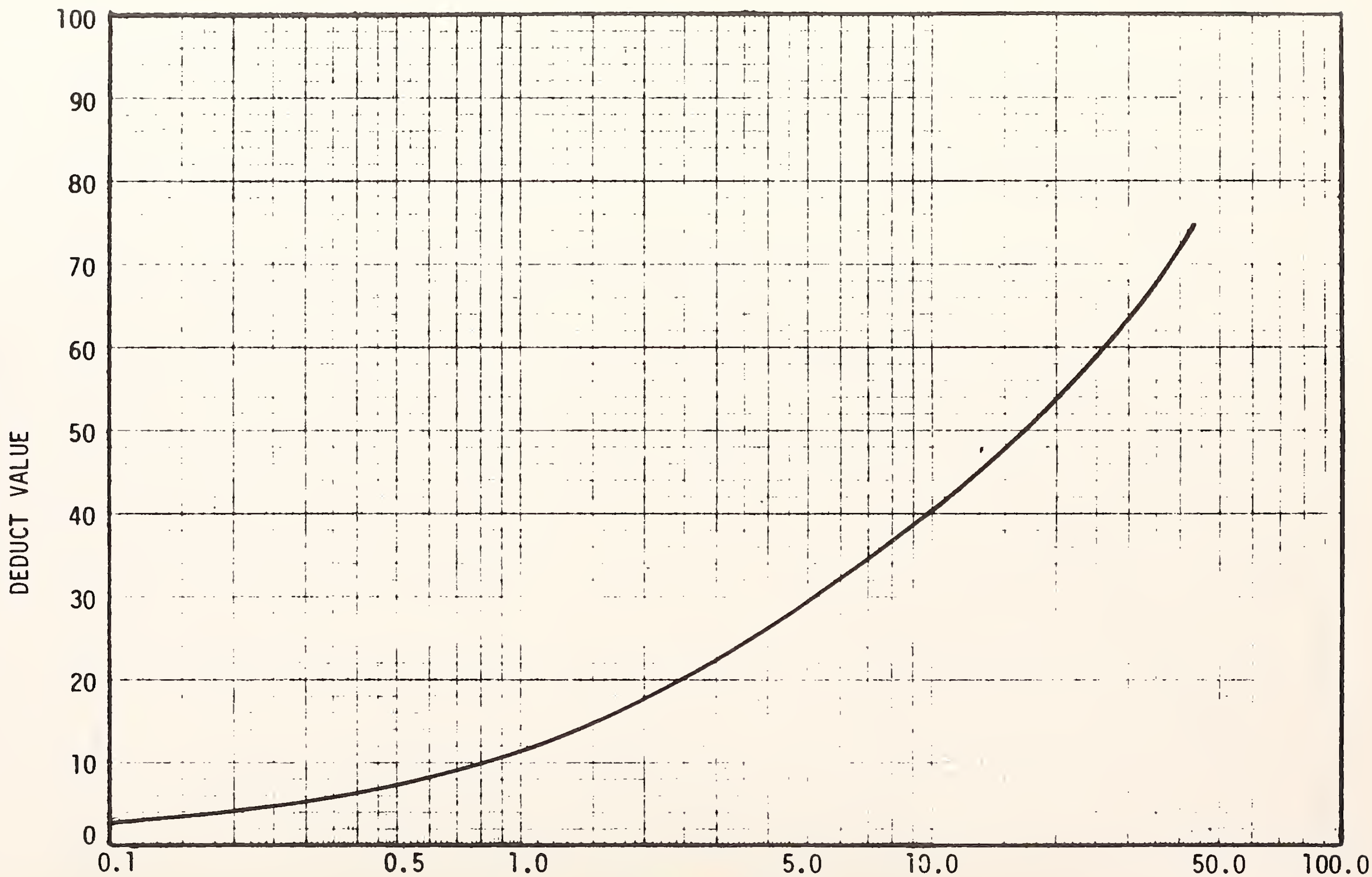


Figure A18. Slippage cracking.

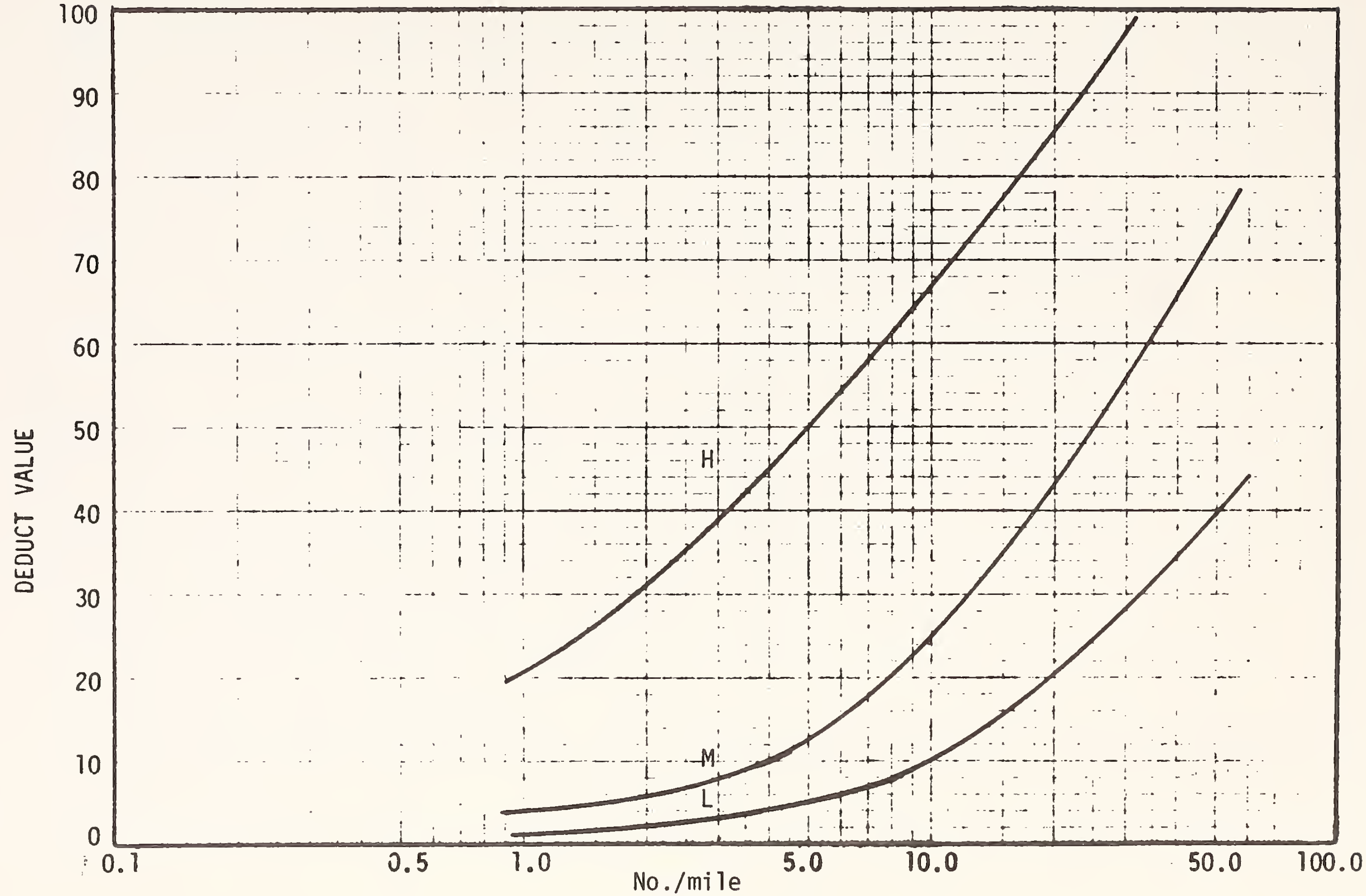


Figure A19. Swell.

Jointed Concrete Deduct Value Curves

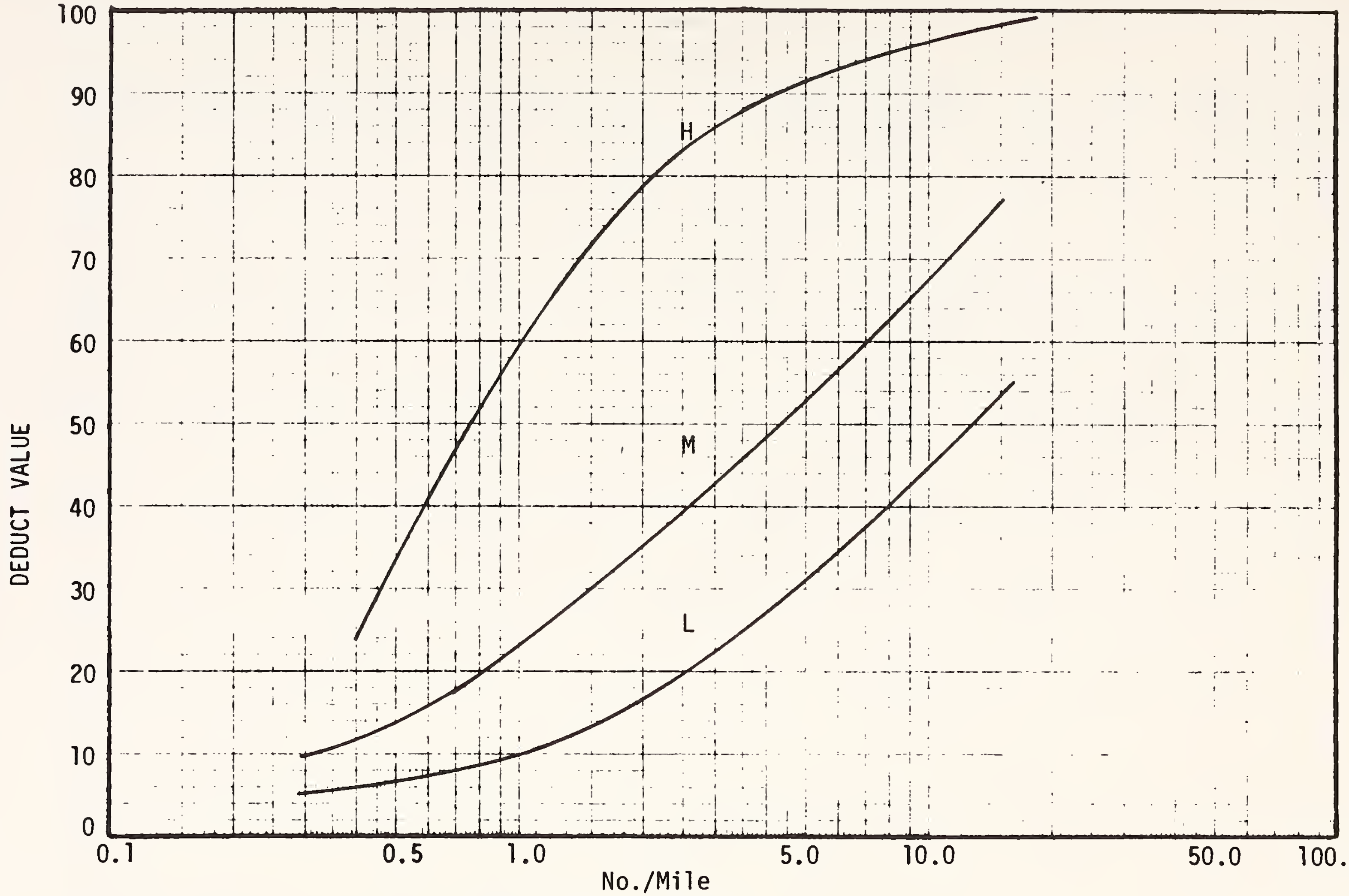


Figure A20. Blow-up.

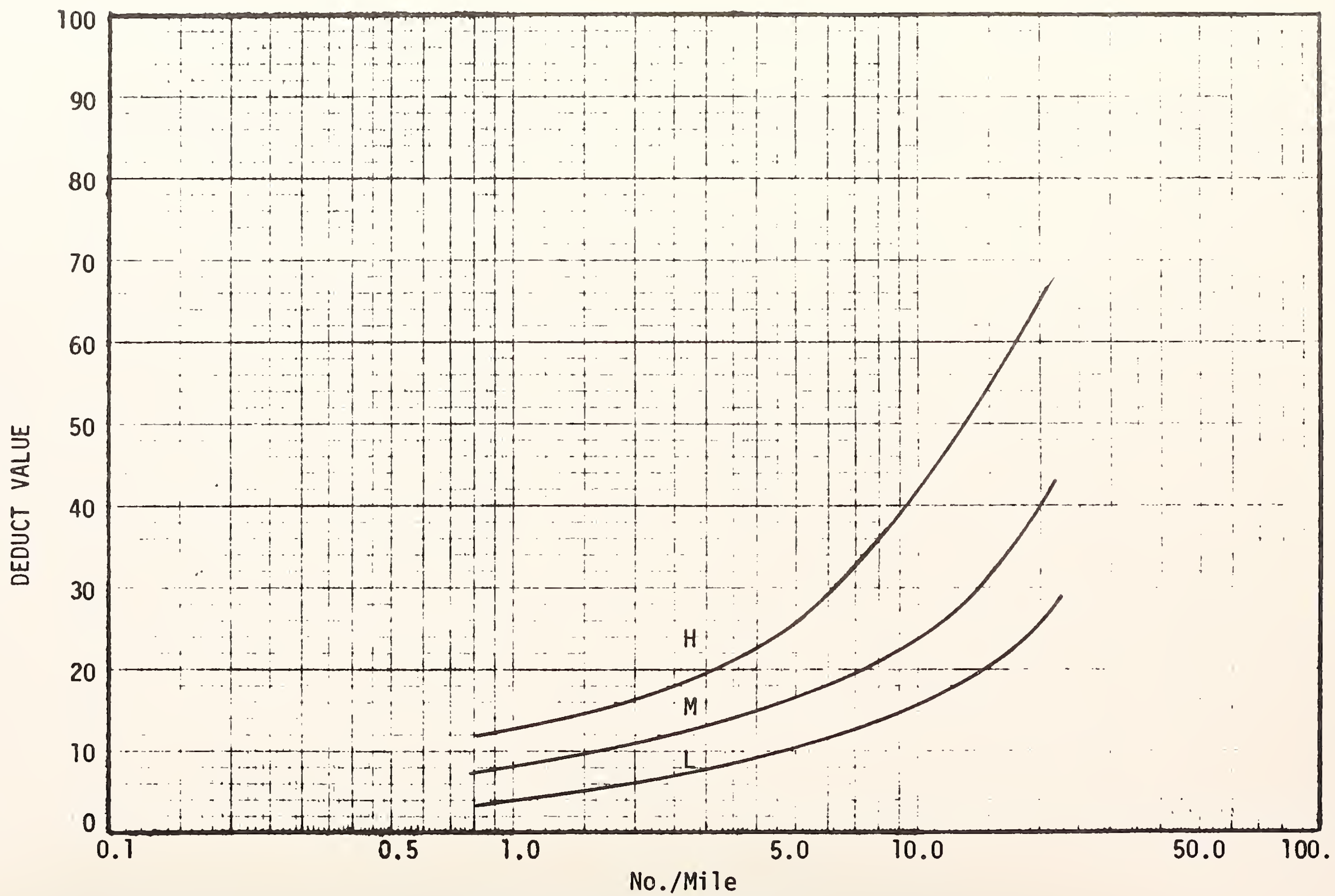


Figure A21. Corner break.

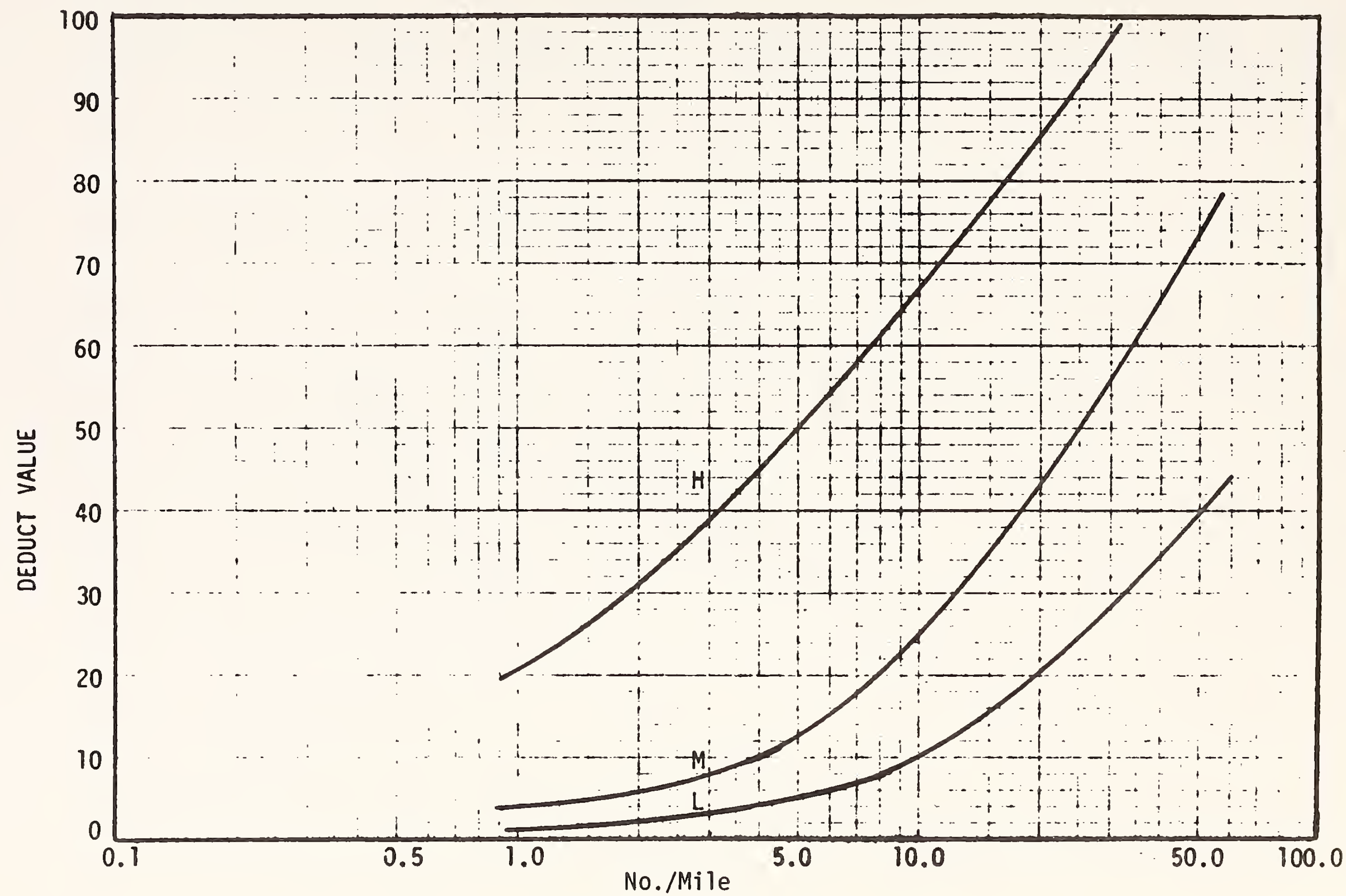


Figure A22. Depression.

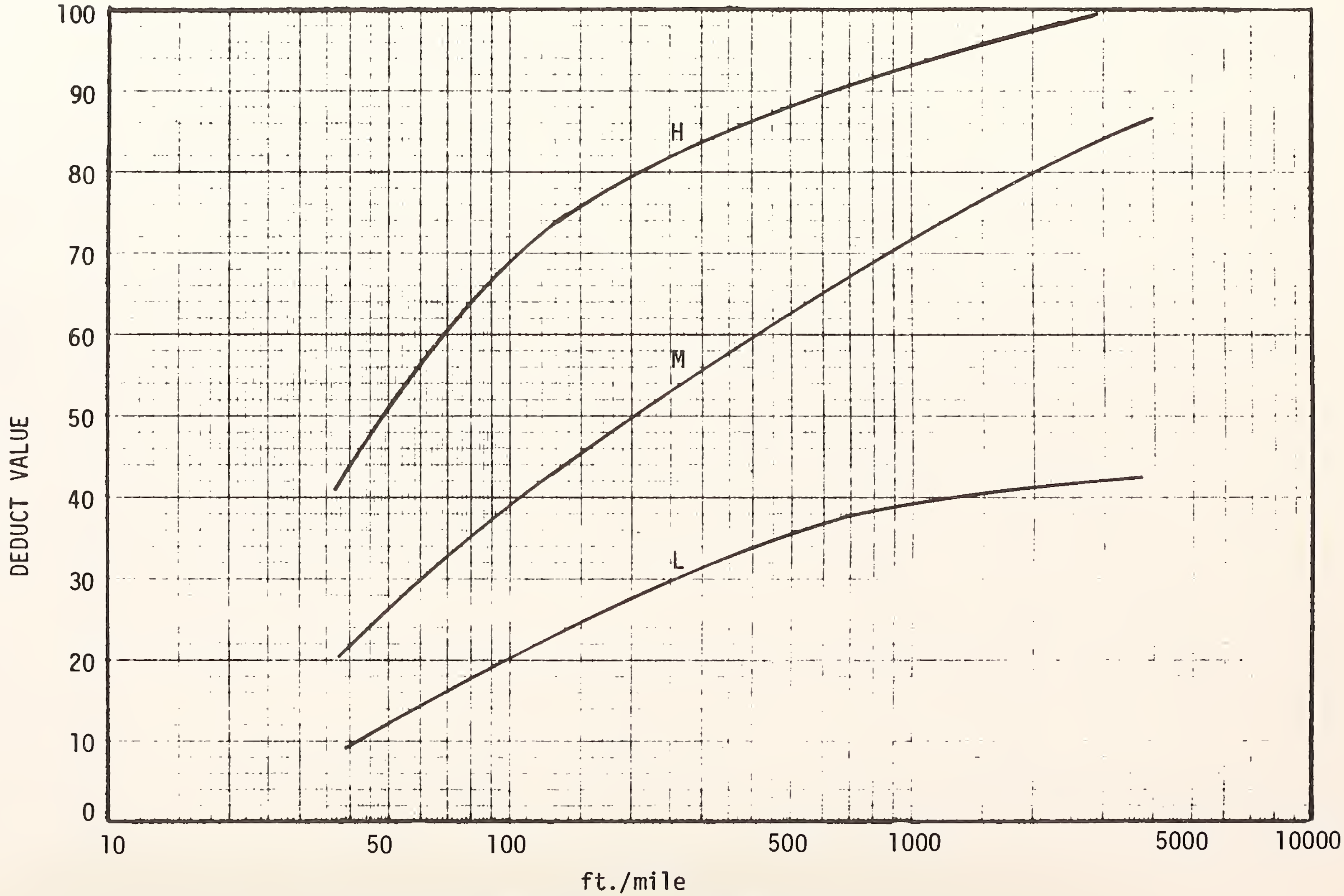


Figure A23. Durability ("D") cracking.

