Development of Revised Pavement Condition Indices for Portland Cement Concrete Pavement for the WSDOT Pavement Management System

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WA State Transportation Center

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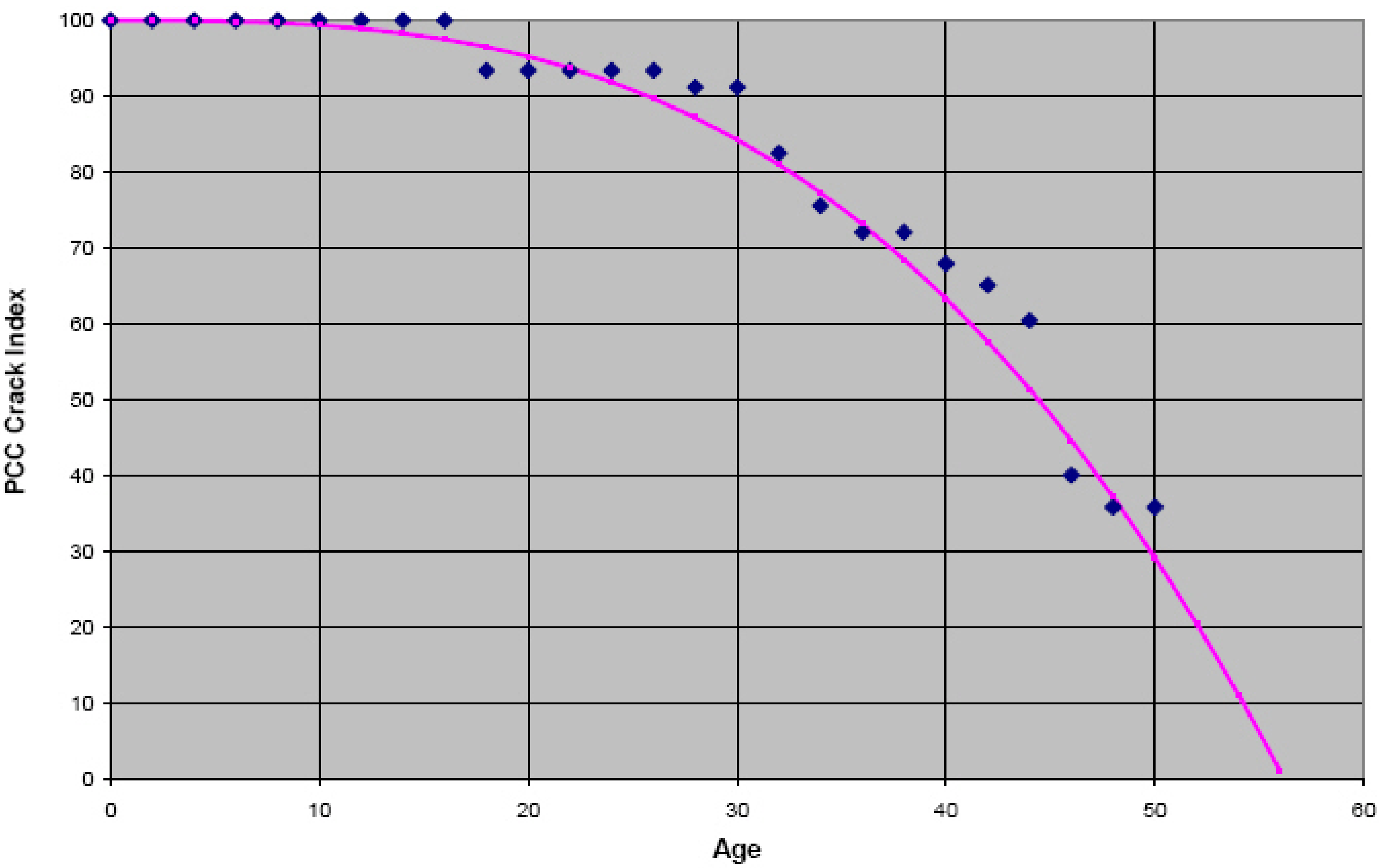

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WSDOT Research Report

RESEARCH REPORT
Agreement T4118, Task 02
Pavement Deterioration

DEVELOPMENT OF REVISED PAVEMENT CONDITION INDICES FOR PORTLAND CEMENT CONCRETE PAVEMENT FOR THE WSDOT PAVEMENT MANAGEMENT SYSTEM

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Revised pavement condition indices that address specific pavement distress types have been proposed for WSDOT to use on PCC pavements. The indices are related to the types of distress that WSDOT experiences on its PCC pavements and are calibrated to the damage levels that it has adopted for rehabilitation or reconstruction activities.

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INTRODUCTION AND BACKGROUND

The pavement condition indices currently used in the Washington State Pavement Management System (WSPMS) were established in 1981 during the original development of the system. (Nelson and LeClerc 1982) WSDOT had been monitoring pavement condition from 1967 as part of its Priority Programming process. The original WSDOT pavement condition indices were developed in the mid 1960s for that program. (LeClerc and Marshall 1970)

The Priority Program Portland Cement Concrete Pavement (PCCP) condition index was a composite index composed of cracking, scaling, spalling at joints and cracks, pumping, blowups, faulting, patching, and rutting. In the development of the WSPMS, the PCC pavement condition index was simplified by applying weighting values only to cracking, spalling, and faulting, as shown in Table 1.

Table 1. WSPMS PCCP Defect Deductions. (Kay et al. 1993) [i]

				Percent of Panels		
				1-25	26-50	51+
Cracking Averaging 1/8+	Units per Panel Length	(1)	1-2	5	10	20
		(2)	3-4	10	20	35
		(3)	4+	15	30	50
				Percent of Joints		
				1-15	16-50	51+
Spalling at Joints and Cracks	Average Width in Inches	(1)	1/4-1	5	10	15
		(2)	1-3	10	20	30
		(3)	3+	15	30	50
				Percent of Panels		
				1-15	16-35	36+
Faulting, Settlement	Average Displacement in Inches	(1)	1/8-1/4	5	10	20
		(2)	1/4-1/2	10	20	30
		(3)	1/2+	15	30	40

The Pavement Condition Rating (PCR) was calculated by applying the deduction values noted in Table 1 to the predominate distress surveyed in the field and subtracting the sum of those values from 100. The composite pavement condition index produced ranged from 100 (no distresses measured) to 0 indicating significant pavement distress.

$$PCR = 100 - \Sigma \text{ Deducts} \quad \text{(Equation 1)}$$

In addition to simply summing the deduct values, there was also an adjustment factor that truncated the values as they approached 0 to eliminate negative values.

