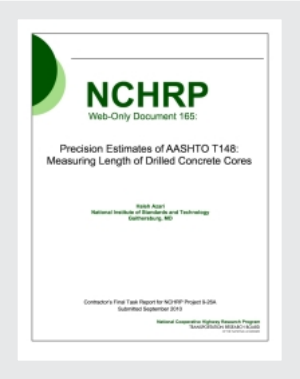

Precision Estimates of AASHTO T148: Measuring Length of Drilled Concrete Cores

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AUTHORS

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Precision Estimates of AASHTO T148: Measuring Length of Drilled Concrete Cores

Haleh Azari
National Institute of Standards and Technology
Gaithersburg, MD

Contractor's Final Task Report for NCHRP Project 9-26A
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National Cooperative Highway Research Program
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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State Department of Transportation Laboratories:

Pennsylvania Department of Transportation, Harrisburg, Pennsylvania

New Jersey Department of Transportation, Trenton, New Jersey

Delaware Department of Transportation, Dover, Delaware

Maryland Department of Transportation, Hanover, MD

North Carolina Department of Transportation, Raleigh, NC

Virginia Department of Transportation, Richmond, VA

Other Participating Laboratories:

Craig Testing Laboratories, Inc., Mays Landing, New Jersey

ATC Associates, Burlington, New Jersey

Specialized Engineering, Ijamsville, MD

McKinney and Company, Ashland, VA

Summit Engineering, Hillsborough, NC

ABSTRACT

This report presents the results of a round robin study to prepare precision estimates for AASHTO T148 test method used for determining the length of a core drilled from a concrete pavement or structural element. The materials for the round robin included six concrete cores taken from LTPP test sections of FHWA. The cores were either 4” or 6” in diameter with varying length in the range of 4” to 12”. The cores were representative of different FHWA LTPP concrete pavement test sections from which they were removed. The apparatus for measuring the length of the cores was a 3-point callipering device specified in AASHTO T148 test method. The six specimens were carried around to eleven laboratories and the length measurements were collected. The results indicated that the repeatability and reproducibility precisions are significantly different for different core diameters. Therefore, the precision estimates were prepared separately for 4” and 6” diameter specimens.

CHAPTER 1- INTRODUCTION AND RESEARCH APPROACH

1.1 Background

The AASHTO Materials Reference Laboratory has been conducting the NCHRP 9-26A research project to determine or update estimates of precision for AASHTO test methods that lack precision statement or need update of precision estimates. Since T148 test method "Measuring Length of Drilled Concrete Cores" [1] lacks precision estimates, AASHTO Highway Subcommittee on Materials (HSOM) has requested that precision estimates be developed for this test method. A round robin study was conducted to collect length measurement data of drilled concrete cores for determining within-laboratory and between-laboratory precision estimates for AASHTO T148. The precision statistics computed from the round robin study were incorporated in the AASHTO T148 precision statement proposed in this report.

1.2 Problem Statement

The measurement of pavement thickness is an important aspect of determining if concrete construction is in compliance with design specifications. Therefore, the precision and accuracy of the measurements has a significant effect on the acceptance of a constructed concrete pavement and consequently on its performance as a whole. However, the AASHTO T148 test method that should define the accuracy requirements for measuring length of drilled concrete elements lacks precision estimates. Therefore, the purpose of this study is to determine the repeatability and reproducibility precision of drilled concrete cores length measurements following AASHTO T148 test method.

1.3 Research Objectives

The overall objective of this study is to determine precision estimates for the AASHTO T148, "Measuring Length of Drilled Concrete Cores" test method. The effect of the core surface condition and dimensions on the single-operator and multi-laboratory precision estimates are also being investigated.

1.4 Scope of Study

The scope of the project involved the following major activities:

I. Design and conduct a round robin study:
   a. Select drilled cores for length measurements.
   b. Select laboratories to participate in the study.
II. Analyze the measured data to determine the within-laboratory and between laboratories variability.
III. Develop precision estimates for T148 test method based on the computed variability statistics.
IV. Prepare a precision statement for AASHTO T148 using the developed precision estimates.
V. Make conclusions and recommendations based on the findings of the study.

CHAPTER 2- DESIGN AND EXECUTION OF THE ROUND ROBIN

The availability of precision estimates for AASHTO T148 test method is essential for reliable use of the drilled concrete cores length measurements for quality acceptance. In this respect, a round robin study was designed and conducted in which variability of the measurements of length of six drilled cores, each having either 4" or 6" diameter and varying length in the range of 4" to 12", was examined. The following sections will report the details of the design of the round robin study based on ASTM E691-07, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method" [2]. As specified in E691, the development of a precision statement required participation of a minimum of 6 laboratories. The precision estimates in this study were developed using the data collected from 11 laboratories.

