3-1-2008

Portland Cement Concrete Pavement Over Rubblized PCC

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Portland Cement Concrete Pavement Over Rubblized PCC (WHRP 08-03). Milwaukee, Wisconsin, Marquette University, Transportation Research Center (2008).

Wisconsin Highway Research Program

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SPR #0092-00-11

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March 2008

WHRP 08-03

PORTLAND CEMENT CONCRETE PAVEMENT OVER RUBBLIZED PCC

FINAL REPORT WHRP 08-03

WisDOT Highway Research Study
SPR # 0092-00-11

by

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March 2008

for

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This research was funded through the Wisconsin Highway Research Program by the Wisconsin Department of Transportation and the Federal Highway Administration under Project # 0092-00-11. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

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Technical Report Documentation Page

1. Report No. WHRP 08-03	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Portland Cement Concrete Pavements Over Rubblized PCC		5. Report Date March 2008 6. Performing Organization Code Wisconsin Highway Research Program
7. Authors James A. Crovetti		8. Performing Organization Report No.
9. Performing Organization Name and Address Transportation Research Center Marquette University PO Box 1881 Milwaukee, WI 53201		10. Work Unit No. (TRAIS) 11. Contract or Grant No. WisDOT SPR# 0092-00-11
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Bureau of Business Services Research Coordination Section 4802 Sheboygan Ave. Rm 104 Madison, WI 53707		13. Type of Report and Period Covered Final Report, 2000-2008 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report has presented findings of research conducted to determine the viability of constructing Portland cement concrete pavements over rubblized PCC. Rubblization of aged PCC pavements is a common technique for in-place recycling of these pavements. For the vast majority of applications, the rubblized PCC layer is surfaced with hot mix asphalt (HMA).
The use of Portland cement concrete as a surfacing material offers designers another option which may provide good performance and be cost-effective under certain conditions.
The current concrete pavement design procedures utilized by WisDOT allow for the incorporation of a rubblized PCC base layer and an increase in the design value for the subgrade support k-value based on AASHTO guidelines. Over the practical range of rubblized concrete layer thicknesses investigated during this research, composite k-values were shown to increase by a factor of approximately 2 to 4 times, depending on the thickness of the rubblized layer and the quality of the natural subgrade support. This increase in composite k-value was shown to reduce the concrete layer thickness requirement between 0.25 to 1.45 inches, depending on subgrade quality and design ESAL loadings. The greatest reduction in required PCC thickness was seen for the combination of high subgrade support and low design ESAL loadings. As design ESAL levels increase, the allowable PCC thickness reduction decreases for all subgrade qualities. Based on the research results collected to date, there are no restrictions to the continued design and construction of Portland cement concrete pavements over rubblized PCC.

17. Key Words Concrete pavement, rubblization, stress analysis, Base layer effects.	18. Distribution Statement No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield VA 22161		
19. Security Classif.(of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages	21. Price

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TABLE OF CONTENTS

Executive Summary

This report presents findings of research conducted to determine the viability of constructing Portland cement concrete pavements over rubblized PCC. Rubblization of aged PCC pavements is a common technique for in-place recycling of these pavements. For the vast majority of applications, the rubblized PCC layer is surfaced with hot mix asphalt (HMA). The use of Portland cement concrete as a surfacing material offers designers another option which may provide good performance and be cost-effective under certain conditions.

The current concrete pavement design procedures utilized by WisDOT allow for the incorporation of a rubblized PCC base layer and an increase in the design value for the subgrade support k-value based on AASHTO guidelines. Over the practical range of rubblized concrete layer thicknesses and moduli investigated during this research, composite k-values were shown to increase by a factor of approximately 2 to 4 times, depending on the thickness and modulus of the rubblized layer and the quality of the natural subgrade support. This increase in composite k-value was shown to reduce the concrete layer thickness requirement between 0.25 to 1.45 inches, depending on subgrade quality and design ESAL loadings. The greatest reduction in required PCC thickness was seen for the combination of high subgrade support and low design ESAL loadings. As design ESAL levels increase, the allowable PCC thickness reduction decreases for all subgrade qualities.

A mechanistic appraisal is also presented based on critical load-induced edge stresses with and without the inclusion of a rubblized PCC base layer. For the range of parameters investigated, the mechanistic appraisal yields a lower equivalent top-of-base k-values and lower PCC thickness reductions than were obtained using the WisDOT/AASHTO procedures. On average, the mechanistic top-of-base composite k-value is approximately half of that determined based on the AASHTO design process, and the concurrent PCC thickness reduction is approximately ½ to ¼ of the AASHTO/WisDOT value.

Two field projects incorporating Portland cement concrete pavements over rubblized PCC layers are reported on. An urban application of a 5-inch PCC bus pad placed directly over the rubblized PCC base layer has shown good performance after 4+ years of service. A rural interstate application of an 11-inch PCC slab constructed over a 9-inch rubblized PCC base with the inclusion of a 4-inch open graded separation layer has shown good performance after 3+ years of service. Analysis results backcalculated from two separate series of deflection tests indicate a more significant structural contribution from the rubblized layer than is currently considered within the WisDOT design procedures. A rubblized PCC modulus approaching 200 ksi may be warranted based on the results of FWD testing.

Based on the result presented in this report, no restrictions to the continued design and construction of Portland cement concrete pavements over rubblized PCC are recommended. More observations are required to validate the need for the inclusion of an open graded aggregate interlayer between the PCC slab and rubblized PCC base layer, which is current WisDOT design practice. The structural contribution of the rubblized layer may lead to a savings of up to 1.45 inches of concrete, depending on design traffic levels and subgrade quality. This may prove to be a cost-effective alternative to complete removal and replacement of aged concrete pavements.

This report also presents the impacts of using higher allowable concrete working stress values, which would reflect the use of higher flexural strength concrete (> 650 psi) and/or lower reduction factors (< 1.33). Using higher working stress values would not significantly affect the aforementioned thickness reductions due to the inclusion of a rubblized PCC base layer; however, significant reductions in design PCC thicknesses (for any given design ESAL loadings) or significant extensions in expected service life (for any given design PCC thickness) could be realized.

Chapter 1
Introduction

This report presents the results of research conducted to investigate the design and analysis requirements of Portland cement concrete (PCC) pavements constructed over a rubblized PCC pavement layer. This research was sponsored by the Wisconsin Highway Research Program to provide an additional design alternative for aged concrete pavements in need of major structural repair.

Concrete pavement rubblization is a common technique for in-place recycling of aged concrete pavements which have deteriorated to the point where localized repairs are no longer cost-effective. The primary function of the rubblization process is to destroy the slab-like behavior of the existing concrete pavement, thereby reducing or eliminating the likelihood of reflection cracking propagating into the new surface material.

Guidance provided in the WisDOT Facilities Development Manual (FDM) Procedure 14-25-15 *Concrete Pavement Rubblization* indicates that concrete pavement rubblization should be considered when one or more of the following conditions have been met:

- Pavement Distress Index (PDI) values exceed 60
- More than 20% of the concrete joints are in need of repair
- More than 20% of the concrete surface has been patched
- More than 20% of the of the slabs exhibit slab breakup
- More than 20% of the project length exhibits longitudinal joint distress greater than 4 inches wide

The guidance provided above, intended to effectively delay the consideration for rubblization until maximum economic benefit has been attained from the original PCC pavement, is also promoted in Transportation Research Circular E-C087 (Decker & Hansen, 2006). The American Concrete Pavement Association (ACPA 1998) suggests that “the only appropriate time to rubblize an existing concrete pavement is when it has severe material durability problems, such as alkali-silica reactivity (ASR), D-cracking, or freeze-thaw damage."

To date, hot mix asphalt (HMA) overlays are the most common overlay material used over rubblized PCC layers. Pavements of this type are commonly considered as new construction and are designed according to accepted practice for new flexible pavements. However, the terminology of an HMA overlay, in contrast to a new HMA surface layer, still persists in the literature when describing these pavement types. Within Wisconsin, FDM Procedures 14-10-5 and 14-25-15 allow for the usage of a rubblized concrete layer structural coefficient in the range of 0.20 – 0.24, which essentially equates one inch of rubblized PCC to ½ inch of HMA in the pavement design procedure.

In states where mechanistic design procedures are utilized, the rubblized layers are assigned an elastic modulus based on typical tabulated values or on values backcalculated from deflection testing data. Witczak and Rada (1992) reported backcalculated moduli for 22 nationwide rubblized concrete layers ranging from 200 to 700 ksi, with a mean value of 412 ksi. Thompson (1999) reported an average backcalculated moduli of 134 ksi based on 7 years of deflection data collected along a 10-inch rubblized PCC section of I-57 in central Illinois. Galal, et al. (1999) reported average moduli of 181 ksi for rubblized PCC sections in Indiana. Buncher, et al. (2007) presented results for backcalculated moduli obtained from deflection data collected on rubblized PCC layers ranging in thickness from 8 to 21 inches and indicated a general relationship between the slab thickness and rubblized modulus as:

$$E_{rubb} = 17.2\ H \qquad (R^2 = 0.32) \qquad \text{Eq 1.1}$$

Where: E_{rubb} = backcalculated modulus, ksi

H = slab thickness, inches

Figure 1.1 provides an illustration of the data used by Buncher, et al. to develop this relationship. The regression line generated for this data indicates a coefficient of 16.9 is more appropriate for use in Eq 1.1.

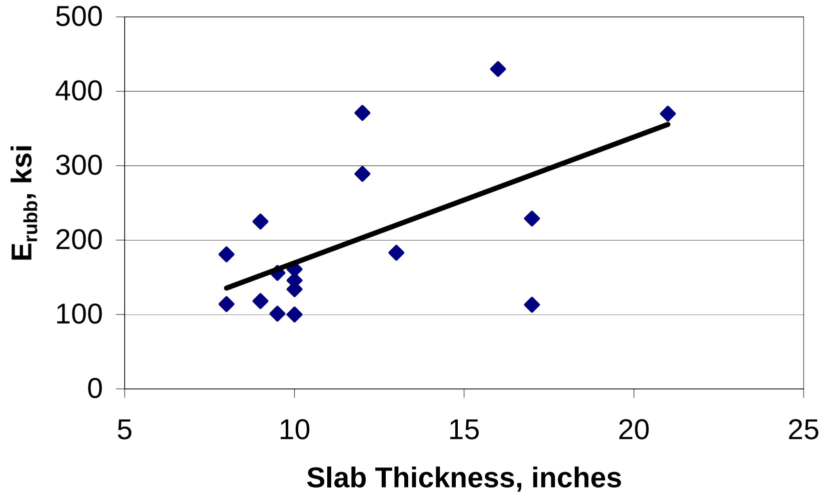

Figure 1.1 Average Moduli Versus Rubblized Slab Thickness (Buncher, et al. 2007)

Buncher, et al. further suggest that for slabs ranging from 8 to 14 inches, a moduli from 135 to 235 ksi should be selected for design on airfields.

Little literature exists on the characterization of rubblized concrete layers for specific use within the design of concrete pavements. Considering the rubblized concrete as an angular, unbound aggregate layer, one would expect the material to act as a stress-hardening layer with a resilient modulus dependent on the stress state within the layer. Because the concrete surface over the rubblized layer is an order of magnitude stiffer than conventional HMA materials, the stresses within the underlying rubblized layer would be lower. For equal surface thicknesses, a lower-end modulus in the range of 100 – 200 ksi would appear more appropriate for concrete pavement design and analysis.

In Illinois, concrete overlays are considered acceptable alternates to HMA overlays on rubblized PCC, but these pavements are still considered as experimental and little guidance is given in the selection of appropriate design parameters (IDOT 2005). In Wisconsin, FDM 14-25-15 recommends the use of a typical rubblized layer modulus of 100 ksi. FDM 14-25-15 further recommends the use of the AASHTO design process which allows for increasing the effective subgrade k-value based on the thickness of the rubblized layer. This "increased k-value" design process is also supported by ACPA (1998). ACPA (1998) also promotes the use of an unbonded concrete overlay placed over an HMA separator layer without rubblization of the existing concrete pavement.

The State of Michigan (2004) has also considered the use of unbonded concrete overlays in place of HMA overlays of rubblized concrete pavements, but the few examples provided indicate this choice not to be cost effective. Gulen, et al. (2004) examined the cost-effectiveness of unbonded concrete overlays on I-65 in Indiana. In their study it was concluded that the unbonded overlay, which used an open graded HMA layer between the new and existing concrete (not rubblized), was very effective in eliminating reflection cracking and was slightly more cost-effective than the traditional HMA overlay on rubblized concrete.

Based on the literature cited above, the use of a concrete pavement over a rubblized concrete slab appears warranted. Chapter 2 of this report provides a detailed analysis on the use of the existing AASHTO/WisDOT design process for concrete pavements over rubblized PCC and its effects on the thickness requirements for the new PCC slab. Chapter 3 of this report provides the results of field testing on two separate construction projects in Wisconsin which utilized concrete pavements over rubblized PCC. Chapter 4 provides a summary of the research findings to date and recommendations for continued analysis of existing pavement sections.

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Witczak, M. and Rada, G., ***Nationwide Evaluation Study of Asphalt Concrete Overlays Placed on Fractured Portland Cement Concrete Pavements***, Transportation Research Record 1374, 1992.

Chapter 2
Base Layer Contributions in Concrete Pavement Design

This chapter presents an analysis of the contributions of the rubblized concrete base layer in the structural design of a new concrete pavement.

2.1 AASHTO Appraisal of Base Layer Effects

WisDOT FDM Procedure 14-25-15 establishes the modulus of rubblized concrete at 100 ksi and allows for an increase in the subgrade k-value following guidance included in the AASHTO (1993) pavement design procedures. These AASHTO procedures establish a "top-of-base" k-value based on the thickness and stiffness of the base layer and the resilient modulus of the subgrade. The base layer effect is based on the decrease in subgrade deflection resulting from the in-place base layer. When comparing the effects of the base layer on the effective k-value, a 30 inch diameter rigid loading plate is considered to effectively simulate the standard plate load test for in-place testing of the subgrade k-value.

For standard plate load tests, the subgrade k-value is determined as:

$$k = \frac{p}{w_o} \qquad \text{Eq 2.1}$$

Where: k = modulus of subgrade reaction, psi/in

p = applied pressure (p=10 psi)

w_o = vertical plate deflection, inches

Boussinesq theory for the maximum deflection of a semi-infinite homogeneous layer under the action of a rigid plate can be stated as:

$$w_o = \frac{\pi(1-\upsilon^2)\,pa}{2E_{sg}} \qquad \text{Eq 2.2}$$

Where: υ = Poisson's ratio of subgrade (υ = 0.45)

a = radius of applied load (a = 15 inches)

E_{sg} = subgrade modulus of elasticity ($E_{sg} \underset{\sim}{} $ Mr)

Combining the above equations and setting υ = 0.45 and a = 15 inches yields:

$$w_o = \frac{p}{k} = \frac{\pi(1-\upsilon^2)pa}{2E_{sg}} = \frac{\pi p(1-.45^2)15}{2E_{sg}} \qquad \text{Eq 2.3}$$

$$k = \frac{2pE_{sg}}{\pi(1-\upsilon^2)pa} = \frac{2E_{sg}}{\pi(1-.45^2)15} = \frac{E_{sg}}{18.8} \qquad \text{Eq 2.4}$$

For a 2-layer system, represented by a rubblized PCC layer over subgrade soil, the maximum surface deflection under a rigid plate loading may be computed as:

$$w_o = \frac{\pi(1-\upsilon^2)pa}{2E_{sg}}F_2 \qquad \text{Eq 2.5}$$

Where: F_2 = Burmister deflection factor

The deflection factor F2 is a function of the modular ratio of the rubblized PCC layer and the subgrade (Erubb/Esg = E1/E2) and the thickness ratio of the rubblized PCC layer and the radius of the loading plate (Hrubb/a=h1/a), as shown in **Figure 2.1**.

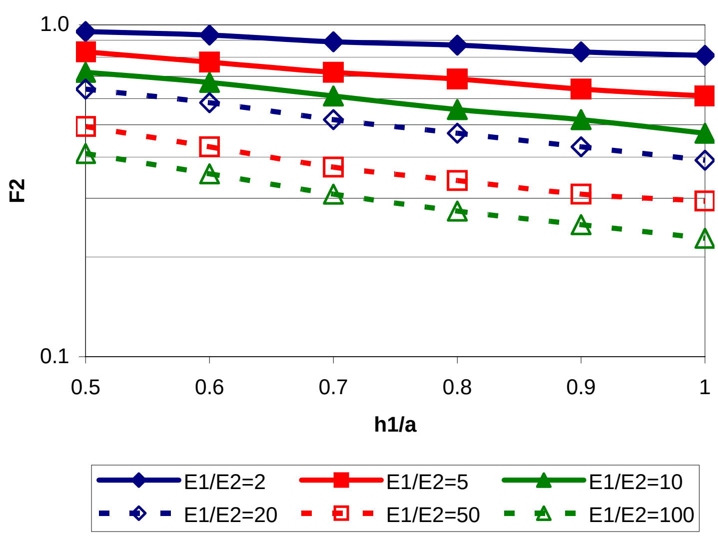

Figure 2.1: Vertical Deflection Factor for 2-Layer Pavement Systems

As indicated in **Figure 2.1**, as the modular ratio E1/E2 (Erubb/Esg) and/or the thickness ratio h1/a (Hrubb/a) increase, the deflection factor F2 decreases, resulting in a reduced surface deflection, w_o.

As the contribution of the base course increases (i.e., increased E1/E2 and/or h1/a), the equivalent "top-of-base" k-value (k_{eq}), will increase due to the reduction in w_o, and can be computed as:

$$k_{eq} = \frac{k}{F_2} = \frac{E_{sg}}{18.8F_2} \qquad \text{Eq 2.6}$$

Equation 2.6 indicates the "bump" in subgrade k-value due to the presence of a rubblized PCC base layer is a function of the F2 factor, which is dependent on the thickness of the rubblized layer (Hrubb) and the stiffness of the subgrade (Esg or k-value). Using a fixed radius of loading of a = 15 inches, **Figure 2.1** can be re-plotted in terms of F2 vs subgrade k-value for various rubblized layer thicknesses (Hrubb) and moduli (Erubb). **Figures 2.2 and 2.3** illustrate F_2 trends for a range of subgrade k-values using Erubb values of 100 ksi and 200 ksi, respectively.

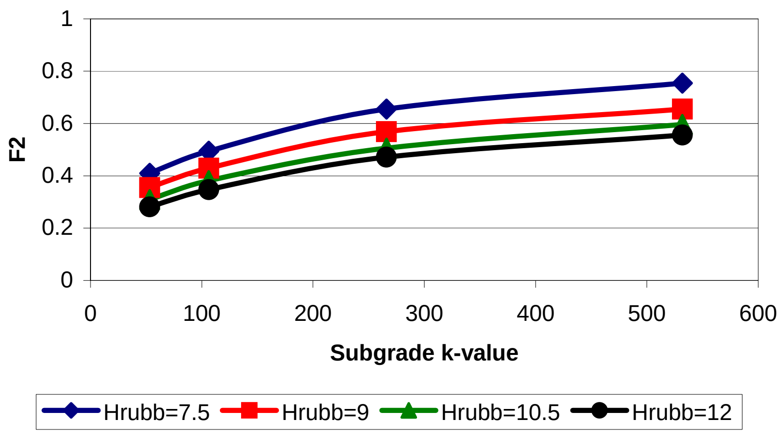

Figure 2.2: F_2 Trends vs Subgrade k-value with Erubb=100ksi

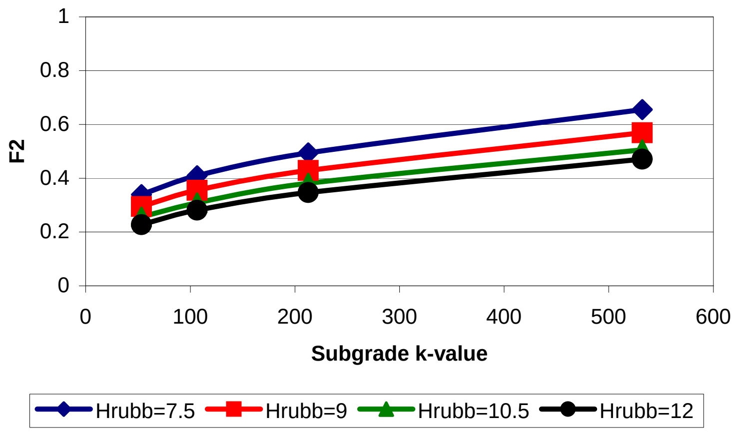

Figure 2.3: F_2 Trends vs Subgrade k-value with Erubb=200ksi

A regression analysis of the trends illustrated in **Figures 2.2 and 2.3** yielded the following:

$$F_2 = Ak^B \qquad \text{Eq 2.7}$$

Where: k = subgrade k-value, pci

$A = 0.27540 - 0.00025E_{rubb} - 0.01745H_{rubb} + 0.00032H_{rubb}^2$ $\quad R^2=0.9879$

$B = 0.35978 - 0.00013E_{rubb} - 0.02642H_{rubb} + 0.00172H_{rubb}^2$ $\quad R^2=0.9792$

E_{rubb} = modulus of rubblized layer, ksi

H_{rubb} = thickness of rubblized layer, inches

Combining equations 2.6 and 2.7 yields the following equation for computing the equivalent "top-of-base" k-value:

$$k_{eq} = \frac{k}{F_2} = \frac{k}{Ak^B} \qquad \text{Eq 2.8}$$

Equation 2.8 eliminates the need for the AASHTO graphical solution and is valid for 100 ksi $\leq E_{rubb} \leq$ 200 ksi and 7.5 inches $\leq H_{rubb} \leq$ 12 inches. This equation can be considered to provide a conservative deflection-based "top-of-base" k-value because it ignores the contribution of any existing aggregate base layer below the rubblized PCC layer.

2.2 Impacts on PCC Thickness Requirements

The current WisDOT concrete pavement thickness design procedures establish required PCC thickness as a function of design ESALs and subgrade k-values using default values for terminal serviceability (P_t = 2.5), concrete modulus of elasticity (Ec = 4.2 MPsi) and allowable working stress in the concrete (f_t = 490 psi). **Figure 2.4** illustrates the sensitivity of the WisDOT PCC design equation for a range of subgrade k-values, using default values for P_t, Ec and f_t. As shown, there is an expected increase in the allowable ESALs as the design subgrade k-values increases.