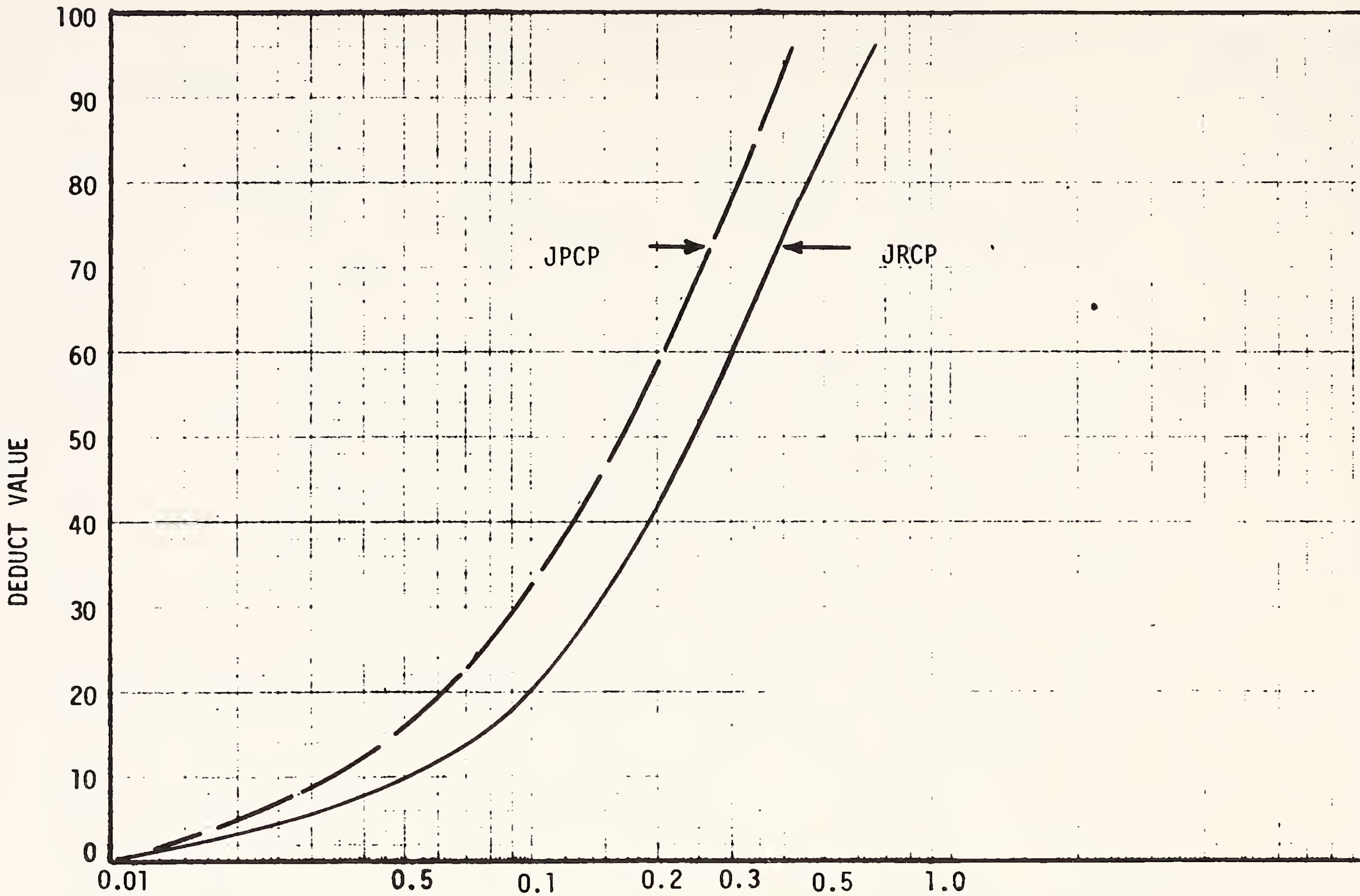


Figure A24. Faulting of transverse joints and cracks.

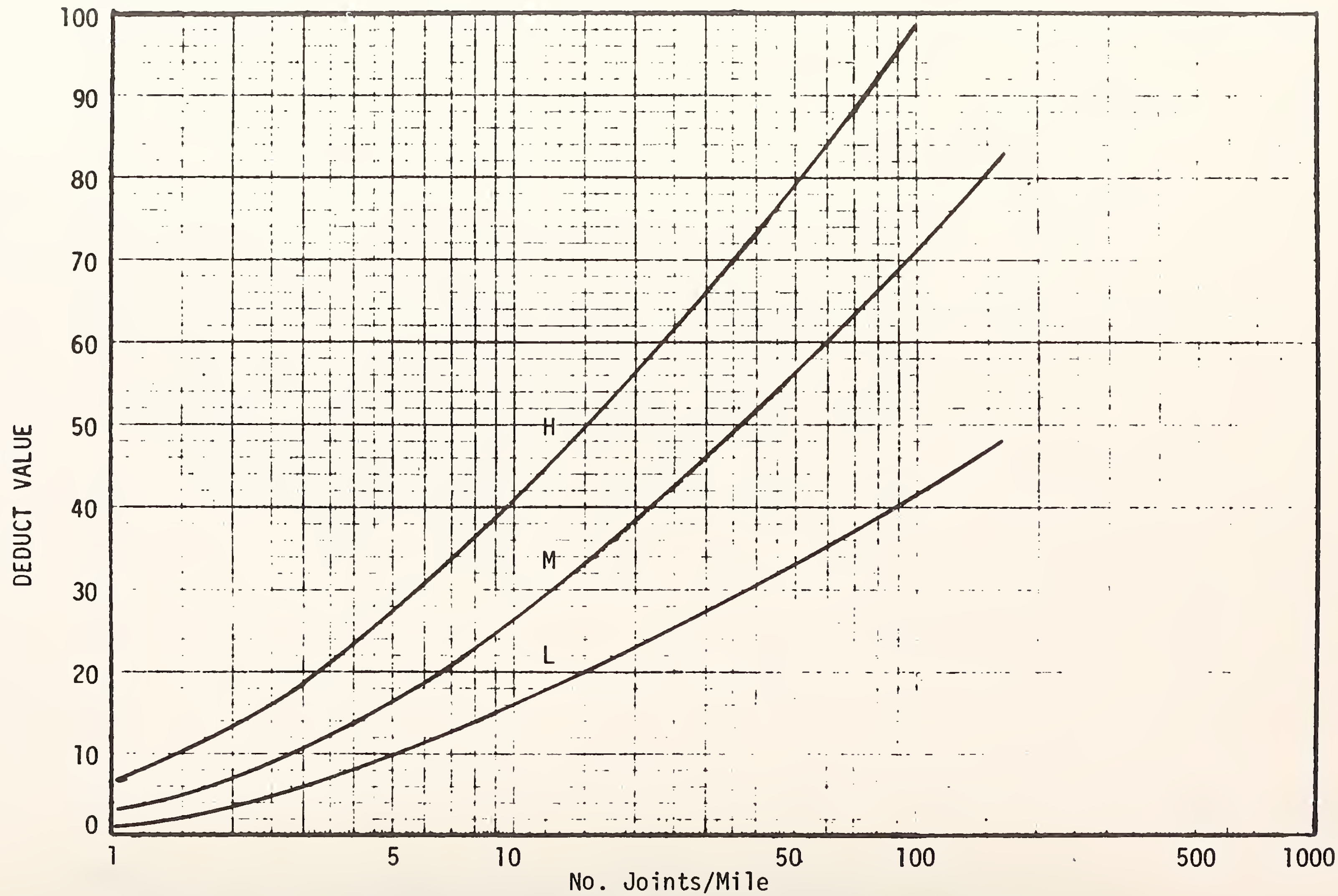


Figure A25. Joint load transfer system associated deterioration.

Figure A26. Joint seal damage of transverse joints.

L 2 deduct points
M 12 deduct points
H 35 deduct points

Figure A27. Lane/shoulder dropoff or heave.

L 10 deduct points
M 25 deduct points
H 59 deduct points

Figure A28. Lane/shoulder joint separation.

L 6 deduct points
M 14 deduct points
H 26 deduct points

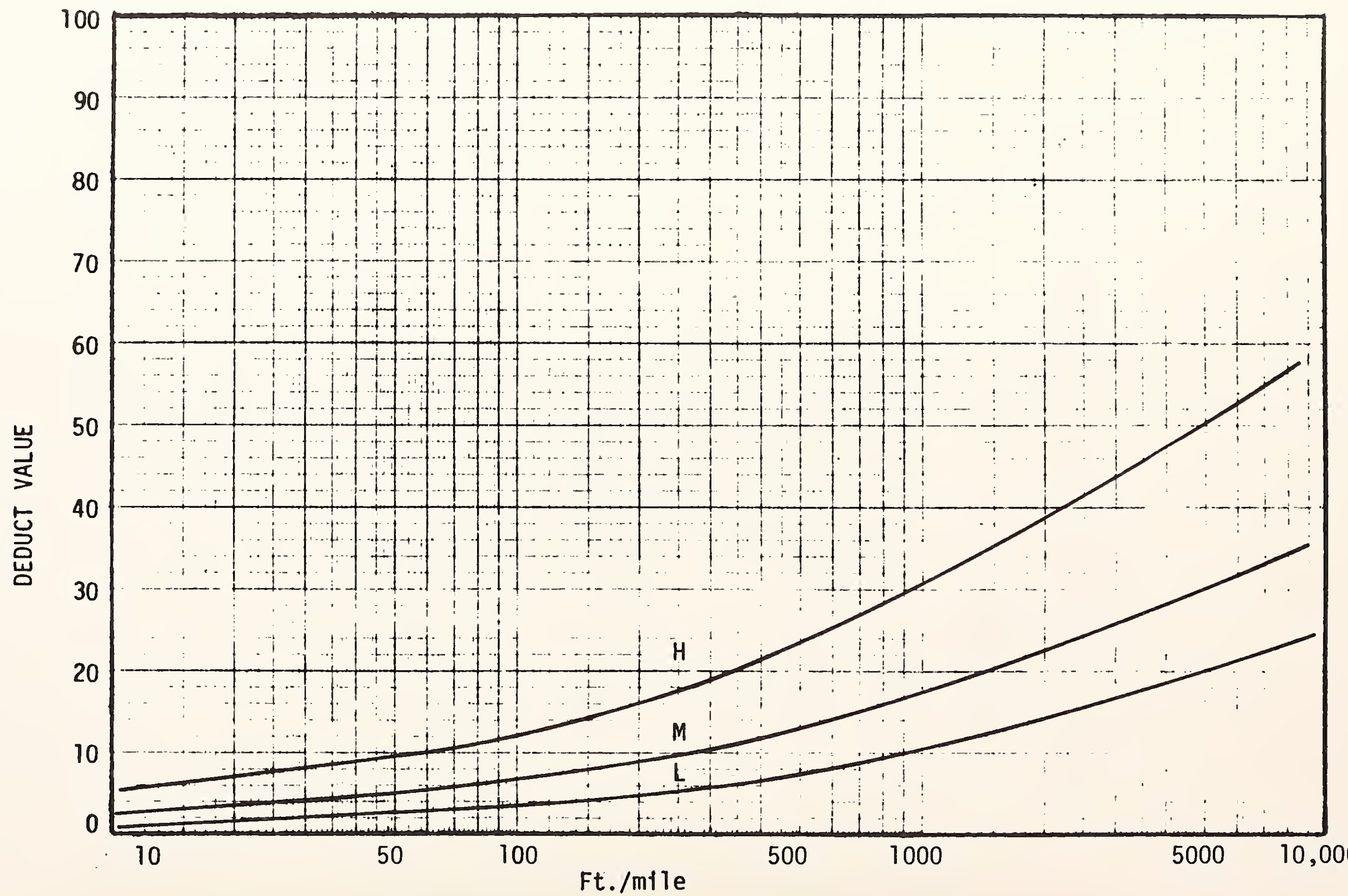


Figure A29. Longitudinal cracks.

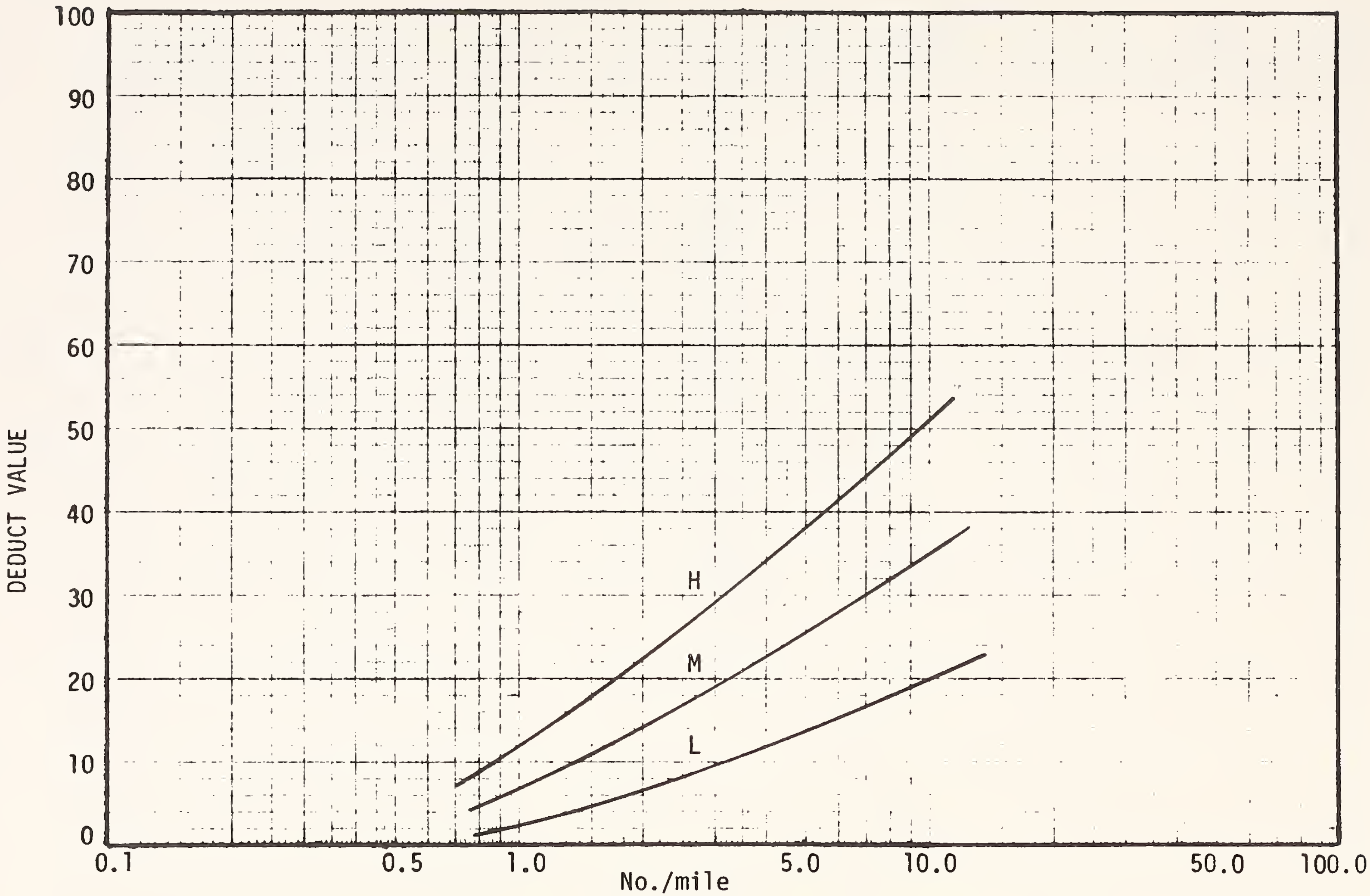


Figure A30. Longitudinal joint faulting.

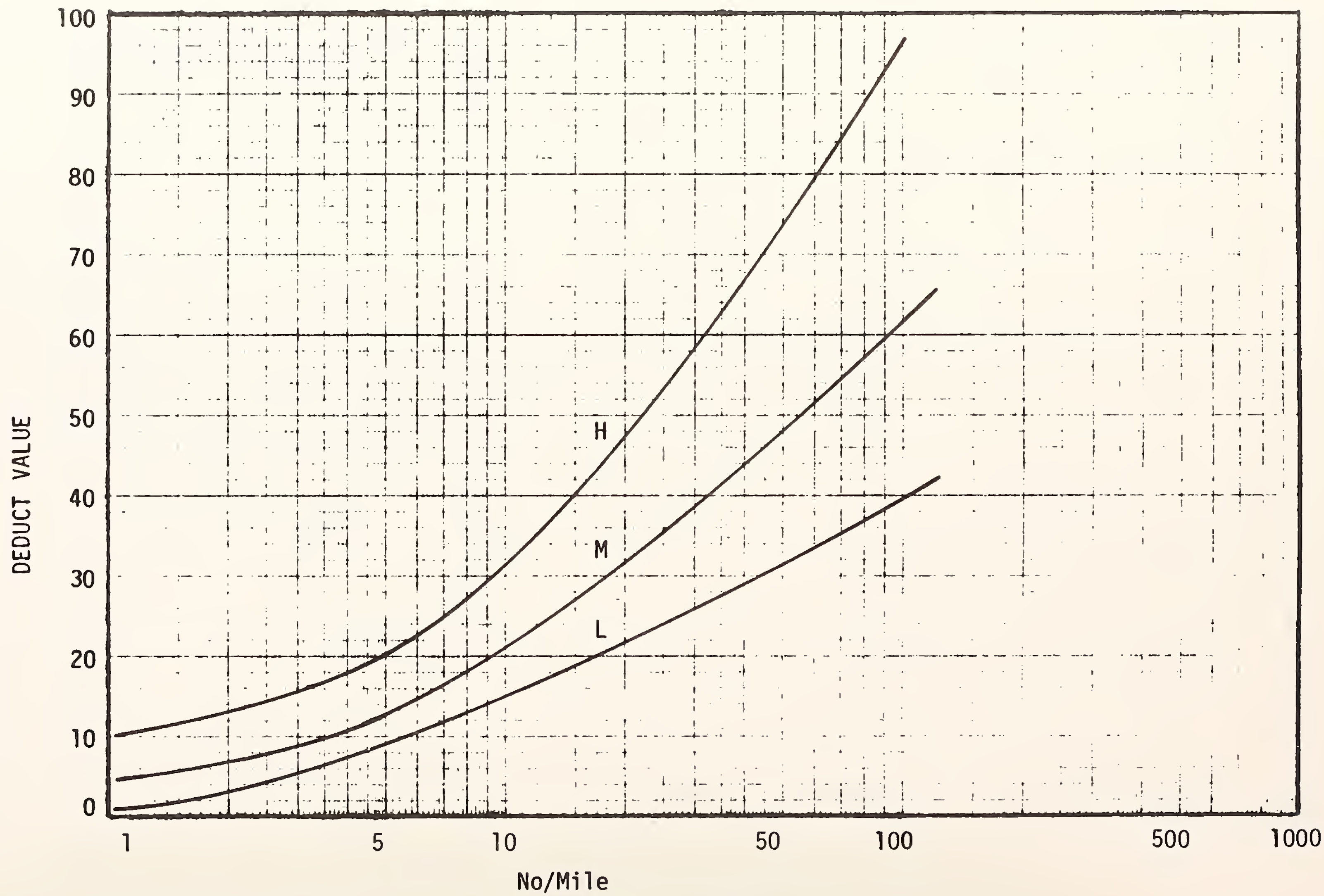


Figure A31. Patch deterioration.

Figure A32. Patch adjacent slab deterioration.
Rate according to type of distress.

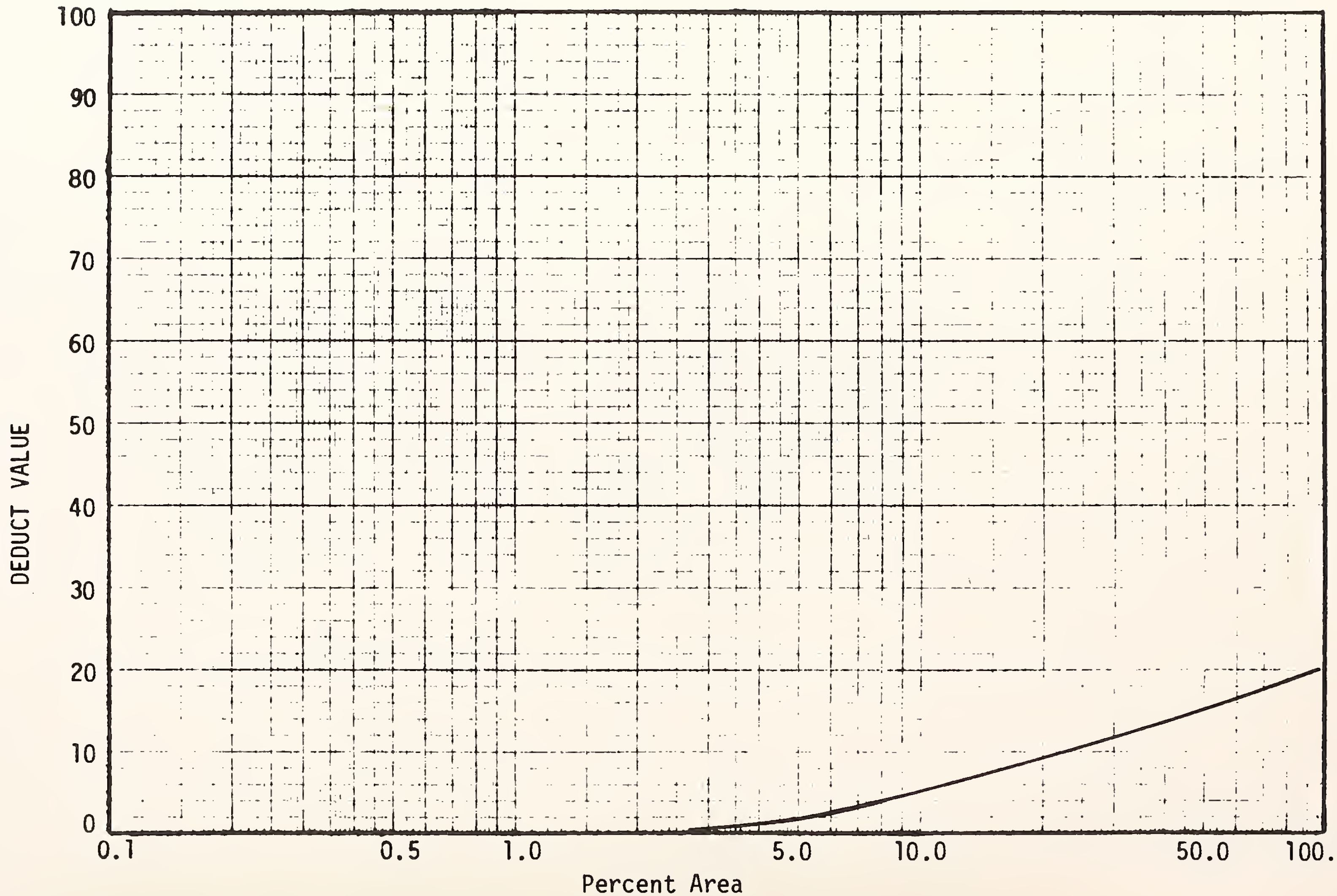


Figure A33. Popouts.

A34. Pumping and water bleeding.

