Evaluation of Probing vs. Coring for Determination of PCC Pavement Thickness

Final Report

December 15, 2008

Submitted to the Wisconsin Department of Transportation

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BACKGROUND

The Wisconsin Department of Transportation (WisDOT) uses the probing of fresh concrete to determine the thickness of Portland Cement Concrete (PCC) pavements and is one of several measurements used for acceptance and the basis of payment. The use of probes for both quality control and quality verification (QC/QV) was initiated in 1998. Prior to that WisDOT relied upon coring of new pavements for thickness acceptance, and it is considered the standard method for determining pavement thickness. Coring, however, is time-consuming, expensive, destructive, and representative of only a small portion of the pavement structure. The advantages of using probes include cost savings to WisDOT by eliminating cores, less contract administration resources needed for the simpler probing process, and immediate feedback to field engineers and contractors which allows the contractor to make real time adjustments to avoid paving less that the required plan thickness.

The switch to the use of probes rather than cores was based largely upon the results of a study conducted by WisDOT in 1998 where they compared the results of both methods on eight construction projects. That study concluded that probing could be considered an acceptable method of measuring PCC pavement thickness and recommended that a standard methodology for conducting probing be developed.

WisDOT utilizes the contractor's QC probing measurements of the freshly placed concrete as the primary method for determining thickness. Two probes are required for each paving unit where a unit is defined as being one lane wide and 250 feet long. Probes are taken at randomly selected longitudinal points within the section and at pre-selected transverse locations as agreed upon by the engineer and contractor. For each ½ day of paving at least one verification test is done by the engineer. This involves observing the contractor's probing operation and verifying the measurement taken by the contractor.

In 2007 WisDOT undertook an investigation to verify that the probing of fresh concrete still provided an accurate measure of constructed pavement thickness and that their QC/QV process remained valid. Ten projects constructed in 2006 and 2007 were selected for coring by WisDOT and the resulting core depths were compared to probe measurements taken in the fresh concrete by the contractor. The cores were taken by WisDOT and the probe depths were obtained from project records or the paving contractor's field notes. The Construction and Materials Support Center (CMSC) at the University of Wisconsin – Madison was asked to perform the analysis and provide conclusions to WisDOT.

The ten projects selected for the study are shown in Table 1. The size of projects ranged from 25,350 to 155,500 square yards of pavement and plan thicknesses varied from 8 to 10 ½ inches. The projects were constructed by five different paving contractors, with one contractor building five of the projects, another contractor constructing two projects, and three contractors each building one of the projects. The individual contractors are not identified by name, but rather by letter designation.

Table 1. List of Study Projects

WisDOT Contract ID	Project Description	Year of Construction	Plan Thickness (Inches)	Pavement Area (SY)	Contractor
20070213045	STH 95 - Alma Center	2007	8.00	54,748	A
20060613038	Chippewa Falls (Local Street)	2006	9.00	44,653	D
20060411001	USH 151 - Columbus Bypass	2006	10.50	68,083	B
20060711005	USH 14/61 - Coon Valley	2006	8.50	155,500	E
20060214019	STH 31 - Green Bay Road	2006	8.50	55,600	A
20060314045	N 91st St. (Local Street)	2006	8.50	25,350	A
20060314016	STH 100 - Ryan Road	2006	9.00	125,640	B
20060411013	S 11th St (Local Street)	2006	8.00	32,500	C
20070213022	Sumner Street (Local Street)	2007	10.50	28,330	A
20060214015	STH 190 - West Capitol Drive	2006	8.50	65,400	A

EVALUATION

A statistical analysis was done on each of the projects to determine if the core and probe measurements yielded the same results for each project. The initial evaluation consisted of simply looking at the means (μ) of both the core and probe data sets. The results of that analysis are shown in Table 2.

