BOND ENHANCEMENT TECHNIQUES FOR PCC WHITETOPPING

Final Report
Iowa Highway Research Board
Project HR-341

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Project Development Division

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Final Report
for
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Bond Enhancement Techniques for PCC Whitetopping

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8. ABSTRACT

This research was initiated in 1991 as a part of a whitetopping project to study the effectiveness of various techniques to enhance bond strength between a new portland cement concrete (PCC) overlay and an existing asphalt cement concrete (ACC) pavement surface. A 1,676 m (5,500 ft) section of county road R16 in Dallas County was divided into 12 test sections. The various techniques used to enhance bond were power brooming, power brooming with air blast, milling, cement and water grout, and emulsion tack coat. Also, two sections were planed to a uniform cross-section, two pavement thicknesses were placed, and two different concrete mix proportions were used. Bond strength was perceived to be the key to determining an appropriate design procedure for whitetopping. If adequate bond is achieved, a bonded PCC overlay technique can be used for design. Otherwise, an unbonded overlay procedure may be more appropriate.

Conclusions:

1. Bond Strength Differences.

Milling increased bond strength versus no milling. Tack coat showed increased bond strength versus no tack coat. Planing, Air Blast and Grouting did not provide noticeable improvements in bond strength; nor did different PCC types or thicknesses affect bond strength significantly.

2. Structure

Structural measurements correlated strongly with the wide variation in pavement thicknesses. They did not provide enough information to determine the strength of bonding or the level of support being provided by the ACC layer. Longitudinal cracking correlated with PCC thicknesses and with planing

3. Bonding Over Time

The bond between PCC and ACC layers is degrading over time in the outside wheel path in all of the sections except tack coat (section 12). The bond strength in the section with tackcoat was lower than the others, but remained relatively steady.

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DISCLAIMER

INTRODUCTION

Whitetopping, PCC resurfacing over existing ACC, has been used successfully throughout the country. In Iowa, over 500 km (300 mi) of whitetopping overlays have been placed. They have been predominantly placed on the county road system, with projects constructed in Boone, Dallas and Washington Counties in 1977 regarded as the beginning of whitetopping in Iowa. However, an appropriate design methodology has not been determined for the design of the thicknesses of these overlays. The difficulty stems from how to treat the structural contribution of the underlying ACC. If it becomes a part of the monolithic pavement, then a bonded PCC overlay design method utilizing the existing ACC should be appropriate. If no bond is formed, or if the bond degrades under traffic loads then (1) an unbonded design procedure should be used, (2) the ACC should be considered as a base or separate layer, and (3) the PCC thickness cannot be reduced. The bond between the PCC and ACC is the key to how the two materials act in relation to each other. This research investigated that bond and the use of conventional methods to enhance that bond.

OBJECTIVE

The primary aim of this research project was to determine what techniques could be used to enhance the bond between the old ACC and the new PCC overlay. This involved evaluating the bond both initially and over time under normal, relatively low-volume traffic.

LOCATION AND EXISTING CONDITIONS

The research project was constructed in Dallas County on county route R16, from Dallas Center south 7.2 km (4.5 mi) to Ortonville. The existing pavement was 6.7 m (22 ft) wide and was built in 1959. The original pavement was composed of a 64 mm (2.5 in.) ACC surface placed on a 150 mm (6 in.) rolled stone base, over 100 cm (4 in.) of soil base. In 1971, the road received an 80 mm (3 in.) ACC resurfacing. The traffic on this route ranges from 830 to 1050 vehicles per day. The pavement surface was distorted with ruts averaging 12 mm (0.5 in.) in depth. The pavement was heavily cracked with transverse, longitudinal and random cracks.

VARIABLES AND TECHNIQUES TESTED

The research test sections were developed to evaluate several factors. Eight variables were tested. Figure 1 lists the makeup and layout of each of the twelve test sections. A description of the variables appears below. Note that the test sections are numbered from 2 to 13; they were initially 1 to 12. Unfortunately, the tack coat (originally section 1) was not available at the start of paving. As a result, that section was moved to the end of the project and relabeled section 13.

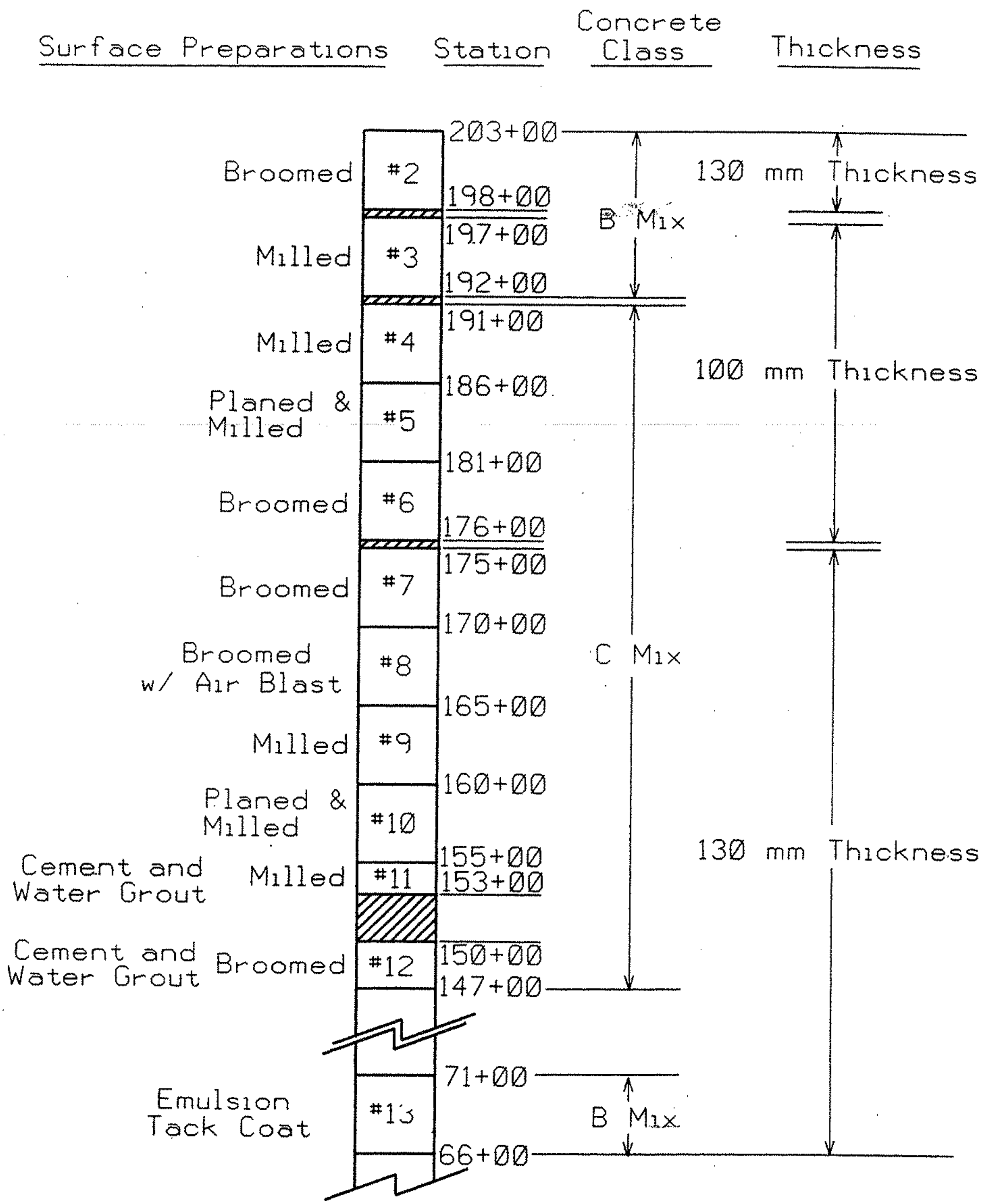


FIGURE 1
Test Sections Layout

Surface Preparation

The surface preparation was considered the most important in regard to bond strength. The current Iowa DOT Specification requires only that the surface of the ACC be power broomed prior to concrete placement. Therefore, four sections were prepared in that fashion in order to compare this research to past projects and to provide a baseline for bond strengths.

If this was a PCC to PCC bonded overlay, then cleanliness would be considered very important. Therefore, one power broomed section was also air blasted prior to concrete placement. Also with bonded PCC to PCC overlays, the surface is milled or shot-blasted in order to remove dirt, oil and other foreign materials or any loose material. The milling also roughens the surface providing more surface area for bonding and some keying action. To test this idea, the surfaces of six sections were milled just deeply enough to roughen the surface.

Bonding Agents

When PCC overlays are bonded to existing PCC in Iowa, a cement and water grout is required. When ACC overlays are placed over existing ACC, a tack coat is used. With these techniques in mind, test sections were placed using each of these bonding agents.

Planing

Older ACC pavements often have rutting in the wheel paths. In this project, the ruts had an average depth of 12 mm (0.5 in.). Whitetopping over pavements with existing ruts may not be detrimental and may provide a benefit from additional PCC thickness in the wheel path. However, the ruts might be indicative of a weaker portion of underlying ACC pavement or subgrade. As such, the support along the wheel path may be weakened and result in longitudinal cracking. Additionally, the bond in the vicinity of the ruts may have to resist a variety of shear stresses due to the irregularity of the asphalt surface. The PCC will also need to resist longitudinal cracking due to differential vertical forces acting upon it between the section that is thicker over the rut and that which is thinner (such as over the quarter point).

In order to test the effects of planing two sections were planed to eliminate the distorted surface and create a more uniform PCC cross-section thickness. This planing also resulted in a milled surface.

Thickness

Two thicknesses of overlay were chosen for the research, nominal 130 mm (5 in.) and nominal 100 mm (4 in.). This allowed the evaluation of any effect that different pavement thicknesses may have on bonding over time. Actual PCC thicknesses varied considerably from these values. Also, the appropriate design thickness to use for PCC whitetopping (from a strength standpoint) is still a matter of some debate.

Mix Proportions

Two standard Iowa Department of Transportation mixes were used in this research. Traditionally, counties have used a Class B concrete in highway paving. A Class C concrete is usually required on the primary system and many counties are now using these proportions for county paving. Therefore, sections with each class of concrete were constructed. See Appendix A for a description of the concrete proportions. Additionally, part of section 10 had an early strength type M concrete to allow early opening of an intersection.

CONSTRUCTION

The contract for this 7.2 km (4.5 mi) PCC overlay was awarded to Cedar Valley Corporation of Waterloo, Iowa. The week of June 17-21, 1991 was devoted to surface preparation of the selected research sections. An Iowa DOT milling machine was used to plane the existing surface in two test sections and to mill a roughened surface in four sections. Paving began on Monday, June 24, 1991, starting at the north end of the project and progressing southward. The contractor located the batch plant at the south end of the project just north of US 6. The daytime high temperature was 28°C (83°F) with wind gusts to 26 km per hour (16 mph).

During the construction of section 6 the concrete trucks were observed tracking dust onto the roadway from a turn-around area. This may have affected the bond strength in the section due to dust contamination on the surface of the ACC.

The second day of paving, June 25, 1991, brought a considerable change in the weather with the temperature climbing to 31°C (88°F) and wind gusts up to 45 km per hour (28 mph).

Paving on section 10 was affected by several factors. (1) About 9 meters (30 lineal feet) of the section was paved with a high early strength mix (M-4) in order to allow early opening of an intersection to cross-traffic. (2) Paving was interrupted in this section due to a paver malfunction and the PCC mix change. (3) Some concrete had to be rejected at the plant and some hand finishing was required due to the delay. (4) A portion of the ACC was wet (a result of paver cleaning operations) prior to paving. All bond tests in this section were made south of station 157+00 which avoids the trouble areas.

Sections 11 and 12 involved the use of a cement and water grout as a possible bond enhancement. The grout was delivered in ready mix trucks, dumped onto the surface, and spread with hand squeegees. In section 11, the grout was much too dry and was drying quickly on the hot ACC. Sufficient water was not available on site to dilute it to a more fluid consistency. As a result, only a 61 m (200 ft) section was placed. The grout used in section 12 was of a proper watery consistency and placement was much easier. However, the section was also shortened to 91 m (300 ft) to expedite the paving operation. Tracking in the grout occurred in both sections from trucks backing into the grouted area as they dumped concrete. This could have affected bonding. Transverse cracking was discovered in section 11 on June 27. This was probably a result of late control joint sawing (one saw joint was through a crack) combined with the elevated temperatures.