L 10 deduct points
M 20 deduct points
H 50 deduct points

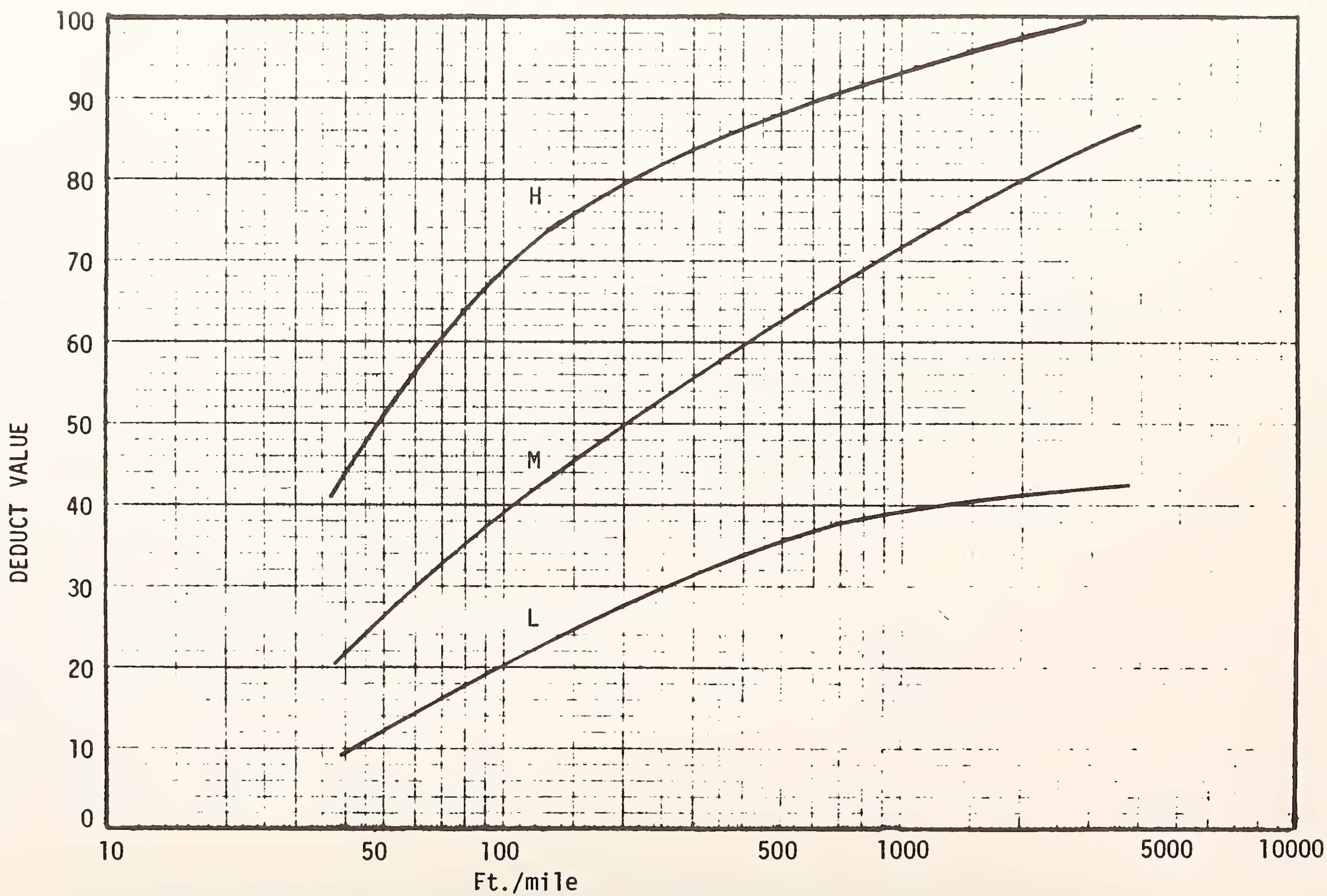


Figure A35. Reactive aggregate durability distress.

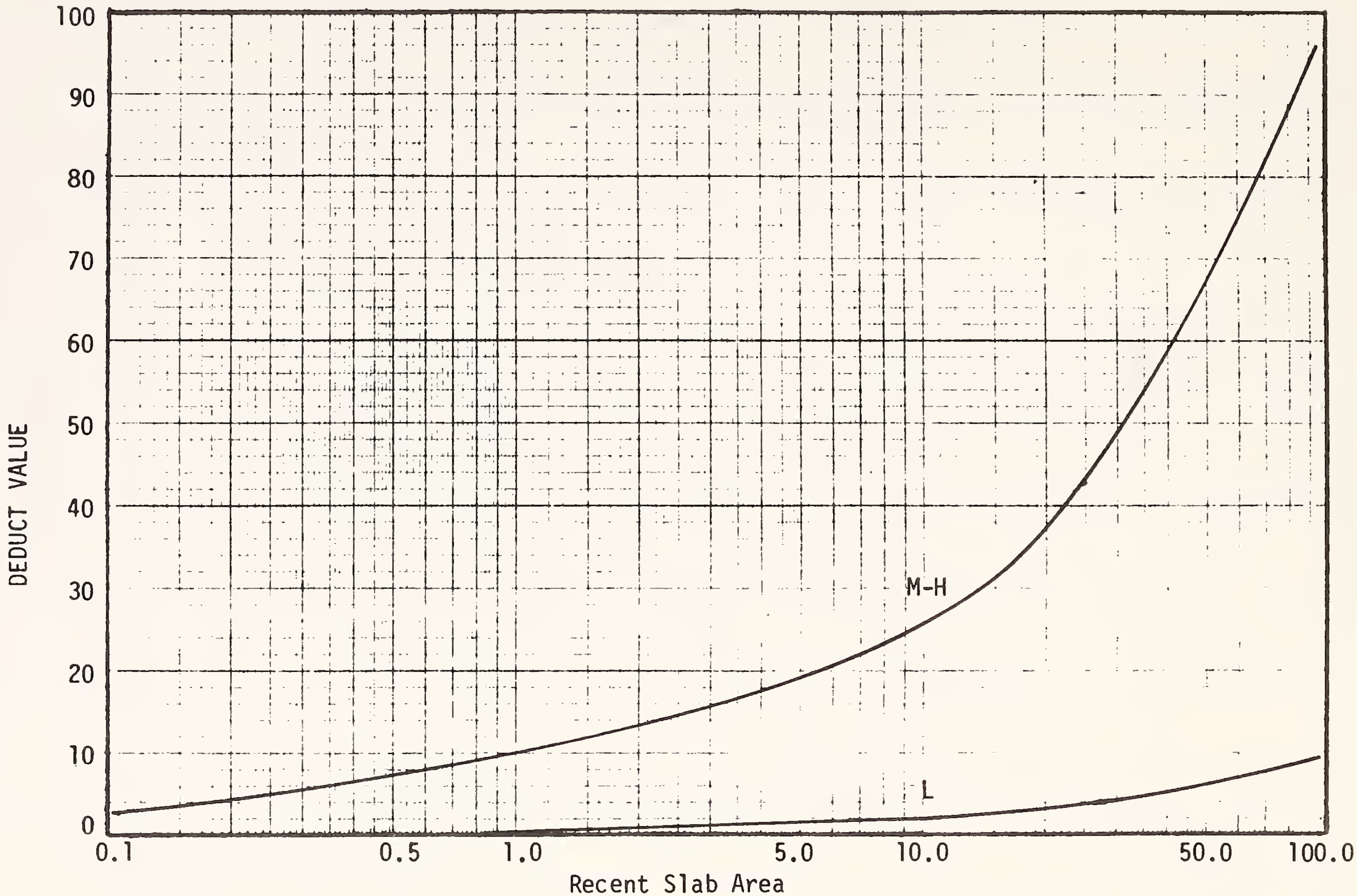


Figure A36. Scaling, map cracking and crazing.

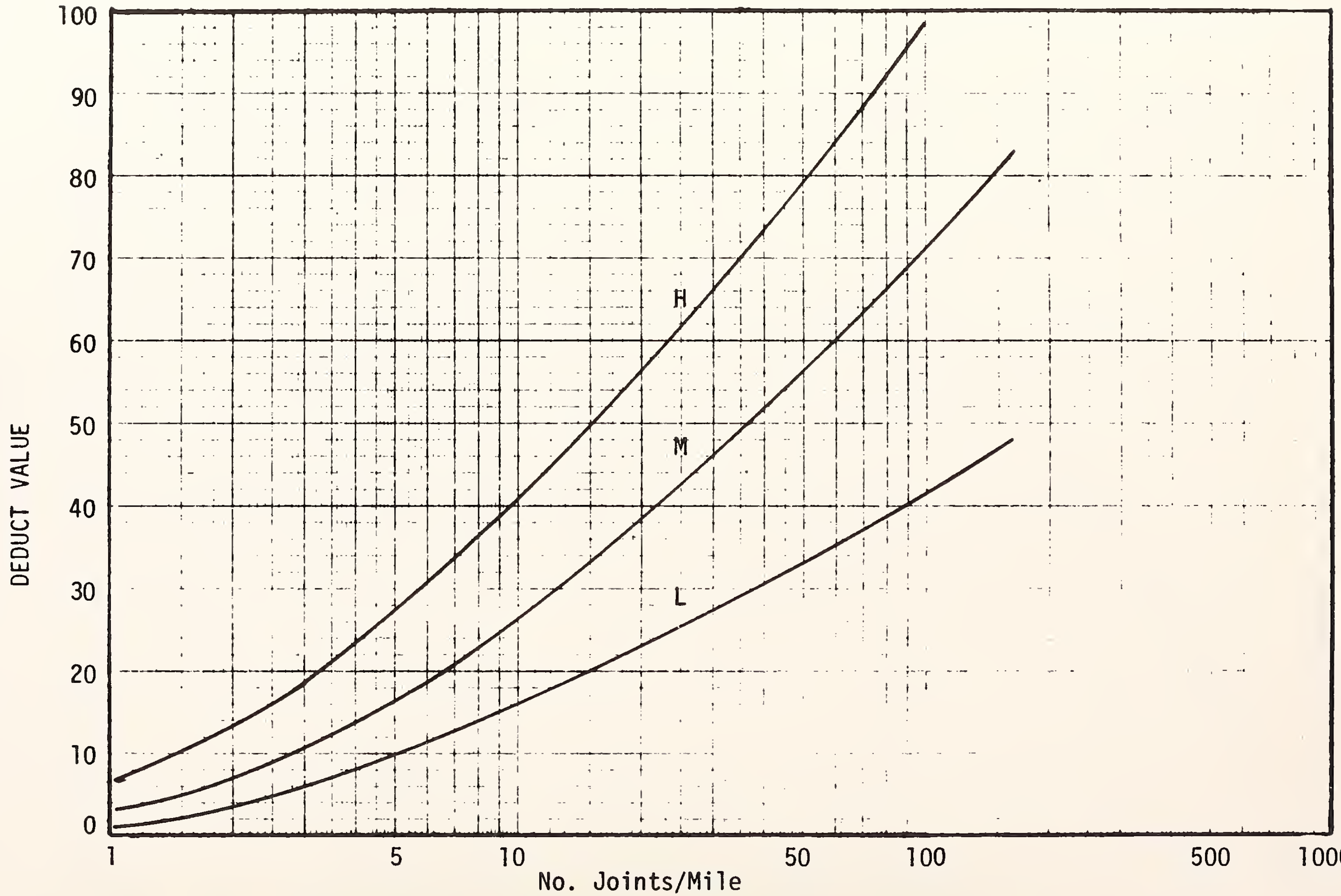
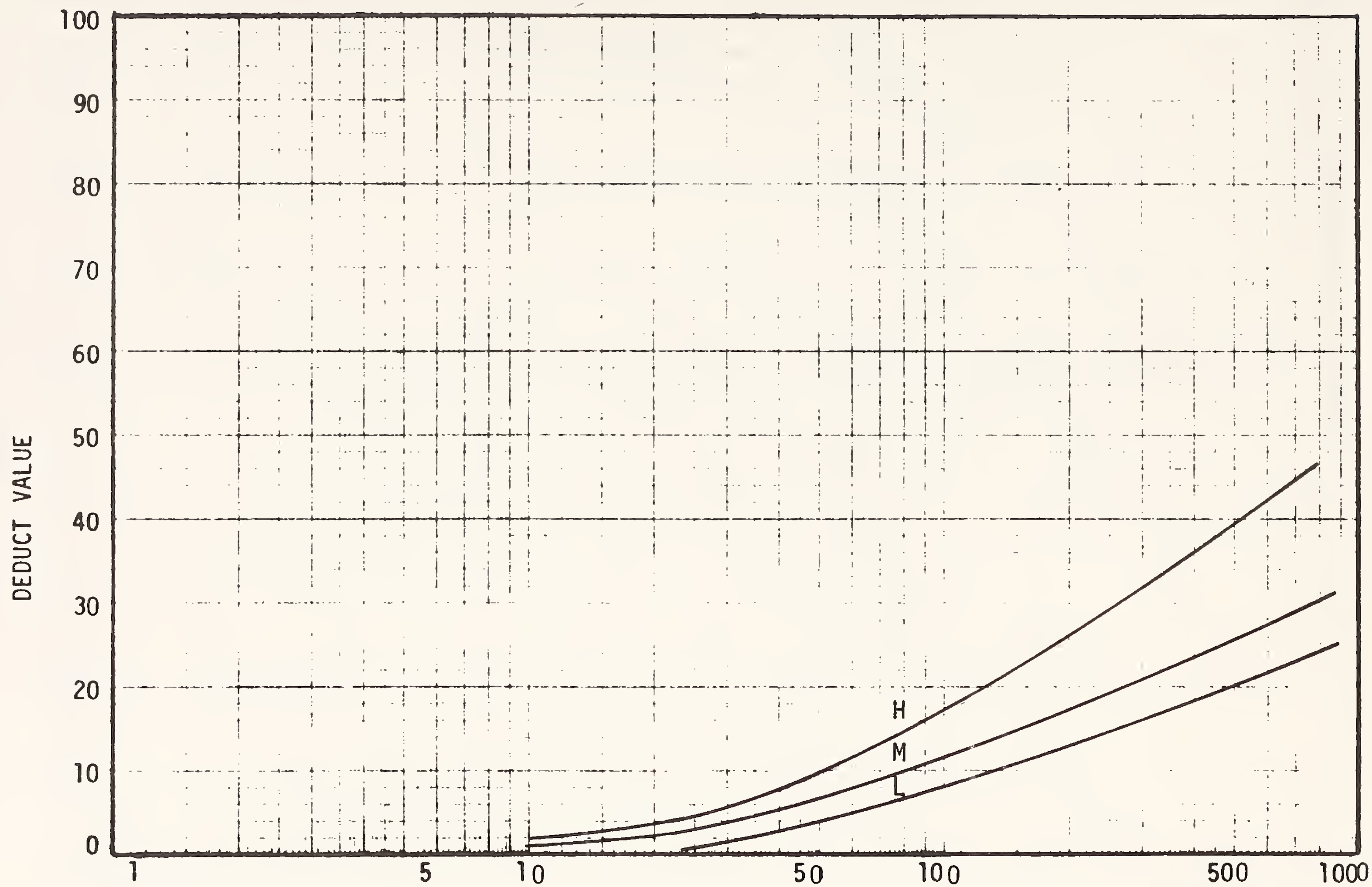


Figure A37. Spalling (transverse and longitudinal joints).



No. Corners/Mile

Figure A38. Spalling (corner)

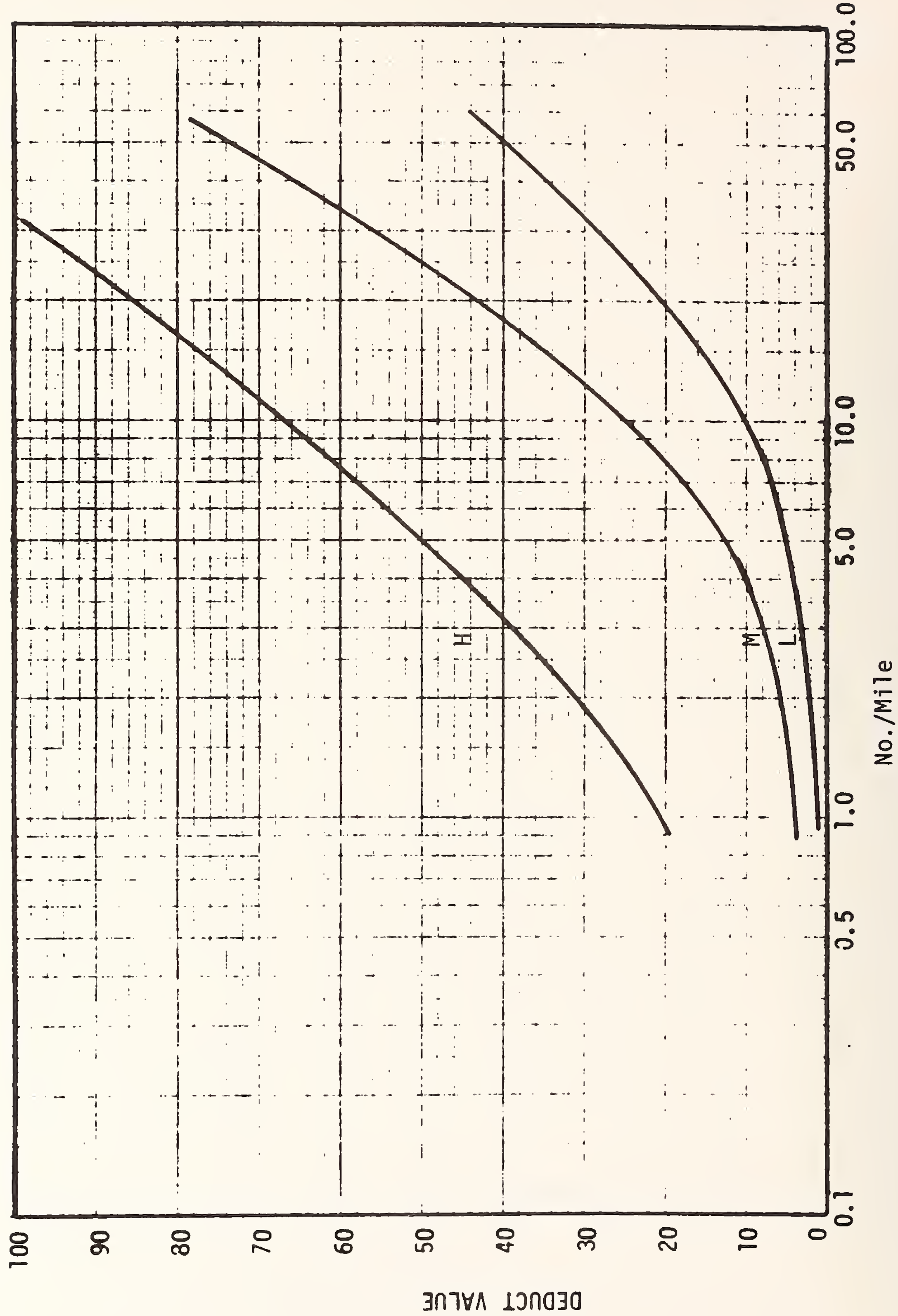


Figure A39. Swell.

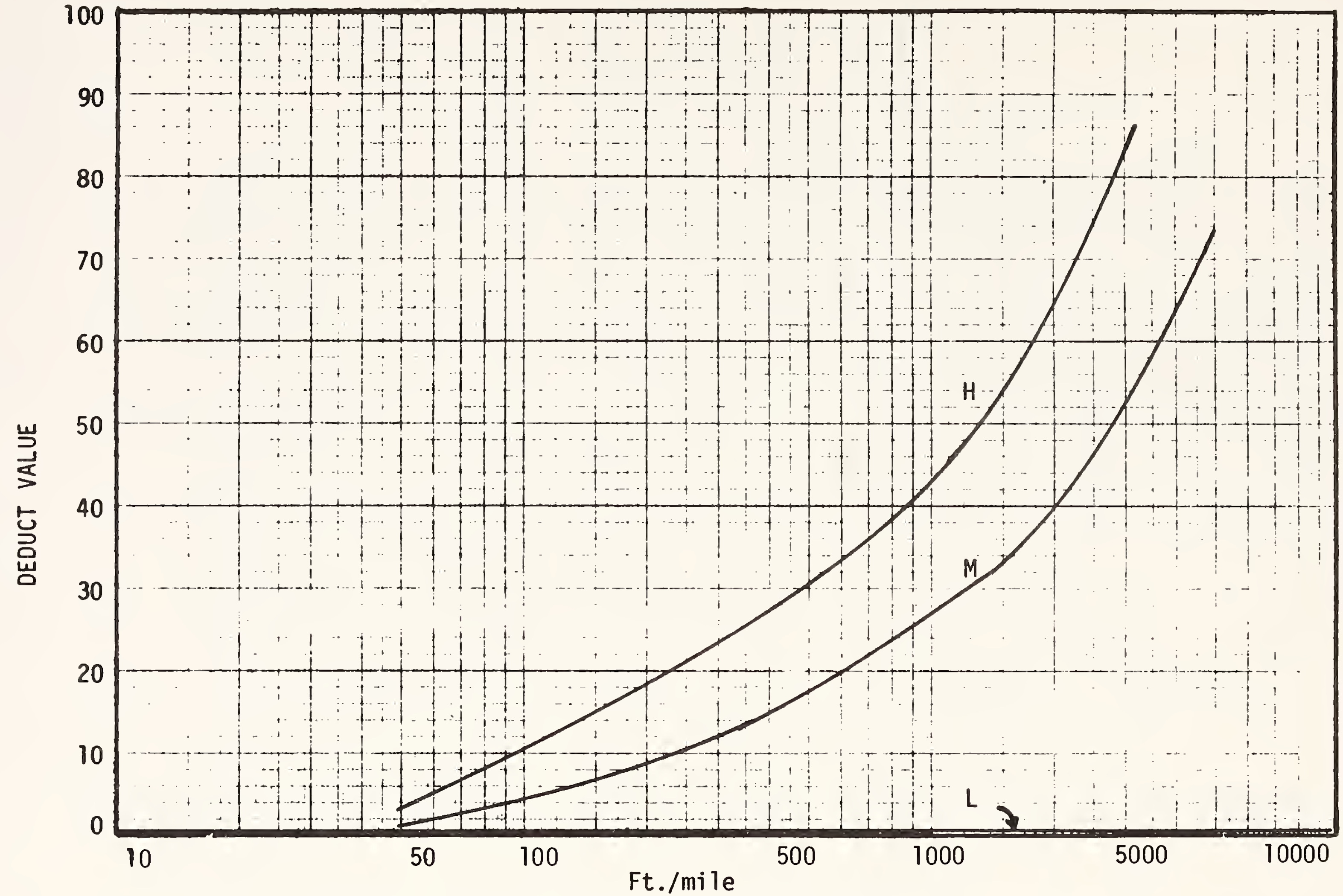


Figure A40. Transverse and diagonal cracks.

APPENDIX B

DISTRESS IDENTIFICATION MANUAL

ASPHALT SURFACED PAVEMENTS

INTRODUCTION

The distress definitions were developed based initially on the airfield distress identification manual by Shahin, Darter and Kohn[1] and the "Standard Nomenclature and Definitions for Pavement Components and Deficiencies" (Special Report 113, Highway Research Board); and considerably further developed through extensive field surveys and discussions with state highway engineers. The photographs were obtained during many field trips and surveys conducted on highways located throughout the United States. This manual can be used as a standard guide for distress identification and measurement for highway asphalt surfaced pavements, including both typical flexible pavements and asphalt overlays of concrete pavements.

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[1] Shahin, M. Y., M. I. Darter, and S. D. Kohn, "Development of a Pavement Maintenance Management System, Vol. V, Proposed Revision of Chapter 3, AFR 93-5," Report No. CEE-DO-TR-77-44, U.S. Air Force, 1977.

Name of Distress: Alligator or Fatigue Cracking

Description: Alligator or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface (or stabilized base) under repeated traffic loading. The cracking initiates at the bottom of the asphalt surface (or stabilized base) where tensile stress and strain is highest under a wheel load. The cracks propagate to the surface initially as one or more longitudinal parallel cracks. After repeated traffic loading the cracks connect, forming many-sided, sharp-angled pieces that develop a pattern resembling chicken wire or the skin of an alligator. The pieces are usually less than 1 ft. on the longest side. Alligator cracking occurs only in areas that are subjected to repeated traffic loadings. Therefore, it would not occur over an entire area unless the entire area was subjected to traffic loading. Alligator cracking does not occur in asphalt overlays over concrete slabs. Pattern-type cracking which occurs over an entire area that is <u>not</u> subjected to loading is rated as block cracking which is not a load-associated distress. Alligator cracking is considered a major structural distress.