In all cases there were more probe measurements (n_p) taken than cores (n_c), in some cases considerably more. This is understandable given the time and expense of coring done at the end of construction, as compared to probing which is done at the time of construction. In all cases the mean of the probe data was greater than the plan thickness while the mean of the cores exceeded plan thickness on eight of the ten projects. A comparison of the means of the core and mean of the probes show close agreement for most of the projects, the largest differences coming from the two projects where the probe depths exceeded the plan thickness and the cores were less than the plan thickness. Of the ten projects, eight had a difference between means of less than 5/32 inch. The other two projects had differences of around 1/4 inch. Table 2 also shows the standard deviation (σ) and the variance (σ^2), which are measures of the spread of the data, for each set of measurements.

The mean values for the Probes and Cores from the 1998 study are shown in Appendix B, Table B-1. In that study there too was close agreement between the means, and of the eight projects in that study, seven had a difference in core and probe means of less than 1/4 inch. The means of the cores and probes also all exceeded the plan depth.

Table 2. Mean, Standard Deviation, Variance and Sample Size

SUMMARY OF WISDOT PROJECTS										
		Probe				Core				
Project	Plan Depth (Inches)	Mean (μ_p)	Std. Dev. (σ_p)	Var. (σ_p^2)	Sample Size (n_p)	Mean (μ_c)	Std. Dev. (σ_c)	Var. (σ_c^2)	Sample Size (n_c)	$\mu_p - \mu_c$ (Inches)
Alma Ctr.	8.00	8.06	0.18	0.03	1174	8.12	0.22	0.05	102	-0.06
Chippewa Falls	9.00	9.38	0.35	0.12	176	9.31	0.40	0.16	27	0.07
Columbus Bypass	10.50	10.53	0.42	0.18	68	10.32	0.41	0.17	48	0.21
Coon Valley	8.50	8.80	0.33	0.11	674	8.69	0.35	0.12	71	0.11
Green Bay Road	8.50	8.59	0.26	0.07	264	8.31	0.40	0.16	12	0.28
N 91st Street	8.50	8.61	0.27	0.07	80	8.66	0.61	0.37	12	-0.05
Ryan Road	9.00	9.12	0.31	0.10	309	9.18	0.19	0.04	24	-0.06
S.11th Street	8.00	8.39	0.23	0.05	164	8.43	0.52	0.27	14	-0.04
Sumner Street	10.50	10.55	0.20	0.04	60	10.61	0.23	0.05	20	-0.06
West Capitol Dr.	8.50	8.69	0.35	0.12	233	8.84	0.48	0.23	32	-0.15

A simple comparison of the means, however, can be misleading because the data is based upon two different measuring techniques with differing numbers of measurements taken at different locations. Use of statistical hypothesis testing allows us to judge if the means of two sample populations are equal.

A **t-test** provides a statistical approach for indicating the confidence that can be placed in conclusions drawn from relatively small numbers of samples of the population. For this study, the sample sizes were quite large, making use of the **t-test** a very rigorous standard regarding the confidence levels for comparing the two population means. It also provides useful information in comparing and predicting the difference between two population means, and it was done for all the projects.

Such hypothesis testing is an essential part of statistical inference and was utilized to evaluate whether the probe and core data gave comparable results. The null hypothesis used in testing the means was that "the mean of the contractor's probe measurements is equal to the mean of the WisDOT core measurements" and the alternative hypothesis was then "the mean of the contractor's probe is not equal to the mean of the WisDOT core". In other words, the null hypothesis was $\mu_p - \mu_c = 0$ and the alternative hypothesis was that $\mu_p - \mu_c \neq 0$.

Using the two sided **t-test**, confidence intervals were calculated for the 95% confidence level and are shown in Table 3. Intervals were also calculated for the assumption of both equal and unequal variances within the populations. The hypothesis test results for the assumption of equal variances are summarized in Table 4. The assumption of equal variance for both data sets is not likely to be applicable; however, it is an assumption often made in hypothesis testing as it provides a more stringent test. For that reason we have used the assumption of equal variances in drawing conclusions regarding the null hypothesis. The statistical results for the assumption of unequal variances, which is more likely, are provided in Appendix A for comparison purposes.