Section 13 was paved on Thursday, June 27. An anionic tack coat was planned for this section, but only a cationic (type CSS-1H) was available. The CSS-1H tack coat was applied at approximately 7:30 PM on June 26 in an area that would be paved the next morning. By the time the paving commenced there had been quite a few vehicles tracking across the tack coat. Also, wind had blown dust across the surface during the night. Either of these could have affected the bond in this area.

CONSTRUCTION TESTING

Iowa DOT research personnel performed pre-construction and post-construction tests on this project. The tests included slump and entrained air tests, beam and cylinder strengths, rut depths and crack surveys (results are shown in Appendix A); as well as core dimensions and shear strengths (discussed below).

DISCUSSION

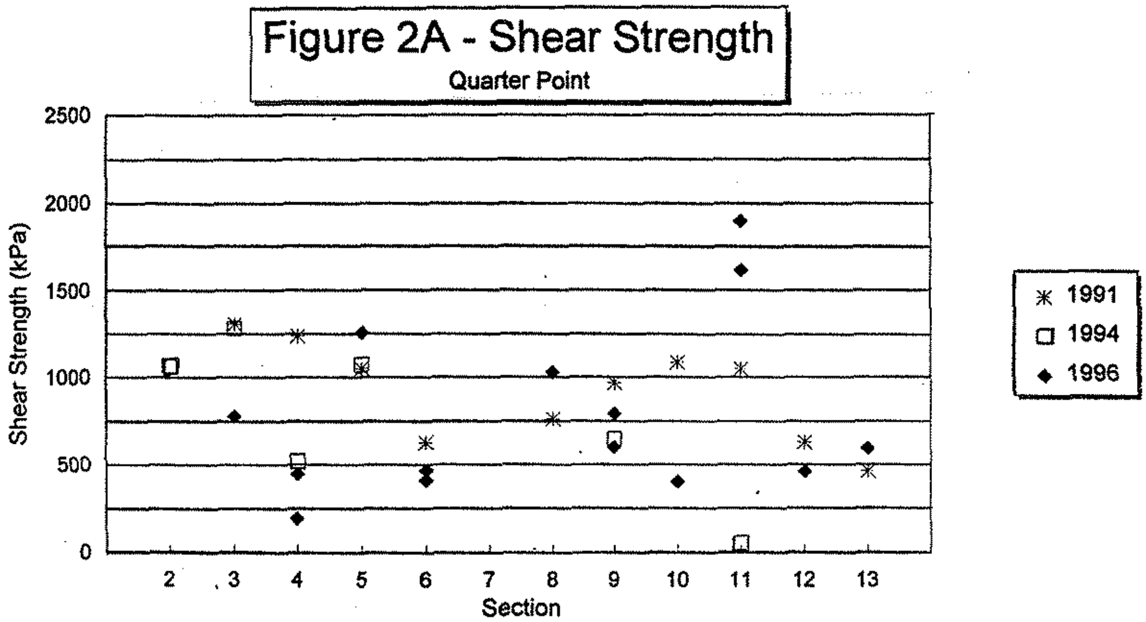
The focus of this research is to determine what factors have an impact on bond strength between new PCC and the existing ACC. After an overview of bond strength and pavement structural strength issues, this discussion will cover the differences (if any) in bond strength for each variable.

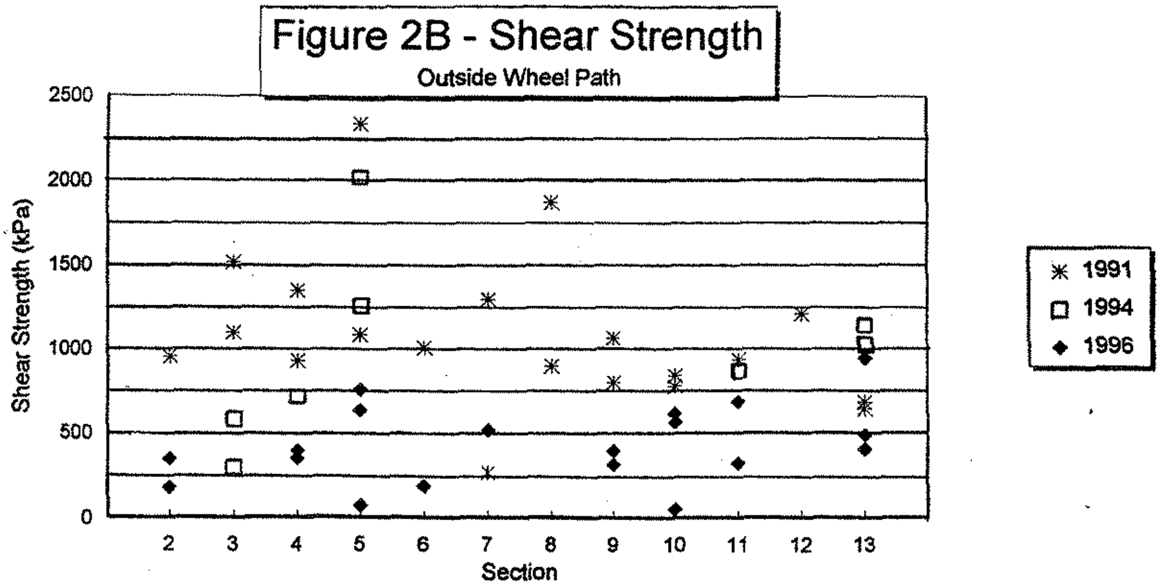
SHEAR STRENGTH OVERVIEW

Cores were removed from the project in 1991, 1994 and 1996. At least three were taken from each section, distributed between the quarter point and outside wheel path locations. Shear strength measurements were made, where possible, and the ACC and PCC thicknesses were measured. A number of cores could not be tested for shear strength because the bond was broken when the core was removed from the core drill barrel or, occasionally, the ACC was broken into pieces. A complete list of core data is provided in Appendix B.

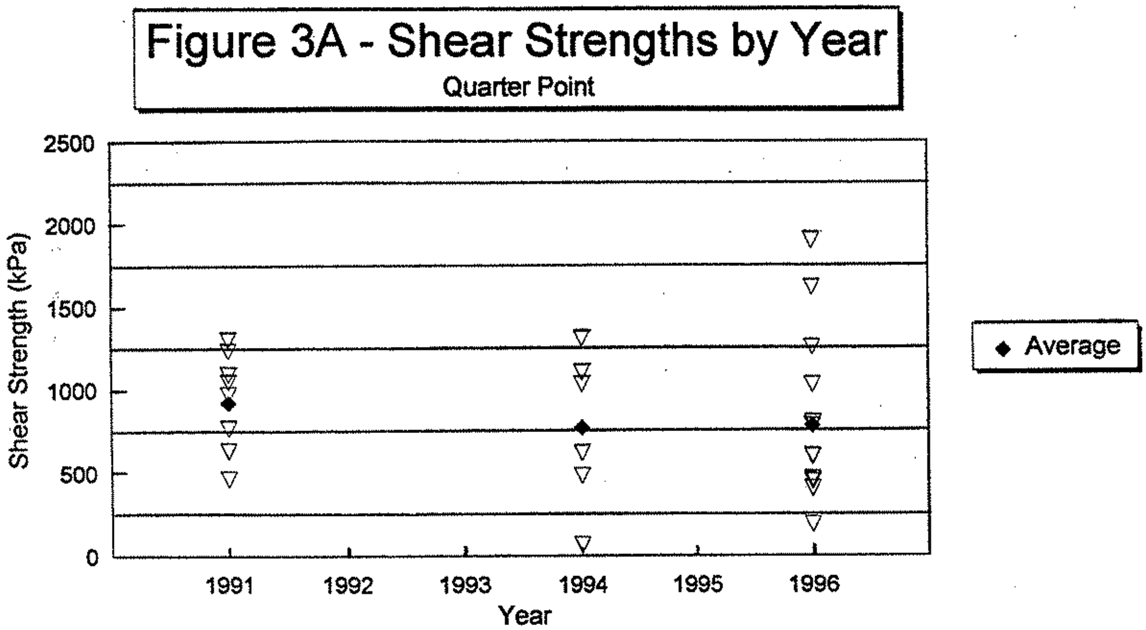
There was some confusion about the unbonded cores. It is not possible to determine with any degree of confidence whether they were in an unbonded condition initially or if they were bonded and the drilling process broke the bond. A large number of cores (60% overall) were indeed bonded when they were removed from the barrel. It is probably safe, therefore, to assume that the bond strength of any that were unbonded during coring was lower than the bond strength of those that were not unbonded. With this in mind, the analysis of shear test results was performed considering only the cores that were recovered in a bonded state. The number of unbonded versus whole cores for each section, each year was also tabulated. This provided another measure of bond strength, albeit a rough one.

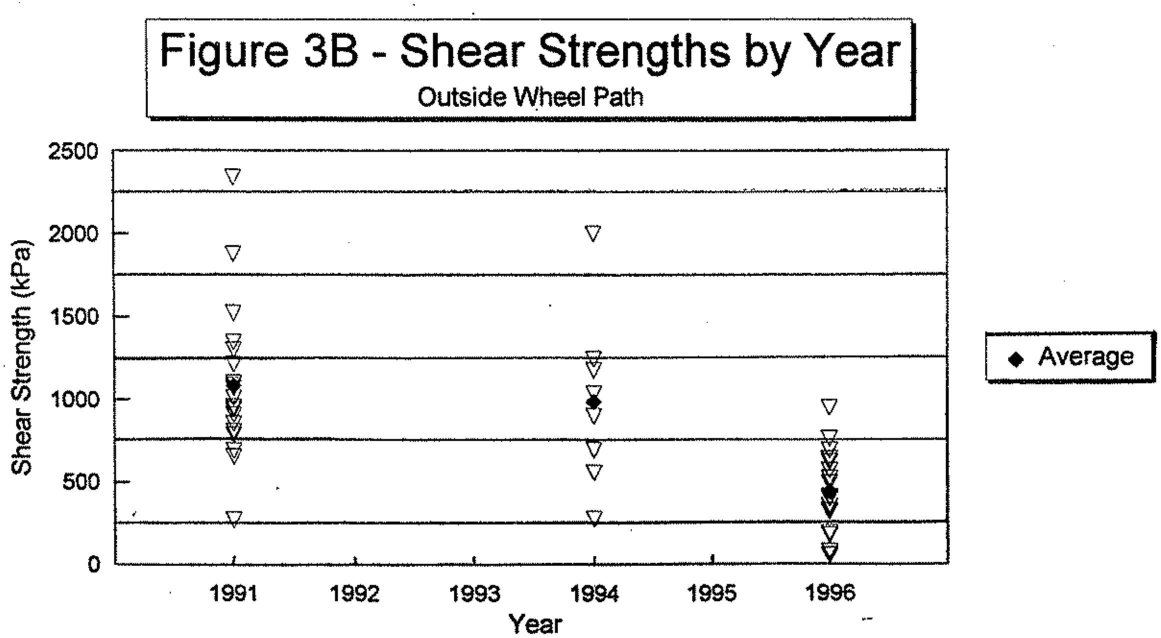
Data for shear strengths are graphed in Figures 2A, 2B, 3A and 3B, and are listed in Appendix B. Figures 2A and 2B show shear strength for quarter point and outside wheel path locations respectively, divided by test section. It is interesting to note the qualitative differences in the two graphs.



