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DEVELOPMENT OF A PAVEMENT CONDITION RATING PROCEDURE FOR ROADS,--ETC(U)
JUL 79 M Y SHAHIN, S D KOHN
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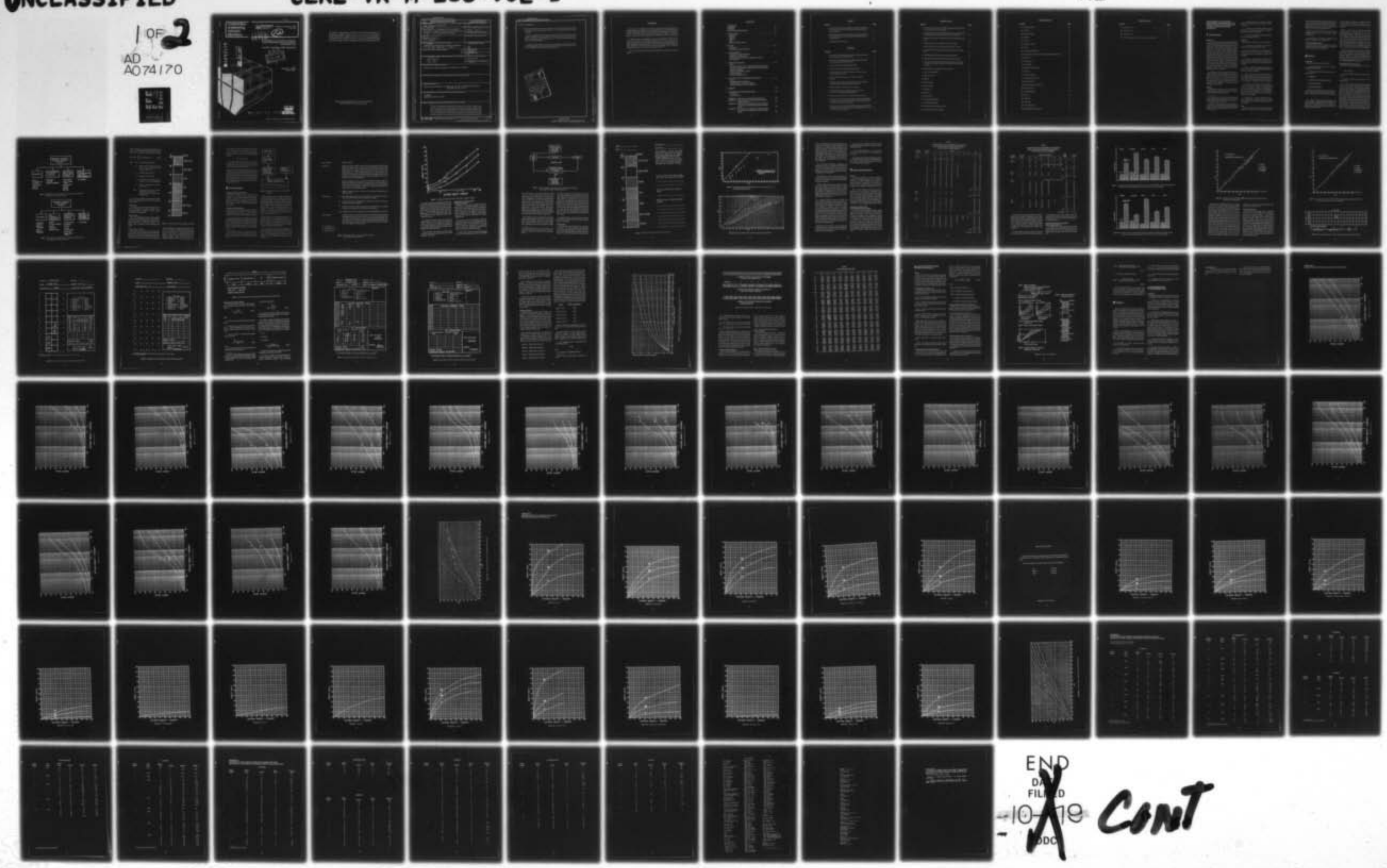

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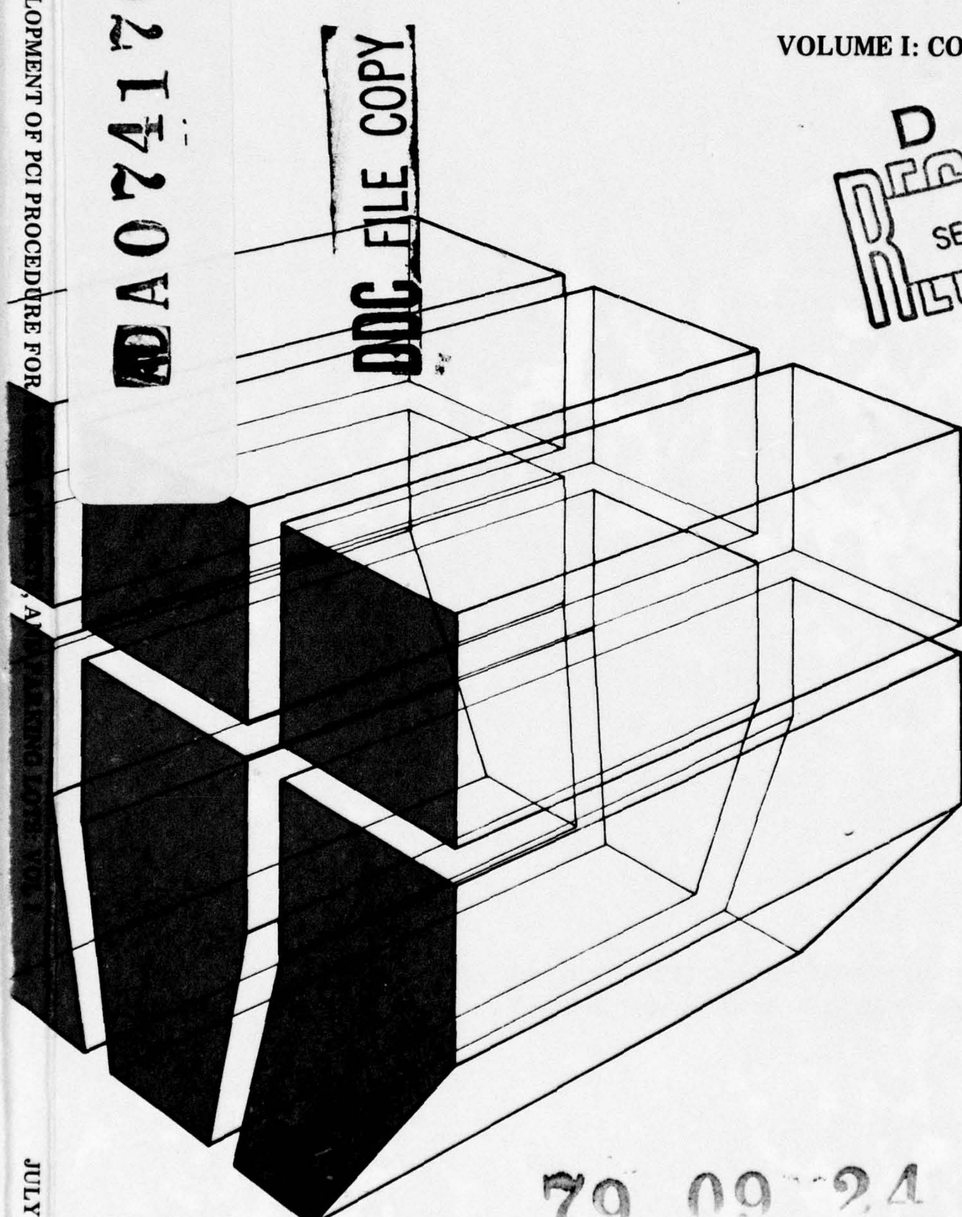
TECHNICAL REPORT M-268
July 1979

LEVEL II

DEVELOPMENT OF A PAVEMENT CONDITION RATING PROCEDURE FOR ROADS, STREETS, AND PARKING LOTS

VOLUME I: CONDITION RATING PROCEDURE



by
Mohamed Y. Shahin
Starr D. Kohn

CERL

DEVELOPMENT OF PCI PROCEDURE FOR ... AND PARKING LOTS VOL I

JULY 1979

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Volume I describes the development and verification of a pavement condition index (PCI) for rating jointed concrete (plain and reinforced) and asphalt surfaced roads, streets, parking lots, and hardstands subjected to pneumatic tired and tracked vehicular traffic. A similar method for air fields has been developed and officially adopted by the U.S. Air Force. The PCI, which measures pavement structural integrity and surface operational condition, is calculated based on measured pavement distress types, severities, → cont

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and densities obtained during pavement inspection. Volume II describes the distress types and severity levels, and the measurement criteria to use when collecting data for the PCI calculation.

Field tests indicate that the PCI closely agrees with the collective judgment (mean rating) of experienced pavement engineers. The PCI was found to be much more consistent than ratings by individual engineers since it is based on measured distress data, and not on subjective judgment.

*Mohamed Y. Shahin, Michael I. Darter, and Starr D. Kohn, *Development of a Pavement Maintenance Management System, Volumes I through V*, AFCEC-TR-76-22 and CEEDO-TR-77-44 (Air Force Civil Engineering Center, November 1976 and October 1977).

FOREWORD

This research was conducted for the Directorate of Military Programs with Operation and Maintenance, Army (O&MA) funds under WESMIS No. RA-9 by the Engineering and Materials (EM) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. Mohamed Shahin was the CERL Principal Investigator. The Technical Monitor was Mr. Leo Price, DAEN-MPO. Dr. G.R. Williamson is Chief of CERL-EM.

Dr. Michael I. Darter is acknowledged for his help in developing the initial PCI procedure. The assistance of the following individuals from the U.S. Army is also acknowleged and appreciated: Mr. Don Engelking, TRADOC; Messrs Tom Brown and Jack Armstrong, DFAE Fort Benning; Messrs B.F. Flaherty and K.G. Baer, DARCOM; Mr. Jack Hinte, TRADOC; Mr. F.R. Bourque, DFAE Fort Eustis; Mr. William Taylor, FORSCOM; and Messrs W. Ament, J. Syers, and B. Garnet, DFAE Fort Hood.

COL J.E. Hays is Commander and Director of CERL and Dr. L.R. Shaffer is Technical Director.

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DEVELOPMENT OF A PAVEMENT CONDITION RATING PROCEDURE FOR ROADS, STREETS, AND PARKING LOTS VOLUME I: CONDITION RATING PROCEDURE

1 INTRODUCTION

Background

The U.S. Army Construction Engineering Research Laboratory (CERL) is developing a computer system to help Facility Engineering staffs manage the maintenance and repair (M&R) of pavements on Army installations.[1] The system, called PAVER, includes (1) input forms for entering relevant pavement information into a computer data base, (2) report outputs for retrieving information, (3) an interactive computer program for performing economic analysis of various M&R alternatives, and (4) a computer program to help determine work requirements based on maintenance policy and inspection results. In addition, it was also necessary to devise a method for determining a pavement condition index (PCI) based on data gathered from pavement inspections. This index would help the pavement engineer evaluate pavement and determine M&R requirements and priorities.

The PCI method was originally devised by CERL for airfield pavements. After successful field testing by several Air Force Major Commands, it was formally adopted by the Air Force.[2] The development of a PCI for roads, streets, and parking lots is based on experience gained during the development of the PCI for airfields, field validation, and information from experienced Army engineers.

Objective

The objective of this study was to develop a PCI to rate the pavement condition of roads, streets, and parking lots that gives the pavement engineer:

1. A standard method for rating the structural integrity and operational surface condition of pavement sections.

2. A method of determining M&R needs and priorities by comparing the condition of different pavement sections on an installation.

3. A method of determining pavement performance from accumulated PCI data.

Approach

This study was conducted in the following steps:

1. A rating scale was selected to be used as a standard for comparing different pavements.

2. Pavements distress types were identified and described. Three levels of severity were defined for each distress type and measurement criteria were established.

3. Each given distress severity and amount was weighted based on its negative effect (deduct value) on pavement structural integrity and operational surface condition.

4. Deduct values were combined (nonlinearly) and subtracted from the maximum possible score (selected in Step 1) to determine the PCI.

5. Steps 2 through 4 required many iterations of field testing, revision, and improvement to insure that the distress definitions accurately described field conditions and that the PCI agreed closely with the collective judgment of experienced pavement engineers.

The concepts and theory for the development of the PCI are presented in Chapter 2, and development details are presented in Chapter 3. Field inspection procedure and a step-by-step method of calculating the PCI are presented in Chapters 4 and 5, respectively. Chapter 6 is a summary; Chapter 7 contains conclusions and recommendations.

A complete list of distress definitions, severity levels, and measurement criteria for asphalt and jointed concrete (plain and reinforced) pavements is presented in Volume II.

Scope

This report describes the development and field validation of the PCI method for asphalt and jointed

[1] M. Y. Shahin and F. M. Rozanski, *Automated Pavement Maintenance and Repair Management System*, Interim Report C-79/ADA042582 [U.S. Army Construction Engineering Research Laboratory (CERL), June 1977].

[2] Mohamed Y. Shahin, Michael I. Darter, and Starr D. Kohn, *Development of a Pavement Maintenance Management System, Volumes I through V*, AFCEC-TR-76-22 and CEEDO-TR-44 (Air Force Civil Engineering Center, November 1976 and October 1977).

concrete (plain and reinforced) surfaced pavements of roads, streets, parking lots, and hardstands subjected to pneumatic tired and tracked vehicular traffic. The PCI presented in this report has not been validated for high-speed roads such as interstate highways.

When using the PCI method in the field, distress identification must be done as described in Volume II of this report.

The information in this report supercedes that included in CERL Reports C-48 and M-232.[3]

Mode of Technology Transfer

The PCI method will be published as an Army Technical Manual and incorporated into the PAVER computer system for Army installations.

2 CONCEPT

Introduction

Several factors affect pavement condition:

1. Structural integrity (how well a pavement holds together under traffic)

2. Structural capacity (the maximum load a pavement can carry)

3. Roughness

4. Skid resistance/hydroplaning potential

5. Rate of deterioration

6. Required maintenance.

To reflect the pavement's condition accurately, a condition index should consider all of these factors. Direct measurement of all these condition indicators requires expensive equipment and highly trained personnel. Indirect measurement, however, can be accomplished by measuring observable distress in the pavement.

Figures 1 and 2 show how observable pavement distresses relate to condition indicators in concrete and asphalt pavements, respectively. In most cases, the observable pavement distress gives a good indication of pavement condition; structural integrity, roughness, and rate of deterioration can be determined in this way. In a few cases, however, this is not so; e.g., skid resistance/hydroplaning potential of concrete-surfaced pavements is not so detectable. Skid resistance, on the other hand, is not a significant problem on the low-speed roads common to Army installations.

The PCI method described in this report is based on information collected by observing visible pavement distress. This is the same kind of information used by pavement engineers to determine the M&R needs of pavement. Therefore, the PCI, along with the distress data needed for its determination, is an excellent tool for establishing M&R needs and priorities.

Mathematical Expression of the PCI

The degree of pavement deterioration is a function of:

1. Types of distress

2. Severity of distress (width of cracks, depth of ruts, etc.)

3. Density of distress (in a percentage of total pavement area).

Each of these distress characteristics has a significant effect on how the overall amount of physical pavement deterioration is determined. Because there are several types of distress, several possible degrees of severity for each type, and a wide range of amount or density for each type, combining the effects of these three characteristics into one index is the major problem in deriving a condition index. The PCI method described here is based on weighted (deduct) values that are functions of the types, severities, and densities of visible distresses. The deduct values for distresses in a given pavement are added and then adjusted according to the number of deduct values and their sum. The adjusted sum is subtracted from the maximum possible PCI, i.e., the PCI of a pavement with no visible distress.

[3] M. Y. Shahin, M. I. Darter, and F. M. Rozanski, *Pavement Inspection Manual*, Technical Information Pamphlet C-48/ ADA017329 (CERL, September 1975); M. Y. Shahin, M. I. Darter, and S. D. Kohn, *Development of a Pavement Condition Index for Roads and Streets*, Interim Report M-232/ ADA057148 (CERL, May 1978).

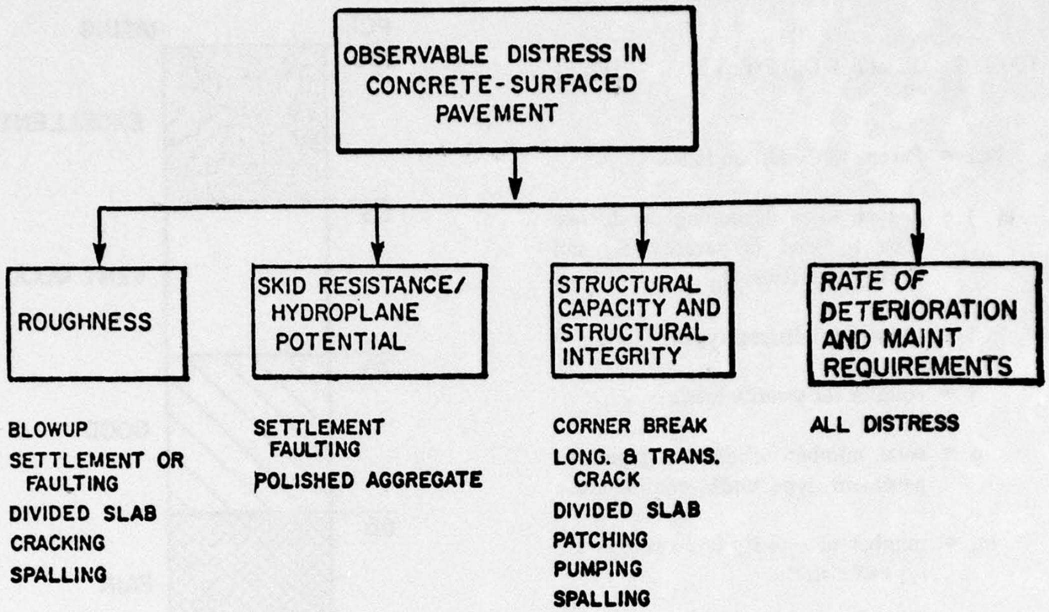


Figure 1. Relationship of observable distress in concrete-surfaced pavements to various pavement condition indicators.

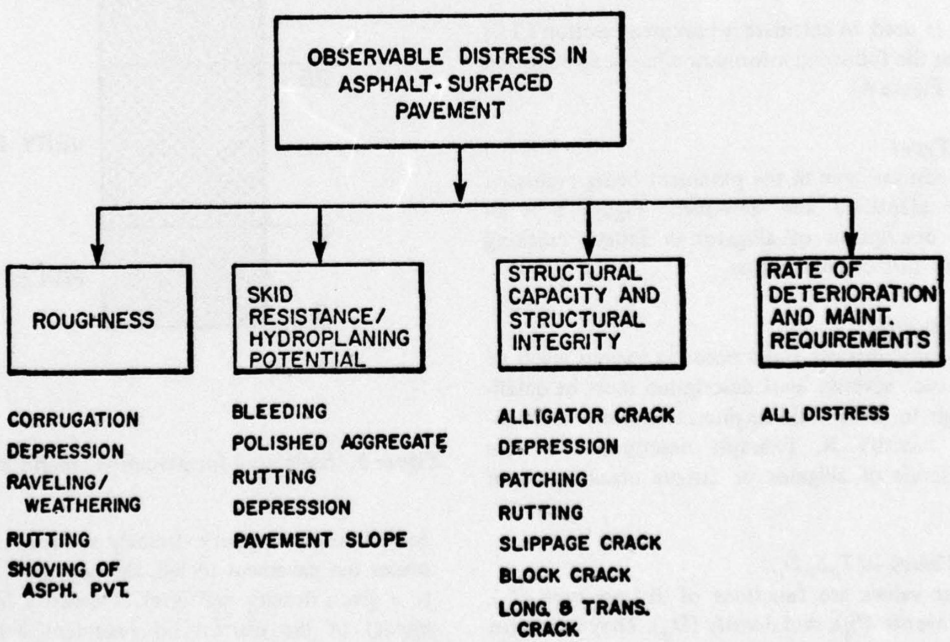


Figure 2. Relationship of observable distress in asphalt-surfaced pavements to various pavement condition indicators.

The scale selected for determining the PCI shown in Figure 3 uses 100 as the maximum possible PCI. This model can be expressed mathematically as follows:

$$PCI = 100 - \sum_{i=1}^{p} \sum_{j=1}^{m_i} a(T_i, S_j D_{ij}) F(t,q) \qquad \text{[Eq 1]}$$

where PCI = Pavement Condition Index

a( ) = deduct value depending on distress type t_i, level of severity S_j, and density of distress D_{ij}

i = counter for distress types

j = counter for severity levels

p = total number of distress types for pavement type under consideration

m_i = number of severity levels for the i^{th} type of distress

F(t,q) = an adjustment function for multiple distresses that vary with total summed deduct value (t) and number of deducts (q).

Eq 1 is used to calculate a pavement section's PCI only after the following information has been collected (also see Figure 4).

Distress Types

Each distress type in the pavement being evaluated must be identified and described. Figure 5 is an example description of alligator or fatigue cracking for asphalt-surfaced pavements.

Distress Severity

Since most distress types occur at various levels of severity, each severity level description must be detailed enough to allow field engineers to easily and consistently identify it. Example descriptions of the severity levels of alligator or fatigue cracking are in Figure 5.

Deduct Values–$a(T_i,S_j,D_{ij})$

Deduct values are functions of distress type (T_i), level of severity (S_j), and density (D_{ij}). They must also be based on some selected rating scale, such as a scale ranging from 0 to 100, with 0 deduct indicating the distress has no impact on pavement condition and 100 deduct indicating an extremely serious distress which causes the pavement to fail. Deduct values are assigned to a given density and level of severity based on the impact of the distress on pavement condition (see Chapter 3). Figure 6 gives example deduct curves for alligator cracking–a major structural distress of asphalt-surfaced pavement–for three levels of severity

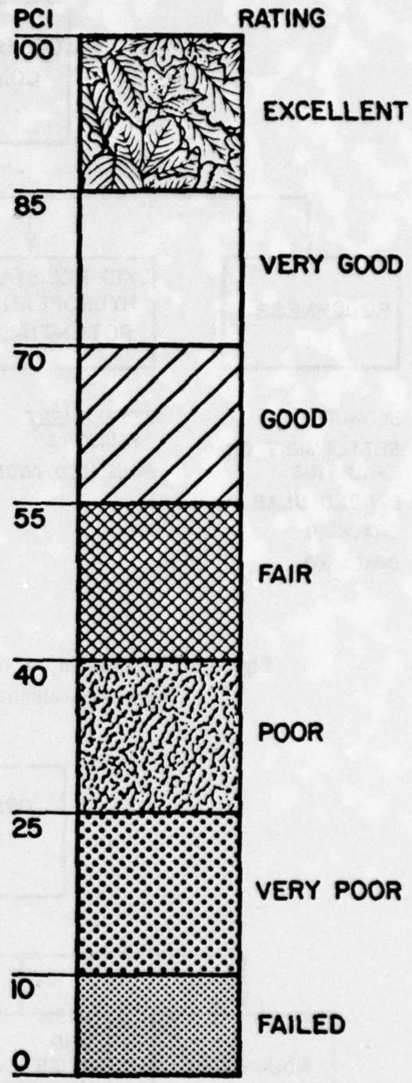


Figure 3. Scale used for pavement condition index (PCI).

(low, medium, and high) and densities ranging from 0.1 to 100 percent of total pavement area. A pavement section having 1 percent of high-severity alligator cracking would have a deduct value of 30, and the PCI would be:

$$PCI = 100 - 30 = 70$$

Curves like those shown in Figure 6 must be derived for each distress type. These curves are based on the assumption that only one distress type at a given level of severity exists in the pavement section.

Adjustment Function for Multiple Distress Types--(F)

Deduct values cannot be added linearly, because as additional distress types and/or severity levels occur in a given pavement section, the resulting impacts of those distresses become smaller. However, an adjustment function allows the curves described above to be used to evaluate pavement sections with more than one distress (see Chapter 3).

3 PCI DEVELOPMENT

Development of Distress Definitions

The distress definitions used in this report were developed over several years and required several iterations of writing, field evaluations, and revision. The final definitions are the result of extensive municipal, county, and Army installation field surveys by CERL, major command, and local installation pavement engineers.

Development of Deduct Values

Deduct values are numbers that represent the effects that distresses have on a pavement's structural integrity and surface operational condition. A deduct value is a function of the type, severity, and density of a distress.

Initial deduct values were developed by evaluating hypothetical sample units of pavement. Sample unit sizes of 2500 sq ft (225 m²) for asphalt and 20 slabs less than 30 ft (9 m) each for jointed concrete were assumed. Each hypothetical sample unit had one distress at a particular severity level at one of five density levels.*

*Concrete distress densities were computed by dividing the number of distressed slabs by the total number of slabs in the sample unit. The densities of most asphalt distresses were computed by dividing the surface area of distress by the sample unit area.

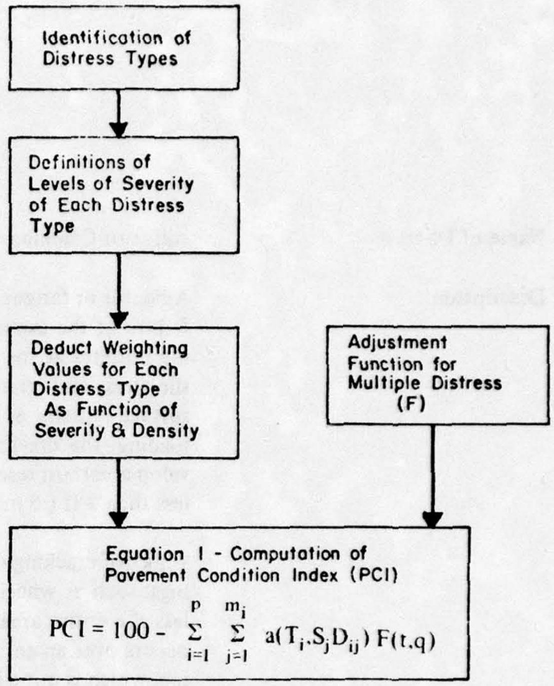


Figure 4. Information needed to determine the PCI using Eq 1.

CERL investigators then separately evaluated each sample unit and described the condition of the sample units with numerical ratings called Pavement Condition Ratings (PCRs) according to the PCI scale (Figure 3). The PCR ratings were averaged for each sample unit and subtracted from 100 to produce the tentative deduct values for each distress/severity/density combination. For example, for medium-severity block cracking at 30 percent density, the average of the sample unit ratings was 73 (very good). The deduct value was, therefore, 100 - 73 = 27.

Deduct values for each distress severity level were plotted against the corresponding densities, and smooth curves were drawn through the points to produce the deduct curves. Figure 6 shows an example of the development of the deduct curves for alligator cracking of asphalt-surfaced pavements.

The initial deduct value curves were field tested on pavements at local city and county roads and at two Army installations as shown in Figure 7. Pavement sections with one distress type and severity level were rated by a panel of engineers according to the scale in Figure 8.

Name of Distress:	Alligator Cracking
Description:	Alligator or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface 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 a series of parallel longitudinal 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 less than 2 ft (.6 m) on the longest side. Alligator cracking occurs only in areas that are subjected to repeated traffic loadings, such as wheel paths. Therefore, it would not occur over an entire area unless the entire area was subjected to traffic loading. Pattern-type cracking which occurs over an entire area that is not subjected to loading is rated as block cracking, which is not a load-associated distress. Alligator cracking is considered a major structural distress and is usually accompanied by rutting.
Severity Levels:	L* – Fine, longitudinal hairline cracks running parallel to each other with none or only a few interconnecting cracks. The cracks are not spalled. M – Further development of light alligator cracking into a pattern or network of cracks that may be lightly spalled. H – Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges; some of the pieces rock under traffic. Note: Spalling of the cracks is a breakdown of the material along the sides of the crack.
How to Measure:	Alligator cracking is measured in square feet of surface area. The major difficulty in measuring this type of distress is that two or three levels of severity often exist within one distressed area. If these portions can be distinguished easily from each other, they should be measured and recorded separately. However, if the different levels of severity cannot be divided easily, the entire area should be rated at the highest severity level present.

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

Figure 5. Example description of a distress, definition of severity levels, and how to measure criteria.

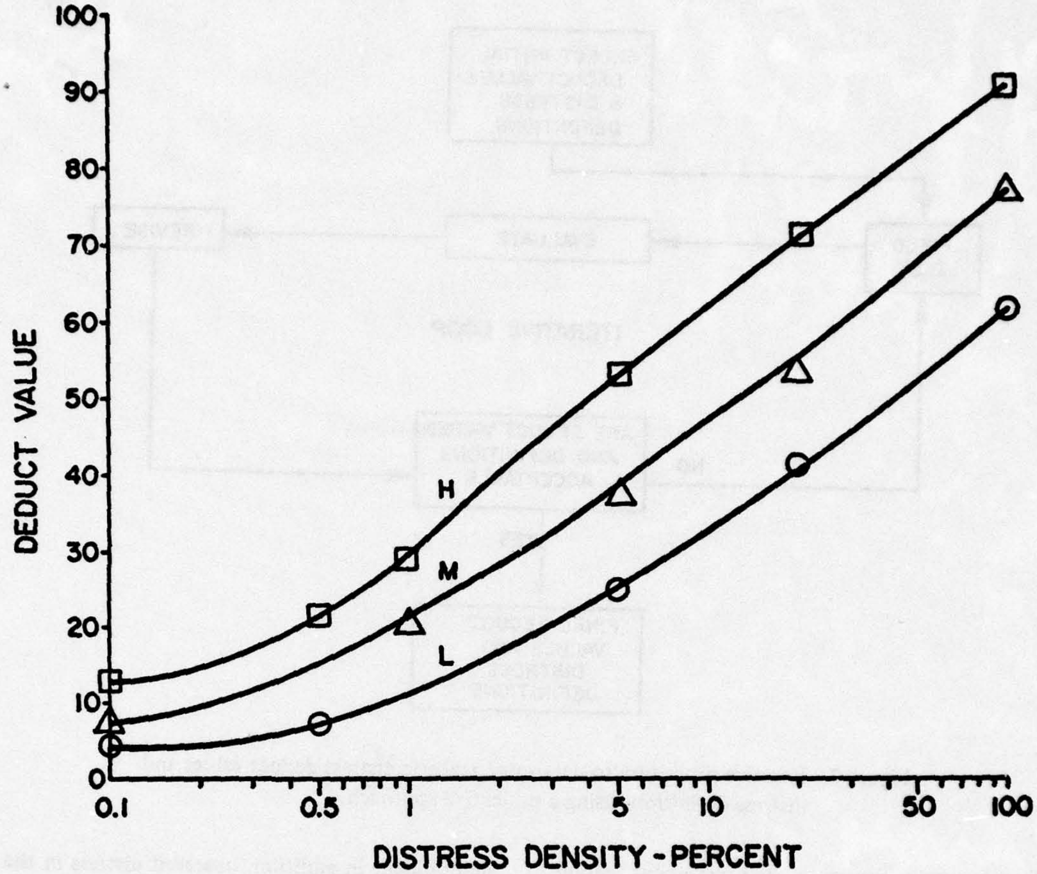


Figure 6. Example development of deduct value curves for alligator cracking.