The author was involved in the development of the deduct values noted in Table 1 for the WSPMS. The general trends in pavement deterioration were evaluated for all eight deficiencies included in the existing system. The surveys between 1967 and 1979 were reviewed in detail, looking for consistent trends over time. There were few or no consistent trends for the categories of scaling, pumping, blowups, patching, and rutting. Only the distress categories of cracking, spalling, and faulting showed a reasonable progression of increasing distress with time.

The progression of pavement distress should be consistent with the accumulation of structural deterioration over time and loading. Thus it makes sense that one should see a progression of distress with cracking and faulting that directly relates to structural deterioration. Scaling and blowups are caused by environmental and material combinations rather than structural loading and will not deteriorate in a uniform trend with time.

In 1991–1992, a study was conducted to re-evaluate the WSDOT pavement condition indices, and a new defect deduction scheme was proposed that modified deduct values for cracking, spalling at joints and cracks, faulting, pumping, patching, and scaling. (Kay et al. 1993) The proposed deduct values were more consistent with that used in the “Paver” PCI system. At the time, few or no PCCP rehabilitation or reconstruction projects were planned for the foreseeable future, so the proposed procedure was not implemented.

Since the mid 1990s, more state highway agencies (SHAs) have started implementing individual distress indices rather that composite indices. Individual distress indices have an advantage in that the progression of specific distresses can be tracked, and agencies can clearly identify pavement deterioration specific to distress type. This is lost when different distresses are combined into a single composite index as the averaging effect tends to reduce the impact of single critical distresses. (Jackson et al. 1996) In addition, whereas the individual distress index represents a specific structural response, that form of index tends to be more continuous over time and thus more predictable with time.

A more detailed discussion of the development of Pavement Condition Indices was written by the author for a FHWA National Highway Institute Class on “Pavement Management”. (Yap et al. 1998)

DEVELOPMENT OF DISTRESS SPECIFIC PAVEMENT CONDITION INDICES

BASIS OF INDIVIDUAL DISTRESS INDICES

A review of the WSPMS indicates that the primary distresses observed for the PCCP in Washington State are panel cracking, faulting, and rutting/wear. The pavement smoothness or ride (as defined by the International Roughness Index (IRI)) characteristics result from a combination of these three distresses but are largely an indication of the progression of faulting. As cracking progresses WSDOT can expect a significant increase in IRI values.

It is recommended that WSDOT use individual pavement condition indices for cracking, faulting, and rutting/wear. Pavement smoothness or ride should continue to be measured and reported in terms of IRI values.

There are no nationally accepted standards for the development of pavement condition indices. In general, commonly adopted systems, such as "Paver," typically establish the defect deductions on the basis of a group consensus of experts (Shahin et al. 1976) or agency engineers. Baladi gave some guidance as part of the NHI Class on "Highway Pavements" that he developed and taught in the early 1990s. (Baladi and Snyder 1992) In his class presentation, Baladi indicated a process he referred to as "Engineering Criteria." In this process one would establish a primary decision criterion that would indicate at what distress level action would be required, such as 1/8 inch (3mm) of faulting, which would be considered the "Engineering Criterion." The deduct values for that level of distress should be such that the resulting pavement condition index would be about the midpoint in the index range.

As an example of this process, assume that an agency has set a policy to take action when over 25 percent of the concrete panels have multiple cracks. The engineering criteria approach would establish the distress deduct value at approximately 50. Subtracting 50 from 100 would produce a cracking index of 50, which would be in the middle of the 100 to 0 scale. The agency may also have assumed that the pavement is essentially destroyed when cracking exceeds 50 percent of the panels. In that case, the deduct value would be set at 100 and the resulting index would be 0. The WSDOT distress deduct values were developed along those same lines, except they require higher cracking levels. It takes over 50 percent of the panels with multiple cracking to produce a deduct value of 50. The deduct values for PCCP currently used in the WSPMS are basically those developed in the mid 1960s for the priority array program. They do not correlate to current understanding of PCCP deterioration stages.

The pavement condition index, which is the numeric representation of the pavement condition in the field, should have the same trends with time as field observations. For most pavements and locations, the pavement condition tends to deteriorate at an ever increasing rate with time. The basic WSDOT PMS damage model was developed to represent this trend quite well. (Key et al. 1993)

$$PCR = C - mA^{P} \qquad \text{(Equation 2)}$$

where

PCR = Pavement Condition Rating

A = Pavement Age (time since construction or resurfacing)

C = model constant for maximum rating (100)

m = slope coefficient and

P = “selected” constant that controls the degree of the performance curve

On the basis of the author’s experience working with the WSPMS data, the typical value for P ranges from 1.5 to 3, and values of between 2.0 to 2.5 are the most common. It has been shown that the trend of the distress deduct values can be developed by using a trend line from a Log - Log plot (Jackson et al. 1996) to expand the deduct values beyond the engineering criteria point. Deduct values developed with this approach generally provide deterioration trends with a P value of 2.0 to 2.5. This produces a reasonably smooth transition in values over time. P values in this range provide a gradual downward trend in the early part of the curve, with a more pronounced downward trend toward the end of the curve. This is similar to what is observed in pavement deterioration trends in the northwest environment of Washington State.

WSDOT has established a set of trigger values for PCC pavement rehabilitation. Grinding is called for when average wear values for a monitored section (0.10 mile) exceeds 0.4 inch. Grinding and dowel bar retrofit are called for when the average wear values are greater than 0.4 inch and faulting is greater than 1/8 inch. Reconstruction is called for when the number of multiple cracked panels exceeds 10 percent of the panels in the monitored lane. The decision points are shown in Table 2.

These values are significantly different from those implied in the existing WSPMS PCC pavement defect deduction values. The current values tend to require significant faulting and cracking for the deduct values to be large enough for the PSC to drop to 50 or lower.

Table 2. WSDOT Trigger Values

	Faulting	Cracking	Wear
Do Nothing	<1/8"	<10%	0 - .39"
Grinding	-	-	.4"+
DBR + Grinding	1/8" - 1/2"	<10%	-
Reconstruction	>1/2"	>10%	1"+

There is a clear need to develop individual distress indices for the WSPMS, and to develop a new range of deduct values to better align the distress indices with the accepted trigger levels.

Deduct values were developed for these distress categories by using the trigger levels noted as the engineering criteria.