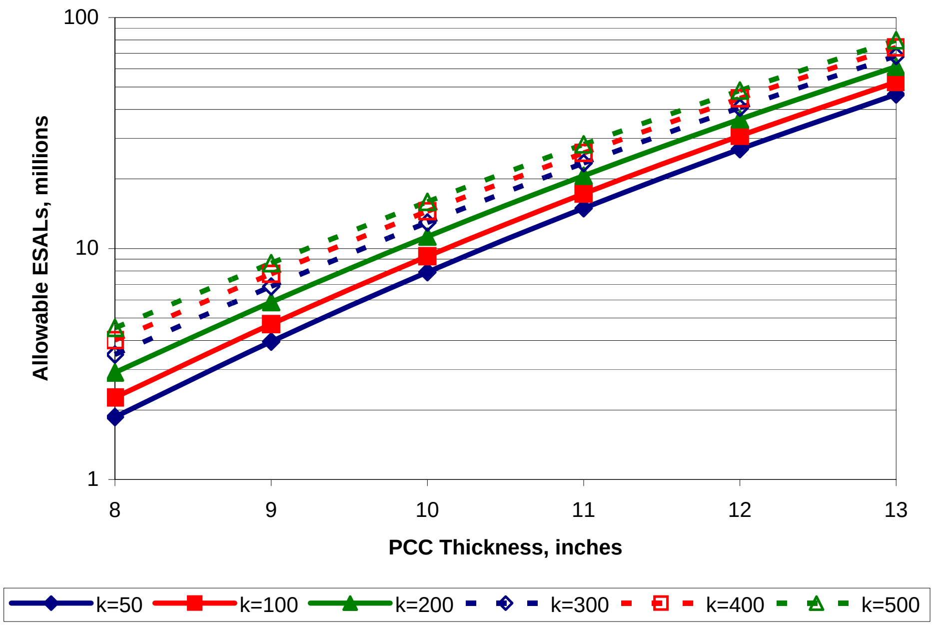

Figure 2.4: WisDOT PCC Thickness Design Sensitivity

(P_t=2.5, Ec=4.2Mpsi, f_t=490 psi)

Concrete strength testing completed during WHRP Project 0092-01-04, ***Early Opening of Portland Cement Concrete (PCC) Pavements to Traffic*** indicated compressive strengths exceeding 6,000 psi for concrete paving projects in Wisconsin, which equates to flexural strengths exceeding 750 psi. **Figure 2.5** illustrates ESAL trends versus PCC thickness using an increased allowable working stress (f_t = 750 / 1.33 = 564 psi) which may be more appropriate for concrete mixtures currently used in Wisconsin.

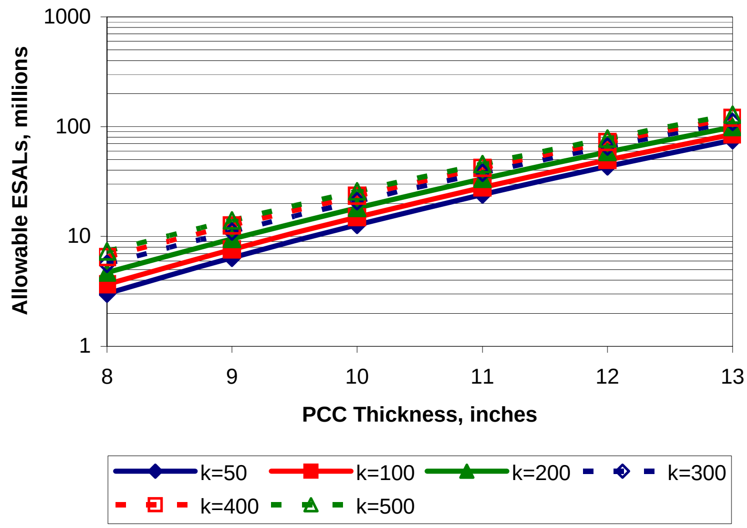

Figure 2.5: WisDOT PCC Thickness Design Sensitivity

(P_t=2.5, Ec=4.2Mpsi, f_t = 564 psi)

The trends illustrated in **Figures 2.4 and 2.5** clearly indicate the impact of increased PCC thicknesses, design k-values and/or working stress values on the expected life of the pavement. With respect to working stress values, allowable ESAL loadings increase significantly with increases in the allowable concrete working stress. F**igure 2.6** illustrates the impact of increases in the allowable working stress on the design life of ther PCC pavement.

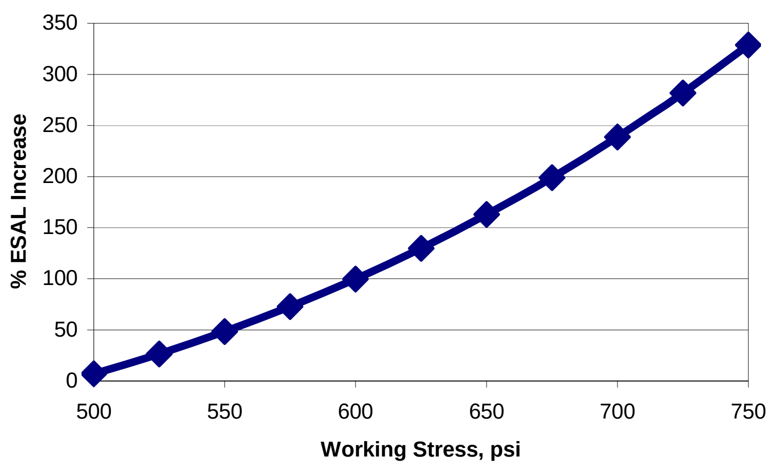

Figure 2.6: WisDOT Concrete Working Stress Sensitivity

The sensitivity of the WisDOT concrete pavement design equation to increased top-of-base k-values was investigated for a range of PCC design thicknesses, allowable working stress levels, subgrade k-values, rubblized PCC layer thicknesses, and rubblized PCC layer moduli. In each case, the baseline allowable ESALs were determined in relation to the design PCC thickness and subgrade k-value. The equivalent top-of-base k-value was then computed by **Eq. 2.8** based on the subgrade k-value, thickness and modulus of the rubblized PCC base layer. The required PCC thickness was then computed by iteration to provide the same number of baseline allowable ESALs computed previously. The PCC thickness reduction, due to the increased top-of-base k-value was then computed with and without consideration for rounding up to the nearest ½ inch.

The results of this sensitivity analysis are presented in **Tables 2.1 through 2.4 and Figures 2.4 to 2.19**. As shown, the PCC thickness reductions realized due to the presence of a rubblized PCC base layer range from 0.29 to 0.98 inches when rounding up on the required PCC thickness is ignored. Furthermore, for any given design subgrade k-value and rubblized PCC thickness, the PCC thickness reductions decrease as the design ESAL loadings increase. Also, for any given rubblized PCC thickness and design ESAL loadings, the PCC thickness reductions increase as the design subgrade k-value increases.

If rounding up of the required PCC thickness to the nearest ½ inch is incorporated into the top-of-base sensitivity analysis, the PCC thickness reductions due to the presence of a rubblized PCC base layer reduce to a maximum of ½ inch.

Table 2.1: WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	75	0.4	8	100	177	5.54	0.46	6.0	0.0
7	2.5	490	4.2E+06	75	0.9	8	100	177	6.58	0.42	7.0	0.0
8	2.5	490	4.2E+06	75	2.1	8	100	177	7.61	0.39	8.0	0.0
9	2.5	490	4.2E+06	75	4.4	8	100	177	8.63	0.37	9.0	0.0
10	2.5	490	4.2E+06	75	8.6	8	100	177	9.64	0.36	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	8	100	177	10.65	0.35	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	8	100	177	11.65	0.35	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	8	100	177	12.65	0.35	13.0	0.0
6	2.5	490	4.2E+06	75	0.4	9	100	192	5.49	0.51	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	9	100	192	6.53	0.47	7.0	0.0
8	2.5	490	4.2E+06	75	2.1	9	100	192	7.57	0.43	8.0	0.0
9	2.5	490	4.2E+06	75	4.4	9	100	192	8.59	0.41	9.0	0.0
10	2.5	490	4.2E+06	75	8.6	9	100	192	9.60	0.40	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	9	100	192	10.61	0.39	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	9	100	192	11.61	0.39	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	9	100	192	12.61	0.39	13.0	0.0
6	2.5	490	4.2E+06	75	0.4	10	100	207	5.43	0.57	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	10	100	207	6.48	0.52	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	10	100	207	7.52	0.48	8.0	0.0
9	2.5	490	4.2E+06	75	4.4	10	100	207	8.55	0.45	9.0	0.0
10	2.5	490	4.2E+06	75	8.6	10	100	207	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	10	100	207	10.57	0.43	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	10	100	207	11.58	0.42	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	10	100	207	12.58	0.42	13.0	0.0
6	2.5	490	4.2E+06	75	0.4	11	100	220	5.39	0.61	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	11	100	220	6.43	0.57	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	11	100	220	7.48	0.52	7.5	0.5
9	2.5	490	4.2E+06	75	4.4	11	100	220	8.52	0.48	9.0	0.0
10	2.5	490	4.2E+06	75	8.6	11	100	220	9.53	0.47	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	11	100	220	10.54	0.46	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	11	100	220	11.54	0.46	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	11	100	220	12.55	0.45	13.0	0.0
6	2.5	490	4.2E+06	75	0.4	12	100	232	5.35	0.65	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	12	100	232	6.40	0.60	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	12	100	232	7.45	0.55	7.5	0.5
9	2.5	490	4.2E+06	75	4.4	12	100	232	8.49	0.51	8.5	0.5
10	2.5	490	4.2E+06	75	8.6	12	100	232	9.50	0.50	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	12	100	232	10.51	0.49	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	12	100	232	11.52	0.48	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	12	100	232	12.52	0.48	13.0	0.0

Table 2.1 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	100	0.4	8	100	218	5.53	0.47	6.0	0.0
7	2.5	490	4.2E+06	100	1.0	8	100	218	6.57	0.43	7.0	0.0
8	2.5	490	4.2E+06	100	2.3	8	100	218	7.61	0.39	8.0	0.0
9	2.5	490	4.2E+06	100	4.7	8	100	218	8.63	0.37	9.0	0.0
10	2.5	490	4.2E+06	100	9.2	8	100	218	9.64	0.36	10.0	0.0
11	2.5	490	4.2E+06	100	17.3	8	100	218	10.65	0.35	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	8	100	218	11.66	0.34	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	8	100	218	12.66	0.34	13.0	0.0
6	2.5	490	4.2E+06	100	0.4	9	100	237	5.47	0.53	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	9	100	237	6.51	0.49	7.0	0.0
8	2.5	490	4.2E+06	100	2.3	9	100	237	7.56	0.44	8.0	0.0
9	2.5	490	4.2E+06	100	4.7	9	100	237	8.58	0.42	9.0	0.0
10	2.5	490	4.2E+06	100	9.2	9	100	237	9.60	0.40	10.0	0.0
11	2.5	490	4.2E+06	100	17.3	9	100	237	10.61	0.39	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	9	100	237	11.61	0.39	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	9	100	237	12.61	0.39	13.0	0.0
6	2.5	490	4.2E+06	100	0.4	10	100	255	5.41	0.59	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	10	100	255	6.46	0.54	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	10	100	255	7.51	0.49	8.0	0.0
9	2.5	490	4.2E+06	100	4.7	10	100	255	8.54	0.46	9.0	0.0
10	2.5	490	4.2E+06	100	9.2	10	100	255	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	100	17.3	10	100	255	10.57	0.43	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	10	100	255	11.57	0.43	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	10	100	255	12.58	0.42	13.0	0.0
6	2.5	490	4.2E+06	100	0.4	11	100	270	5.36	0.64	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	11	100	270	6.41	0.59	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	11	100	270	7.47	0.53	7.5	0.5
9	2.5	490	4.2E+06	100	4.7	11	100	270	8.51	0.49	9.0	0.0
10	2.5	490	4.2E+06	100	9.2	11	100	270	9.53	0.47	10.0	0.0
11	2.5	490	4.2E+06	100	17.3	11	100	270	10.54	0.46	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	11	100	270	11.54	0.46	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	11	100	270	12.55	0.45	13.0	0.0
6	2.5	490	4.2E+06	100	0.4	12	100	284	5.31	0.69	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	12	100	284	6.37	0.63	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	12	100	284	7.44	0.56	7.5	0.5
9	2.5	490	4.2E+06	100	4.7	12	100	284	8.47	0.53	8.5	0.5
10	2.5	490	4.2E+06	100	9.2	12	100	284	9.50	0.50	9.5	0.5
11	2.5	490	4.2E+06	100	17.3	12	100	284	10.51	0.49	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	12	100	284	11.51	0.49	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	12	100	284	12.52	0.48	13.0	0.0

Table 2.1 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	200	0.6	8	100	361	5.49	0.51	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	8	100	361	6.56	0.44	7.0	0.0
8	2.5	490	4.2E+06	200	2.9	8	100	361	7.61	0.39	8.0	0.0
9	2.5	490	4.2E+06	200	5.9	8	100	361	8.64	0.36	9.0	0.0
10	2.5	490	4.2E+06	200	11.3	8	100	361	9.66	0.34	10.0	0.0
11	2.5	490	4.2E+06	200	20.7	8	100	361	10.67	0.33	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	8	100	361	11.68	0.32	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	8	100	361	12.68	0.32	13.0	0.0
6	2.5	490	4.2E+06	200	0.6	9	100	392	5.40	0.60	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	9	100	392	6.48	0.52	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	9	100	392	7.55	0.45	8.0	0.0
9	2.5	490	4.2E+06	200	5.9	9	100	392	8.58	0.42	9.0	0.0
10	2.5	490	4.2E+06	200	11.3	9	100	392	9.60	0.40	10.0	0.0
11	2.5	490	4.2E+06	200	20.7	9	100	392	10.61	0.39	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	9	100	392	11.62	0.38	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	9	100	392	12.63	0.37	13.0	0.0
6	2.5	490	4.2E+06	200	0.6	10	100	419	5.32	0.68	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	10	100	419	6.41	0.59	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	10	100	419	7.49	0.51	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	10	100	419	8.53	0.47	9.0	0.0
10	2.5	490	4.2E+06	200	11.3	10	100	419	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	200	20.7	10	100	419	10.57	0.43	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	10	100	419	11.58	0.42	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	10	100	419	12.59	0.41	13.0	0.0
6	2.5	490	4.2E+06	200	0.6	11	100	442	5.25	0.75	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	11	100	442	6.36	0.64	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	11	100	442	7.44	0.56	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	11	100	442	8.49	0.51	8.5	0.5
10	2.5	490	4.2E+06	200	11.3	11	100	442	9.52	0.48	10.0	0.0
11	2.5	490	4.2E+06	200	20.7	11	100	442	10.53	0.47	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	11	100	442	11.54	0.46	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	11	100	442	12.55	0.45	13.0	0.0
6	2.5	490	4.2E+06	200	0.6	12	100	460	5.20	0.80	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	12	100	460	6.31	0.69	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	12	100	460	7.41	0.59	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	12	100	460	8.46	0.54	8.5	0.5
10	2.5	490	4.2E+06	200	11.3	12	100	460	9.49	0.51	9.5	0.5
11	2.5	490	4.2E+06	200	20.7	12	100	460	10.51	0.49	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	12	100	460	11.52	0.48	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	12	100	460	12.52	0.48	13.0	0.0

Table 2.1 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	300	0.8	8	100	486	5.47	0.53	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	8	100	486	6.56	0.44	7.0	0.0
8	2.5	490	4.2E+06	300	3.5	8	100	486	7.62	0.38	8.0	0.0
9	2.5	490	4.2E+06	300	6.9	8	100	486	8.66	0.34	9.0	0.0
10	2.5	490	4.2E+06	300	13.0	8	100	486	9.68	0.32	10.0	0.0
11	2.5	490	4.2E+06	300	23.4	8	100	486	10.69	0.31	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	8	100	486	11.70	0.30	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	8	100	486	12.70	0.30	13.0	0.0
6	2.5	490	4.2E+06	300	0.8	9	100	526	5.35	0.65	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	9	100	526	6.47	0.53	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	9	100	526	7.55	0.45	8.0	0.0
9	2.5	490	4.2E+06	300	6.9	9	100	526	8.59	0.41	9.0	0.0
10	2.5	490	4.2E+06	300	13.0	9	100	526	9.61	0.39	10.0	0.0
11	2.5	490	4.2E+06	300	23.4	9	100	526	10.63	0.37	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	9	100	526	11.64	0.36	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	9	100	526	12.64	0.36	13.0	0.0
6	2.5	490	4.2E+06	300	0.8	10	100	561	5.25	0.75	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	10	100	561	6.39	0.61	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	10	100	561	7.48	0.52	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	10	100	561	8.53	0.47	9.0	0.0
10	2.5	490	4.2E+06	300	13.0	10	100	561	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	300	23.4	10	100	561	10.58	0.42	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	10	100	561	11.59	0.41	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	10	100	561	12.60	0.40	13.0	0.0
6	2.5	490	4.2E+06	300	0.8	11	100	590	5.16	0.84	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	11	100	590	6.32	0.68	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	11	100	590	7.43	0.57	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	11	100	590	8.49	0.51	8.5	0.5
10	2.5	490	4.2E+06	300	13.0	11	100	590	9.52	0.48	10.0	0.0
11	2.5	490	4.2E+06	300	23.4	11	100	590	10.54	0.46	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	11	100	590	11.55	0.45	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	11	100	590	12.56	0.44	13.0	0.0
6	2.5	490	4.2E+06	300	0.8	12	100	610	5.09	0.91	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	12	100	610	6.28	0.72	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	12	100	610	7.39	0.61	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	12	100	610	8.46	0.54	8.5	0.5
10	2.5	490	4.2E+06	300	13.0	12	100	610	9.49	0.51	9.5	0.5
11	2.5	490	4.2E+06	300	23.4	12	100	610	10.51	0.49	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	12	100	610	11.53	0.47	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	12	100	610	12.54	0.46	13.0	0.0

Table 2.2: WisDOT Top-of-Base Sensitivity Analysis
(E_{rubb} = 200ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	75	0.4	8	200	207	5.44	0.56	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	8	200	207	6.48	0.52	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	8	200	207	7.52	0.48	8.0	0.0
9	2.5	490	4.2E+06	75	4.4	8	200	207	8.55	0.45	9.0	0.0
10	2.5	490	4.2E+06	75	8.6	8	200	207	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	8	200	207	10.57	0.43	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	8	200	207	11.58	0.42	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	8	200	207	12.58	0.42	13.0	0.0
6	2.5	490	4.2E+06	75	0.4	9	200	230	5.36	0.64	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	9	200	230	6.40	0.60	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	9	200	230	7.46	0.54	7.5	0.5
9	2.5	490	4.2E+06	75	4.4	9	200	230	8.49	0.51	8.5	0.5
10	2.5	490	4.2E+06	75	8.6	9	200	230	9.51	0.49	10.0	0.0
11	2.5	490	4.2E+06	75	16.2	9	200	230	10.52	0.48	11.0	0.0
12	2.5	490	4.2E+06	75	29.0	9	200	230	11.52	0.48	12.0	0.0
13	2.5	490	4.2E+06	75	49.8	9	200	230	12.52	0.48	13.0	0.0
6	2.5	490	4.2E+06	75	0.4	10	200	255	5.27	0.73	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	10	200	255	6.33	0.67	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	10	200	255	7.39	0.61	7.5	0.5
9	2.5	490	4.2E+06	75	4.4	10	200	255	8.43	0.57	8.5	0.5
10	2.5	490	4.2E+06	75	8.6	10	200	255	9.45	0.55	9.5	0.5
11	2.5	490	4.2E+06	75	16.2	10	200	255	10.46	0.54	10.5	0.5
12	2.5	490	4.2E+06	75	29.0	10	200	255	11.47	0.53	11.5	0.5
13	2.5	490	4.2E+06	75	49.8	10	200	255	12.47	0.53	12.5	0.5
6	2.5	490	4.2E+06	75	0.4	11	200	281	5.18	0.82	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	11	200	281	6.25	0.75	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	11	200	281	7.32	0.68	7.5	0.5
9	2.5	490	4.2E+06	75	4.4	11	200	281	8.37	0.63	8.5	0.5
10	2.5	490	4.2E+06	75	8.6	11	200	281	9.39	0.61	9.5	0.5
11	2.5	490	4.2E+06	75	16.2	11	200	281	10.41	0.59	10.5	0.5
12	2.5	490	4.2E+06	75	29.0	11	200	281	11.41	0.59	11.5	0.5
13	2.5	490	4.2E+06	75	49.8	11	200	281	12.42	0.58	12.5	0.5
6	2.5	490	4.2E+06	75	0.4	12	200	308	5.09	0.91	5.5	0.5
7	2.5	490	4.2E+06	75	0.9	12	200	308	6.17	0.83	6.5	0.5
8	2.5	490	4.2E+06	75	2.1	12	200	308	7.26	0.74	7.5	0.5
9	2.5	490	4.2E+06	75	4.4	12	200	308	8.31	0.69	8.5	0.5
10	2.5	490	4.2E+06	75	8.6	12	200	308	9.34	0.66	9.5	0.5
11	2.5	490	4.2E+06	75	16.2	12	200	308	10.35	0.65	10.5	0.5
12	2.5	490	4.2E+06	75	29.0	12	200	308	11.36	0.64	11.5	0.5
13	2.5	490	4.2E+06	75	49.8	12	200	308	12.37	0.63	12.5	0.5