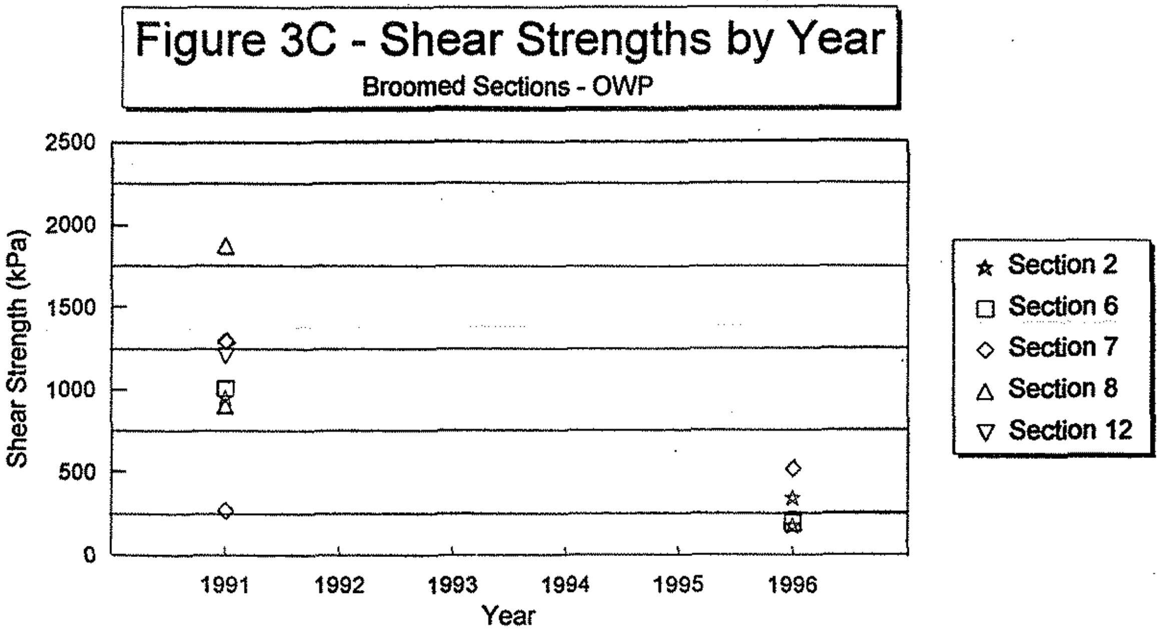


Shear strengths vary widely for the quarter point data, but without any significant differences between the test dates (1991, 1994, 1996). However, the data for the outside wheel path cores suggest significantly lower shear strength for all sections for the 1996 test. Figures 3a and 3b show the same data segregated only by date for quarter point and outside wheel path locations respectively. These results indicate that the two layers are becoming unbonded at the wheel path location over time.





Figures 3C through 3F show shear strengths broken down by both year and test regimen. Note that except for section 13, all of the sections began with higher shear strengths in 1991 that degraded with time. Section 13 had a low initial shear strength, but didn't degrade significantly with time.



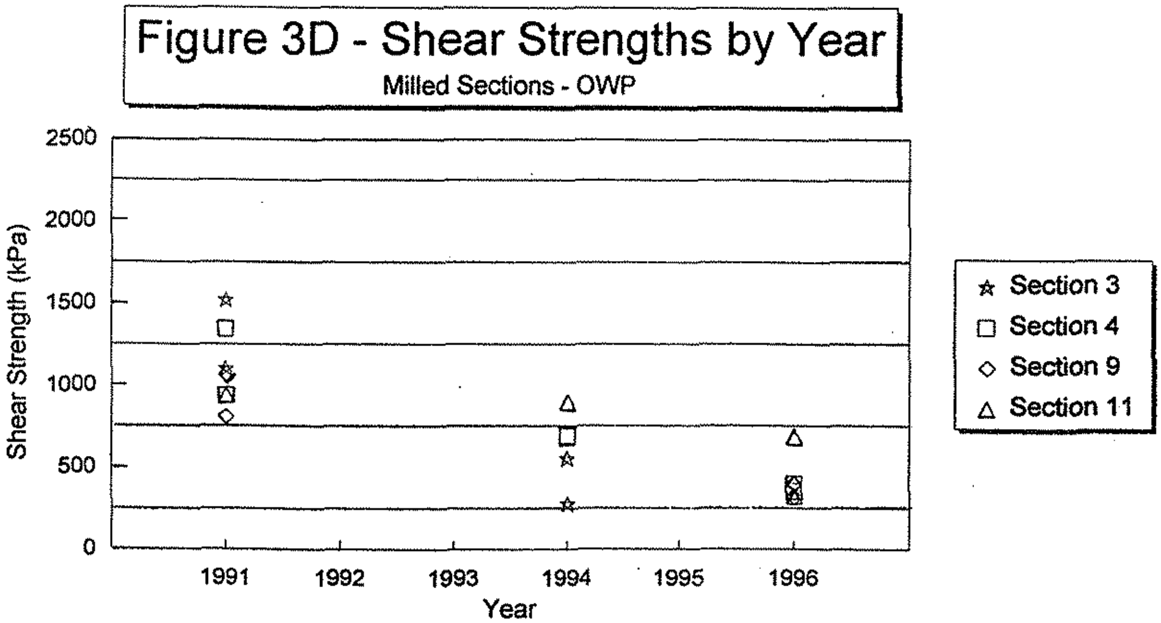


Figure 3E - Shear Strengths by Year
Milled & Planed Sections - OWP

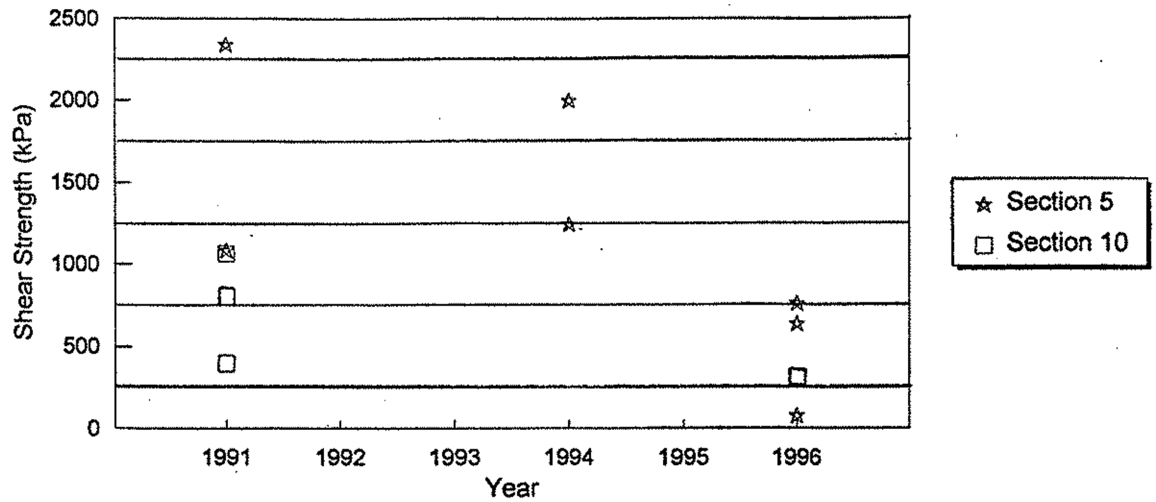
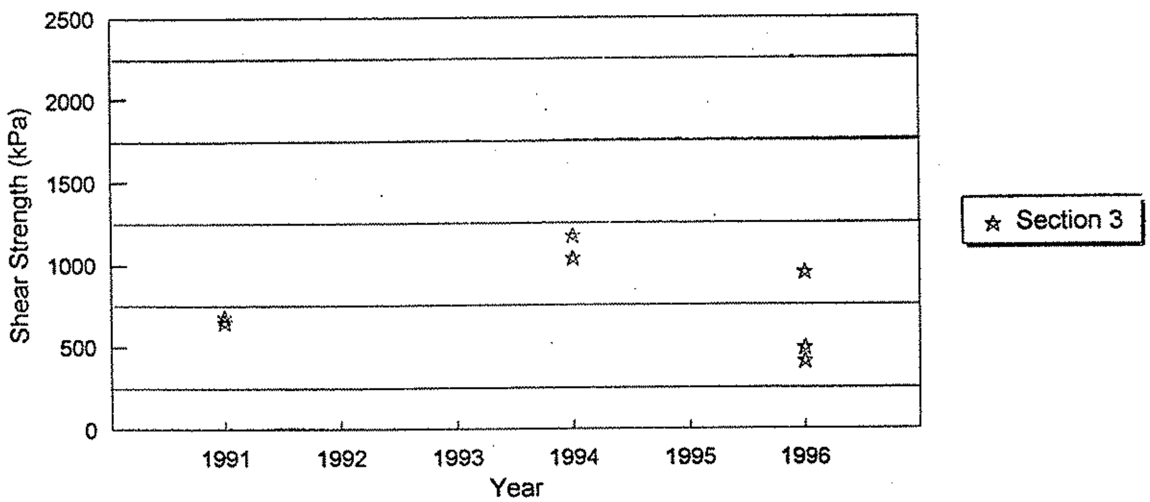


Figure 3F - Shear Strengths by Year
Tack Coat Section - OWP



Structural Evaluation Overview

Structural evaluation was performed using the Road Rater test equipment. Road Rater is a non-destructive, frequency based test of pavement structure. Data for all Road Rater testing is tabulated in Appendix C. The Road Rater structural ratings simulate AASHTO structural numbers under springtime conditions assuming the coefficients shown in Table 1. For example, the coefficient of sound PCC is estimated to be a structural number of 0.02 per mm (0.5 per in.) of thickness. For design purposes, the structural ratings are corrected to 27°C (80°F). Road Rater tests were performed with the intention that the results would provide information on bonding between the layers and the level of support being provided by the ACC layer.

A graph of the Road Rater results is shown in Figure 4. Data is provided in Appendix C. Note that the values track very closely from year to year with vertical offsets for some years. These offsets are due to seasonal variations and are common for structural rating measurements. How wet, warm or frozen the subgrade is has a big impact on the actual measurement. The important point is that the data tracks very well from year to year.

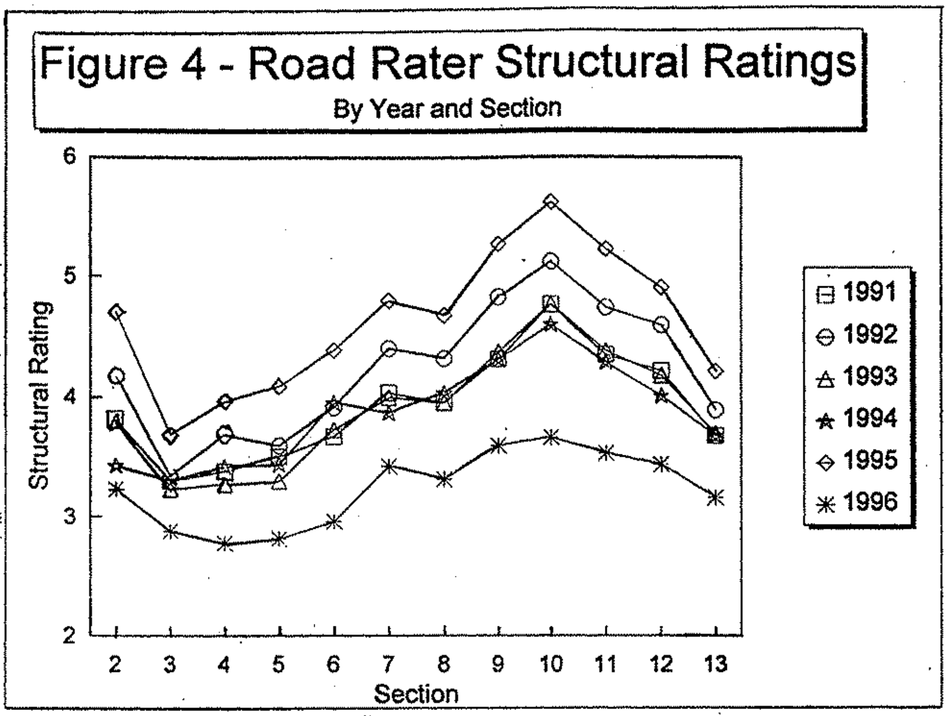
Table 1
AASHTO Road Rater Coefficients

Component	Coefficient		Minimum Thickness Permitted
New	Old Road	Road	
Surface Course			
Type A Asphalt Cement Concrete	0.44*	0.35	3 (>300 tpd)
Type B Asphalt Cement Concrete	0.44*	0.35	2 (<300 tpd)
Type B Asphalt Cement Concrete Class 2	0.40	0.30	
Inverted Penetration	0.20	0.20	
Base Course			
Type A Binder Placed as Base	0.40	0.30	
Type B Asphalt Cement Concrete Base Class I	0.38	0.30	2
Type B Asphalt Cement Concrete Base Class II	0.30	0.25	2
Asphalt Treated Base Class I	0.34*	0.25	4
Bituminous Treated Aggregate Base	0.23	0.20	6
Asphalt Treated Base Class II	0.26	0.20	4
Cold-Laid Bituminous Concrete Base	0.23	0.15	6
Cement Treated Granular (Aggregate) Base	0.20*	0.15	6
Soil-Cement Base	0.15	0.10	6
Crushed (Graded) Stone Base ***	0.14*	0.10	6
Macadam Stone Base	0.12	0.10	6
Portland Cement Concrete Base (New)	0.50	0.40	
Old Portland Cement Concrete	0.40**		
Subbase Course			
Soil-Cement Subbase	0.10	0.10	6
Soil-Lime Subbase	0.10	0.10	6
Granular Subbase	0.10*	0.10	4
Soil-Aggregate Subbase	0.05*	0.05	4