2.1 Test Specimens

Six drilled concrete cores; either 4" or 6" in diameter and 4" to 12" in length were used in the study. The cores were obtained from different LTPP test sections of Federal Highway Administration (FHWA). Table 2-1 provides the identification number and the dimensions of the concrete cores. As shown the table, the largest core was LT 659 with the dimensions of 6" x 12" and the smallest core was LT 523 with the dimensions of 4" x 4". As specified in Section 3.3 of AASHTO T148, the height of 12" is outside the recommended operating range and the height of 4" is the lower limit of the operating range of the apparatus. It also needs to be noted that LT 1119 had more irregularities at the top surface than the rest of the specimens, however, to create more realistic estimates of precision it was decided to include the core in the study.

Table 2-1- Sample ID and dimensions of the LTPP drilled concrete cores

Sample ID	D x L* (inches)
LT 659	6" x 12"
LT 425	6" x 6"
LT 755	6" x 8"
LT 2894	4" x 9"
LT 1119	4" x 7"
LT 523	4" x 4"

* D and L stand for diameter and length of the cores

2.2 Test Apparatus

The apparatus used for measuring the length of the concrete cores was a 3-point callipering device conforming to the requirements of Sections 3.2 to 3.6 of AASHTO T148. As shown in Figure 2-1, the apparatus holds the specimen in a vertical position by means of three symmetrically placed support bearings.

Figure 2-1- A 3-point caliper core measuring apparatus (courtesy of ASTM C 174 [3])

2.3 Participating Laboratories

Approximately 20 laboratories were contacted and invited to participate in the T148 round robin study. However, only 11 of them had the proper apparatus to conduct the test. The laboratories were located in 7 East Coast states within few driving hours from the NIST campus.

2.4 Specimens' Delivery

A visit to each of the 11 laboratories was scheduled in two separate trips. The first trip covered the laboratories in Pennsylvania, Delaware, New Jersey, and Maryland and the second trip covered the laboratories in Virginia and North Carolina. Extra care was taken so the specimens were not chipped between the measurements. To protect the specimens from any impact during transportation, they were fitted in a carved piece of foam inside a hard shield suitcase.

2.5 Round Robin Study Instructions

The laboratory participants were provided with the testing instructions and data sheets to record the data. The laboratories were requested to follow AASHTO T148 to measure the length of concrete cores to the nearest 0.1 mm. They were also instructed to repeat each length measurement five times. The operators were asked to conduct one complete set of measurements on all six cores before performing the next round of measurements. The repeat data was collected for calculating the within-laboratory precision estimates. Each set of data included nine measurements of a length of specimen, one at the center and one at each of eight additional positions equally spaced along the circumference of the circle of measurement. The readings at each of these nine measurements were requested to be to the nearest 0.1 mm.

CHAPTER 3- ROUND ROBIN TEST RESULTS AND ANALYSIS

3.1 Test Data

Five sets of length measurements were collected on each of the six concrete cores. Among the 11 laboratories visited, nine laboratories conducted complete sets of measurements on each of the six cores. One laboratory, which did not have the capability of measuring the length of the 4" high core, completed full-sets of measurements on five of the cores. Another laboratory, which did not have the capability of measuring the length of 4" diameter cores, completed the measurements on only the three 6" diameter cores. The length data are provided in Table of Appendix B. The empty cells in the tables indicate that the laboratory did not submit data. Figure 3-1 presents the collected data. The middle point of each data point represents the median and the lower and upper bars represent the minimum and maximum data values, respectively.

3.2 Method of Analysis

Test results of the round robin study were analyzed for precision in accordance to ASTM E 691[2]. Prior to the analysis, any outlier data was eliminated by following the procedures described in E691 for determining repeatability (S_r) and reproducibility (S_R) estimates of precision. For each set of data, the h and k statistics, representing the between and within-laboratory consistency respectively, were used to identify the outlier data. Data exceeding the critical *h* and *k* values was eliminated as described in Sections 3.3. Once identified for elimination, the same data was eliminated from any smaller subsets analyzed. Figure B-1 of Appendix B provides the graphical representation of the computed and critical h- and k-statistics.