PAVEMENT CRACKING INDEX

The proposed pavement cracking index is based on the same approach that WSDOT has used for the last 40 years and is shown as equation 1 earlier. So as not to be confused with earlier indices, the new cracking index for rigid pavements will be referred to as the Rigid Pavement Cracking Index (RPCI). It is assumed that WSDOT will select its own term for this crack-based index.

$$RPCI = 100 - \Sigma \text{ Deducts}$$

In the past, the PCC pavement cracking distress was separated into three basic categories of crack severity:

Percentage of panels with 1 crack per panel

Percentage of panels with 2 to 3 cracks per panel

Percentage of panels with 4 or more cracks per panel

WSDOT has recently modified the way in which it classifies PCC pavement cracking and is now categorizing PCC pavement cracking distress severity as follows:

Number of panels (or %) with a single longitudinal crack (LC)

Number of panels (or %) with a single transverse crack (TC)

Number of panels (or %) with multiple cracks (MC)

Pavement distress deduct values have been developed for these last three categories of cracking distress. The proposed RPCI is produced by summing the three deduct values for a given section and subtracting the total value from 100. Because there was no attempt to truncate the values as they approached 100, it will be possible to have negative values under extreme conditions.

The resulting RPCI is:

$$RPCI = 100 - (LCDV + TCDV + MCDV) \quad \text{(Equation 3)}$$

where

LCDV = Longitudinal Cracking Deduct Value

TCDV = Transverse Cracking Deduct Value

MCDV = Multiple Cracks Deduct Value

The only trigger level noted for PCC pavement cracking is based on 10 percent multiple panel cracking. As a starting point the trigger level for single longitudinal cracking was set at 35 percent and that for single transverse cracking was set at 25 percent. If these latter two trigger levels seem to initiate projects a little too early, WSDOT can adjust them to a higher percentage value.

The past survey data were collected by using single panel cracking, 2 to 3 cracks per panel, and 4 or more cracks per panel; therefore, they do not relate on a one-to-one basis with the new categories. It is recommended that the existing three categories be combined into two categories to use the proposed deduct values on past data. The old single cracked panel would be converted to the new longitudinal cracked panel. The old category of 2 to 3 cracks per panel and the category of 4 or more cracks per panel would be combined to represent the new multiple cracked panel category. The proposed defect values for longitudinal cracking would be applied to single cracked panels, and multiple cracked panels would be applied to the combined category of 2 to 3 cracks and 4 or more cracks per panel.

The recommended deduct values for PCC pavement cracking can be determined from the following equations:

For Longitudinal Cracked Slabs use:

$$LCDV = 1.223(PLC)^{1.0437} \quad \text{(Equation 4)}$$

where

LCDV = Longitudinal Cracking Deduct Value

PLC = Percentage of panels with longitudinal cracks

For Transversely Cracked Slabs use:

$$TCDV = 1.5038(PLC)^{1.0886} \quad \text{(Equation 5)}$$

where

TCDV = Transverse Cracking Deduct Value

PTC = Percentage of panels with transverse cracks

and for Multiple Cracked Slabs use:

$$MCDV = 2.2361(PMC)^{1.3495} \quad \text{(Equation 6)}$$

where

MCDV = Multiple Cracking Deduct Value

PMC = Percentage of panels with multiple cracks

The three equations were developed from exponential equations determined from Log – Log plots and are shown in Appendix A.

To demonstrate how the resulting defect values will accumulate over time, the following hypothetical example is given in Table 3.

Table 3. Example PCC Pavement Deterioration and Proposed RPCI Values

Year	LC (%)	TC (%)	MC (%)	LCDV	TCDV	MCDV	RPCI
0	0	0	0	0	0	0	100
10	0	0	0	0	0	0	100
20	5	0	0	7	0	0	93
30	5	0	1	7	0	2	91
40	10	5	3	14	9	10	68
50	15	10	6	21	18	25	36

Note the actual example contained data for every two-year interval, but only the 10-year increments are shown on the table. The resulting performance trend is shown in Figure 1.