The mean rating of the group ($\overline{PCR}$) was subtracted from 100 to give the deduct value. Each point was then compared to the initial deduct value curves, and when necessary, the curves were adjusted to reflect the new field ratings. This procedure was repeated as shown in Figure 7 until acceptable deduct value curves were established. Thus, the individual deduct value curves were validated to reflect engineering ratings under actual field conditions.

The individual deduct curves were derived for asphalt-surfaced and jointed (plain and reinforced) concrete pavements; joint spacing was less than 30 ft (9 m). Slabs longer than 30 ft (9 m) are divided into approximately equal-length slabs with imaginary joints assumed to be in perfect condition.

The final deduct value curves are shown in Appendices A and B for asphalt- and jointed concrete-surfaced pavements, respectively.

Development of Correction Curves (Adjustment Function)

Correction curves are used to adjust the sum of deduct values for pavements having more than one combination of distress type and severity. The adjustment is a function of the magnitude of the sum of deduct values and of the number of distress type/severity combinations. The higher the sum of deduct values and the number of combinations, the higher the adjustment.

The correction curves were developed at CERL by having each member of the investigating team rate hypothetical sample units containing more than one distress type/severity combination. For each sample unit, the ratings were averaged and subtracted from 100 to produce the corrected deduct values.

Corrected deduct values were then plotted against the sum of the individual deduct values for the sample

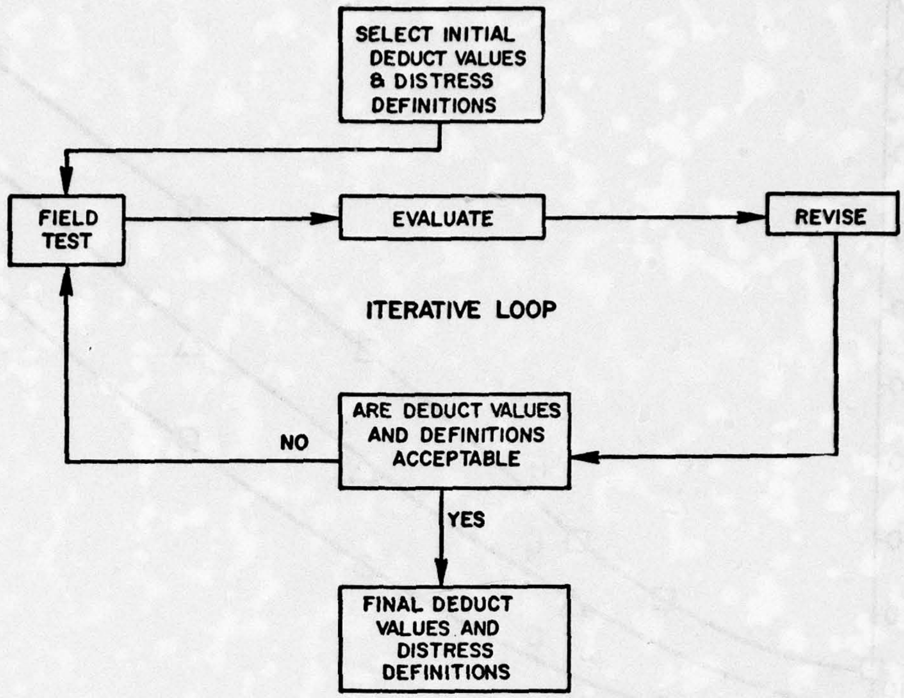


Figure 7. Iterative procedure to determine realistic distress deduct values and distress definitions using a subjective approach.

unit. For example, for an asphalt pavement sample unit with a sum of deduct values of 50 and a three distress type/severity combination, the average rating of the investigating team was 68. The corrected deduct value was, therefore, 100 - 68 = 32. This was plotted against the sum of the individual deduct values, which was 50 in this example. Other sample units with three distresses (each having an individual deduct value greater than 5) were plotted on the same graph.* Figure 9 is a dot diagram for q = 3 (q is the number of individual deduct values greater than 5). This analysis was repeated for different values of q. The results show that curves shift as the q increases (see Figure 10).

The correction curves were field tested and revised where necessary. During the field tests, many asphalt and concrete pavements with two or more distress types or severities were rated by a group of experienced engineers and the group mean rating or $\overline{PCR}$ determined. In addition, observed distress in the pavement was measured and the individual deduct values determined from the deduct curves. The total deduct value (TDV) was computed for each section by summing all the individual deduct values. The correct deduct value was obtained by subtracting the mean $\overline{PCR}$ from 100. The correct deduct values were then plotted against TDV and compared with the initial correction curves. Where the field data differed from the curves, the curves were adjusted to more closely reflect the field data. This procedure was repeated as shown in Figure 7 until acceptable correction curves were derived.

The final correction curves are shown in Figures A20 and B20 for asphalt- and jointed concrete-surfaced pavement, respectively.

Field Validation

Field tests were conducted at local city and county roads, and at two Army installations (Fort Benning, GA, and Rock Island Arsenal, IL) to verify, revise, and improve the distress definitions and deduct curves. To validate the entire PCI procedure, it was decided to

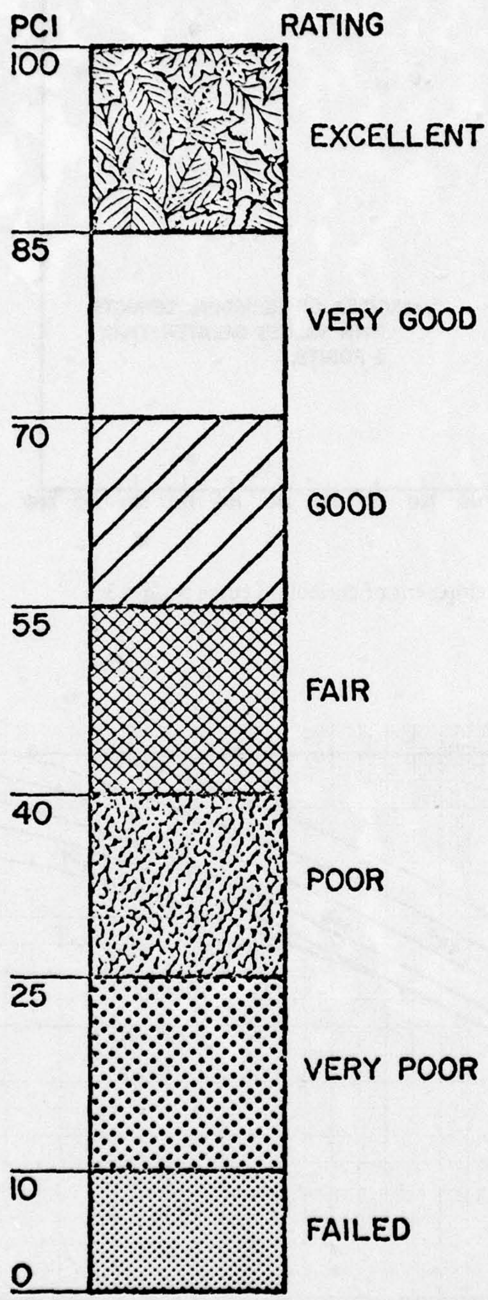
*Previous experience had shown that since distresses with deduct values of less than 5 had little effect on pavement condition, counting them would distort the adjustment function.

BASE: ____________________

SECTION NO: ____________________

DATE: ____________________

INSPECTOR: ____________________



INSTRUCTIONS: Please rate pavement with regard to its overall structural integrity and operational condition (excellent rating indicates none or very minor distress present and very poor rating indicates severe distress and imminent failure).

On the rating scale shown here, how would you rate this section?

____

____

Give an approximate numerical score.

____

Major factors influencing your rating:

____

____

____

____

____

____

____

Figure 8. Subjective rating form used by pavement engineer.

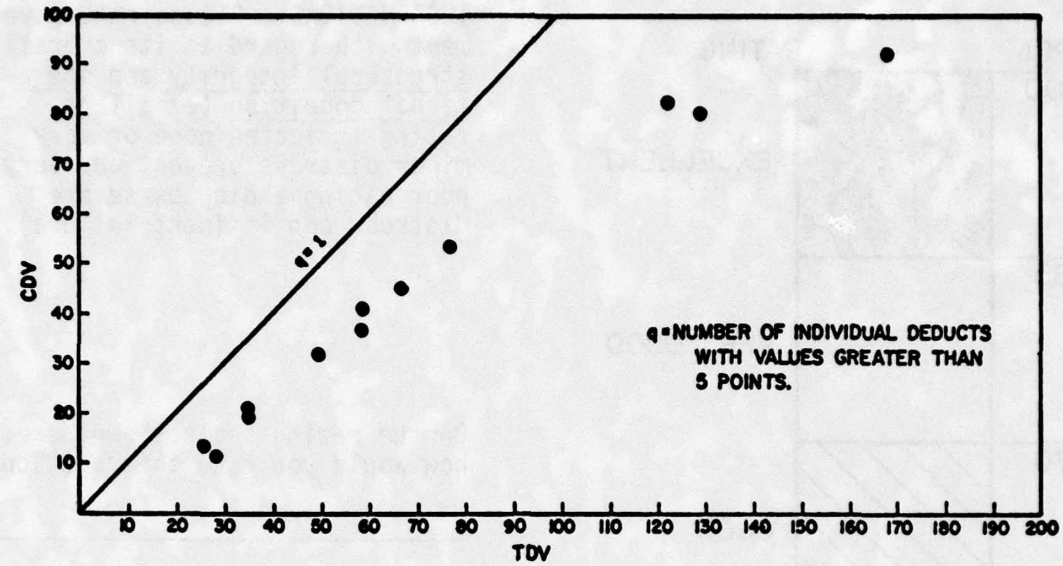


Figure 9. Example dot diagram showing development of correction curve for q = 3 for asphalt-surfaced pavements.

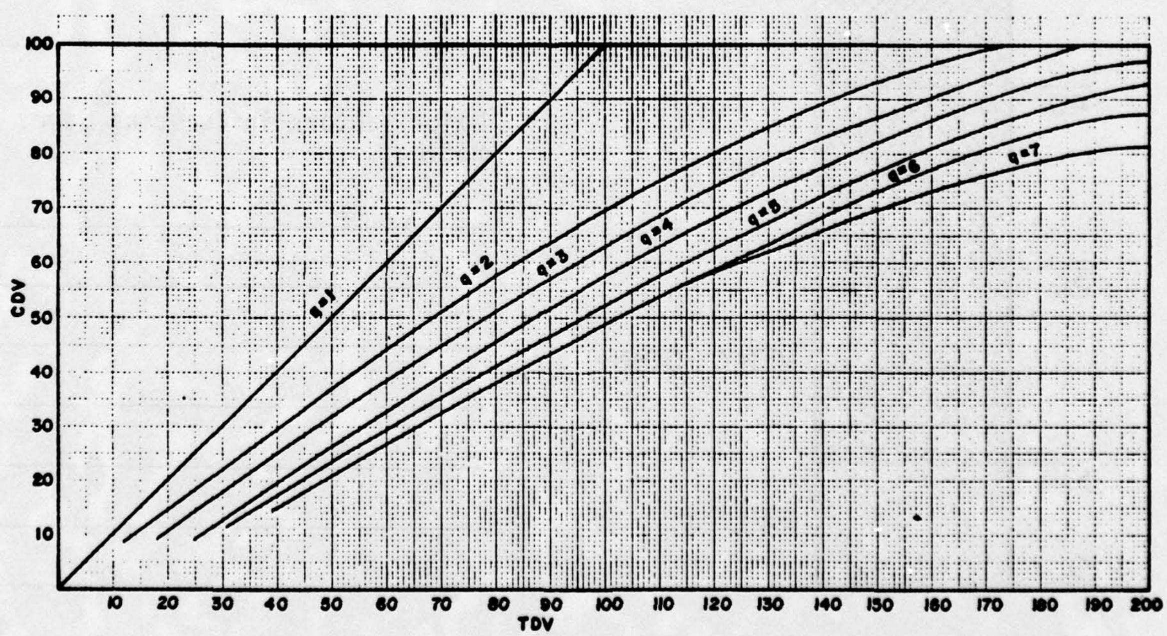


Figure 10. Corrected deduct value curves for asphalt-surfaced pavements.

survey two additional sites so that the procedure could be tested with data other than that from which it was developed. Two additional Army installations were visited (Fort Eustis, VA and Fort Hood, TX) and many asphalt- and jointed concrete-surfaced pavements were surveyed. During the visits it was found that the mean rating $\overline{\text{PCR}}$ by the engineers agreed closely with the computed PCI. A few deficiencies in distress definitions and deduct curves were identified and corrected, but the changes were not significant enough to warrant further field visits.

The final distress definitions, photographs, and measurement criteria are presented in Volume II of this report; when determining the PCI for a pavement section, it is imperative that the inspector follow the definitions and criteria provided in Volume II to obtain a meaningful and consistent PCI.

The final deduct curves for each distress and the correction deduct curves are presented in Appendices A and B for asphalt- and jointed concrete-surfaced pavements, respectively.

Tables 1 and 2 summarize the individual ratings, mean rating ($\overline{\text{PCR}}$), and computed PCI for asphalt and concrete pavement sections surveyed at Army installations. The distress data used to compute the PCI are presented in Appendices C and D. As noted in Tables 1 and 2, absolute difference between the mean $\overline{\text{PCR}}$ and mean PCI for all pavement sections is 1.1 for asphalt and 0.7 for concrete.

The absolute difference between the $\overline{\text{PCR}}$ and PCI for individual sections can be compared to the range between the individuals who assigned the ratings. The results of this comparison are shown for each Army installation in Figures 11 and 12 for asphalt and concrete pavements, respectively. For example, at Fort Eustis, the average absolute difference between the $\overline{\text{PCR}}$ and PCI for jointed concrete pavement is 2.7 points for 12 sections. However, the average range between the highest and lowest raters (four raters were usually involved) for each of these 12 sections is 18.9 points, illustrating the high variability in opinion from one rater to another, even though all four raters were experienced pavement engineers.

Figures 13 and 14 show the correlation between PCI and $\overline{\text{PCR}}$ for all sections surveyed for asphalt and concrete pavements, respectively. Analysis of the data resulted in the following statistics:

1. The correlation coefficient between the PCI and $\overline{\text{PCR}}$ is 0.98 for both asphalt- and jointed concrete-surfaced pavements.

2. The standard deviation of the differences between the PCI and $\overline{\text{PCR}}$ is 2.5 for asphalt and 2.1 for concrete.

These statistics indicate that the final PCI procedure is a reliable pavement condition rating technique, in that it closely reproduces the mean rating of a group of experienced pavement engineers.

4 INSPECTION PROCEDURE

General

To calculate the PCI for a section of pavement accurately, a thorough inspection must be made to determine the types, quantities, and severities of distress existing in the pavement. The pavement inspection must be carefully planned and performed according to the guidelines presented in this report.

There are two methods of performing pavement inspections; for both methods, the pavement section must be divided into subsections called sample units. The first method requires inspection of all sample units in the section (inspection of the entire section); the second method requires inspection of only a portion of the sample units in the section (inspection by sampling). For both methods, all the sample units in the section must be assigned sample unit numbers.

Inspection of Sample Units for Jointed Concrete Pavement Sections

For jointed concrete pavement sections, a sample unit should consist of approximately 20 slabs. If the slabs are longer than 30 ft (9 m), they should be divided with imaginary joints (assumed in perfect condition) into slabs less than 30 ft (9 m) each. Figure 15 shows jointed concrete pavement section divided into sample units. Each sample unit is individually inspected by walking over each slab of the unit (or over the shoulder or sidewalk if traffic control is not provided) and recording distress(es) on the Sample Unit Inspection Sheet (Figure 16). (Figure 17 is a blank form of Figure 16 that can be used for reproduction.)

Table 1

Individual Ratings, Mean Rating ($\overline{PCR}$), and Computed PCI Based on Distress Data for Asphalt-Surfaced Pavement Sections Surveyed at Army Installations

Pavement Location	Pavement Section	Raters C_1	C_2	C_3	C_4	C_5	C_6	C_7	$\overline{PCR}$	PCI
Fort Benning	1	79	85	60	65	. . .			72	68
	2	71	68	56	55	. . .			63	63
	3	Demonstration section – data not used								
	4	79	75	87	75	. . .			79	80
	5	43	47	52	45	. . .			47	50
	6	37	38	46	39	. . .			40	33
	7	85	86	92	80	83			85	84
	8	85	88	92	85	83			87	86
	9	82	83	89	80	81			83	78
	10	76	80	88	78	81			81	80
	11	82	83	89	80	78			82	74
	12	91	90	94	85	96			91	86
	13	. . .	85	92	88	92			89	85
	14	88	88	92	88	92			90	90
	15	98	93	94	90	92			94	98
	16	93	75	68	80	. . .			79	75
	17	76	78	80	75	. . .			77	72
	18	86	72	. . .	80	. . .			79	75
	19	74	67	69	75	. . .			71	78
	20	67	69	69	68	. . .			68	62
	21	22	37	38	38	. . .			34	26
	22	17	20	28	30	. . .			24	23
	23	17	20	23	20	. . .			20	19
								Mean	69.8	67.5
Rock Island	1	40	50	30	50				43	37
	2	68	55	53	65				61	57
								Mean	52	47
Fort Eustis	1	55	55	55	53				55	57
	2	73	. . .	70	80				74	81
	3	95	85	85	88				88	89
	4	71	75	70	68				71	78
	5	49	65	55	65				59	62
	6	47	57	51	55				52	58
	7	8	8	8	8				8	7
	8	20	11	7	38				19	18
	9	60	. . . .	56	. . .				58	62
	10	40	70	. . .	84				65	60
								Mean	54.9	57.2
Fort Hood	1	93	95	75	95	98	90	98	92	90
	2	85	84	75	80	80	84	90	83	77
	3	82	80	70	75	78	70		76	76
	4	51	40	35	30	40			39	45
	5	20	25	22	12	10			18	24
	6	87	88	85	80	92			86	83
	7	84	62	58	75				70	71
	8	77	71	80	72				75	69
	9	68	56	75	58				64	57
								Mean	67	65.8
								Overall Mean	64.9	63.8

Table 2

Individual Ratings, Mean Rating ($\overline{PCR}$), and Computed PCI Based on Distress Data for Jointed Concrete Pavement Sections Surveyed at Army Installations

Pavement Location	Pavement Section	$\overline{PCR}$ of Individual Raters C_1	C_2	C_3	C_4	C_5	C_6	Mean Rating $\overline{PCR}$	Computed PCI
Fort Benning	1	75	80	80	75	68	60	73	69
	2	43	50	...	50	53	50	49	45
	3	70	73	84	80	85	75	78	75
	4	Demonstration section – data not used							
	5	85	80	90	80	85	90	85	88
	6	27	33	52	35	55		40	34
							Mean	65	62.2
Rock Island	1	53	42	...	...			47	49
	2	60	60	65	60			61	67
	3	60	65	65	70			65	71
							Mean	57.7	62.3
Fort Eustis	1	Demonstration section – data not used							
	2	12	2	5	22			18	16
	3	70	75	90	41			62	63
	4	50	65	60	80			64	67
	5	25	35	35	27			30	24
	6	43	56	56	55			52	50
	7	85	90	90	83			87	84
	8	40	58	55	70			56	58
	9	78	78	89	92			84	84
	10	78	81	93	90			86	83
	11	...	73	83	68			75	81
	12	73	72	68	...			71	73
							Mean	62.3	62.1
Fort Hood	1	73	75	92	90	70		80	73
	2	82	87	75	80	80		81	82
	3	55	56	50	45			52	55
	4	85	80	90	91			86	80
	5	90	92	90	95			92	87
	6	94	95	95	98			95	95
							Mean	81	78.7
							Overall Mean	66.8	66.1

A sketch of the sample unit should be made on the inspection sheet, using the preprinted dots as joint intersections. The distress codes and severities of each distress except joint seal damage should be recorded on the sketch in the square that corresponds to the slab in which the distress was found. For example, in Figure 16, the notation "8M" indicates that medium-severity linear cracking was found in the first slab.

The total number of slabs for each severity level of each distress type in the sketch should be summarized on the right-hand side of the inspection sheet. The overall rating for joint seal damage should also be recorded by entering L, M, or H on the line preprinted with distress code "6."

Inspection of Sample Units for Asphalt-Surfaced Pavement Sections

For asphalt-surfaced pavements (including asphalt overlay over concrete), sample units should be approximately 2500 sq ft (255 m²). Figure 18 shows an asphalt-surfaced pavement section divided into sample units.

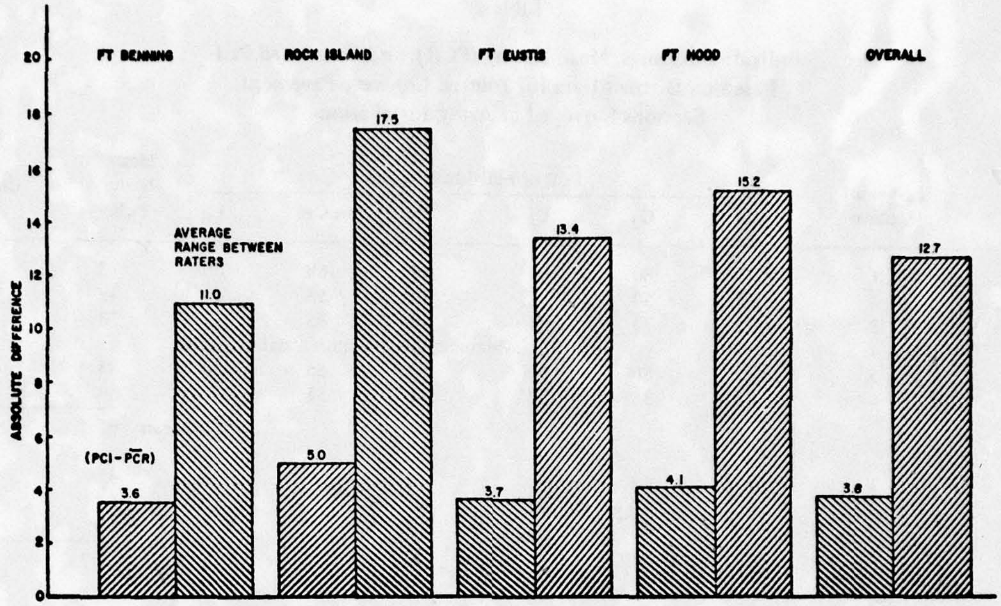


Figure 11. Comparison of the average absolute difference between PCI and $\overline{PCR}$ of individual asphalt-surfaced sections and the average range between rater's scores for each Army installation.

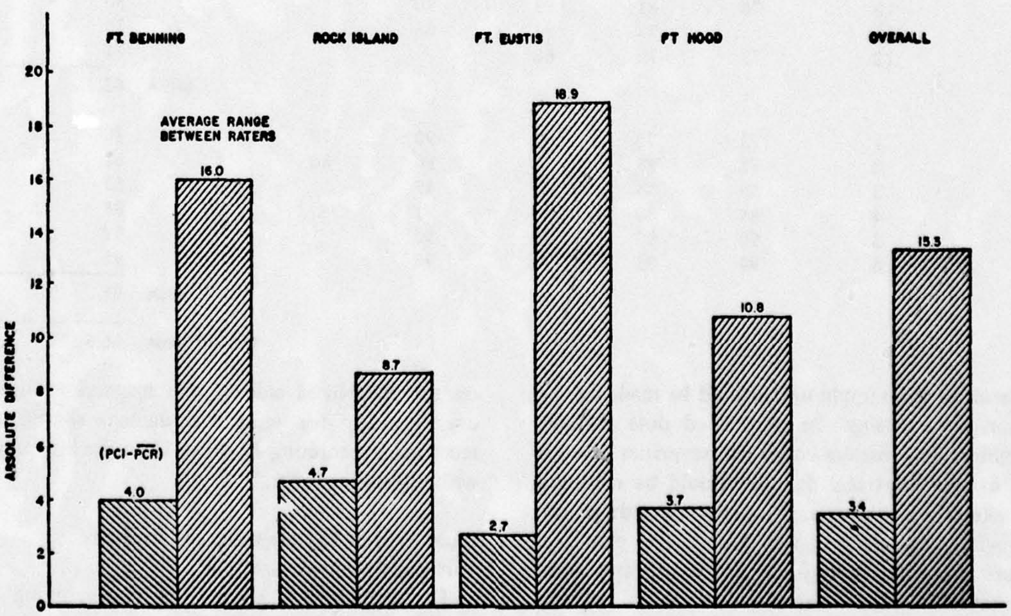


Figure 12. Comparison of the average absolute difference between PCI and PCR of individual concrete sections and the average range between the rater's scores for each Army installation.

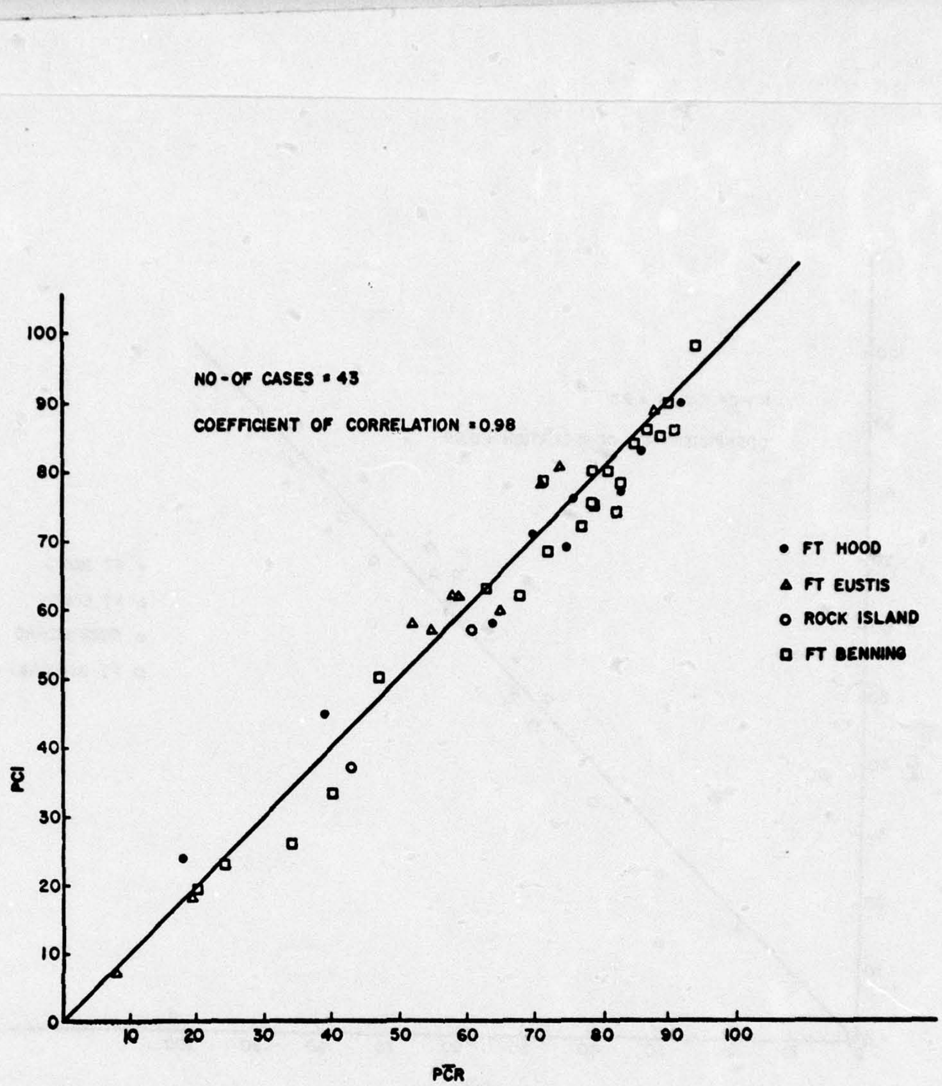


Figure 13. Comparison between the PCI and $\overline{PCR}$ for asphalt-surfaced pavement sections surveyed at Army installations.

Each sample is individually inspected by walking over the unit (or over the shoulder or sidewalk if traffic control is not provided), measuring each distress type and severity, and recording the data on the Sample Unit Inspection Sheet (Figure 19). (Figure 20 is a blank of Figure 19 that can be used for reproduction purposes). A separate column is used to record the quantities and severities of each distress type found in the sample unit. In the example shown in Figure 19, the first distress encountered was 10 ft (3 m) of low-severity level longitudinal cracking, so the first column was headed with distress code 10, and "10L" was entered in that column. The next distress encountered was a 16 sq ft (1.4 m^2) area of medium-severity level alligator cracking, so the second column was headed with distress code 1, and "16M" was entered in that column. The next distress was 5 ft (1.5 m) of low-severity level transverse cracking, so "5L" was entered in the column headed by distress code 8. After the inspection is completed, quantities should be totaled at the bottom of each column.

Inspection by Sampling

Inspection of every sample unit in a pavement section may require considerable effort, especially if the section is very large. Because of the time and effort involved, frequent surveys of an entire section subjected to heavy traffic volume may be beyond available manpower, funds, and time. Therefore, a sampling plan was developed to allow adequate determination of the PCI and M&R needs by inspecting only a portion of the sample units in a pavement section. This statistical sampling plan will reduce inspection time considerably without significant loss of accuracy. However, use of the sampling plan is optional. In fact, inspection of the entire section may be necessary if exact quantities of distress must be known for contractual maintenance work.

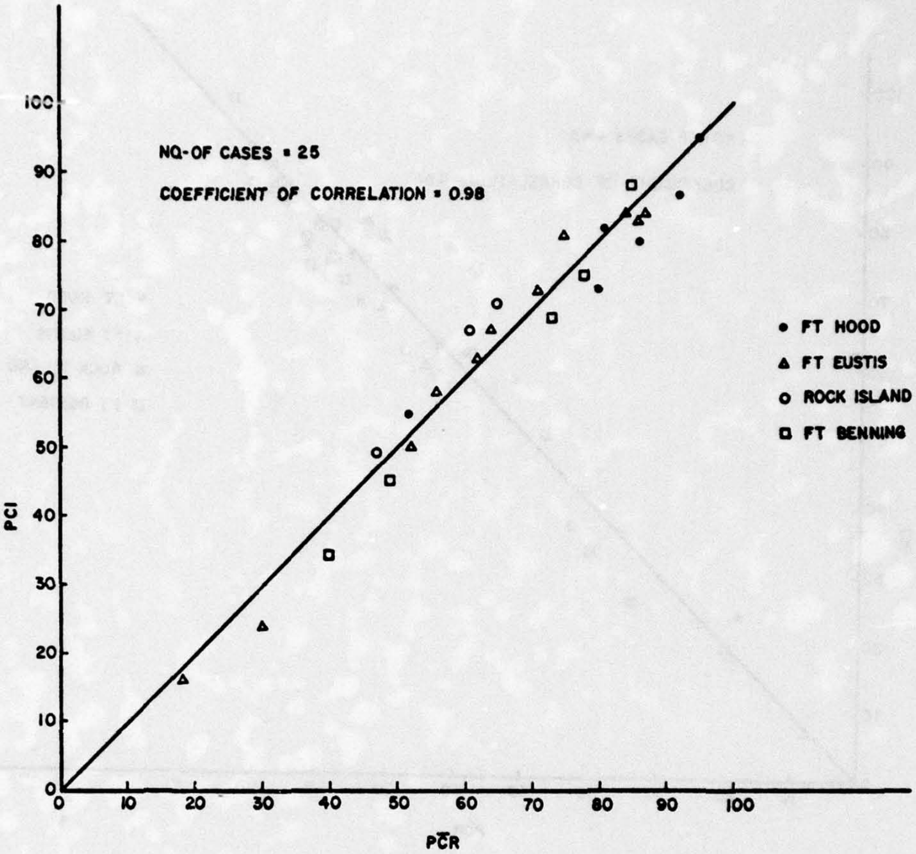


Figure 14. Comparison between the PCI and PCR for jointed concrete (plain and reinforced) pavement sections surveyed at Army installations.