3.3 Analysis of Results

The averages and the repeatability and reproducibility standard deviations of the data were determined after eliminating the outlier data. The eliminated data is shown shaded in Table B-2 and in Figures B-1 and B-2 of Appendix B. As indicated from the table and the figures in Appendix B, at least one set of measurements on each concrete core was eliminated from the analysis. All remaining data was re-analyzed according to E691 method to determine the S_r and S_R precision estimates.

The summary of statistics of the measurements is shown in Table 3-1. As shown in the table, LT659 with the largest dimensions of 6" x 12" and LT523 with the smallest dimensions of 4"x 4" did not measure up to their expected lengths. LT659 was measured 10 mm more than its expected height and LT523 was measured 7 mm more than its expected height. In addition, both LT659 and LT523 provided the largest between-laboratory variability. This indicates that the 3-point apparatus best accommodates specimens with nominal lengths within the applicable measuring range of apparatus, which are 4" to 10". As shown in Table 3-1, the measured heights of the remaining cores with nominal lengths of 6" to 9" coincide properly with their expected heights.

In addition to the effect of height, the effect of surface irregularities on variability of length measurements was investigated. As mentioned earlier, LT1119 core with 4" diameter had more top surface irregularities that the rest of the cores. As indicated from Table 3-1 the within-variability corresponding to LT1119 was larger than that of other 4" cores. This was expected since replicate measurements were obtained by measuring the length of the cores in five different trials, it seems sensible for the measurements of each trial to be more different that the next trail if the core surface was rough than if it was smooth. The statistical tests in the next section would examine the significance of the differences in variability of the length measurements due the effect of height, diameter, and surface roughness.