Table 3. Hypothesis Test - Summary of All Projects (Equal Variance)

TWO SAMPLE *T*-TEST (Assuming Equal Variance) 95% CI				
Project	**Lower**	**Upper**	**p-value**	**Estimated Difference (inches)**
Alma Ctr.	-0.0933	-0.0183	0.0040	-0.0558
Chippewa	-0.0715	0.2171	0.3210	0.0728
Columbus	0.0536	0.3645	0.0090	0.2091
Coon Valley	0.0278	0.1896	0.0080	0.1087
Green Bay	0.1243	0.4342	0.0000	0.2793
N 91st St.	-0.2500	0.1590	0.6570	-0.0460
Ryan Rd.	-0.1844	0.0655	0.3500	-0.0594
S 11th St.	-0.1837	0.1040	0.5850	-0.0399
Sumner St.	-0.1720	0.0437	0.2400	-0.0642
West Cap. Dr.	-0.2874	-0.0174	0.0270	-0.1524

Table 4. Hypothesis Test Results (Equal Variance)

HYPOTHESIS TESTING PROBE vs. CORE (Assuming Equal Variance)	
$\mu_{probe} = \mu_{core}$ (alternative, $\mu_{probe} \neq \mu_{core}$)	
Project	**95%CI**
Alma Center	NO
Chippewa Falls	YES
Columbus Bypass	NO
Coon Valley	NO
Green Bay	NO
N. 91st Street	YES
Ryan Road	YES
S. 11th Street	YES
Sumner Street	YES
West Capitol Dr.	NO

The assumption of a 95% confidence level is often used in statistical analysis. Table 4 shows that at the 95% confidence level, with the assumption of equal variances, 5 of the 10 projects failed to meet the test for equivalent measures. In the 1998 WisDOT study which compared probe data to core data for 8 paving projects, they assumed a 95% confidence level with equal variances and 6 of the 8 projects did not meet the test for equivalency.

What is more important than the inferences that can be made from the hypothesis testing is the consideration of predicted differences in the means based upon the statistical modeling. These too are shown in the last column of Table 3. This predicted difference is significant in this study because of the large number of measurements taken for the probes and the cores and the fact that this predicted value is not based upon any confidence level or assumptions about variance. The difference between the probe and the core is predicted to be less than 5/32 inches (0.156 inches) for 8 of the 10 projects in the study. The other two projects were predicted to have differences of less than 9/32 inches (0.28 inches). This shows that the two data sets, probes and cores, compare very closely to each other.

As shown in Figure 1, the close correlation between the probe and core measurements can be shown graphically by plotting the mean values of the probe and cores for each project data set. Because the data points represent different data sets with different sizes and degrees of accuracy, one can argue that such a plot is not statistically persuasive. However, even if the data is only as good as the least accurate point, it gives a representation of the correlation between the means of the probes and cores for all 10 projects.