Table 2.2 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 200ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	100	0.4	8	200	254	5.41	0.59	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	8	200	254	6.46	0.54	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	8	200	254	7.51	0.49	8.0	0.0
9	2.5	490	4.2E+06	100	4.7	8	200	254	8.54	0.46	9.0	0.0
10	2.5	490	4.2E+06	100	9.2	8	200	254	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	100	17.3	8	200	254	10.57	0.43	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	8	200	254	11.58	0.42	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	8	200	254	12.58	0.42	13.0	0.0
6	2.5	490	4.2E+06	100	0.4	9	200	282	5.32	0.68	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	9	200	282	6.38	0.62	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	9	200	282	7.44	0.56	7.5	0.5
9	2.5	490	4.2E+06	100	4.7	9	200	282	8.48	0.52	8.5	0.5
10	2.5	490	4.2E+06	100	9.2	9	200	282	9.50	0.50	9.5	0.5
11	2.5	490	4.2E+06	100	17.3	9	200	282	10.51	0.49	11.0	0.0
12	2.5	490	4.2E+06	100	30.8	9	200	282	11.52	0.48	12.0	0.0
13	2.5	490	4.2E+06	100	52.6	9	200	282	12.52	0.48	13.0	0.0
6	2.5	490	4.2E+06	100	0.4	10	200	312	5.22	0.78	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	10	200	312	6.30	0.70	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	10	200	312	7.37	0.63	7.5	0.5
9	2.5	490	4.2E+06	100	4.7	10	200	312	8.41	0.59	8.5	0.5
10	2.5	490	4.2E+06	100	9.2	10	200	312	9.44	0.56	9.5	0.5
11	2.5	490	4.2E+06	100	17.3	10	200	312	10.45	0.55	10.5	0.5
12	2.5	490	4.2E+06	100	30.8	10	200	312	11.46	0.54	11.5	0.5
13	2.5	490	4.2E+06	100	52.6	10	200	312	12.46	0.54	12.5	0.5
6	2.5	490	4.2E+06	100	0.4	11	200	343	5.12	0.88	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	11	200	343	6.21	0.79	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	11	200	343	7.30	0.70	7.5	0.5
9	2.5	490	4.2E+06	100	4.7	11	200	343	8.35	0.65	8.5	0.5
10	2.5	490	4.2E+06	100	9.2	11	200	343	9.38	0.62	9.5	0.5
11	2.5	490	4.2E+06	100	17.3	11	200	343	10.39	0.61	10.5	0.5
12	2.5	490	4.2E+06	100	30.8	11	200	343	11.40	0.60	11.5	0.5
13	2.5	490	4.2E+06	100	52.6	11	200	343	12.41	0.59	12.5	0.5
6	2.5	490	4.2E+06	100	0.4	12	200	375	5.02	0.98	5.5	0.5
7	2.5	490	4.2E+06	100	1.0	12	200	375	6.12	0.88	6.5	0.5
8	2.5	490	4.2E+06	100	2.3	12	200	375	7.23	0.77	7.5	0.5
9	2.5	490	4.2E+06	100	4.7	12	200	375	8.29	0.71	8.5	0.5
10	2.5	490	4.2E+06	100	9.2	12	200	375	9.32	0.68	9.5	0.5
11	2.5	490	4.2E+06	100	17.3	12	200	375	10.34	0.66	10.5	0.5
12	2.5	490	4.2E+06	100	30.8	12	200	375	11.35	0.65	11.5	0.5
13	2.5	490	4.2E+06	100	52.6	12	200	375	12.36	0.64	12.5	0.5

Table 2.2 (Cont.): WisDOT Top-of-Base Sensitivity Analysis
(E_{rubb} = 200ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	200	0.6	8	200	417	5.33	0.67	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	8	200	417	6.42	0.58	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	8	200	417	7.49	0.51	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	8	200	417	8.54	0.46	9.0	0.0
10	2.5	490	4.2E+06	200	11.3	8	200	417	9.56	0.44	10.0	0.0
11	2.5	490	4.2E+06	200	20.7	8	200	417	10.57	0.43	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	8	200	417	11.58	0.42	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	8	200	417	12.59	0.41	13.0	0.0
6	2.5	490	4.2E+06	200	0.6	9	200	463	5.19	0.81	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	9	200	463	6.31	0.69	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	9	200	463	7.40	0.60	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	9	200	463	8.46	0.54	8.5	0.5
10	2.5	490	4.2E+06	200	11.3	9	200	463	9.48	0.52	9.5	0.5
11	2.5	490	4.2E+06	200	20.7	9	200	463	10.50	0.50	11.0	0.0
12	2.5	490	4.2E+06	200	36.3	9	200	463	11.51	0.49	12.0	0.0
13	2.5	490	4.2E+06	200	61.3	9	200	463	12.52	0.48	13.0	0.0
6	2.5	490	4.2E+06	200	0.6	10	200	509	5.04	0.96	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	10	200	509	6.20	0.80	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	10	200	509	7.31	0.69	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	10	200	509	8.38	0.62	8.5	0.5
10	2.5	490	4.2E+06	200	11.3	10	200	509	9.41	0.59	9.5	0.5
11	2.5	490	4.2E+06	200	20.7	10	200	509	10.43	0.57	10.5	0.5
12	2.5	490	4.2E+06	200	36.3	10	200	509	11.45	0.55	11.5	0.5
13	2.5	490	4.2E+06	200	61.3	10	200	509	12.45	0.55	12.5	0.5
6	2.5	490	4.2E+06	200	0.6	11	200	556	5.04	0.96	5.5	0.5
7	2.5	490	4.2E+06	200	1.4	11	200	556	6.20	0.80	6.5	0.5
8	2.5	490	4.2E+06	200	2.9	11	200	556	7.31	0.69	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	11	200	556	8.38	0.62	8.5	0.5
10	2.5	490	4.2E+06	200	11.3	11	200	556	9.41	0.59	9.5	0.5
11	2.5	490	4.2E+06	200	20.7	11	200	556	10.43	0.57	10.5	0.5
12	2.5	490	4.2E+06	200	36.3	11	200	556	11.45	0.55	11.5	0.5
13	2.5	490	4.2E+06	200	61.3	11	200	556	12.45	0.55	12.5	0.5
6	2.5	490	4.2E+06	200	0.6	12	200	603	4.70	1.30	5.0	1.0
7	2.5	490	4.2E+06	200	1.4	12	200	603	5.96	1.04	6.0	1.0
8	2.5	490	4.2E+06	200	2.9	12	200	603	7.13	0.87	7.5	0.5
9	2.5	490	4.2E+06	200	5.9	12	200	603	8.22	0.78	8.5	0.5
10	2.5	490	4.2E+06	200	11.3	12	200	603	9.27	0.73	9.5	0.5
11	2.5	490	4.2E+06	200	20.7	12	200	603	10.30	0.70	10.5	0.5
12	2.5	490	4.2E+06	200	36.3	12	200	603	11.32	0.68	11.5	0.5
13	2.5	490	4.2E+06	200	61.3	12	200	603	12.33	0.67	12.5	0.5

Table 2.2 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 200ksi, f_t = 490psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	490	4.2E+06	300	0.8	8	200	557	5.26	0.74	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	8	200	557	6.40	0.60	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	8	200	557	7.49	0.51	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	8	200	557	8.54	0.46	9.0	0.0
10	2.5	490	4.2E+06	300	13.0	8	200	557	9.57	0.43	10.0	0.0
11	2.5	490	4.2E+06	300	23.4	8	200	557	10.59	0.41	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	8	200	557	11.60	0.40	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	8	200	557	12.60	0.40	13.0	0.0
6	2.5	490	4.2E+06	300	0.8	9	200	618	5.07	0.93	5.5	0.5
7	2.5	490	4.2E+06	300	1.7	9	200	618	6.26	0.74	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	9	200	618	7.38	0.62	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	9	200	618	8.45	0.55	8.5	0.5
10	2.5	490	4.2E+06	300	13.0	9	200	618	9.48	0.52	9.5	0.5
11	2.5	490	4.2E+06	300	23.4	9	200	618	10.50	0.50	11.0	0.0
12	2.5	490	4.2E+06	300	40.7	9	200	618	11.52	0.48	12.0	0.0
13	2.5	490	4.2E+06	300	68.2	9	200	618	12.53	0.47	13.0	0.0
6	2.5	490	4.2E+06	300	0.8	10	200	678	4.84	1.16	5.0	1.0
7	2.5	490	4.2E+06	300	1.7	10	200	678	6.12	0.88	6.5	0.5
8	2.5	490	4.2E+06	300	3.5	10	200	678	7.28	0.72	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	10	200	678	8.36	0.64	8.5	0.5
10	2.5	490	4.2E+06	300	13.0	10	200	678	9.40	0.60	9.5	0.5
11	2.5	490	4.2E+06	300	23.4	10	200	678	10.43	0.57	10.5	0.5
12	2.5	490	4.2E+06	300	40.7	10	200	678	11.44	0.56	11.5	0.5
13	2.5	490	4.2E+06	300	68.2	10	200	678	12.46	0.54	12.5	0.5
6	2.5	490	4.2E+06	300	0.8	11	200	737	4.55	1.45	5.0	1.0
7	2.5	490	4.2E+06	300	1.7	11	200	737	5.97	1.03	6.0	1.0
8	2.5	490	4.2E+06	300	3.5	11	200	737	7.17	0.83	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	11	200	737	8.27	0.73	8.5	0.5
10	2.5	490	4.2E+06	300	13.0	11	200	737	9.32	0.68	9.5	0.5
11	2.5	490	4.2E+06	300	23.4	11	200	737	10.35	0.65	10.5	0.5
12	2.5	490	4.2E+06	300	40.7	11	200	737	11.37	0.63	11.5	0.5
13	2.5	490	4.2E+06	300	68.2	11	200	737	12.39	0.61	12.5	0.5
6	2.5	490	4.2E+06	300	0.8	12	200	795	n.a.	n.a.	n.a.	n.a.
7	2.5	490	4.2E+06	300	1.7	12	200	795	5.82	1.18	6.0	1.0
8	2.5	490	4.2E+06	300	3.5	12	200	795	7.07	0.93	7.5	0.5
9	2.5	490	4.2E+06	300	6.9	12	200	795	8.19	0.81	8.5	0.5
10	2.5	490	4.2E+06	300	13.0	12	200	795	9.25	0.75	9.5	0.5
11	2.5	490	4.2E+06	300	23.4	12	200	795	10.29	0.71	10.5	0.5
12	2.5	490	4.2E+06	300	40.7	12	200	795	11.31	0.69	11.5	0.5
13	2.5	490	4.2E+06	300	68.2	12	200	795	12.33	0.67	12.5	0.5

Table 2.3: WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	75	1.0	8	100	177	5.54	0.46	6.0	0.0
7	2.5	650	4.2E+06	75	2.5	8	100	177	6.58	0.42	7.0	0.0
8	2.5	650	4.2E+06	75	5.5	8	100	177	7.61	0.39	8.0	0.0
9	2.5	650	4.2E+06	75	11.4	8	100	177	8.63	0.37	9.0	0.0
10	2.5	650	4.2E+06	75	22.7	8	100	177	9.64	0.36	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	8	100	177	10.65	0.35	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	8	100	177	11.65	0.35	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	8	100	177	12.65	0.35	13.0	0.0
6	2.5	650	4.2E+06	75	1.0	9	100	192	5.49	0.51	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	9	100	192	6.53	0.47	7.0	0.0
8	2.5	650	4.2E+06	75	5.5	9	100	192	7.57	0.43	8.0	0.0
9	2.5	650	4.2E+06	75	11.4	9	100	192	8.59	0.41	9.0	0.0
10	2.5	650	4.2E+06	75	22.7	9	100	192	9.60	0.40	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	9	100	192	10.61	0.39	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	9	100	192	11.61	0.39	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	9	100	192	12.61	0.39	13.0	0.0
6	2.5	650	4.2E+06	75	1.0	10	100	207	5.44	0.56	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	10	100	207	6.48	0.52	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	10	100	207	7.52	0.48	8.0	0.0
9	2.5	650	4.2E+06	75	11.4	10	100	207	8.55	0.45	9.0	0.0
10	2.5	650	4.2E+06	75	22.7	10	100	207	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	10	100	207	10.57	0.43	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	10	100	207	11.58	0.42	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	10	100	207	12.58	0.42	13.0	0.0
6	2.5	650	4.2E+06	75	1.0	11	100	220	5.39	0.61	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	11	100	220	6.43	0.57	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	11	100	220	7.48	0.52	7.5	0.5
9	2.5	650	4.2E+06	75	11.4	11	100	220	8.52	0.48	9.0	0.0
10	2.5	650	4.2E+06	75	22.7	11	100	220	9.53	0.47	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	11	100	220	10.54	0.46	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	11	100	220	11.54	0.46	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	11	100	220	12.55	0.45	13.0	0.0
6	2.5	650	4.2E+06	75	1.0	12	100	232	5.35	0.65	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	12	100	232	6.40	0.60	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	12	100	232	7.45	0.55	7.5	0.5
9	2.5	650	4.2E+06	75	11.4	12	100	232	8.49	0.51	8.5	0.5
10	2.5	650	4.2E+06	75	22.7	12	100	232	9.50	0.50	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	12	100	232	10.51	0.49	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	12	100	232	11.52	0.48	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	12	100	232	12.52	0.48	13.0	0.0

Table 2.3 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	100	1.2	8	100	218	5.53	0.47	6.0	0.0
7	2.5	650	4.2E+06	100	2.7	8	100	218	6.57	0.43	7.0	0.0
8	2.5	650	4.2E+06	100	6.0	8	100	218	7.61	0.39	8.0	0.0
9	2.5	650	4.2E+06	100	12.4	8	100	218	8.63	0.37	9.0	0.0
10	2.5	650	4.2E+06	100	24.3	8	100	218	9.64	0.36	10.0	0.0
11	2.5	650	4.2E+06	100	45.4	8	100	218	10.65	0.35	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	8	100	218	11.66	0.34	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	8	100	218	12.66	0.34	13.0	0.0
6	2.5	650	4.2E+06	100	1.2	9	100	237	5.47	0.53	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	9	100	237	6.51	0.49	7.0	0.0
8	2.5	650	4.2E+06	100	6.0	9	100	237	7.56	0.44	8.0	0.0
9	2.5	650	4.2E+06	100	12.4	9	100	237	8.58	0.42	9.0	0.0
10	2.5	650	4.2E+06	100	24.3	9	100	237	9.60	0.40	10.0	0.0
11	2.5	650	4.2E+06	100	45.4	9	100	237	10.61	0.39	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	9	100	237	11.61	0.39	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	9	100	237	12.61	0.39	13.0	0.0
6	2.5	650	4.2E+06	100	1.2	10	100	255	5.41	0.59	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	10	100	255	6.46	0.54	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	10	100	255	7.51	0.49	8.0	0.0
9	2.5	650	4.2E+06	100	12.4	10	100	255	8.54	0.46	9.0	0.0
10	2.5	650	4.2E+06	100	24.3	10	100	255	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	100	45.4	10	100	255	10.57	0.43	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	10	100	255	11.57	0.43	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	10	100	255	12.58	0.42	13.0	0.0
6	2.5	650	4.2E+06	100	1.2	11	100	270	5.36	0.64	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	11	100	270	6.41	0.59	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	11	100	270	7.47	0.53	7.5	0.5
9	2.5	650	4.2E+06	100	12.4	11	100	270	8.51	0.49	9.0	0.0
10	2.5	650	4.2E+06	100	24.3	11	100	270	9.53	0.47	10.0	0.0
11	2.5	650	4.2E+06	100	45.4	11	100	270	10.54	0.46	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	11	100	270	11.54	0.46	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	11	100	270	12.55	0.45	13.0	0.0
6	2.5	650	4.2E+06	100	1.2	12	100	284	5.31	0.69	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	12	100	284	6.37	0.63	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	12	100	284	7.44	0.56	7.5	0.5
9	2.5	650	4.2E+06	100	12.4	12	100	284	8.47	0.53	8.5	0.5
10	2.5	650	4.2E+06	100	24.3	12	100	284	9.50	0.50	9.5	0.5
11	2.5	650	4.2E+06	100	45.4	12	100	284	10.51	0.49	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	12	100	284	11.51	0.49	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	12	100	284	12.52	0.48	13.0	0.0

Table 2.3 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 100ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	200	1.7	8	100	361	5.49	0.51	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	8	100	361	6.56	0.44	7.0	0.0
8	2.5	650	4.2E+06	200	7.6	8	100	361	7.61	0.39	8.0	0.0
9	2.5	650	4.2E+06	200	15.4	8	100	361	8.64	0.36	9.0	0.0
10	2.5	650	4.2E+06	200	29.6	8	100	361	9.66	0.34	10.0	0.0
11	2.5	650	4.2E+06	200	54.3	8	100	361	10.67	0.33	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	8	100	361	11.68	0.32	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	8	100	361	12.68	0.32	13.0	0.0
6	2.5	650	4.2E+06	200	1.7	9	100	392	5.40	0.60	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	9	100	392	6.48	0.52	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	9	100	392	7.55	0.45	8.0	0.0
9	2.5	650	4.2E+06	200	15.4	9	100	392	8.58	0.42	9.0	0.0
10	2.5	650	4.2E+06	200	29.6	9	100	392	9.60	0.40	10.0	0.0
11	2.5	650	4.2E+06	200	54.3	9	100	392	10.61	0.39	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	9	100	392	11.62	0.38	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	9	100	392	12.63	0.37	13.0	0.0
6	2.5	650	4.2E+06	200	1.7	10	100	419	5.32	0.68	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	10	100	419	6.41	0.59	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	10	100	419	7.49	0.51	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	10	100	419	8.53	0.47	9.0	0.0
10	2.5	650	4.2E+06	200	29.6	10	100	419	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	200	54.3	10	100	419	10.57	0.43	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	10	100	419	11.58	0.42	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	10	100	419	12.59	0.41	13.0	0.0
6	2.5	650	4.2E+06	200	1.7	11	100	442	5.25	0.75	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	11	100	442	6.36	0.64	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	11	100	442	7.44	0.56	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	11	100	442	8.49	0.51	8.5	0.5
10	2.5	650	4.2E+06	200	29.6	11	100	442	9.52	0.48	10.0	0.0
11	2.5	650	4.2E+06	200	54.3	11	100	442	10.53	0.47	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	11	100	442	11.54	0.46	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	11	100	442	12.55	0.45	13.0	0.0
6	2.5	650	4.2E+06	200	1.7	12	100	460	5.20	0.80	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	12	100	460	6.31	0.69	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	12	100	460	7.41	0.59	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	12	100	460	8.46	0.54	8.5	0.5
10	2.5	650	4.2E+06	200	29.6	12	100	460	9.49	0.51	9.5	0.5
11	2.5	650	4.2E+06	200	54.3	12	100	460	10.51	0.49	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	12	100	460	11.52	0.48	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	12	100	460	12.52	0.48	13.0	0.0

Table 2.3 (Cont.): WisDOT Top-of-Base Sensitivity Analysis
(E_{rubb} = 100ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	300	2.1	8	100	486	5.47	0.53	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	8	100	486	6.56	0.44	7.0	0.0
8	2.5	650	4.2E+06	300	9.1	8	100	486	7.62	0.38	8.0	0.0
9	2.5	650	4.2E+06	300	18.0	8	100	486	8.66	0.34	9.0	0.0
10	2.5	650	4.2E+06	300	34.0	8	100	486	9.68	0.32	10.0	0.0
11	2.5	650	4.2E+06	300	61.6	8	100	486	10.69	0.31	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	8	100	486	11.70	0.30	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	8	100	486	12.70	0.30	13.0	0.0
6	2.5	650	4.2E+06	300	2.1	9	100	526	5.35	0.65	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	9	100	526	6.47	0.53	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	9	100	526	7.55	0.45	8.0	0.0
9	2.5	650	4.2E+06	300	18.0	9	100	526	8.59	0.41	9.0	0.0
10	2.5	650	4.2E+06	300	34.0	9	100	526	9.61	0.39	10.0	0.0
11	2.5	650	4.2E+06	300	61.6	9	100	526	10.63	0.37	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	9	100	526	11.64	0.36	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	9	100	526	12.64	0.36	13.0	0.0
6	2.5	650	4.2E+06	300	2.1	10	100	561	5.25	0.75	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	10	100	561	6.39	0.61	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	10	100	561	7.48	0.52	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	10	100	561	8.53	0.47	9.0	0.0
10	2.5	650	4.2E+06	300	34.0	10	100	561	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	300	61.6	10	100	561	10.58	0.42	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	10	100	561	11.59	0.41	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	10	100	561	12.60	0.40	13.0	0.0
6	2.5	650	4.2E+06	300	2.1	11	100	590	5.16	0.84	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	11	100	590	6.32	0.68	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	11	100	590	7.43	0.57	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	11	100	590	8.49	0.51	8.5	0.5
10	2.5	650	4.2E+06	300	34.0	11	100	590	9.52	0.48	10.0	0.0
11	2.5	650	4.2E+06	300	61.6	11	100	590	10.54	0.46	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	11	100	590	11.55	0.45	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	11	100	590	12.56	0.44	13.0	0.0
6	2.5	650	4.2E+06	300	2.1	12	100	610	5.09	0.91	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	12	100	610	6.28	0.72	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	12	100	610	7.39	0.61	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	12	100	610	8.46	0.54	8.5	0.5
10	2.5	650	4.2E+06	300	34.0	12	100	610	9.49	0.51	9.5	0.5
11	2.5	650	4.2E+06	300	61.6	12	100	610	10.51	0.49	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	12	100	610	11.53	0.47	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	12	100	610	12.54	0.46	13.0	0.0

Table 2.4: WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 200ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	75	1.0	8	200	207	5.44	0.56	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	8	200	207	6.48	0.52	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	8	200	207	7.52	0.48	8.0	0.0
9	2.5	650	4.2E+06	75	11.4	8	200	207	8.55	0.45	9.0	0.0
10	2.5	650	4.2E+06	75	22.7	8	200	207	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	8	200	207	10.57	0.43	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	8	200	207	11.58	0.42	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	8	200	207	12.58	0.42	13.0	0.0
6	2.5	650	4.2E+06	75	1.0	9	200	230	5.36	0.64	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	9	200	230	6.40	0.60	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	9	200	230	7.46	0.54	7.5	0.5
9	2.5	650	4.2E+06	75	11.4	9	200	230	8.49	0.51	8.5	0.5
10	2.5	650	4.2E+06	75	22.7	9	200	230	9.51	0.49	10.0	0.0
11	2.5	650	4.2E+06	75	42.6	9	200	230	10.52	0.48	11.0	0.0
12	2.5	650	4.2E+06	75	76.2	9	200	230	11.52	0.48	12.0	0.0
13	2.5	650	4.2E+06	75	130.9	9	200	230	12.52	0.48	13.0	0.0
6	2.5	650	4.2E+06	75	1.0	10	200	255	5.27	0.73	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	10	200	255	6.33	0.67	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	10	200	255	7.39	0.61	7.5	0.5
9	2.5	650	4.2E+06	75	11.4	10	200	255	8.43	0.57	8.5	0.5
10	2.5	650	4.2E+06	75	22.7	10	200	255	9.45	0.55	9.5	0.5
11	2.5	650	4.2E+06	75	42.6	10	200	255	10.46	0.54	10.5	0.5
12	2.5	650	4.2E+06	75	76.2	10	200	255	11.47	0.53	11.5	0.5
13	2.5	650	4.2E+06	75	130.9	10	200	255	12.47	0.53	12.5	0.5
6	2.5	650	4.2E+06	75	1.0	11	200	281	5.18	0.82	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	11	200	281	6.25	0.75	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	11	200	281	7.32	0.68	7.5	0.5
9	2.5	650	4.2E+06	75	11.4	11	200	281	8.37	0.63	8.5	0.5
10	2.5	650	4.2E+06	75	22.7	11	200	281	9.39	0.61	9.5	0.5
11	2.5	650	4.2E+06	75	42.6	11	200	281	10.41	0.59	10.5	0.5
12	2.5	650	4.2E+06	75	76.2	11	200	281	11.41	0.59	11.5	0.5
13	2.5	650	4.2E+06	75	130.9	11	200	281	12.42	0.58	12.5	0.5
6	2.5	650	4.2E+06	75	1.0	12	200	308	5.09	0.91	5.5	0.5
7	2.5	650	4.2E+06	75	2.5	12	200	308	6.17	0.83	6.5	0.5
8	2.5	650	4.2E+06	75	5.5	12	200	308	7.26	0.74	7.5	0.5
9	2.5	650	4.2E+06	75	11.4	12	200	308	8.31	0.69	8.5	0.5
10	2.5	650	4.2E+06	75	22.7	12	200	308	9.34	0.66	9.5	0.5
11	2.5	650	4.2E+06	75	42.6	12	200	308	10.35	0.65	10.5	0.5
12	2.5	650	4.2E+06	75	76.2	12	200	308	11.36	0.64	11.5	0.5
13	2.5	650	4.2E+06	75	130.9	12	200	308	12.37	0.63	12.5	0.5