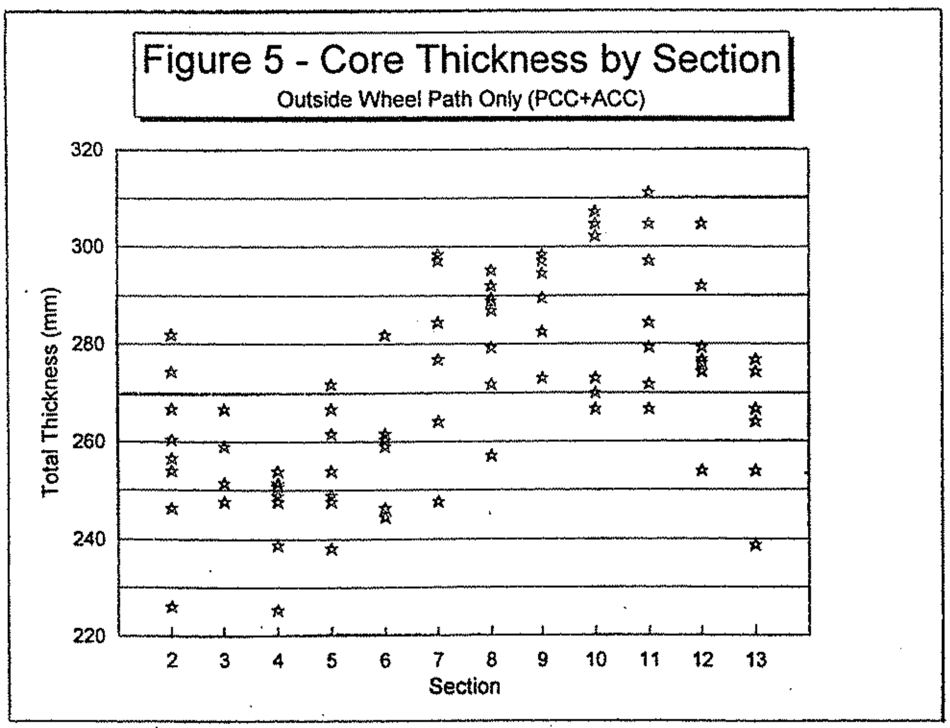
* Indicates coefficients taken from AASHTO Interim Guide for the Design of Flexible Pavement

** This value is for reasonably sound existing concrete. Actual value used may be lower, depending on the amount of deterioration that has occurred.

*** No current specification



A graph of actual full pavement thicknesses are shown below. The PCC and ACC depths are shown in Figures 6A and 6B. Overall pavement thickness and PCC thickness correlate well with the Road Rater results.



Generally speaking, the structural numbers can be converted to an equivalent pavement depth for each type of pavement. As stated above, the coefficient of sound PCC is estimated to be a structural number of 0.02 per mm (0.5 per in.) of thickness. Using the road rater results (from an average of data over the five years) and the known PCC and ACC pavement thicknesses (from cores), we can get an idea of the fraction of support being provided by the PCC and from the ACC and sub-base below. What is not readily apparent from the data is any indication of bond strength or the percentage of contribution from ACC and subbase respectively. Additionally, the actual pavement depths (both PCC and ACC) vary considerably within most sections (see Figures 6A and 6B).

Figure 6A - Core Thickness by Section
Outside Wheel Path Only, PCC Only

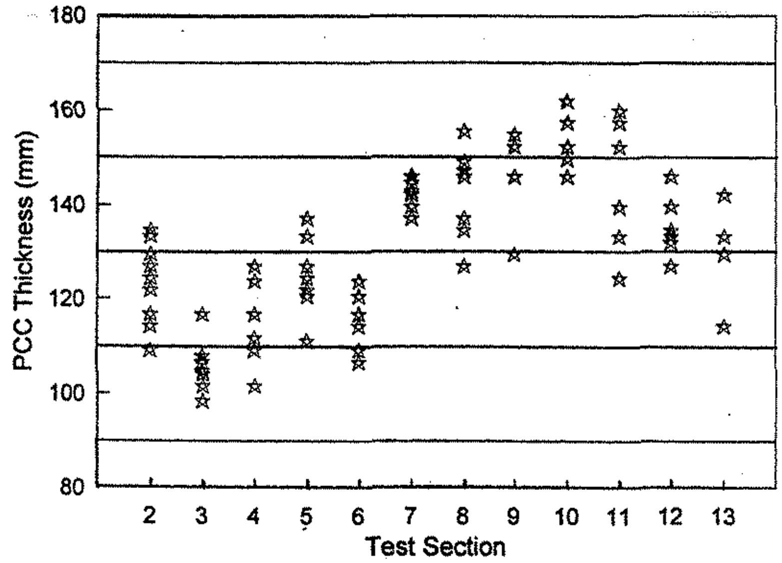
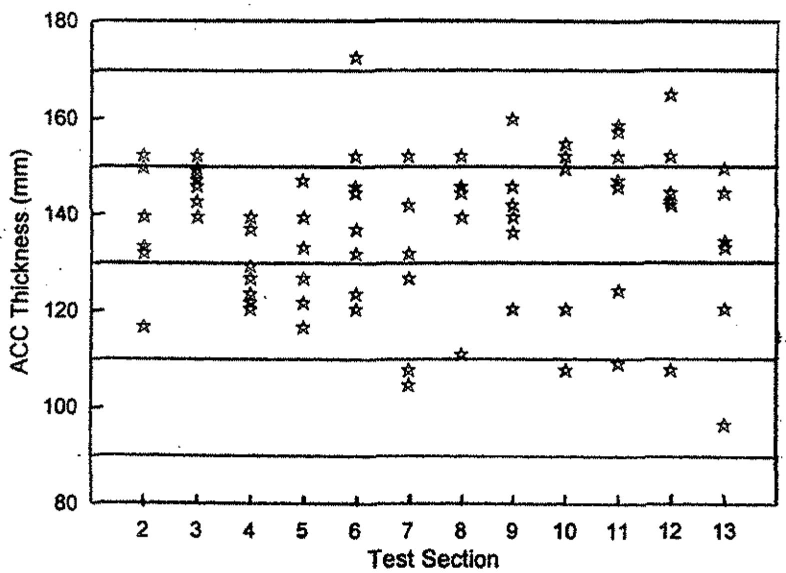


Figure 6B - Core Thickness by Section
Outside Wheel Path Only, ACC Only

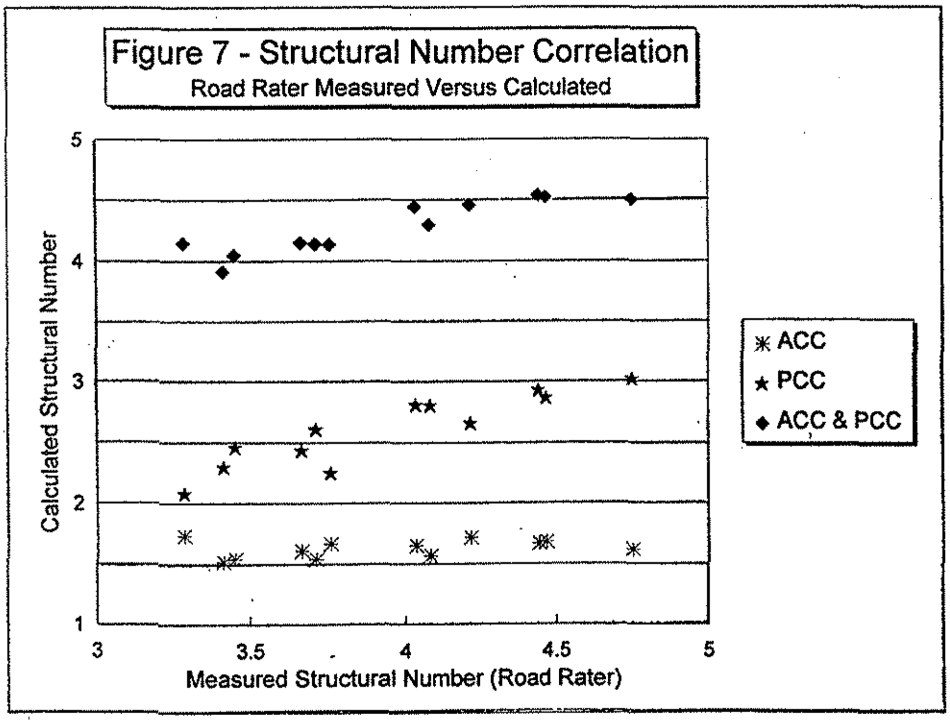


Knowing the actual ACC and PCC thicknesses of many Road Rater test sites, it is possible to subtract out the portion of the structure being provided by the PCC and quantify the structure of the remaining layers. For example, at station 166+00 the average structural rating was 4.2. At the same location, the actual PCC thickness was 122 mm (4.8 in.). Assuming a coefficient for sound PCC of 0.5 (note: calculations are in English units), this PCC would have a structural rating of 2.4. Subtracting gives a structural rating for the remaining structure of 1.8. What is not apparent is how much of this remaining support is due to the ACC and how much is from the underlying subbase.

Another approach can be used to test the support of the ACC. Figure 7 shows values of averaged Road Rater measurements for each section plotted versus the expected structural numbers obtained from actual pavement thicknesses. The latter values were calculated by applying the appropriate coefficients (0.5 for PCC, 0.3 for ACC in English units) to the average actual thicknesses in each section. Correlations among the data sets are shown below.

Table 2
Correlations for Actual Thicknesses Versus Road Rater

	SN vs ACC	SN vs PCC	SN vs ACC+PCC
Slope/Intercept	0.07/1.5	0.35/0.3	0.42/2.6
R^2	0.08	0.82	0.83



The data indicate that the ACC layer is not providing a significant improvement in correlation between actual and predicted structural numbers. In essence this is another way to look at the comparison between Figures 4, 5 and 6: the Road Rater data are tracking strongly with PCC thickness and overall thickness but not with ACC thickness. As a result the Road Rater data is not providing evidence for the level of support being provided by the ACC.

Distress Evaluation

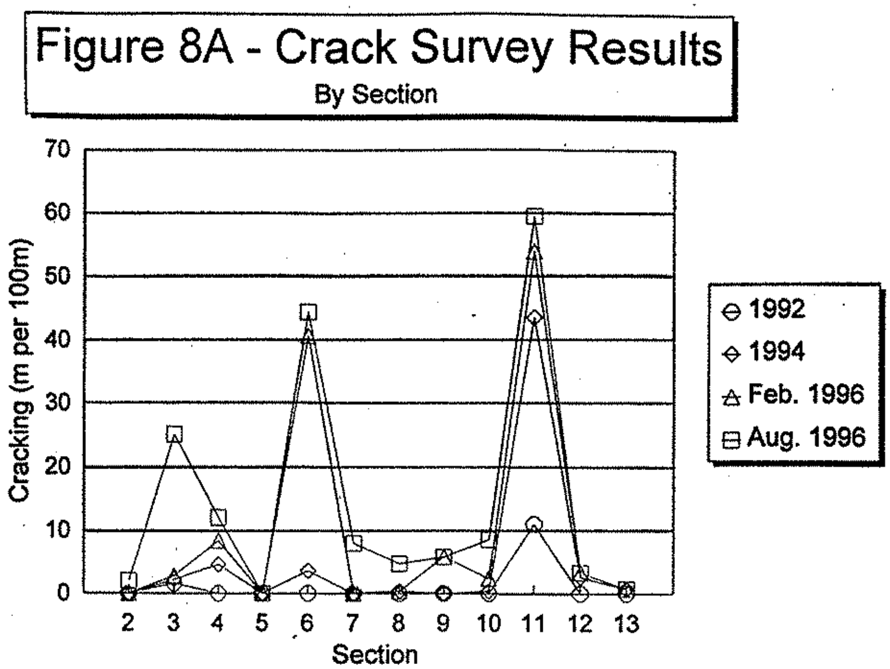
Crack surveys were performed in 1992, 1994 and 1996. The results are shown in Figures 8A and 8B (pavement thicknesses in these two graphs are actual not design). Two items are notable.