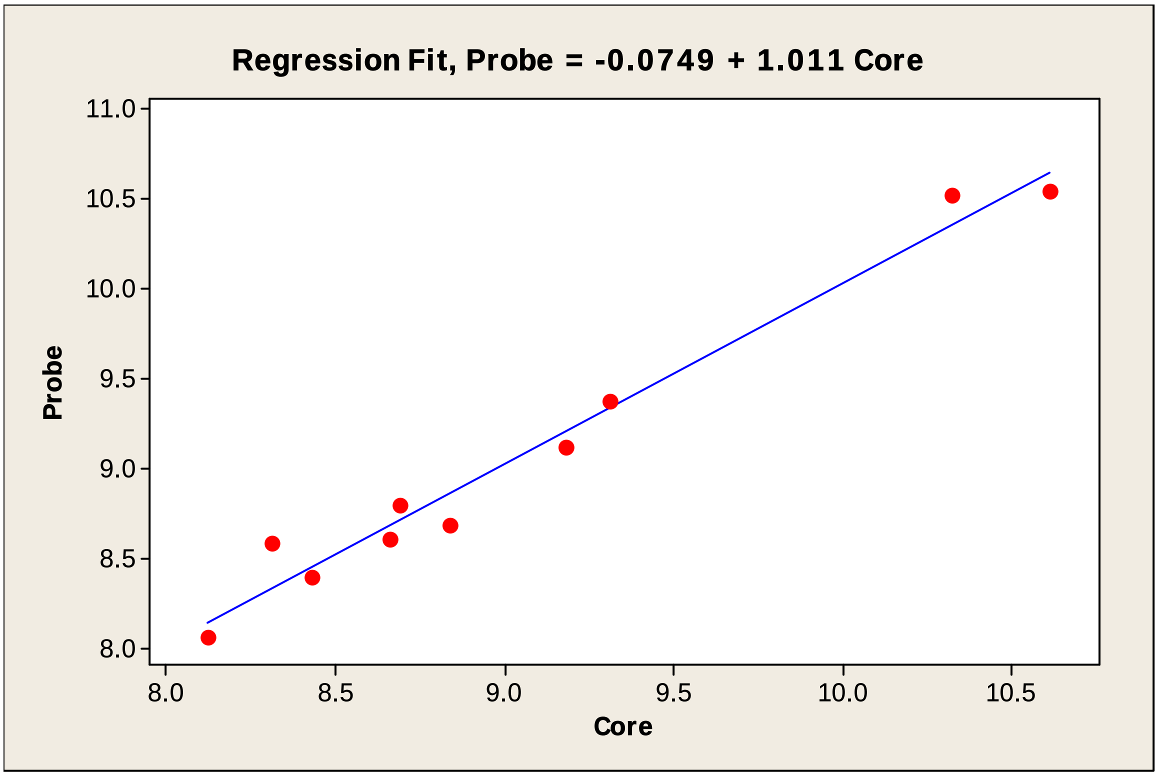

Figure 1: Probe vs. Core

A regression analysis of the data results in a line with the regression equation shown in Figure 1. With a slope very nearly equal to one and a y-intercept very near zero, this graphically demonstrates that there is very little difference between the probe data and core data.

This type analysis was not done in the WisDOT 1998 study and report. However, a plot of the means for the cores and probes was produced using data in that report and is shown in Appendix B, Figure B-1. The 1998 study results show a regression line that also has a slope of one and a y-intercept near zero.

STATISTICAL QUALITY CONTROL

WisDOT utilizes quality control charts to insure that construction processes are controlled and that materials being supplied by contractors meet specifications for many of the products used in construction. This technique, however, is not used in monitoring the thickness of PCC pavement being constructed. There are many benefits in using a statistical control chart, including:

- early detection of process trouble before rejections occur
- decrease in product variability
- establishment of process capabilities
- provision of a rational basis for altering specification requirements
- sense of "quality awareness" in the construction team

As part of the data analysis, statistical quality control charts were made for the probe data to confirm that the construction processes on the study projects were under control. For this analysis, the Average or X-bar Chart was used and the upper control limits (UCL) and lower control limits (LCL) were calculated using statistical methods. The target value was the plan thickness. The UCL and LCL levels were calculated since WisDOT has no criteria for thicknesses greater than plan depth. An example of the statistical control chart for the Columbus Bypass project is shown in Figure 2.