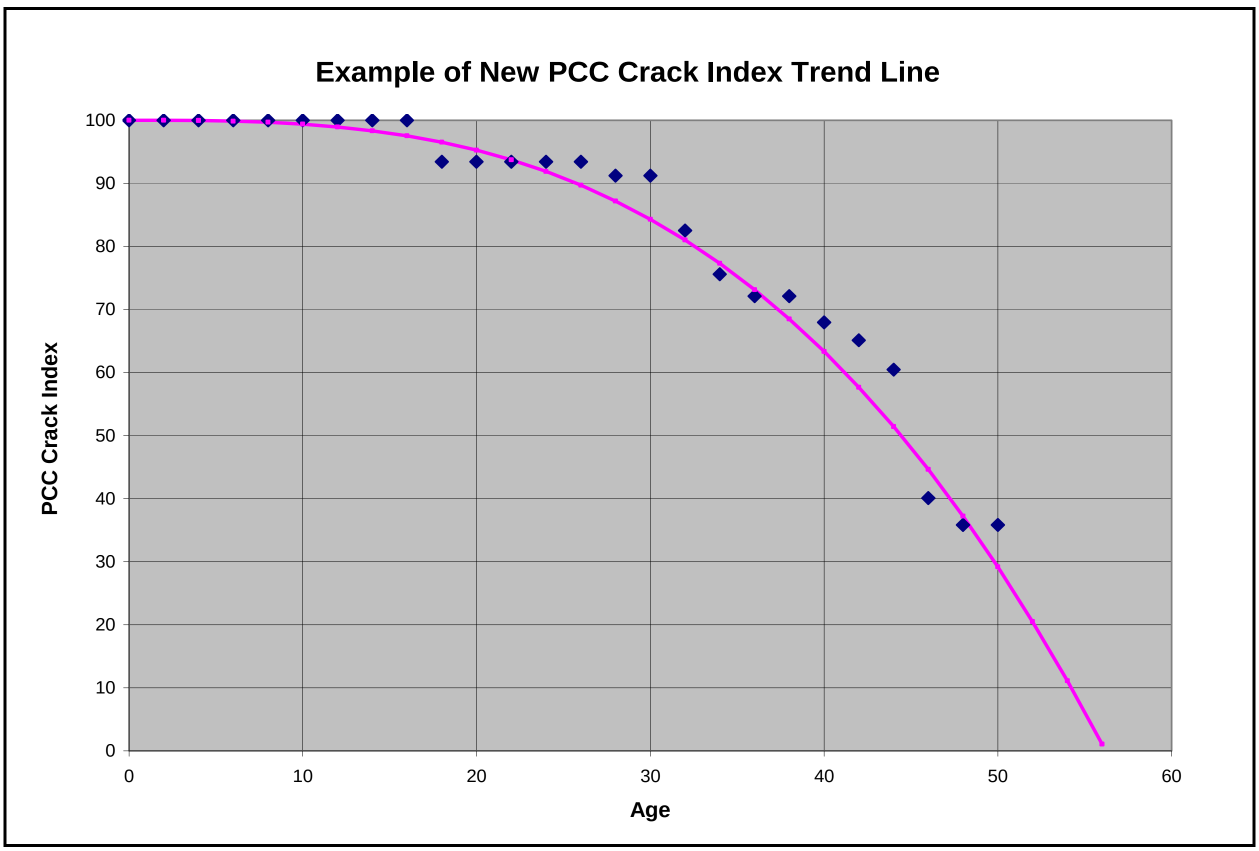

Figure 1. Example of Proposed Rigid Pavement Cracking Index Deterioration Trend

In addition, the proposed Rigid Pavement Cracking Index was also checked against existing WSPMS data. The general trend for I-5 pavement in King County is questionable at best. Because of concern for the safety of the raters, the old shoulder survey conducted in the past was done at highway speeds through the Seattle area. The resulting pavement condition data tend to be somewhat erratic. The WSDOT Materials Laboratory provided the raw PMS data for I-5 between 1969 and 2004. The data in Table 4 are indicative of the trends found in the file.

Table 4. Example of WSPMS Data for I-5 in Seattle MP 174 Vicinity

Year	1971	1975	1979	1983	1986	1989	1992	1995	1998	2001
Rating	1 - 2	0	1 - 3	1 - 3	1 - 3	1 - 3	1 - 2	1 - 2	1 - 2	1 - 1

The first number in the cell is the distress severity for cracking in terms of number of cracks per panel; the second number indicates the extent of damage in ranges: 1–10 percent, 11–25 percent, and 26+ percent. As can be seen, there is no real trend in distress severity or extent over time. The severity indicated 1 or 0 panel cracks, while the extent range progressed from the 11–25 percent range to the over 26 percent range and then back to the 1–10 percent range. For that reason, the proposed cracking index could not be checked against actual WS PMS time series data.

However, as a further check the cracking index was tested against condition data taken in 2004 at two different locations. The trends shown are for sections of I-5 around Spokane Street northbound (figures 2 and 3) and around Northgate northbound.

The distress survey for 2004 was one of the more accurate surveys. As such, it was used to develop the Rigid Pavement Cracking Index for that date. The value represents the average for about a 2-mile section of I-5. Individual sections will vary considerably within that 2-mile summary. The other known point is that when the pavement was built there would be little or no distress evident. The trend line represents a normal trend line for WSDOT where the exponent selected was 2.5.

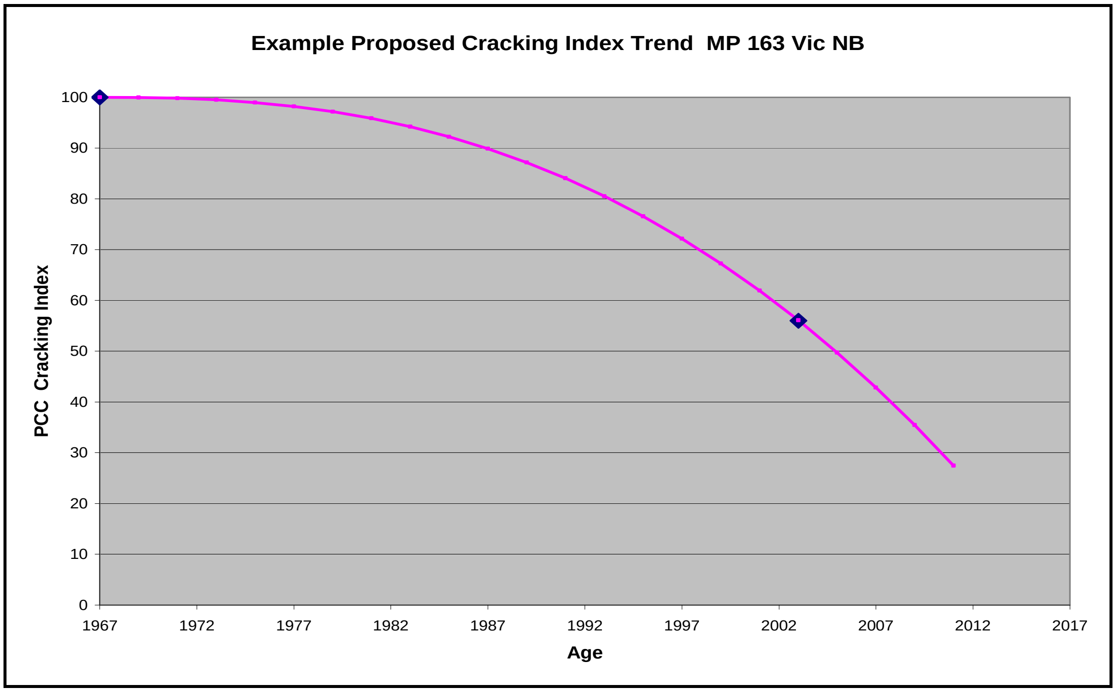

Figure 2. Example of General Trends for Rigid Pavement Cracking Index, I-5 Spokane St. Vicinity

Figure 3. Photo Log from WSDOT of Pavement Around Spokane St.

A similar example was taken from the area between MP 174 and 175 northbound. The pavement is generally in worse condition in this area, which is indicated by the cracking trend shown in Figure 4.