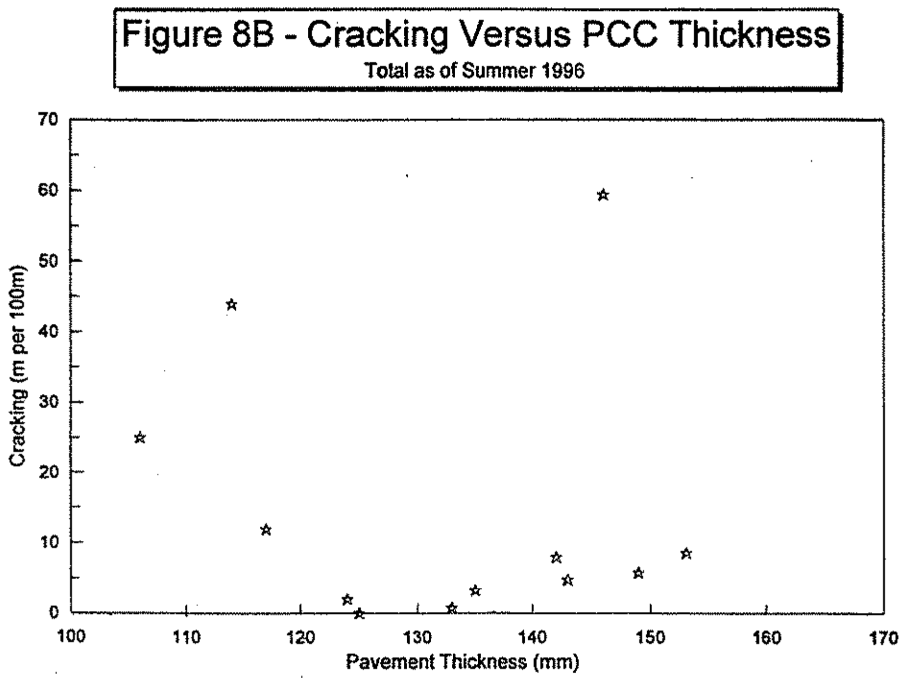
- The majority of cracking was longitudinal, implying base weakness.
- The cracks are concentrated in sections 11, 6, 3 and 4 (in decreasing order).

There is no obvious connection between the cracking and any of the surface preparations involved in the project. Cracking does correlate to actual PCC thickness and to planing. This is apparent from Figure 8B. The three thinnest PCC sections are 3, 4 and 6. These are also the sections (ignoring for a moment section 11) that have the majority of longitudinal cracking. Section 5 is specified as nominally 100 mm thick but is actually closer to the nominal 130 mm specified for the "thicker" PCC; it was also planed. Section 5 had exhibited no cracking as of summer 1996.

Table 3
Average PCC Thicknesses by Section from Cores

Section	2	3	4	5	6	7	8	9	10	11	12	13
Design PCC Thickness	130	100	100	100	100	130	130	130	130	130	130	130
PCC Thickness (mm)	124	106	117	125	114	142	143	149	153	146	135	133
ACC Thickness (mm)	136	147	129	130	141	133	140	141	137	142	145	130





Of the remaining sections only section 11 shows any significant cracking (note the highest point of graph in Figure 8B). However, (1) it was exhibiting this cracking during the first year after paving when none of the other areas were cracking appreciably, and (2) the longitudinal cracks are localized within about ±10 meters. This indicates that there are probably significant subgrade problems under that portion of section 11.

Correlation between the PCC thickness and cracking remains when the data is stratified between quarter point and outside wheel path. The conclusion from all of this is that significant longitudinal cracking is occuring for PCC thicknesses less than about 120 mm (5 in.).

Variable Comparisons for Bonding

The starting point for all of the test sections was simple power brooming as per current Iowa specification. As such, initial evaluations of variables will use the power brooming regimen as a basis of comparison. This should provide for maintaining all other variables constant while changing the variable of interest in each case. Each of the evaluations below will follow a three step process: (1) Identify the variable of interest; (2) Detail which sections to compare in such a way as to minimize the number of variables; and (3) Compare shear strengths and number of unbonded cores in each section versus its control section.

Refer to the descriptions of test sections and layout in Figure 1 to assist in understanding each variable combination. Complete data and worksheets for these analyses are provided in Appendix B.

Milling

Sections 3, 4, 9 and 11 were milled to a rough surface prior to placement of the PCC pavement. These can be compared to sections 2, 6, 7 and 12 respectively, while keeping other variables constant in each case. Shear strength data for these combinations are shown below. The data indicate an improved bond performance for those that were milled versus those that were simply broomed. The shear strength data combined with the number of unbonded cores indicate a significantly improved performance for those that were milled rather than just broomed.

Table 4
Bond Comparisons for Milling

Section	3*	2*	4	6	9	7	11	12
Description	Mill	No Mill	Mill	No Mill	Mill	No Mill	Mill	No Mill
Avg. Shear (kPa)	976	627	674	540	696	695	(1059)	767
Std. Dev.	454	429	408	304	261	536	(538)	390
Number Tests (bonded/total)	7/11	4/15	9/11	5/14	8/11	3/12	(7/11)	3/14
Percent Unbonded	36	73	18	64	27	75	(36)	79

* These two sections have different nominal PCC thicknesses
Parentheses indicate one outlier removed (refer to Appendix B).

Air Blast

Only section 8 was subjected to an air-blast cleaning regimen as well as brooming. The comparison section for this case is section 7. Shear strengths are shown below. Despite the apparently higher average shear strength shown in section 8, the data does not significantly show improved bond. The problem is that both sections did poorly in terms of the number of bonded cores. There are not enough samples to make the difference in shear strength significant. Refer to the worksheet in Appendix B for a breakdown of the data.

Table 5
Bond Comparisons for Air Blast

Section	8	7
Description	Air Blast	No Air Blast
Avg. Shear (kPa)	1143	695
Std. Dev.	500	536
Number Tests (bonded/total)	4/11	3/12
Percent Unbonded	64	75

Planing

The ACC in sections 5 and 10 was planed to provide a more uniform PCC cross-section. The planing also resulted in a milled surface. This provides the possibility of comparing both planing and milling versus just milling as well as the combination of planing and milling versus simply brooming. Planing and milling versus simply milling compares sections 5 and 10 to sections 4 and 9 respectively. Planing and milling versus simply brooming compares sections 5 and 10 to sections 6 and 7 respectively. The results are shown below. In this case, section 5 performed better than the two controls whereas section 10 did not show any significant improvement over its two controls. Additionally, the percentages unbonded do not show a significant difference between the two. The only difference between sections 5 and 10 is the pavement thickness (10 is thicker). An improvement in milled versus non milled is indicated by the percentages unbonded.

Table 6
Bond Comparisons for Planing

Section	5	4	6	10	9	7
Description	Plane Mill	No Plane Mill	No Plane No Mill	Plane Mill	No Plane Mill	No Plane No Mill
Avg. Shear (kPa)	(1273)	674	540	(717)	696	695
Std. Dev.	(554)	408	304	(241)	261	536
Number Tests (bonded/total)	(9/11)	9/11	5/14	(6/11)	8/11	3/12
Percent Unbonded	(18)	18	64	(45)	27	75

Note: Parentheses indicate one outlier removed (refer to Appendix B).

Grouting

Sections 11 and 12 were prepared with a cement and water grout; section 11 was also milled. These provide the opportunity to compare grouting and milling to just milling (section 11 versus section 9) and to just brooming (sections 11 and 12 versus section 7). There is no clear evidence to indicate an improvement in bond between grouting and not grouting. Again, milling does show up as the majority of bond improvement.

Table 7
Bond Comparisons for Grouting

Section	11	9	7	12	7
Description	Grout Mill	No Grout Mill	No Grout No Mill	Grout No Mill	No Grout No Mill
Avg. Shear (kPa)	(1059)	696	695	767	695
Std. Dev.	(538)	261	536	390	536
Number Tests (bonded/total)	(7/11)	8/11	3/12	3/14	3/12
Percent Unbonded	(36)	27	75	79	75

Note: Parentheses indicate one outlier removed (refer to Appendix B).

Emulsion Tack Coat

Section 13 received a tack coat prior to paving. The comparison section for this case is section 2. There is an indication of improved shear strengths from section 13 and a stronger indication from the percent unbonded figures. Note that this section had no unbonded cores from the wheel path. It was also the only regimen that didn't have a strong indication of bond degradation over time.

Table 8
Bond Comparisons for Tack Coat

Section	13	2
Description	Tack	No Tack
Avg. Shear (kPa)	715	627
Std. Dev.	272	429
Number Tests (bonded/total)	9/12	4/15
Percent Unbonded	25	73

Concrete Mixes

Two concrete mixes were used on this project. Comparison sections for these two variables are sections 7 and 4 versus sections 2 and 3 respectively. There is no indication of any difference in bond strength between the two concrete types.

Table 9
Bond Comparisons for Concrete Mixes

Section	7	2	4	3
Description	C-Mix	B-Mix	C-Mix	B-Mix
Avg. Shear (kPa)	695	627	674	976
Std. Dev.	536	429	408	454
Number Tests (bonded/total)	3/12	4/15	9/11	7/11
Percent Unbonded	75	73	18	36

Concrete Thicknesses

Concrete was placed in two nominal thicknesses of 100 mm and 130 mm. Comparisons of bond strength between the two thicknesses holding the other variables constant give the results shown below. Note that actual PCC thicknesses, as measured from cores, varied widely around these values. Again there is no evidence to indicate a difference in bond strength between the two thicknesses.

Table 10
Bond Comparisons for Thicknesses

Section	9	4	10	5	7	6
Description	130 mm (149)	100 mm (117)	130 mm (153)	100 mm (125)	130 mm (142)	100 mm (114)
Avg. Shear (kPa)	696	674	622	1154	695	540
Std. Dev.	261	408	333	645	536	304
Number Tests (bonded/total)	8/11	9/11	7/11	10/11	3/12	5/14
Percent Unbonded	27	18	36	9	75	64

Note: Parentheses indicate actual thickness values for PCC

CONCLUSIONS

1. Bond Strength Differences.

Milling increased bond strength versus no milling. Tack coat showed increased bond strength versus no tack coat. Planing, Air Blast and Grouting did not provide noticeable improvements in bond strength; nor did different PCC types or thicknesses affect bond strength significantly.

2. Structure

Structural measurements correlated strongly with the wide variation in pavement thicknesses. They did not provide enough information to determine the strength of bonding or the level of support being provided by the ACC layer. Longitudinal cracking correlated with PCC thicknesses and with planing

3. Bonding Over Time

The bond between PCC and ACC layers is degrading over time in the outside wheel path in all of the sections except tack coat (section 12). The bond strength in the section with tackcoat was lower than the others, but remained relatively steady.

FUTURE RESEARCH NEEDS

Milling and tack coat showed the most promise for improved bonding of the two pavement layers. One area to explore in future would be milling with deeper and/or more closely spaced grooves (perhaps diamond grinding?). This would presumably provide more surface area for bonding. Additionally, an anionic tack coat may provide a better bond than the cationic tack coat used here. This research also did not examine a combination of milling and tack coat. There is a possibility that the two would combine synergistically.

However, the data indicate that the bond is failing over time in all of the cases tested with the possible exception of tack coat. The tack coat does seem to be providing a weak but consistent bond over the five years tested. However, the strength of the bond is not adequate to provide for a bonded design. If no bonding method is available that will improve the bond to last at least as long as the design life of the PCC pavement, then future bond enhancement research would be moot. In that case, the whitetopping design would have to be thicker and assume that the ACC is only acting as a base layer.

Perhaps some future research should involve continued monitoring of this project for cracking of the thicker PCC and the bond performance of the tack coat section.

ACKNOWLEDGMENT

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We want to extend our appreciation to the Dallas County Board of Supervisors, the Iowa Department of Transportation, the Iowa Concrete Paving Association and Cedar Valley Corporation for their support in the development and implementation of this project.