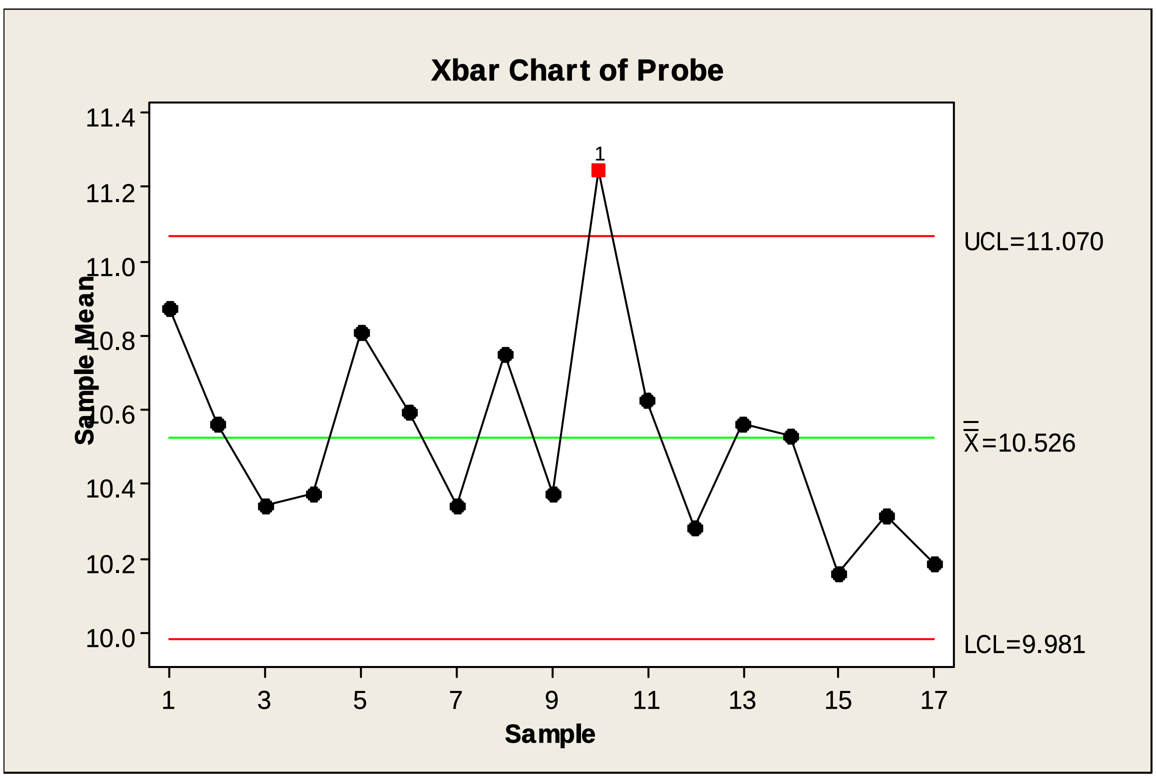

Figure 2: Quality Control X-bar Chart for Columbus Bypass

To judge whether the paving process was under control, the "theory of runs" was utilized. This theory states that if there are seven consecutive points on the same side of the center (target value) line, there is a lack of control. All ten projects passed this criterion and were judged to have been in control. This helps explain the close agreement between the probe and core measurements.

CONCLUSIONS

A total of ten projects were analyzed to determine if probing of fresh concrete is still a valid quality assurance method for determining pavement thickness as compared to coring of hardened concrete. Sample means were compared, statistically calculated estimates of differences were examined, and a statistical analysis at the 95% confidence interval was carried out. Based upon these analyses, probing does provide an acceptable measure of pavement thickness.

Results from this study were compared against the results of a similar study done in 1998 by WisDOT. The two studies show almost identical results and policy decisions made on the basis of the 1998 report remain valid.

OBSERVATIONS

The current quality assurance validation process requires that project personnel simply observe the probe test for the validation test and then verify the measured depth. We believe this procedure can potentially lead to questions about the independent nature of the validation test. For that reason, we think it prudent for WisDOT to change the verification test procedures to require that project personnel both perform the probe test and make the depth measurement.

Both the 1998 Study and this study conclude that probing does provide an acceptable measure of pavement thickness. However, we believe that it would be prudent for WisDOT to reestablish an annual coring program to verify that probing continues to give acceptable results. The coring program could be made part of the PCC paving quality assurance program. One or two projects per year would be adequate, and the projects should be randomly selected at the end of the paving season so paving contractors are unaware of which projects will be cored.