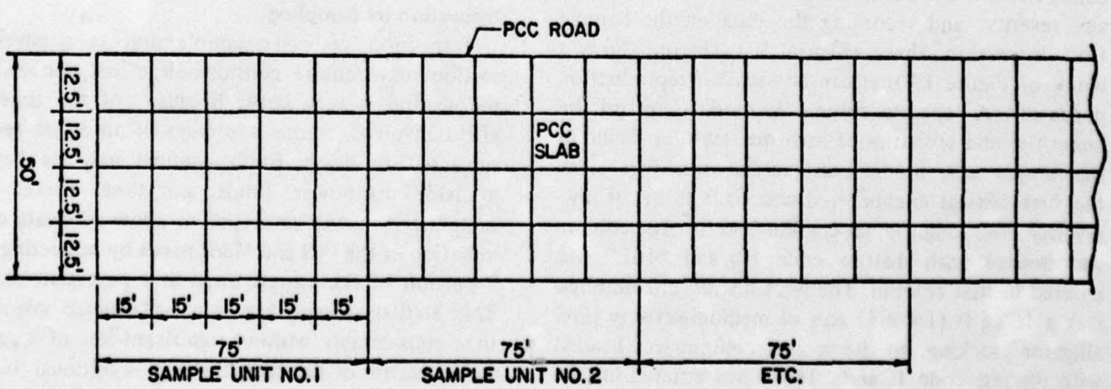
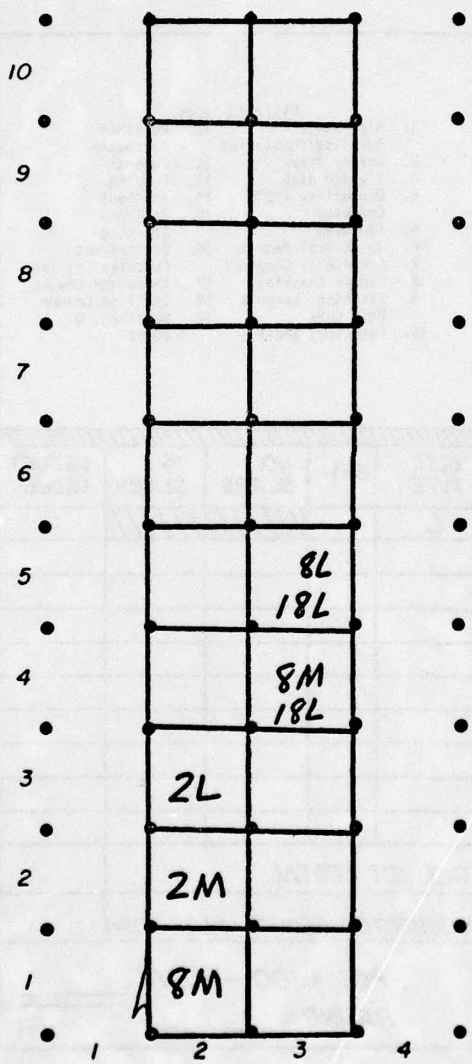


Figure 15. Illustration of division of a pavement section into sample units of 20 slabs.

FACILITY FIRST ST SECTION 1

DATE 7 DEC 78 SAMPLE UNIT 1

SURVEYED BY MVS SLAB SIZE 12 X 20 ft



Distress Types

1. Blow-Up, Buckling/Shattering
2. Corner Break
3. Divided Slab
4. Durability ("D") Cracking
5. Faulting
*6. Joint Seal Damage
7. Lane/Shldr Drop Off
8. Linear Cracking
9. Patching, Large & Util Cuts
10. Patching, Small
11. Polished Aggregate
12. Popouts
13. Pumping
14. Punchout
15. Railroad Crossing
16. Scaling/Map Cracking/Crazing
17. Shrinkage Cracks
18. Spalling, Corner
19. Spalling, U Joint

DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
6	M			4
2	L	1	5	4
2	M	1	5	8
8	L	1	5	3
8	M	2	10	9
18	L	2	10	1
DEDUCT TOTAL				29
CORRECTED DEDUCT VALUE (CDV)				23

PCI = 100 − CDV = 77

RATING = V. GOOD

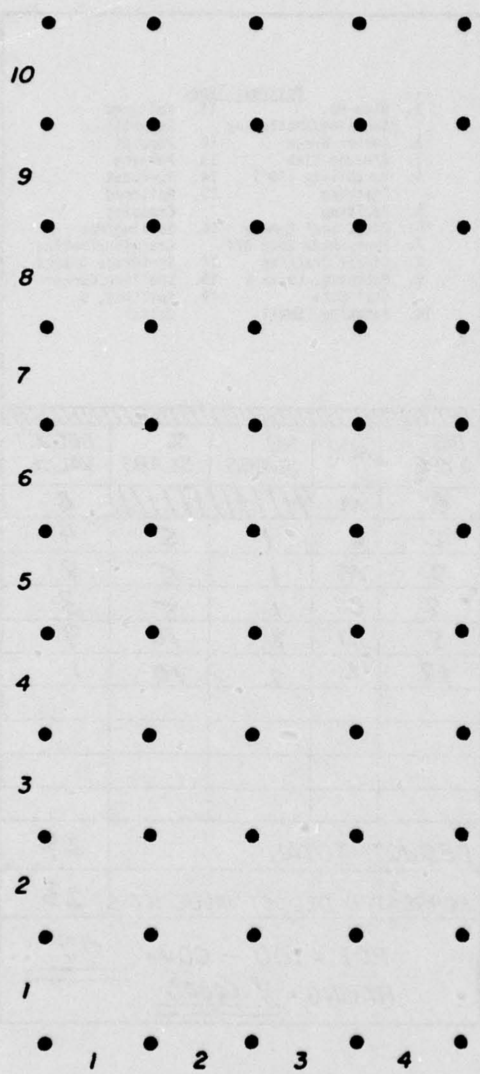
*All distresses are counted on a slab-by-slab basis except distress 6, which is rated for the entire sample unit.

Figure 16. Jointed concrete pavement sample unit inspection sheet.

FACILITY________________ SECTION________________

DATE ________________ SAMPLE UNIT________________

SURVEYED BY________________ SLAB SIZE________________



Distress Types

1. Blow-Up, Buckling/Shattering
2. Corner Break
3. Divided Slab
4. Durability ("D") Cracking
5. Faulting
*6. Joint Seal Damage
7. Lane/Shldr Drop Off
8. Linear Cracking
9. Patching, Large & Util Cuts
10. Patching, Small
11. Polished Aggregate
12. Popouts
13. Pumping
14. Punchout
15. Railroad Crossing
16. Scaling/Map Cracking/Crazing
17. Shrinkage Cracks
18. Spalling, Corner
19. Spalling, U Joint

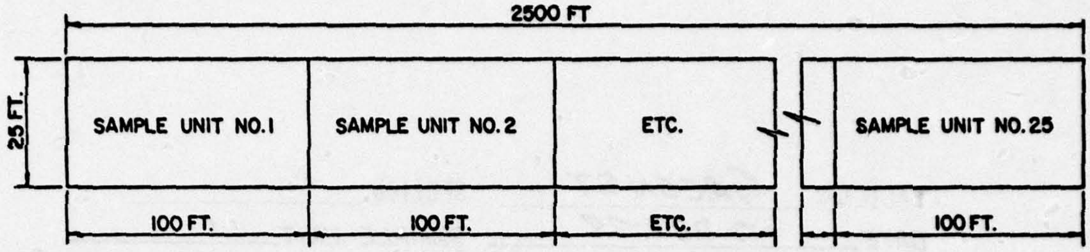
DIST. TYPE	SEV.	NO. SLABS	% SLABS	DEDUCT VALUE
6		//////	//////	
DEDUCT TOTAL				
CORRECTED DEDUCT VALUE (CDV)				

PCI = 100 − CDV = ______

RATING = ______

*All distresses are counted on a slab-by-slab basis except distress 6, which is rated for the entire sample unit.

Figure 17. Blank jointed concrete pavement sample unit inspection sheet.



SECTION DIMENSION = 25 x 2500 FT.

SAMPLE UNIT = 25 x 100 FT.

NUMBER OF SAMPLE UNITS = 25

Figure 18. Example division of asphalt-surfaced pavement section into sample units.

Determining the Number of Samples

The minimum number of sample units (n) that must be surveyed is determined from the following equation:[4]

$$n = \frac{N\sigma^2}{\frac{e^2}{4}(N-1) + \sigma^2} \quad \text{[Eq 2]}$$

where:

N = total number of sample units in the pavement section

e = allowable error in the estimate of the section PCI, i.e., when determining the section PCI by surveying n sample units instead of surveying N sample units

σ = standard deviation of the PCI between sample units in the section.

$$\sigma = \frac{\sum_{i=1}^{R} (PCI_i - \overline{PCI})^2}{R-1} \quad \text{[Eq 3]}$$

where:

R = number of sample units in the pavement section based upon which σ is determined.

PCI_i = PCI of sample unit i.

$$\overline{PCI} = \frac{\sum_{i=1}^{R} PCI_i}{R} \quad \text{[Eq 4]}$$

Eq 2 provides 95 percent confidence that the error in estimating the section PCI is within ±e if a minimum of n sample units is surveyed.

For example, consider the pavement section shown in Figure 18. It is desired to determine the minimum number of sample units to be surveyed so that there is 95 percent confidence that the error (e) is within ±5 points. Based on previous inspections, it is known that the standard deviation of the PCI between the sample units is 10 points. The parameters are therefore:

N = 25

e = 5 points

σ = 10 points

$$n = \frac{25\,(10)^2}{\frac{(5)^2}{4}(25-1) + (10)^2} \quad \text{[Eq 5]}$$

Therefore a minimum of 10 sample units must be selected (see next section) and surveyed.

In the above example, it was assumed that the standard deviation (σ) is known based on results of previous inspections. However, when performing

[4]Mohamed Y. Shahin, Michael I. Darter, and S. D. Kohn, *Development of a Pavement Maintenance Management System, Volume V, Proposed Revision of Chapter 3, AFR 93-5*, Report No. AFCEC-TR-76-27 (Air Force Civil Engineering Center, November 1976).

FACILITY GREEN ST SECTION 1

DATE 7 DEC 78 SAMPLE UNIT 1

SURVEYED BY MYS AREA OF SAMPLE 2500 sq ft

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

SKETCH:

EXISTING DISTRESS TYPES

	(10)	(1)	(15)			
	10L	16M	50L			
	5L	6L				
	15L					
	5M					
	10L					
	5M					
TOTAL SEVERITY L	40	6	50			
TOTAL SEVERITY M	10	16				
TOTAL SEVERITY H						

PCI CALCULATION

DISTRESS TYPE	DENSITY	SEVERITY	DEDUCT VALUE
1	0.24	L	5
1	0.64	M	18
10	1.6	L	4
10	0.4	M	3
15	2.0	L	13
DEDUCT TOTAL			43
CORRECTED DEDUCT VALUE (CDV)			32

PCI = 100 − CDV = 68

RATING = GOOD

*All distresses are measured in square feet except distresses 4, 7, 8, 9, and 10 which are measured in linear ft; distress 13 is measured in number of potholes.

Figure 19. Asphalt-surfaced pavement sample unit inspection sheet.

FACILITY ________ SECTION ________

DATE ________ SAMPLE UNIT ________

SURVEYED BY ________ AREA OF SAMPLE ________

SKETCH:

Distress Types

1. Alligator Cracking	*10. Long & Trans Cracking
2. Bleeding	11. Patching & Util Cut Patching
3. Block Cracking	12. Polished Aggregate
*4. Bumps and Sags	*13. Potholes
5. Corrugation	14. Railroad Crossing
6. Depression	15. Rutting
*7. Edge Cracking	16. Shoving
*8. Jt Reflection Cracking	17. Slippage Cracking
*9. Lane/Shldr Drop Off	18. Swell
	19. Weathering and Raveling

EXISTING DISTRESS TYPES

TOTAL SEVERITY L							
TOTAL SEVERITY M							
TOTAL SEVERITY H							

PCI CALCULATION

DISTRESS TYPE	DENSITY	SEVERITY	DEDUCT VALUE
DEDUCT TOTAL			
CORRECTED DEDUCT VALUE (CDV)			

PCI = 100 − CDV = ________

RATING = ________

*All distresses are measured in square feet except distresses 4, 7, 8, 9, and 10 which are measured in linear ft; distress 13 is measured in number of potholes.

Figure 20. Blank asphalt-surfaced pavement sample unit inspection sheet.

inspection for the first time, σ is not known. Therefore, every sample unit must be surveyed or σ may be assumed (an assumption of $\sigma = 10$ for initial inspection is reasonable). After the initial inspection is completed, the actual σ is determined.

Curves which permit the number of required samples to be readily obtained were developed using Eq 2. These curves, shown in Figure 21, can be used to select the minimum number of sample units that must be inspected to provide a reasonable estimate of the true mean PCI of the section. This estimate will be within ±5 points of the true mean PCI approximately 95 percent of the time.

As illustrated in Figure 21, when the total number of samples in section N is less than 5, every sample unit should be surveyed. If N is greater than 5, at least five sample units should be surveyed. This is recommended to insure accuracy in the estimate of σ and thus in determining the minimum number of samples to be surveyed.

Selection of Samples

Determining which sample units to inspect is as important as determining the minimum number of samples to be surveyed. Samples must be selected randomly to insure an unbiased result. Random selection can be done by using a random number table. If the number of sample units in a section is 10 or more, it is recommended that the section be stratified. This is done by dividing the section into a number of parts called strata. An equal number of sample units is then randomly selected from each stratum, as illustrated in the following example.

Figure 22a shows the section to be inspected; it contains a total of 25 sample units numbered from 1 to 25. Assuming a standard deviation (σ) of 10, the required minimum number of sample units is determined to be 10 (from Figure 21). The section can be divided into five strata of five sample units each:

Stratum 1	Sample units 1 through 5
Stratum 2	Sample units 6 through 10
Stratum 3	Sample units 11 through 15
Stratum 4	Sample units 16 through 20
Stratum 5	Sample units 21 through 25

Two sample units are selected at random from each stratum using a random number table, such as shown in Table 3. Units can be selected by starting with any two digits in the table. The starting point in this example is at columns 5 and 6 of row 10 where the two-digit number "17" is located. To select two sample units for Stratum 1, two random numbers between 01 and 05 must be selected. Proceeding down columns 5 and 6 from the starting point, the first two random numbers encountered that fall between 01 and 05 are 03 (row 16) and 01 (row 25); therefore, sample units 01 and 03 will be inspected. The process would then be repeated for the other four strata. If the required units have not been obtained when the bottom of the column is reached, they can be obtained by proceeding as before from any other row-column combination; in this example, row 00 and columns 20 and 21 were selected. The numbers selected using this procedure are circled in Table 3 and are listed below:

Stratum	Sample Units Selected
Stratum 1 (1-5)	01,03
Stratum 2 (6-10)	09,10
Stratum 3 (11-15)	12,13
Stratum 4 (16-20)	16,17
Stratum 5 (21-25)	21,23

Therefore, sample units numbered 01, 03, 09, 10, 12, 13, 16, 17, 21, and 23 must be inspected (Figure 22b).

A different approach from the stratified random selection of samples is to select samples that are equally spaced; however, the first sample should be selected at random. This technique is known as systematic sampling[5] and is briefly described below.

1. The "sampling interval, i," is determined from the following equation:

$$i = N/M$$

where

N = total number of available sample units,

[5] Seymour Sudman, *Applied Sampling*, Academic Press, 1976.

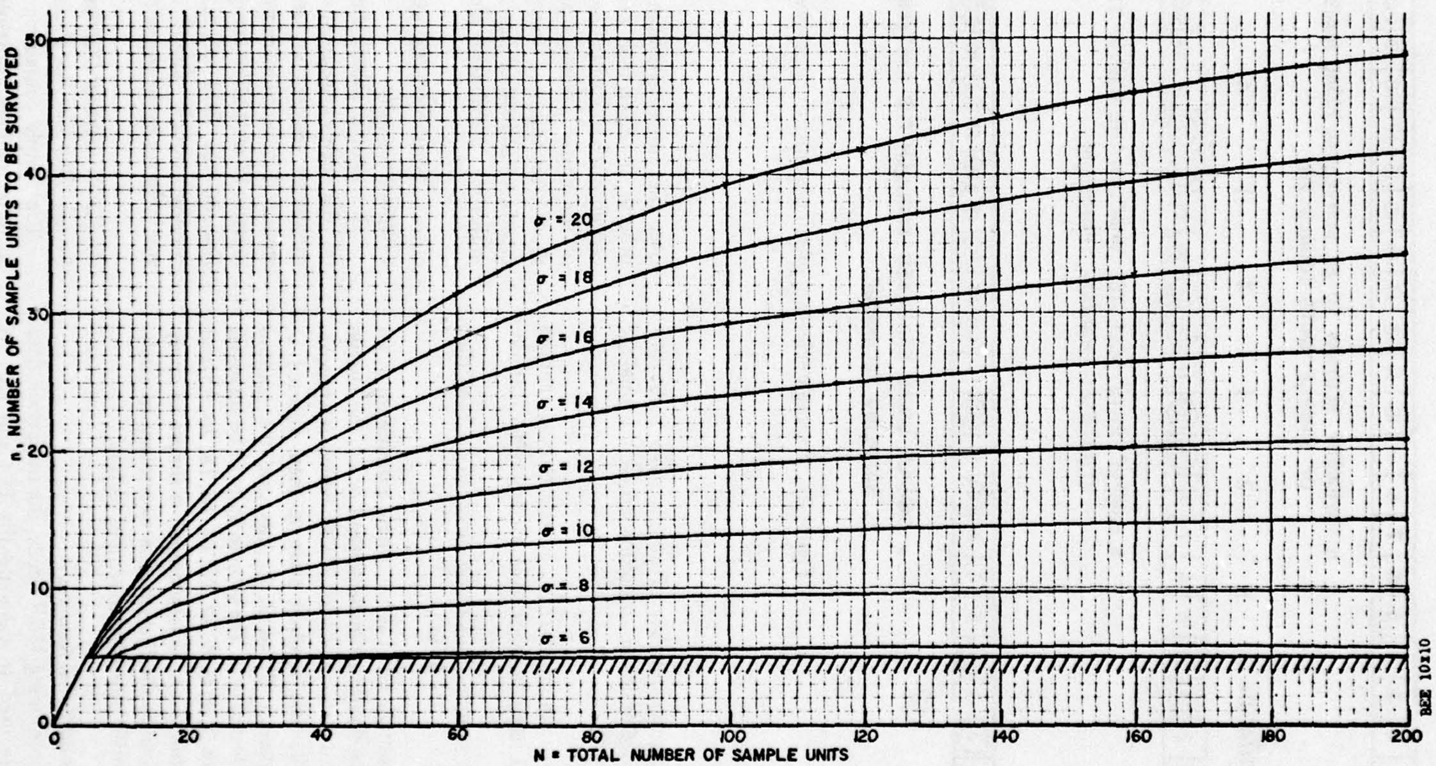


Figure 21. Determination of minimum number of sample units to be surveyed for 95 percent confidence that the error in PCI of section is within ±5 points.

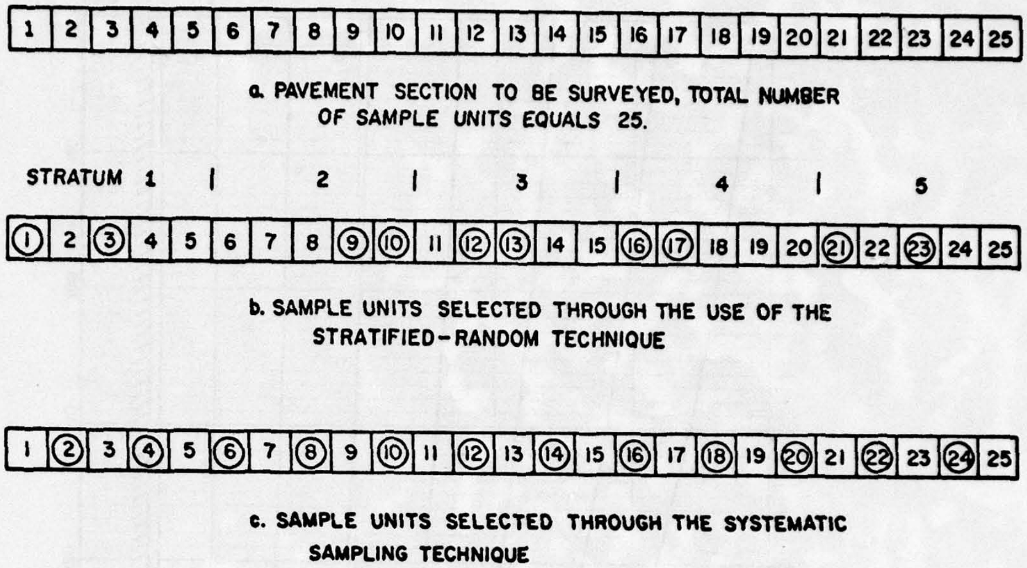


Figure 22. Example selection of sample units to be surveyed.

M = minimum number of sample units to be surveyed and i should be approximated to the smallest integer number.

2. The random start, s, is selected at random between 1,i using random tables or any other method.

3. The sample units to be surveyed are identified as s, s + i, s + 2i, s + 3i, etc.

In the example cited above, where a minimum of 10 sample units should be inspected out of 25, the sample interval (i) is determined as 25/20, which is approximated to 2. The random start is then selected at random between 1 and 2. In this case the random start was selected as 2. The sample units to be surveyed are therefore 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 (see Figure 22c). This technique is simple to apply and also provides the information necessaary to establist a PCI profile along the pavement section.

Inspecting Additional Samples

When determining M&R needs, the inspection data obtained are used to calculate the PCI and also to extrapolate the quantities and densities of each distress over the entire pavement section. The extrapolation process, however, will produce erroneous results for certain distresses which are not typical of the behavior of the entire pavement section. A special procedure should be followed for potholes, blow-ups, railroad crossings, and other distresses that are obviously not uniformly distributed along the pavement section.

Case 1–Nontypical Distress Falls Within a Random Sample

The sample should be identified as "additional" on the field inspection sheet, and another sample should be selected at random to replace it. For example, if a pothole is found in random sample 17, sample 17 should be completely inspected and identified on the field inspection sheet as "additional." Another sample should then be chosen randomly and included in the inspection.

Case 2–Nontypical Distress Occurs in a Sample That Was Not Randomly Selected

The sample containing the nontypical distress and all other samples containing the same distress should be inspected and recorded as additional samples.

Table 3

Typical Random Number Table

	00–04	05–09	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49
00	54463	22662	65905	70639	79365	67382	29085	69831	47058	08186
01	15389	85205	18850	39226	42249	90669	96325	23248	60933	26927
02	85941	40756	82414	02015	13858	78030	16269	65978	01385	15345
03	61149	69440	11286	88218	58925	03638	52862	62733	33451	77455
04	05219	81619	10651	67079	92511	59888	84502	72095	83463	75577
05	41417	98326	87719	92294	46614	50948	64886	20002	97365	30976
06	28357	94070	20652	35774	16249	75019	21145	05217	47286	76305
07	17783	00015	10806	83091	91530	36466	39981	62481	49177	75779
08	40950	84820	29881	85966	62800	70326	84740	62660	77379	90279
09	82995	64157	66164	41180	10089	41757	78258	96488	88629	37231
10	96754	17676	55659	44105	47361	34833	86679	23930	53249	27083
11	34357	88040	53364	71726	45690	66334	60332	22554	90600	71113
12	06318	37403	49927	57715	50423	67372	63116	48888	21505	80182
13	62111	52820	07243	79931	89292	84767	85693	73947	22278	11551
14	47534	09243	67879	00544	23410	12740	02540	54440	32949	13491
15	98614	75993	84460	62846	59844	14922	48730	73443	48167	34770
16	24867	03648	44898	09351	98795	18644	39765	71058	90368	44104
17	96887	12479	80621	66223	86085	78285	02432	53342	42846	94771
18	90801	21472	42815	77408	37390	76766	52615	32141	30268	18106
19	55165	77312	83666	36028	28420	70219	81369	41943	47366	41067
20	75884	12952	84318	95108	72305	64620	91381	89872	45375	85436
21	16777	37116	58550	42958	21460	43910	01175	87894	81378	10620
22	46230	43877	80207	88877	89380	32992	91380	03164	98656	59337
23	42902	66892	46134	01432	94710	23474	20423	60137	60609	13119
24	81007	00333	39693	28039	10154	95425	39220	19774	31782	49037
25	68089	01122	51111	72373	06902	74373	96199	97017	41273	21546
26	20411	67081	89950	16944	93054	87687	96693	87236	77054	33848
27	58212	13160	06468	15718	82627	76999	05999	58680	96739	63700
28	70577	42866	24969	61210	76046	67699	42054	12696	93758	03283
29	94522	74358	71659	62038	79643	79169	44741	05437	39038	13163
30	42626	86819	85651	88678	17401	03252	99547	32404	17918	62880
31	16051	33763	57194	16752	54450	19031	58580	47629	54132	60631
32	08244	27647	33851	44705	94211	46716	11738	55784	95374	72655
33	59497	04392	09419	89964	51211	04894	72882	17805	21896	83864
34	97155	13428	40293	09985	58434	01412	69124	82171	59058	82859
35	98409	66162	95763	47420	20792	61527	20441	39435	11859	41567
36	45476	84882	65109	96597	25930	66790	65706	61203	53634	22557
37	89300	69700	50741	30329	11658	23166	05400	66669	48708	03887
38	50051	95137	91631	66315	91428	12275	24816	68091	71710	33258
39	31753	85178	31310	89642	98364	02306	24617	09609	83942	23716
40	79152	53829	77250	20190	56535	18760	69942	77448	33278	48805
41	44560	38750	83635	56540	64900	42912	13953	79149	18710	68618
42	68328	83378	63369	71381	39564	05615	42451	64559	97501	65747
43	46939	38689	58625	08342	30459	85863	20781	09284	26333	91777
44	83544	86141	15707	96256	23068	13782	08467	89469	93842	55349
45	91621	00881	04900	54224	46177	55309	17852	27491	89415	23466
46	91896	67126	04151	03795	59077	11848	12630	98375	52068	60142
47	55751	62515	21108	80830	02263	29303	37204	96926	30506	09808
48	85156	87689	95493	88842	00664	55017	55539	17771	69448	87530
49	07521	56898	12236	60277	39102	62315	12239	07105	11844	01117

5 CALCULATION OF PCI FROM INSPECTION RESULTS

General

Chapter 4 presented the two methods of inspecting a pavement section, i.e., inspecting every sample unit in the section and inspection by sampling. The data collected for each sample unit in the section are used to calculate the PCI. This chapter will explain how to calculate the PCI for a particular sample unit, and how to calculate the PCI for the entire pavement section.

Calculating PCI for a Sample Unit

Calculating the PCI for an individual sample unit is a relatively simple procedure which involves six basic steps (also see Figure 23):

Step 1 – Each sample unit is inspected and distress data recorded as described in Chapter 4.

Step 2 – The deduct values are determined from the deduct value curves for each distress type and severity (Appendices A and B).

Step 3 – A TDV is computed by summing all individual deduct values.

Step 4 – Once the TDV is computed, the corrected deduct value (CDV) can be determined from the correction curves (Appendices A and B).

When determining the CDV, the q (number of individual deducts with values more than 5 points) that results in the highest CDV should be used. For example, assume the case where two distresses were found in an asphalt pavement, one with a deduct value of 50 and the second with a deduct value of 10. Using Figure A20, the CDV for q = 2 is 44. If the second distress is ignored, however, the CDV for q = 1 is 50 which is higher than 44 and should be used.

Step 5 – The PCI is now computed as PCI = 100 - CDV.

Step 6 – The condition rating of the sample unit is determined by using the scale shown in Step 6, Figure 23.

Calculating the PCI for a Pavement Section

If all sample units in the section are surveyed, the PCI of the section is computed by averaging the PCIs of all sample units. Inspection by sampling, however, requires a different method. If all surveyed sample units are selected randomly, the PCI of the pavement section is determined by averaging the PCI of the sample units. If any additional sample units are inspected, a weighted average must be used. The weighted average can be computed by using the following equation:

$$PCI_s = \frac{N-A}{N}\overline{PCI}_1 + \frac{A}{N}\overline{PCI}_2 \qquad \text{[Eq 6]}$$

where

PCI_s = PCI of pavement section

$\overline{PCI}_1$ = average PCI of random samples

$\overline{PCI}_2$ = average PCI of additional samples

N = total number of samples in feature

A = number of additional samples inspected.

Example Calculations of PCI for a Sample Unit

Referring to the field data sheets presented in Chapter 4 (Figures 16 and 19), the calculation of the PCI for each sample unit is presented below.

Jointed Concrete Sample Unit (Figure 16)

The first step after inspection is to calculate the density of distress by dividing the number of slabs containing a particular distress and severity level by the total number of slabs in the sample unit. For example, two slabs contained linear cracking (distress 8) at medium severity, so the density is therefore calculated as 2/20, or 10 percent. The deduct values are then determined for each distress combination, from Appendix B, Figures B1 through B19. The corrected deduct value is determined from Figure B20, and the PCI is calculated as shown in Figure 16.