APPENDICES

Appendix A
Construction & Prepaving Tests

Appendix A
Concrete Proportions

Mix No.	Cement kg/m^3	Fly Ash (Class C) kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Air Entrainment Admixture ml/kg	Water Reducer Admixture ml/kg
B-4-C	248	44	952	938	0.54	----
C-4WR-C	298	56	933	914	0.56	2.6

Strength Test Results

Section	Sample ID	Mix	% Air	Slump (mm)	28 Day Compression Strength (MPa)	28 Day Flexural Strength (MPa)
2	25-1-A	B	7.4	65	23.2	4.34
2	25-2-A	B	6.0	55	26.8	4.52
3	25-3-A	B	6.3	50	26.5	4.60
4	25-1-B	C	7.2	65	27.8	4.75
5	25-2-B	C	7.5	65	28.4	4.75
6	25-3-B	C	9.5	75	26.3	4.56

Appendix A Cont'd
Meters of Cracks per 100 Meters

Section	03/09/92	02/15/94	02/21/96	08/02/96
2	0.0	0.0	0.0	2.0
3	1.6	2.2	2.8	25.0
4	0.0	4.6	8.4	12.0
5	0.0	0.0	0.0	0.0
6	0.0	3.6	40.6	44.4
7	0.0	0.0	0.0	8.0
8	0.0	0.4	0.4	4.8
9	0.0	0.0	5.8	5.8
10	0.0	0.4	2.4	8.6
11	11.0	43.5	54.0	59.5
12	0.0	2.7	3.3	3.3
13	0.0	0.8	0.8	0.8

Appendix B
Core Data

Appendix B
Core Data

Section	Station	Core Date	Core Location	Bond	ACC Thickness (in.)	ACC Thickness (mm)	PCC Thickness (in.)	PCC Thickness (mm)	Load (lbs.)	Load (N)	Shear (psi.)	Shear (kPa)
2	200+62	1991	1/4 PT	U	5.3	134.6	5.0	127.0	==	==	==	==
2	199+40	1991	OWP	U	5.2	132.1	4.8	121.9	==	==	==	==
2	199+00	1991	OWP	B	5.9	149.9	4.9	124.5	1730	7714	138	952
2	198+50	1991	OWP	U	6.0	152.4	5.1	129.5	==	==	==	==
3	193+50	1991	1/4 PT	B	5.2	132.1	4.5	114.3	2380	1080	189	1303
3	196+40	1991	OWP	B	3.0	76.2	4.5	114.3	2760	1252	220	1517
3	194+50	1991	OWP	B	6.0	152.4	4.2	106.7	1995	905	159	1096
4	188+50	1991	1/4 PT	B	5.1	129.5	4.4	111.8	2255	1023	179	1234
4	190+50	1991	OWP	B	5.5	139.7	4.4	111.8	2455	1114	195	1345
4	187+50	1991	OWP	B	5.4	137.2	4.6	116.8	1695	769	135	931
5	183+50	1991	1/4 PT	B	4.8	121.9	4.9	124.5	1915	869	152	1048
5	185+50	1991	OWP	B	5.5	139.7	4.8	121.9	4260	1932	339	2337
5	182+50	1991	OWP	B	5.8	147.3	4.9	124.5	1975	896	157	1083
6	180+50	1991	1/4 PT	B	4.9	124.5	3.7	94.0	1145	519	91	627
6	180+00	1991	OWP	B	6.8	172.7	4.3	109.2	1840	835	146	1007
6	179+25	1991	OWP	U	0.8	20.3	4.4	111.8	==	==	==	==
7	173+00	1991	1/4 PT	U	6.0	152.4	5.3	134.6	==	==	==	==
7	174+50	1991	OWP	B	6.0	152.4	5.7	144.8	2360	1070	188	1296
7	171+50	1991	OWP	B	5.0	127.0	5.4	137.2	490	222	39	269
8	166+00	1991	1/4 PT	B	5.3	134.6	4.8	121.9	1390	631	111	765
8	169+00	1991	OWP	B	6.0	152.4	5.4	137.2	3415	1549	272	1875
8	167+50	1991	OWP	B	5.7	144.8	5.0	127.0	1640	744	131	903
9	162+50	1991	1/4 PT	B	6.0	152.4	5.1	129.5	1770	803	141	972
9	164+00	1991	OWP	B	6.3	160.0	5.1	129.5	1940	880	154	1062
9	161+00	1991	OWP	B	5.5	139.7	6.1	154.9	1460	662	116	800
10	156+25	1991	1/4 PT	B	5.5	139.7	6.5	165.1	1980	898	158	1089
10	156+75	1991	OWP	B	6.0	152.4	6.0	152.4	1540	699	123	848
10	156+00	1991	OWP	B	6.1	154.9	5.9	149.9	1420	644	113	779
11	153+75	1991	1/4 PT	B	6.0	152.4	4.5	114.3	1915	869	152	1048
11	154+50	1991	OWP	B	6.2	157.5	5.5	139.7	1710	776	136	938
11	153+20	1991	OWP	U	4.9	124.5	6.3	160.0	==	==	==	==
12	148+50	1991	1/4 PT	B	6.6	167.6	4.6	116.8	1150	522	92	634
12	149+50	1991	OWP	B	5.7	144.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix B
Core Data

Section	Station	Core Date	Core Location	Bond	ACC Thickness (in.)	ACC Thickness (mm)	PCC Thickness (in.)	PCC Thickness (mm)	Load (lbs.)	Load (N)	Shear (psi.)	Shear (kPa)
12	147+50	1991	OWP	U	6.5	165.1	5.5	139.7	==	==	==	==
13	68+50	1991	1/4 PT	B	5.3	134.6	4.7	119.4	845	383	67	462
13	70+00	1991	OWP	B	5.7	144.8	5.1	129.5	1180	535	94	648
13	67+00	1991	OWP	B	3.8	96.5	5.6	142.2	1250	567	99	683
2	200+72	1994	1/4 PT	B	5.7	144.8	4.8	121.9	1945	882	150	1034
2	199+96	1994	OWP	U	5.2	132.1	4.5	114.3	==	==	==	==
2	199+86	1994	OWP	U	5.5	139.7	4.6	116.8	==	==	==	==
2	199+76	1994	OWP	U	4.6	116.8	4.3	109.2	==	==	==	==
2	198+50	1994	OWP	U	5.5	139.7	5.3	134.6	==	==	==	==
3	193+95	1994	1/4 PT	B	4.4	111.8	4.1	104.1	2336	1060	190	1310
3	196+40	1994	OWP	B	5.9	149.9	4.6	116.8	1050	476	80	552
3	194+50	1994	OWP	B	5.8	147.3	4.1	104.1	536	243	40	276
4	188+60	1994	1/4 PT	B	5.0	127.0	4.3	109.2	940	426	70	483
4	190+50	1994	OWP	U	5.1	129.5	4.3	109.2	==	==	==	==
4	187+75	1994	OWP	B	4.8	121.9	5.0	127.0	1300	590	100	690
5	183+50	1994	1/4 PT	B	4.7	119.4	5.0	127.0	1960	889	160	1103
5	185+50	1994	OWP	B	4.6	116.8	5.4	137.2	3680	1669	290	2000
5	182+85	1994	OWP	B	4.8	121.9	5.0	127.0	2290	1039	180	1241
6	180+70	1994	1/4 PT	U	5.6	142.2	4.1	104.1	==	==	==	==
6	180+60	1994	1/4 PT	U	5.5	139.7	4.1	104.1	==	==	==	==
6	179+85	1994	OWP	U	5.7	144.8	4.6	116.8	==	==	==	==
6	179+75	1994	OWP	U	6.0	152.4	4.2	106.7	==	==	==	==
6	179+65	1994	OWP	U	5.4	137.2	4.3	109.2	==	==	==	==
6	179+25	1994	OWP	U	5.2	132.1	4.5	114.3	==	==	==	==
7	173+00	1994	1/4 PT	U	5.9	149.9	5.4	137.2	==	==	==	==
7	174+50	1994	OWP	U	5.6	142.2	5.6	142.2	==	==	==	==
7	171+00	1994	OWP	U	5.6	142.2	5.6	142.2	==	==	==	==
7	171+00	1994	OWP	U	5.2	132.1	5.7	144.8	==	==	==	==
8	166+75	1994	1/4 PT	U	5.4	137.2	5.4	137.2	==	==	==	==
8	169+00	1994	OWP	U	5.5	139.7	5.8	147.3	==	==	==	==
8	167+25	1994	OWP	U	5.7	144.8	5.3	134.6	==	==	==	==
9	162+50	1994	1/4 PT	B	5.6	142.2	5.2	132.1	1180	535	90	621
9	164+00	1994	OWP	U	5.6	142.2	6.1	154.9	==	==	==	==

Appendix B
Core Data

Section	Station	Core Date	Core Location	Bond	ACC Thickness (in.)	ACC Thickness (mm)	PCC Thickness (in.)	PCC Thickness (mm)	Load (lbs.)	Load (N)	Shear (psi.)	Shear (kPa)
9	161+00	1994	OWP	U	5.6	142.2	6.0	152.4	==	==	==	==
10	156+25	1994	1/4 PT	U	5.6	142.2	6.5	165.1	==	==	==	==
10	156+75	1994	OWP	U	5.9	149.9	6.2	157.5	==	==	==	==
10	156+00	1994	OWP	U	5.9	149.9	6.0	152.4	==	==	==	==
11	153+75	1994	1/4 PT	B	5.8	147.3	4.6	116.8	100	45	10	69
11	154+50	1994	OWP	B	5.8	147.3	4.9	124.5	1590	721	130	896
11	153+20	1994	OWP	U	4.3	109.2	6.2	157.5	==	==	==	==
12	148+50	1994	1/4 PT	U	6.7	170.2	5.0	127.0	==	==	==	==
12	149+38	1994	OWP	U	5.6	142.2	5.2	132.1	==	==	==	==
12	149+28	1994	OWP	U	5.7	144.8	5.2	132.1	==	==	==	==
12	149+18	1994	OWP	U	5.6	142.2	5.2	132.1	==	==	==	==
12	147+50	1994	OWP	U	6.0	152.4	5.5	139.7	==	==	==	==
13	68+45	1994	1/4 PT	U	5.5	139.7	4.6	116.8	==	==	==	==
13	68+32	1994	1/4 PT	U	5.2	132.1	4.7	119.4	==	==	==	==
13	69+68	1994	OWP	B	5.9	149.9	4.5	114.3	2090	948	170	1172
13	67+00	1994	OWP	B	5.3	134.6	5.6	142.2	1880	853	150	1034
2	200+45	1996	1/4 PT	U	4.50	114.3	4.75	120.7	==	==	==	==
2	200+20	1996	1/4 PT	U	4.75	120.7	4.50	114.3	==	==	==	==
2	199+30	1996	OWP	B	5.25	133.4	5.00	127.0	628	285	50	345
2	199+15	1996	OWP	B	5.25	133.4	5.00	127.0	324	147	26	178
2	198+95	1996	OWP	U	5.25	133.4	5.25	133.4	==	==	==	==
3	193+00	1996	1/4 PT	B	4.25	108.0	3.75	95.3	1416	642	113	777
3	196+25	1996	OWP	U	5.63	142.9	4.13	104.8	==	==	==	==
3	196+10	1996	OWP	U	5.88	149.2	3.88	98.4	==	==	==	==
3	194+20	1996	OWP	U	5.75	146.1	4.00	101.6	==	==	==	==
3	194+00	1996	OWP	U	5.50	139.7	4.25	108.0	==	==	==	==
4	188+35	1996	1/4 PT	B	5.25	133.4	4.25	108.0	812	368	65	446
4	188+20	1996	1/4 PT	B	5.25	133.4	4.25	108.0	349	158	28	191
4	190+20	1996	OWP	U	4.75	120.7	5.00	127.0	==	==	==	==
4	190+00	1996	OWP	B	5.00	127.0	4.88	123.8	640	290	51	351
4	187+20	1996	OWP	B	4.88	123.8	4.00	101.6	717	325	57	393
5	183+45	1996	1/4 PT	U	4.13	104.8	4.88	123.8	==	==	==	==
5	183+25	1996	1/4 PT	B	4.50	114.3	4.75	120.7	[illegible]	[illegible]	[illegible]	[illegible]