During the study, most of the data collected by the paving contractor was recorded in field notebooks. In some cases these were difficult to obtain and in most cases they were difficult to decipher and enter into electronic format for analysis. WisDOT should at a minimum make sure that legible probe data is part of the permanent project file and preferably should be retained in an electronic format. This would facilitate future analysis and comparative study.

Use of statistical quality control charts has many benefits, and WisDOT should consider adopting their use on future PCC paving projects. It would give both contractors and WisDOT project personnel a tool for determining if the paving process is under control and would provide further assurances that the probe measurements are providing adequate results. The upper control limits (UPC) and lower control limits (LCL) should be established based upon contract requirements and agreed upon values with the paving industry.

REFERENCES

1. Allison, G.W. *Evaluation of Probing Measurement for Determination of Portland Cement Concrete Pavement Thickness*, Master of Science Thesis, University of Wisconsin-Madison, Madison, Wisconsin, May, 2008.

2. Wisconsin Department of Transportation, January 8, 1998, Report #WI/SPR-11-97 *Alternative Methods for Determining PCCP Thickness,* 3502 Kinsman Blvd. Madison, WI 53704

APPENDIX A: Unequal Variance Results

Table A-1. Hypothesis Test - All Projects (Unequal Variance)

TWO SAMPLE *T*-TEST (Assuming Unequal Variance)				
	95% CI			
Project	Lower	Upper	p-value	Estimated Difference
Alma Ctr.	-0.0996	-0.0120	0.0130	-0.0558
Chippewa	-0.0940	0.2395	0.3810	0.0728
Columbus	0.0537	0.3645	0.0090	0.2091
Coon Valley	0.0234	0.1940	0.0130	0.1087
Green Bay	0.0230	0.5350	0.0350	0.2790
N 91st St.	-0.4380	0.3460	0.8020	-0.0460
Ryan Rd.	-0.1473	0.0284	0.1780	-0.0594
S 11th St.	-0.3430	0.2630	0.7810	-0.0400
Sumner St.	-0.1836	0.0552	0.2810	-0.0642
West Cap. Dr.	-0.3292	0.0244	0.0890	-0.1524

Table A-2. Hypothesis Test Results (Unequal Variance)

HYPOTHESIS TESTING PROBE vs. CORE (Unequal Variance)	
$\mu_{probe} = \mu_{core}$ (alternative, $\mu_{probe} \neq \mu_{core}$)	
Project	**95% CI**
Alma Center	NO
Chippewa Falls	YES
Columbus Bypass	NO
Coon Valley	NO
Green Bay	NO
N. 91st Street	YES
Ryan Road	YES
S. 11th Street	YES
Sumner Street	YES
West Capitol Dr.	YES

APPENDIX B: 1998 WisDOT Study Results

Table B-1. Summary of 1998 Study Core and Probe Means

Project	Plan Depth (Inches)	Mean Core (Inches)	Mean Probe (Inches)	Difference Probe-Core (Inches)
I-94, Jackson Co.	12.00	12.42	12.33	-0.09
STH 69, Waukesha Co.	10.00	10.43	10.14	-0.29
USH 51, Lincoln Co. (A)	10.00	10.31	10.22	-0.09
STH 29, Clark Co. (A)	10.83	11.20	11.09	-0.11
STH 29, Marathon Co.	11.00	11.18	11.21	0.03
USH 51, Lincoln Co. (B)	10.00	10.42	10.20	-0.22
USH 10, Waupaca Co.	10.00	10.26	10.38	0.12
STH 29 Clark Co. (B)	10.83	11.31	11.17	-0.14