Table 2.4 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 200ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	100	1.2	8	200	254	5.41	0.59	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	8	200	254	6.46	0.54	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	8	200	254	7.51	0.49	8.0	0.0
9	2.5	650	4.2E+06	100	12.4	8	200	254	8.54	0.46	9.0	0.0
10	2.5	650	4.2E+06	100	24.3	8	200	254	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	100	45.4	8	200	254	10.57	0.43	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	8	200	254	11.58	0.42	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	8	200	254	12.58	0.42	13.0	0.0
6	2.5	650	4.2E+06	100	1.2	9	200	282	5.32	0.68	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	9	200	282	6.38	0.62	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	9	200	282	7.44	0.56	7.5	0.5
9	2.5	650	4.2E+06	100	12.4	9	200	282	8.48	0.52	8.5	0.5
10	2.5	650	4.2E+06	100	24.3	9	200	282	9.50	0.50	9.5	0.5
11	2.5	650	4.2E+06	100	45.4	9	200	282	10.51	0.49	11.0	0.0
12	2.5	650	4.2E+06	100	80.8	9	200	282	11.52	0.48	12.0	0.0
13	2.5	650	4.2E+06	100	138.2	9	200	282	12.52	0.48	13.0	0.0
6	2.5	650	4.2E+06	100	1.2	10	200	312	5.22	0.78	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	10	200	312	6.30	0.70	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	10	200	312	7.37	0.63	7.5	0.5
9	2.5	650	4.2E+06	100	12.4	10	200	312	8.41	0.59	8.5	0.5
10	2.5	650	4.2E+06	100	24.3	10	200	312	9.44	0.56	9.5	0.5
11	2.5	650	4.2E+06	100	45.4	10	200	312	10.45	0.55	10.5	0.5
12	2.5	650	4.2E+06	100	80.8	10	200	312	11.46	0.54	11.5	0.5
13	2.5	650	4.2E+06	100	138.2	10	200	312	12.46	0.54	12.5	0.5
6	2.5	650	4.2E+06	100	1.2	11	200	343	5.12	0.88	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	11	200	343	6.21	0.79	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	11	200	343	7.30	0.70	7.5	0.5
9	2.5	650	4.2E+06	100	12.4	11	200	343	8.35	0.65	8.5	0.5
10	2.5	650	4.2E+06	100	24.3	11	200	343	9.38	0.62	9.5	0.5
11	2.5	650	4.2E+06	100	45.4	11	200	343	10.39	0.61	10.5	0.5
12	2.5	650	4.2E+06	100	80.8	11	200	343	11.40	0.60	11.5	0.5
13	2.5	650	4.2E+06	100	138.2	11	200	343	12.41	0.59	12.5	0.5
6	2.5	650	4.2E+06	100	1.2	12	200	375	5.02	0.98	5.5	0.5
7	2.5	650	4.2E+06	100	2.7	12	200	375	6.12	0.88	6.5	0.5
8	2.5	650	4.2E+06	100	6.0	12	200	375	7.22	0.78	7.5	0.5
9	2.5	650	4.2E+06	100	12.4	12	200	375	8.29	0.71	8.5	0.5
10	2.5	650	4.2E+06	100	24.3	12	200	375	9.32	0.68	9.5	0.5
11	2.5	650	4.2E+06	100	45.4	12	200	375	10.34	0.66	10.5	0.5
12	2.5	650	4.2E+06	100	80.8	12	200	375	11.35	0.65	11.5	0.5
13	2.5	650	4.2E+06	100	138.2	12	200	375	12.35	0.65	12.5	0.5

Table 2.4 (Cont.): WisDOT Top-of-Base Sensitivity Analysis (E_{rubb} = 200ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	200	1.7	8	200	417	5.33	0.67	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	8	200	417	6.42	0.58	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	8	200	417	7.49	0.51	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	8	200	417	8.54	0.46	9.0	0.0
10	2.5	650	4.2E+06	200	29.6	8	200	417	9.56	0.44	10.0	0.0
11	2.5	650	4.2E+06	200	54.3	8	200	417	10.57	0.43	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	8	200	417	11.58	0.42	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	8	200	417	12.59	0.41	13.0	0.0
6	2.5	650	4.2E+06	200	1.7	9	200	463	5.19	0.81	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	9	200	463	6.31	0.69	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	9	200	463	7.40	0.60	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	9	200	463	8.46	0.54	8.5	0.5
10	2.5	650	4.2E+06	200	29.6	9	200	463	9.48	0.52	9.5	0.5
11	2.5	650	4.2E+06	200	54.3	9	200	463	10.50	0.50	11.0	0.0
12	2.5	650	4.2E+06	200	95.4	9	200	463	11.51	0.49	12.0	0.0
13	2.5	650	4.2E+06	200	161.1	9	200	463	12.52	0.48	13.0	0.0
6	2.5	650	4.2E+06	200	1.7	10	200	509	5.04	0.96	5.5	0.5
7	2.5	650	4.2E+06	200	3.6	10	200	509	6.20	0.80	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	10	200	509	7.31	0.69	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	10	200	509	8.38	0.62	8.5	0.5
10	2.5	650	4.2E+06	200	29.6	10	200	509	9.41	0.59	9.5	0.5
11	2.5	650	4.2E+06	200	54.3	10	200	509	10.43	0.57	10.5	0.5
12	2.5	650	4.2E+06	200	95.4	10	200	509	11.45	0.55	11.5	0.5
13	2.5	650	4.2E+06	200	161.1	10	200	509	12.45	0.55	12.5	0.5
6	2.5	650	4.2E+06	200	1.7	11	200	556	4.88	1.12	5.0	1.0
7	2.5	650	4.2E+06	200	3.6	11	200	556	6.08	0.92	6.5	0.5
8	2.5	650	4.2E+06	200	7.6	11	200	556	7.22	0.78	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	11	200	556	8.30	0.70	8.5	0.5
10	2.5	650	4.2E+06	200	29.6	11	200	556	9.34	0.66	9.5	0.5
11	2.5	650	4.2E+06	200	54.3	11	200	556	10.37	0.63	10.5	0.5
12	2.5	650	4.2E+06	200	95.4	11	200	556	11.38	0.62	11.5	0.5
13	2.5	650	4.2E+06	200	161.1	11	200	556	12.39	0.61	12.5	0.5
6	2.5	650	4.2E+06	200	1.7	12	200	603	4.70	1.30	5.0	1.0
7	2.5	650	4.2E+06	200	3.6	12	200	603	5.96	1.04	6.0	1.0
8	2.5	650	4.2E+06	200	7.6	12	200	603	7.13	0.87	7.5	0.5
9	2.5	650	4.2E+06	200	15.4	12	200	603	8.22	0.78	8.5	0.5
10	2.5	650	4.2E+06	200	29.6	12	200	603	9.27	0.73	9.5	0.5
11	2.5	650	4.2E+06	200	54.3	12	200	603	10.30	0.70	10.5	0.5
12	2.5	650	4.2E+06	200	95.4	12	200	603	11.32	0.68	11.5	0.5
13	2.5	650	4.2E+06	200	161.1	12	200	603	12.33	0.67	12.5	0.5

Table 2.4 (Cont.): WisDOT Top-of-Base Sensitivity Analysis
(E_{rubb} = 200ksi, f_t = 650psi)

Design D in	Terminal Serviceability Pt	Working Stress psi	Concrete Modulus psi	Subgrade k-value pci	Design ESALs millions	Rubblized Thickness in	Rubblized Modulus ksi	Top-of-Base k-value pci	Required D in	Reduced D in	Rounded D in	Reduced D in
6	2.5	650	4.2E+06	300	2.1	8	200	557	5.26	0.74	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	8	200	557	6.40	0.60	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	8	200	557	7.49	0.51	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	8	200	557	8.54	0.46	9.0	0.0
10	2.5	650	4.2E+06	300	34.0	8	200	557	9.57	0.43	10.0	0.0
11	2.5	650	4.2E+06	300	61.6	8	200	557	10.59	0.41	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	8	200	557	11.60	0.40	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	8	200	557	12.60	0.40	13.0	0.0
6	2.5	650	4.2E+06	300	2.1	9	200	618	5.07	0.93	5.5	0.5
7	2.5	650	4.2E+06	300	4.5	9	200	618	6.26	0.74	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	9	200	618	7.38	0.62	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	9	200	618	8.45	0.55	8.5	0.5
10	2.5	650	4.2E+06	300	34.0	9	200	618	9.48	0.52	9.5	0.5
11	2.5	650	4.2E+06	300	61.6	9	200	618	10.50	0.50	11.0	0.0
12	2.5	650	4.2E+06	300	107.0	9	200	618	11.52	0.48	12.0	0.0
13	2.5	650	4.2E+06	300	179.2	9	200	618	12.53	0.47	13.0	0.0
6	2.5	650	4.2E+06	300	2.1	10	200	678	4.84	1.16	5.0	1.0
7	2.5	650	4.2E+06	300	4.5	10	200	678	6.12	0.88	6.5	0.5
8	2.5	650	4.2E+06	300	9.1	10	200	678	7.28	0.72	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	10	200	678	8.36	0.64	8.5	0.5
10	2.5	650	4.2E+06	300	34.0	10	200	678	9.40	0.60	9.5	0.5
11	2.5	650	4.2E+06	300	61.6	10	200	678	10.43	0.57	10.5	0.5
12	2.5	650	4.2E+06	300	107.0	10	200	678	11.44	0.56	11.5	0.5
13	2.5	650	4.2E+06	300	179.2	10	200	678	12.46	0.54	12.5	0.5
6	2.5	650	4.2E+06	300	2.1	11	200	737	4.55	1.45	5.0	1.0
7	2.5	650	4.2E+06	300	4.5	11	200	737	5.97	1.03	6.0	1.0
8	2.5	650	4.2E+06	300	9.1	11	200	737	7.17	0.83	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	11	200	737	8.27	0.73	8.5	0.5
10	2.5	650	4.2E+06	300	34.0	11	200	737	9.32	0.68	9.5	0.5
11	2.5	650	4.2E+06	300	61.6	11	200	737	10.35	0.65	10.5	0.5
12	2.5	650	4.2E+06	300	107.0	11	200	737	11.37	0.63	11.5	0.5
13	2.5	650	4.2E+06	300	179.2	11	200	737	12.39	0.61	12.5	0.5
6	2.5	650	4.2E+06	300	2.1	12	200	795	n.a.	n.a.	n.a.	n.a.
7	2.5	650	4.2E+06	300	4.5	12	200	795	5.82	1.18	6.0	1.0
8	2.5	650	4.2E+06	300	9.1	12	200	795	7.07	0.93	7.5	0.5
9	2.5	650	4.2E+06	300	18.0	12	200	795	8.19	0.81	8.5	0.5
10	2.5	650	4.2E+06	300	34.0	12	200	795	9.25	0.75	9.5	0.5
11	2.5	650	4.2E+06	300	61.6	12	200	795	10.29	0.71	10.5	0.5
12	2.5	650	4.2E+06	300	107.0	12	200	795	11.31	0.69	11.5	0.5
13	2.5	650	4.2E+06	300	179.2	12	200	795	12.32	0.68	12.5	0.5