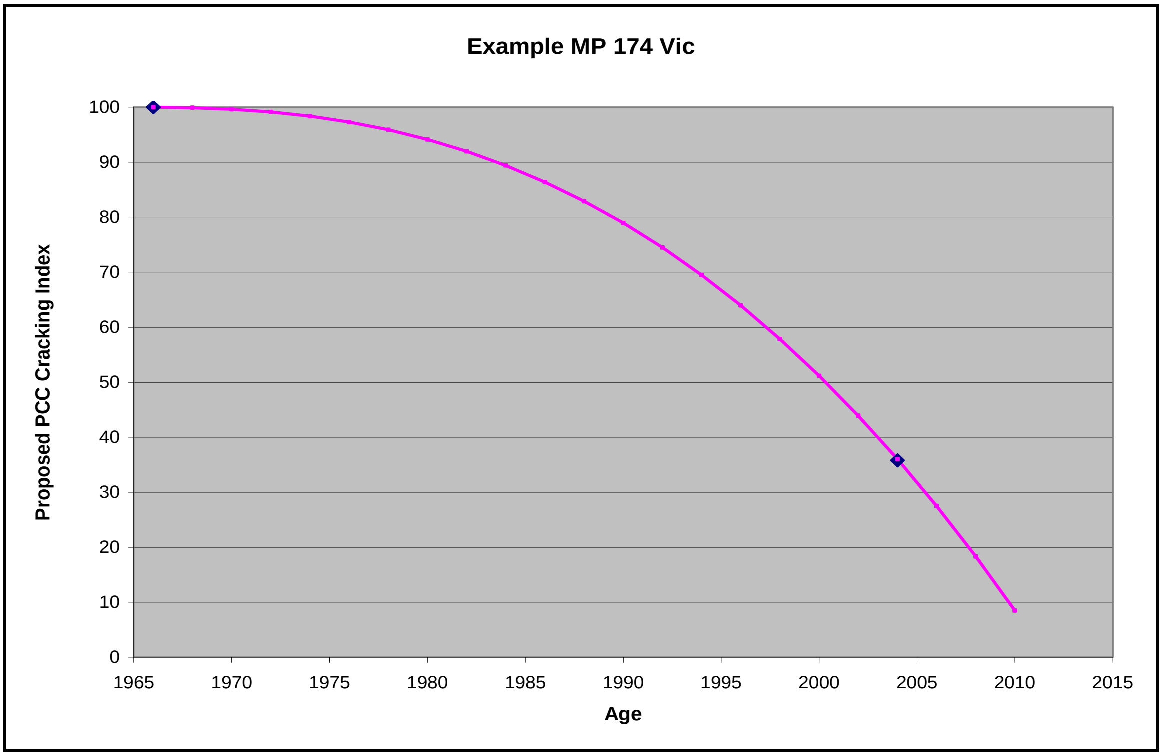

Figure 4. Example of General Trends for Rigid Pavement Cracking Index, I-5 Northgate Vicinity

Figure 5. Photo Log from WSDOT of Pavement around Northgate Vicinity

Given the general condition of the existing pavement, the indices are in about the right range for identifying projects that are about (or past) due for rehabilitation based on an RPCI of 50.

One issue that may be a problem in the future will be the effects of patching. The amount of patching is captured in the pavement condition survey; however, the deduct values are 0 for that distress. In the future, as the PCC pavement continues to deteriorate, there could be significantly more panel replacements and temporary patching with hot mixed asphalt (HMA). When broken panels are replaced with full-depth PCC panel replacement, the value of the distress deducts will become lower for that section of pavement. With an anticipated panel replacement life of 10 to 20 years, the improvement in the cracking index is warranted. However, if the panel is replaced with a temporary HMA patch, the cracking index will also improve because the cracked panel rating may be replaced with a patched panel rating that, at this time, does not have a deduct value. It is strongly recommended that patching also be included in the distress deduct value for the Rigid Pavement Cracking Index because it is replacing cracked PCC. Patching has three categories of severity: 1 to 9 percent, 10 to 24 percent, and over 25 percent of the panel area. Where any patching is recorded it can be assumed that it is replacing broken concrete, which usually occurs on panels with multiple cracks. Any panels that are patched should be added to the percentage of multiple cracked panels for the computation of the multiple cracked deduct values. Thus as the PCC panels break up and are patched, the resulting cracking index for that section will not improve.

FAULTING AND RUT/WEAR INDICES

Both faulting and wear trends could be monitored by using direct measurement values, but to keep the PMS approach consistent they can also be converted to an index (on a scale of 100 to 0) and be tracked just like the cracking index. This would also allow the three indices to be summarized in a statistic to provide one index that identified the condition of the pavement in a more simplified form to the general public. This process will be discussed later in the report.

For the faulting index, the trigger points are a little spread out. The first trigger value is 1/8 inch (3 mm), which is used to initiate action early. The second trigger value is ½ inch (12 mm), which is used to identify major rehabilitation or reconstruction. This wide spread in trigger values makes it very difficult to set a continuous function. It is also difficult to determine an appropriate deduct value in the middle of the index range. WSDOT had initially set two action points, which it referred to as the "should" and "must" levels (pavement condition ratings of 60 and 40, respectively). (Nelson and LeClerc 1982) This approach was used for the faulting index, in which a fault depth of 1/8 inch (3 mm) would produce a deduct value of 40, and a fault value of 1/4 inch (6 mm) would produce a deduct value of 60. Fault depths of ½ inch would produce a deduct value of 80, and 1 inch (24.8 mm) a deduct value of 100. This trend did not fit the Log – Log approach used for cracking, so a polynomial equation was developed to produce a continuous function that fit through these points.

The resulting deduct equation for faulting is:

$$FDV = 0.0009(FD)^4 + 0.0582(FD)^3 - 1.4124(FD)^2 + 16.69(FD) \qquad \text{(Equation 7)}$$

where

FDV = Faulting Deduct Value

FD = Average Fault Depth

A plot of the equation is included in Appendix A.

The Rigid Pavement Faulting Index (RPFI) is then computed as:

$$RPFI = 100 - FDV \qquad \text{(Equation 8)}$$

For rut or wear depth the average depth may be reported, or a Rut/Wear index value can be computed to be consistent with the other pavement distress measures of cracking and faulting.

The trigger point for grinding is 0.4 inch (10 mm). By using a deduct value of 50 for a wear depth of 0.4 inch (10 mm) and the same Log – Log approach as noted for the cracking index, a wear deduct equation was developed.

The resulting deduct equation for rutting/wear is:

$$R/WDV = (R/WD)^{1.699} \qquad \text{(Equation 9)}$$

where

R/WDV = Rut/Wear Deduct Value

R/WD = Average Rut/Wear Depth (mm)

A plot of the equation is included in Appendix A.

The Rigid Pavement Rut/Wear Index (RPR/WI) is then computed as:

$$RPR/WI = 100 - R/WDV \qquad \text{(Equation 10)}$$

COMBINING PAVEMENT CONDITION INDICES

Combining pavement condition deduct values for a range of pavement distresses usually produces a composite index that is not consistent with time, since some pavements may experience cracking, others faulting, others spalling or scaling at different times and for different reasons. Prediction of future pavement condition on the basis of a composite pavement condition index is problematic at best for these reasons. A pavement condition index based on a specific pavement distress that relates to a basic and specific structural response such as a cracking index provides the best opportunity to have an index that progresses uniformly with time and can be used to make reasonable estimates of future pavement conditions (Jackson et al. 1996; Yap et al. 1998). The proposed cracking, faulting, and wear/rutting indices should provide these attributes. The advantage that a composite index provides is that it can give a good indication of the overall pavement condition for presentation purposes without having to show two, three, or even four indices to describe the general pavement condition at a given location.