Asphalt Pavement Sample Unit (Figure 19)

The difference in the procedure for calculating a PCI for an asphalt sample unit and that for a concrete sample unit is in the calculation of the distress density. Distress density in the asphalt sample unit is calculated by dividing the distressed area by the sample unit area and multiplying the result by 100, with the following exceptions:

1. Bumps, edge cracking, joint reflection cracking, lane/shoulder drop off, and longitudinal and transverse cracking are calculated as follows:

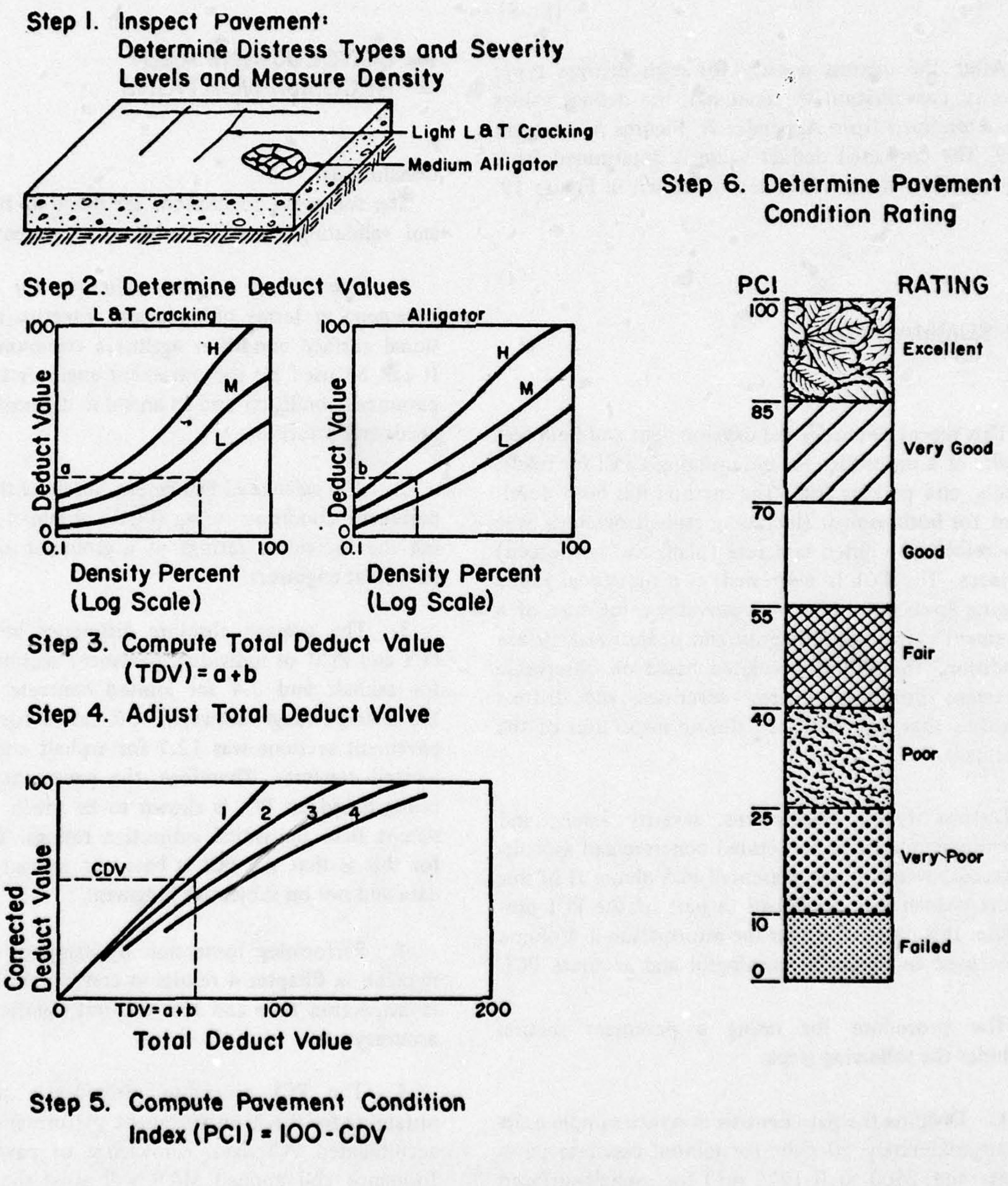


Figure 23. Steps for calculating PCI.

$$\text{Density} = \frac{\text{distress amount in linear feet}}{\text{sample unit area in square feet}} \times 100$$

[Eq 7]

2. Potholes are calculated as follows:

$$\text{Density} = \frac{\text{number of potholes}}{\text{sample unit area in square feet}} \times 100$$

[Eq 8]

After the distress density for each distress type/ severity combination is calculated, the deduct values are determined from Appendix A, Figures A1 through A19. The corrected deduct value is determined from Figure A20, and is calculated as shown in Figure 19.

6 SUMMARY

This report describes the development and field test results of a procedure for determining a PCI for roads, streets, and parking lots. The method has been developed for both asphalt (including asphalt overlays over concrete) and jointed concrete (plain and reinforced) surfaces. The PCI is expressed as a numerical rating ranging from 0 to 100, and provides a measure of a pavement's structural integrity and operational surface condition. The PCI is calculated based on observable pavement distresses, distress severities, and distress densities that are measured during inspection of the pavement.

Distress types, descriptions, severity levels, and measurement criteria for jointed concrete-and asphalt-surfaced pavements are presented in Volume II of this report, which was developed as part of the PCI procedure. It is imperative that the information in Volume II be used to obtain a meaningful and accurate PCI.

The procedure for rating a pavement section includes the following steps:

1. Dividing the pavement section into sample units of approximately 20 slabs for jointed concrete pavements and 2500 sq ft (225 m^2) for asphalt-surfaced pavements.

2. Inspect either each sample unit in the pavement section or only a number of sample units determined by using the sampling techniques described in Chapter 4.

3. Calculate the PCI for each sample unit surveyed (Figure 23).

4. Average the PCIs of the sample units to obtain the overall PCI of the pavement section.

7 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions are based on field testing and validating the PCI on many pavement sections:

1. The PCI is a valid technique for comparing pavement in terms of structural integrity and operational surface condition against a common standard. It can be used by the pavement engineer to compare pavement condition and as an aid in determining M&R needs and priorities.

2. The calculated PCI agrees closely with the mean pavement condition rating ($\overline{PCR}$) obtained by averaging the individual ratings of a group of experienced pavement engineers.

3. The average absolute difference between the PCI and $\overline{PCR}$ of individual pavement sections was 3.8 for asphalt and 3.4 for jointed concrete. However, the average range between PCR raters for the same pavement sections was 12.7 for asphalt and 15.3 for jointed concrete. Therefore, the pavement condition rating based on PCI is shown to be much more consistent than individual subjective ratings. The reason for this is that the PCI is based on measured distress data and not on subjective judgment.

4. Performing inspection by sampling as recommended in Chapter 4 results in considerable reduction in inspection time and cost without significant loss in accuracy.

5. The PCI procedure provides a method of obtaining feedback on pavement performance through accumulated PCI data. Knowledge of pavement performance and applied M&R will assist the pavement engineer in validating and improving M&R policies.

Recommendations

1. The PCI method for roads, streets, and parking lots has been field tested and verified. It is recommended that the procedure be implemented Army-wide.

2. Measurement of the PCI of a pavement section over a number of years would provide valuable data which can be used to determine the rate of deterioration of the pavement section and the optimum time for performing M&R.

APPENDIX A:
DEDUCT CURVES FOR ASPHALT-SURFACED PAVEMENTS

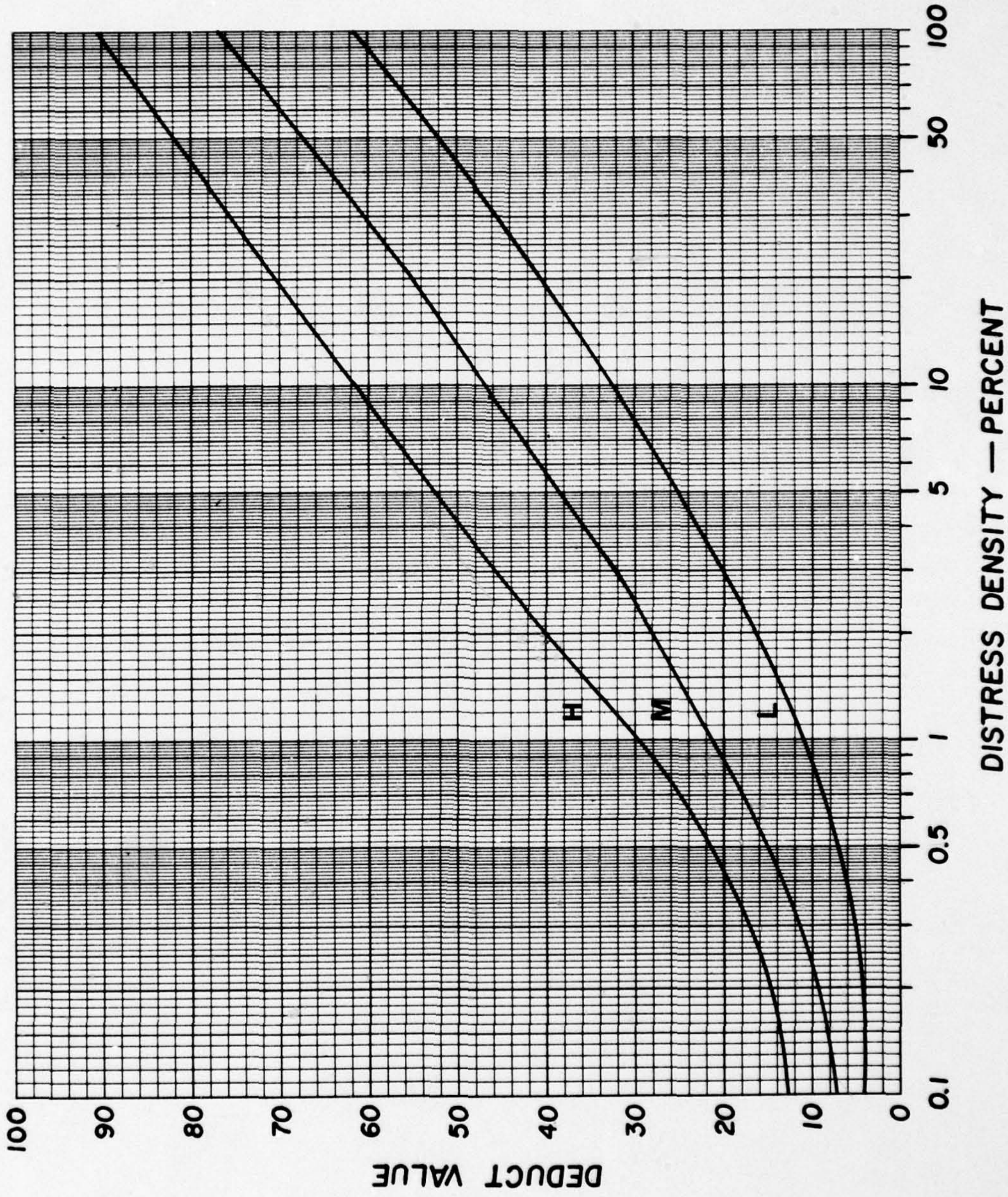


Figure A1. Alligator cracking.

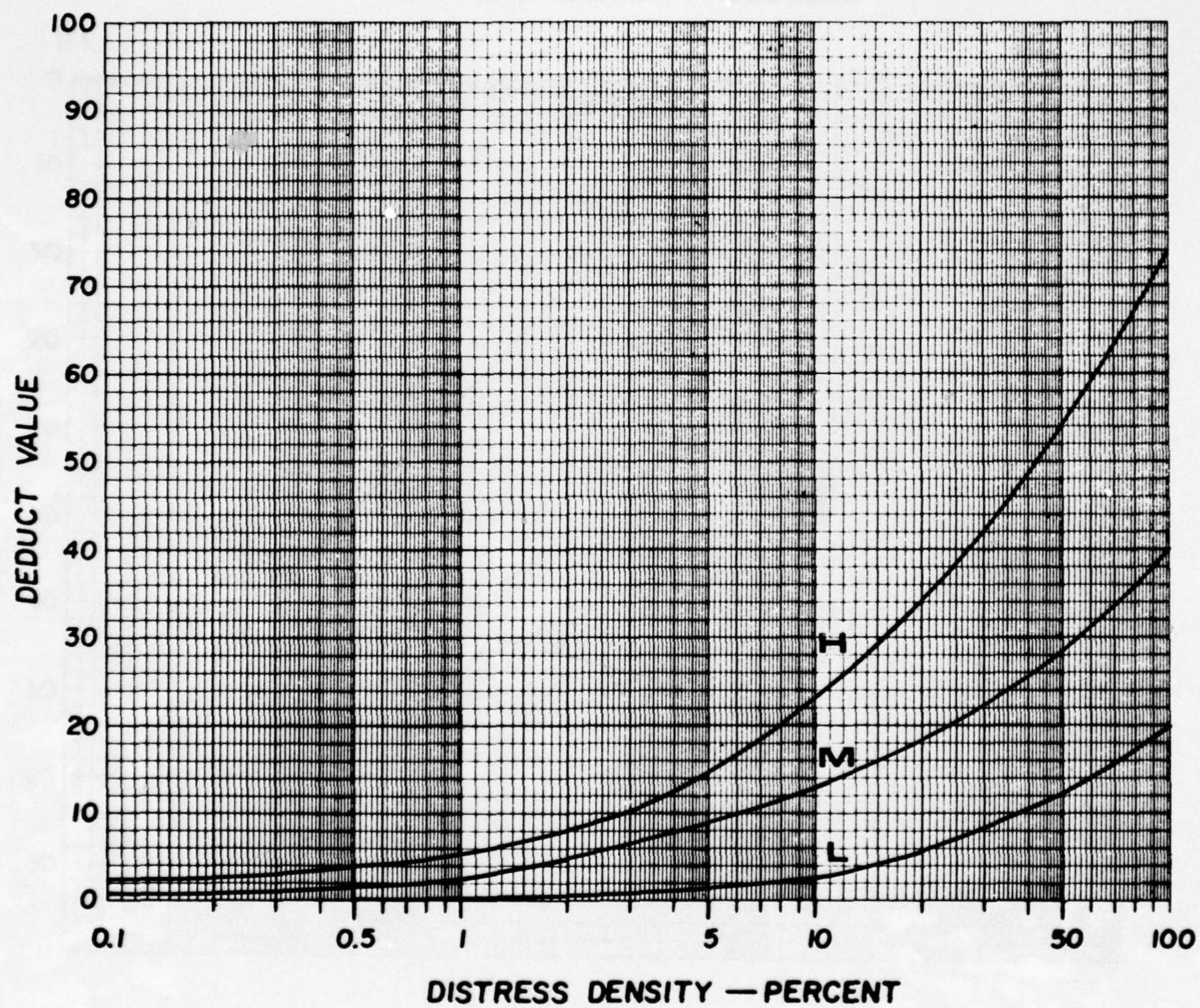


Figure A2. Bleeding.

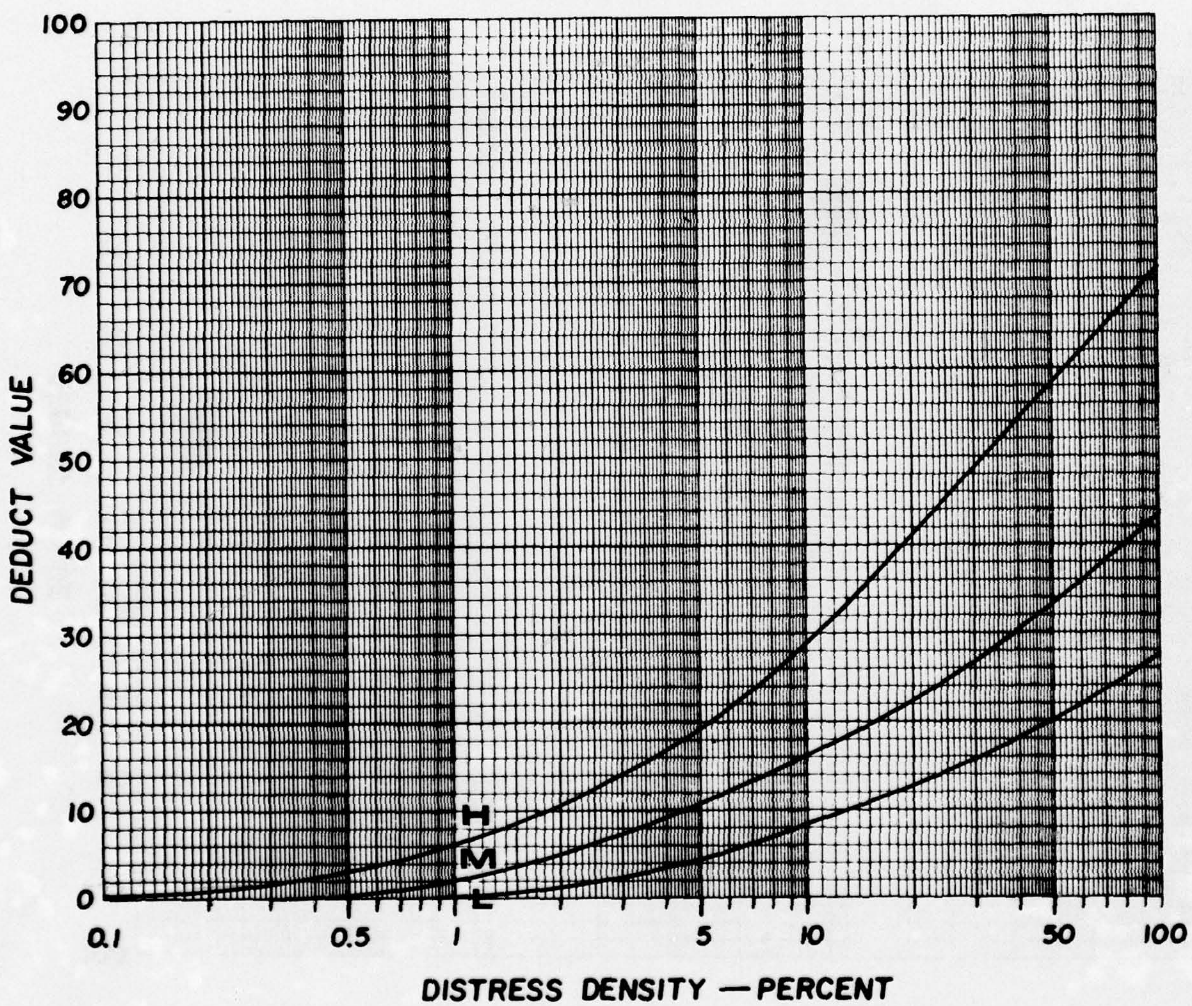


Figure A3. Block cracking.

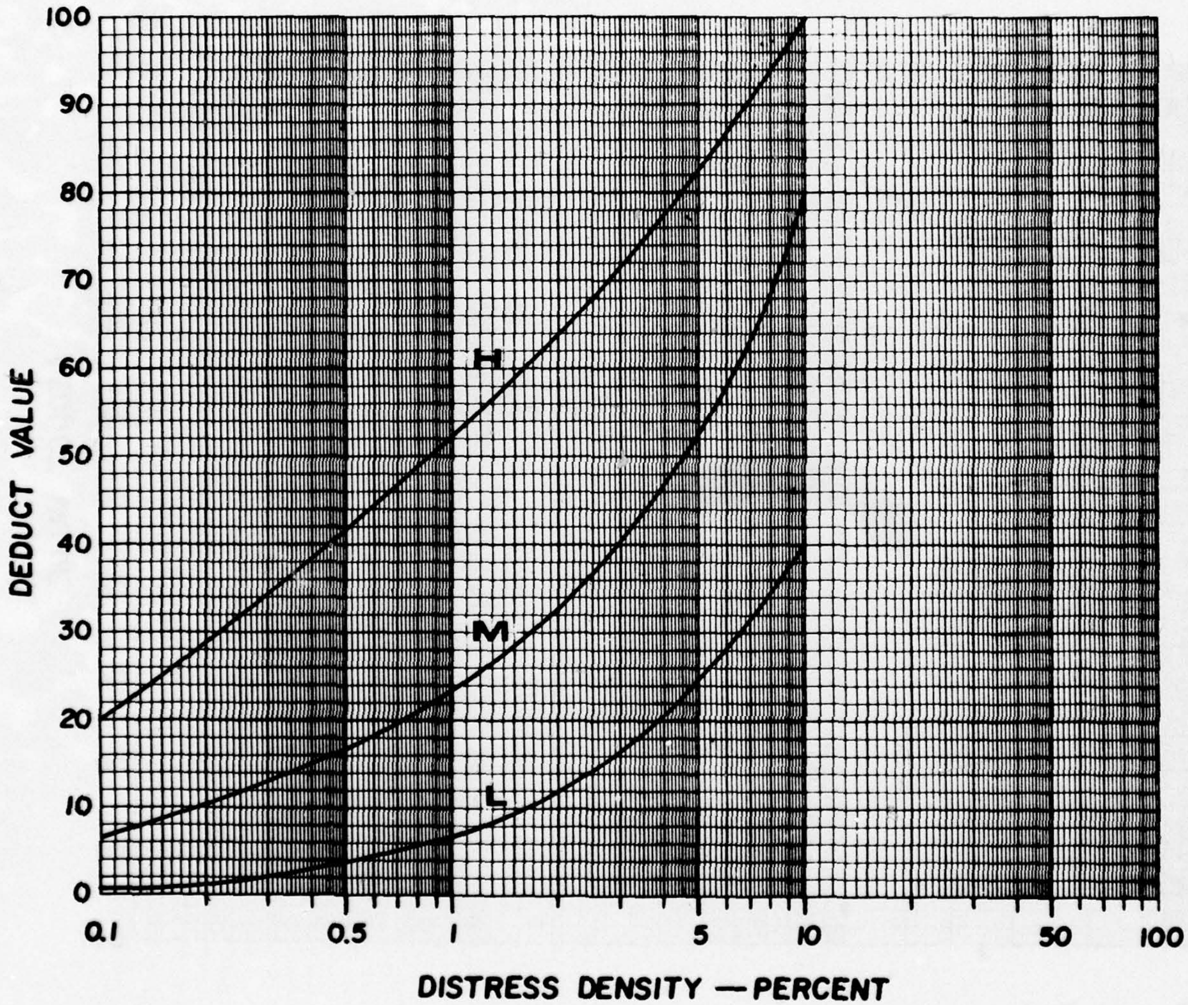


Figure A4. Bumps and sags.

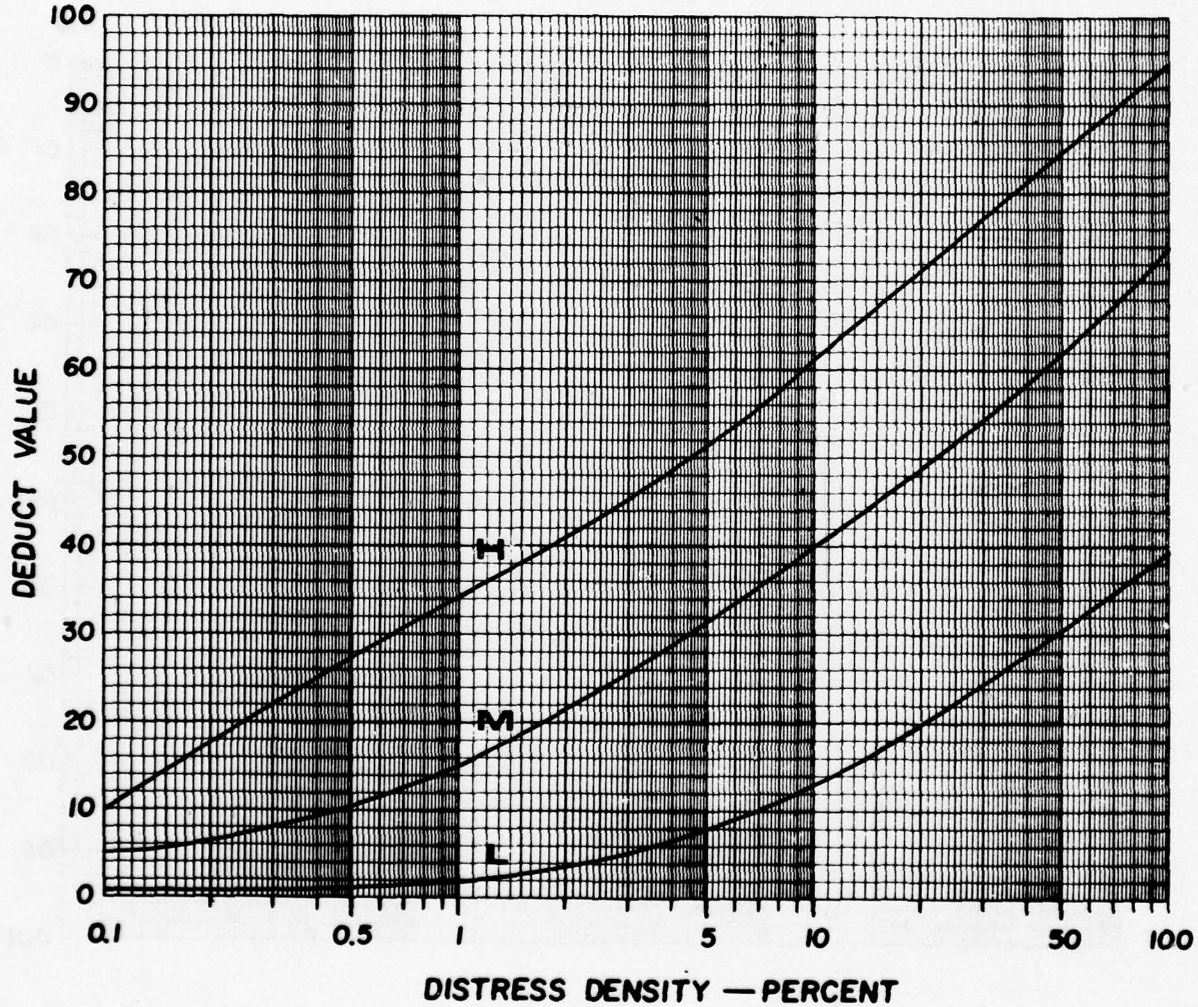


Figure A5. Corrugation.

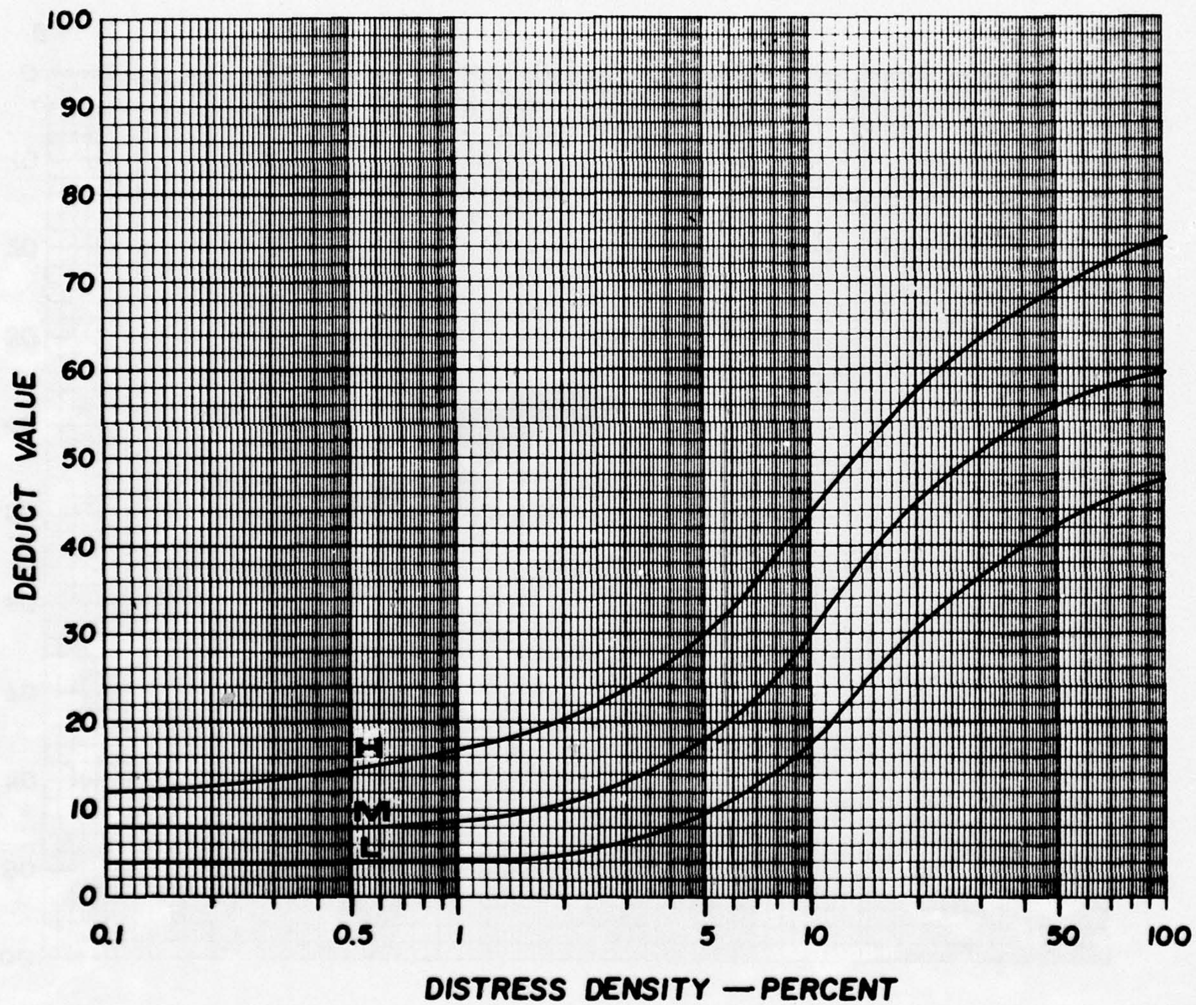


Figure A6. Depression.

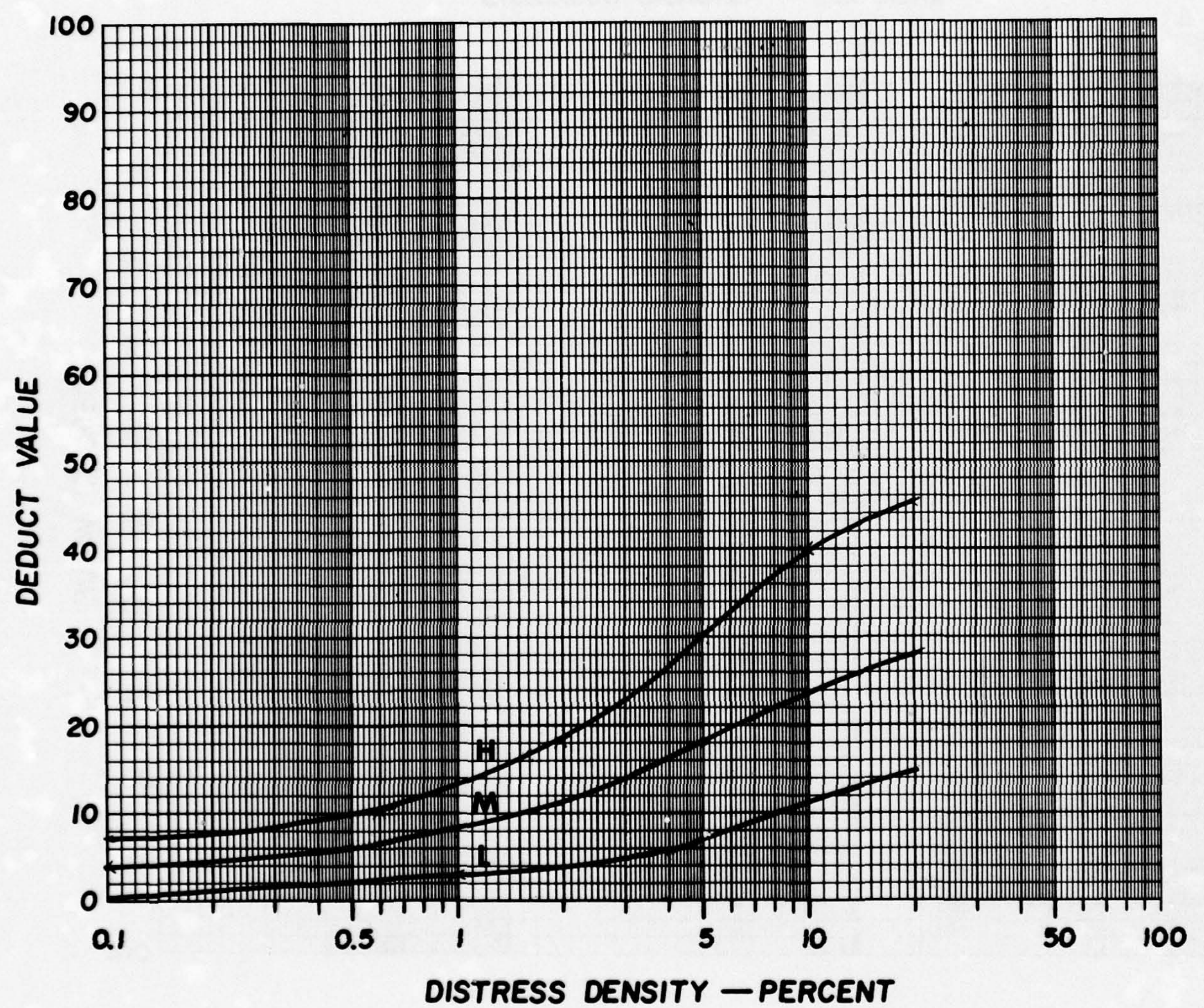


Figure A7. Edge cracking.