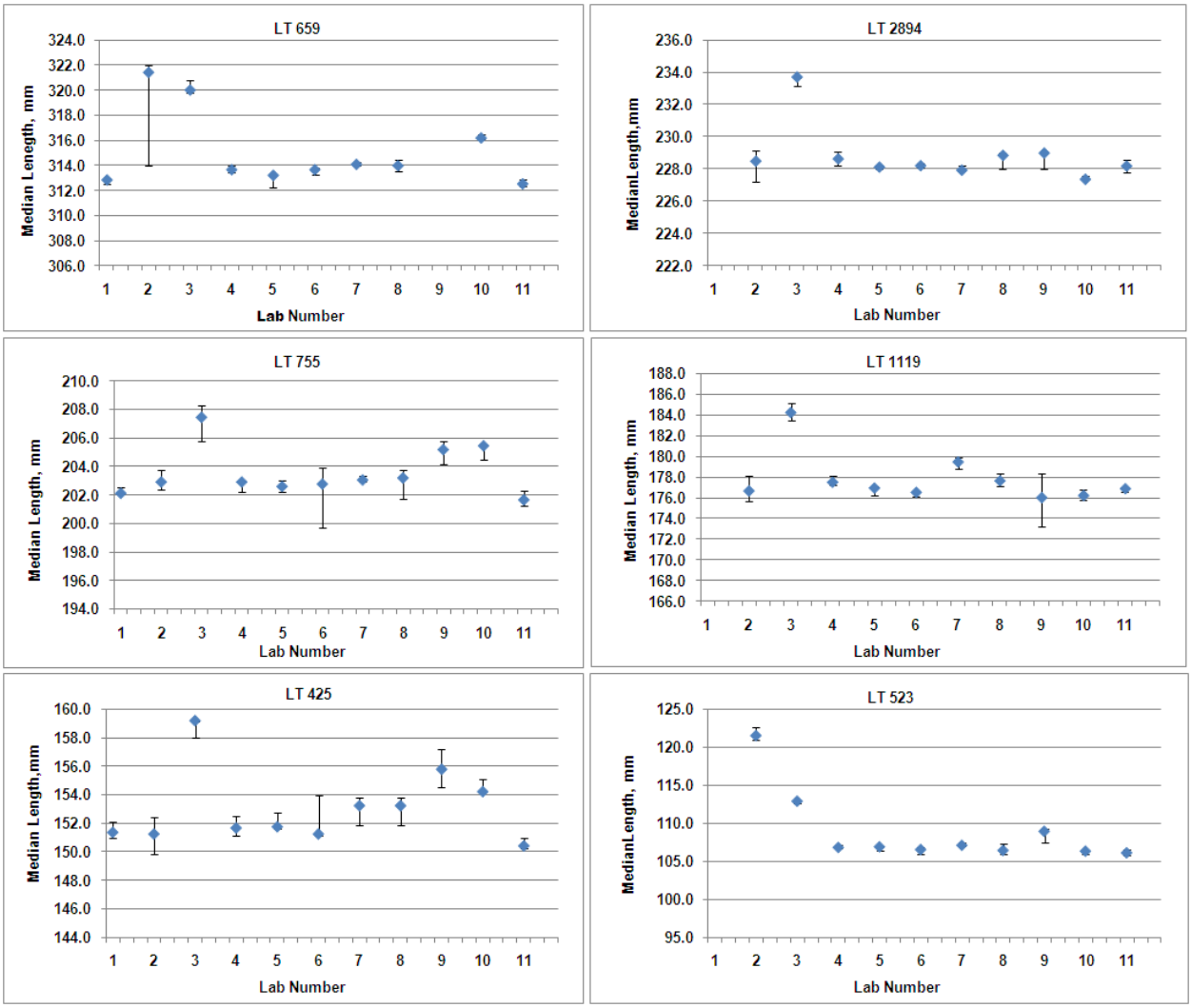

Figure 3-1- Median length values (mm) and their corresponding error bands

Table 3-1- Summary of statistics of concrete core length measurements (mm)

Sample ID	# of Labs	D x L *(inches)	Intended Height (mm)	Average Measured Height (mm)	STD S_x (mm)	CV%	Repeatability (S_r)		Reproducibility (S_R)	
							1s, (mm)	CV %	1s (mm)	CV %
LT 659	9	6" x 12"	304.80	314.47	2.40	0.76	0.29	0.09	2.41	0.77
LT 755	10	6" x 8"	203.20	203.55	1.70	0.83	0.60	0.29	1.78	0.87
LT 425	10	6" x 6"	152.40	152.48	1.58	1.03	0.76	0.50	1.72	1.13
LT 2894	8	4" x 9"	228.60	228.23	0.43	0.19	0.28	0.12	0.50	0.22
LT 1119	8	4" x 7"	177.80	177.22	1.01	0.57	0.49	0.28	1.10	0.62
LT 523	8	4" x 4"	101.60	107.36	2.24	2.09	0.31	0.29	2.26	2.10

*** D and L stand for diameter and length of the cores**

3.4 Test of Statistical Significance

Test of statistical significance on the round robin data was performed using an *F*-test. The *F*-test was to determine if S_r and S_R precision estimates of the properties for different concrete cores were significantly different. The F-test was conducted on the variability values of all cores, except LT 659, whose length was out of the measuring range of the 3-point caliper. The results of the F test on the five remaining concrete cores at 1% level of significance are shown in Table 3-2**Error! Reference source not found.** and Table 3-3. The rejection probabilities larger than 0.01 would indicate that the differences between standard deviations are not significant and they can be combined. The discussions of the statistical tests on within- and between-laboratory standard deviations are provided in the following sections.

3.4.1 F-test on Repeatability

The results of the *F*-test on within-laboratory standard deviations of length measurements are shown in Table 3-2. As shown in the table, the rejection probability for comparison of the within-laboratory variability of the 6" diameter cores (LT 425 and LT755) is greater than 0.01 meaning that the repeatability values are not significantly different and therefore they can be combined. The sum square of within-laboratory standard deviations resulted in the combined repeatability standard deviation of 0.69 mm for 6" diameter cores.

The within-laboratory variability of three cores was used for preparing the repeatability estimates of precision of 4" diameter cores. Table 3-2 shows that the rejection probability values of 0.0852, 0.3999, and 0.1290 from comparison of the within-laboratory variability of LT2894, LT1119, and LT523 were greater than 0.01. This indicates that the within-laboratory variability was not significantly different and, therefore, they could be combined. The sum square of the standard deviations resulted in the combined repeatability standard deviation of 0.37 mm for 4" cores.

The results of comparisons in Table 3-2 also show if the effect of surface roughness was significant on within-laboratory variability. As was shown above, although LT1119 with the largest surface irregularity had the largest within-laboratory variability, yet its standard deviation was not significantly different from that of other 4” diameter cores with less surface irregularity.

The combined repeatability of the 4” cores were compared statistically with the combined repeatability of 6” cores to examine if they can be further combined. The F test on the combined repeatability standard deviations of the 6” and 4” cores (0.69 vs. 0.37) resulted in rejection probability of 0.0041, which is smaller than 0.01 (Table 3-2). This indicates that the repeatability values of the two groups are significantly different and they should be reported separately.