Severity Levels: L* - Longitudinal disconnected hairline cracks running parallel to each other. The cracks are not spalled. Initially there may only be a single crack in the wheel path (defined as Class 1 cracking at AASHO Road Test).

M* - Further development of low severity alligator cracking into a pattern of pieces formed by cracks that may be lightly surface spalled. Cracks may be sealed (defined as Class 2 cracking at AASHO Road Test).

H* - Medium alligator cracking has progressed so that pieces are more severely spalled at the edges and loosened until the cells rock under traffic. Pumping may exist (defined as Class 3 cracking at AASHO Road Test).

How to Measure: Alligator cracking is measured in square feet or square meters of surface area. The major difficulty in measuring this type of distress is that many times two or three levels of severity exist whthin one distressed area. If these portions can be easily distinguished from each other, they should be measured and recorded separately. However, if the different levels of severity cannot be easily divided, the entire area should be rated at the highest severity level present.

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*L - Low severity level
*M - Medium severity level
*H - High severity level

Acceleration of Alligator Cracking by Moisture: Low severity alligator cracks allow moisture to enter the pavement structure. Moisture can greatly accelerate alligator cracking severity by softening the underlying granular or fine grain soil layers which results in increased deflections and stresses/strains under load. Saturation of granular materials or soils greatly decreases their capability to support loads and also leads to pumping of fines. The area of an asphalt shoulder near the lane/shoulder joint is particularly susceptible to excessive moisture infiltration and is also subjected to some encroachment and shoulder parking loads. Thus excess moisture in combination with freeze/thaw action can greatly decrease the base/subbase support and lead to accelerated occurrence of alligator cracking. Once low severity alligator cracking begins, moisture can infiltrate into the cracks causing accelerated increase in severity (i.e. changing from low to medium to high severity).

Figure B.1. Low Severity Alligator Cracking (fine longitudinal cracks in wheel path).

Figure B.2. Low Severity Alligator Cracking (fine longitudinal cracks in wheel path).

Figure B.3. Low Severity Alligator Cracking (sealed longitudinal cracks in wheel path of outer truck lane).

Figure B.4. Medium Severity Alligator Cracking in Wheel Paths.

Figure B.5. Medium Severity Alligator Cracking in Wheel Paths.

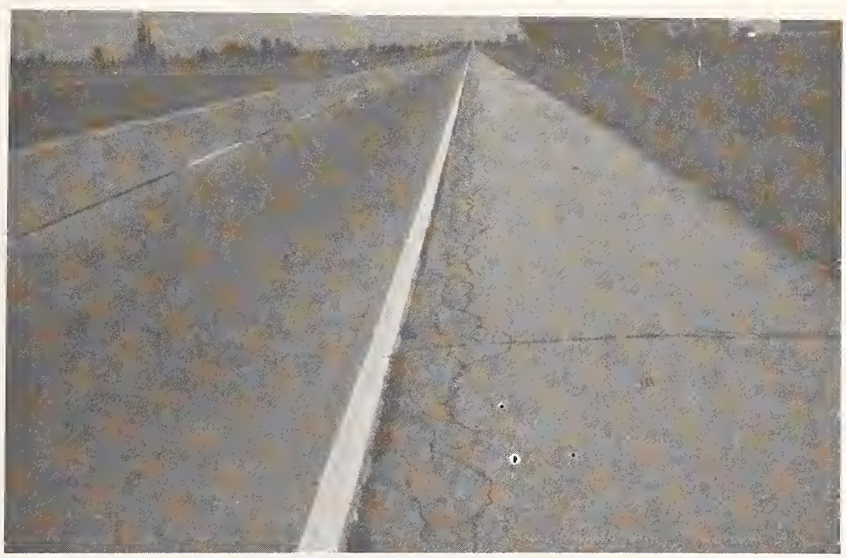

Figure B.6. Medium Severity Alligator Cracking in Wheel Paths Near Longitudinal Joint in Shoulder Due to Encroaching Traffic and Loss of Support.

Figure B.7. Medium Severity Alligator Cracking in Wheel Paths.

Figure B.8. Medium Alligator Cracking at Free Edge of Lane.

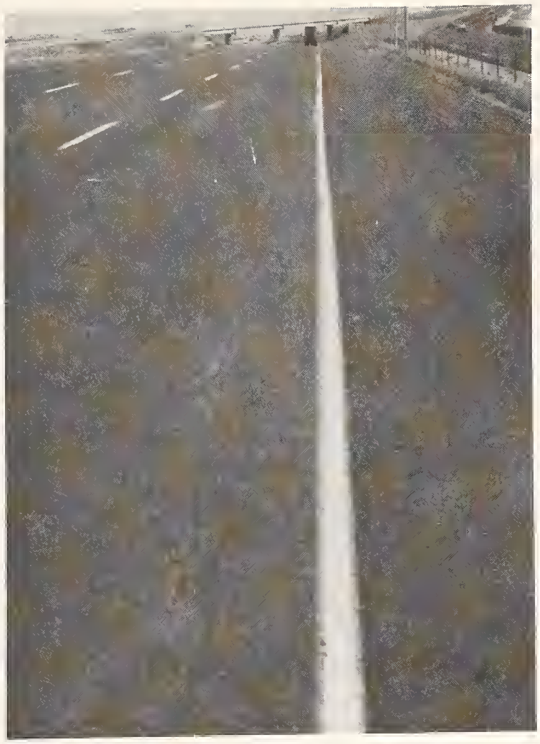

Figure B9. Medium Alligator Cracking in Outer Wheel Path (pumping also exists).

Figure B.10. High Severity Alligator Cracking (in portions of picture where pieces are severely spalled).

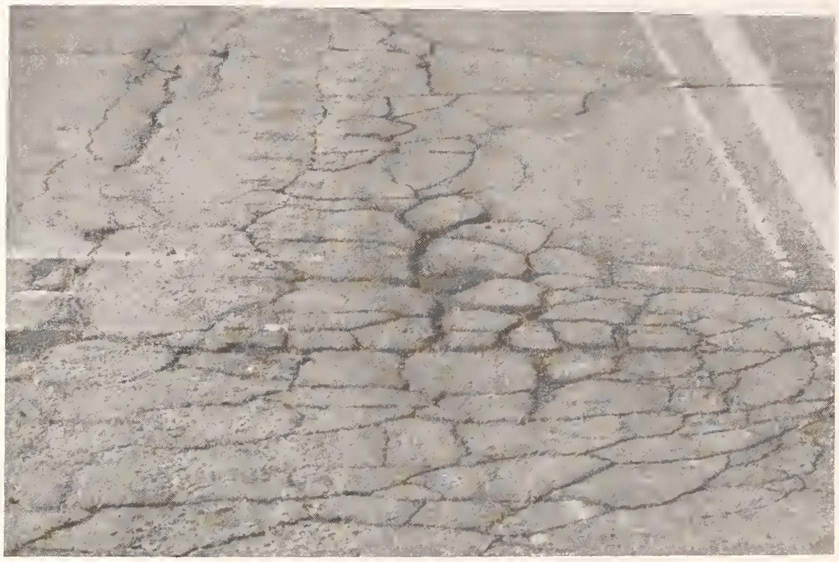

Figure B.11. High Severity Alligator Cracking in Center of Photo Where Pieces Are Severely Spalled.

Figure B.12. High Severity Alligator Cracking of Shoulder Where Large Amount of Trucks Park.

Name of Distress:	Bleeding
Description:	Bleeding is a film of bituminous material on the pavement surface which creates a shiny, glass-like, reflecting surface that usually becomes quite sticky. Bleeding is caused by excessive amounts of asphalt cement in the mix and/or low air void contents. It occurs when asphalt fills the voids of the mix during hot weather and then expands out onto the surface of the pavement. Since the bleeding process is not reversible during cold weather, asphalt will accumulate on the surface.
Severity Levels:	No degrees of severity are defined. Bleeding should be noted when it is extensive enough to cause a reduction in skid resistance.
How to Measure:	Bleeding is measured in square feet or square meters of surface area.

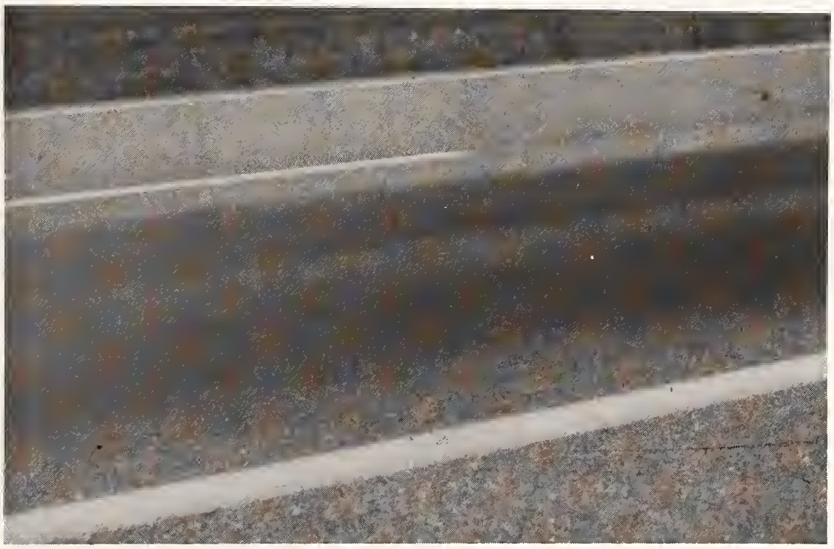

Figure B.13. Bleeding in Wheel Paths.

Acceleration of Bleeding Due to Moisture:	Water does not normally affect bleeding. However, on some projects during the early stages of stripping, asphalt cement floats to the surface and gives the appearance and symptoms of bleeding. The surface looks overasphalted, while under layers are under asphalted due to stripping.

Figure B.14. Bleeding in Wheel Paths.

Name of Distress: Block Cracking

Description: Block cracks divide the asphalt surface into approximately rectangular pieces. The blocks range in size from approximately 1 ft^2 to 100 ft^2. Cracking into larger blocks are generally rated as longitudinal and transverse cracking. Block cracking is caused mainly by shrinkage of the asphalt concrete and daily temperature cycling (which results in daily stress/strain cycling). It is not load-associated, although load can increase the severity of individual cracks from low to medium to high. The occurrence of block cracking usually indicates that the asphalt has hardened significantly. Block cracking normally occurs over a large proportion of pavement area, but sometimes will occur only in nontraffic areas. This type of distress differs from alligator cracking in that alligator cracks form smaller, many-sided pieces with sharp angles. Also unlike block cracks, alligator cracks are caused by repeated traffic loadings, and are, therefore, located only in trafficked areas (i.e., wheel paths).

Severity Levels:

L - Blocks are defined by (1) nonsealed cracks that are nonspalled (sides of the crack are vertical) or only minor spalling with a 1/4 in. (6 mm) or less mean width; or (2) sealed cracks have a sealant in satisfactory condition to prevent moisture infiltration.

M - Blocks are defined by either (1) sealed or nonsealed cracks that are moderately spalled; (2) nonsealed cracks that are not spalled or have only minor spalling, but have a mean width greater than approximately 1/4 in. (6 mm) or (3) sealed cracks that are not spalled or have only minor spalling, but have sealant in unsatisfactory condition.

H - Blocks are well-defined by cracks that are severely spalled.

How to Measure: Block cracking is measured in square feet or square meters of surface area. It usually occurs at one severity level in a given pavement section; however, any areas of the pavement section having distinctly different levels of severity should be measured and recorded separately.

Acceleration of Block Cracking by Moisture: Moisture does not affect the initiation of block cracking, but significant infiltration into the cracks can lead to accelerated increase in severity of the crack if heavy traffic uses the pavement. Excess water infiltration into the cracks can also lead to other distress such as frost heaving near the crack.

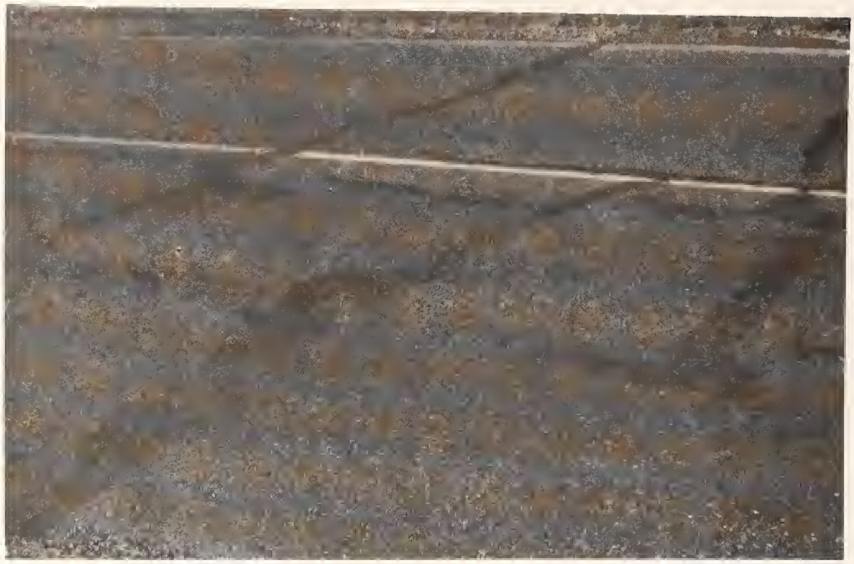

Figure B.15. Low Severity Block Cracking.

Figure B.16. Low Severity Block Cracking Near Centerline.

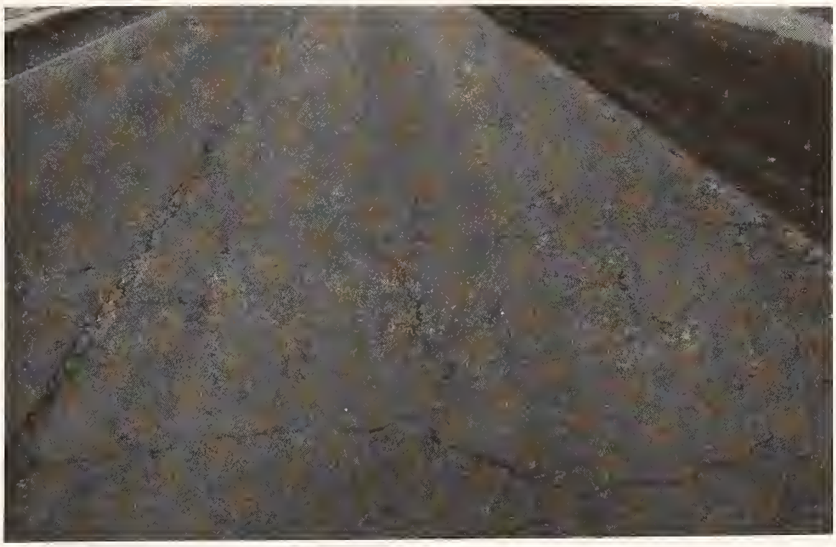

Figure B.17. Medium Severity Block Cracking.

Figure B.18. Medium Severity Block Cracking.

Figure B.19. High Severity Block Cracking.

Figure B.20. High Severity Block Cracking.

Name of Distress: Corrugation

Description: Corrugation is a form of plastic movement typified by ripples across the asphalt pavement surface. It occurs usually at points where traffic starts and stops. Corrugation usually occurs in asphalt layers that lack stability in warm weather, but may also be attributed to excessive moisture in a subgrade, contamination of the mix, or lack of aeration of liquid asphalt mixes.

Severity Levels:

L - Corrugations cause some vibration of the vehicle which creates no discomfort.

M - Corrugations cause significant vibration of the vehicle which creates some discomfort.

H - Corrugations cause excessive vibration of the vehicle which creates substantial discomfort, and/or a safety hazard, and or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Corrugation is measured in square feet or square meters of surface area. Severity levels are determined by riding in a mid to full sized sedan weighing approximately 3000-3800 lbs (13.3-16.9 kN) over the pavement inspection unit at the posted speed limit.

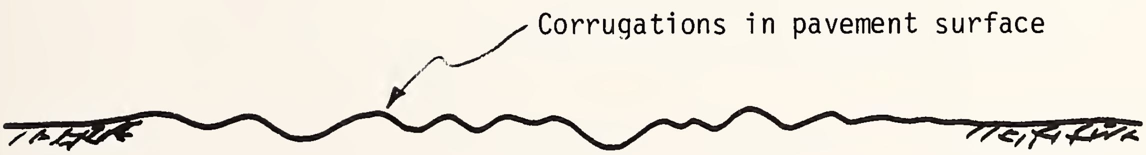

Figure B.21. Illustrative Diagram of Corrugation Profile.

Acceleration of Corrugation Due to Moisture: Moisture may accelerate ride quality distress by reducing the stiffness of asphalt mixes. Significant moisture may permeate into the asphalt mix, particularly cold mixes (cut backs and emulsions). The excess moisture causes the resilient modulus to decrease and this increases the potential for permanent deformation under repeated load. Excessive moisture in the subgrade will result in increased deflections in the surface. Repeated dynamic loads may result in small surface deformations, which cause increased roughness. Dynamic loading and depressions can create the corrugations which affect ride quality.

Name of Distress: Depression

Description: Depressions are localized pavement surface areas having elevations slightly lower than those of the surrounding pavement. In many instances, light depressions are not noticeable until after a rain, when ponding water creates "birdbath" areas; but the depressions can also be located without rain because of strains created by oil droppings from vehicles. Depressions can be caused by settlement of the foundation soil or can be "built in" during construction. Depressions cause roughness, and when filled with water of sufficient depth could cause hydroplaning of vehicles.

Severity Levels:

L - Depressions cause some bounce of the vehicle which creates no discomfort.

M - Depressions cause significant bounce of the vehicle which creates some discomfort.

H - Depressions cause excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Depressions are measured in square feet or meters in each inspection unit. Each depression is rated according to its level of severity. Severity level is determined by riding in a mid to full sized sedan weighing approximately 3000-3800 lbs (13.3-16.9 kN) over the pavement inspection unit at the posted speed limit.

Acceleration of Depression by Moisture:	Depressions delay the runoff of water after a rain storm. The water is collected in the depressions, thus increasing the exposure time of the water to infiltrate through the pavement surface. Higher moisture contents within the pavement will accelerate various distresses such as pumping, rutting and alligator cracking.

Name of Distress: Joint Reflection Cracking from PCC Slab

Description: This distress occurs only on pavements having an asphalt concrete surface over a jointed portland cement concrete (PCC) slab and they occur at transverse and longitudinal joints (i.e., widening joints). This distress does not include reflection cracking away from a joint or from any other type of base (i.e., cement stabilized, lime stabilized) as these cracks are identified as "Longitudinal and Transverse Cracking." Joint reflection cracking is caused mainly by movement of the PCC slab beneath the asphalt concrete (AC) surface because of thermal and moisture changes; it is generally not load initiated. However, traffic loading may cause a breakdown of the AC near the initial crack, resulting in spalling. A knowledge of slab dimensions beneath the AC surface will help to identify these cracks.

Severity Levels:

L - Cracks have either minor spalling or no spalling and can be sealed or nonsealed. If nonsealed, the cracks have a mean width of 1/4 in. (6 mm) or less; sealed cracks are of any width, but their sealant material is in satisfactory condition to substantially prevent water infiltration. No significant bump occurs when a vehicle crosses the crack.

M - One of the following conditions exists: (1) cracks are moderately spalled and can be either sealed or nonsealed of any width; (2) sealed cracks are not spalled or have only minor spalling, but the sealant is in a condition so that water can freely infiltrate; (3) nonsealed cracks are not spalled or are only lightly spalled, but the mean crack width is greater than 1/4 in. (6 mm); (4) low severity random cracking exists near the crack or at the corners of intersecting cracks; or (5) the crack causes a significant bump to a vehicle.

H - (1) Cracks are severely spalled and/or there exists medium or high random cracking near the crack or at the corners of intersecting cracks, or (2) the crack causes a severe bump to a vehicle.

How to Measure: Joint reflection cracking is measured in lineal feet or meters. The length and severity level of each crack should be identified and recorded. If the crack does not have the same severity level along its entire length, each general portion should be recorded separately. The vehicle used to determine bump severity is a mid to full sized sedan weighing approximately 3000-3800 lbs (13.3-16.9 kN) over the pavement inspection unit at the posted speed limit.

Acceleration of Joint Reflection Cracking Due to Moisture:	The initiation of this cracking is not moisture related, but after the crack forms, water can infiltrate into the pavement if it is not properly sealed. Excessive free moisture in the crack may accelerate the change in severity of the crack due to softening of the asphalt concrete from stripping or loss of bond with aggregate, or freeze-thaw action.

Figure B.22. Low Severity Depression (identified by oil droppings on pavement surface).

Figure B.23. High Severity Depression in Shoulder (high severity alligator cracking also exists and would be recorded in addition to the depression).

Figure B.24. Low Severity Joint Reflection Cracking from Transverse Joint in PCC Slab.

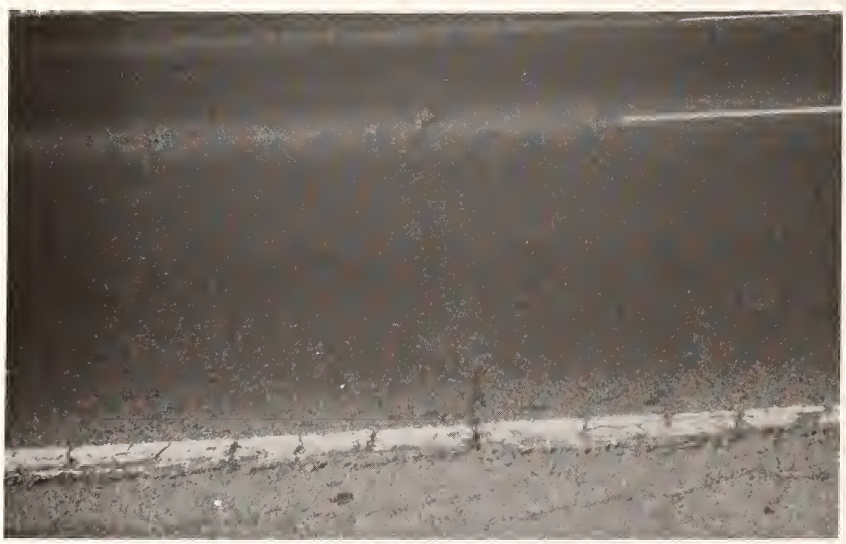

Figure B.25. Low Severity Joint Reflection Cracking from Transverse Joint in PCC Slab.