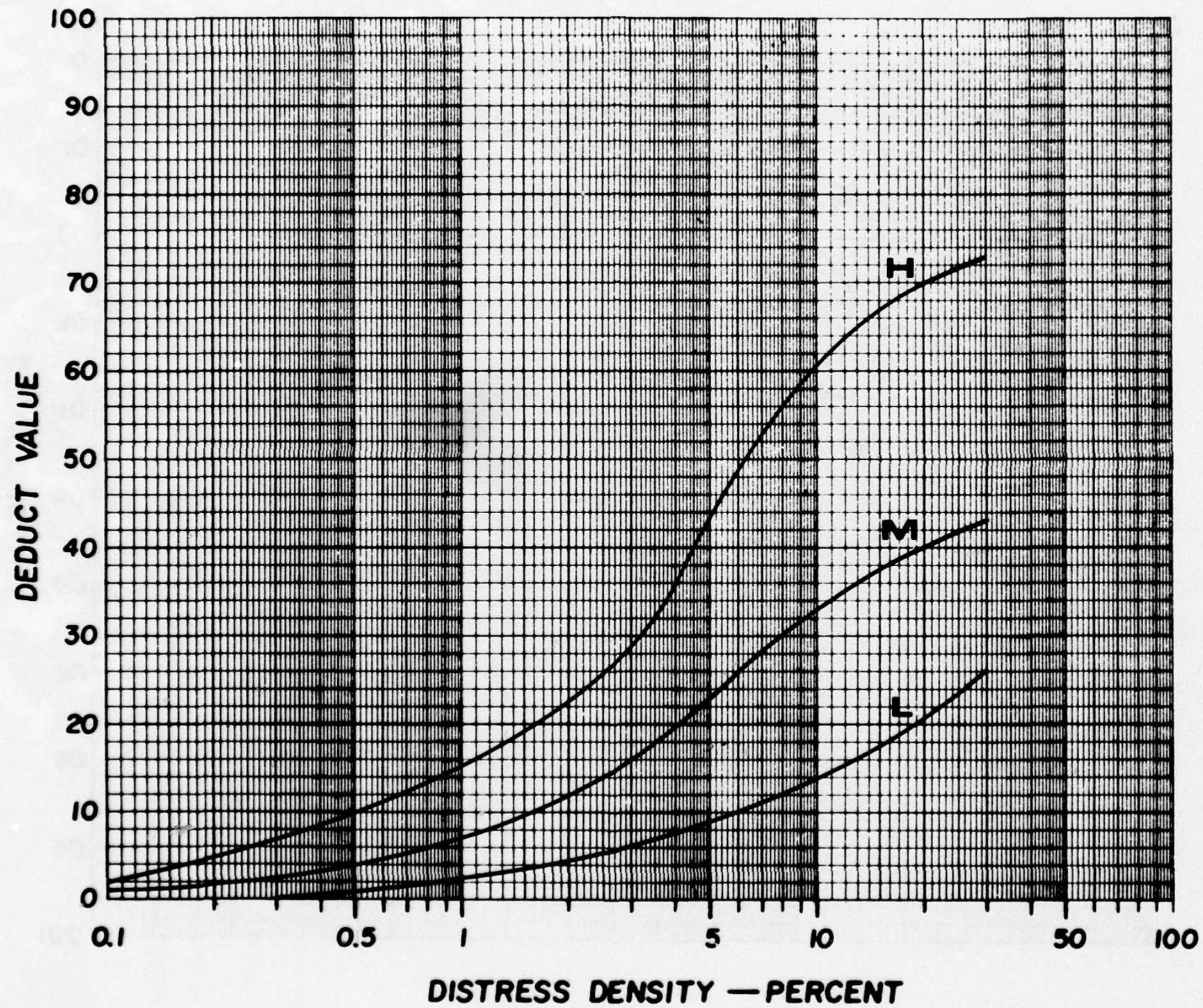


Figure A8. Joint reflection cracking.

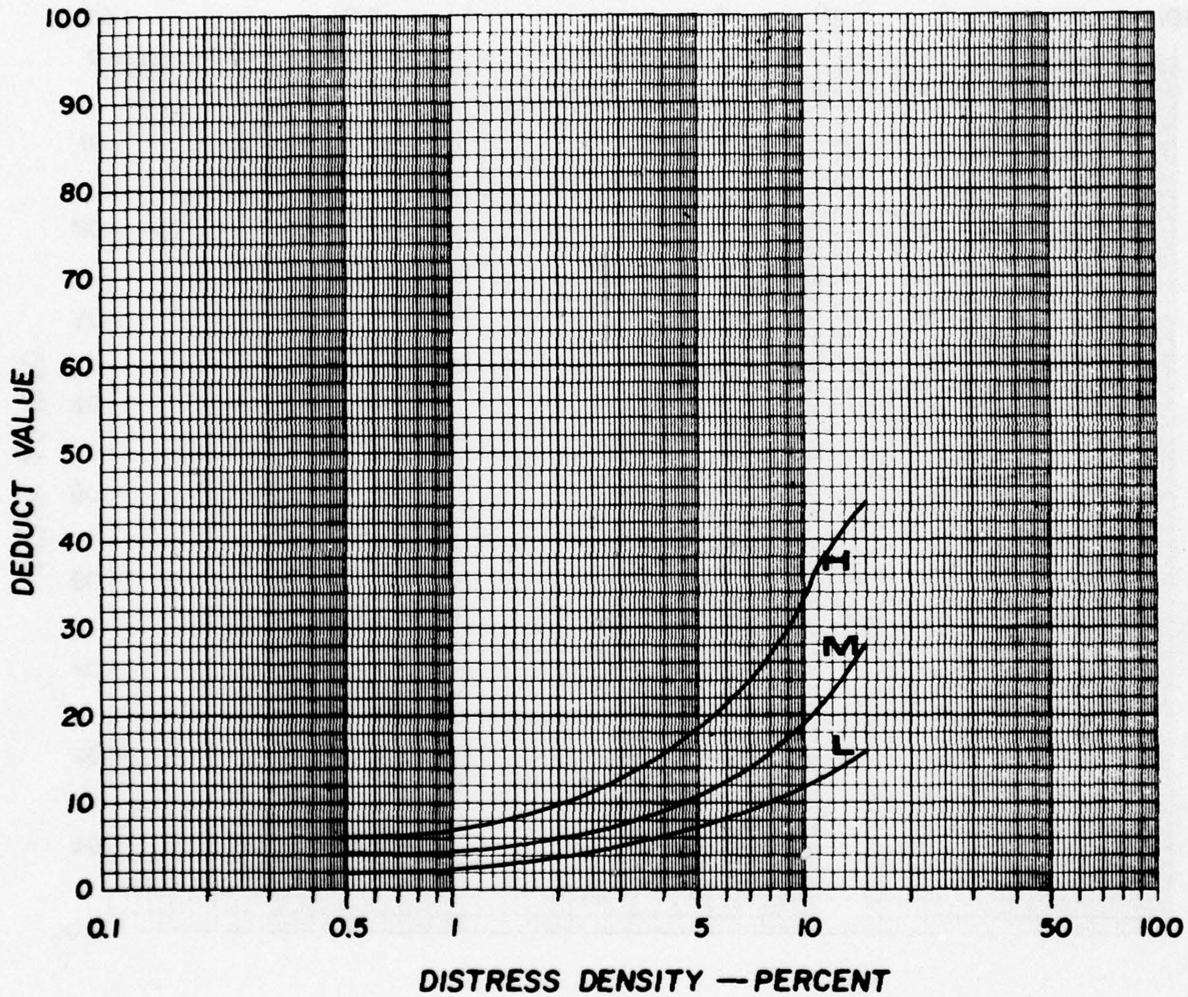


Figure A9. Lane/shoulder drop off.

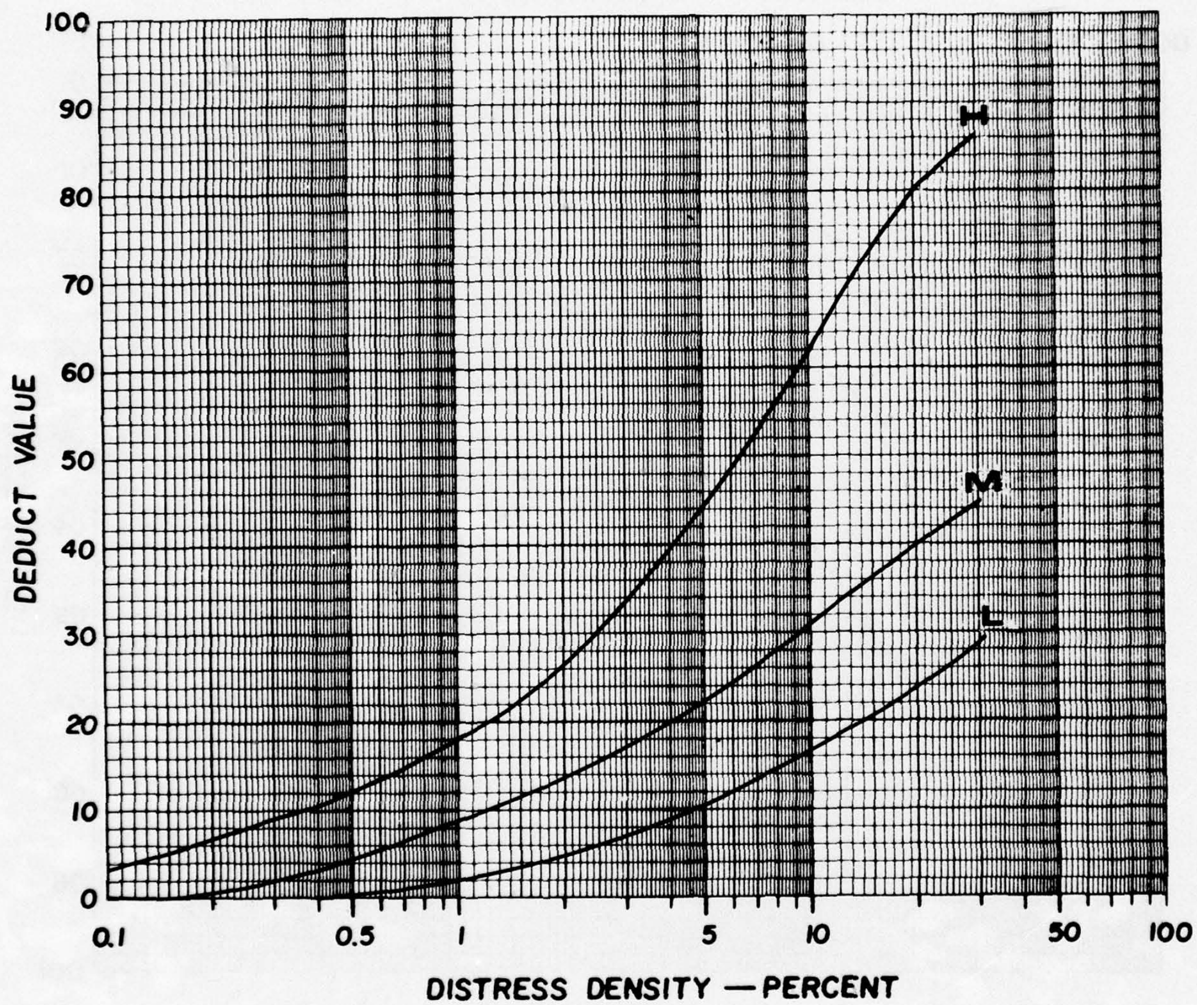


Figure A10. Longitudinal and transverse cracking.

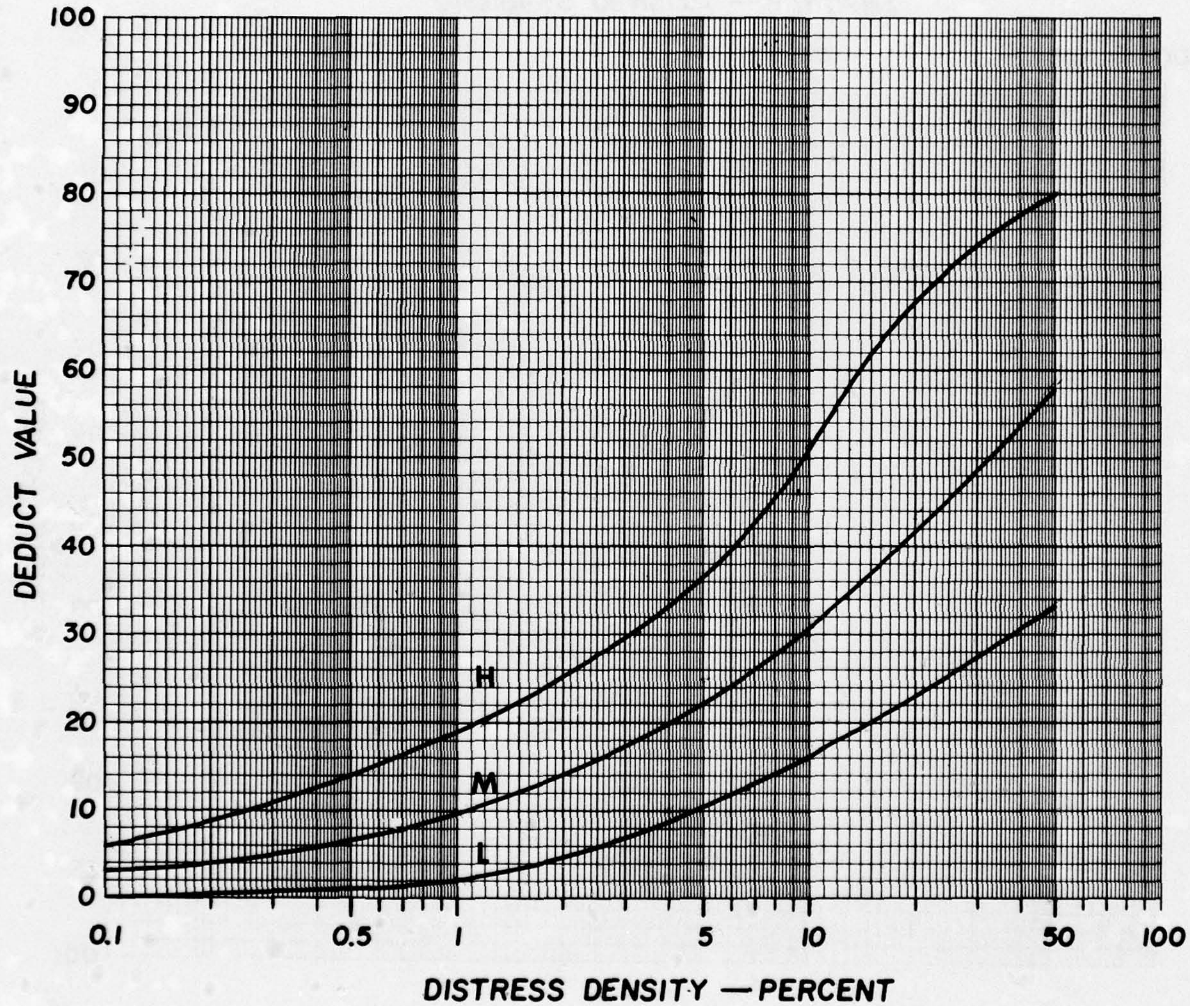


Figure A11. Patching and utility cut patching.

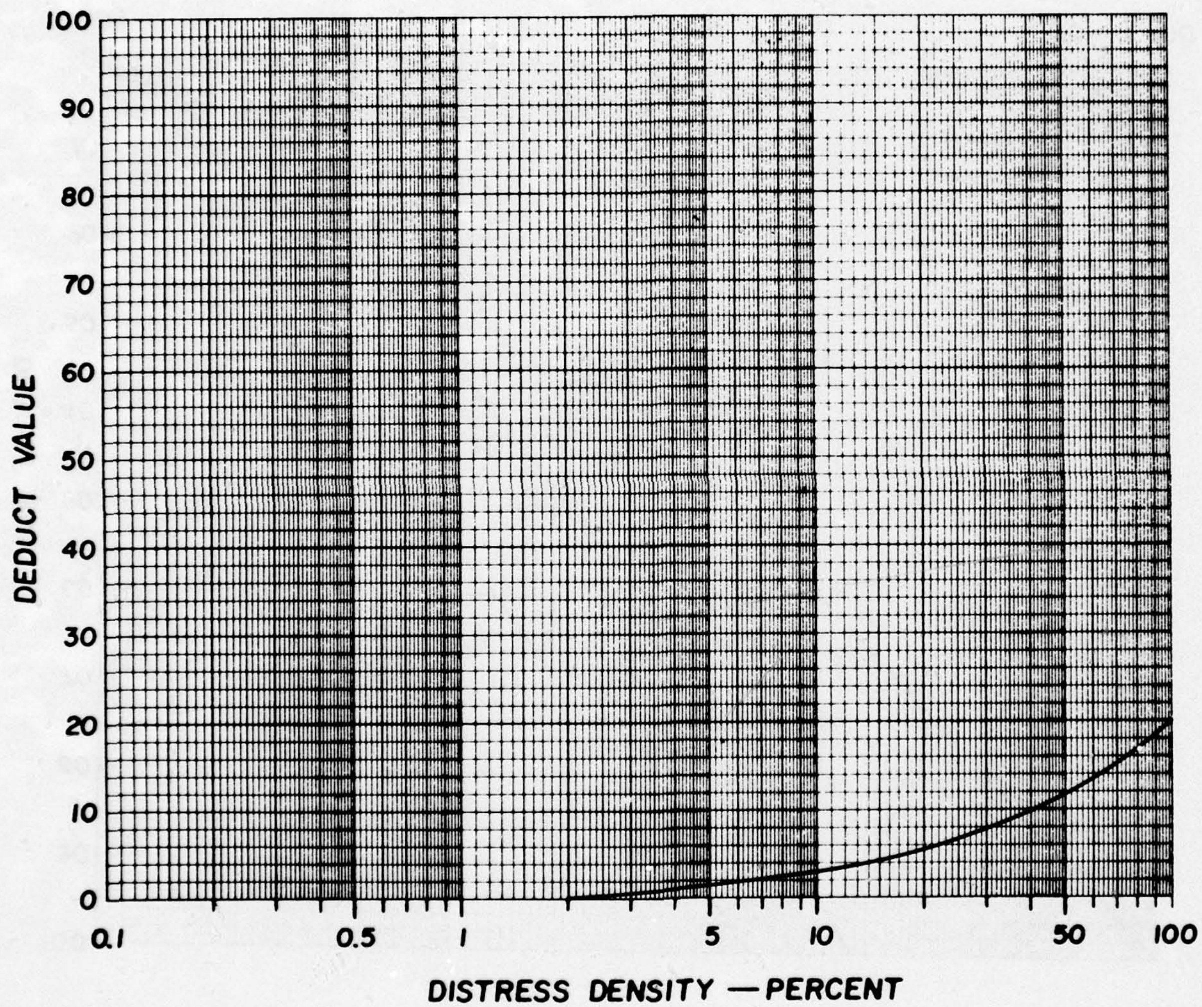


Figure A12. Polished aggregate.

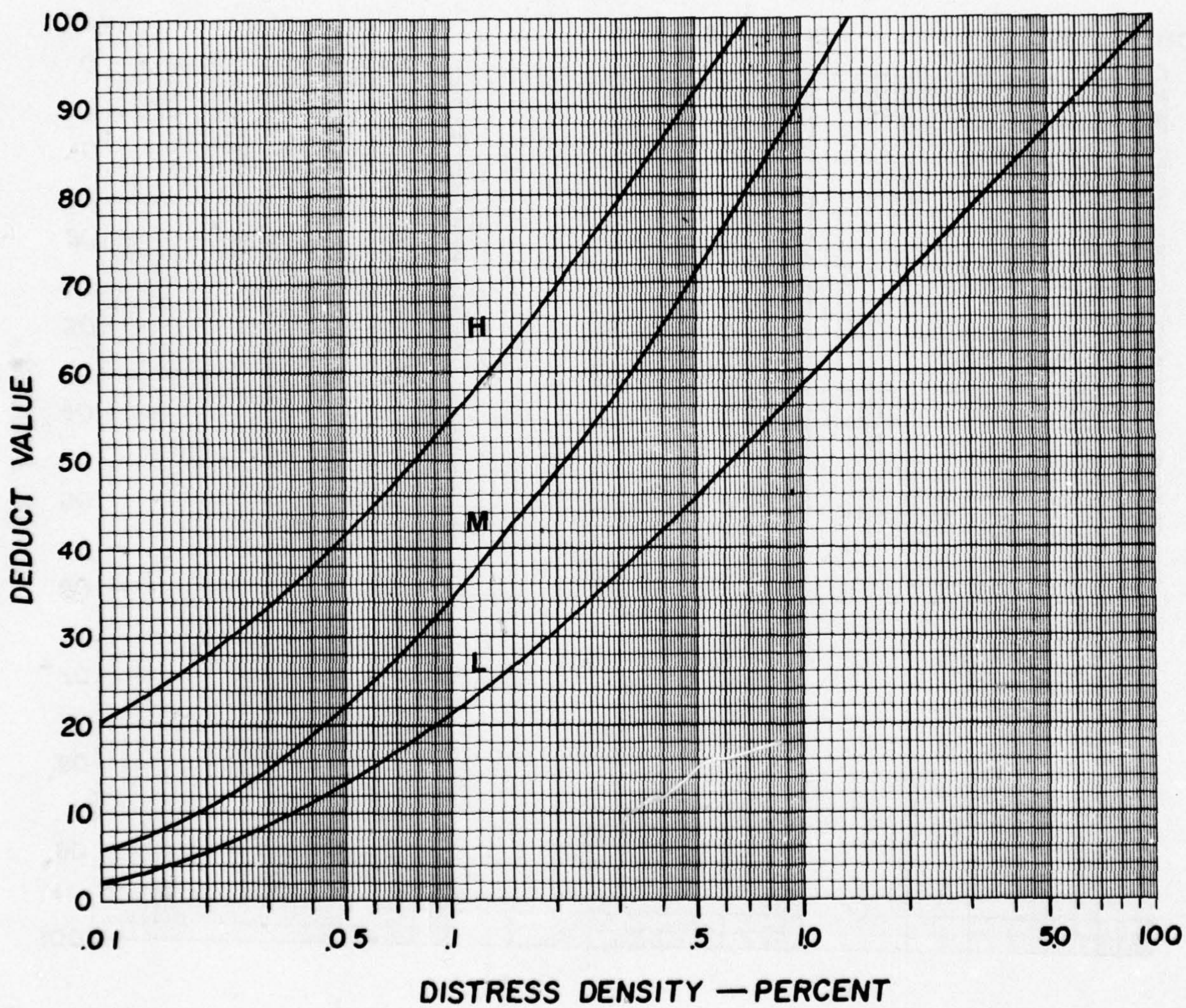


Figure A13. Potholes.

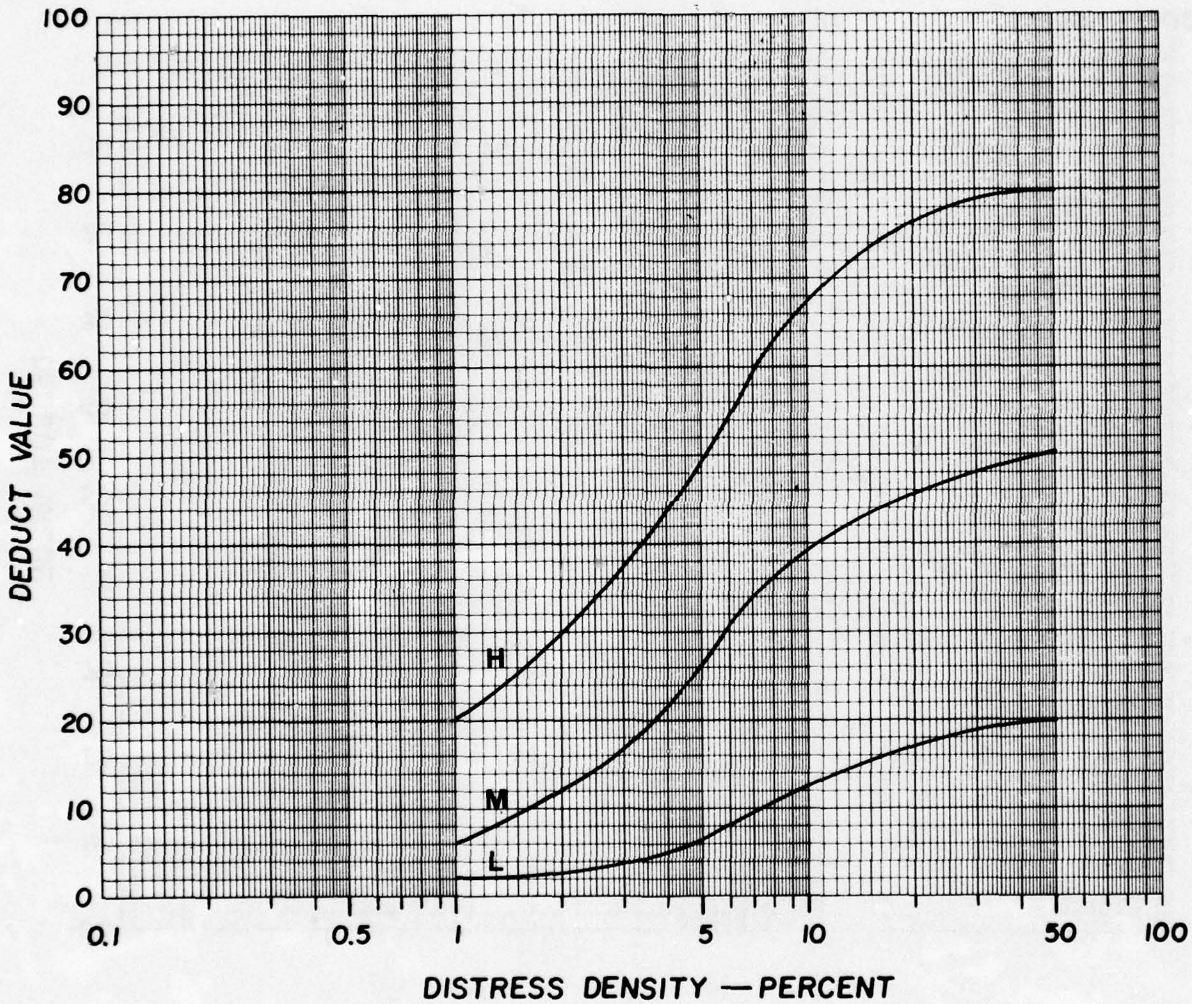


Figure A14. Railroad crossing.

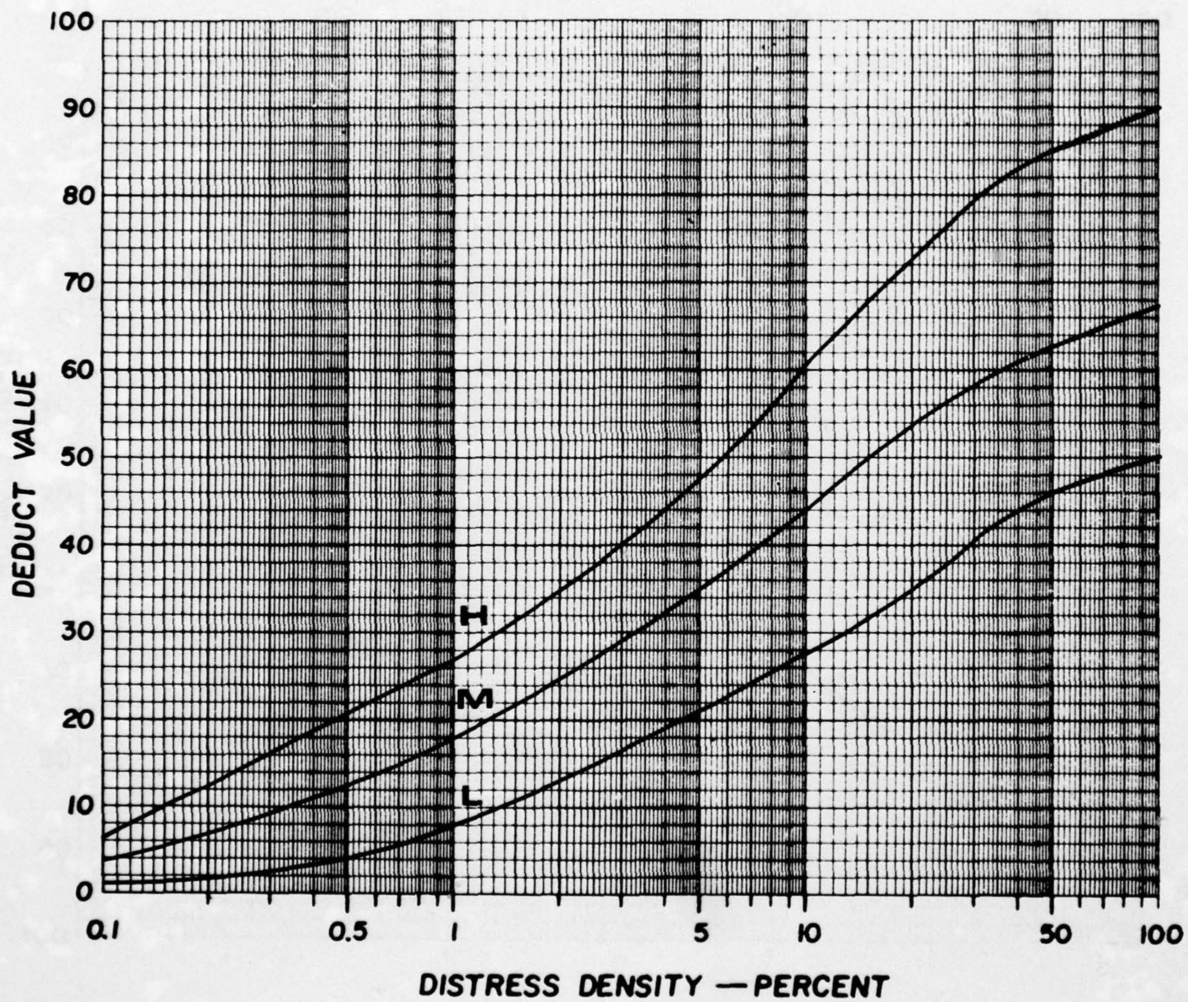


Figure A15. Rutting.