Appendix B
Core Data

Section	Station	Core Date	Core Location	Bond	ACC Thickness (in.)	ACC Thickness (mm)	PCC Thickness (in.)	PCC Thickness (mm)	Load (lbs.)	Load (N)	Shear (psi.)	Shear (kPa)
5	185+15	1996	OWP	B	5.25	133.4	5.25	133.4	140	64	11	77
5	185+00	1996	OWP	B	5.00	127.0	4.75	120.7	1380	626	110	757
5	182+20	1996	OWP	B	5.00	127.0	4.38	111.1	1156	524	92	634
6	180+45	1996	1/4 PT	B	3.88	98.4	5.25	133.4	743	337	59	408
6	180+25	1996	1/4 PT	B	5.00	127.0	4.00	101.6	847	384	67	465
6	179+95	1996	OWP	B	4.75	120.7	4.88	123.8	348	158	28	191
6	179+85	1996	OWP	U	4.88	123.8	4.75	120.7	==	==	==	==
6	178+90	1996	OWP	U	5.75	146.1	4.50	114.3	==	==	==	==
7	173+15	1996	1/4 PT	U	6.00	152.4	5.38	136.5	==	==	==	==
7	172+90	1996	1/4 PT	U	5.63	142.9	5.38	136.5	==	==	==	==
7	174+45	1996	OWP	U	6.00	152.4	5.75	146.1	==	==	==	==
7	174+15	1996	OWP	U	4.13	104.8	5.63	142.9	==	==	==	==
7	171+15	1996	OWP	B	4.25	108.0	5.50	139.7	946	429	75	519
8	166+10	1996	1/4 PT	B	5.50	139.7	4.50	114.3	1875	851	149	1029
8	169+25	1996	OWP	U	5.50	139.7	6.13	155.6	==	==	==	==
8	169+10	1996	OWP	U	5.50	139.7	5.88	149.2	==	==	==	==
8	167+10	1996	OWP	U	5.75	146.1	5.75	146.1	==	==	==	==
8	166+95	1996	OWP	U	4.38	111.1	5.75	146.1	==	==	==	==
9	162+65	1996	1/4 PT	B	6.00	152.4	5.00	127.0	1448	657	115	794
9	162+45	1996	1/4 PT	B	5.25	133.4	5.25	133.4	1099	499	87	603
9	164+30	1996	OWP	U	4.75	120.7	6.00	152.4	==	==	==	==
9	163+90	1996	OWP	B	5.75	146.1	6.00	152.4	576	261	46	316
9	160+80	1996	OWP	B	5.38	136.5	5.75	146.1	723	328	58	397
10	155+95	1996	1/4 PT	U	5.75	146.1	6.25	158.8	==	==	==	==
10	155+80	1996	1/4 PT	B	5.50	139.7	6.25	158.8	734	333	58	403
10	156+40	1996	OWP	B	4.25	108.0	6.38	162.1	1030	467	82	565
10	156+25	1996	OWP	B	4.75	120.7	6.00	152.4	1127	511	90	618
10	155+65	1996	OWP	B	4.75	120.7	5.75	146.1	100	45	8	55
11	154+05	1996	1/4 PT	B	5.50	139.7	5.50	139.7	2950	1338	235	1619
11	153+85	1996	1/4 PT	B	5.00	127.0	5.63	142.9	3460	1569	275	1898
11	154+25	1996	OWP	U	6.00	152.4	6.00	152.4	==	==	==	==
11	154+15	1996	OWP	B	6.25	158.8	6.00	152.4	590	268	47	324
11	153+10	1996	OWP	B	5.75	146.1	5.25	133.4	1254	569	100	688

Appendix B
Core Data

		Core	Core		ACC Thickness		PCC Thickness		Load		Shear	
Section	Station	Date	Location	Bond	(in.)	(mm)	(in.)	(mm)	(lbs.)	(N)	(psi.)	(kPa)
12	148+60	1996	1/4 PT	U	6.50	165.1	5.00	127.0	==	==	==	==
12	148+40	1996	1/4 PT	B	6.50	165.1	4.75	120.7	840	381	67	461
12	149+00	1996	OWP	U	2.75	69.9	5.50	139.7	==	==	==	==
12	148+90	1996	OWP	U	4.25	108.0	5.75	146.1	==	==	==	==
12	148+90	1996	OWP	U	6.50	165.1	5.00	127.0	==	==	==	==
12	147+65	1996	OWP	U	5.63	142.9	5.25	133.4	==	==	==	==
13	068+50	1996	1/4 PT	B	4.75	120.7	4.75	120.7	1084	492	86	595
13	068+00	1996	1/4 PT	U	4.50	114.3	5.00	127.0	==	==	==	==
13	070+35	1996	OWP	B	5.25	133.4	5.25	133.4	1724	782	137	946
13	070+05	1996	OWP	B	5.25	133.4	5.25	133.4	892	405	71	489
13	067+10	1996	OWP	B	4.75	120.7	5.25	133.4	742	337	59	407

Appendix B Cont'd
Cores Shear Test Worksheet

The remainder of Appendix B consists of data evaluation worksheets for the shear tests of cores in this project. Below is an example of one of the calculations with explanatory notes.

		Section 2
	D	**OWP**
1991	2	952
1994	4	- -
1996	1	178
		345
Avg		492
s		407
n		3/10
%D		70%

Section 2 is the test section. "OWP" indicates this data is all from cores taken in the outside wheel path ("QPT" indicates quarter point) . The column headed by "D" is the actual number of unbonded cores removed from this section in the outside wheel path for each of the dates listed to the left. The data under "OWP" are the shear values (in kPa) for the cores at each of the dates listed. Dashes indicate that there were no bonded cores that year at that location. "Avg" and "s" are the arithmetic average and sample standard deviation respectively for the valid shear values. "n" is a two part count of samples. In this case there were three bonded out of ten total cores. "%D" is the percentage of cores which were unbonded. Parentheses around a shear value indicate that it's an outlier which is considered low enough to move into the unbonded category. Calculations for both cases (with or without the outlier) are included where applicable with the outlier-removed calculations indicated by parentheses.

Appendix B Cont'd
Cores Shear Test Worksheet

	D	Section 2 OWP
1991	2	952
1994	4	- -
1996	1	178
		345
Avg		492
s		407
n		3/10
%D		70%

	D	Section 2 QPT
1991	1	- -
1994		1034
1996	2	- -
Avg		1034
s		- -
n		1/4
%D		75%

	D	Section 2 Both
1991	3	952
1994	4	1034
1996	3	178
		345
Avg		627
s		429
n		4/14
%D		73%

	D	Section 3 OWP
1991		1517
		1096
1994		552
		276
1996	4	- -
Avg		860
s		555
n		4/8
%D		50%

	D	Section 3 QPT
1991		1303
1994		1310
1996		777
Avg		1130
s		305
n		3/3
%D		0%

	D	Section 3 Both
1991		1517
		1096
		1303
1994		552
		276
		1310
1996	4	777
Avg		976
s		454
n		7/11
%D		36%

	D	Section 4 OWP
1991		931
		1345
1994	1	690
1996	1	393
		351
Avg		742
s		411
n		5/7
%D		29%

	D	Section 4 QPT
1991		1234
1994		483
1996		191
		446
Avg		588
s		449
n		4/4
%D		0%

	D	Section 4 Both
1991		931
		1345
		1234
1994	1	690
		483
1996	1	393
		351
		191
		446
Avg		674
s		408
n		9/11
%D		18%

Appendix B Cont'd

Cores Shear Test Worksheet

	D	Section 5 OWP
1991		2337
		1083
1994		1241
		2000
1996	(1)	77
		634
		757
Avg		1161(1342)
s		786(685)
n		7/7(6/7)
%D		0%(14%)

	D	Section 5 QPT
1991		1048
1994		1103
1996	1	1256
Avg		1136
s		108
n		3/4
%D		25%

	D	Section 5 Both
1991		2337
		1083
		1048
1994		1241
		2000
		1103
1996	1	77
	(1)	634
		757
		1256
Avg		1154(1273)
s		645(554)
n		10/11(9/11)
%D		9%(18%)

	D	Section 6 OWP
1991	1	1007
1994	4	
1996	2	191
Avg		599
s		577
n		2/9
%D		82%

	D	Section 6 QPT
1991		627
1994	2	465
1996		408
Avg		500
s		114
n		3/5
%D		40%

	D	Section 6 Both
1991	1	1007
		627
1994	6	465
1996	2	191
		408
Avg		540
s		304
n		5/14
%D		64%

	D	Section 7 OWP
1991		1296
		269
1994	3	--
1996	2	519
Avg		695
s		536
n		3/8
%D		63%

	D	Section 7 QPT
1991	1	--
1994	1	--
1996	2	--
Avg		--
s		--
n		0/4
%D		100%

	D	Section 7 Both
1991	1	1296
		269
1994	4	--
1996	4	519
Avg		695
s		536
n		3/12
%D		75%

Appendix B Cont'd
Cores Shear Test Worksheet

	D	Section 8 OWP
1991		903
		1875
1994	2	- -
1996	4	- -
Avg		1389
s		687
n		2/8
%D		75%

	D	Section 8 QPT
1991		765
1994	1	- -
1996		1029
Avg		897
s		187
n		2/3
%D		33%

	D	Section 8 Both
1991		903
		1875
		765
1994	3	- -
1996	4	1029
Avg		1143
s		500
n		4/11
%D		64%

	D	Section 9 OWP
1991		800
		1062
1994	2	- -
1996	1	397
		316
Avg		644
s		350
n		4/7
%D		43%

	D	Section 9 QPT
1991		972
1994		621
1996		603
		794
Avg		748
s		173
n		4/4
%D		0%

	D	Section 9 Both
1991		800
		1062
		972
1994	2	621
1996	1	397
		316
		603
		794
Avg		696
s		261
n		8/11
%D		27%

	D	Section 10 OWP
1991		848
		779
1994	2	- -
1996	(1)	55
		618
		565
Avg		573(703)
s		312(133)
n		5/7(4/7)
%D		29%(43%)

	D	Section 10 QPT
1991		1089
1994	1	- -
1996	1	403
Avg		746
s		485
n		2/4
%D		50%

	D	Section 10 Both
1991		848
		779
		1089
1994	3	- -
1996	(1)	55
	1	618
		565
		403
Avg		622(717)
s		333(241)
n		7/11(6/11)
%D		36%(45%)

Cores Shear Test Worksheet

Section 11

	D	OWP
1991	1	938
1994	1	896
1996	1	688
		324
Avg		712
s		281
n		4/7
%D		43%

	D	QPT
1991		1048
1994	(1)	69
1996		1898
		1619
Avg		1159(1522)
s		808(433)
n		4/4(3/4)
%D		0%(25%)

	D	Both
1991	1	938
		1048
1994	1	896
	(1)	69
1996	1	688
		324
		1898
		1619
Avg		935(1059)
s		609(538)
n		8/11(7/11)
%D		27%(36%)

Section 12

	D	OWP
1991	1	1207
1994	4	- -
1996	4	- -
Avg		1207
s		- -
n		1/10
%D		90%

	D	QPT
1991		634
1994	1	- -
1996	1	461
Avg		547
s		122
n		2/4
%D		50%

	D	Both
1991	1	1207
		634
1994	5	- -
1996	5	461
Avg		767
s		390
n		3/14
%D		79%

Section 13

	D	OWP
1991		648
		683
1994		1034
		1172
1996		946
		489
		407
Avg		768
s		287
n		7/7
%D		0%

	D	QPT
1991		462
1994	2	- -
1996	1	595
Avg		529
s		94
n		2/5
%D		60%

	D	Both
1991		648
		683
		462
1994	2	1034
		1172
1996	1	946
		489
		407
		595
Avg		715
s		272
n		9/12
%D		25%