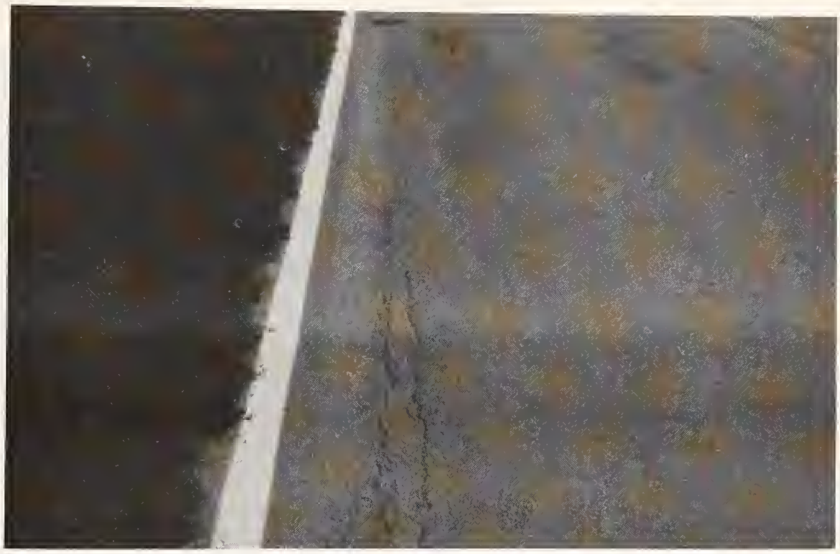

Figure B.26. Medium Severity Joint Reflection Cracking from Longitudinal Widening Joint in PCC Slab.

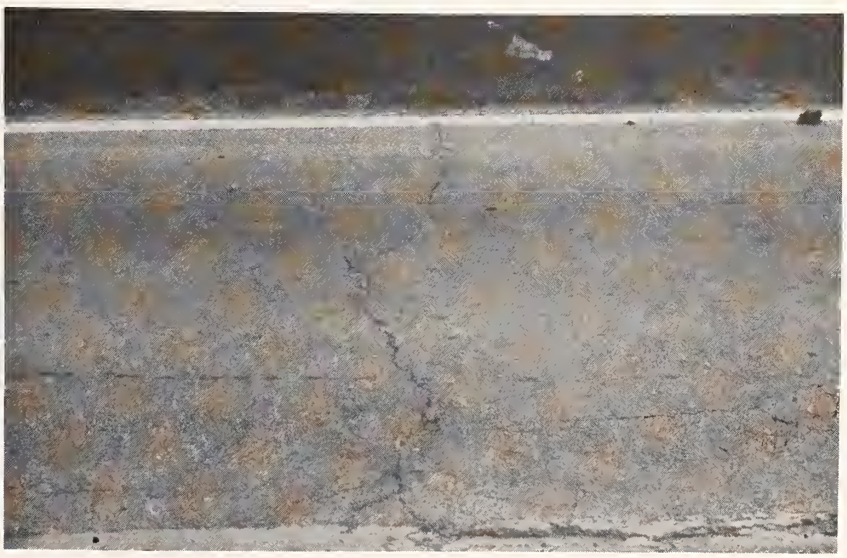

Figure B.27. Medium Severity Joint Reflection Cracking from Transverse Joint in PCC Slab.

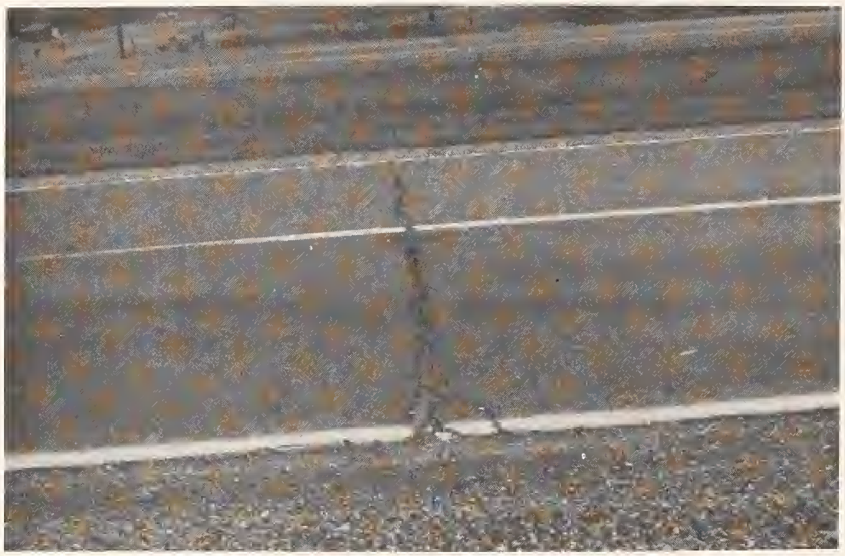

Figure B.28. High Severity Joint Reflection Cracking from Transverse Joint in PCC Slab.

Figure B.29. High Severity Joint Reflection Cracking from Longitudinal Widening Joint in PCC Slab.

Figure B.30. High Severity Joint Reflection Cracking from Transverse Joint in PCC Slab.

Name of Distress: Lane/Shoulder Dropoff or Heave

Description: Lane/Shoulder dropoff or heave occurs wherever there is a difference in elevation between the traffic lane and shoulder. Typically the outside shoulder settles due to consolidation or a settlement of the underlying granular or subgrade material, or pumping of the underlying material. Heave of the shoulder may occur due to frost action or swelling soils. Dropoff of granular or soil shoulder is generally caused from blowing away of shoulder material from passing trucks.

Severity Level: Severity level is determined by computing the mean difference in elevation between the traffic lane and shoulder:

L	1/4 - 1/2 in.	(6 - 13 mm)
M	1/2 - 1 in.	(3 - 25 mm)
H	> 1 in.	(> 25 mm)

How to Measure: Lane/shoulder dropoff or heave is measured every 100 ft. (30 m) in inches (or mm) along the joint. The mean difference in elevation is computed from the data and used to determine severity level.

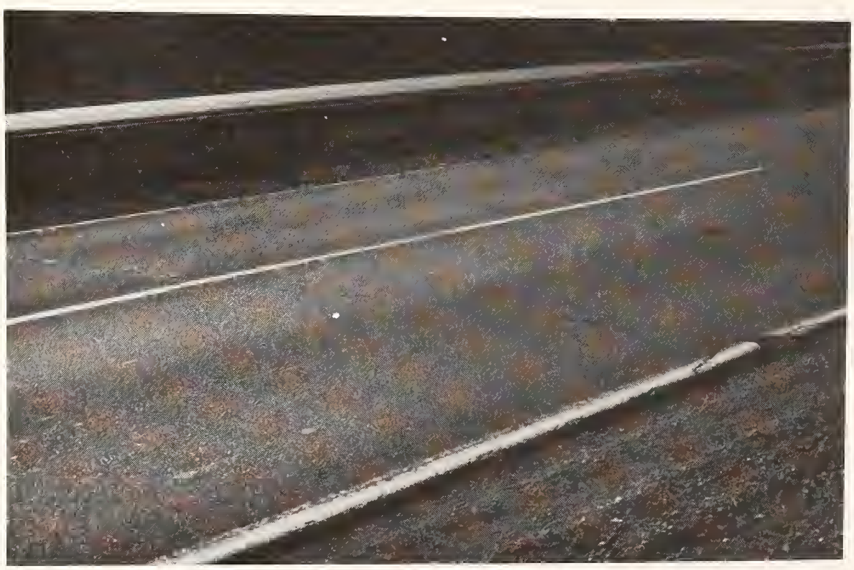

Figure B.31. Medium Severity Lane/Shoulder Dropoff.

Acceleration of Dropoff Due to Moisture: Moisture entering through the longitudinal joint between the shoulder and lane results in excess free moisture in the underlying material. The material then becomes soft and settles under load, and/or pumping may occur disintegrating the material and creating a voids. In both cases the shoulder will then settle downward producing the dropoff. Heave is caused by (1) frost heave from ice lenses, or (2) swelling subgrade soils. Both settlement and heave usually results in shoulder edge cracking and breakup in conjunction with traffic load encroachment.

Name of Distress: Lane/Shoulder Joint Separation

Description: Lane/Shoulder joint separation is the widening of the joint between the traffic lane and the shoulder generally due to movement in the shoulder. If the joint is tightly closed or well sealed so water cannot enter (or if there is no joint due to full width paving), then lane/shoulder joint separation is not considered a distress. If the shoulder is not paved (i.e., gravel or grass) then the severity should be rated as high. If a curbing exists, then it should be rated according to the width of the joint between the asphalt surface and curb.

Severity Level: Severity level is determined by the mean joint opening. No severity level is counted if the joint is well sealed to prevent moisture intrusion.

L	0.04 - .12 in.	(1 - 3 mm)
M	> .12 - .40 in.	(> 3 - 10 mm)
H	> .40 in	(> 10 mm) (also a nonpaved shoulder)

How to Measure: Lane/Shoulder joint separation is measured in inches (or millimeters) at about 50 ft. (15.2 m) intervals along the sample unit. The mean separation is used to determine severity level.

Figure B.32. Medium Severity Lane/Shoulder Joint Separation (note separation near outside of edge paint strip). (See Figure 2.31 for photo of high severity lane/shoulder joint separation.)

Acceleration of Lane/Shoulder Joint Separation Due to Moisture: Excess moisture beneath the shoulder may result in frost heave and/or settlement of the shoulder which would cause lane/shoulder joint opening. Once the joint is open additional moisture can enter which accelerates many distresses as described under lane/shoulder dropoff or heave.

Name of Distress: Longitudinal and Transverse Cracking (Non-PCC Slab Joint Reflective)

Description: Longitudinal cracks are parallel to the pavement's centerline or laydown direction. They may be caused by (1) a poorly constructed paving lane joint, (2) shrinkage of the AC surface due to low temperatures or hardening of the asphalt, or (3) a reflective crack caused by cracks beneath the surface course, including cracks in PCC slabs (but not at PCC slab joints). Transverse cracks extend across the pavement centerline or direction of laydown. They may be caused by items 2 or 3 above. These types of cracks are not usually load associated.

Severity Levels:

L - Cracks have either minor spalling or no spalling, and cracks can be sealed or nonsealed. If sealed, cracks have a mean width of 1/4 in. (6 mm) or less; sealed cracks are of any width, but their sealant material is in satisfactory condition to substantially prevent water infiltration. No significant bump occurs when a vehicle crosses the crack.

M - One of the following conditions exists: (1) cracks are moderately spalled and can either be sealed or nonsealed of any width; (2) sealed cracks are not spalled or have only minor spalling, but the sealant is in a condition so that water can freely infiltrate; (3) nonsealed cracks are not spalled or have only minor spalling, but mean crack width is greater than 1/4 in. (6 mm); (4) low severity random cracking exists near the crack or at the corners of intersecting cracks; or (5) the crack causes a significant bump to a vehicle.

H - (1) Cracks are severely spalled; and/or medium or high random cracking exists near the crack or at the corners of intersecting cracks, or (2) the crack causes a severe bump to a vehicle.

How to Measure: Longitudinal and transverse cracks are measured in lineal feet or lineal meters. The length and severity of each crack should be identified and recorded. If the crack does not have the same severity level along its entire length, each general portion of the crack having a different severity level should be recorded separately. The vehicle used to determine bump severity is a mid to full sized sedan weighing approximately 3000-3800 lbs. (13.3-16.9 kN) over the pavement inspection unit at the posted speed limit.

Acceleration of Longitudinal and Transverse Cracking Due to Moisture: The initiation of this cracking is generally not moisture related, but after the cracking occurs water can infiltrate into the pavement if it is not properly sealed. Excessive free moisture in the crack may accelerate a change in severity of the crack due to stripping or loss of bond with the aggregate, or freeze-thaw action causing spalling of the crack. Water that infiltrates into the base, subbase and subgrade will increase the degree of saturation. The loss of support causes increased stress near the crack which may lead to alligator cracking, settlement or rutting. Also, a saturated base will produce ice lenses during the winter causing heaving or "tenting" near the crack. After spring thaw the material will settle and again the stress concentration along the crack increases.

Figure B.33. Low Severity Transverse Cracking.

Figure B.34. Low Severity Longitudinal and Transverse Cracking.

Figure B.35. Low Severity Transverse Cracking Across Shoulder.

Figure B.36. Medium Severity Transverse Cracking.

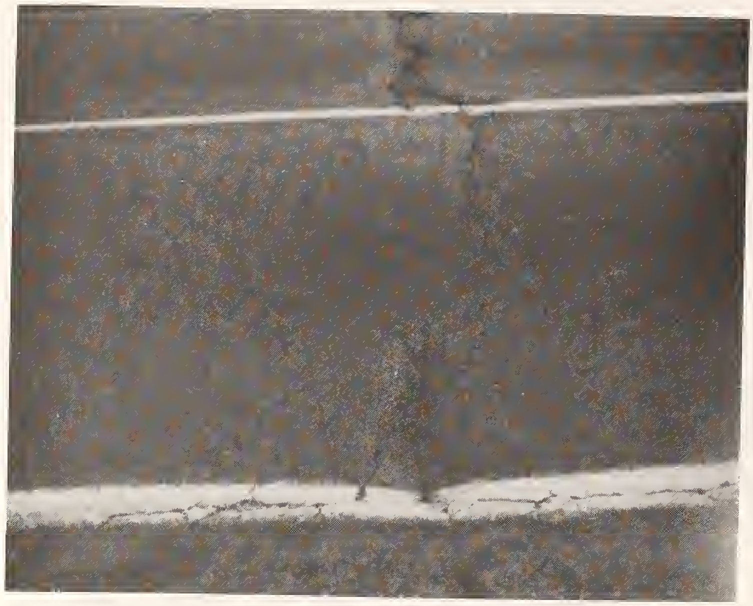

Figure B.37. Medium Severity Transverse Cracking.

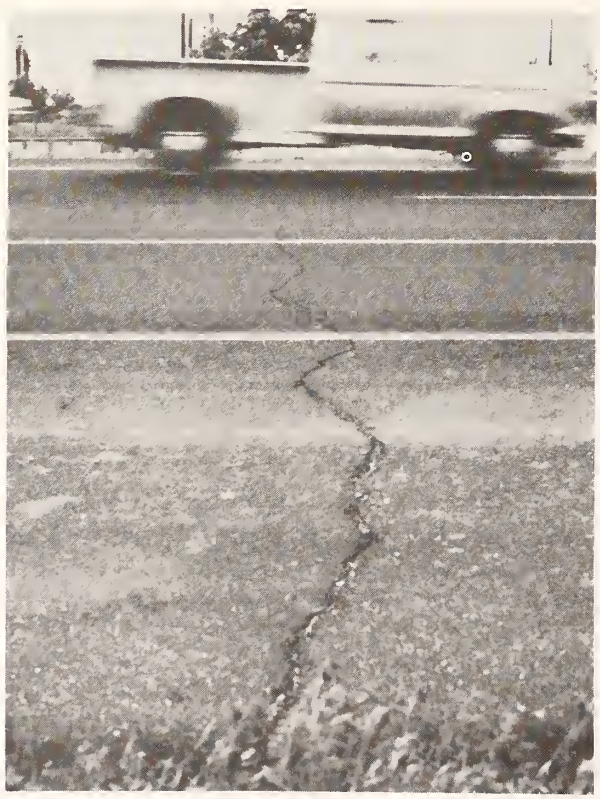

Figure B.38. Medium Severity Transverse Cracking.

Figure B.39. Medium Severity Transverse Cracking.

Figure B.40. Medium Severity Transverse Cracking Across Shoulder.

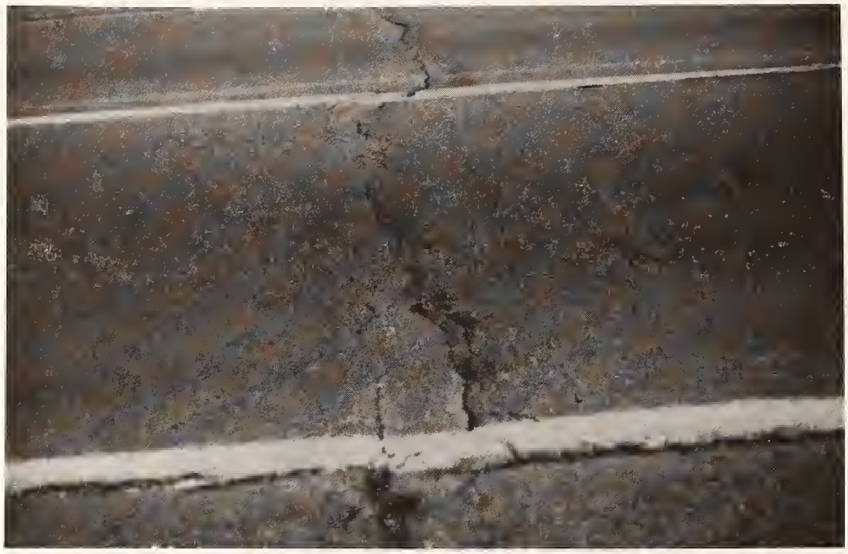

Figure B.41. High Severity Transverse Cracking.

Figure B.42. High Severity Longitudinal Cracking.

Figure B.43. High Severity Transverse Cracking.

Figure B.44. High Severity Transverse Cracking (this crack is caused initially by reflection from cement stabilized base).

Name of Distress:	Patch Deterioration
Description:	A patch is an area where the original pavement has been removed and replaced with either similar or different material.
Severity Levels:	L - Patch is in very good condition and is performing satisfactorily.
	M - Patch is somewhat deteriorated, having low to medium levels of any types of distress.
	H - Patch is badly deteriorated and soon needs replacement.
How to Measure:	Each patch is measured in square feet or square meters of surface area. Even if a patch is in excellent condition it is still rated low severity.

Figure B.45. Low Severity Patch.

Acceleration of Patch Distress Due to Moisture: Excess moisture accumulated beneath the patch or in the patch/pavement joint can cause high deflections and pumping near the edges and cracking or disintegration of the patch. Excess moisture can also accelerate the breakdown of the bond between the patch and pavement. Thus the severity of patch distress would increase more rapidly.

Figure B.46. Low Severity Patch.

Figure B.47. Low Severity Patch Along Shoulder Joint.

Figure B.48. Medium Severity Patch.

Figure B.49. Medium Severity Patch (see also Figure 2.76 for medium severity patch).

Figure B .50. High Severity Patch.

Name of Distress: Polished Aggregate

Description: Aggregate polishing is caused by repeated traffic applications. Polished aggregate is present when close examination of a pavement reveals that the portion of aggregate extending above the asphalt is either very small, or there are no rough or angular aggregate particles to provide good skid resistance.

Severity Levels: No degrees of severity are defined. However, the degree of polishing should be significant in reducing skid resistance before it is included as a distress.

How to Measure: Polished aggregate is measured in square ft. or square meters of surface area. The existance of polishing can be detected by both visually observing and running the fingers over the surface.

Figure B.51. Polished Aggregate (photo taken in wheel path of 23 year old high traffic volume turnpike).

Acceleration of Polished Aggregate Due to Moisture:	None.

Name of Distress: Potholes

Description: A bowl shaped hole of various sizes in the pavement surface. The surface has broken into small pieces by alligator cracking or by localized disintegration of the mixture and the material is removed by traffic. Traffic loads force the underlying materials out of the hole, increasing the depth.

Severity Levels:

Area	(ft^2)	< 1	1 - 3	> 3
Depth - ins.(mm)	(m^2)	< 1/3	1/3- 1	> 1
< 1 (< 25)		L	L	M
1-2 (25-50)		M	M	H
> 2 (> 51)		M	H	H

How to Measure: Potholes are counted in numbers of holes of each severity level in the inspection unit.

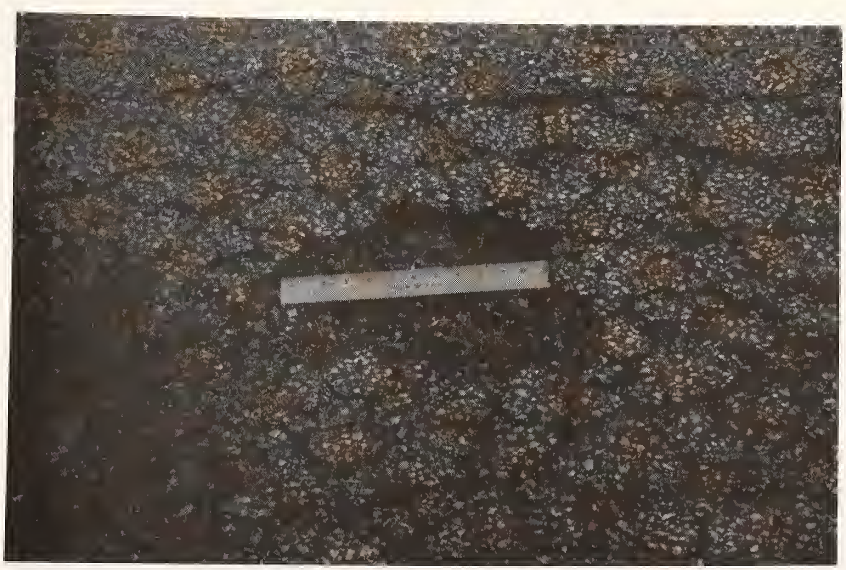

Figure B.52. Low Severity Pothole.

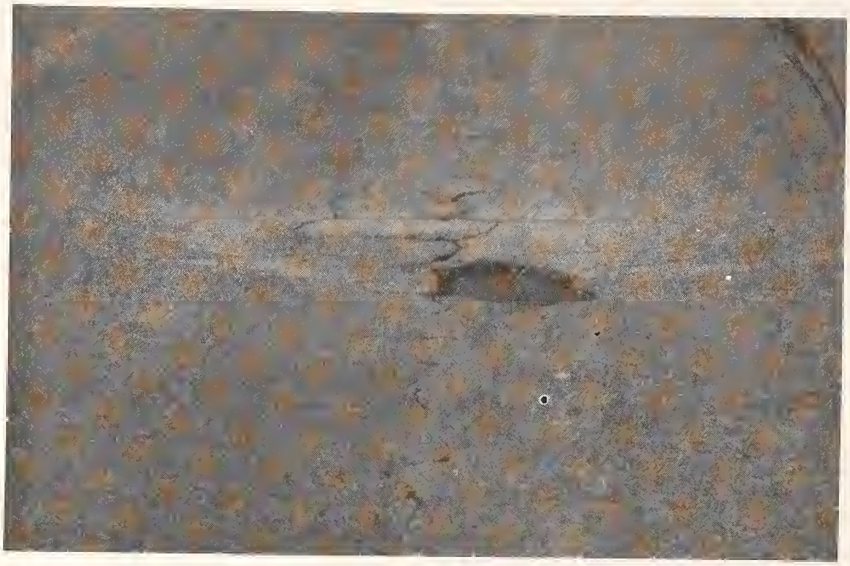

Figure B.53 Low Severity Pothole.

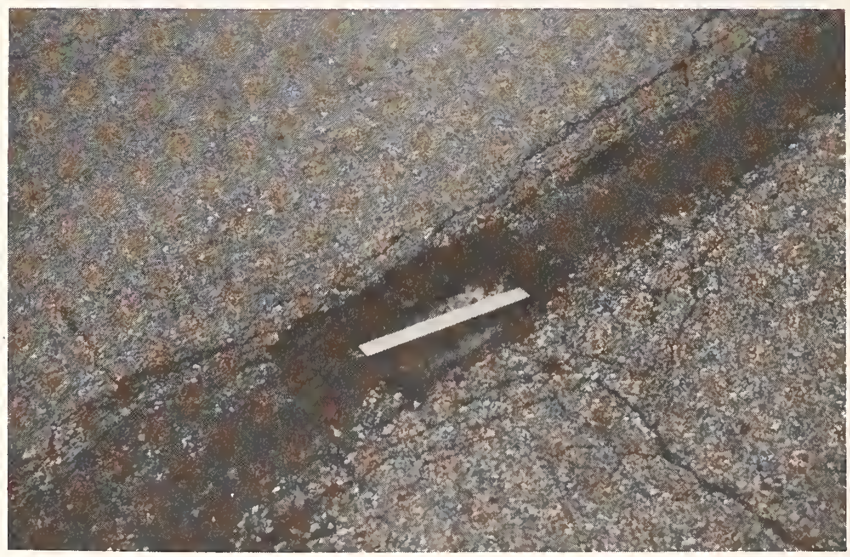

Figure B.54. Medium Severity Pothole.