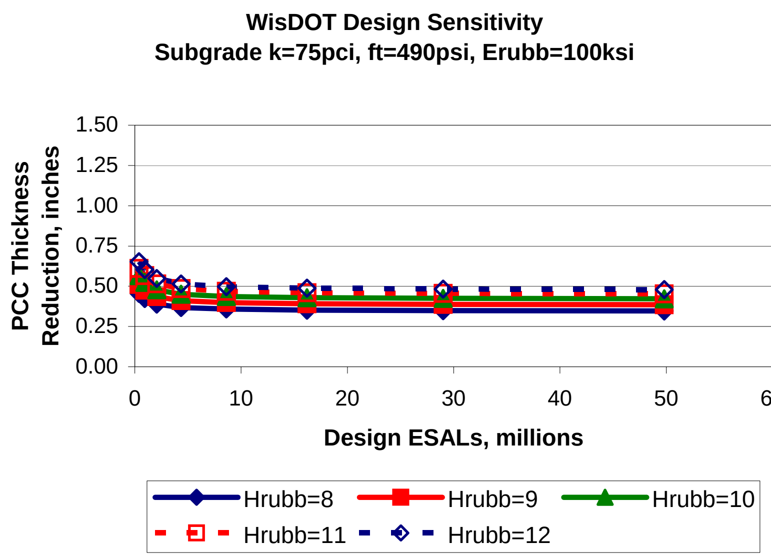

Figure 2.4: WisDOT PCC Thickness Reduction Sensitivity

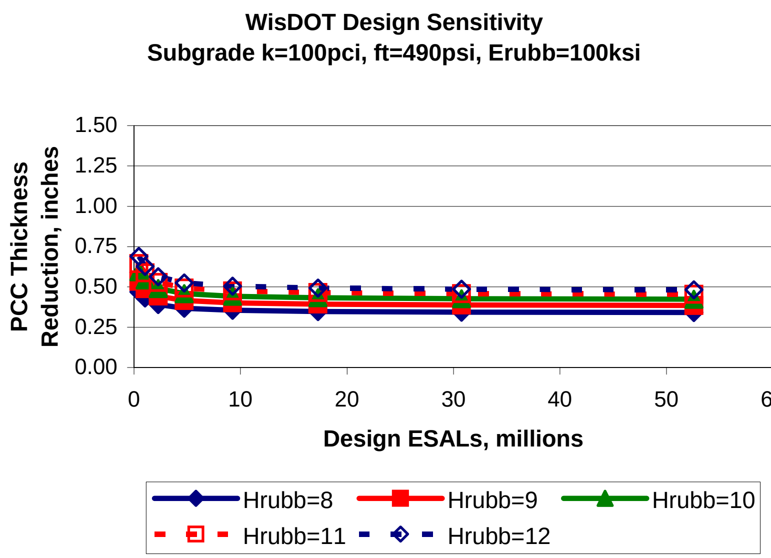

Figure 2.5: WisDOT PCC Thickness Reduction Sensitivity

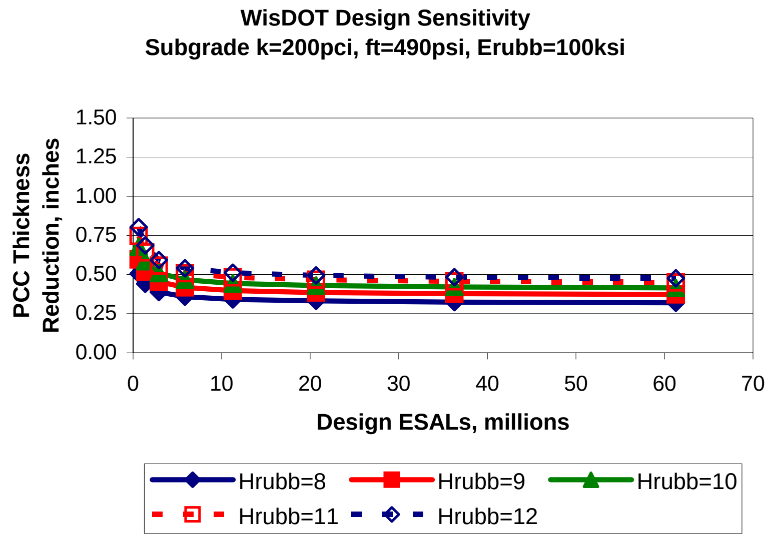

Figure 2.6: WisDOT PCC Thickness Reduction Sensitivity

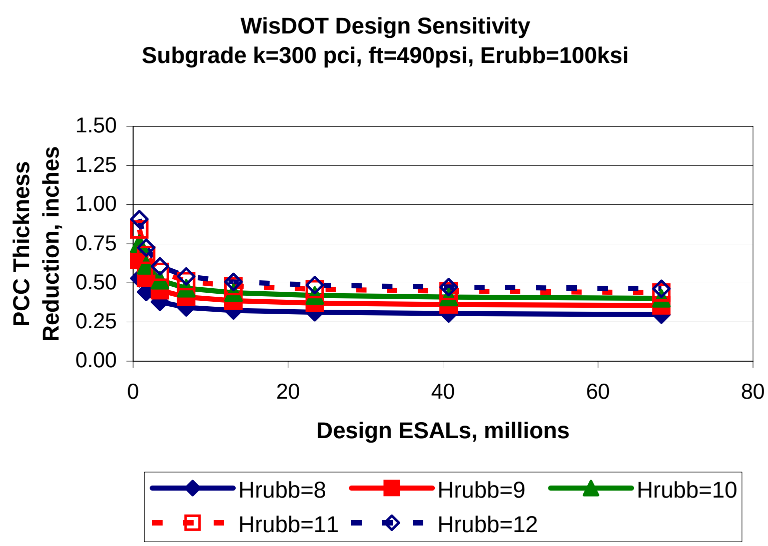

Figure 2.7: WisDOT PCC Thickness Reduction Sensitivity

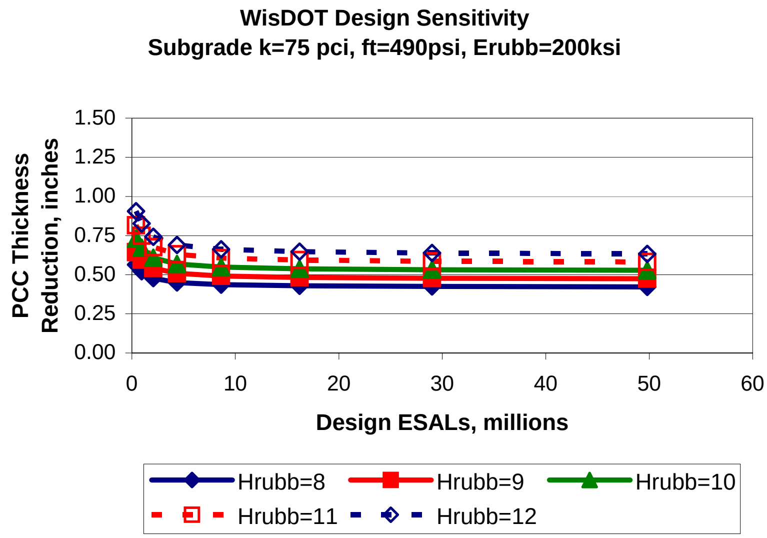

Figure 2.8: WisDOT PCC Thickness Reduction Sensitivity

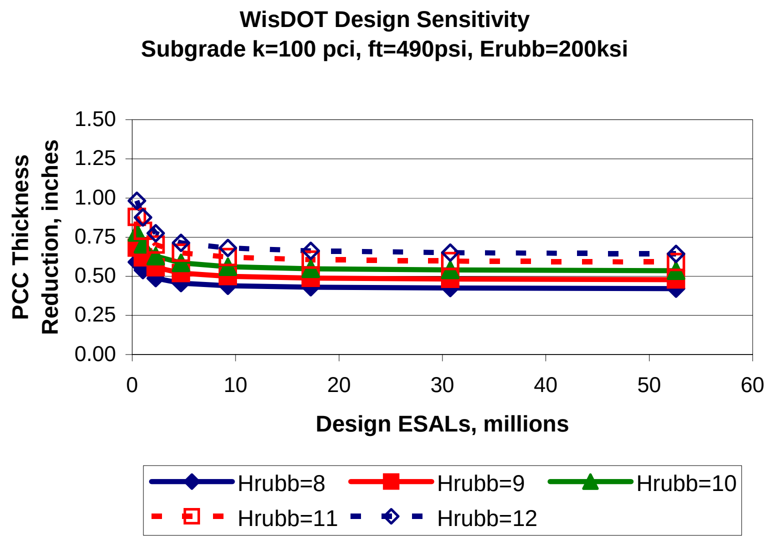

Figure 2.9: WisDOT PCC Thickness Reduction Sensitivity

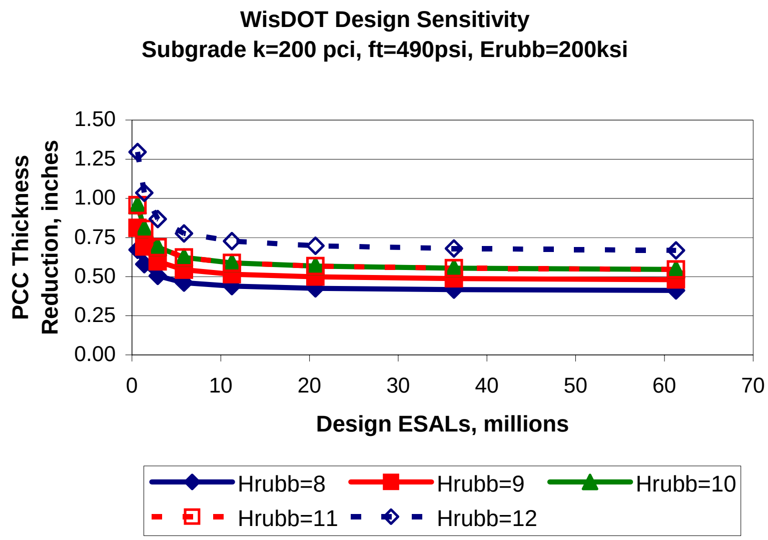

Figure 2.10: WisDOT PCC Thickness Reduction Sensitivity

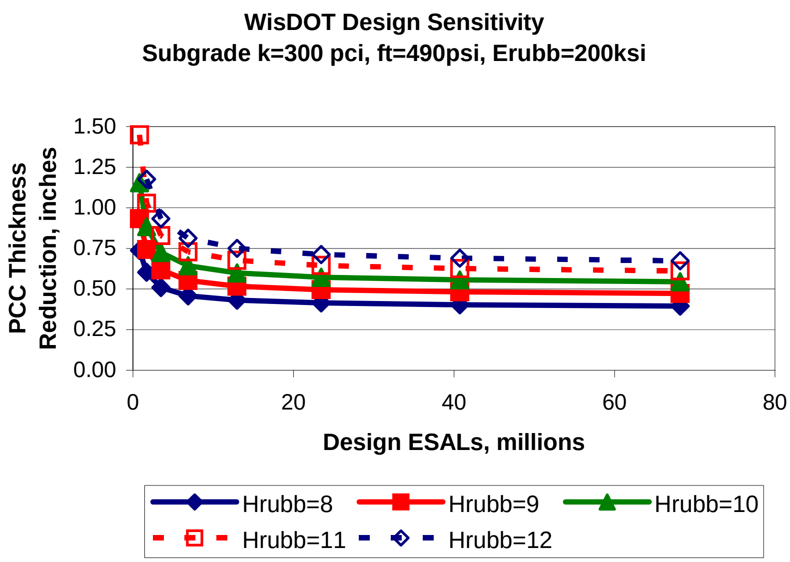

Figure 2.11: WisDOT PCC Thickness Reduction Sensitivity

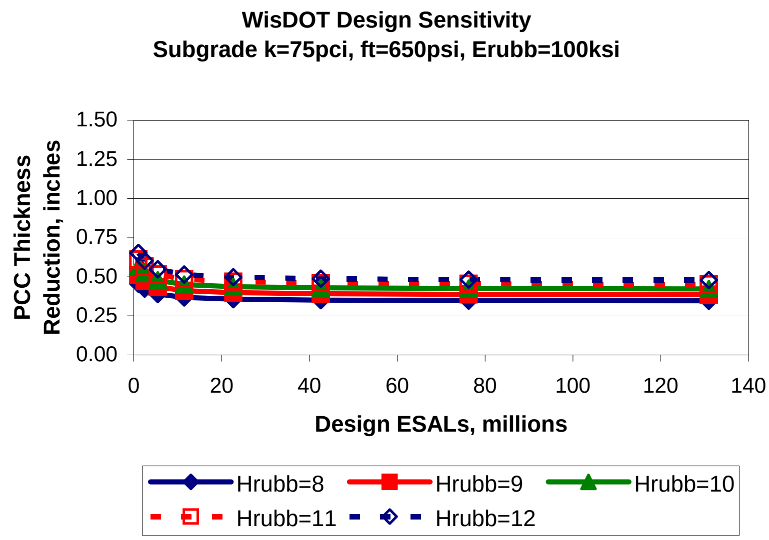

Figure 2.12: WisDOT PCC Thickness Reduction Sensitivity

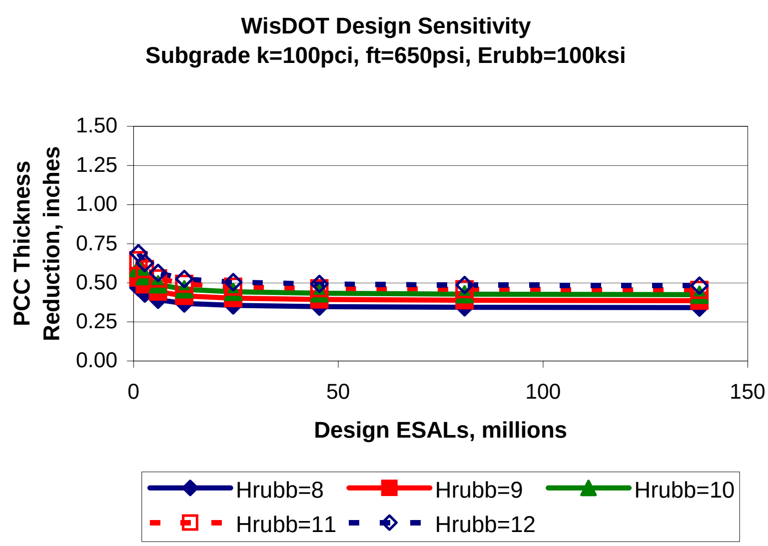

Figure 2.13: WisDOT PCC Thickness Reduction Sensitivity

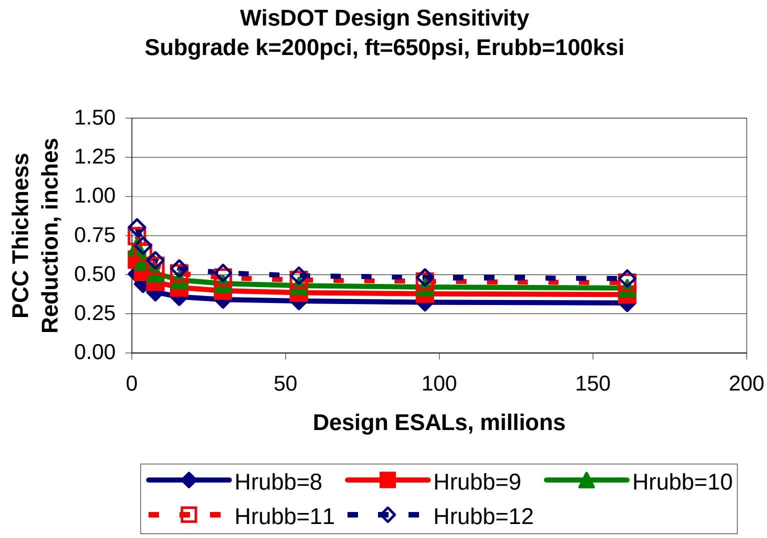

Figure 2.14: WisDOT PCC Thickness Reduction Sensitivity

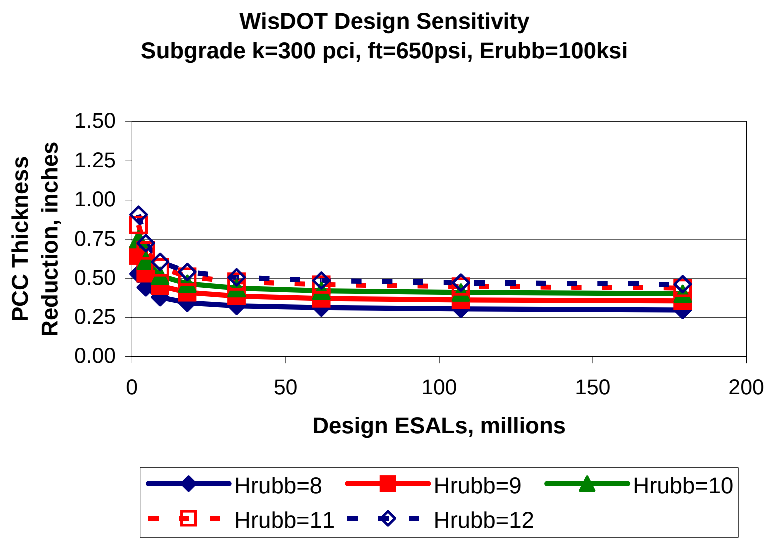

Figure 2.15: WisDOT PCC Thickness Reduction Sensitivity

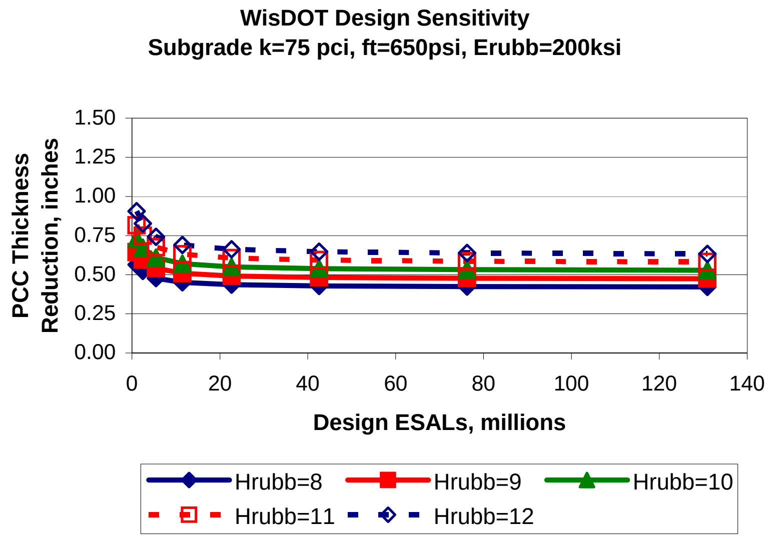

Figure 2.16: WisDOT PCC Thickness Reduction Sensitivity

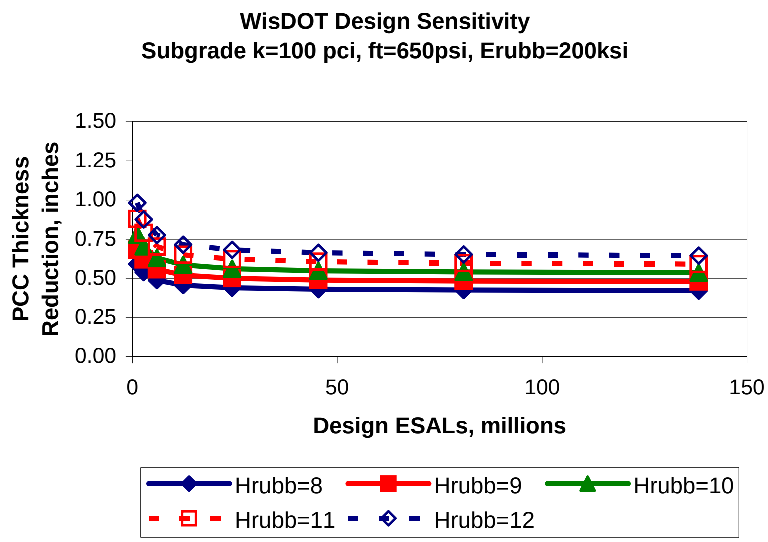

Figure 2.17: WisDOT PCC Thickness Reduction Sensitivity

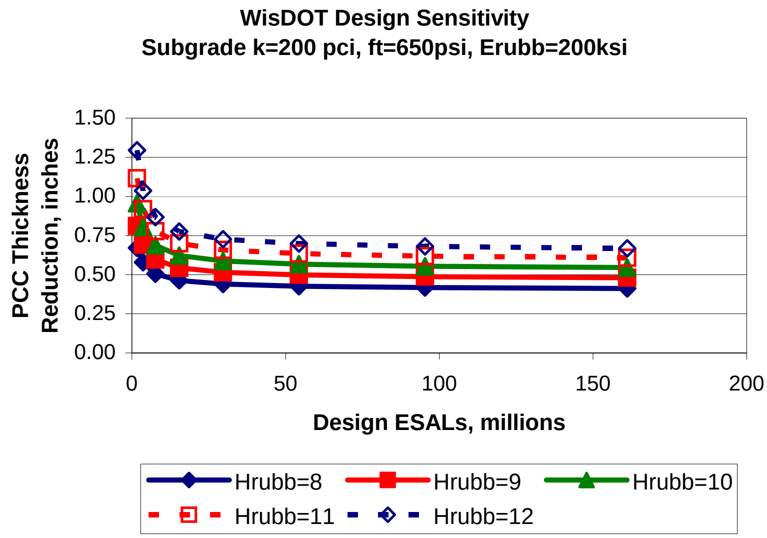

Figure 2.18: WisDOT PCC Thickness Reduction Sensitivity

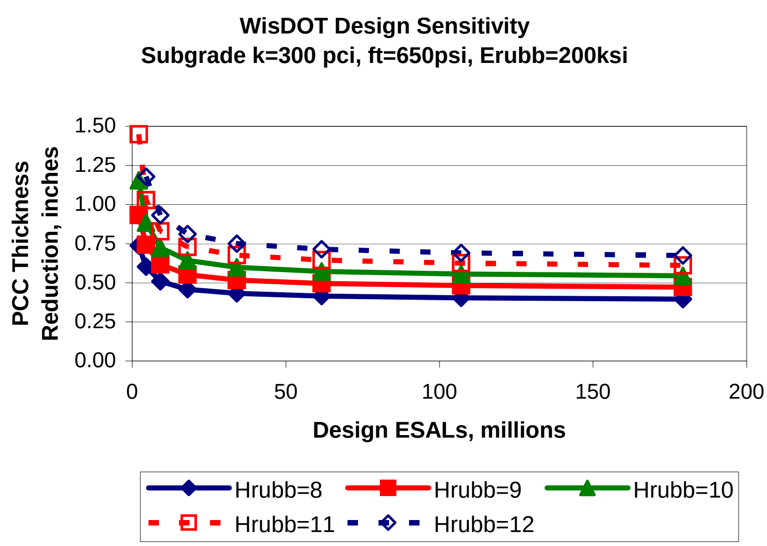

Figure 2.19: WisDOT PCC Thickness Reduction Sensitivity

2.3 Mechanistic Appraisal of Base Layer Effects

From a mechanistic point of view, the contribution of a base layer should be considered relative to the entire pavement system, including the subgrade and PCC surface layers. For this type of analysis, the PCC pavement should be considered as a three-layer system with the PCC surface and rubblized PCC base layers appropriately represented as thin, unbonded man-made layers constructed over the semi-infinite native subgrade soil.

Neglecting the Poisson's ratio effect, the combined flexural rigidity of the unbonded PCC and rubblized layers may be computed as:

$$E_{eq}H_{eq}^{3} = E_{pcc}H_{pcc}^{3} + E_{rubb}H_{rubb}^{3} \qquad \text{Eq 2.9}$$

Where: Epcc = modulus of elasticity of PCC layer, psi

Hpcc = thickness of PCC layer, inches

Erubb = modulus of elasticity of rubblized PCC layer, psi

Hrubb = thickness of rubblized PCC layer, inches

Eeq = modulus of elasticity of equivalent PCC layer, psi

Heq = thickness of equivalent PCC layer, inches

Equation 2.9 may be reordered in a number of ways to determine the effects of the rubblized PCC base layer on the thickness requirements of the PCC surface layer. For example, the allowable thickness reduction of the PCC layer may be estimated by setting Eeq = Epcc, Heq, Erubb and Hrubb to design values and solving for the reduced Hpcc to provide an equivalent flexural rigidity using:

$$H_{req} = \left[\frac{\left(E_{pcc}H_{des}^{3} - E_{rubb}H_{rubb}^{3} \right)}{E_{pcc}} \right]^{1/3} \qquad \text{Eq 2.10}$$

Where: Epcc = Eeq = design modulus of elasticity of PCC layer, psi (= 4,200,000)

Hdes = Heq = design thickness of PCC layer for slab-on-grade, inches

Erubb = modulus of elasticity of rubblized PCC layer, psi

Hrubb = thickness of rubblized PCC layer, inches

Hreq = required thickness of PCC layer above rubblized PCC base, inches

The allowable thickness reduction due to the presence of the rubblized PCC base layer would then be computed as:

$$H_{red} = H_{des} - H_{req} \qquad \text{Eq 2.11}$$

Table 2.5 provides the estimated PCC thickness reductions computed by **Equations 2.10 and 2.11** for a range of design PCC thicknesses (Heq), rubblized PCC layer thicknesses (Hrubb) and rubblized PCC moduli (Eruub). As shown, the PCC thickness reductions range from 0.02 to 0.41 inches for Erubb = 100 ksi and from 0.04 to 0.89 inches for Erubb = 200 ksi. Furthermore, for each Erubb value, as the design PCC thickness increases and/or rubblized PCC thickness decreases, PCC thickness reductions (Hred) decrease.

An alternative analysis path for investigating the effects of the rubblized PCC base layer considers the critical load-induced bending stresses within the PCC slab. For this comparative analysis, a standard 9,000 single wheel loading with a radius of 6 inches will be considered (inflation pressure ~ 80 psi), as illustrated in **Figure 2.20**.

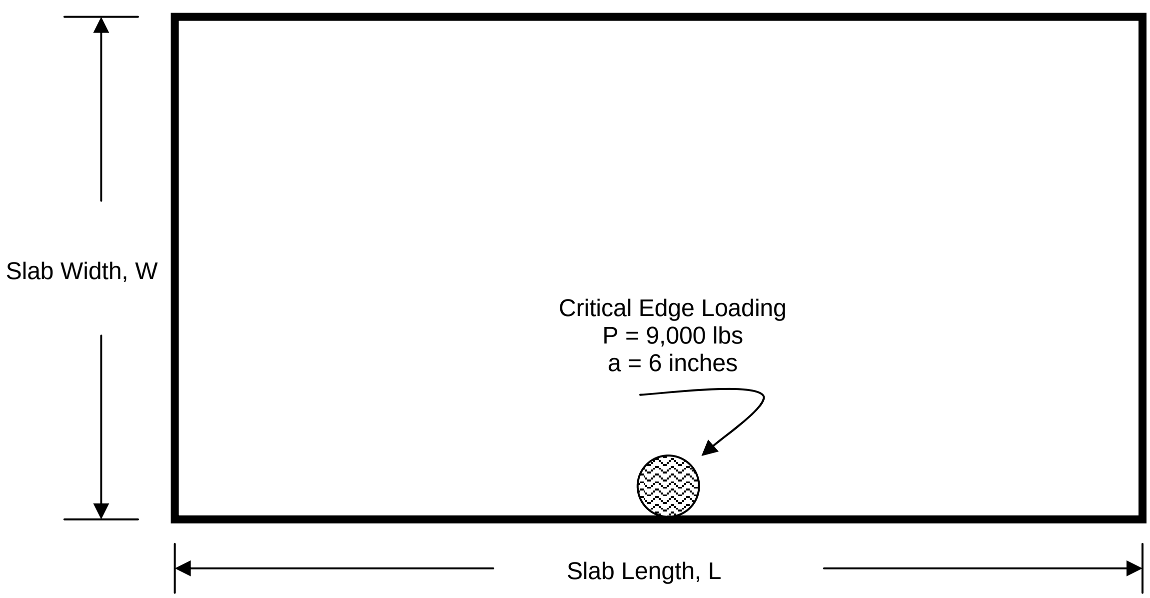

Figure 2.20: Standard Critical Edge Loading Used for Comparative Analysis

Table 2.5: Rubblized PCC Base Effects Based on Surface Flexural Rigidity (Erubb = 100 ksi)

Eeq=Epcc psi	Hdes inch	Erubb ksi	Hrubb inch	Hreq inch	Hred inch
4.20E+06	6.00	100	8.00	5.88	0.12
4.20E+06	8.00	100	8.00	7.94	0.06
4.20E+06	10.00	100	8.00	9.96	0.04
4.20E+06	12.00	100	8.00	11.97	0.03
4.20E+06	14.00	100	8.00	13.98	0.02
4.20E+06	6.00	100	9.00	5.83	0.17
4.20E+06	8.00	100	9.00	7.91	0.09
4.20E+06	10.00	100	9.00	9.94	0.06
4.20E+06	12.00	100	9.00	11.96	0.04
4.20E+06	14.00	100	9.00	13.97	0.03
4.20E+06	6.00	100	10.00	5.77	0.23
4.20E+06	8.00	100	10.00	7.87	0.13
4.20E+06	10.00	100	10.00	9.92	0.08
4.20E+06	12.00	100	10.00	11.94	0.06
4.20E+06	14.00	100	10.00	13.96	0.04
4.20E+06	6.00	100	11.00	5.69	0.31
4.20E+06	8.00	100	11.00	7.83	0.17
4.20E+06	10.00	100	11.00	9.89	0.11
4.20E+06	12.00	100	11.00	11.93	0.07
4.20E+06	14.00	100	11.00	13.95	0.05
4.20E+06	6.00	100	12.00	5.59	0.41
4.20E+06	8.00	100	12.00	7.78	0.22
4.20E+06	10.00	100	12.00	9.86	0.14
4.20E+06	12.00	100	12.00	11.90	0.10
4.20E+06	14.00	100	12.00	13.93	0.07

Table 2.5 (Cont.): Rubblized PCC Base Effects Based on Surface Flexural Rigidity (Erubb = 200 ksi)

Eeq=Epcc psi	Hdes inch	Erubb ksi	Hrubb inch	Hreq inch	Hred inch
4.20E+06	6.00	200	8.00	5.77	0.23
4.20E+06	8.00	200	8.00	7.87	0.13
4.20E+06	10.00	200	8.00	9.92	0.08
4.20E+06	12.00	200	8.00	11.94	0.06
4.20E+06	14.00	200	8.00	13.96	0.04
4.20E+06	6.00	200	9.00	5.66	0.34
4.20E+06	8.00	200	9.00	7.81	0.19
4.20E+06	10.00	200	9.00	9.88	0.12
4.20E+06	12.00	200	9.00	11.92	0.08
4.20E+06	14.00	200	9.00	13.94	0.06
4.20E+06	6.00	200	10.00	5.52	0.48
4.20E+06	8.00	200	10.00	7.74	0.26
4.20E+06	10.00	200	10.00	9.84	0.16
4.20E+06	12.00	200	10.00	11.89	0.11
4.20E+06	14.00	200	10.00	13.92	0.08
4.20E+06	6.00	200	11.00	5.34	0.66
4.20E+06	8.00	200	11.00	7.66	0.34
4.20E+06	10.00	200	11.00	9.78	0.22
4.20E+06	12.00	200	11.00	11.85	0.15
4.20E+06	14.00	200	11.00	13.89	0.11
4.20E+06	6.00	200	12.00	5.11	0.89
4.20E+06	8.00	200	12.00	7.55	0.45
4.20E+06	10.00	200	12.00	9.72	0.28
4.20E+06	12.00	200	12.00	11.81	0.19
4.20E+06	14.00	200	12.00	13.86	0.14

The critical edge stress due to a circular loading may be computed for slab-on-grade systems based on Westergaard's (1948) equation:

$$\sigma_e = \frac{0.803P}{H_{pcc}^2}\left[4\log\left(\frac{l_k}{a}\right) + 0.666\left(\frac{a}{l_k}\right) - 0.034\right] \qquad \text{Eq 2.12}$$

Where: σ_e = critical edge stress, psi

P = applied load, lbs

Hpcc = PCC slab thickness, inch

a = radius of applied load, inch

l_k = radius of relative stiffness, inch = $(\text{Epcc Hpcc}^3 / 11.73\ k)^{0.25}$

As shown, **Equation 2.12** is valid for a typical PCC Poisson's ratio $\nu = 0.15$. The critical edge stress computed by **Equation 2.12** may also be estimated by:

$$\sigma_e = \frac{P}{H_{pcc}^2}\left[0.336 - 1.2589\ln\left(\frac{a}{l_k}\right)\right] \qquad \text{Eq 2.13}$$

Equations 2.12 and 2.13 can both be written in non-dimensional form as follows:

$$S_e = \frac{\sigma_e H_{pcc}^2}{P} = 0.803\left[4\log\left(\frac{l_k}{a}\right) + 0.666\left(\frac{a}{l_k}\right) - 0.034\right] \qquad \text{Eq 2.14}$$

$$S_e = \frac{\sigma_e H_{pcc}^2}{P} = \left[0.336 - 1.2589\ln\left(\frac{a}{l_k}\right)\right] \qquad \text{Eq 2.15}$$

As shown, both **Equations 2.14 and 2.15** are of the general form:

$$S_e = fn\left\{\frac{a}{l_k}\right\} \qquad \text{Eq 2.16}$$

Figure 2.21 illustrates the trend of S_e vs a/l_k computed by **Equations 2.14 and 2.15**. As shown, both are in excellent agreement within the normal range of a/l_k values typical for most highway applications ($0.10 < a/l_k < 0.25$).