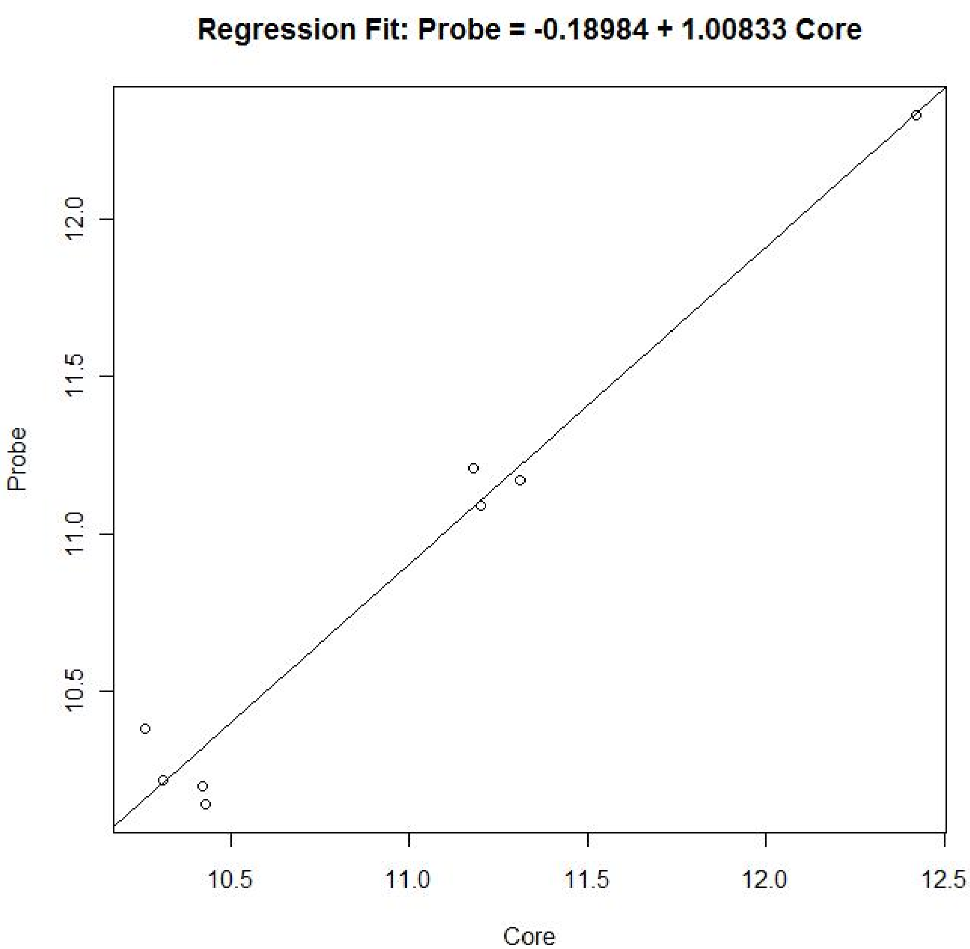

Figure B-1: 1998 Study Core vs. Probe

The Construction and Materials Support Center (CMSC) is housed in the Department of Civil and Environmental Engineering on the University of Wisconsin-Madison campus. The CMSC was formed in partnership with the Wisconsin Department of Transportation (WisDOT) to focus on implementing research findings within the department and other local, state, and federal transportation agencies. In addition, the CMSC functions as a service and applied research group to deliver timely solutions to construction management and materials engineering problems for a variety of organizations. The mission of the Center is to develop research implementation strategies and tools to help WisDOT, public agencies, and industry rapidly implement new and relevant technologies throughout the project development process. The Center draws upon university expertise to collaborate with department personnel and the private sector to find solutions to problems, minimize delays to construction, and improve the quality and efficiency in which materials are used throughout the construction process. Emphases areas for the Center are:

- Accelerated construction techniques
- Construction project management
- Innovative project delivery processes
- Materials performance and production

The Center is staffed to conduct research, develop tools and techniques to enhance project cost-control and minimize scheduling delays in project construction, identify methods and processes to accelerate project delivery and construction activities, create strategies for departments of transportation and others to implement new techniques and technologies, assess new construction materials and create project specifications.

Services include training staff on new techniques and processes, developing application guidance tools for inclusion in manuals, and holding workshops and seminars. Academic staff incorporate the field applications and lessons learned into undergraduate and graduate level engineering courses taught at the UW-Madison.

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