If WSDOT wants to consider a single composite pavement condition index to report general pavement condition, that can be accomplished by taking the average of the three indices minus one standard deviation. Thus if the faulting index is fairly high, but there is little cracking or rut/wear, the resulting composite index will produce an index that is reasonably representative of the faulting conditions. This approach eliminates the averaging that occurs with most of the existing composite index approaches. The composite index should not be used to predict future pavement condition. Rather, the individual pavement condition indices should be used to predict future pavement condition and then summarized as noted to provide a single composite index for presentation purposes.

One example of the use of this approach to a composite index is in mapping pavement condition. One of the common ways to present pavement condition is with a map of the highways, with color coding used to indicate the pavement conditions along a route or all routes in an area. Typically, pavements with pavement condition index values of between say 100 and 75 would be considered “good” and would be shown in green. Pavements with condition values of between 75 and 50 would be considered “fair” and would be shown in yellow. And pavement conditions of below 50 would be considered “poor” and would be shown in red. Using individual distress indices would complicate this process in that three different maps would be needed to show the pavement condition for the different distress categories. Because mapping is used to show pavement condition in the simplest of presentations, complicating this approach would be counter-productive. The simplest approach for producing a single map with pavement condition would be to compute a composite index by using the mean condition value minus one standard deviation, as noted above, to provide the values shown in the color codes on the map. WSDOT does not need to report a composite index, but such an index makes processes like reporting the percentages of a route corridor needing action or mapping easier.

SUMMARY AND CONCLUSIONS

Revised pavement condition indices that address specific pavement distress types have been proposed for WSDOT to use on PCC pavements. The indices are related to the types of distress that WSDOT experiences on its PCC pavements and are calibrated to the damage levels that it has adopted for rehabilitation or reconstruction activities.

WSDOT's current pavement index is based on priority array development work conducted over 40 years ago (LeClerc and Marshal 1970) and modified to be used in the WSPMS about 25 years ago (Nelson and LeClerc 1982). It does not represent the pavement condition trigger levels now used by WSDOT, and because it combines various pavement distresses and mechanisms, its predictive capability is questionable. The proposed cracking, faulting, and rut/wear indices address specific distresses and distress mechanisms, which significantly improve the predictive capabilities of those indices.

The approach taken in the development of the revised indices was kept purposefully simple. It has been the author's experience that pavement condition indices don't need to be more complicated and—as is true for most engineering processes—the simpler the better. There are several advantages to keeping the system simple. The primary one is that it can be easily understood by all of the users of the PMS. Additionally, if after using the indices for a cycle or two WSDOT finds that they produce values that seem either too high or too low in comparison to conditions seen on the roadway, WSDOT can easily adjust those indices as needed. The author of this report personally made several adjustments in the flexible PSC equations and deduct values during the first several years of implementing the WSPMS to bring the resulting values more in line with the general impression of the existing pavement conditions. The flexible PSC index was modified again by Keith Kay in the early 1990s to transition better from low levels of fatigue cracking to higher levels of fatigue cracking and to be more in line with the relative pavement condition where action should be taken. It is recommended that WSDOT adopt the new index approach but also look carefully at the general values that come from the revised indices and, if needed, be prepared to make adjustments to the proposed deduct equations to best fit the field conditions represented.