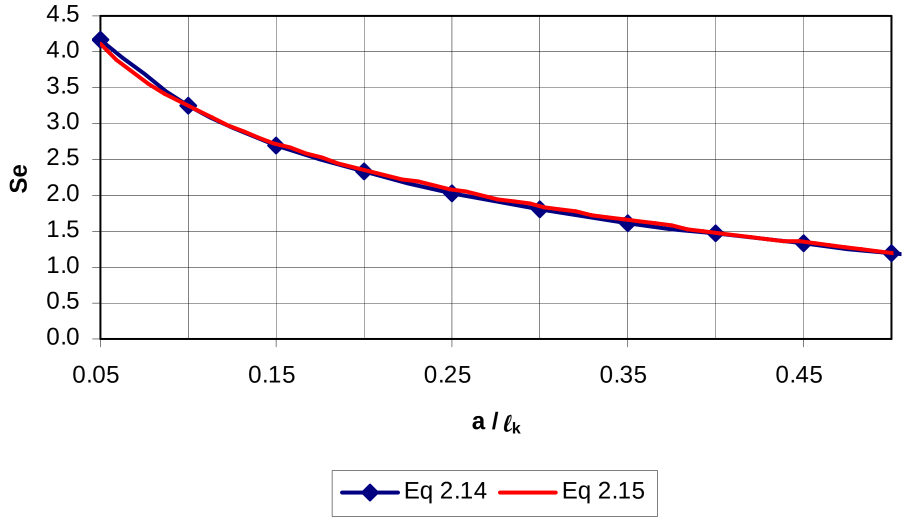

Figure 2.21 Critical Non-Dimensional Edge Stress S_e vs a/l_k

Figure 2.22 illustrates the computed critical edge stresses for a slab-on-grade system over a practical range of subgrade k-values and PCC slab thicknesses. As expected, the critical edge stresses reduce as the subgrade k-value and/or the slab thickness increases.

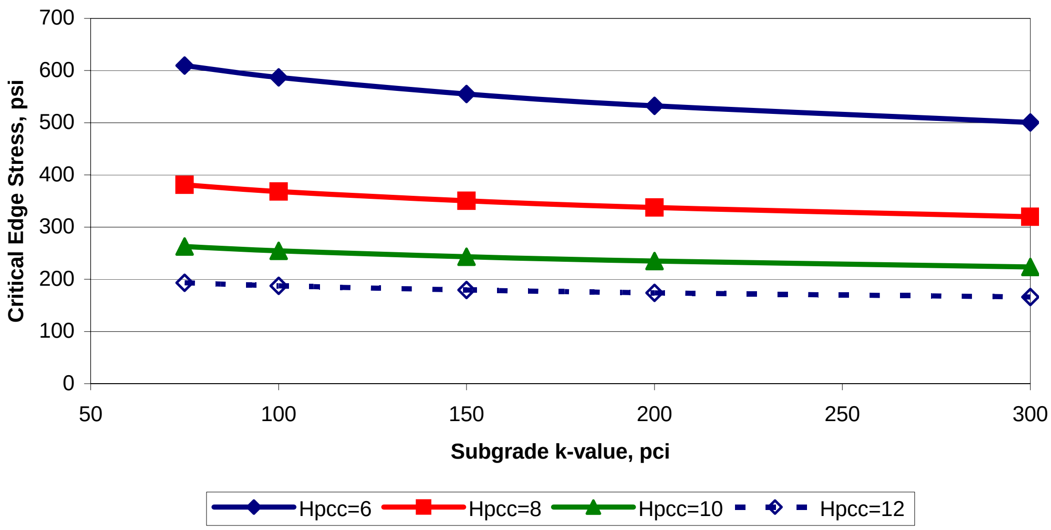

Figure 2.22 Critical Edge Stresses for Slab-on-Grade System

As indicated by **Equation 2.9** with Eeq = Epcc, the inclusion of an unbonded rubblized PCC base layer can be analyzed to determine the equivalent slab-on-grade PCC slab thickness as:

$$H_{eq} = \left[\frac{\left(E_{pcc} H_{pcc}^{3} + E_{rubb} H_{rubb}^{3} \right)}{E_{pcc}} \right]^{1/3} \qquad \text{Eq 2.17}$$

The equivalent PCC thickness, Heq, may be used as a substitute for the actual PCC thickness, Hpcc, to determine the equivalent radius of relative stiffness, lk-eq, and equivalent critical edge stress, $\sigma_{e\text{-}eq}$, using **Equations 2.14 and 2.15**. **Table 2.6** provides the computed critical edge stresses for the baseline slab-on-grade systems (Epcc = 4.2 MPsi) and the critical edge stress for the equivalent systems ($\sigma_{e\text{-}eq}$) which incorporate a rubblized PCC base layer. As shown, the inclusion of the rubblized PCC base layer results in a critical edge stress reduction ranging from 0.4% to 9.0% for Erubb = 100 ksi and from 0.8% to 16.0% for Erubb = 200 ksi, which would equate to longer service lives for all cases. For constant slab thickness and subgrade k-values, as the thickness of the rubblized PCC layer increases, so does the stress reduction. Also, for a given rubblized PCC layer thickness, the edge stress reduction decreases as the PCC slab thickness and/or subgrade k-value increases.

Table 2.6: Critical Edge Stresses for Slab-on-Grade and Equivalent Systems

Epcc psi	Hpcc inch	k pci	lk inch	se psi	Erubb ksi	Hrubb inch	Heq inch	lkeq inch	se psi	Stress Reduction
4.20E+06	6	75	31.87	610	100	8	6.11	32.31	592	2.9%
4.20E+06	6	75	31.87	610	100	9	6.16	32.49	585	4.1%
4.20E+06	6	75	31.87	610	100	10	6.21	32.71	576	5.5%
4.20E+06	6	75	31.87	610	100	11	6.28	32.98	566	7.1%
4.20E+06	6	75	31.87	610	100	12	6.36	33.29	555	9.0%
4.20E+06	6	100	29.66	587	100	8	6.11	30.07	570	2.9%
4.20E+06	6	100	29.66	587	100	9	6.16	30.23	563	4.0%
4.20E+06	6	100	29.66	587	100	10	6.21	30.44	555	5.4%
4.20E+06	6	100	29.66	587	100	11	6.28	30.69	546	7.0%
4.20E+06	6	100	29.66	587	100	12	6.36	30.98	535	8.9%
4.20E+06	6	200	24.94	532	100	8	6.11	25.28	517	2.8%
4.20E+06	6	200	24.94	532	100	9	6.16	25.42	511	3.9%
4.20E+06	6	200	24.94	532	100	10	6.21	25.60	504	5.3%
4.20E+06	6	200	24.94	532	100	11	6.28	25.81	496	6.9%
4.20E+06	6	200	24.94	532	100	12	6.36	26.05	486	8.7%
4.20E+06	6	300	22.53	500	100	8	6.11	22.84	487	2.8%
4.20E+06	6	300	22.53	500	100	9	6.16	22.97	481	3.9%
4.20E+06	6	300	22.53	500	100	10	6.21	23.13	474	5.2%
4.20E+06	6	300	22.53	500	100	11	6.28	23.32	467	6.8%
4.20E+06	6	300	22.53	500	100	12	6.36	23.54	458	8.5%
4.20E+06	8	75	39.54	381	100	8	8.06	39.77	376	1.3%
4.20E+06	8	75	39.54	381	100	9	8.09	39.87	374	1.8%
4.20E+06	8	75	39.54	381	100	10	8.12	39.99	372	2.5%
4.20E+06	8	75	39.54	381	100	11	8.16	40.14	369	3.3%
4.20E+06	8	75	39.54	381	100	12	8.21	40.31	365	4.2%
4.20E+06	8	100	36.80	368	100	8	8.06	37.01	364	1.3%
4.20E+06	8	100	36.80	368	100	9	8.09	37.10	362	1.8%
4.20E+06	8	100	36.80	368	100	10	8.12	37.22	359	2.5%
4.20E+06	8	100	36.80	368	100	11	8.16	37.35	356	3.2%
4.20E+06	8	100	36.80	368	100	12	8.21	37.51	353	4.1%
4.20E+06	8	200	30.94	338	100	8	8.06	31.12	333	1.3%
4.20E+06	8	200	30.94	338	100	9	8.09	31.20	332	1.8%
4.20E+06	8	200	30.94	338	100	10	8.12	31.30	330	2.4%
4.20E+06	8	200	30.94	338	100	11	8.16	31.41	327	3.2%
4.20E+06	8	200	30.94	338	100	12	8.21	31.55	324	4.1%
4.20E+06	8	300	27.96	320	100	8	8.06	28.12	316	1.2%
4.20E+06	8	300	27.96	320	100	9	8.09	28.19	314	1.7%
4.20E+06	8	300	27.96	320	100	10	8.12	28.28	312	2.4%
4.20E+06	8	300	27.96	320	100	11	8.16	28.38	310	3.1%
4.20E+06	8	300	27.96	320	100	12	8.21	28.50	307	4.0%

Table 2.6 (Cont.): Critical Edge Stresses for Slab-on-Grade and Equivalent Systems

Epcc psi	Hpcc inch	k pci	lk inch	se psi	Erubb ksi	Hrubb inch	Heq inch	lkeq inch	se psi	Stress Reduction
4.20E+06	10	75	46.74	263	100	8	10.04	46.89	261	0.7%
4.20E+06	10	75	46.74	263	100	9	10.06	46.95	260	1.0%
4.20E+06	10	75	46.74	263	100	10	10.08	47.02	259	1.3%
4.20E+06	10	75	46.74	263	100	11	10.10	47.11	258	1.7%
4.20E+06	10	75	46.74	263	100	12	10.14	47.22	257	2.2%
4.20E+06	10	100	43.50	255	100	8	10.04	43.63	253	0.7%
4.20E+06	10	100	43.50	255	100	9	10.06	43.69	252	1.0%
4.20E+06	10	100	43.50	255	100	10	10.08	43.76	251	1.3%
4.20E+06	10	100	43.50	255	100	11	10.10	43.84	250	1.7%
4.20E+06	10	100	43.50	255	100	12	10.14	43.94	249	2.2%
4.20E+06	10	200	36.58	235	100	8	10.04	36.69	234	0.7%
4.20E+06	10	200	36.58	235	100	9	10.06	36.74	233	0.9%
4.20E+06	10	200	36.58	235	100	10	10.08	36.79	232	1.3%
4.20E+06	10	200	36.58	235	100	11	10.10	36.87	231	1.7%
4.20E+06	10	200	36.58	235	100	12	10.14	36.95	230	2.2%
4.20E+06	10	300	33.05	224	100	8	10.04	33.15	222	0.7%
4.20E+06	10	300	33.05	224	100	9	10.06	33.20	222	0.9%
4.20E+06	10	300	33.05	224	100	10	10.08	33.25	221	1.3%
4.20E+06	10	300	33.05	224	100	11	10.10	33.31	220	1.7%
4.20E+06	10	300	33.05	224	100	12	10.14	33.39	219	2.2%
4.20E+06	12	75	53.59	193	100	8	12.03	53.69	193	0.4%
4.20E+06	12	75	53.59	193	100	9	12.04	53.73	192	0.6%
4.20E+06	12	75	53.59	193	100	10	12.05	53.78	192	0.8%
4.20E+06	12	75	53.59	193	100	11	12.07	53.84	191	1.0%
4.20E+06	12	75	53.59	193	100	12	12.09	53.91	191	1.3%
4.20E+06	12	100	49.87	188	100	8	12.03	49.96	187	0.4%
4.20E+06	12	100	49.87	188	100	9	12.04	50.00	187	0.6%
4.20E+06	12	100	49.87	188	100	10	12.05	50.04	186	0.8%
4.20E+06	12	100	49.87	188	100	11	12.07	50.10	186	1.0%
4.20E+06	12	100	49.87	188	100	12	12.09	50.17	185	1.3%
4.20E+06	12	200	41.94	174	100	8	12.03	42.01	173	0.4%
4.20E+06	12	200	41.94	174	100	9	12.04	42.04	173	0.6%
4.20E+06	12	200	41.94	174	100	10	12.05	42.08	173	0.8%
4.20E+06	12	200	41.94	174	100	11	12.07	42.13	172	1.0%
4.20E+06	12	200	41.94	174	100	12	12.09	42.19	172	1.3%
4.20E+06	12	300	37.90	166	100	8	12.03	37.96	165	0.4%
4.20E+06	12	300	37.90	166	100	9	12.04	37.99	165	0.5%
4.20E+06	12	300	37.90	166	100	10	12.05	38.03	165	0.7%
4.20E+06	12	300	37.90	166	100	11	12.07	38.07	164	1.0%
4.20E+06	12	300	37.90	166	100	12	12.09	38.12	164	1.3%

Table 2.6 (Cont.): Critical Edge Stresses for Slab-on-Grade and Equivalent Systems

Epcc psi	Hpcc inch	k pci	lk inch	se psi	Erubb ksi	Hrubb inch	Heq inch	lkeq inch	se psi	Stress Reduction
4.20E+06	6	75	31.87	610	200	8	6.22	32.73	575	5.6%
4.20E+06	6	75	31.87	610	200	9	6.31	33.08	562	7.7%
4.20E+06	6	75	31.87	610	200	10	6.41	33.49	547	10.2%
4.20E+06	6	75	31.87	610	200	11	6.54	33.98	531	13.0%
4.20E+06	6	75	31.87	610	200	12	6.68	34.54	512	16.0%
4.20E+06	6	100	29.66	587	200	8	6.22	30.46	554	5.5%
4.20E+06	6	100	29.66	587	200	9	6.31	30.78	542	7.6%
4.20E+06	6	100	29.66	587	200	10	6.41	31.17	528	10.1%
4.20E+06	6	100	29.66	587	200	11	6.54	31.63	511	12.9%
4.20E+06	6	100	29.66	587	200	12	6.68	32.15	494	15.9%
4.20E+06	6	200	24.94	532	200	8	6.22	25.61	504	5.4%
4.20E+06	6	200	24.94	532	200	9	6.31	25.88	493	7.5%
4.20E+06	6	200	24.94	532	200	10	6.41	26.21	480	9.9%
4.20E+06	6	200	24.94	532	200	11	6.54	26.59	465	12.6%
4.20E+06	6	200	24.94	532	200	12	6.68	27.03	450	15.5%
4.20E+06	6	300	22.53	500	200	8	6.22	23.14	474	5.3%
4.20E+06	6	300	22.53	500	200	9	6.31	23.39	464	7.3%
4.20E+06	6	300	22.53	500	200	10	6.41	23.68	452	9.7%
4.20E+06	6	300	22.53	500	200	11	6.54	24.03	439	12.4%
4.20E+06	6	300	22.53	500	200	12	6.68	24.43	424	15.3%
4.20E+06	8	75	39.54	381	200	8	8.13	40.00	371	2.5%
4.20E+06	8	75	39.54	381	200	9	8.18	40.19	368	3.5%
4.20E+06	8	75	39.54	381	200	10	8.24	40.43	363	4.8%
4.20E+06	8	75	39.54	381	200	11	8.32	40.71	357	6.2%
4.20E+06	8	75	39.54	381	200	12	8.41	41.04	351	7.9%
4.20E+06	8	100	36.80	368	200	8	8.13	37.23	359	2.5%
4.20E+06	8	100	36.80	368	200	9	8.18	37.40	355	3.5%
4.20E+06	8	100	36.80	368	200	10	8.24	37.62	351	4.7%
4.20E+06	8	100	36.80	368	200	11	8.32	37.89	346	6.2%
4.20E+06	8	100	36.80	368	200	12	8.41	38.19	339	7.8%
4.20E+06	8	200	30.94	338	200	8	8.13	31.30	329	2.5%
4.20E+06	8	200	30.94	338	200	9	8.18	31.45	326	3.5%
4.20E+06	8	200	30.94	338	200	10	8.24	31.64	322	4.7%
4.20E+06	8	200	30.94	338	200	11	8.32	31.86	317	6.1%
4.20E+06	8	200	30.94	338	200	12	8.41	32.12	312	7.7%
4.20E+06	8	300	27.96	320	200	8	8.13	28.29	312	2.4%
4.20E+06	8	300	27.96	320	200	9	8.18	28.42	309	3.4%
4.20E+06	8	300	27.96	320	200	10	8.24	28.59	305	4.6%
4.20E+06	8	300	27.96	320	200	11	8.32	28.79	301	6.0%
4.20E+06	8	300	27.96	320	200	12	8.41	29.02	295	7.6%

Table 2.6 (Cont.): Critical Edge Stresses for Slab-on-Grade and Equivalent Systems

Epcc psi	Hpcc inch	k pci	lk inch	se psi	Erubb ksi	Hrubb inch	Heq inch	lkeq inch	se psi	Stress Reduction
4.20E+06	10	75	46.74	263	200	8	10.08	47.03	259	1.3%
4.20E+06	10	75	46.74	263	200	9	10.11	47.14	258	1.9%
4.20E+06	10	75	46.74	263	200	10	10.16	47.29	256	2.6%
4.20E+06	10	75	46.74	263	200	11	10.21	47.47	254	3.4%
4.20E+06	10	75	46.74	263	200	12	10.27	47.68	251	4.3%
4.20E+06	10	100	43.50	255	200	8	10.08	43.76	251	1.3%
4.20E+06	10	100	43.50	255	200	9	10.11	43.87	250	1.9%
4.20E+06	10	100	43.50	255	200	10	10.16	44.01	248	2.6%
4.20E+06	10	100	43.50	255	200	11	10.21	44.17	246	3.4%
4.20E+06	10	100	43.50	255	200	12	10.27	44.37	244	4.3%
4.20E+06	10	200	36.58	235	200	8	10.08	36.80	232	1.3%
4.20E+06	10	200	36.58	235	200	9	10.11	36.89	231	1.8%
4.20E+06	10	200	36.58	235	200	10	10.16	37.01	229	2.5%
4.20E+06	10	200	36.58	235	200	11	10.21	37.15	227	3.3%
4.20E+06	10	200	36.58	235	200	12	10.27	37.31	225	4.2%
4.20E+06	10	300	33.05	224	200	8	10.08	33.25	221	1.3%
4.20E+06	10	300	33.05	224	200	9	10.11	33.34	219	1.8%
4.20E+06	10	300	33.05	224	200	10	10.16	33.44	218	2.5%
4.20E+06	10	300	33.05	224	200	11	10.21	33.56	216	3.3%
4.20E+06	10	300	33.05	224	200	12	10.27	33.71	214	4.2%
4.20E+06	12	75	53.59	193	200	8	12.06	53.78	192	0.8%
4.20E+06	12	75	53.59	193	200	9	12.08	53.86	191	1.1%
4.20E+06	12	75	53.59	193	200	10	12.11	53.96	190	1.5%
4.20E+06	12	75	53.59	193	200	11	12.14	54.08	189	2.0%
4.20E+06	12	75	53.59	193	200	12	12.19	54.22	188	2.6%
4.20E+06	12	100	49.87	188	200	8	12.06	50.05	186	0.8%
4.20E+06	12	100	49.87	188	200	9	12.08	50.12	186	1.1%
4.20E+06	12	100	49.87	188	200	10	12.11	50.21	185	1.5%
4.20E+06	12	100	49.87	188	200	11	12.14	50.33	184	2.0%
4.20E+06	12	100	49.87	188	200	12	12.19	50.46	183	2.6%
4.20E+06	12	200	41.94	174	200	8	12.06	42.09	173	0.8%
4.20E+06	12	200	41.94	174	200	9	12.08	42.15	172	1.1%
4.20E+06	12	200	41.94	174	200	10	12.11	42.22	171	1.5%
4.20E+06	12	200	41.94	174	200	11	12.14	42.32	171	2.0%
4.20E+06	12	200	41.94	174	200	12	12.19	42.43	170	2.5%
4.20E+06	12	300	37.90	166	200	8	12.06	38.03	165	0.8%
4.20E+06	12	300	37.90	166	200	9	12.08	38.08	164	1.1%
4.20E+06	12	300	37.90	166	200	10	12.11	38.15	164	1.5%
4.20E+06	12	300	37.90	166	200	11	12.14	38.24	163	2.0%
4.20E+06	12	300	37.90	166	200	12	12.19	38.34	162	2.5%

The reduced equivalent critical edge stresses ($\sigma_{e\text{-}eq}$), resulting from the inclusion of the rubblized PCC base layer, can be used to estimate an equivalent top-of-base k-value. For example, **Equation 2.15** can be re-ordered to provide:

$$Ln\left(\frac{a}{l_{keq}}\right) = \frac{0.336 - \left[\frac{(\sigma_{e-eq})Hpcc^2}{P}\right]}{1.2589} \qquad \text{Eq 2.18}$$

$$l_{keq} = \frac{a}{\exp\left(\frac{0.336 - \left[\frac{(\sigma_{e-eq})Hpcc^2}{P}\right]}{1.2589}\right)} \qquad \text{Eq 2.19}$$

$$k_{eq} = \left[\frac{E_{pcc}H_{pcc}^{3}}{11.73(l_{keq})^4}\right] \qquad \text{Eq 2.20}$$

The increased top-of-base k-value computed with **Equations 2.18 to 2.20** can also be used to estimate the reduced PCC thickness requirement necessary to maintain slab-on-grade stress conditions. Because PCC fatigue life is related to critical edge stress conditions, this essentially determines the contribution of the rubblized PCC base layer in maintaining an equivalent service life with a reduced PCC slab thickness.