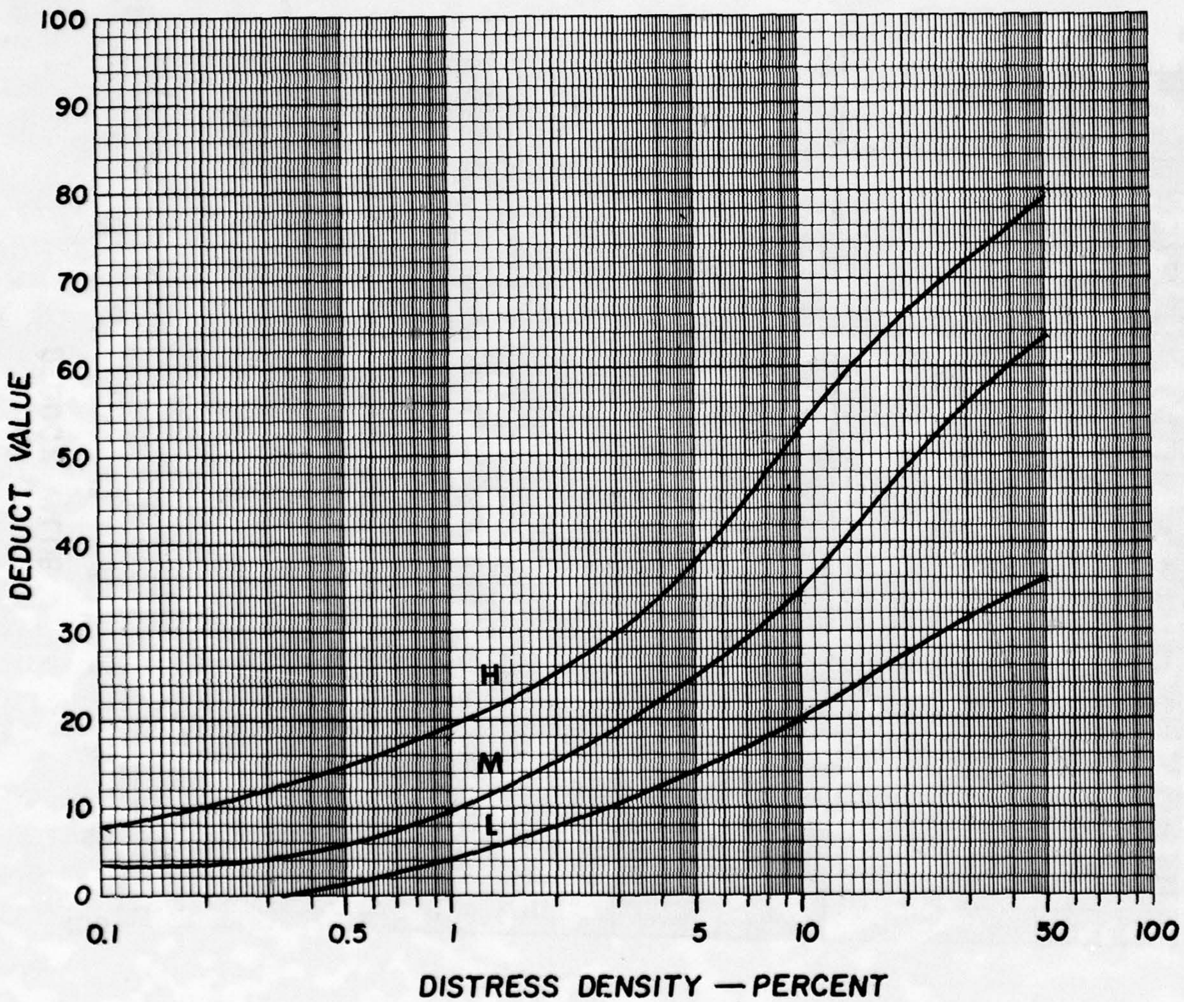


Figure A16. Shoving.

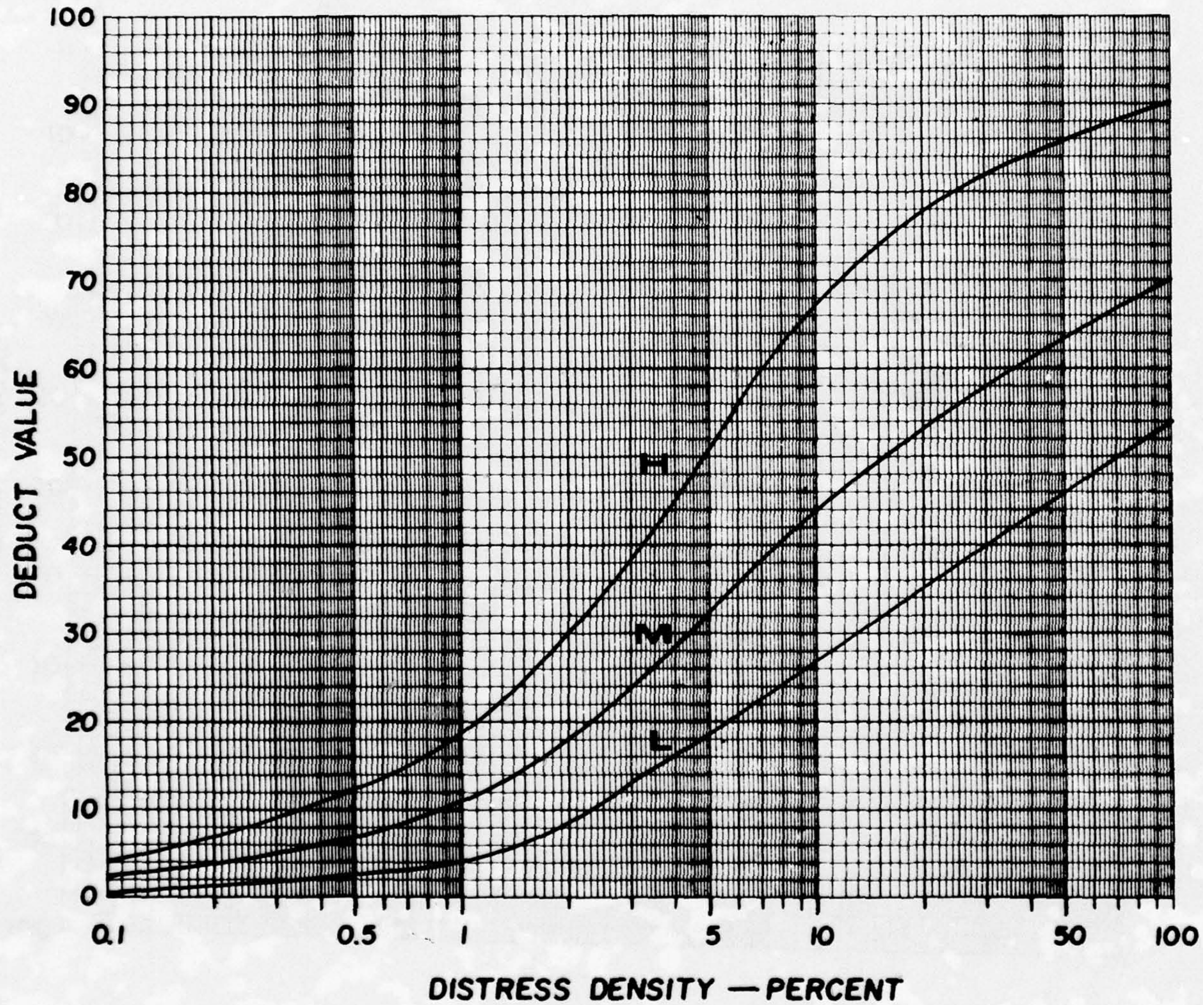


Figure A17. Slippage cracking.

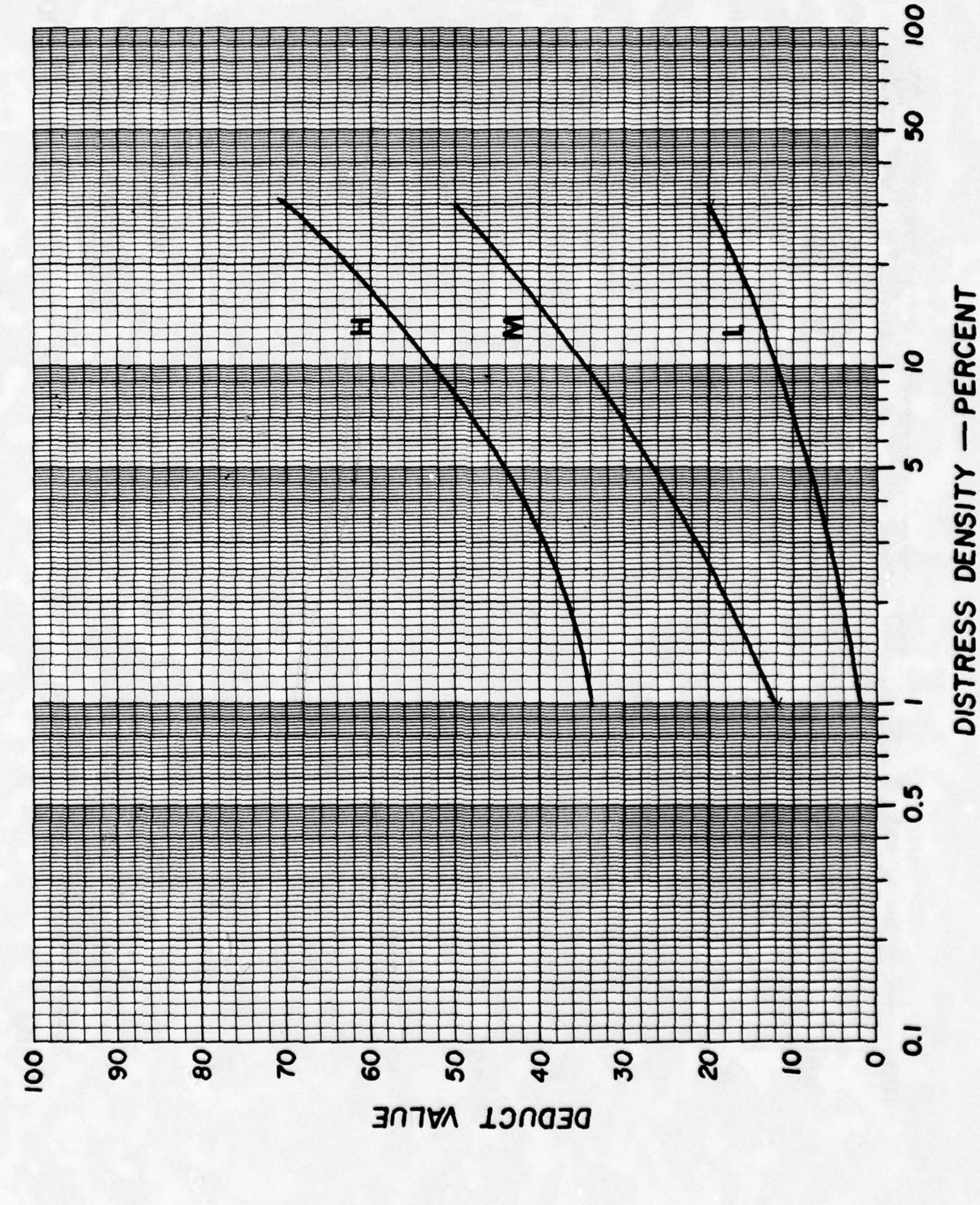


Figure A18. Swell.

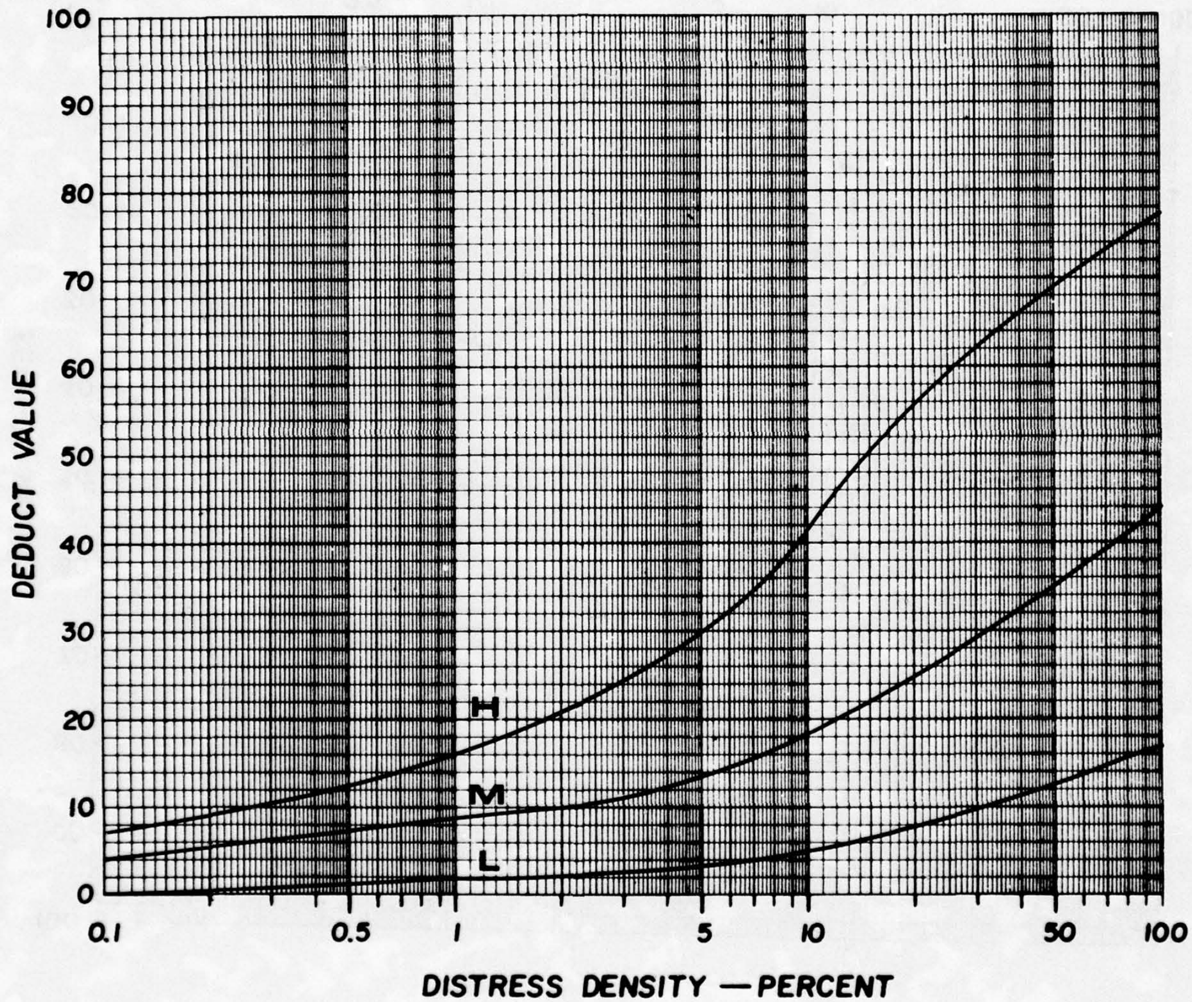


Figure A19. Weathering and raveling.

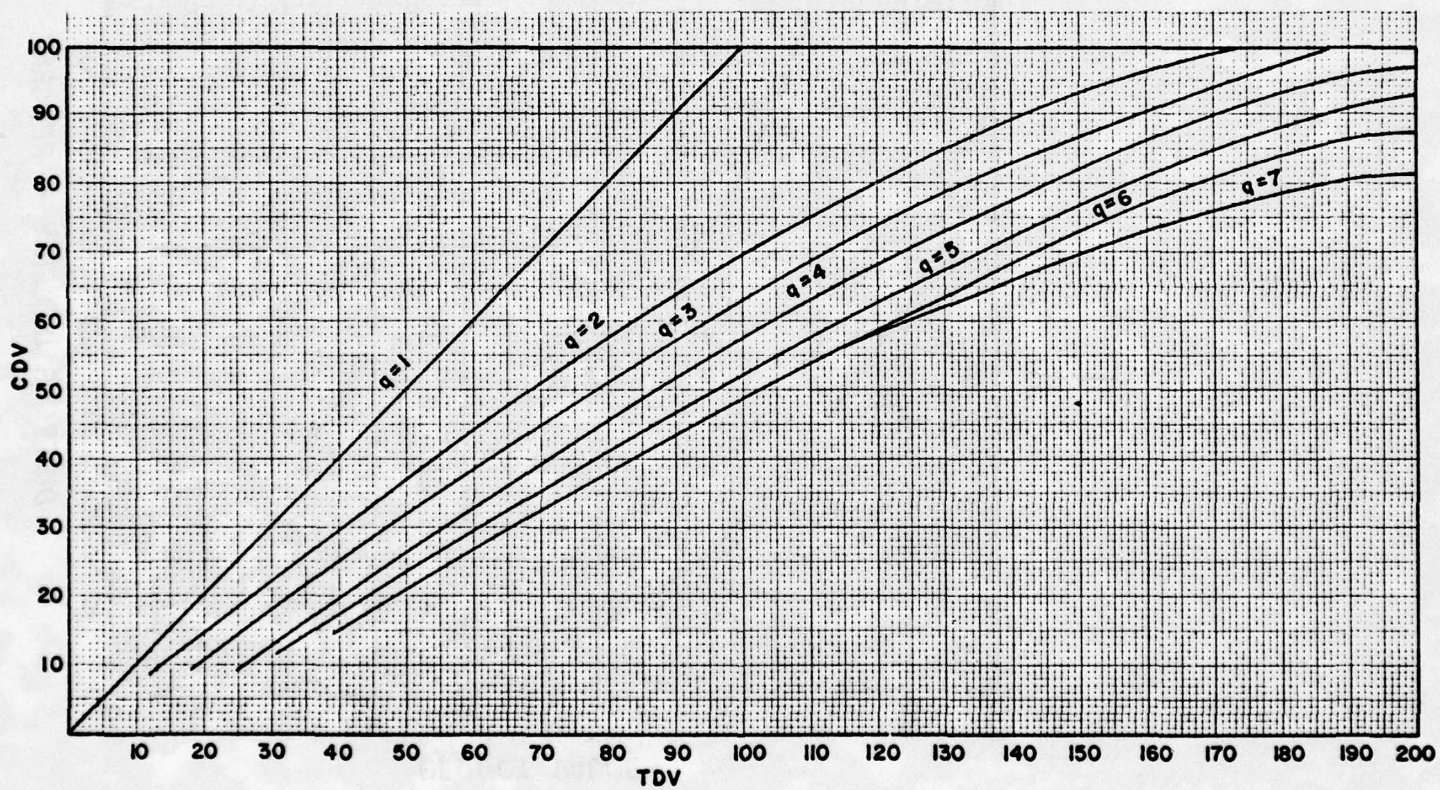


Figure A20. Corrected deduct value curves for asphalt-surfaced pavements.

APPENDIX B:
DEDUCT CURVES FOR CONCRETE (PLAIN AND REINFORCED) SURFACE PAVEMENTS

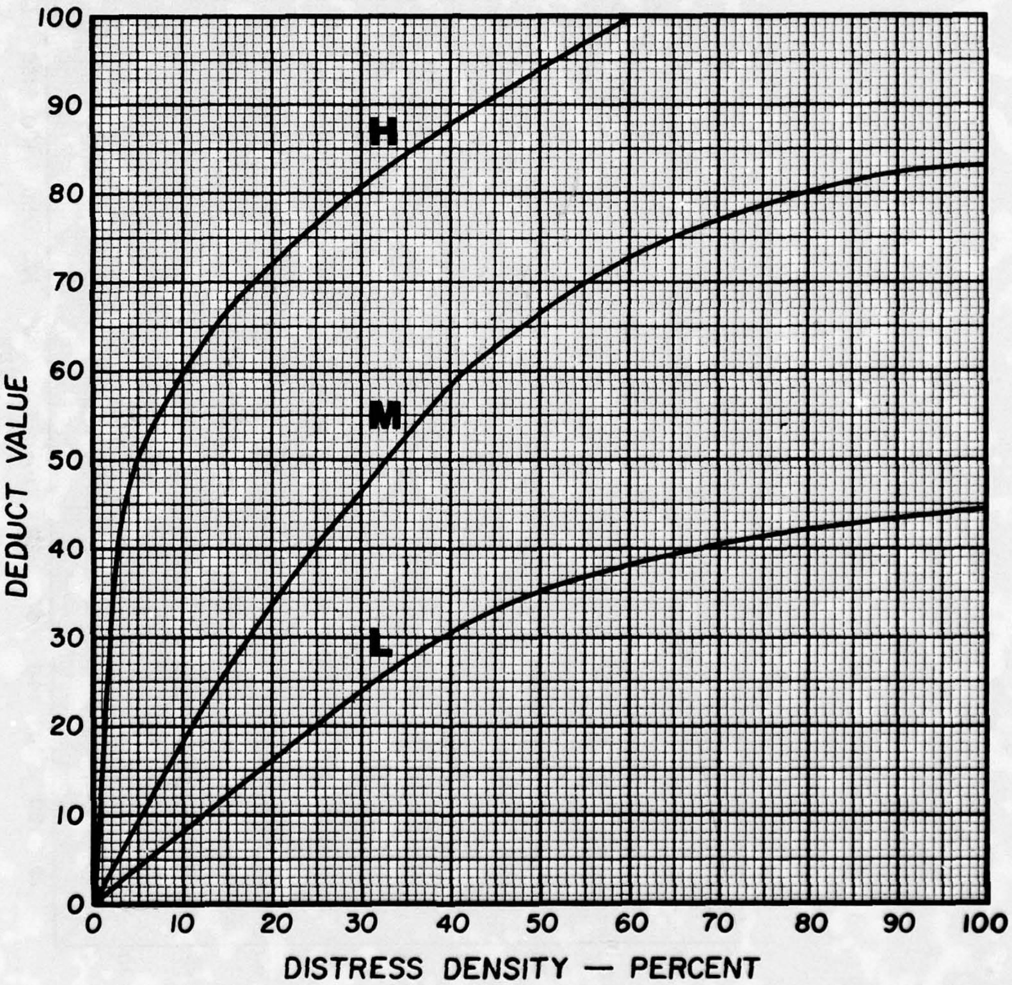


Figure B1 Blow-ups.

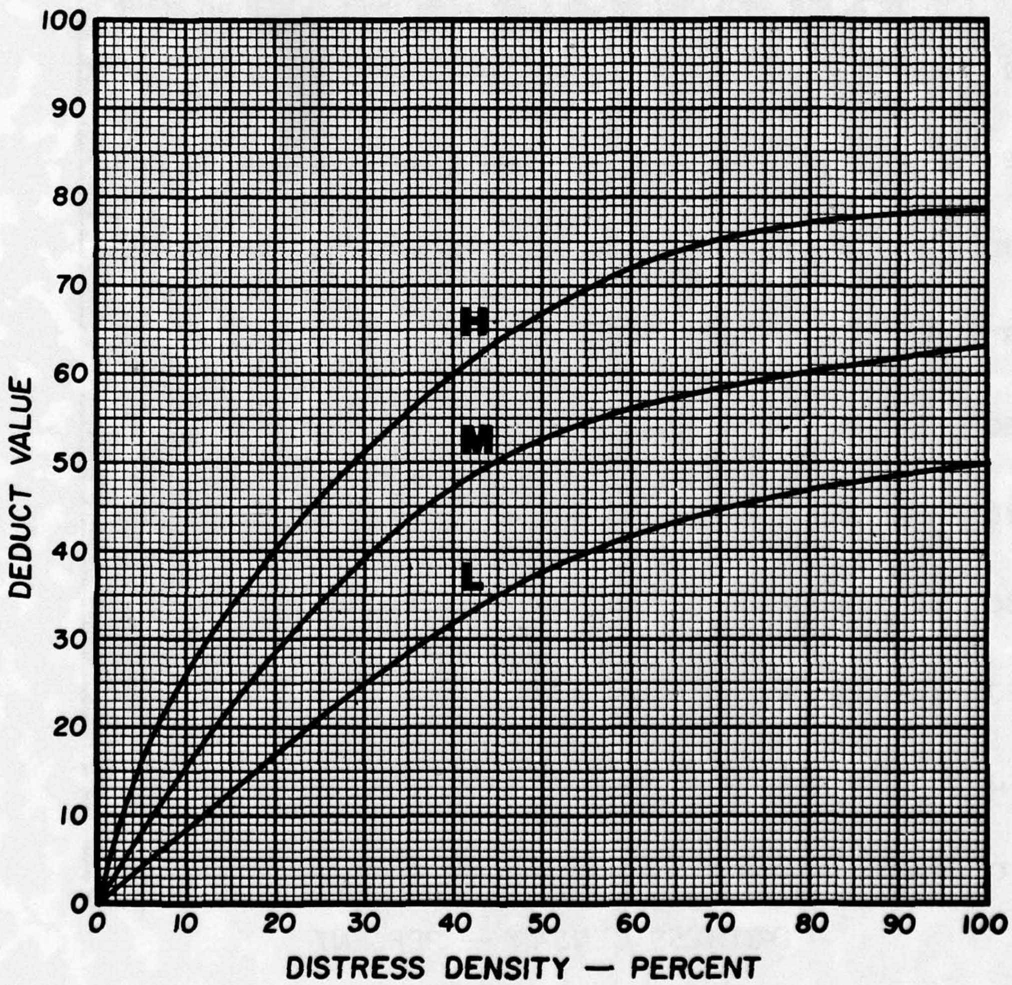


Figure B2. Corner break.

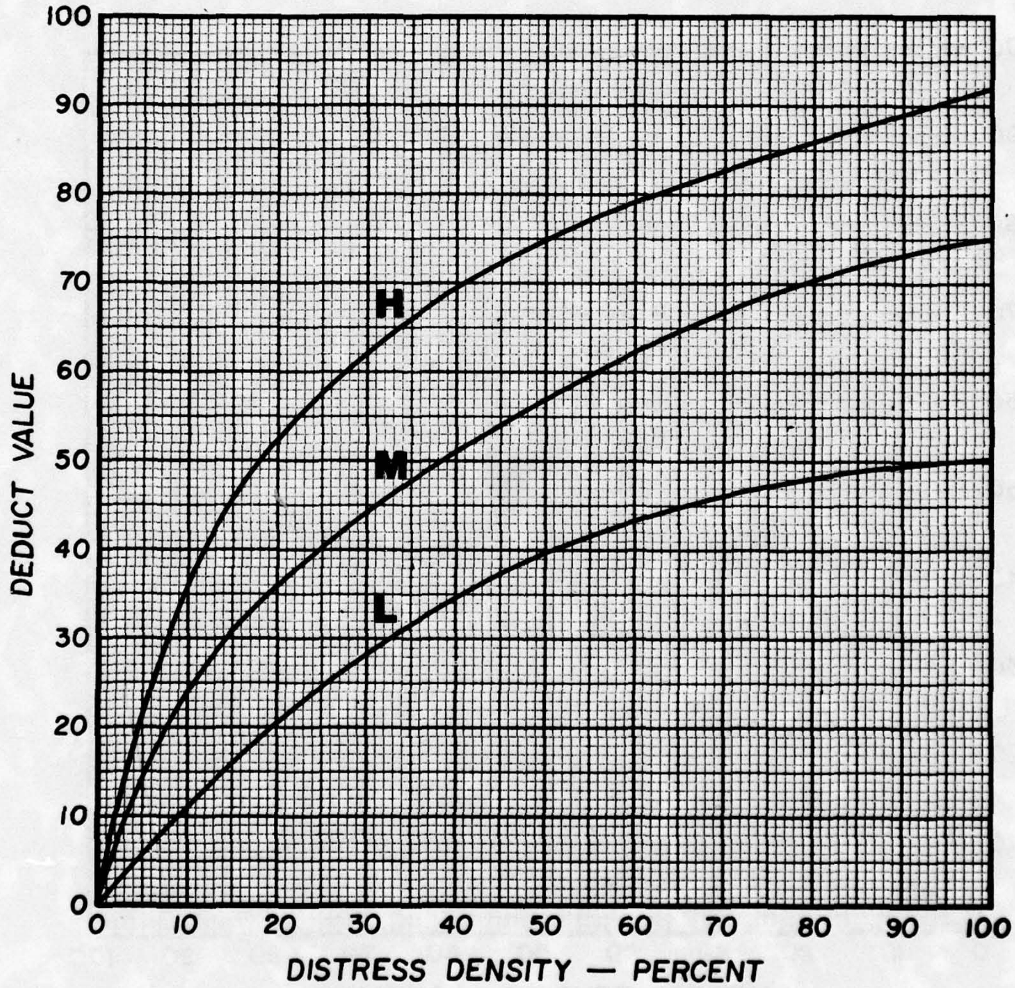


Figure B3. Divided slab.

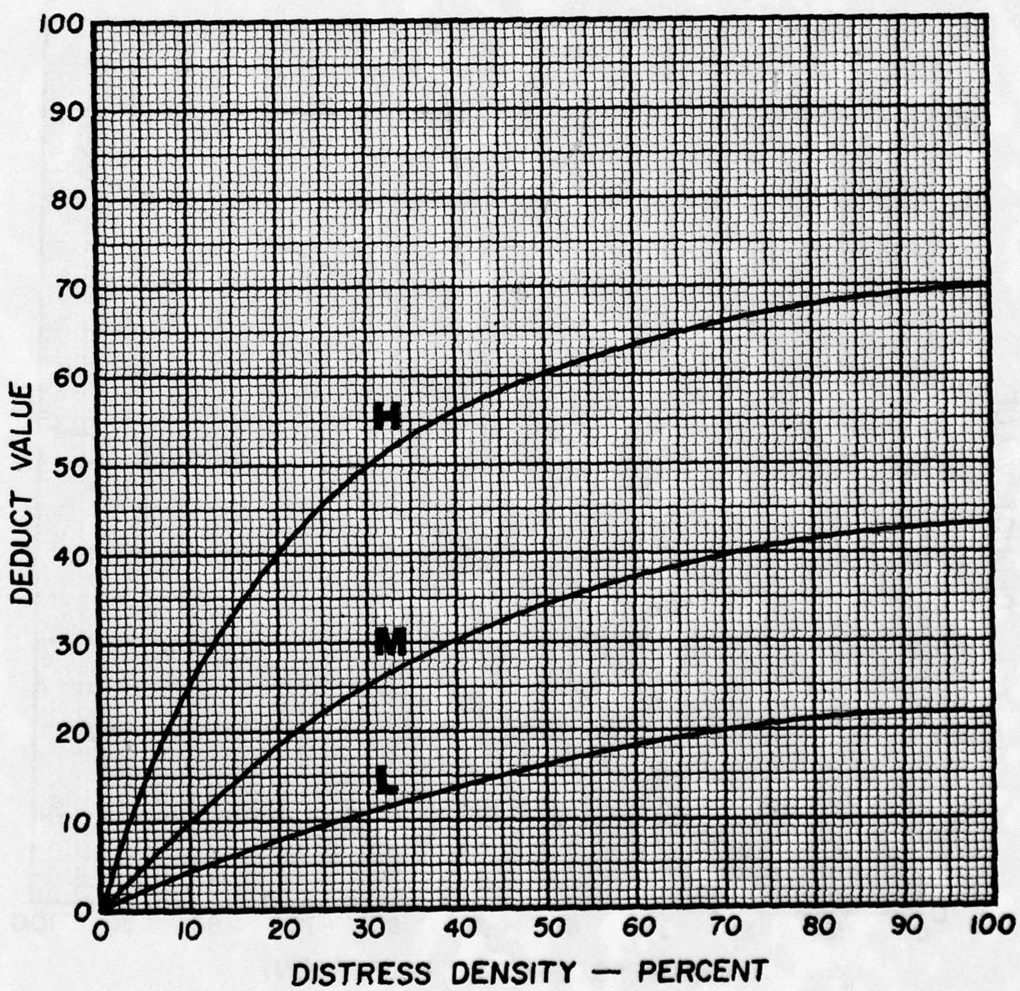


Figure B4. Durability ("D") cracking.