Figure B.55. Medium Severity Pothole.

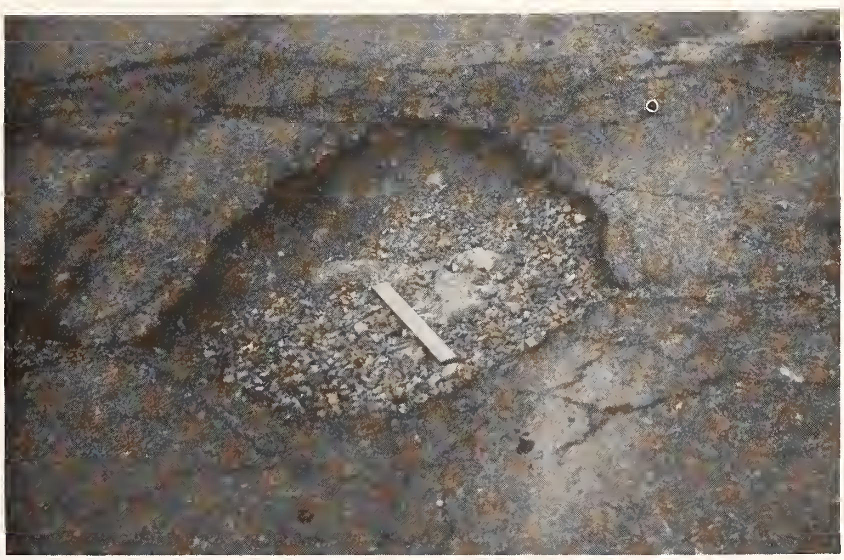

Figure B.56. High Severity Pothole.

Figure B.57. High Severity Pothole.

Acceleration of Pothole Distress Due to Moisture: Potholes occur due to the breakdown or disintegration of the asphalt surface material from alligator cracking, linear cracking, or raveling and weathering, all of which are accelerated by free moisture. Once a small hole exists, free moisture will accumulate and through freeze-thaw and/or pumping action additional material will be broken out of the hole and it will increase in severity.

Name of Distress: Pumping and Water Bleeding

Description: Pumping is the ejection of water and fine materials under pressure through cracks under moving loads. As the water is ejected it carries fine material resulting in progressive material deterioration and loss of support. Several cases of pumping of stabilized base materials have been observed for example. Surface staining or accumulation of material on the surface close to cracks is evidence of pumping. Water bleeding occurs where water seeps slowly out of cracks in the pavement surface.

Severity Levels:

L - Water bleeding exists or water pumping can be observed when heavy loads pass over the pavement, however no fines (or only a very small amount) can be seen on the surface of the pavement.

M - Some pumped material can be observed near cracks in the pavement surface.

H - A significant amount of pumped material exists on the pavement surface near the cracks.

How to Count: If pumping or water bleeding exists anywhere in the sample unit it is counted as occurring.

Figure B.58. Medium Severity Pumping (stabilized base is pumping)(Note: see also Figure 2.9 for medium severity pumping photo).

Acceleration of Pumping Due to Moisture:	Pumping or water bleeding is caused by excess free water and significant pumping will lead to disintegration of the base/subbase resulting in the occurrence of several distresses.

Figure B.59. High Severity Pumping (stabilized base is pumping).

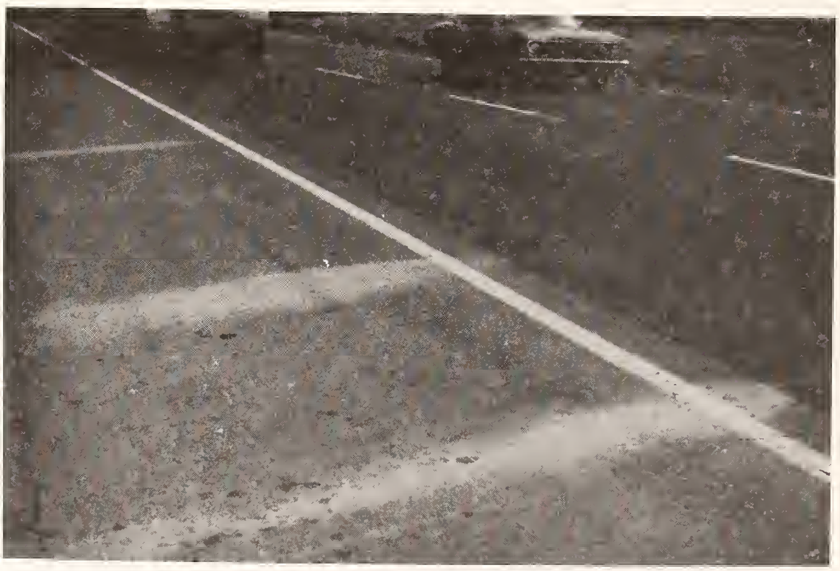

Figure B.60. High Severity Pumping (stabilized base is pumping).

Name of Distress: Raveling and Weathering

Description: Raveling and weathering are the wearing away of the pavement surface caused by the dislodging of aggregate particles (raveling) and loss of asphalt binder (weathering). They generally indicate that the asphlat binder has hardened significantly.

Severity Levels:

L - Aggregate or binder has started to wear away, but has not progressed significantly.

M - Aggregate and/or binder has worn away and the surface texture is moderately rough and pitted. Loose particles generally exist.

H - Aggregate and/or binder has worn away and the surface texture is severely rough and pitted.

How to Measure: Raveling and weathering are measured in square ft. or square meters of surface area.

Figure B.61. Low Severity Raveling and Weathering.

Acceleration of Raveling and Weathering Due to Moisture:	Prolonged soaking of the asphalt stabilized materials causes moisture to penetrate between the asphalt and aggregate surface that wets the surface of the aggregate. The moisture may penetrate the asphalt films by emulsion formation causing stripping and thus contributing to raveling and weathering.

Figure B.62. Medium Severity Raveling and Weathering.

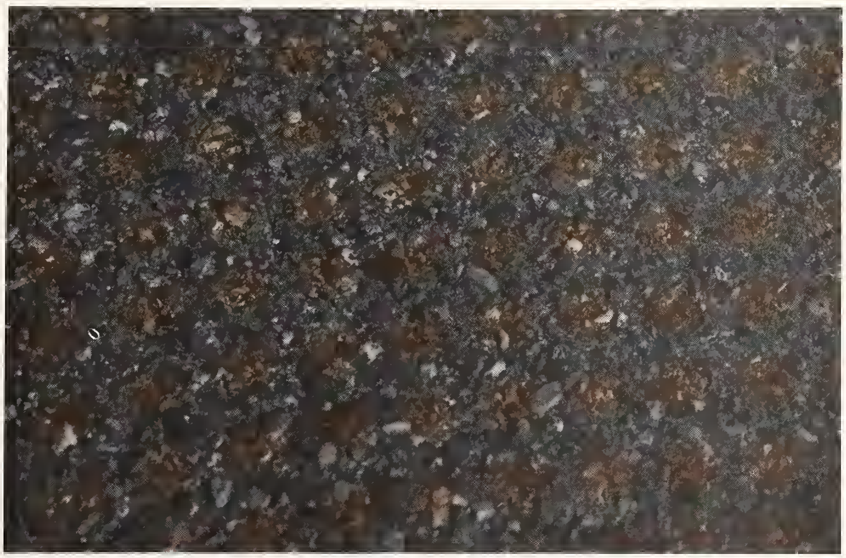

Figure B.63. Medium Severity Raveling and Weathering.

Figure B.64. Medium Severity Raveling and Weathering.

Figure B.65. Medium Severity Raveling and Weathering.

Figure B.66. High Severity Raveling and Weathering.

Figure B.67. High Severity Raveling and Weathering.

Name of Distress: Rutting

Description: A rut is a surface depression in the wheel paths. Pavement uplift may occur along the sides of the rut; however, in many instances ruts are noticeable only after a rainfall, when the wheel paths are filled with water. Rutting stems from a permanent deformation in any of the pavement layers or subgrade, usually caused by consolidation or lateral movement of the materials due to traffic laods. Rutting may be caused by plastic movement in the mix in hot weather, or inadequate compaction during construction. Significant rutting can lead to major structural failure of the pavement and hydroplaning potential. Wear of the surface in the wheel paths from studded tires can also cause a type of "rutting."

Severity Levels:

Severity	Mean Rut Depth Criteria
L	1/4 - 1/2 in. (6 - 13 mm)
M	>1/2 - 1 in. (13 - 25 mm)
H	>1 in. (> 25 mm)

How to Measure: Rutting is measured in square feet or square meters of surface area, and its severity is determined by the mean depth of the rut. To determine the mean rut depth, a 4 ft. (1.2 m) straightedge should be laid across the rut and the maximum depth measured. The mean depth should be computed from measurements taken every 20 ft. (6 m) along the length of the rut.

Acceleration of Rutting Due to Moisture:

Moisture may accelerate rutting in several ways: 1) by softening the asphalt mix, 2) outward displacement of non-stabilized material in the pavement structure through pumping and 3) reduction of strength of the base/subbase/subgrade soil.

Moisture may cause the strength of the asphalt mix to decrease through stripping or loss of bond between asphalt and aggregate. This will increase the potential for permanent deformation in the mix. Moisture may cause outward displacement of non-stabilized material in two ways. At high degrees of saturation (i.e., 80% or greater), granular material tends to lose stability under repeated loading due to the development of excess pore water pressures. At high moisture contents under heavy dynamic loads, fine grain material will go into suspension and move under water pressure away from the loaded area. Both of these conditions result in decreasing the layer thickness in the wheel paths.

Excess moisture softens subgrade soils, which results in increased deflections and stresses/strains under load. The capability of the subgrade soil to support loads may be decreased to the point where permanent deformation may occur. Also, freeze-thaw cycles on near saturated soils causes great loss in strength and resiliency.

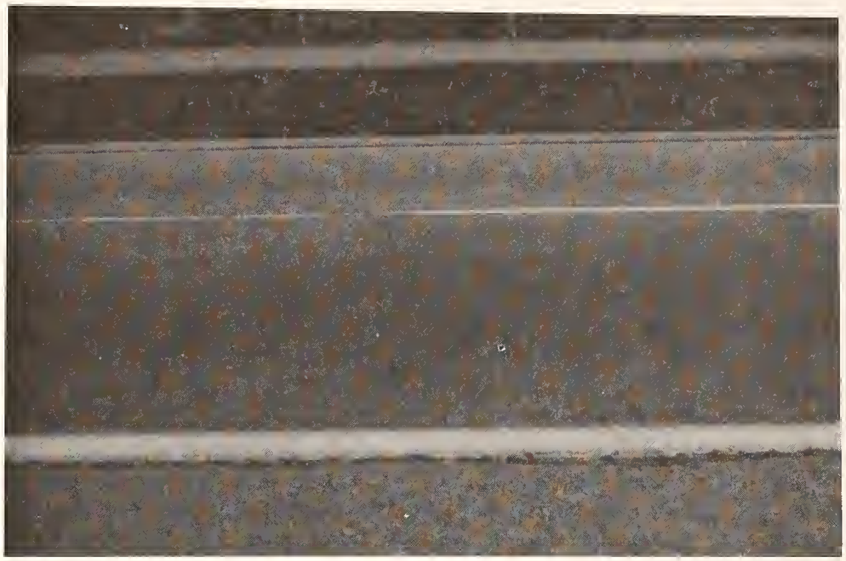

Figure B.68. Low Severity Rutting.

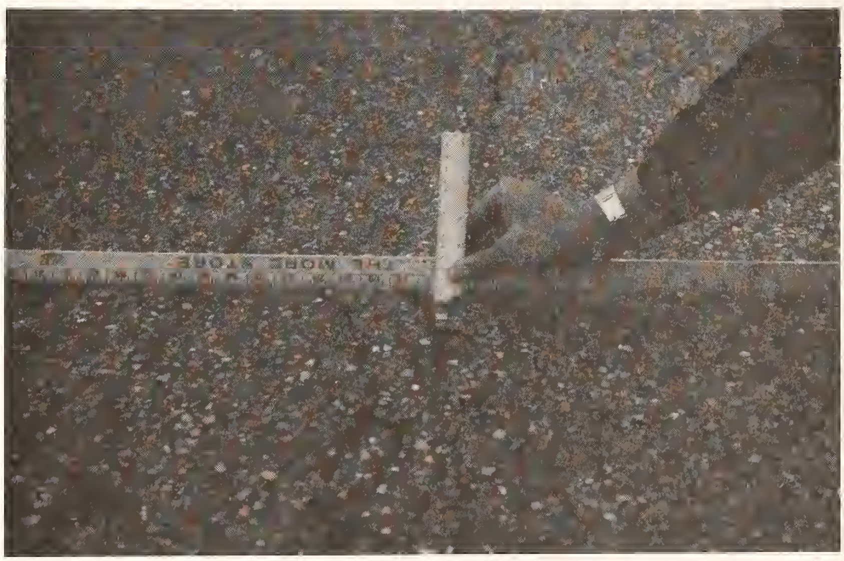

Figure B.69. Medium Severity Rutting.

Figure B.70. High Severity Rutting.

Name of Distress: Slippage Cracking

Description: Slippage cracks are crescent or half-moon shaped cracks generally having two ends pointed into the direction of traffic. They are produced when braking or turning wheels cause the pavement surface to slide and deform. This usually occurs when there is a low strength surface mix or poor bond between the surface and next layer of pavement structure.

Severity Levels: No degrees of severity are defined. It is sufficient to indicate that a slippage crack exists.

How to Measure: Slippage cracking is measured in square meters or in square feet of surface area within the inspection unit.

Figure B.71. Slippage Cracking.

Figure B.72. Slippage Cracking.

Figure B.73. Slippage Cracking.

Name of Distress: Swell

Description: Swell is characterized by an upward bulge in the pavement's surface. A swell may occur sharply over a small area or as a longer, gradual wave. Either type of swell can be accompanied by surface cracking. A swell is usually caused by frost action in the subgrade or by swelling soil, but a swell can also occur on the surface of an asphalt overlay (over PCC) as a result of a blowup in the PCC slab. They can often be identified by oil droppings on the surface.

Severity Levels:

L - Swell causes some bounce of the vehicle which creates no discomfort.

M - Swell causes significant bounce of the vehicle which creates some discomfort.

H - Swell causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring reduction in speed for safety.

How to Measure: Swells within the inspection unit are measured in square feet or meters. Severity level is determined by riding in a mid to full sized sedan weighing approximately 3000-3800 lbs (13.3-16.9 kN) over the pavement inspection unit at the posted speed limit.

Figure B.74. Medium Severity Swell Occurring at a Patch Due to Buckling of Concrete Slab Beneath Asphalt Surface.

Acceleration of Slippage Cracking Due to Moisture:	Free moisture between the asphalt concrete surface and granular layer may weaken the bond between the layers. Once this bond is lost the potential for slippage cracking in areas of breaking or turning traffic increases dramatically.

Acceleration of Swell Due to Moisture:	Swells can be accelerated by moisture in two ways: (1) frost heaves may occur in freeze climates, (2) an expansive soil will swell when exposed to moisture, and (3) heave over culverts, when colder soils draw in moisture and create local heaves. Frost heave is caused by the formation of ice crystals in a frost susceptible subgrade. The ice crystals grow until ice lenses form which produce frost heave. A swelling soil increases in volume when content increases, and decreases its volume when water content is reduced. A swelling soil has a high plasticity index and can be determined by lab test or experience.

Figure B.75. High Severity Swell Due to Buckling of Concrete Slab Beneath Asphalt Surface.

APPENDIX C

DISTRESS IDENTIFICATION MANUAL

JOINTED REINFORCED CONCRETE PAVEMENTS

INTRODUCTION

The distress definitions were developed based initially on the airfield distress identification manual by Shahin, Darter and Kohn[1] and the "Standard Nomenclature and Definitions for Pavement Components and Deficiencies" (Special Report 113, Highway Research Board); and considerably further developed through extensive field surveys and discussions with state highway engineers. This manual Distress Identification Manual for Jointed Reinforced Concrete Pavements was developed under NCHRP Project 1-19, Development of a Nationwide Concrete Pavement Evaluation System.

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[1] Shahin, M. Y., M. I. Darter, and S. D. Kohn, "Development of a Pavement Maintenance Management System, Vol. V, Proposed Revision of Chapter 3, AFR 93-5," Report No. CEE-DO-TR-77-44, U.S. Air Force, 1977.

Name of Distress: Blow-up

Description: Most blow-ups occur during the spring and hot summer at a transverse joint or wide crack. Infiltration of incompressible materials into the joint or crack during cold periods results in high compressive stresses in hot periods. When this compressive pressure becomes too great, a localized upward movement of the slab or shattering occurs at the joint or crack. Blow-ups are accelerated due to a spalling away of the slab at the bottom creating reduced joint contact area. The presence of "D" cracking or freeze-thaw damage also weakens the concrete near the joint resulting in increased spalling and blow-up potential.

Severity Levels:

*L - Blow-up has occurred, but only causes some bounce of the vehicle which creates no discomfort.

*M - Blow-up causes a significant bounce of the vehicle which creates some discomfort. Temporary patching may have been placed because of the blow-up.

*H - Blow-up causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Blow-ups are measured by counting the number existing in each uniform section. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lbs. (13.3-16.9 kN) over the uniform section at the posted speed limit. The number is not as important as the fact that initial blow-ups signal a problem with "lengthening" or gradual down hill movement -- and others should be expected to occur until the maximum distance is down to 1000' between blowups. The distance required to develop full restraint of an interior section.

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*L = Low severity level
*M = Medium severity level
*H = High severity level

Acceleration of Blow-ups Due to Moisture:	A significant amount of moisture infiltrating into a joint may carry incompressibles into the joint. Over a long time period this action would accelerate the buildup of incompressibles and thus increase the potential for blow-ups.

Figure C.1. High Severity Buckling Type Blow-up.

Figure C.2. High Severity Shattering Type Blow-up.

Name of Distress: Corner Break

Description: A corner break is a crack that intersects the joints at a distance less than 6 ft (1.8 m) on each side measured from the corner of the slab. A corner break extends vertically through the entire slab thickness. It should not be confused with a corner spall which intersects the joint at an angle through the slab and is typically within 1 ft (0.3 m) from the slab corner. Heavy repeated loads combined with pumping, poor load transfer across the joint, and thermal curling and moisture warping stresses result in corner breaks.

Severity Levels:

L - Crack is tight (hairline). Well sealed cracks are considered tight. No faulting or break-up of broken corner exists. Crack is not spalled.

M - Crack is working and spalled at medium severity, but break-up of broken corner has not occurred. Faulting of crack or joint is less than 1/2 inch (13 mm). Temporary patching may have been placed because of corner break.

H - Crack is spalled at high severity, the corner piece has broken into two or more pieces, or faulting of crack or joint is more than 1/2 inch (13 mm).

How to Measure: Corner breaks are measured by counting the number that exists in the uniform section. Different levels of severity should be counted and recorded separately. Corner breaks adjacent to a patch will be counted as "patch adjacent slab deterioration."

Figure C.3. Low Severity Corner Break.

Acceleration of Corner Breaks Due to Moisture: Moisture will usually infiltrate into the subsurface of a pavement through a transverse and longitudinal joint. If excess moisture accumulates beneath the slab and heavy repeated loads are applied, pumping of the subbase will occur creating a void under the slab corner. A loss of support under the corner of the slab greatly increases load stresses and corner cracking may occur.

Figure C.4. High Severity Corner Break.

Name of Distress: Depression

Description: Depressions in concrete pavements are localized settled areas. There is generally significant slab cracking in these areas due to uneven settlement. The depressions can be located by stains caused by oil droppings from vehicles, and by riding over the pavement. Depressions can be caused by settlement or consolidation of the foundation soil or can be "built in" during construction. They are frequently found near culverts. This is usually caused by poor compaction of soil around the culvert during construction. Depressions cause slab cracking, roughness, and hydroplaning when filled with water of sufficient depth.

Severity Levels:

L - Depression causes a distinct bounce of vehicle which creates no discomfort.

M - Depression causes significant bounce of the vehicle which creates some discomfort.

H - Depression causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: Depressions are measured by counting the number that exists in each uniform section. Each depression is rated according to its level of severity. Severity level is determined by riding in a mid- to full-sized sedan weighing approximately 3000-3800 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Acceleration of Depression by Moisture: Depressions will hinder the runoff of water after a rainstorm. The water will be collected in the depressions, thus increasing the exposure time of the water to cracks and joints. This allows more water to infiltrate through the pavement surface into the base, subbase, and subgrade. Higher moisture contents in the subgrade will propagate other distress such as pumping and corner cracking.

Name of Distress: Durability ("D") Cracking

Description: "D" cracking is a series of closely spaced crescent-shaped hairline cracks that appear at a PCC pavement slab surface adjacent and roughly parallel to transverse and longitudinal joints, transverse and longitudinal cracks, and the free edges of pavement slab. The fine surface cracks often curve around the intersection of longitudinal joints/cracks and transverse joints/cracks. These surface cracks often contain calcium hydroxide residue which causes a dark coloring of the crack and immediate surrounding area. This may eventually lead to disintegration of the concrete within 1-2 ft. (0.30-0.6 m) or more of the joint or crack, particularly in the wheelpaths. "D" cracking is caused by freeze-thaw expansive pressures of certain types of coarse aggregates and typically begins at the bottom of the slab which disintegrates first. Concrete durability problems caused by reactive aggregates are rated under "Reactive Aggregate Distress."

Severity Levels:

L - The characteristic pattern of closely spaced fine cracks has developed near joints, cracks, and/or free edges; however, the width of the affected area is generally <12 in. (30 cm) wide at the center of the lane in transverse cracks and joints. The crack pattern may fan out at the intersection of transverse cracks/joints with longitudinal cracks/joints. No joint/crack spalling has occurred, and no patches have been placed for "D" cracking.

M - The characteristic pattern of closely spaced cracks has developed near the crack, joint or free edge and: (1) is generally wider than 12 in. (30 cm) at the center of the lane in transverse cracks and/or joints; or (2) low or medium severity joint/crack or corner spalling has developed in the affected area; or (3) temporary patches have been placed due to "D" cracking induced spalling.

H - The pattern of fine cracks has developed near joints or cracks and (1) a high severity level of spalling at joints/cracks exists and considerable material is loose in the affected area; or (2) the crack pattern has developed generally over the entire slab area between cracks and/or joints.

How to Measure: "D" cracking is measured by counting the number of joints or cracks (including longitudinal) affected. Different severity levels are counted and recorded separately. "D" cracking adjacent to a patch is rated as patch-adjacent slab deterioration. "D" cracking should not be counted if the fine crack pattern has not developed near cracks, joints and free edges. Pop-outs and discoloration of joints, cracks and free edges may occur without "D" cracking.

Acceleration of "D" Cracking Due to Moisture: "D" cracking is believed to be directly related to moisture which infiltrates into the concrete and saturates certain aggregates (such as limestone) which are highly absorptive. These aggregates, which are relatively weak, become saturated and expand upon freezing. The expanded aggregate, confined by the concrete matrix, will either break apart or stress the concrete around it. The concrete gradually breaks down after many cycles of freeze-thaw forming the characteristic crack pattern. Areas such as joints and cracks subjected to constant free moisture exhibits much more "D" cracking than concrete in dryer areas such as the slab interior.