The required PCC thickness above the rubblized PCC base layer is computed by:

$$\sigma_e = \frac{P}{H_{req}^{2}}\left(0.336 - 1.2589\ln\left(\frac{a}{l_{k-req}}\right)\right) \qquad \text{Eq 2.21}$$

$$l_{k-req} = \sqrt[4]{\frac{E_{pcc}H_{req}^{3}}{11.73k_{eq}}} \qquad \text{Eq 2.22}$$

$$H_{red} = H_{pcc} - H_{req} \qquad \text{Eq 2.23}$$

Where: σ_e = critical edge stress for slab-on-grade system, psi

k_{eq} = top-of-base equivalent k-value, pci

Epcc = design modulus of elasticity of PCC (= 4.2 Mpsi)

Hpcc = design slab-on-grade PCC thickness, inch

Hreq = required PCC thickness above rubblized PCC base, inch

As indicated by **Equations 2.21 and 2.22**, the required PCC thickness (Hreq) must be determined by iteration and then used to establish the PCC thickness reduction attributed to the rubblized PCC base layer.

Table 2.7 provides a listing of the equivalent top-of-base k-values and PCC thickness reductions attributed to the rubblized PCC base layers. As shown, the PCC thickness reductions range from 0.03 to 0.35 inches for Erubb = 100ksi and from 0.06 to 0.66 inches for Erubb = 200 ksi. For any given combination of rubblized PCC base thickness (Hrubb) and subgrade k-value, the PCC thickness reductions decrease as the design slab-on-grade PCC thickness (Hpcc) increases. Also, for any combination of slab-on-grade PCC thickness (Hpcc) and rubblized PCC base thickness (Hrubb), the PCC slab thickness reductions are relatively unaffected by the design subgrade k-value.

Table 2.7: Equivalent Top-of-Base k-values and PCC Thickness Reductions

H_{pcc} inch	k pci	σ_e psi	H_{rubb} inch	E_{rubb} ksi	$\sigma_{e\text{-}eq}$ psi	k_{eq} pci	H_{req} inch	H_{red} inch
6	75	610	8	100	592	94	5.89	0.11
6	75	610	9	100	585	103	5.85	0.15
6	75	610	10	100	576	115	5.79	0.21
6	75	610	11	100	566	130	5.73	0.27
6	75	610	12	100	555	150	5.65	0.35
6	100	587	8	100	570	124	5.89	0.11
6	100	587	9	100	563	135	5.85	0.15
6	100	587	10	100	555	150	5.79	0.21
6	100	587	11	100	546	169	5.73	0.27
6	100	587	12	100	535	194	5.65	0.35
6	200	532	8	100	517	242	5.89	0.11
6	200	532	9	100	511	261	5.85	0.15
6	200	532	10	100	504	286	5.79	0.21
6	200	532	11	100	496	318	5.73	0.27
6	200	532	12	100	486	360	5.65	0.35
6	300	500	8	100	487	358	5.89	0.11
6	300	500	9	100	481	384	5.84	0.16
6	300	500	10	100	474	418	5.79	0.21
6	300	500	11	100	467	461	5.73	0.27
6	300	500	12	100	458	516	5.65	0.35
8	75	381	8	100	376	84	7.94	0.06
8	75	381	9	100	374	88	7.91	0.09
8	75	381	10	100	372	93	7.88	0.12
8	75	381	11	100	369	99	7.84	0.16
8	75	381	12	100	365	107	7.79	0.21
8	100	368	8	100	364	111	7.94	0.06
8	100	368	9	100	362	116	7.91	0.09
8	100	368	10	100	359	123	7.88	0.12
8	100	368	11	100	356	131	7.84	0.16
8	100	368	12	100	353	141	7.80	0.20
8	200	338	8	100	333	220	7.94	0.06
8	200	338	9	100	332	229	7.91	0.09
8	200	338	10	100	330	240	7.88	0.12
8	200	338	11	100	327	255	7.84	0.16
8	200	338	12	100	324	273	7.80	0.20
8	300	320	8	100	316	328	7.94	0.06
8	300	320	9	100	314	340	7.91	0.09
8	300	320	10	100	312	356	7.88	0.12
8	300	320	11	100	310	376	7.84	0.16
8	300	320	12	100	307	401	7.80	0.20

Table 2.7 (Cont.): Equivalent Top-of-Base k-values and PCC Thickness Reductions

H_{pcc} inch	k pci	σ_e psi	H_{rubb} inch	E_{rubb} ksi	σ_{e-eq} psi	k_{eq} pci	H_{req} inch	H_{red} inch
10	75	263	8	100	261	80	9.96	0.04
10	75	263	9	100	260	82	9.94	0.06
10	75	263	10	100	259	85	9.92	0.08
10	75	263	11	100	258	88	9.89	0.11
10	75	263	12	100	257	92	9.86	0.14
10	100	255	8	100	253	106	9.95	0.05
10	100	255	9	100	252	109	9.94	0.06
10	100	255	10	100	251	112	9.92	0.08
10	100	255	11	100	250	117	9.89	0.11
10	100	255	12	100	249	122	9.86	0.14
10	200	235	8	100	234	211	9.95	0.05
10	200	235	9	100	233	216	9.94	0.06
10	200	235	10	100	232	222	9.92	0.08
10	200	235	11	100	231	230	9.89	0.11
10	200	235	12	100	230	240	9.86	0.14
10	300	224	8	100	222	316	9.95	0.05
10	300	224	9	100	222	323	9.94	0.06
10	300	224	10	100	221	331	9.92	0.08
10	300	224	11	100	220	342	9.89	0.11
10	300	224	12	100	219	356	9.86	0.14
12	75	193	8	100	193	78	11.97	0.03
12	75	193	9	100	192	79	11.96	0.04
12	75	193	10	100	192	81	11.95	0.05
12	75	193	11	100	191	83	11.93	0.07
12	75	193	12	100	191	85	11.91	0.09
12	100	188	8	100	187	104	11.97	0.03
12	100	188	9	100	187	105	11.96	0.04
12	100	188	10	100	186	108	11.95	0.05
12	100	188	11	100	186	110	11.93	0.07
12	100	188	12	100	185	113	11.91	0.09
12	200	174	8	100	173	207	11.97	0.03
12	200	174	9	100	173	210	11.96	0.04
12	200	174	10	100	173	214	11.95	0.05
12	200	174	11	100	172	219	11.93	0.07
12	200	174	12	100	172	224	11.91	0.09
12	300	166	8	100	165	310	11.97	0.03
12	300	166	9	100	165	314	11.96	0.04
12	300	166	10	100	165	320	11.95	0.05
12	300	166	11	100	164	326	11.93	0.07
12	300	166	12	100	164	334	11.91	0.09

Table 2.7 (Cont.): Equivalent Top-of-Base k-values and PCC Thickness Reductions

H_{pcc} inch	k pci	σ_e psi	H_{rubb} inch	E_{rubb} ksi	σ_{e-eq} psi	k_{eq} pci	H_{req} inch	H_{red} inch
6	75	610	8	200	575	116	5.79	0.21
6	75	610	9	200	562	136	5.70	0.30
6	75	610	10	200	547	165	5.60	0.40
6	75	610	11	200	531	205	5.49	0.51
6	75	610	12	200	512	259	5.34	0.66
6	100	587	8	200	554	151	5.79	0.21
6	100	587	9	200	542	177	5.70	0.30
6	100	587	10	200	528	212	5.60	0.40
6	100	587	11	200	511	261	5.49	0.51
6	100	587	12	200	494	327	5.35	0.65
6	200	532	8	200	504	288	5.79	0.21
6	200	532	9	200	493	331	5.70	0.30
6	200	532	10	200	480	390	5.60	0.40
6	200	532	11	200	465	468	5.48	0.52
6	200	532	12	200	450	571	5.35	0.65
6	300	500	8	200	474	421	5.79	0.21
6	300	500	9	200	464	478	5.70	0.30
6	300	500	10	200	452	556	5.60	0.40
6	300	500	11	200	439	658	5.48	0.52
6	300	500	12	200	424	792	5.34	0.66
8	75	381	8	200	371	93	7.88	0.12
8	75	381	9	200	368	102	7.83	0.17
8	75	381	10	200	363	113	7.76	0.24
8	75	381	11	200	357	128	7.69	0.31
8	75	381	12	200	351	148	7.60	0.40
8	100	368	8	200	359	123	7.88	0.12
8	100	368	9	200	355	134	7.83	0.17
8	100	368	10	200	351	148	7.76	0.24
8	100	368	11	200	346	167	7.69	0.31
8	100	368	12	200	339	192	7.60	0.40
8	200	338	8	200	329	241	7.88	0.12
8	200	338	9	200	326	260	7.82	0.18
8	200	338	10	200	322	285	7.76	0.24
8	200	338	11	200	317	318	7.69	0.31
8	200	338	12	200	312	360	7.60	0.40
8	300	320	8	200	312	358	7.88	0.12
8	300	320	9	200	309	384	7.82	0.18
8	300	320	10	200	305	418	7.76	0.24
8	300	320	11	200	301	462	7.69	0.31
8	300	320	12	200	295	519	7.60	0.40

Table 2.7 (Cont.): Equivalent Top-of-Base k-values and PCC Thickness Reductions

H_{pcc} inch	k pci	σ_e psi	H_{rubb} inch	E_{rubb} ksi	$\sigma_{e\text{-}eq}$ psi	k_{eq} pci	H_{req} inch	H_{red} inch
10	75	263	8	200	259	85	9.92	0.08
10	75	263	9	200	258	89	9.89	0.11
10	75	263	10	200	256	95	9.85	0.15
10	75	263	11	200	254	103	9.79	0.21
10	75	263	12	200	251	112	9.74	0.26
10	100	255	8	200	251	113	9.92	0.08
10	100	255	9	200	250	118	9.89	0.11
10	100	255	10	200	248	126	9.85	0.15
10	100	255	11	200	246	135	9.79	0.21
10	100	255	12	200	244	147	9.74	0.26
10	200	235	8	200	232	223	9.92	0.08
10	200	235	9	200	231	233	9.89	0.11
10	200	235	10	200	229	246	9.84	0.16
10	200	235	11	200	227	263	9.79	0.21
10	200	235	12	200	225	284	9.74	0.26
10	300	224	8	200	221	332	9.92	0.08
10	300	224	9	200	219	347	9.89	0.11
10	300	224	10	200	218	365	9.84	0.16
10	300	224	11	200	216	388	9.79	0.21
10	300	224	12	200	214	417	9.74	0.26
12	75	193	8	200	192	81	11.94	0.06
12	75	193	9	200	191	84	11.92	0.08
12	75	193	10	200	190	87	11.89	0.11
12	75	193	11	200	189	91	11.86	0.14
12	75	193	12	200	188	97	11.81	0.19
12	100	188	8	200	186	108	11.94	0.06
12	100	188	9	200	186	111	11.92	0.08
12	100	188	10	200	185	116	11.89	0.11
12	100	188	11	200	184	121	11.86	0.14
12	100	188	12	200	183	128	11.81	0.19
12	200	174	8	200	173	214	11.94	0.06
12	200	174	9	200	172	220	11.92	0.08
12	200	174	10	200	171	228	11.89	0.11
12	200	174	11	200	171	238	11.86	0.14
12	200	174	12	200	170	250	11.81	0.19
12	300	166	8	200	165	320	11.94	0.06
12	300	166	9	200	164	329	11.92	0.08
12	300	166	10	200	164	340	11.89	0.11
12	300	166	11	200	163	354	11.86	0.14
12	300	166	12	200	162	371	11.81	0.19

2.4 Comparison of Design Methods

The contribution of a rubblized PCC base layer within a concrete pavement system was analyzed based on the current WisDOT design procedures and on a mechanistic appraisal of critical load-induced edge stresses. The WisDOT method, which is based on the 1972 AASHTO Interim Guide for the Design of Pavement Structures, was used to develop equivalent PCC pavement systems in terms of expected performance as enumerated by a design loss in the present serviceability index. The mechanistic appraisal was used to develop equivalent systems in terms of expected fatigue performance as enumerated by an equivalent edge stress under loading.

While both analysis methods are targeted towards different solution paths, some general trends were evident in both. In particular, the contribution of the rubblized PCC base layer is diminished as the structural capacity of the slab-on-grade PCC pavement system is increased as a result of an increase in the PCC slab thickness and/or the subgrade k-value. The effects of the rubblized PCC base layer were evaluated over a practical range of PCC slab thicknesses (6 in $\leq$ Hpcc $\leq$ 12 in), rubblized PCC base layer thicknesses (8 in < Hrubb < 12 in), and design subgrade k-values (75 $\leq$ k $\leq$ 300). To maintain some degree of consistency between analysis methods, fixed design values were utilized for the concrete layer modulus of elasticity (Epcc = 4.2 Mpsi) and the rubblized PCC layer modulus of elasticity (Erubb = 100 ksi and 200 ksi)

Both analysis methods were used to estimate the top-of-base k-value, either a function of plate load deflections (WisDOT/AASHTO) or critical edge slab stresses (Mechanistic). Both analysis methods resulted in an increase in k-values due to the rubblized base, with the WisDOT/AASHTO method producing the larger “bump.” **Figure 2.23** illustrates a comparison of the equivalent top-of-base k-values (keq) estimated for the two methods. As shown, the WisDOT method consistently results in a higher keq value. On average, the WisDOT keq is 89% greater than the Mechanistic keq for Erubb = 100 ksi and 99% greater when Erubb = 200 ksi..

Figure 2.24 illustrates a comparison of the allowable reductions in PCC slab thickness (Hred) due to the inclusion of a rubblized PCC base layer. As shown, the WisDOT method consistently results in a significantly higher Hred value. On average, the WisDOT Hred is 425% greater than the Mechanistic Hred for Erubb = 100 ksi and 260% greater when Erubb = 200 ksi .

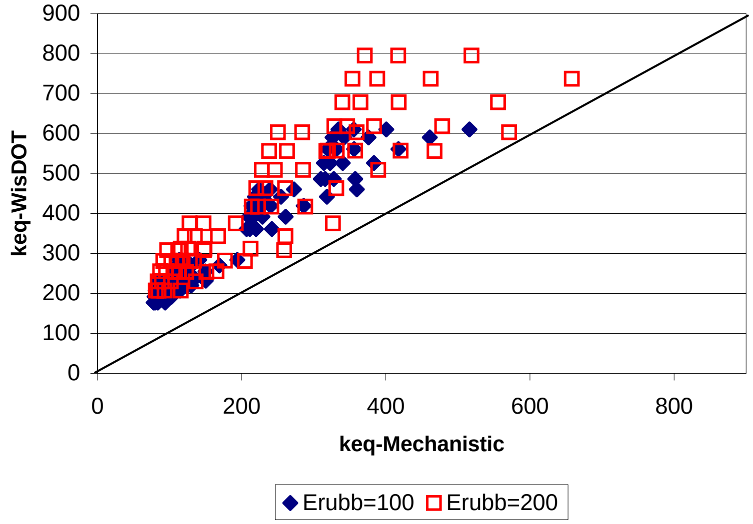

Figure 2.23: Comparison of Top-of-Base Equivalent k-values

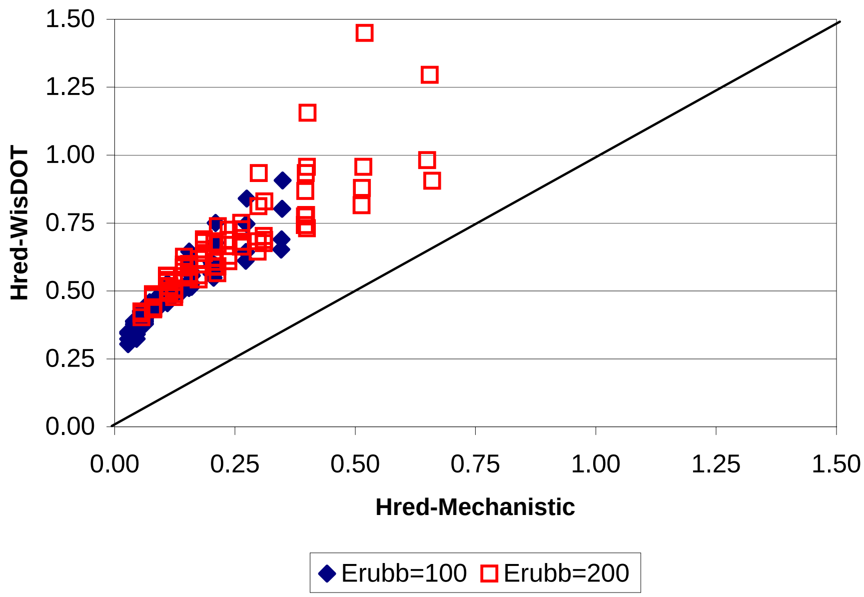

Figure 2.24: Comparison of Allowable PCC Thickness Reductions

Chapter 3
Field Testing

This chapter presents the results of field testing conducted on two separate construction projects which incorporate concrete pavements over rubblized PCC. The initial project was constructed within the City of Milwaukee as a test section to replace the traditional PCC bus pads used throughout the City. The second project represents a significant portion of interstate reconstruction just north of Stevens Point, WI.

3.1 87th St., City of Milwaukee

The 87th Street project, constructed in August, 2003, includes a 5-inch PCC bus pad constructed directly over an 8-inch rubblized PCC slab. This construction occurred at the intersection of 87th St and Wisconsin Ave in the City of Milwaukee, as shown in **Figure 3.1**. The construction of the bus pad test section was included as an add-on to an existing Milwaukee County construction project which included rubblization of the existing PCC and a 5-inch HMA surface. Personal negotiations with Milwaukee County personnel allowed for the inclusion of this test section which replaced a planned 9-inch PCC bus pad. This construction was intended as a proof of concept for the construction of PCC slabs directly over rubblized concrete. Project constraints limited the depth of the PCC bus pad to 5 inches to match the final elevation of the surrounding HMA surface.

The bus pad was constructed using a fiber reinforced PCC mixture which had a relatively slow early strength gain. The newly constructed pad was protected from traffic using standard traffic control barrels with yellow warning tape. Despite this measure of protection, within 2 days after paving an edge crack appeared, most likely the result of an encroached corner wheel loading. Over the past 4+ years of service, this crack has progressed to medium severity with slight spalling and faulting, as shown in **Figure 3.2**. Additional distresses within this bus pad include a small corner spall, another small corner break and a mid-panel shrinkage crack. **Figures 3.3 and 3.4** provide photographs of these distresses.

Figure 3.1: 87th Street Bus Pad Test Section, Looking North

Figure 3.2: 87th Street Bus Pad Test Section, Corner Break

Figure 3.3: 87th Street Bus Pad Test Section, Corner Breaks and Shrinkage Crack

Figure 3.4: 87th Street Bus Pad Test Section, Corner Spall Near Curbline

3.2 I-39, Stevens Point

The first large-scale construction project in Wisconsin incorporating a concrete pavement constructed over rubblized PCC was completed along a 9-mile portion of the southbound lanes of I-39 in Portage/Marathon Counties during the 2004 construction season. The project runs between CTH X and STH 34 and is identified as WisDOT Project ID 1160-00-73. The project has a design designation of 15,563,600 ESAL loadings, with a construction year ADT of 11,200, a design year ADT of 16,100 and 13.8% heavy truck traffic.

Primary pavement details include an 11 inch doweled jointed plain concrete pavement (JPCP) placed over a 4 inch CABC-Open Graded #2 interlayer placed over a 9 inch rubblized PCC base layer. Transverse contraction joints are spaced at 18-foot intervals and are reinforced with 1-1/2 inch diameter dowels. This project also included sections with base layers of hot mix asphalt (HMA) and non-rubblized PCC.

Seven test sections were established along the southern portion of this project, south of CTH DR, based on the base materials remaining prior to JPCP construction. 500 foot monitoring sections were established within each test section. Reference information for each monitoring section is provided in **Table 3.1**. All tests sections include an 11-inch doweled JPCP pavement and a 4-inch CABC-Open Graded #2 overlying the listed base materials.

Table 3.1: I-39 SB Monitoring Sections

Section ID	North End Station	South End Station	Base Materials
1R	1940+37	1935+32	8" Rubblized PCC over 6" CABC
1H	1926+30	1921+30	7" HMA over 6" CABC
2H	1900+20	1895+20	4" HMA over 10" CABC
1C	1885+20	1880+20	4" HMA over 9" PCC
3H	1801+00	1796+00	4" HMA over 10" CABC
2C	1780+00	1775+00	4" HMA over 9" PCC
2R	1759+90	1754+90	9" Rubblized PCC over 6" CABC

3.3 Post-Construction Testing – November 2005

FWD testing was conducted along the southbound lanes of I-39 on November 10, 2005 using the WisDOT KUAB 2m-FWD. Eight consecutive slabs (9 transverse joints) were randomly selected from with each of 7 monitoring sections. Tests were conducted at mid-lane transverse joint and central slab locations using applied loads of approximately 10, 14 and 21 kips. Air and pavement surface temperatures ranged from a low of 35 ^{o}F and 34 ^{o}F, respectively, at the start of testing to a high of 46 ^{o}F and 57 ^{o}F, respectively, at the conclusion of testing. A record of joint/slab distress was also obtained during FWD testing.

Deflection data collected from transverse joint tests were normalized to a 9 kip load level and used to compute total joint deflection and load transfer efficiency based on the following:

$$\Delta_T = \delta_L + \delta_U \qquad \text{Eq 3.1}$$

$$LT_\delta = \frac{\delta_U}{\delta_L} x100\% \qquad \text{Eq 3.2}$$

Where: Δ_T = total joint deflection, mils @ 9k

δ_U = deflection of unloaded slab at 12 inches from the center of loading, mils @ 9kips

δ_L = deflection of loaded slab at center of loading plate, mils @ 9kips

LT_δ = deflection load transfer across transverse joints, %

Figures 3.1 and 3.2 present a summary of the average transverse joint test results obtained within each test section.