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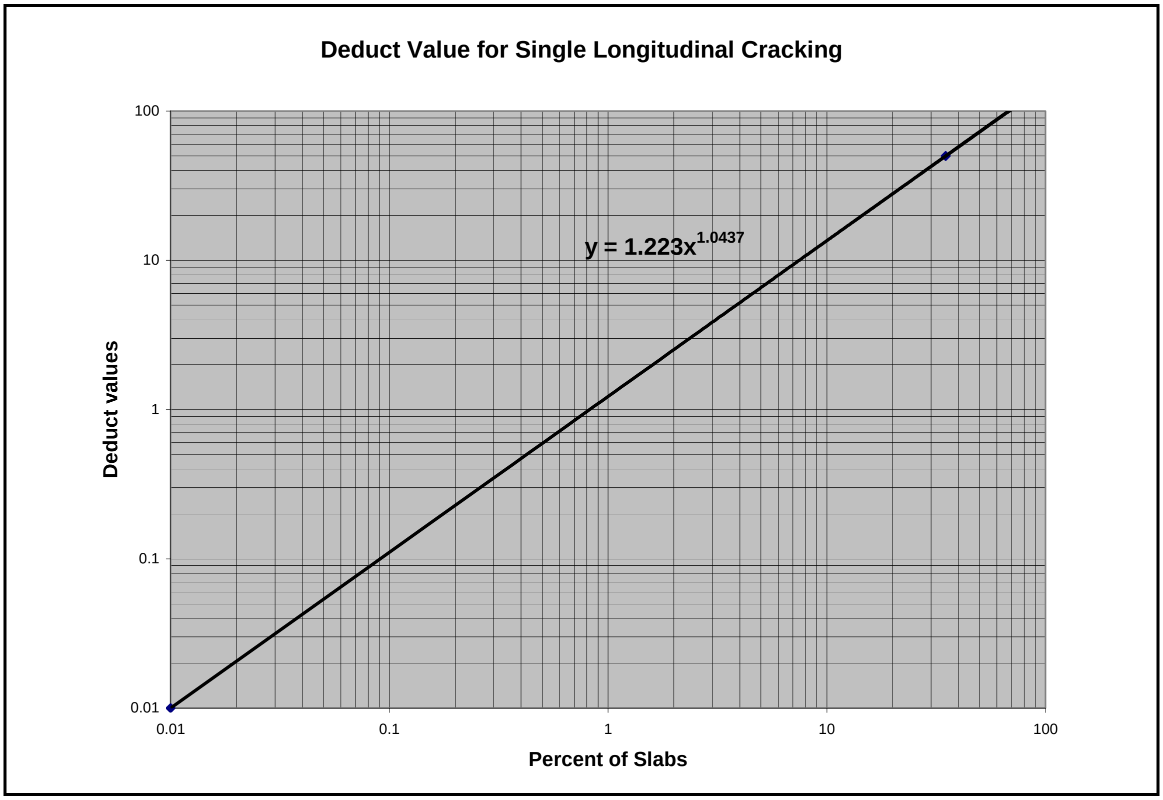
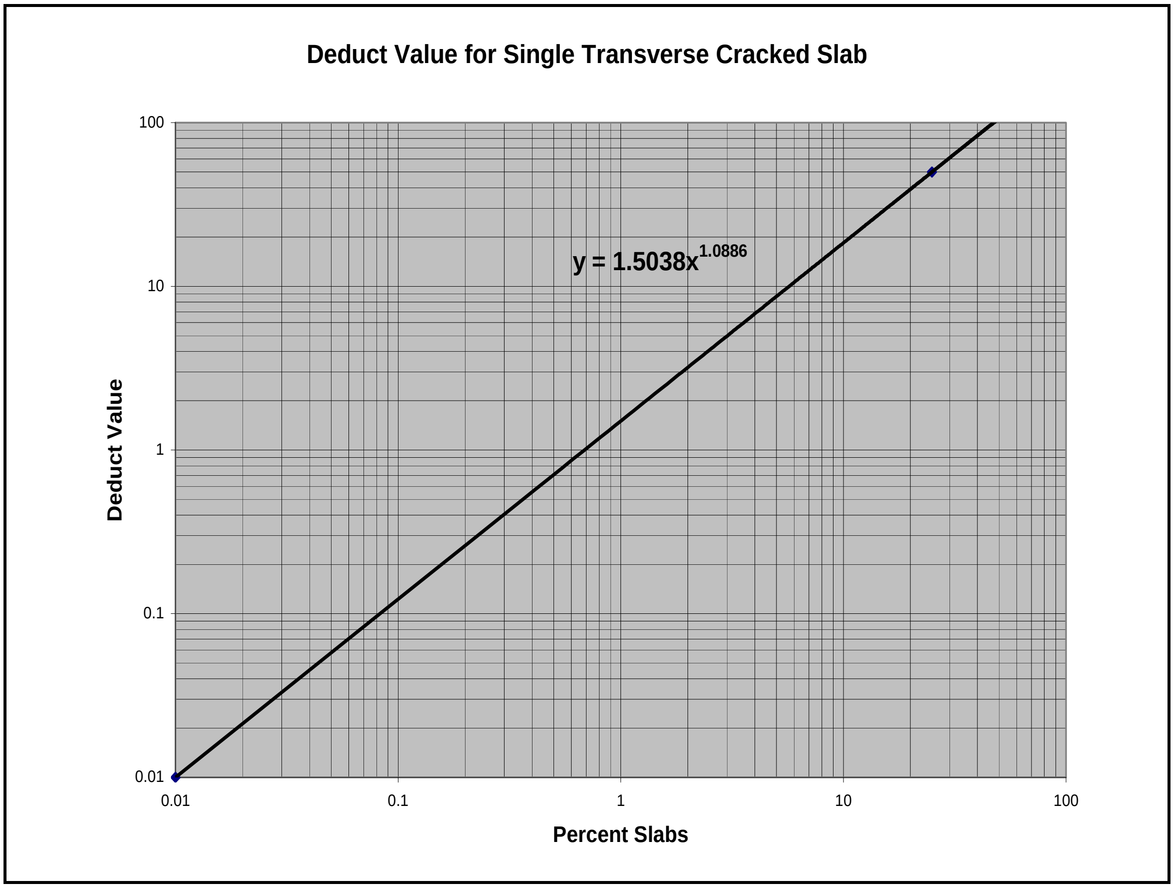
APPENDIX A