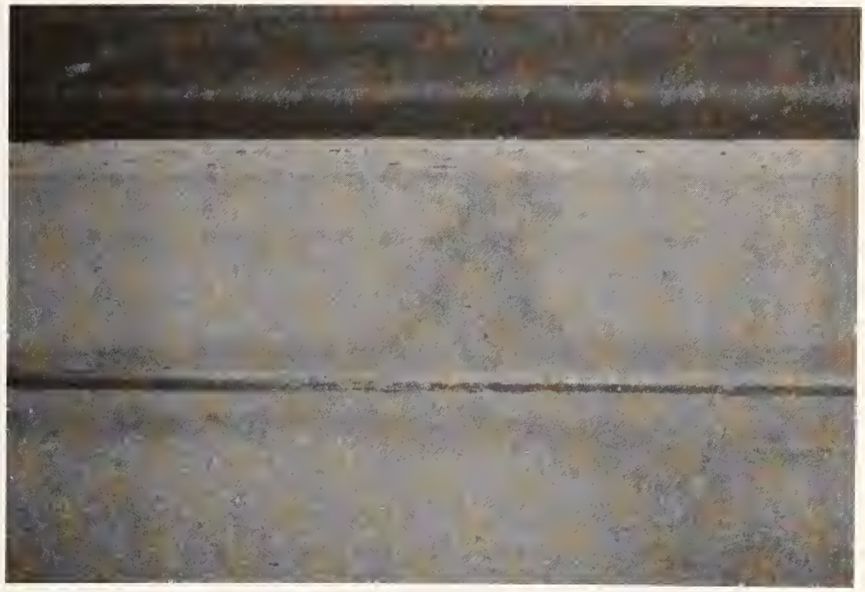

Figure C.5. Low Severity "D" Cracking.

Figure C.6. Medium Severity "D" Cracking.

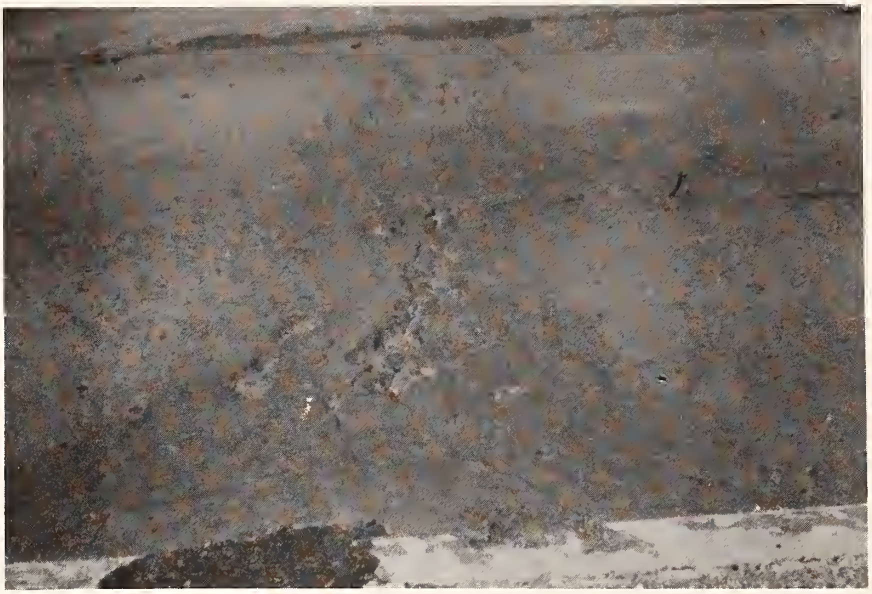

Figure C.7. Medium Severity "D" Cracking.

Figure C.8. High Severity "D" Cracking.

Figure C.9. High Severity "D" Cracking.

Name of Distress: Faulting of Transverse Joints and Cracks

Description: Faulting is the difference of elevation across a joint or crack. Faulting is caused in part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping from under the leave slab and shoulder (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of load transfer contributes greatly to faulting.

Severity Levels: Severity is determined by the average faulting over the joints within the sample unit.

How to Measure: Faulting is determined by measuring the difference in elevation of slabs at transverse joints for the slabs in the sample unit. Faulting of cracks are measured as a guide to determine the distress level of the crack. Faulting is measured one foot in from the outside (right) slab edge on all lanes except the inner-most passing lane. Faulting is measured one foot in from the inside (left) slab edge on the inner passing lane. If temporary patching prevents measurement, proceed on to the next joint. Sign convention: + when approach slab is higher than departure slab, - when the opposite occurs. Faulting never occurs in the opposite direction.

Traffic →

Figure C.10. Crack Faulting.

Acceleration of Faulting Due to Moisture: Studies have shown that faulting is definitely accelerated by free moisture beneath the slab near the joints and cracks. When a heavy load is applied near the joint or crack, this free moisture is subjected to high pressure and consequently moves at high velocity, which erodes the subbase. The fine particles are either pumped out onto the pavement surface, creating a void into which the slab settles, or migrates from the front slab to the back slab, causing the back slab to rise. Free moisture contents may also soften the subgrade so much that the slab settles. Dowels or other mechanical load transfer devices (LTD) used at joints help minimize faulting. However, many times they are not sufficient to prevent faulting because of excess pumping, deteriorated PCC, and high bearing stress of dowel on PCC under load.

Figure C.11. Joint Faulting.

Name of Distress: Joint Load Transfer System Associated Deterioration (Second Stage Cracking)

Description: This distress develops as a transverse crack a short distance (e.g., 9 in. (23 cm)) from a transverse joint at the end of joint dowels. This usually occurs when the dowel system fails to function properly due to extensive corrosion or misalignment. It may also be caused by a combination of small diameter dowels and heavy traffic loadings.

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting or well-sealed crack with no visible faulting or spalling.

M - Any of the following conditions exist: the crack has opened to a width less than 1 inch (25 mm); the crack has faulted less than 1/2 inch (13 mm); the crack may have spalled to a low or medium severity level; the area between the crack and joint has started to break up but pieces have not been dislodged to the point that a tire damage or safety hazard is present; or temporary patches have been placed due to this joint deterioration.

H - Any of the following conditions exist: a crack with width of opening greater than 1 inch (25 mm); a crack with a high severity level of spalling; a crack faulted 1/2 inch (13 mm) or more; or the area between the crack and joint has broken up and pieces have been dislodged to the point that a tire damage or safety hazard is present.

How to Measure: The number of joints with each severity level are counted in the uniform section.

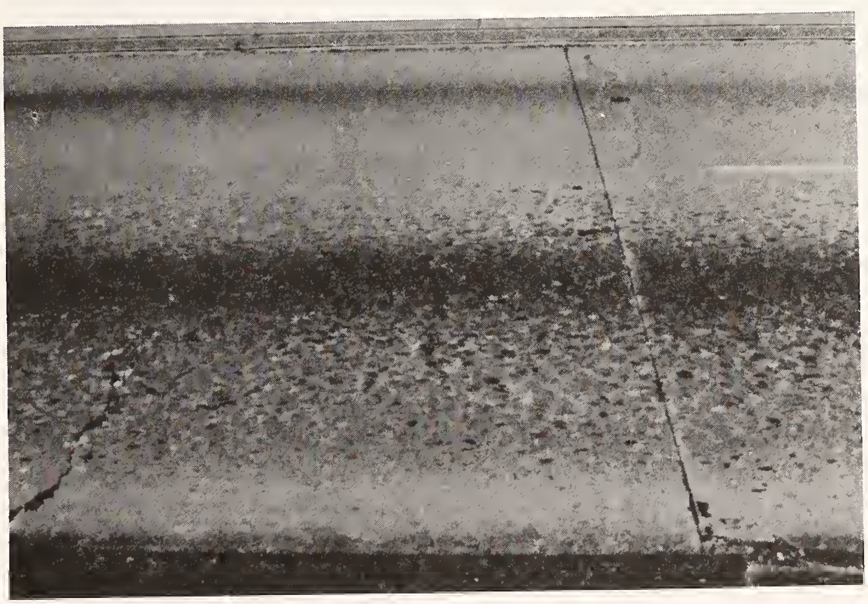

Figure C.12. Low Severity Joint Load Transfer System Associated Deterioration in Traffic Lane at Top of Photo.

Acceleration of Joint Load Transfer System Associated Deterioration Due to Moisture:	If water containing chlorides infiltrates the joint, it may cause corrosion several inches along the dowels. This corrosion may result in a "frozen" joint, which leads to joint deterioration and openness of intermediate cracks. Some corrosion will likely occur even without salt. However use of deicing salt speeds the corrosive action.

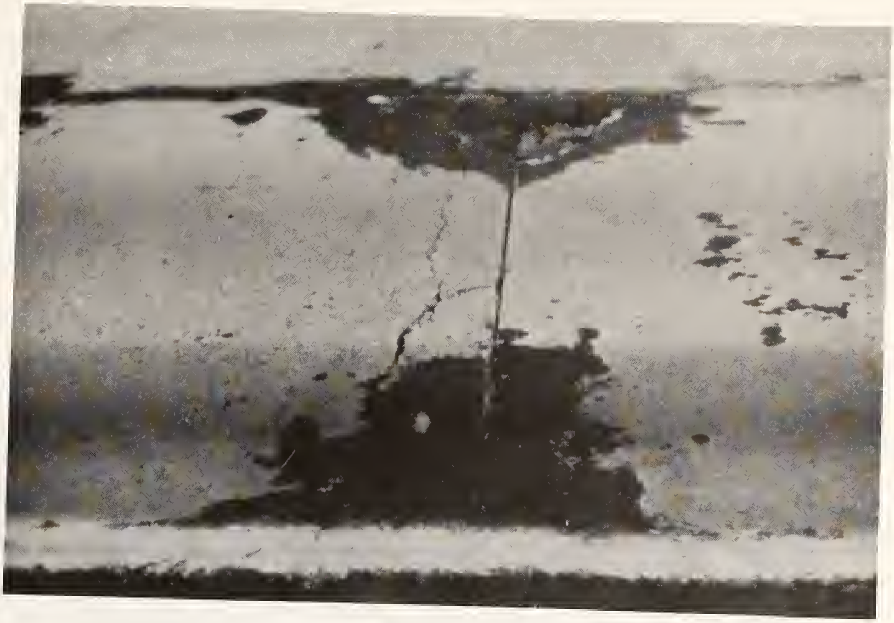

Figure C.13. Medium Severity Joint Load Transfer System Associated Deterioration.

Figure C.14. High Severity Joint Load Transfer System Associated Deterioration.

Figure C.15. High Severity Joint Load Transfer System Associated Deterioration.

Name of Distress: Joint Seal Damage of Transverse Joints

Description: Joint seal damage exists when incompressible materials and/or water can infiltrate into the joints. This infiltration can result in pumping, spalling, and blow-ups. A joint sealant bonded to the edges of the slabs protects the joints from accumulation of incompressible materials, and also reduces the amount of water seeping into the pavement structure. Typical types of joint seal damage are: (1) stripping of joint sealant, (2) extrusion of joint sealant, (3) weed growth, (4) hardening of the filler (oxidation), (5) loss of bond to the slab edges, and (6) lack or absence of sealant in the joint.

Severity Levels:

L - Joint sealant is in good condition throughout the section with only a minor amount of any of the above types of damage present. Little water and no incompressibles can infiltrate through the joint.

M - Joint sealant is in fair condition over the entire surveyed section, with one or more of the above types of damage occuring to a moderate degree. Water can infiltrate the joint fairly easily; some incompressibles can infiltrate the joint. Sealant needs replacement within 1-3 years.

H - Joint sealant is in poor condition over most of the sample unit, with one or more of the above types of damage occurring to a severe degree. Water and incompressibles can freely infiltrate the joint. Sealant needs immediate replacement.

How to Measure: Joint sealant damage of transverse joints is rated based on the overall condition of the sealant over the entire sample unit.

Acceleration of Joint Seal Damage Due to Moisture:	Water will reduce the bond between sealant and PCC to a point that the sealant is easily removed by moisture, vehicle tires and other means. The removal of sealant can lead to many other problems such as pumping, softening of subgrade, "D" cracking and spalling.

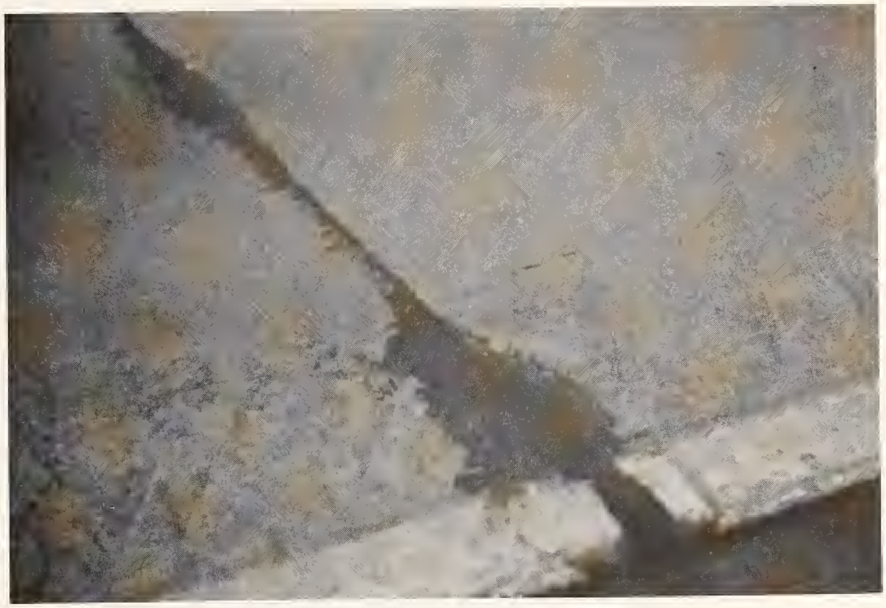

Figure C.16. Low Severity Joint Seal Damage.

Figure C.17. Medium Severity Joint Seal Damage.

Figure C.18. High Severity Joint Seal Damage.

Name of Distress: Lane/Shoulder Dropoff or Heave

Description: Lane/shoulder dropoff or heave occurs when there is a difference in elevation between the traffic lane and shoulder. Typically the outside shoulder settles due to consolidation or a settlement of the underlying granular or subgrade material, or pumping of the underlying material. Heave of the shoulder may occur due to frost action or swelling soils. Dropoff of granular or soil shoulder is generally caused from blowing away of shoulder material from passing trucks.

Severity Level: Severity level is determined by computing the mean difference in elevation between the traffic lane and shoulder.

How to Measure: Lane/shoulder dropoff or heave is measured in the sample unit at all joints when joint spacing is >50 ft. (15 m), at every third joint when spacing is <50 ft. (15 m). It is also measured at mid-slab in each slab measured at the joint. The mean difference in elevation is computed from the data and used to determine severity level. Measurements at joints are made 1 ft. (0.3 m) from the transverse joint on the departure slab only on the outer lane/shoulder.

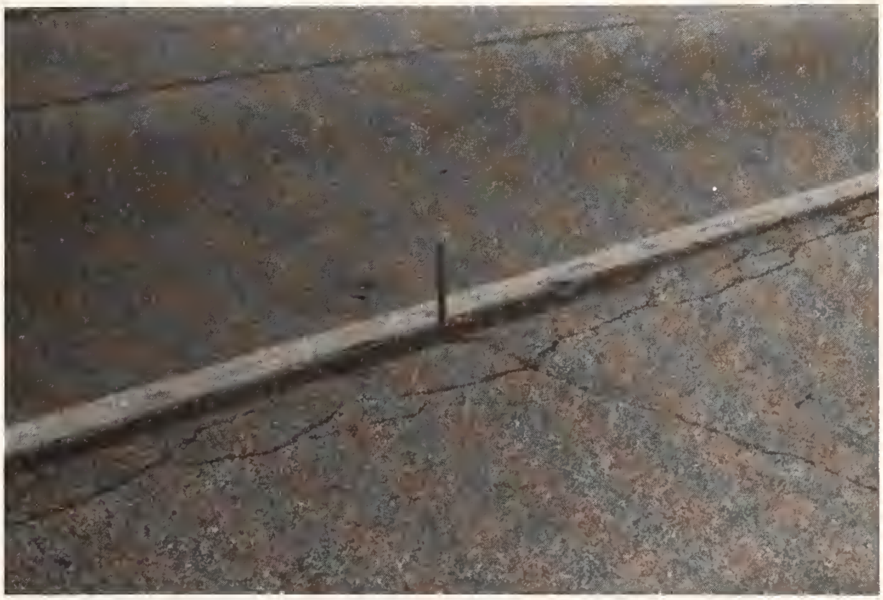

Figure C.19. Lane/Shoulder Dropoff.

Acceleration of Dropoff Due to Moisture:	Moisture entering through the longitudinal joint between the shoulder and lane results in excess free moisture in the underlying material. This material then becomes soft and settles under loads, and/or pumping will occur disintegrating the material and creating a void. In both cases the shoulders will then settle downward producing the dropoff. Heave is caused by (1) frost heave from ice lenses, or (2) swelling subgrade soils. Both settlement or heave usually results in shoulder edge cracking and breakup in conjunction with traffic load encroachment.

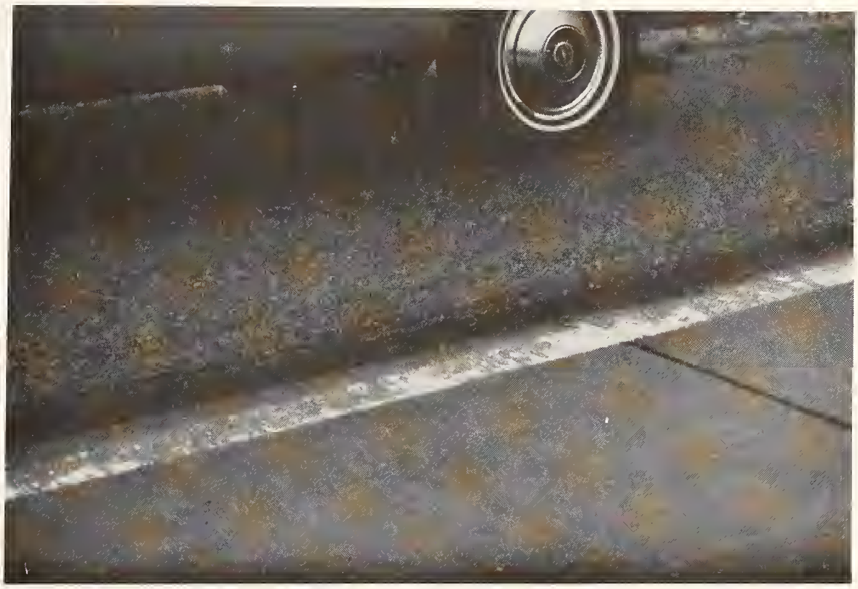

Figure C.20. Lane/Shoulder Heave.

Name of Distress: Lane/Shoulder Joint Separation

Description: Lane/shoulder joint separation is the widening of the joint between the traffic lane and the shoulder generally due to movement in the shoulder. If the joint is tightly closed or well sealed so that water cannot easily infiltrate, then lane/shoulder joint separation is not considered a distress.

Severity Level: No severity level is recorded if the joint is tightly sealed.

L - Some opening but less than or equal to 0.12 inch (3 mm).

M - More than 0.12 inch (3 mm) but equal to or less than 0.4 inch (10 mm) opening.

H - More than 0.4 (10 mm) opening. Gravel or sod shoulders are rated as high.

How to Measure: Lane/shoulder joint separation is measured and recorded in inches (or mm) near transverse joints and at mid-slab. The mean separation is used to determine the severity level.

Figure C.21. Lane/Shoulder Separation (Asphalt Shoulder).

Acceleration of Lane/Shoulder Joint Separation Due to Moisture:	Excess moisture beneath the shoulder may result in frost heave and/or settlement of the shoulder causing lane/shoulder joint opening. Once the joint is open additional moisture can enter which accelerates many distresses as described under Lane/Shoulder Dropoff or Heave.

Figure C.22. Lane/Shoulder Separation (PCC Shoulder).

Figure C.23. Lane/Shoulder Separation (high severity due to gravel shoulder).

Name of Distress: Longitudinal Cracks

Description: Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints, or by a combination of heavy load repetition, loss of foundation support, and thermal and moisture gradient stresses.

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting, or a well sealed crack with no visible faulting or spalling.

M - Working crack with a moderate or less severity spalling and/or faulting less than 1/2 inch (12 mm).

H - A crack with width greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.

How to Measure: Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded.

Figure C.24. Low Severity Longitudinal Crack.

Acceleration of Longitudinal Cracking Due to Moisture:	Longitudinal cracking is generally not initially caused by excess moisture. If, however, excessive moisture accumulates in the slab foundation causing significant loss of support or frost heaving, and this could lead to increased slab cracking.

Figure C.25. High Severity Longitudinal Crack in Center Lane.

Name of Distress:	Longitudinal Joint Faulting
Description:	Longitudinal joint faulting is a difference in elevation of two traffic lanes measured at the longitudinal joint. It is caused primarily by heavy truck traffic and settlement of the foundation.
Severity Levels:	Severity level is determined by measuring the maximum fault.
How to Measure:	Where the longitudinal joint has faulted, the length of the affected area and the maximum joint faulting is recorded.

Figure C.26. Longitudinal Joint Faulting.

Acceleration of Longitudinal Joint Faulting Due to Moisture:	Excess free moisture beneath the slab in a given area may cause the layers to settle or pump under heavy repeated loads resulting in faulting along the lane joint.

Name of Distress: Patch Deterioration (including replaced slabs)

Description: A patch is an area where a portion or all of the original slab has been removed and replaced with a permanent type of material (e.g., concrete or hot-mixed asphalt). Only permanent patches should be considered.

Severity Levels:

L - Patch has little or no deterioration. Some low severity spalling of the patch edges may exist. Faulting across the slab-patch joint must be less than 1/4 inch (6 mm). Patch is rated low severity even if it is in excellent condition.

M - Patch has cracked (low severity level) and/or some spalling of medium severity level exists around the edges. Minor rutting may be present. Faulting of 1/4 to 3/4 inch (6-19 mm) exists. Temporary patches may have been placed because of permanent patch deterioration.

H - Patch has deteriorated by spalling, rutting, or cracking within the patch, to a condition which requires replacement.

How to Measure: The number of patches within each uniform section is recorded. Patches at different severity levels are counted and recorded separately. Additionally, the approximate square footage (or meters) of each patch and type (i.e., PCC or asphalt) is recorded. All patches are rated either L, M, or H.

Figure C.27. Low Severity Asphalt Patch Deterioration.

Acceleration of Patching Deterioration Due to Moisture:	Excess moisture accumulated beneath the patch or in the patch/pavement joint can cause high deflections resulting in pumping, spalling along the joints and eventually breakup of the patch.

Figure C.28. High Severity Asphalt Patch Deterioration.

Figure C.29. Low Severity Concrete Patch Deterioration.