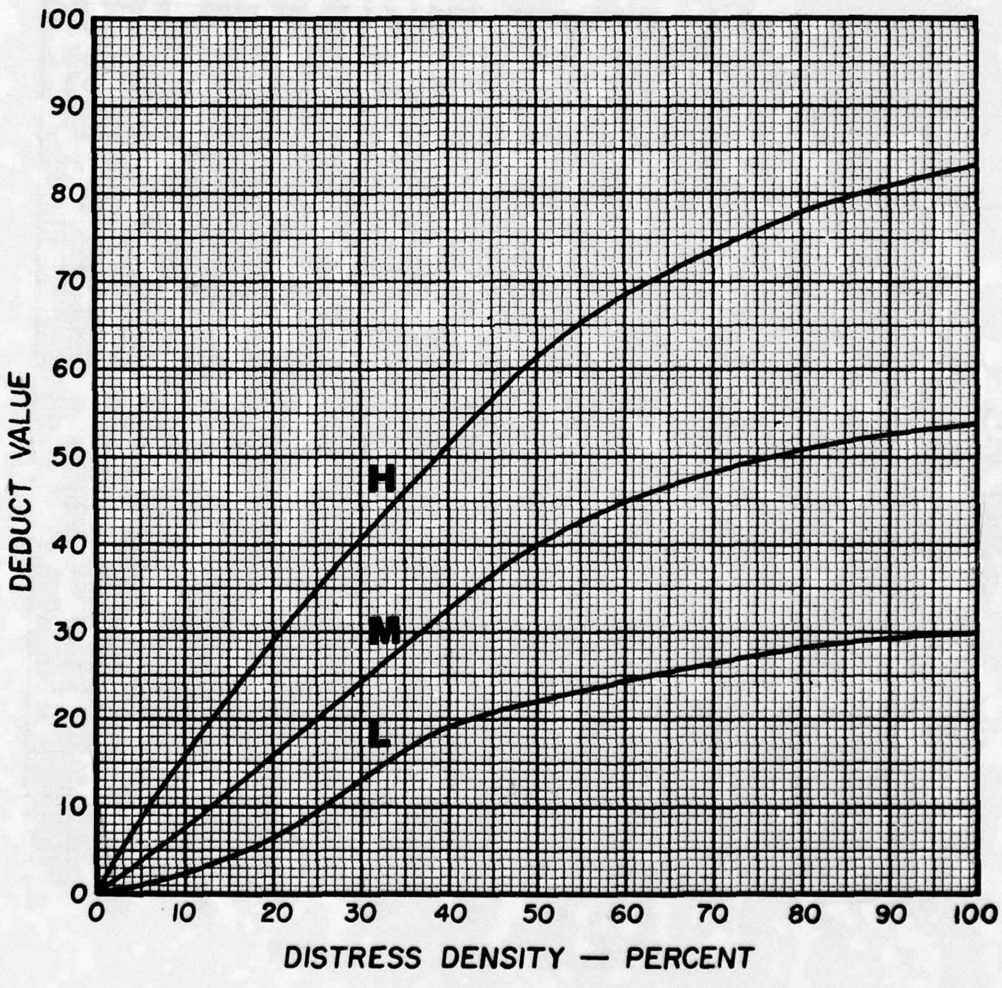


Figure B5. Faulting.

JOINT SEAL DAMAGE

Joint seal damage is not rated by density. The severity of the distress is determined by the sealant's overall condition for a particular sample unit.

The deduct values for the three levels of severity are as follows:

Low	2 points
Medium	4 points
High	8 points

Figure B6. Joint seal damage.

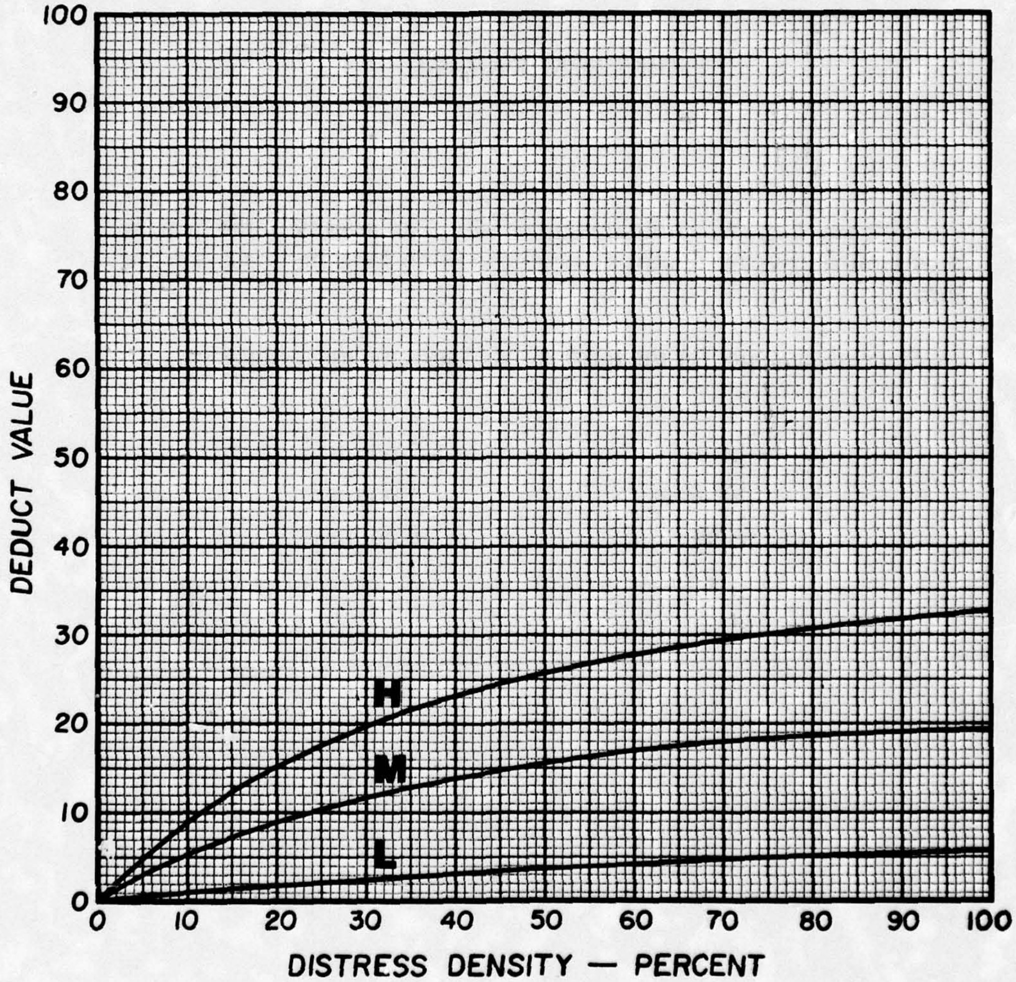


Figure B7. Lane/shoulder drop off.

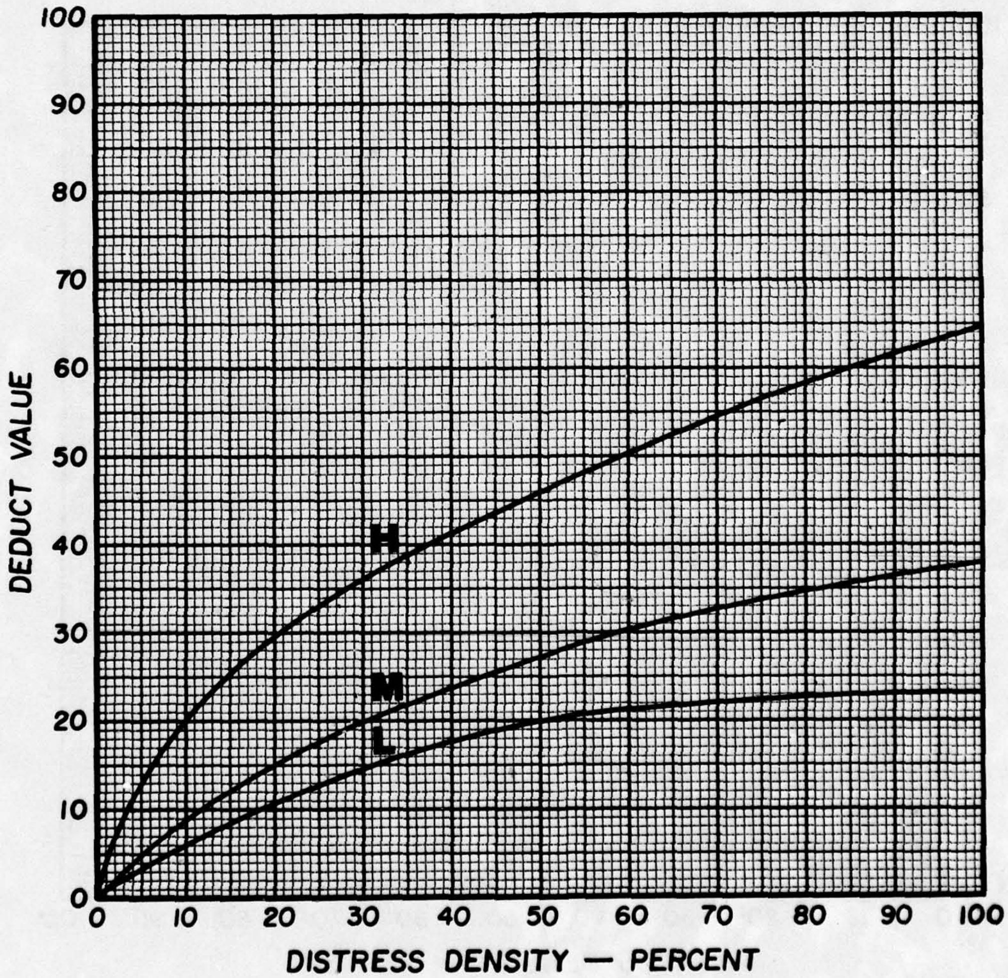


Figure B8. Linear cracking.

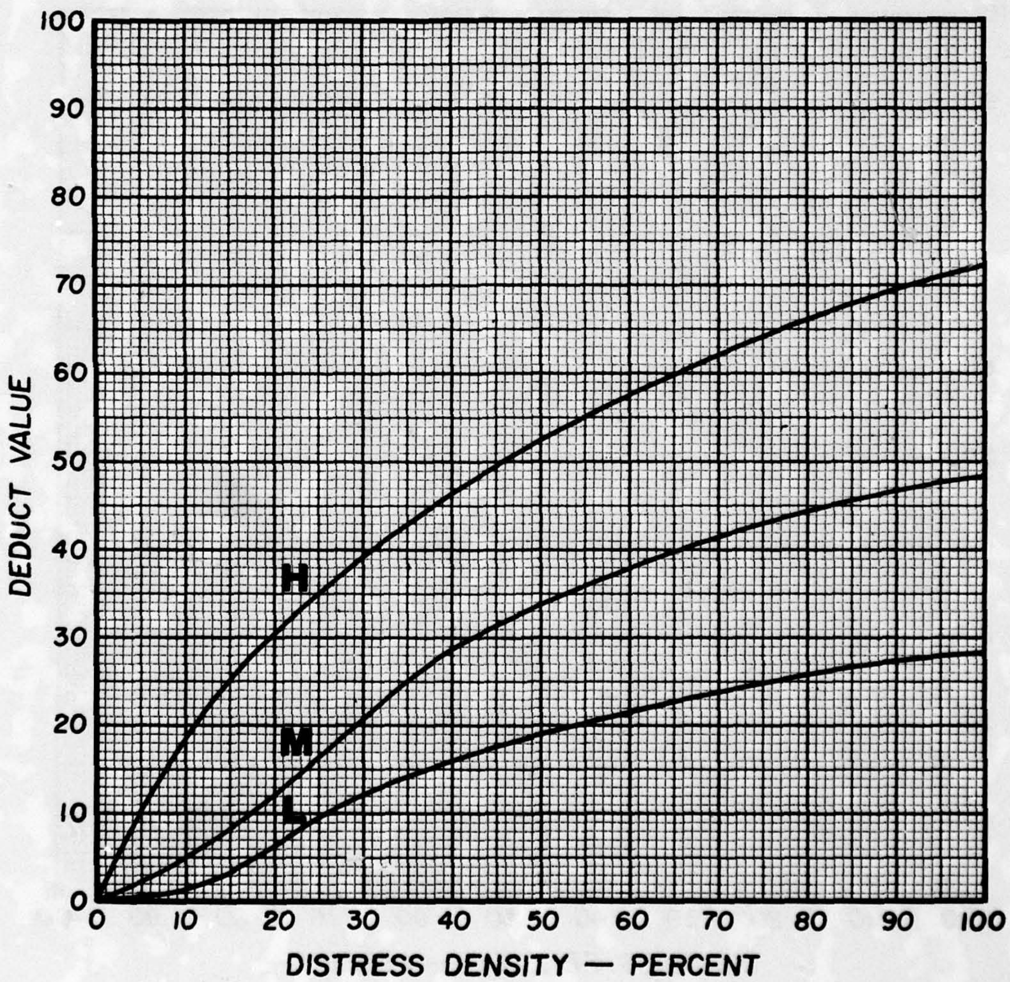


Figure B9. Patching, large and utility cuts.

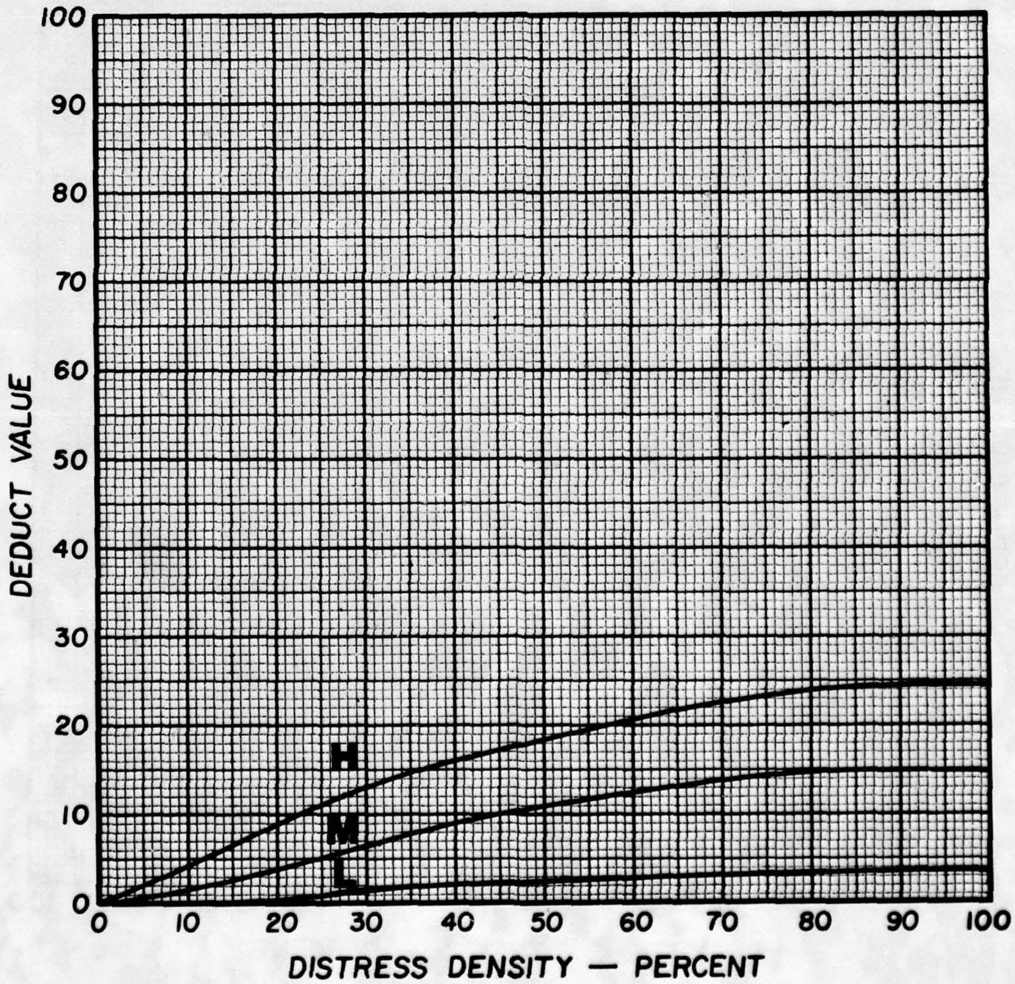


Figure B10. Patching, small.

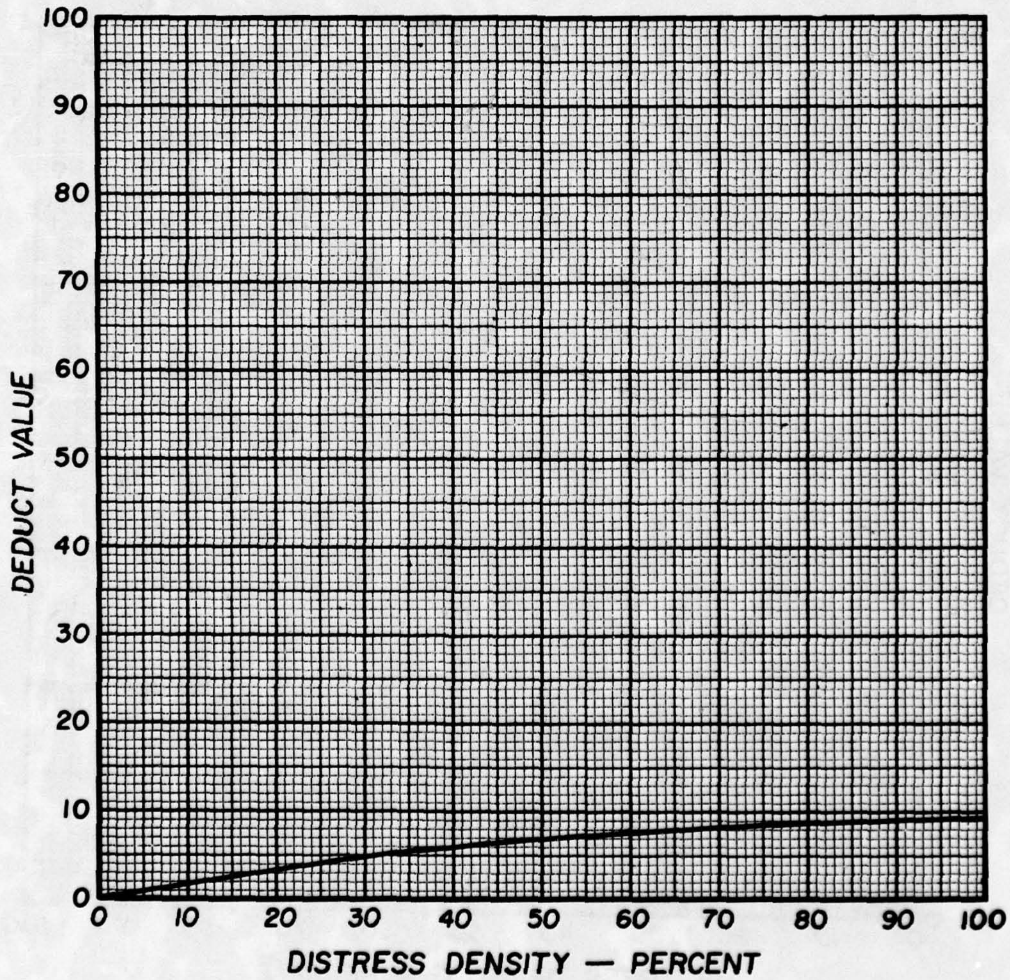


Figure B11. Polished aggregate.

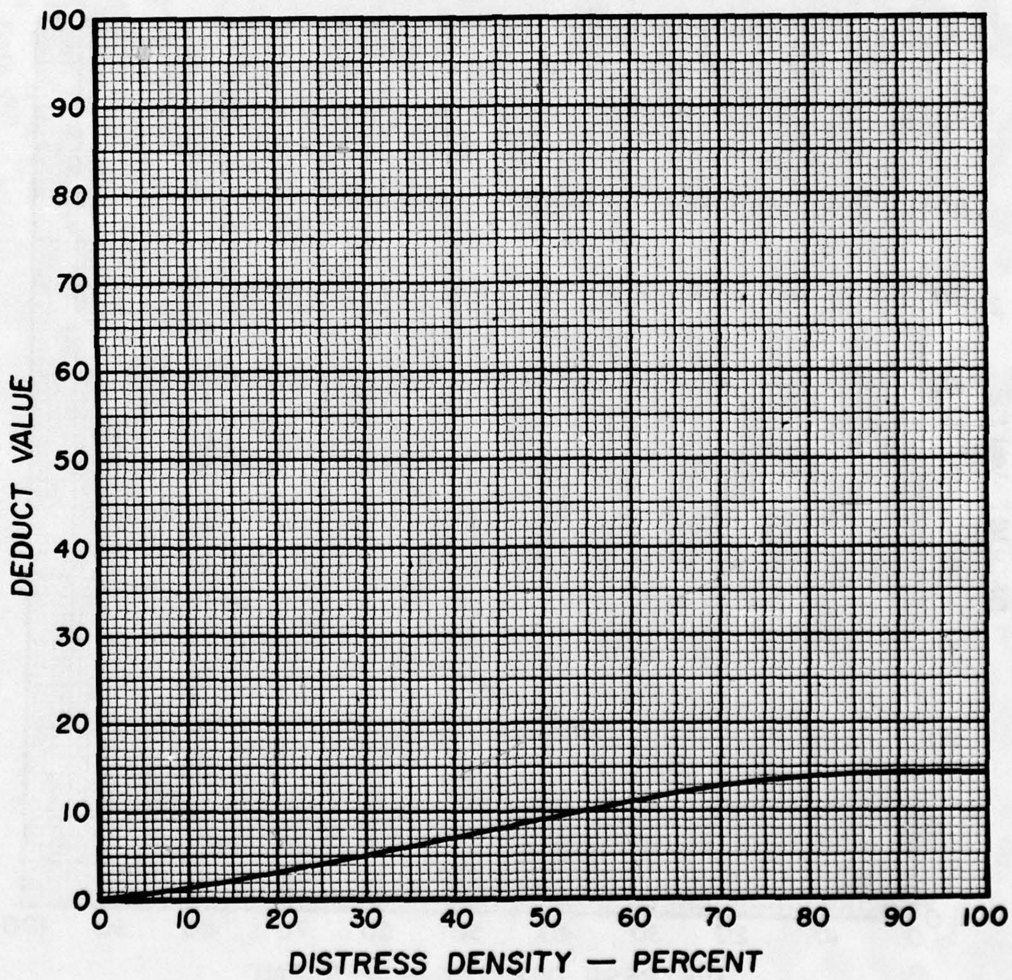


Figure B12. Popouts.

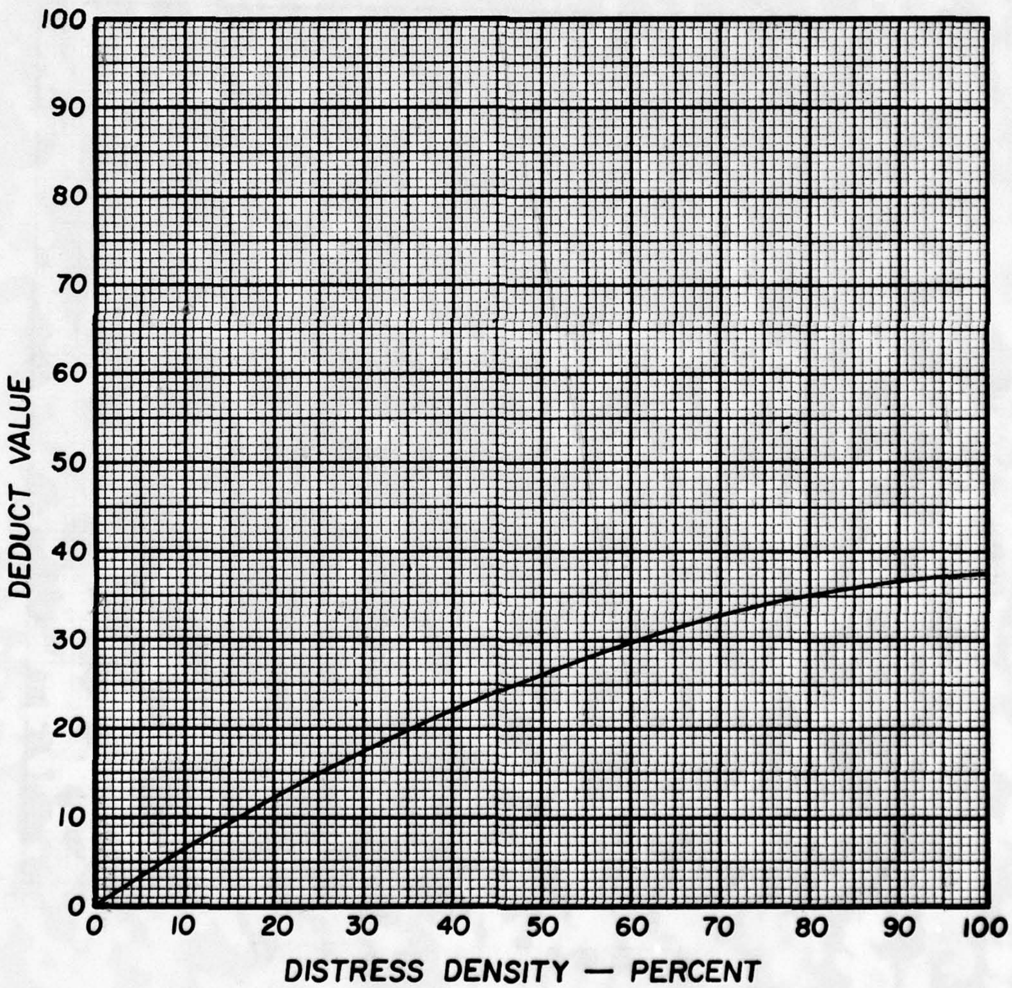


Figure B13. Pumping.

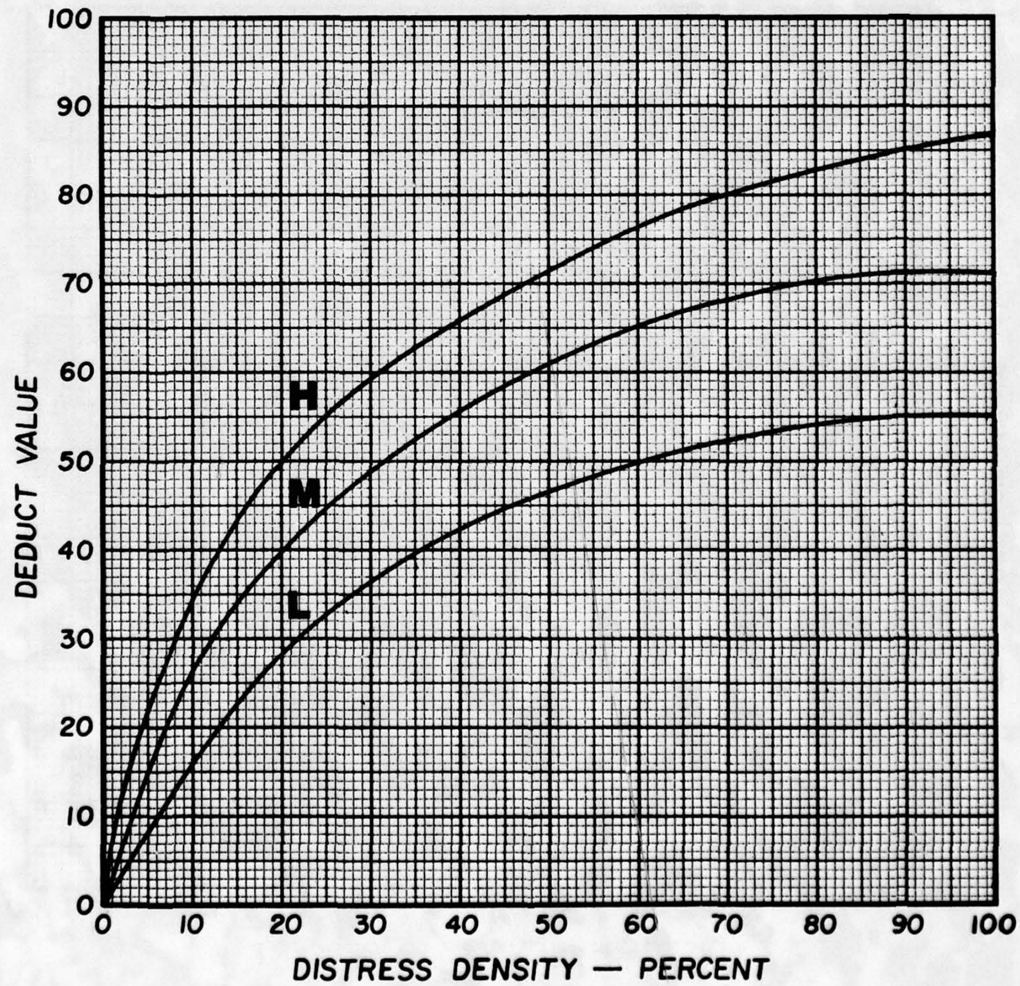


Figure B14. Punchouts.