Appendix C
Structural Ratings and Soil K Values

Appendix C
Structural Ratings and Soil K Values

			1991		1992		1993		1994		1995		1996	
Section	Station	Direction	SR	K	SR	K	SR	K	SR	K	SR	K	SR	K
8	169.00	S	3.60	159	4.27	141	3.80	173	4.36	225	4.30	198	3.08	143
8	168.50	N	4.02	185	4.56	155	4.09	225	4.14	225	5.34	210	3.27	176
8	168.00	S	3.60	89	3.80	107	3.26	174	3.33	225	4.53	195	3.04	157
8	167.50	N	3.80	173	3.80	173	4.00	207	3.60	225	3.84	225	3.18	189
8	167.00	S	4.02	185	4.27	141	4.27	197	3.68	225	5.13	185	3.53	184
8	166.50	N	4.56	155	5.30	182	4.79	221	5.01	225	5.63	210	3.72	206
8	166.00	S	3.80	173	4.56	155	4.00	187	4.53	203	4.83	208	3.18	136
8	165.50	N	3.80	173	3.43	144	3.12	134	3.32	225	3.91	188	2.95	169
8	165.00	S	4.27	141	4.56	155	4.14	165	4.12	225	4.98	198	3.58	189
9	164.50	N	4.27	141	4.27	196	3.91	181	3.95	225	5.05	216	3.18	165
9	164.00	S	4.27	196	4.90	169	4.25	162	4.56	224	4.76	205	3.57	151
9	163.50	N	4.56	155	5.58	183	4.44	224	4.63	225	5.48	225	3.60	178
9	163.00	S	4.02	185	4.90	169	4.41	181	4.25	225	4.90	203	3.44	169
9	162.50	N	4.02	185	4.56	155	4.07	185	4.56	225	5.13	185	3.62	198
9	162.00	S	4.27	141	4.56	155	4.36	186	4.19	225	5.05	201	3.66	168
9	161.50	N	4.27	141	4.56	155	4.41	204	4.33	225	5.21	222	3.36	186
9	161.00	S	4.27	196	4.27	141	4.07	185	3.88	225	5.09	193	3.40	156
9	160.50	N	4.56	155	5.30	182	4.76	205	4.25	225	5.78	205	4.00	180
9	160.00	S	4.56	155	5.30	182	4.98	214	4.44	225	6.18	204	4.04	175
10	159.50	N	4.56	155							5.09	218	3.74	195
10	159.00	S	4.56	155	5.30	182	4.76	219	4.41	225	5.53	188	3.58	212
10	158.50	N	4.27	196	4.90	169	4.44	212	4.59	225	5.30	217	2.95	169
10	158.00	S	5.53	181	5.58	160	5.58	209	5.13	225	6.57	201	3.78	146
10	157.50	N	4.90	169	4.90	169	4.44	219	4.00	225	5.26	225	3.86	185
10	157.00	S	5.30	182	5.43	164	5.01	199	4.00	225	5.89	197	4.02	182
10	156.50	N	5.30	182	5.58	176	4.86	223	4.33	225	5.73	221	3.50	152
10	156.00	S	4.90	215	5.78	181	5.48	214	6.18	225	6.06	225	4.04	191
10	155.50	N	4.02	125	4.02	185	4.00	201	4.07	199	4.98	206	3.06	133
10	155.00	S	4.27	141	4.56	155	4.30	191	4.69	225	5.73	193	4.04	175
11	154.50	N	4.56	155	4.56	155	4.44	164	4.44	219	4.98	225	3.13	164
11	154.00	S	4.56	155	4.90	169	4.73	218	4.63	225	5.83	196	4.02	182
11	153.50	N	4.02	125	4.02	125	3.91	181	4.59	198	4.59	206	3.33	156

Appendix C
Structural Ratings and Soil K Values

			1991		1992		1993		1994		1995		1996	
Section	Station	Direction	SR	K	SR	K	SR	K	SR	K	SR	K	SR	K
4	186.00	S	3.60	159	4.27	141	3.58	169	3.66	225	4.50	186	3.10	154
5	185.50	N	3.60	159	3.46	159	3.53	178	3.82	225	4.12	220	2.85	163
5	185.00	S	3.60	159	4.10	141	3.57	50	4.00	225	4.36	159	3.12	162
5	184.50	N	3.60	159	2.74	131	3.33	170	3.78	163	4.02	202	2.43	130
5	184.00	S	3.43	144	3.63	107	3.23	134	3.12	225	3.66	189	3.06	174
5	183.50	N	3.27	127	3.65	107	3.21	155	3.29	184	4.02	174	2.69	118
5	183.00	S	3.27	176	3.43	89	3.04	64	3.33	225	3.78	115	2.75	139
5	182.50	N	3.00	148	3.46	159	2.66	58	3.20	225	3.70	172	2.69	103
5	182.00	S	3.13	163	3.43	89	2.73	97	3.17	225	3.80	165	2.60	109
5	181.50	N	4.27	141	4.13	141	3.88	172	3.00	225	4.76	189	2.72	95
5	181.00	S	3.80	173	3.85	185	3.74	189	3.64	225	4.59	190	3.21	162
6	180.00	S	3.80	173	4.02	125	3.35	206	3.78	199	4.33	157	2.96	171
6	179.50	N	3.43	188	3.80	173	3.50	187	3.72	225	4.12	202	2.98	172
6	179.00	S	3.13	163	3.00	148	3.35	201	3.36	225	3.40	219	2.83	191
6	178.50	N	3.43	144	3.80	173	3.51	211	3.84	225	4.38	216	2.81	178
6	178.00	S	3.27	176	3.60	89	3.27	156	3.51	225	4.02	196	2.51	172
6	177.50	N	3.80	173	3.80	173	3.74	182	4.19	225	4.86	193	2.86	176
6	177.00	S	4.02	185	4.27	141	3.88	179	4.33	225	3.70	179	2.52	121
6	176.50	N	4.27	141	4.56	155	4.63	214	4.63	225	5.21	214	3.51	200
6	176.00	S	3.80	173	4.27	141	4.22	201	4.12	225	5.43	195	3.62	204
7	175.00	S	4.56	155	4.90	169	4.41	172	4.33	225	4.90	186	3.88	187
7	174.50	N	4.27	196	4.90	169	4.44	183	3.48	225	5.13	203	3.80	187
7	174.00	S	3.60	159	4.02	185	3.76	214	3.70	210	4.25	162	3.30	152
7	173.50	N	4.56	155	4.56	206	4.56	211	3.86	198	5.17	213	3.38	169
7	173.00	S	4.02	185	4.56	155	3.97	170	3.74	225	4.94	196	3.40	170
7	172.50	N	4.02	185	4.02	125	3.91	188	3.72	225	4.79	207	3.38	194
7	172.00	S	3.60	159	4.27	141	3.74	189	3.50	225	4.86	202	2.94	127
7	171.50	N	3.80	173	4.56	155	3.97	186	4.04	225	4.86	184	3.84	203
7	171.00	S	3.80	107	4.02	185	3.48	158	3.53	225	4.22	186	2.90	112
7	170.50	N	4.27	196	4.56	155	4.17	191	4.59	190	5.26	199	3.44	169
7	170.00	S	3.80	173	4.02	125	3.48	172	3.97	225	4.36	201	3.32	168
8	169.50	N	4.02	125	4.56	155	3.97	186	4.17	225	4.22	208	3.55	165

Appendix C
Structural Ratings and Soil K Values

			1991		1992		1993		1994		1995		1996	
Section	Station	Direction	SR	K	SR	K	SR	K	SR	K	SR	K	SR	K
2	203.00	S	3.80	173	4.02	125	3.53	171	3.82	166			3.14	172
2	202.50	N	4.02	125	4.27	141	3.95	204	4.02	225			3.46	164
2	202.00	S	3.80	173	3.80	107	3.72	181	3.76	225			2.85	169
2	201.50	N	4.02	185	4.27	141	4.12	195	4.53	225			3.51	176
2	201.00	S	3.80	107	3.80	173	3.32	161	3.48	225			3.16	161
2	200.50	N	4.02	125	4.56	155	3.97	178	4.38	225			3.40	183
2	200.00	S	3.60	199	4.27	196	4.00	194	3.95	225			3.30	160
2	199.50	N	3.27	176	3.80	107	3.33	140	1.13	225	4.17	157	3.48	
2	199.00	S	3.60	159	4.27	141	3.82	174	3.74	225			3.06	161
2	198.50	N	3.80	208	4.27	141	3.68	162	0.81	192	5.09	218	2.96	159
2	198.00	S	4.27	196	4.56	155	4.33	176	4.09	225	4.86	202	3.20	191
3	197.00	S	3.27	176	3.43	144	3.35	185	3.50	225	4.07	199	2.93	165
3	196.50	N	3.27	176	4.02	185	3.21	187	3.76	225	3.23	204	3.68	197
3	196.00	S	2.88	131	3.00	148	2.75	132	2.98	198	3.33	148	2.40	72
3	195.50	N	3.13	109	2.88	66	2.68	149	1.23	225	3.60	184	2.99	143
3	195.00	S	3.80	173	3.80	173	3.72	166	3.72	225	4.25	209	3.09	165
3	194.50	N	3.43	144	3.60	159	3.26	186	3.53	225	3.68	203	2.38	103
3	194.00	S	3.60	199	3.27	176	3.60	138	3.95	184	3.88	125	2.65	169
3	193.50	N	3.60	159	3.27	176	3.46	164	3.64	225	3.57	181	2.93	153
3	193.00	S	3.27	176	3.27	176	3.16	186	3.48	225	3.88	89	2.94	155
3	192.50	N	2.88	131	2.77	112	2.92	157	3.33	189	3.58	153	2.85	171
3	192.00	S	3.13	109	3.43	144	3.38	146	3.17	225	3.35	172	2.78	151
4	191.00	S	3.13	163	3.00	185	2.83	134	3.10	213	3.14	189	2.82	124
4	190.50	N	3.13	163	3.13	109	3.12	162	2.84	225	3.40	170	2.57	86
4	190.00	S	3.27	127	3.43	144	3.05	131	3.05	225	3.50	174	2.62	113
4	189.50	N	3.13	163	3.80	107	3.01	99	3.30	145	3.01	172	2.47	69
4	189.00	S	3.13	163	3.00	88	2.58	111	3.09	152	3.43	117	2.58	111
4	188.50	N	3.80	173	4.56	155	4.02	202	4.14	225	4.83	222	2.80	134
4	188.00	S	3.60	159	4.02	185	3.60	170	3.29	225	4.25	152	2.98	167
4	187.50	N	3.60	159	4.02	185	3.40	183	4.17	225	4.76	213	3.00	158
4	187.00	S	3.13	163	3.27	176	2.99	174	3.38	225	4.30	183	2.64	144
4	186.50	N	3.60	159	4.02	185	3.82	182	3.55	225	4.41	223	2.95	190

Appendix C
Structural Ratings and Soil K Values

			1991		1992		1993		1994		1995		1996	
Section	Station	Direction	SR	K	SR	K	SR	K	SR	K	SR	K	SR	K
11	153.00	S	4.56	155	5.30	182	4.44	212	4.38	225	5.58	199	3.70	186
12	150.00	S	4.02	185	4.90	169	4.36	186	3.36	225	5.13	219	3.44	194
12	149.50	N	3.80	173	4.27	141	3.72	187	3.30	225	4.25	196	3.04	157
12	149.00	S	4.27	196	4.90	169	4.36	186	4.27	225	5.48	206	3.88	200
12	148.50	N	3.80	173	4.02	125	3.72	187	3.30	225	3.91	188	3.10	154
12	148.00	S	4.27	141	4.90	169	4.07	199	4.41	225	4.79	225	3.32	198
12	147.50	N	4.56	155	4.56	155	4.66	209	4.14	225	5.39	220	3.48	158
12	147.00	S	4.56	155	4.90	169	4.50	177	4.59	225	5.58	209	3.78	199
13	71.00	S	4.02	125	4.27	141	4.19	192	3.76	225	3.97	170	3.36	152
13	70.50	N	3.60	159	3.60	89	3.41	165	3.64	225	4.19	177	3.12	126
13	70.00	S	3.43	144	3.60	159	3.55	186	3.48	225	3.84	190	2.99	156
13	69.50	N	3.80	173	4.27	141	3.76	177	3.70	225	4.94	212	3.30	160
13	69.00	S	3.60	159	3.60	159	3.40	156	3.14	225	4.33	193	3.13	177
13	68.50	N	3.80	173	4.02	125	3.88	179	4.12	214	4.63	174	3.24	110
13	68.00	S	3.27	127	3.27	176	3.17	157	3.55	192	4.09	179	2.69	111
13	67.50	N	3.27	176	4.02	125	3.27	163	3.38	214	4.14	189	3.16	168
13	67.00	S	3.80	107	4.02	125	3.88	172	3.97	212	4.04	197	3.24	190
13	66.50	N	4.02	185	4.27	196	4.19	212	3.70	225	4.33	213	3.06	155
13	66.00	S	3.80	173	3.80	173	3.91	127	3.97	222	3.80	211	3.46	196