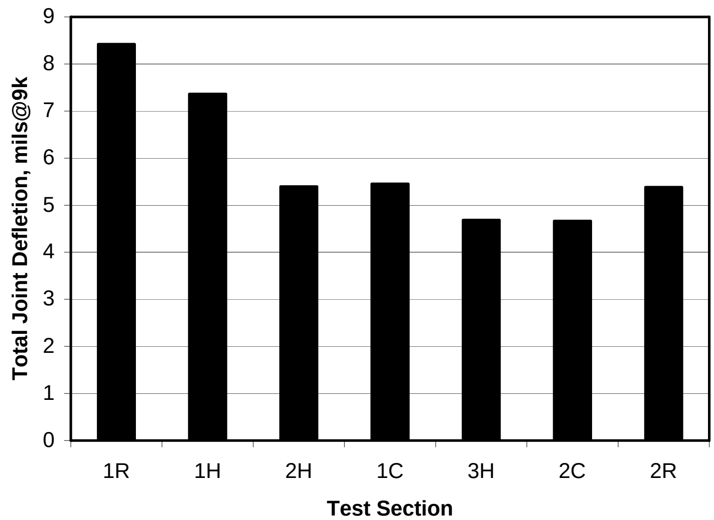

Figure 3.1: Total Joint Deflections, November 2005

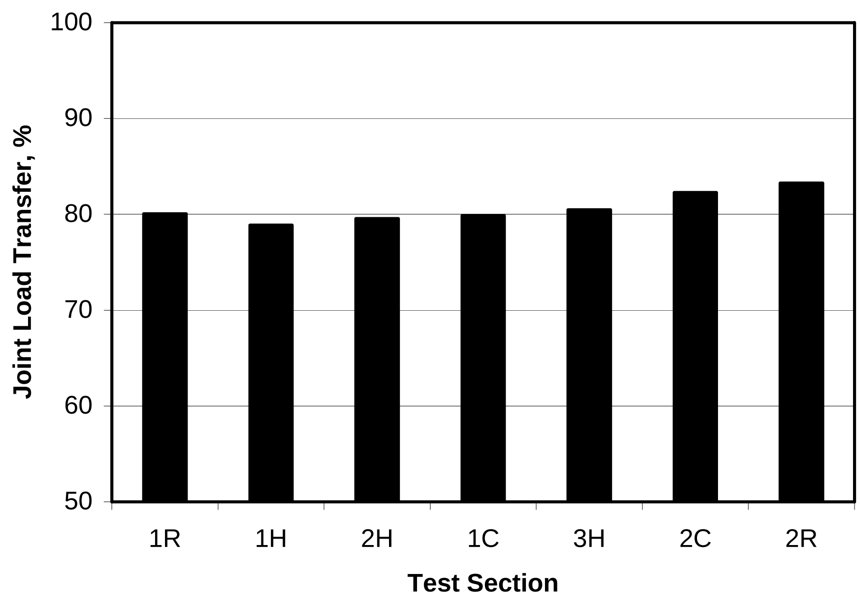

Figure 3.2: Deflection Load Transfer, November 2005

The results displayed in **Figure 3.1** indicate substantially higher joint deflections within sections 1R (JPCP over rubblized PCC) and 1H (JPCP over HMA) which may be a result of decreased edge support and/or temperature curling at the time of early morning testing. The results displayed in **Figure 3.2** indicate general uniformity among all test sections.

Deflection data collected from center slab tests were used to backcalculate structural slab parameters including foundation dynamic k-value and effective slab thickness, corrected for slab size effects, based on the following calculation sequence:

$$AREA = \frac{6}{\delta_0}\left(\delta_0 + 2\delta_{12} + 2\delta_{24} + \delta_{36}\right) \qquad \text{Eq 3.3}$$

Where: AREA = deflection basin area, inch

δ_i = surface deflection measured at i inches from load center, mils

$$l_{kest} = \left[\frac{\ln\left(\frac{36 - AREA}{1812.279133}\right)}{-2.55934}\right]^{4.387009} \qquad \text{Eq 3.4}$$

Where: l_{kest} = first estimate of the radius of relative stiffness, inch

$$CFl_{kest} = 1 - 0.89434\exp\left[-0.61662\left(\frac{L_{eff}}{l_{kest}}\right)^{1.04831}\right] \qquad \text{Eq 3.5}$$

$$CF\delta_0 = 1 - 1.15085\exp\left[-0.71878\left(\frac{W_{eff}}{l_{kest}}\right)^{0.80151}\right] \qquad \text{Eq 3.6}$$

Where: CFl_{kest} = slab size correction factor for l_{kest}

$CF\delta_0$ = slab size correction factor for δ_0

L_{eff} = effective slab length, inch

W_{eff} = effective slab width, inch

$$l_{kadj} = l_{kest} * CFl_{kest} \qquad \text{Eq 3.7}$$

$$\delta_{0adj} = \delta_0 * CF\delta_0 \qquad \text{Eq 3.8}$$

Where: l_{kadj} = adjusted l_{kest}, inch

δ_0adj = adjusted δ_0

$$k_i = \frac{P}{\delta_{0_{adj}} l_{kadj}^{\ 2}} \left[0.1253 - 0.008\left(\frac{a}{l_{kadj}}\right) - 0.028\left(\frac{a}{l_{kadj}}\right)^2 \right] \qquad \text{Eq 3.9}$$

Where: ki = interior dynamic k-value, pci

$$H_{eff} = \sqrt[3]{\frac{l_{kadj}^{\ 4} 11.73 k_i}{E_{pcc}}} \qquad \text{Eq 3.10}$$

Where: H_{eff} = effective slab thickness, inch

E_{pcc} = assumed PCC modulus of elasticity (= 4.2 Mpsi)

Figures 3.3 and 3.4 provide summary plots of the average backcalculated slab parameters for each test section. As shown in **Figure 3.3**, there appears to be two distinct groupings of dynamic k-values which are not well correlated with base types below the JPCP pavement.

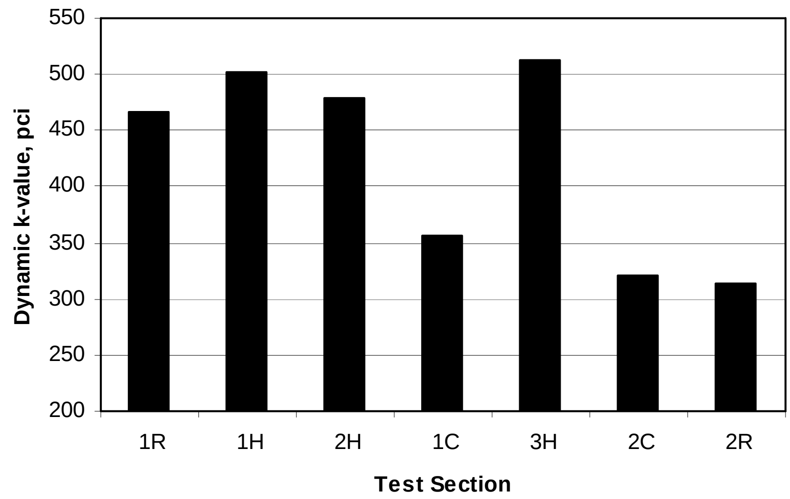

Figure 3.3: Dynamic Interior k-values, November 2005

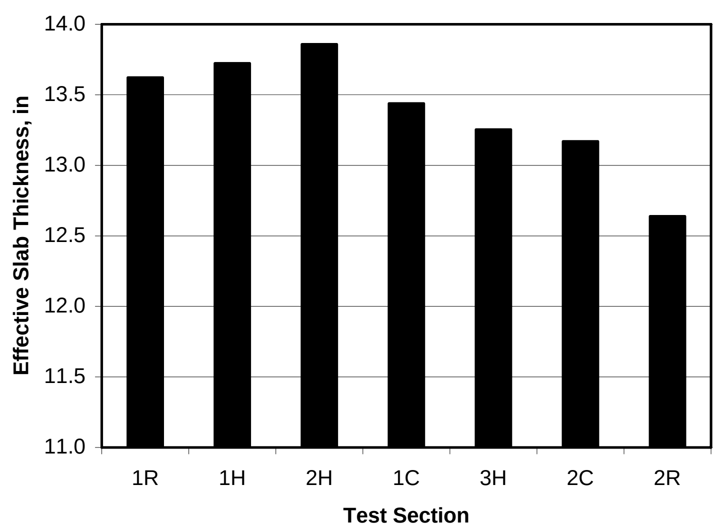

Figure 3.4: Effective Slab Thicknesses, November 2005

The average results displayed in **Figure 3.4** illustrate effective slab thicknesses well in excess of the design JCPC thickness of 11 inches for all test sections. This indicates a significant structural contribution from the layers below the JCPC surface. An estimate of the equivalent combined modulus of all base layers below the JPCP slab may be computed by:

$$E_{base} = \frac{E_{pcc} H_{eff}^{3} - E_{pcc} H_{pcc}^{3}}{H_{base}^{3}} \qquad \text{Eq 3.11}$$

Where: E_{base} = equivalent combined modulus of base layers, psi

E_{pcc} = assumed modulus of JPCP layer, psi (= 4.2 Mpsi)

H_{eff} = effective slab thickness computed by Eq. 3.10, inch

H_{pcc} = design thickness of JPCP slab, inch (= 11.0 inches)

H_{base} = combined thickness of all base layers below the JPCP layer, inch

Figure 3.5 illustrates the estimated equivalent static base modulus values for each test section. As shown, the modulus values for the rubblized PCC base sections (1R & 2R) are well in excess of the standard 100 ksi value assumed within the WisDOT design procedures. It is also interesting to note that the equivalent base moduli within the HMA base sections (1H & 2H) exceed those within the intact PCC base sections (1C, 2C).

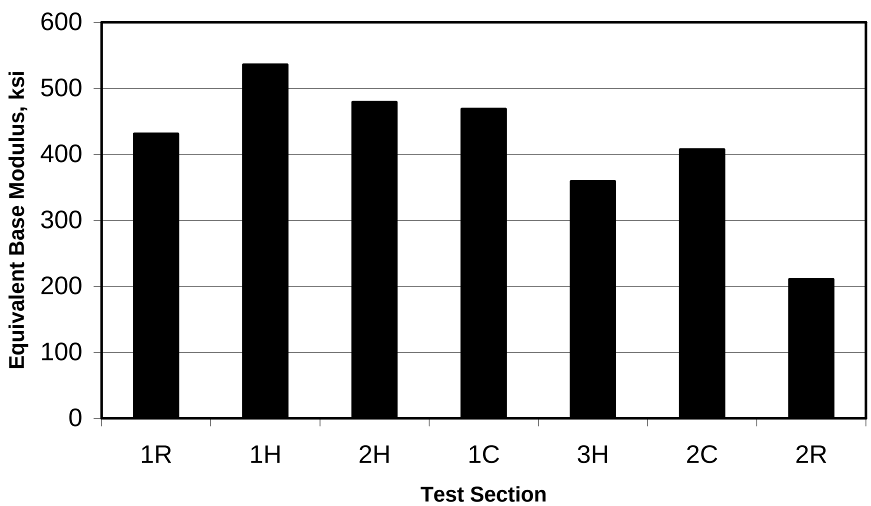

Figure 3.5: Equivalent Base Modulus, November 2005

A visual distress survey conducted in conjunction with the November 2005 FWD tests indicated all pavement sections were performing well with limited surface distress noted after approximately 12 months of trafficking. Observed distress includes limited low severity joint chipping, which is attributable to the joint sawing operations. **Figure 3.6** provides a summary of the percentage of joints containing low severity chipping within each lane of each test section. **Figure 3.7** provides a photo of a typical chipped joint.

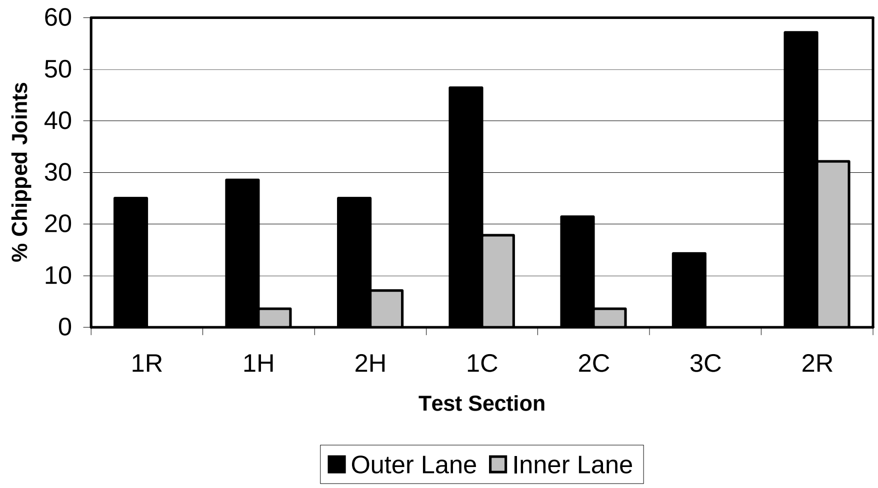

Figure 3.6: Joint Distress Survey Results, November 2005

Figure 3.7: Typical Chipped Joint, November 2005

3.4 Post-Construction Testing – October 2006

FWD testing was conducted along the southbound lanes of I-39 on October 19-20, 2006 using the Marquette University KUAB 2m-FWD. Eight consecutive slabs (8 transverse joints) were randomly selected from with each of 7 monitoring sections. Tests were conducted at mid-lane transverse joint and central slab locations using applied loads of approximately 6, 9 and 12 kips. Air temperatures ranged between 42 ^{o}F and 48 ^{o}F and pavement surface temperatures ranged from 38 ^{o}F and 48 ^{o}F.

Figures 3.8 to 3.12 provide summary plots of transverse joint deflections, transverse joint load transfer, dynamic k-value, effective slab thickness and equivalent base moduli computed from deflection data. As expected, the trends illustrated in these figures are comparable to those described for the results of the November, 2005 deflection testing.

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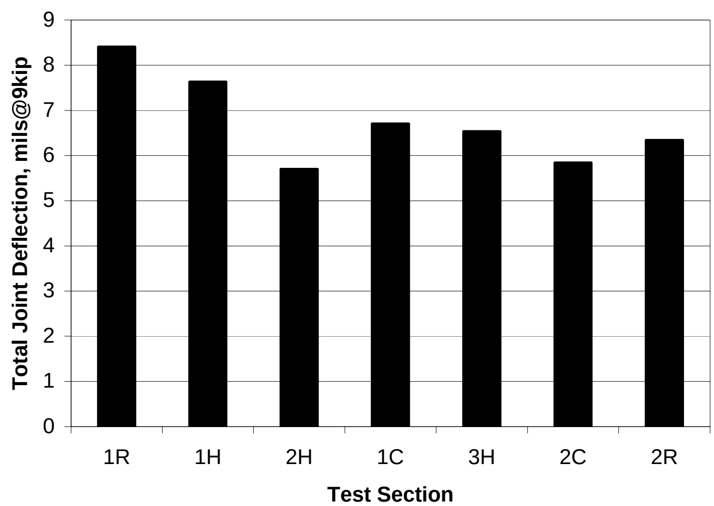

Figure 3.8: Total Joint Deflections, October, 2006

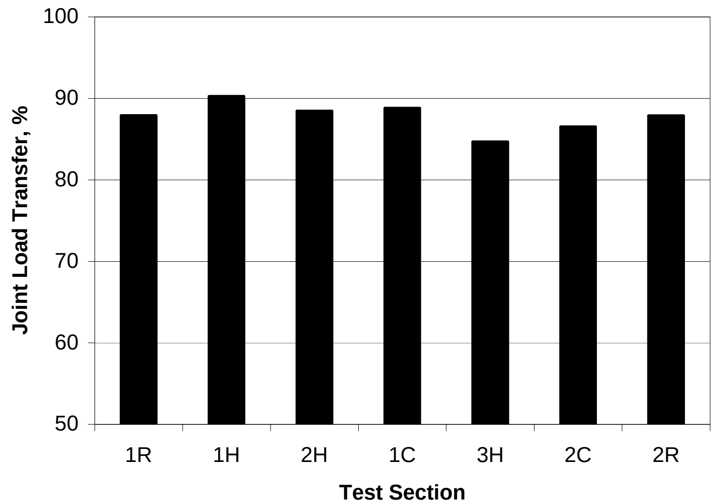

Figure 3.9: Joint Load Transfers, October, 2006

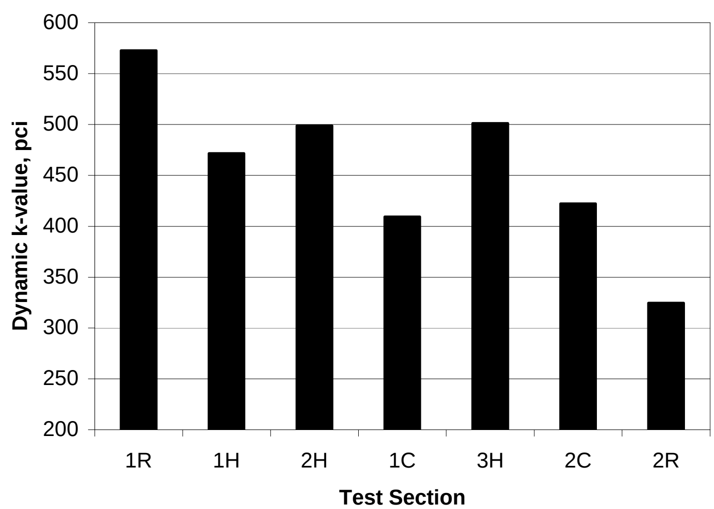

Figure 3.10: Dynamic k-values, October, 2006

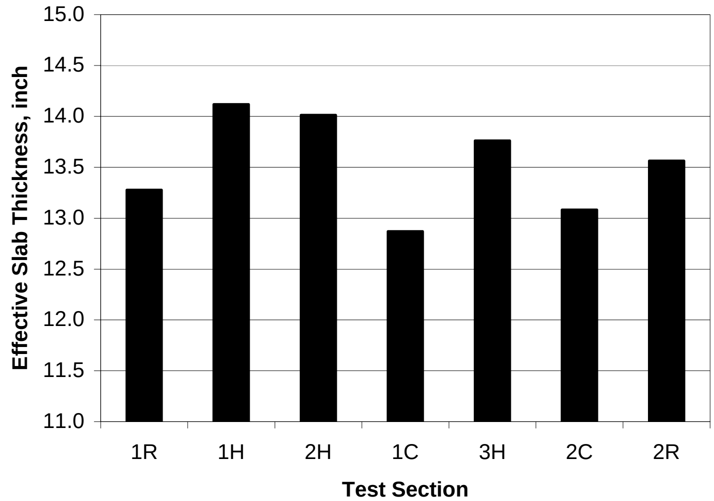

Figure 3.11: Effective Slab Thicknesses, October, 2006

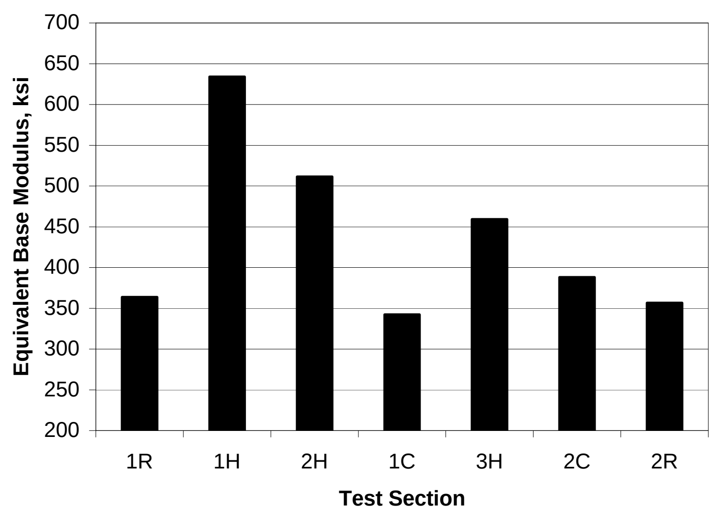

Figure 3.12: Equivalent Base Moduli, October, 2006

Chapter 4
Conclusions and Recommendations

This report has presented findings of research conducted to determine the viability of constructing Portland cement concrete pavements over rubblized PCC. Rubblization of aged PCC pavements is a common technique for in-place recycling of these pavements. For the vast majority of applications, the rubblized PCC layer is surfaced with hot mix asphalt (HMA). The use of Portland cement concrete as a surfacing material offers designers another option which may provide good performance and be cost-effective under certain conditions.

The current concrete pavement design procedures utilized by WisDOT allow for the incorporation of a rubblized PCC base layer and an increase in the design value for the subgrade support k-value based on AASHTO guidelines. Over the practical range of rubblized concrete layer thicknesses and moduli investigated during this research, composite k-values were shown to increase by a factor of approximately 2 to 4 times, depending on the thickness and modulus of the rubblized layer and the quality of the natural subgrade support. This increase in composite k-value was shown to reduce the concrete layer thickness requirement between 0.25 to 1.45 inches, depending on subgrade quality and design ESAL loadings. The greatest reduction in required PCC thickness was seen for the combination of high subgrade support and low design ESAL loadings. As design ESAL levels increase, the allowable PCC thickness reduction decreases for all subgrade qualities.

A mechanistic appraisal was also conducted based on critical load-induced edge stresses with and without the inclusion of a rubblized PCC base layer. For the range of parameters investigated, the mechanistic appraisal yielded lower equivalent top-of-base k-values and lower PCC thickness reductions. On average, the mechanistic top-of-base composite k-value is approximately half of that determined based on the AASHTO design process, and the concurrent PCC thickness reduction is approximately ½ to ¼ of the AASHTO/WisDOT value.

Two field projects incorporating Portland cement concrete pavements over rubblized PCC layers were reported on. For the urban application of a 5-inch PCC bus pad placed directly over the rubblized PCC base layer, good performance has been noted after 4+ years of service. For the rural interstate application of an 11-inch PCC slab constructed over a 9-inch rubblized PCC base with the inclusion of a 4-inch open graded separation layer, good performance has been noted after 3+ years of service. Analysis results backcalculated from two separate series of deflection tests indicate a more significant structural contribution from the rubblized layer than is currently considered within the WisDOT design procedures. A rubblized PCC modulus approaching 200 ksi may be warranted based on the results of FWD testing.

Based on the research results collected to date, no restrictions to the continued design and construction of Portland cement concrete pavements over rubblized PCC are warranted. More observations are required to validate the need for the inclusion of an open graded aggregate interlayer between the PCC slab and rubblized PCC base layer, which is current WisDOT practice. The structural contribution of the rubblized layer may lead to a savings of up to 1.45 inches of concrete, depending on design traffic levels and subgrade quality. This may prove to be a cost-effective alternative to complete removal and replacement of aged concrete pavements.

This report also investigated the impacts of using higher allowable concrete working stress values, which would reflect the use of higher flexural strength concrete (> 650 psi) and/or lower reduction factors (< 1.33). Using higher working stress values would not significantly affect the aforementioned thickness reductions due to the inclusion of a rubblized PCC base layer; however, significant reductions in design PCC thicknesses (for any given design ESAL loadings) or significant extensions in expected service life (for any given design PCC thickness) could be realized.

It is recommended that the rubblized test sections identified along I-39 SB, north of Stevens Point, be continually monitored to establish the performance characteristics of the pavements. Early performance results indicate these pavements should provide acceptable performance for an extended period. Longer term performance data is needed to confirm or deny the cost-effectiveness of this design option.

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