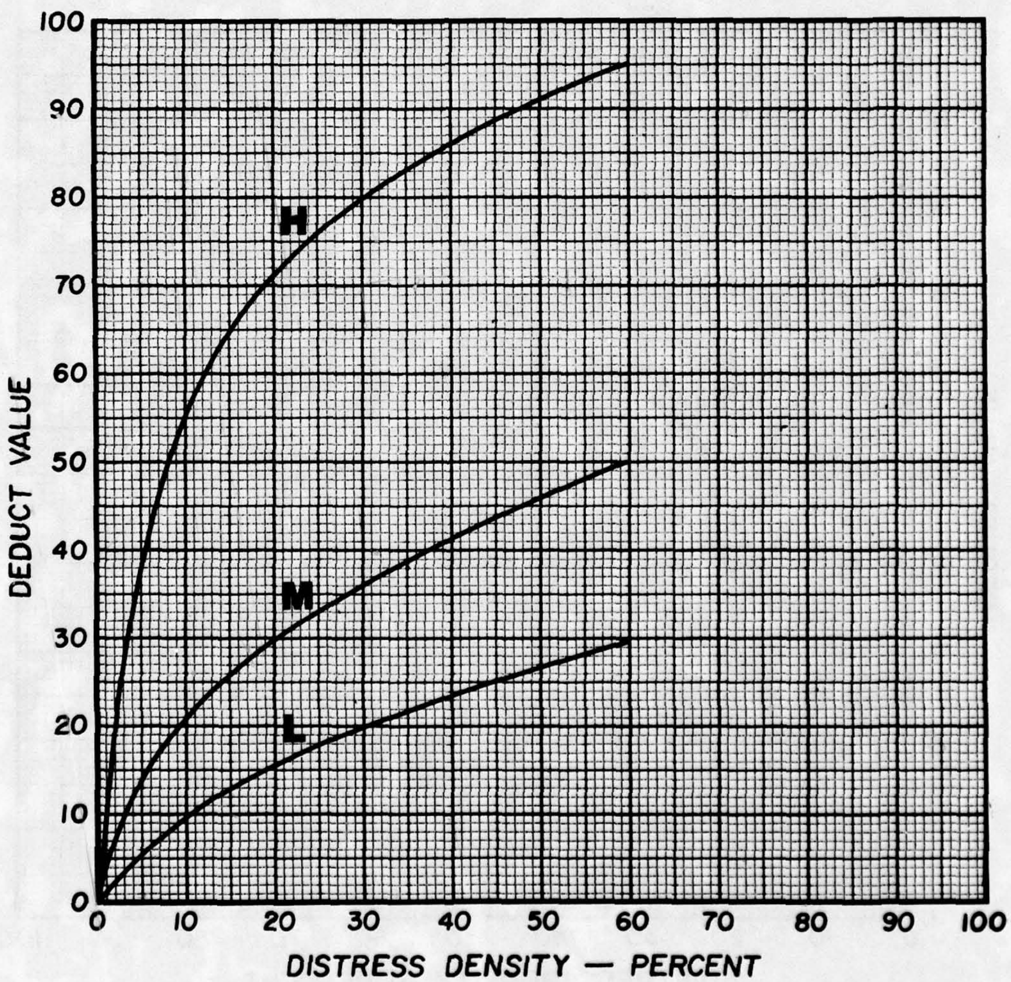


Figure B15. Railroad crossing.

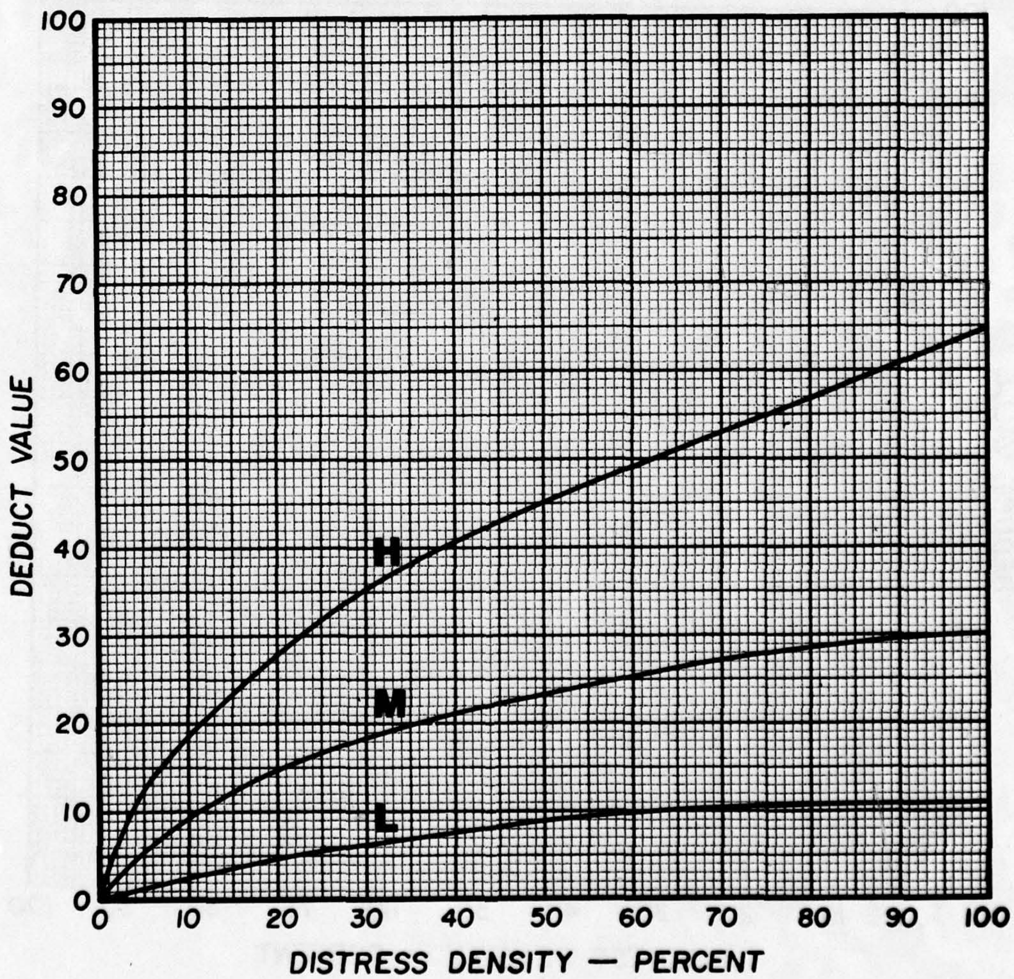


Figure B16. Scaling/map cracking/crazing.

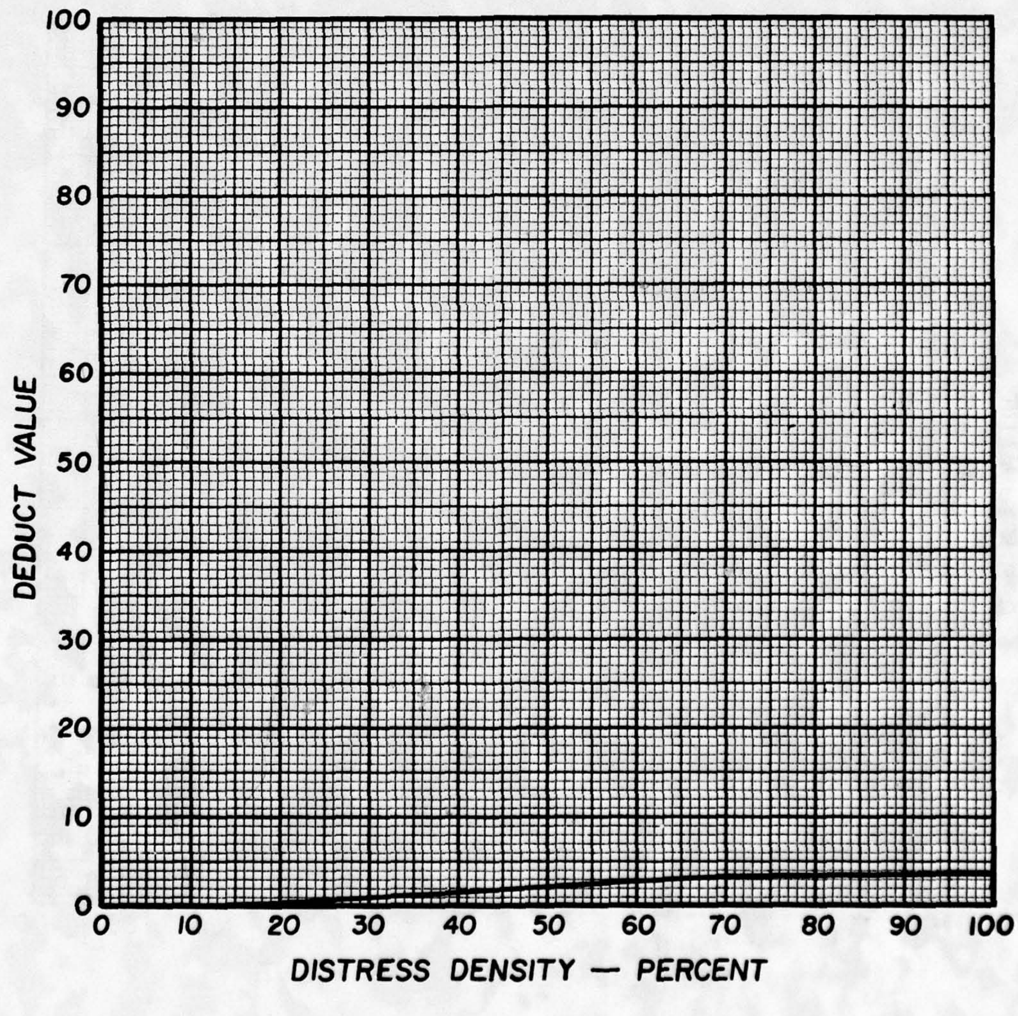


Figure B17. Shrinkage cracks.

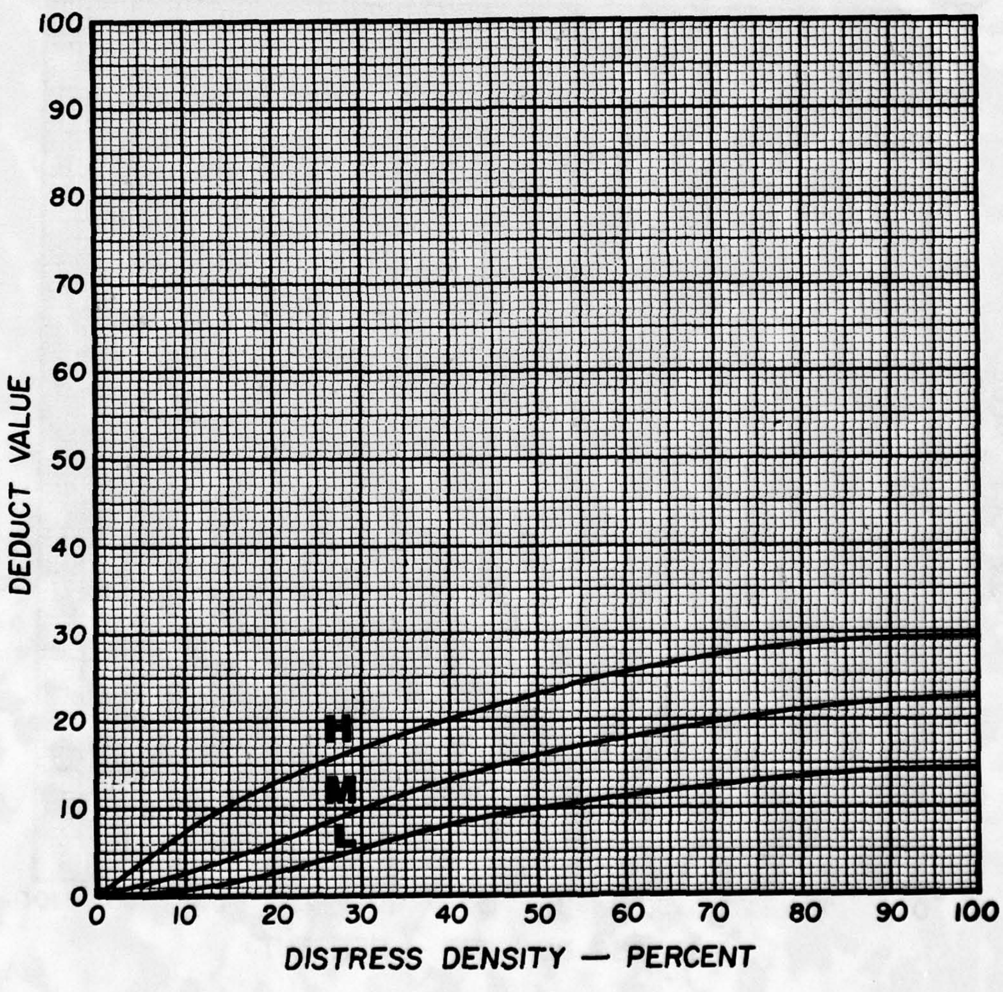


Figure B18. Spalling, corner.

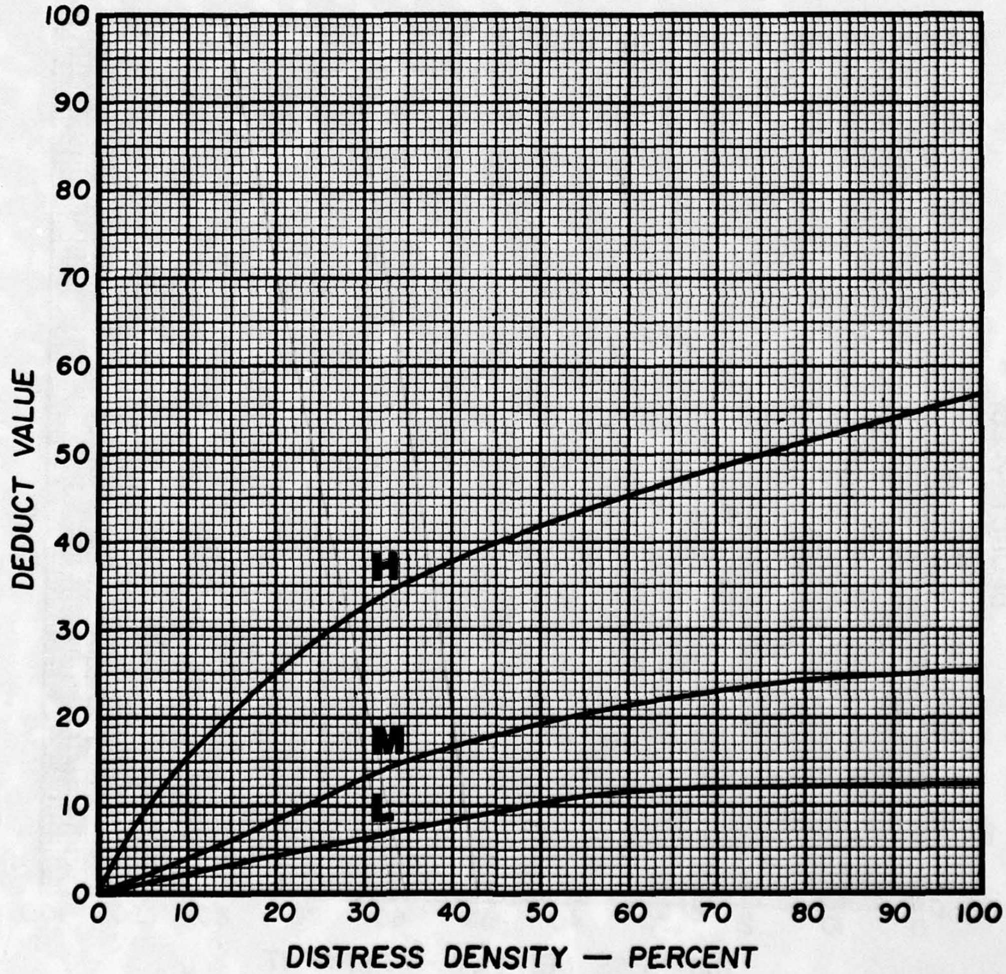


Figure B19. Spalling, joint.

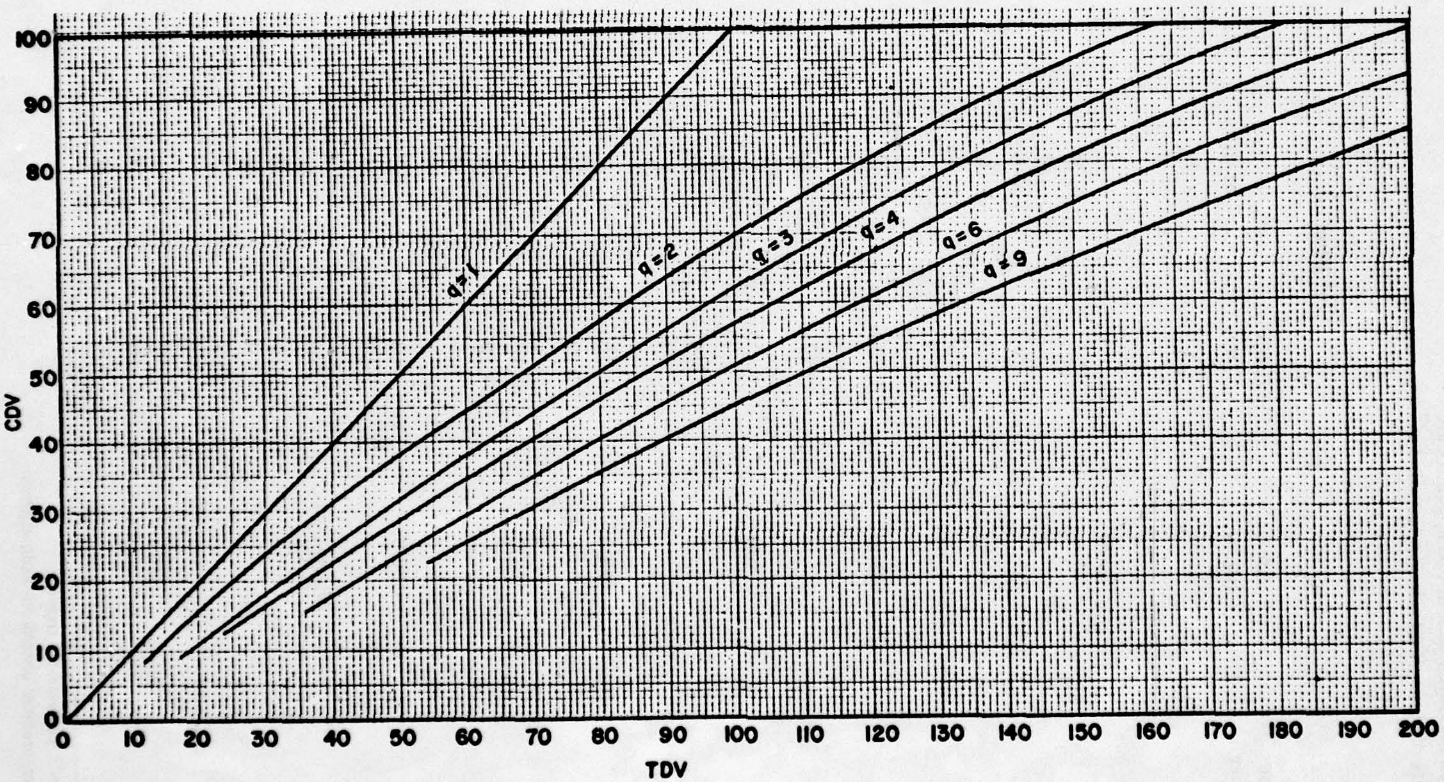


Figure B20. Corrected deduct values for jointed concrete pavements.

APPENDIX C:
DISTRESS DATA FOR ASPHALT-SURFACED PAVEMENT SECTIONS SURVEYED AT ARMY INSTALLATIONS AND USED TO VALIDATE THE PCI

All area measurements in this appendix are in units of square feet. One sq ft = .093 m^2

Fort Benning

Section Number	Area (sq ft)	Distress Type	Severity	Amount†	Density
1	2500	3	L	2250	90
		3	M	250	10
2	2000	3	L	1800	90
		3	M	200	10
		7	H	30	1.5
4*	2400	1	L	10	0.4
		10	L	283	11.8
		9	L	199	8.3
5	2400	1	L	242	10.1
		1	M	103	4.3
		15	L	29	1.2
6	2400	1	L	10	0.4
		1	M	600	25
		15	L	600	25
		9	L	79	3.3
7	2400	10	L	144	6
		9	M	101	4.2
8	2400	10	L	96	4.0
		10	M	19	0.8
		9	M	101	4.2
9	2400	10	L	74	3.1
		10	M	110	4.6
10	2400	10	L	46	1.9
		10	M	65	2.7
		9	M	79	3.3
		9	H	19	0.8
11	2400	10	L	24	1
		10	M	118	4.9
		9	M	101	4.2

*Section 3 was used for training.
†See measurement criteria for each distress.

Fort Benning (Cont'd)

Section Number	Area (sq ft)	Distress Type	Severity	Amount†	Density
12	2400	10	L	6	0.25
		10	M	12	0.5
		9	M	101	4.2
13	2400	7	H	2.4	0.1
		10	L	10	0.4
		10	M	14	0.6
		9	M	60	2.5
		9	H	41	1.7
14	2400	10	L	10	0.4
		10	M	29	1.2
15	2400	10	L	10	0.4
		10	M	7	0.3
16	3600	10	L	36	1
		10	M	58	1.6
		14	L	1296	36
17	2500	3	L	2500	100
18	3600	10	L	47	1.3
		8	M	173	4.8
19	3600	3	L	29	0.8
		4	L	32	0.9
		10	L	101	2.8
		8	L	140	3.9
		8	M	176	4.9
		9	L	22	0.6
20	2200	10	L	17.5	0.8
		10	M	240	10.9
		16	M	44	2
		9	L	200	9.1
21	2200	1	M	409	18.6
		3	M	1100	50
		7	M	35	1.6
		19	H	121	5.5
22	2300	1	H	536	23.3
		7	L	30	1.3
		10	L	22	0.96
23	2400	13	H	4	0.172
		13	M	7	0.296
		7	M	10	0.42

†See measurement criteria for each distress.

Rock Island

Section Number	Area (sq ft)	Distress Type	Severity	Amount†	Density
1	1680	1	M	127	7.56
		1	H	45	2.68
		6	L	63	3.75
		7	M	45	2.68
		7	H	15	0.89
		10	L	8	0.48
		10	M	15	0.89
		11	L	10	0.60
2	2400	10	H	12	0.5
		8	L	187	7.8
		8	M	148	6.2
		8	H	12	0.5
		15	L	162	6.75

Fort Eustis

Section Number	Area (sq ft)	Distress Type	Severity	Amount†	Density
1	2750	1	L	70	2.5
		1	M	145	5.3
		11	M	10	0.4
		19	H	9	0.3
2	2700	7	L	12	0.44
		7	H	44	1.6
		10	L	88	3.3
3	2600	7	L	100	3.8
		10	L	38	1.5
		8	L	18	0.7
4	2550	7	M	36	1.4
		10	L	40	1.6
		10	M	80	3.1
5	2400	1	L	12	0.5
		1	M	105	4.4
		10	L	21	0.9
		10	M	4	0.17
		11	L	162	6.8

†See measurement criteria for each distress.

Fort Eustis (Cont'd)

Section Number	Area (sq ft)	Distress Type	Severity	Amount†	Density
6	2400	1	M	69	2.9
		10	L	16	0.7
		11	L	52	2.2
		11	M	63	2.6
7	2500	1	H	757	30.3
		6	L	34	1.36
		13	H	5	0.2
		19	H	30	1.2
8	2300	1	L	39	1.7
		1	M	339	14.74
		1	H	60	2.61
		10	L	20	0.87
		11	L	200	8.7
		15	L	39	1.7
		15	M	26	1.13
		15	H	66	2.87
9	2625	4	M	12	0.46
		10	L	215	8.2
		10	M	67	2.55
		19	L	2550	97.1
		19	M	75	2.9
10	2150	3	L	40	1.87
		10	L	15	0.7
		10	M	15	0.7
		13	M	1	0.05
		16	H	75.25	3.5

†See measurement criteria for each distress.

Fort Hood

Section Number	Area (sq ft)	Distress Type	Severity	Amount†	Density
1	2500	10	L	15	0.6
		19	L	750	30.0
2	2500	3	L	1600	64.0
3	2500	3	L	1750	70.0
4	2200	3	M	924	42.0
		4	L	3	0.14
		7	L	5	0.23
		7	M	58	2.64
		10	L	39	1.77
		10	M	92	4.2
		10	H	8	0.36
		19	L	27	1.23
		19	M	42	1.91
		15	L	99	4.5
5	1375	1	M	199	14.47
		1	H	90	6.50
		10	L	50	3.60
		11	L	111	8.07
		19	L	400	29.10
6	2500	19	L	2500	100
7	2090	7	L	54	2.6
		10	L	119	5.7
		10	M	5	0.24
		19	L	570	27.3
		8	L	116	5.5
		8	M	66	3.2
8	2200	7	L	13	0.60
		11	L	400	18.20
		10	L	26	1.20
		10	M	15	0.70
		8	L	81	3.70
		8	M	75	3.40
9	2200	7	L	13	0.60
		11	L	400	18.20
		10	L	26	1.20
		10	M	15	0.70
		8	L	81	3.70
		8	M	75	3.40
		15	L	200	9.10

†See measurement criteria for each distress.

APPENDIX D:
DISTRESS DATA FOR JOINTED CONCRETE PAVEMENT SECTIONS SURVEYED AT ARMY INSTALLATIONS AND USED TO VALIDATE THE PCI

Fort Benning

Section Number	Distress Type	Severity	No. of Slabs	Percent of Slabs
1	8	L	4	20
	6	L	...	...
	9	L	8	40
	9	M	2	10
	11	L	20	100
	16	L	10	50
	19	L	1	5
	19	M	2	10
	18	L	1	5
	10	L	4	20
	17	L	7	35
2	1	L	2	10
	1	M	1	5
	8	L	6	30
	8	H	1	5
	5	L	1	5
	5	M	1	5
	6	L	...	...
	9	L	9	45
	9	M	3	15
	11	L	20	100
	16	L	5	25
	19	L	2	10
	19	M	4	20
	19	H	1	5
	18	L	3	15
	10	M	1	5
	10	H	2	10
	17	...	5	25
3	1	L	2	10
	8	L	2	10
	6	L	...	...
	9	L	10	50
	9	M	3	15
	17	...	5	25
5*	6	H	...	...
	11	...	1	5.6
	18	L	4	22
	10	L	1	5.6
	17	...	2	11

*Section 4 was used for training.

Fort Benning (Cont'd)

Section Number	Distress Type	Severity	No. of Slabs	Percent of Slabs
6	8	L	1	5
	8	M	12	60
	6	H	...	...
	3	M	4	20
	3	H	2	10

Rock Island

Section Number	Distress Type	Severity	No. of Slabs	Percent of Slabs
1	8	M	6	33
	8	H	1	6
	6	H	...	...
	11	...	18	100
	19	L	9	50
	19	M	1	6
	19	H	2	11
	10	L	1	6
	14	L	1	6
	14	M	1	6
2	8	L	2	13.3
	8	M	5	33.3
	6	H	...	...
	11	...	15	100
	19	L	6	40
	18	L	3	20
	10	L	6	40
	10	M	1	6.7
3	8	L	4	27
	8	M	3	20
	6	H	...	...
	9	L	1	7
	19	L	12	80
	19	M	1	7
	18	L	1	7

Fort Eustis

Section Number	Distress Type	Severity	No. of Slabs	Percent of Slabs
2	4	L	1	6
	6	M	...	...
	16	L	1	6
	3	M	4	22
	3	H	12	67
3	8	L	2	11
	4	L	7	39
	6	H	...	...
	13	...	18	100
4	8	L	1	6
	4	L	12	67
	4	M	3	17
	19	L	1	6
	2	M	1	6
	6	M	...	...
5	8	L	1	6
	8	M	4	22
	8	H	3	17
	4	L	1	6
	5	L	3	17
	5	M	2	11
	5	H	5	28
	6	H	...	...
	9	L	1	6
	9	M	1	6
	13	...	2	12
	3	M	2	12
	3	H	1	6
6	8	L	1	7
	4	L	2	14.3
	4	M	1	7
	9	L	3	21.4
	9	M	5	35.7
	9	H	3	21.4
	16	L	1	7
	16	M	3	21.4
7	6	H	...	...
	11	...	2	10
	16	L	2	10
	7	L	1	5
	7	M	1	5

Fort Eustis (Cont'd)

Section Number	Distress Type	Severity	No. of Slabs	Percent of Slabs
8	6	L	...	...
	5	L	1	7
	5	M	1	7
	9	L	2	14
	16	L	7	50
	16	M	3	21.4
	16	H	4	28.6
	10	L	3	21.4
9	8	L	2	12.5
	5	L	3	18.75
	5	M	1	6.25
	6	H	...	...
	18	L	1	6.25
10	8	M	2	10
	4	L	1	5
	5	L	1	5
	6	L	...	...
	2	M	1	5
11	8	L	2	10
	8	M	2	10
	5	L	4	20
	5	M	1	5
	6	L	...	...
	19	L	1	5
	18	M	1	5
12	5	M	2	10
	6	H	...	...
	9	L	4	20
	9	M	1	5
	16	L	4	20
	19	M	2	10
	18	M	1	5
	2	L	1	5

Fort Hood

Section Number	Distress Type	Severity	No. of Slabs	Percent of Slabs
1	8	M	10	50
	6	H	20	100
2	8	L	1	5
	8	M	1	5
	6	H	20	100
	17	...	8	40
3	8	L	6	30
	6	H	20	100
	13	...	20	100
	19	M	1	5
	2	L	1	5
	17	...	10	50
4	8	L	5	27.8
	6	M	...	...
	17	...	14	77.8
5	8	L	2	11
	6	M	...	...
	19	L	1	5.5
	17	...	8	44.4
6	6	M	...	...
	19	L	1	5
	18	L	1	5

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Shahin, Mohamed Y
Development of a pavement condition rating procedure for roads, streets, and parking lots / by Mohamed Y. Shahin, Starr D. Kohn. -- Champaign, IL : Construction Engineering Research Laboratory ; Springfield, VA : available from NTIS, 1979.
2v. ; 27 cm. (Technical report ; M-268)

Contents: v.1. Condition rating procedure -- v.2. Distress identification manual.

1. Pavements -- evaluation. I. Kohn, Starr D. II. Title. III. Series: U.S. Army Construction Engineering Research Laboratory. Technical report ; M-268.

AD-A074 170   CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL F/G 13/2
DEVELOPMENT OF A PAVEMENT CONDITION RATING PROCEDURE FOR ROADS,--ETC(U)
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Errata sheet for Technical Report M-268, *Development of a Pavement Condition Rating Procedure for Roads, Streets, and Parking Lots, Volume I: Condition Rating Procedure*, by Mohamed Y. Shahin and Starr D. Kohn, July 1979, ADA074170.

Page 12, line 10 of column 1, change t_i to T_i.

Page 13, line 4 of column 2, change (PCRs) to ($\overline{PCR}$s)

Page 13, line 5 of column 2, change PCR to $\overline{PCR}$.

Pages 25 and 26, in Figures 16 and 17 delete the U from 19. "Spalling, U Joint."

Page 27, Eq 3 should read: $$\sigma = \sqrt{\frac{\sum_{i=1}^{R} (PCI_i - \overline{PCI})^2}{R-1}}$$

Page 27, Eq 5 should read: $$n = \frac{25(10)^2}{\left(\frac{5}{4}\right)^2 (25-1) + (10)^2} = 10$$

Page 32, line 10 of column 1, change 25/20 to 25/10.

Page 34, column 1, step 4, change second paragraph to read:

> When determining the CDV, if an individual deduct value is higher than the CDV, the CDV is set equal to the highest individual deduct value. For example, assume the case where two distresses were found in an asphalt pavement, one with a deduct value of 50 and the second with a deduct value of 10. Using Figure A20, the CDV for $q = 2$ is 44. Since 44 is lower than 50, the CDV is set equal to 50.

Page 36, column 2, line 27, change PCR to $\overline{PCR}$.