PAVEMENT CONDITION DEDUCT VALUE

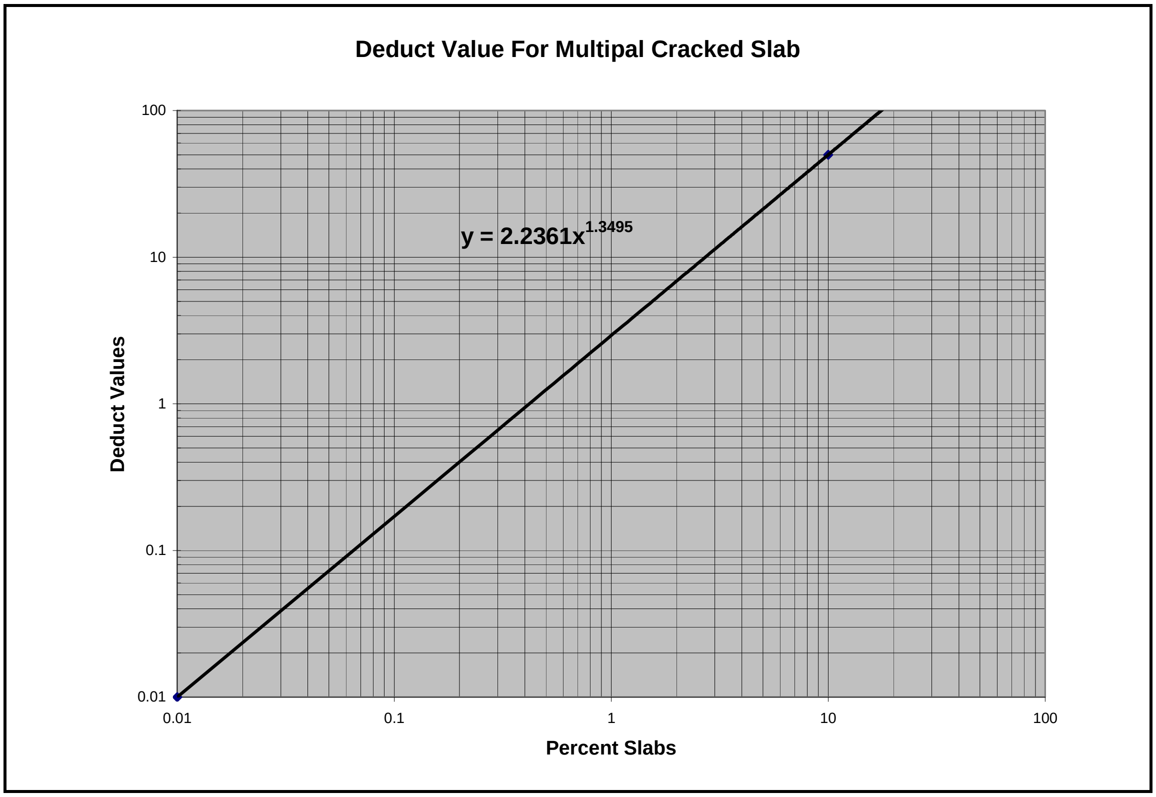
PLOTS



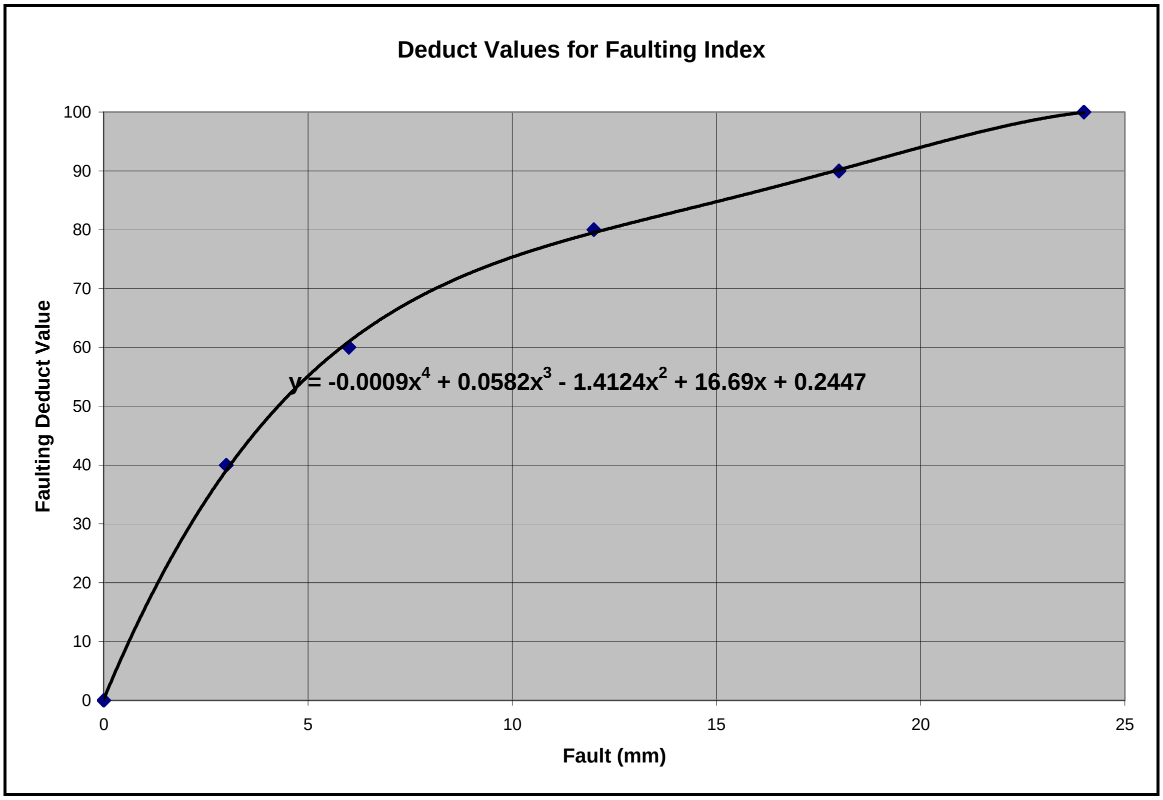
Plot of Deduct Values for Longitudinal Cracking



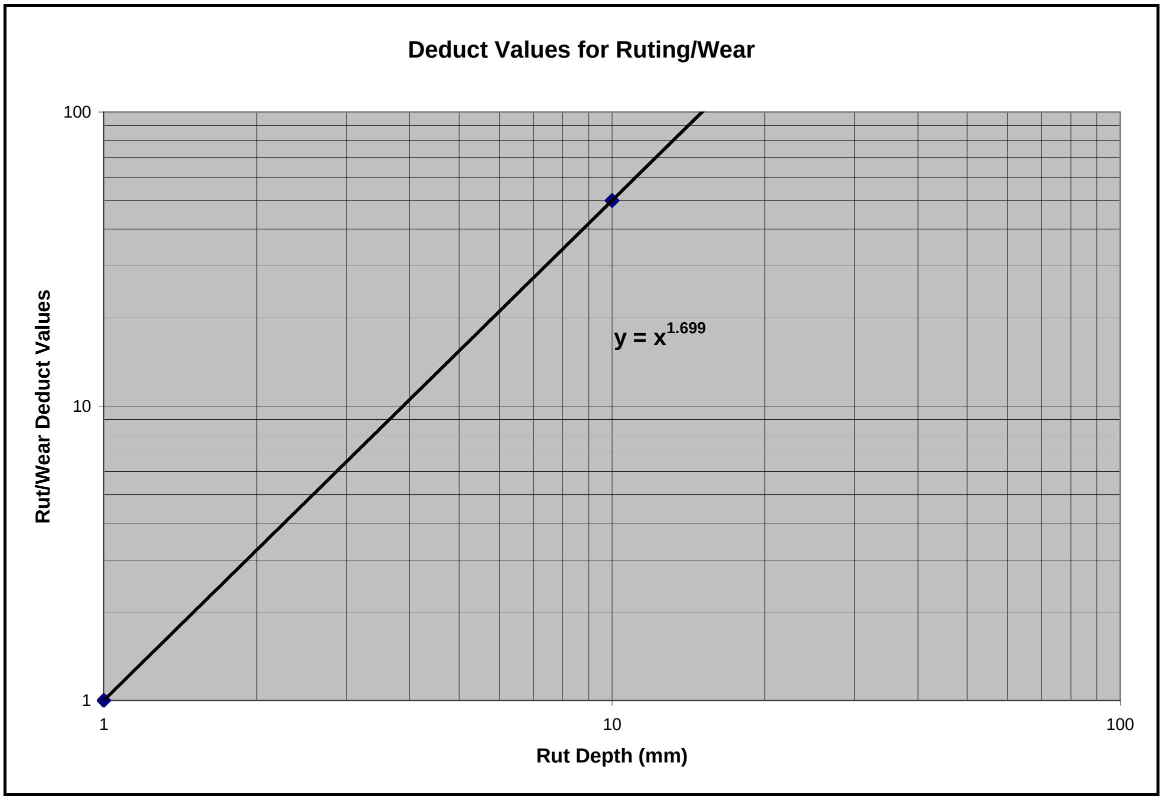
Plot of Deduct Values for Transverse Cracking



Plot of Deduct Values for Multiple Cracked Slabs



Plot of Deduct Values for Faulting



Plot of Deduct Values for Rutting/Wear