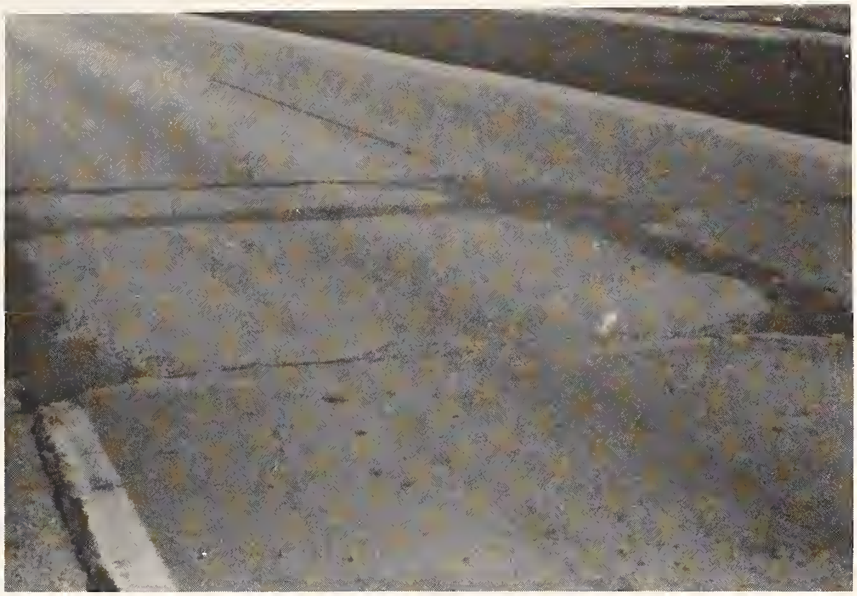

Figure C.30. Medium Severity Concrete Patch Deterioration.

Figure C.31. High Severity Concrete Patch Deterioration.

Name of Distress: Patch Adjacent Slab Deterioration

Description: Deterioration of the original concrete slab adjacent to a permanent patch is given the above name. This may be in the form of spalling of the slab at the slab/patch joint, "D" cracking of the slab adjacent to the patch, a corner break in the adjacent slab, or a second permanent patch placed adjacent to the original patch.

Severity Levels: Severity levels are the same as that described for the particular distress found. A second permanent patch placed adjacent to a previously placed permanent patch will be rated here as medium severity. Temporary patches placed because of this deterioration will also be rated here as medium severity. Temporary patches placed because of this deterioration will also be rated as medium severity.

How to Measure: The number of permanent patches with distress in the original slab adjacent to the patch at each severity level will be counted and recorded separately. Additionally, the type of patch (AC or PCC) and distress will be recorded separately.

Figure C.32. Patch Adjacent Slab Deterioration (Corner Break).

Acceleration of Patch Adjacent Slab Deterioration Due to Moisture:	Excess moisture accumulated beneath the slab adjacent to the patch can cause high deflections resulting in pumping, loss of support, and settlement or breakup of the slab near the patch.

Figure C.33. Patch Adjacent Slab Deterioration ("D" cracking & temporary patching).

Figure C.34. Patch Adjacent Slab Deterioration (second patch, spalling, "D" cracking and temporary patching).

Name of Distress:	Popouts
Description:	A popout is a small piece of concrete that breaks loose from the surface due to freeze-thaw action, expansive aggregates, and/or nondurable materials such as mudballs, chert, and chalcedony. The occurrence of extensive popouts may be indicative of of unsound aggregates and "D" cracking. Popouts typically range from approximately 1 inch (25 mm) to 4 inches (10 cm) in diameter and from 1/2 inch to 2 inches (13-51 mm) deep.
Severity Levels:	No degrees of severity are defined for popouts. The average popout density must exceed approximately one popout per square yard (square meter) over the entire slab area before they are counted as a distress.
How to Measure:	The density of popouts can be determined by counting the number of popouts per square yard (square meter) of surface in areas having typical amounts.

Figure C.35. Popouts.

Acceleration of Popouts Due to Moisture:	Moisture saturation of unsound aggregates results in popouts.

Name of Distress:	Pumping and Water Bleeding
Description:	Pumping is the movement of material by water pressure beneath the slab when it is deflected under a heavy moving wheel load. Sometimes the pumped material moves around beneath the slab, but often it is ejected through joints and/or cracks (particularly along the longitudinal lane/shoulder joint with an asphalt shoulder). Beneath the slab there is typically particle movement counter to the direction of traffic across a joint or crack that results in a buildup of loose materials under the approach slab near the joint or crack. Many times some fine materials (silt, clay, sand) are pumped out leaving a thin layer of relatively loose clean sand and gravel beneath the slab, along with voids causing loss of support. Pumping occurs even in pavement sections containing stabilized subbases. Water bleeding occurs when water seeps out of joints and/or cracks. It many times drains out over the shoulder in low areas.
Severity Levels:	L - Water is forced out of a joint or crack when trucks pass over the joints or cracks; water is forced out of the lane/shoulder longitudinal joint when trucks pass along the joint; or water bleeding exists. No fines can be seen on the surface of the traffic lanes or shoulder. M - A small amount of pumped material can be observed near some of the joints or cracks on the surface of the traffic lane or shoulder. Blow holes may exist. H - A significant amount of pumped materials exist on the pavement surface of the traffic lane or shoulder along the joints or cracks.
How to Measure:	If pumping or water bleeding exists anywhere in the sample unit it is counted as occurring at highest severity level as defined above.

Acceleration of Pumping Due to Moisture:	Pumping of materials cannot occur if excess water is not available. Significant pumping leads to increase of several distresses.

Figure C.36. Low Severity Pumping (Water Bleeding).

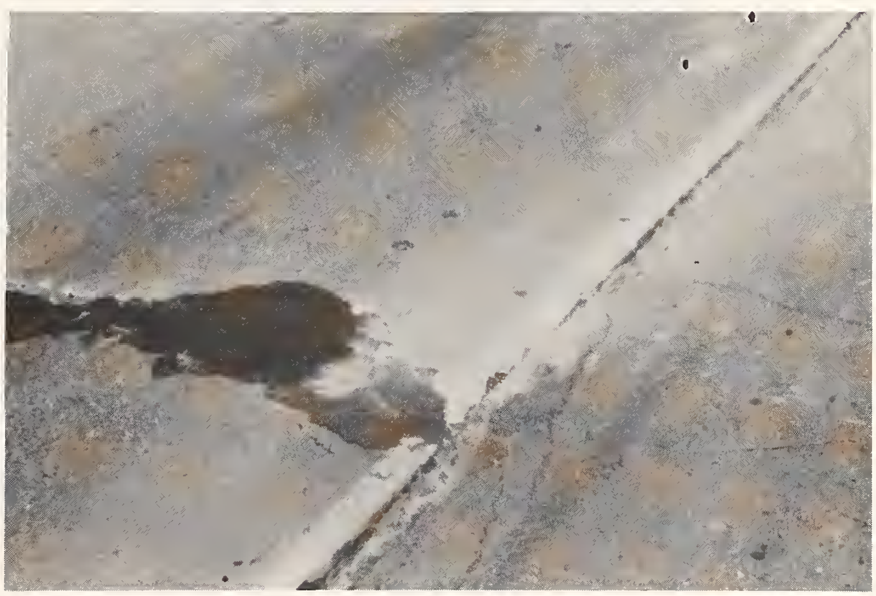

Figure C.37. Medium Severity Pumping (pumped material like this occurs only at a few of the joints and cracks).

Figure C.38. High Severity Pumping.

Name of Distress: Reactive Aggregate Distress

Description: Reactive aggregates either expand in alkaline environments or develop prominent siliceous reaction rims in concrete. It may be an alkali-silica reaction or an alkali-carbonate reaction. As expansion occurs, the cement matrix is disrupted and cracks. It appears as a map cracked area; however, the cracks may go deeper into the concrete than in normal map cracking. It may affect most of the slab or it may first appear at joints and cracks.

Severity Levels: Only one level of severity is defined. If alkali-aggregate cracking occurs anywhere in the slab, it is counted. If the reaction has caused spalling or map cracking, these are also counted.

How to Measure: Reactive-aggregate distress is measured in square feet or square meters.

Figure C.39. Reactive Aggregate Distress (Photo for Jointed Plain Concrete Pavement).

Acceleration of Reactive Aggregate Distress Due to Moisture: The spalling caused by reactive aggregates is not caused by excess moisture.

Name of Distress:	Scaling and Map Cracking or Crazing
Description:	Scaling is the deterioration of the upper 1/8-1/2 inch (3-13 mm) of the concrete slab surface. Map cracking or crazing is a series of fine cracks that extend only into the upper surface of the slab surface. Map cracking or crazing is usually caused by over-finishing of the slab and may lead to scaling of the surface. Scaling can also be caused by reinforcing steel being too close to the surface.
Severity Levels:	L - Crazing or map cracking exists; the surface is in good condition with no scaling. M/H - Scaling exists.
How to Measure:	Scaling and map cracking or crazing are measured by area of slab in square feet or meters.

Figure C.40. Scaling.

Figure C.41. Scaling

Acceleration of Scaling, Map Cracking and Aging Due to Moisture: This distress is not caused by excess free moisture.

Name of Distress:	Spalling (Transverse and Longitudinal Joint/Crack)
Description:	Spalling of cracks and joints is the cracking, breaking, or chipping (or fraying) of the slab edges within 2 ft. (0.6 m) of the joint/crack. A spall usually does not extend vertically through the whole slab thickness, but extends to intersect the joint at an angle. Spalling usually results from (1) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion, (2) disintegration of the concrete from freeze-thaw action of "D" cracking, (3) weak concrete at the joint (caused by honeycombing), (4) poorly designed or constructed load transfer device (misalignment, corrosion), and/or (5) heavy repeated traffic loads.
Severity Levels:	L - The spall or fray does not extend more than 3 ins. (8 cm) on either side of the joint or crack. No temporary patching has been placed to repair the spall.
	M - The spall or fray extends more than 3 ins. (8 cm) on either side of the joint or crack. Some pieces may be loose and/or missing but the spalled area does not present a tire damage or safety hazard. Temporary patching may have been placed because of spalling.
	H - The joint is severly spalled or frayed to the extent that a tire damage or safety hazard exists.
How to Measure:	Spalling is measured by counting and recording separately the number of joints with each severity level. If more than one level of severity exists along a joint, it will be recorded as containing the highest severity level present. Although the definition and severity levels are the same, spalling of cracks should not be recorded. <u>The spalling of cracks is included in rating severity levels of cracks</u>. Spalling of transverse and longitudinal joints will be recorded separately. Spalling of the slab edge adjacent to a permanent patch will be recorded as patch adjacent slab deterioration. If spalling is caused by "D" cracking, it is counted as both spalling and "D" cracking at appropriate severity levels.

Acceleration of Spalling (Joint) Due to Moisture: Free moisture that is retained in the joint has sufficient time to saturate the concrete near the joint. Many years of freeze/thaw cycles may break down the concrete into a spalled condition in combination with traffic and incompressibles. Joint spalling caused by "D" cracking is directly accelerated by moisture.

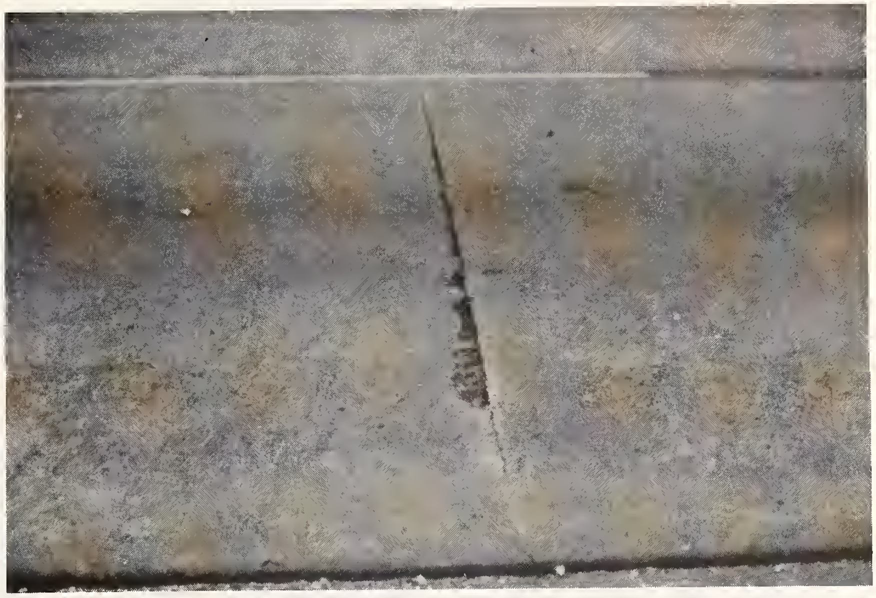

Figure C.42. Low Severity Spalling (Fray).

Figure C.43. Low Severity Spalling.

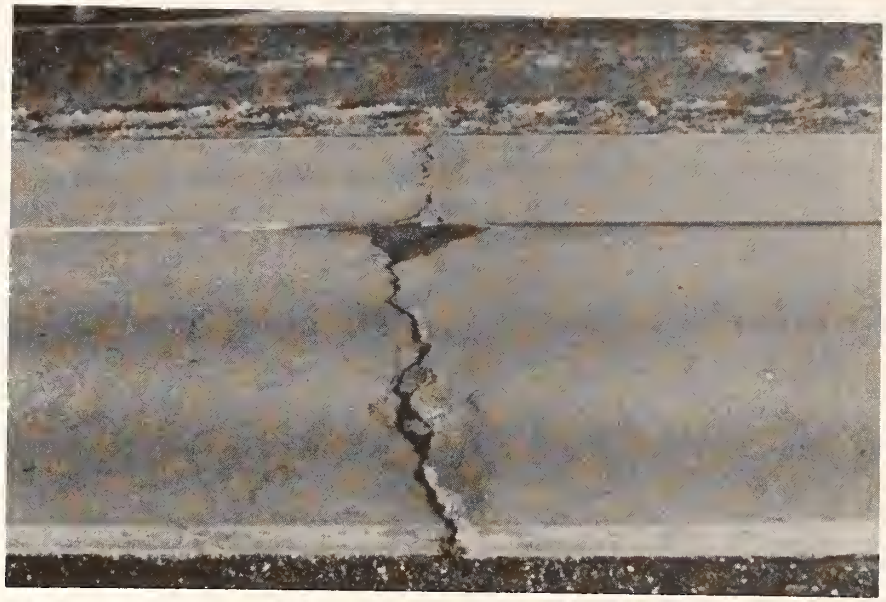

Figure C.44. Medium Severity Spalling.

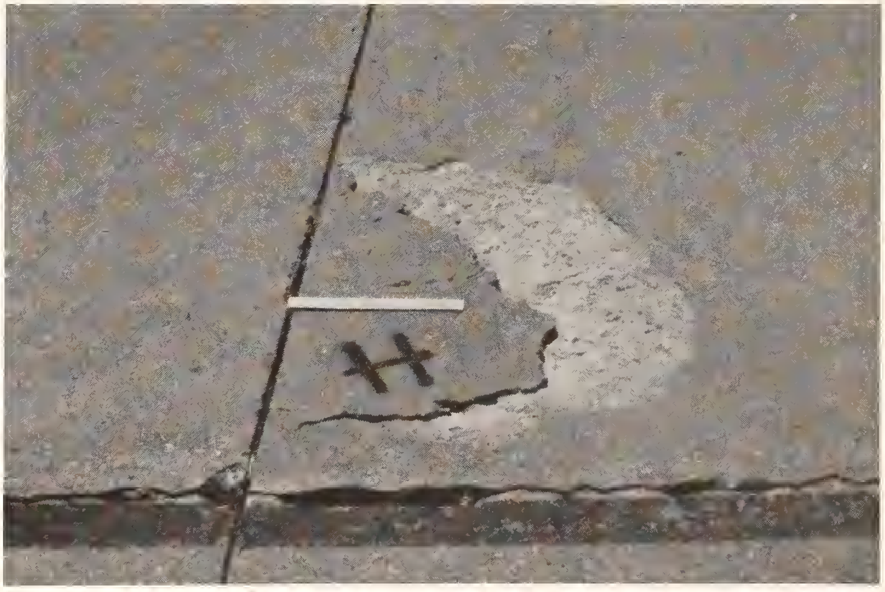

Figure C.45. High Severity Spalling.

Figure C.46. High Severity Spalling.

Figure C.47. High Severity Spalling.

Name of Distress: Spalling (Corner)

Description: Corner spalling is the ravelling or breakdown of the slab within approximately 1 ft. (0.3 m) of the corner. However, corner spalls with both edges less than 3 ins. (8 cm) long will not be recorded. A corner spall differs from a corner break in that the spall usually angles downward at about 45° to intersect the joint, while a break extends vertically through the slab. Corner spalling can be caused by freeze-thaw deterioration, "D" cracking, and other factors.

Severity Level:

L - Spall is not broken into pieces and is in place and not loose.

M - One of the following conditions exists: Spall is broken into pieces; cracks are spalled; some or all pieces are loose or absent but do not present tire damage or safety hazard; or spall is patched.

H - Pieces of the spall are missing to the extent that the hole presents a tire damage or safety hazard.

How to Measure: Corner spalling is measured by counting and recording separately the number of corners spalled at each severity level within the sample unit.

Figure C.48. Medium Severity Corner Spall.

Acceleration of Spalling Corner Due to Moisture:	Free moisture that is retained in the joint has sufficient time to saturate the concrete, particularly near the corners. Many years of freeze/thaw cycles may break down the concrete into a spalled condition in combination with traffic and incompressibles. Corner spalls caused by "D" cracking are directly accelerated by moisture conditions.

Figure C.49. High Severity Corner Spall.

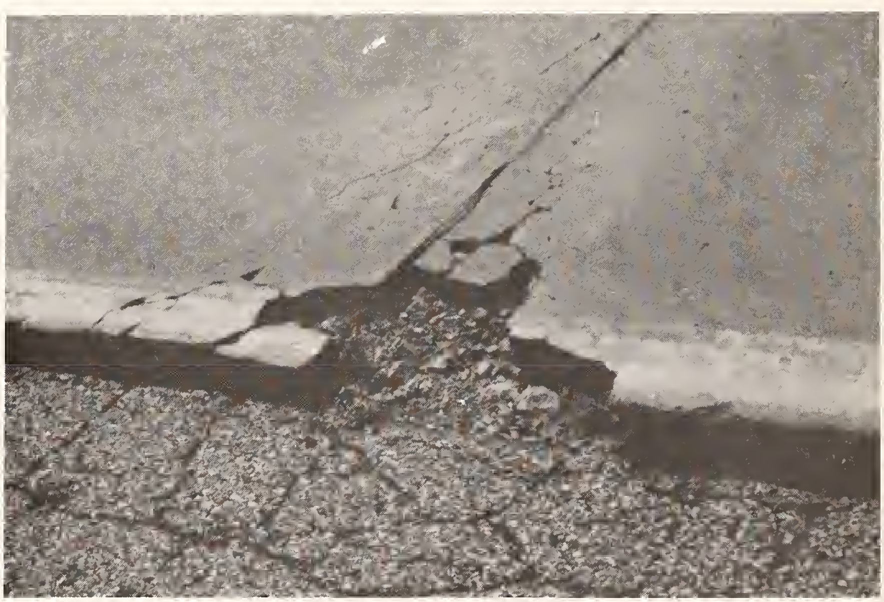

Figure C.50. High Severity Corner Spall.

Name of Distress: Swell

Description: A swell is an upward movement or heave of the slab surface resulting in a sometimes sharp wave. The swell is usually accompanied by slab cracking. It is usually caused by frost heave in the subgrade or by an expansive soil. Swells can often be identified by oil droppings on the surface as well as riding over the pavement in a vehicle.

Severity Levels:

L - Swell causes a distinct bounce of the vehicle which creates no discomfort.

M - Swell causes significant bounce of the vehicle which creates some discomfort.

H - Swell causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage, requiring a reduction in speed for safety.

How to Measure: The number of swells within the uniform section are counted and recorded by severity level. Severity levels are determined by riding in a mid- to full-sized sedan weighing approximately 3000-38000 lb. (13.3-16.9 kN) over the uniform section at the posted speed limit.

Figure C.51. Swell Due to Frost Heave.

Acceleration of Swell Due to Moisture:	Swells can be accelerated by moisture in two ways: (1) frost heaves may occur in freeze climates, and (2) an expansive soil will swell when exposed to moisture. Frost heave is caused by the formation of ice crystals in a frost susceptible subgrade. The ice crystals grow until ice lenses form which produce frost heave. A swelling soil increases in volume when water content in the soil is increased, and decreases its volume when the water content is reduced. A swelling soil has a high plasticity index and can be determined by lab test or experience.

Figure C.52. Swell Due to Expansive Soil.

Name of Distress: Transverse and Diagonal Cracks

Description: Linear cracks are caused by one or a combination of the following: heavy load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high severity cracks are working cracks and are considered major structural distresses. They may sometimes be due to deep seated differential settlement problems. (Note: hairline cracks that are less than 6 feet (1.8 m) long are not rated).

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting, a well sealed crack with no visible faulting or spalling.

M - Working crack with low to medium severity level of spalling, and/or faulting less than 1/2 inch (13 mm). Temporary patching may be present.

H - A crack with width of greater than 1 inch (25 mm); a crack with a high severity level of spalling; or, a crack faulted 1/2 inch (13 mm) or more.

How to Measure: The number and severity level of each crack should be identified and recorded. If the crack does not have the same severity level along the entire length, the crack is rated at the highest severity level present. Cracks in patches are recorded under patch deterioration.

Figure C.53. Low Severity Transverse Crack.

Acceleration of Transverse Cracking Due to Moisture: Transverse and diagonal cracking are generally not initially caused by excess moisture. If, however, excessive moisture accumulates in the slab foundation causing significant loss of support, this could lead to increased slab cracking. However, moisture can accelerate the severity of distress from low to high. Water that accumulates in the cracks could be absorbed into the PCC and possibly increase the potential for spalling along the crack through freeze-thaw action. Water also may infiltrate through a crack and saturate the subbase which increases deflection of the slab under load. Repeated loading of the slab causes the sides of the crack to wear down, spall and widen.

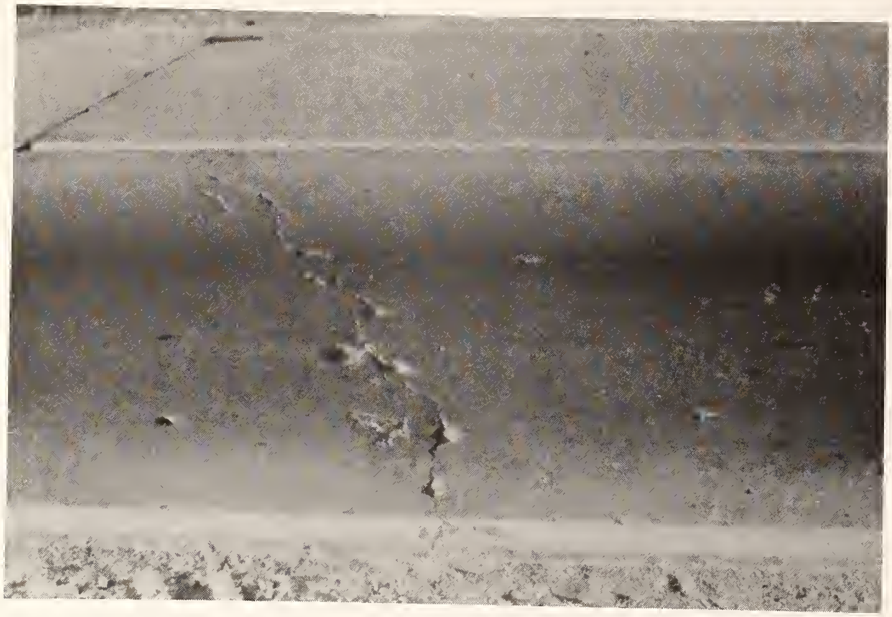

Figure C.54. Medium Severity Diagonal Crack (crack is tignt even though it has some low spalling).

Figure C.55. Medium Severity Transverse Crack.

Figure C.56. High Severity Transverse Crack.

Figure C.57. High Severity Transverse Crack.

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.