Table 3-2- Results of F-test on comparison of within-laboratory variability of length measurements for 1 % level of significance

Compare	Standard Deviations (S_r)	Degrees of Freedom	Critical F	Computed F	Rejection Probability	Decision
6" Comparison						
LT425 vs. LT755	0.76 vs. 0.60	9 & 9	5.35	1.63	0.2390	Accept
4" Comparison						
LT1119 vs. LT2894	0.49 vs. 0.28	7 & 7	6.99	3.00	0.0852	Accept
LT523 vs. LT2894	0.31 vs. 0.28	7 & 7	6.99	1.22	0.3999	Accept
LT1119 vs. LT523	0.49 vs. 0.31	7 & 7	6.99	2.46	0.1290	Accept
6" vs. 4" Comparison						
	0.69 vs. 0.37	18 & 21	2.93	3.41	0.0041	Reject

3.4.2 F-test on Reproducibility

Table 3-3 shows the results of the F-test for comparison of the between-laboratory standard deviations of the cores. As indicated from the rejection probabilities in the table, the between-laboratory variability of the two 6” diameter specimens (LT 755 and LT 425) was not significantly different and hence they could be combined. The sum square of between-laboratory standard deviations resulted in the combined reproducibility standard deviation of 1.75 mm for 6” diameter cores.

The between-laboratory variability of three 4” diameter cores was used for preparing reproducibility estimates of precision. Table 3-3 shows that the between-laboratory variability of two out of three cores (LT2894 and LT1119) was not significantly different and could be combined (rejection probability of 0.0286 and 0.0398 > 0.01). However, the between-laboratory standard deviation of LT523, with the dimensions of 4” x 4”, was significantly larger than that of LT2894 (rejection probability of 0.0004< 0.01) and could not be combined. It is hypothesized that the short length of LT523 is the reason for the large reproducibility standard deviation of

LT523. Since 4” is at the low end of the apparatus measuring range, the large variability might be due to the shortcoming of the apparatus. Besides, some laboratories might have not calibrated their apparatus for measuring length of cores as short as 4”. Due to the significant difference in the variability of the LT523 core with LT2894; the between-laboratory variability corresponding to LT523 was not included in the precision estimate calculation of 4” diameter cores. The sum square of between-laboratory standard deviations for the two remaining cores resulted in the combined reproducibility standard deviation of 0.85 mm for 4” diameter cores.

The combined reproducibility of the 4”diameter cores were compared statistically with the combined reproducibility of 6” diameter cores to examine if they can be further combined. Similar to the repeatability standard deviations of 4” and 6” core, the reproducibility standard deviations of 6” and 4” cores (1.75 vs. 0.85) were significantly different, as indicated by the rejection probability of 0.0046< 0.01 in Table 3-3, and therefore, should be reported separately.

Table 3-3- Results of F-test on comparison of between-laboratory variability of length measurements for 1 % level of significance

Compare	Standard Deviations (S_R)	Degrees of Freedom	Critical F	Computed F	Rejection Probability	Decision
6" Comparison						
LT425 vs. LT755	1.72 vs. 1.78	9 & 9	5.35	1.07	0.4661	Accept
4" Comparison						
LT2894 vs. LT1119	0.50 vs. 1.10	7 & 7	6.99	4.78	0.0286	Accept
LT2894 vs. LT523	0.50 vs. 2.26	7 & 7	6.99	20.15	0.0004	Reject
LT1119 vs. LT523	1.10 vs. 2.26	7 & 7	6.99	4.21	0.0398	Accept
6" vs. 4" Comparison						
6" vs. 4"	1.75 vs. 0.85	18 & 14	3.56	4.19	0.0046	Reject

3.5 Precision Estimates

As discussed in the previous section, the precision estimates for the length measurements of the 4” and 6” diameter cores were computed after combining the standard deviations that were not significantly different. However, based on the significant difference in the precision estimates of 4” and 6” diameter cores, repeatability and reproducibility precision estimates were to be reported separately. The resulting standard deviations and the allowable range of differences between two results within one laboratory and between different laboratories are provided in Table 3-4. A precision statement for AASHTO T148 based on the precision estimates in Table 3-4 is provided in Appendix C.

Table 3-4- Precision estimates for measurement of drilled concrete cores based on AASHTO T148

Condition of Test and Test Property	Standard Deviation, mm	Acceptable Range of Two results, mm
Repeatability (S_r)		
4" Diameter	0.4	1.0
6" Diameter	0.7	1.9
Reproducibility (S_R)		
4" Diameter	0.9	2.4
6" Diameter	1.8	4.9

CHAPTER 4- CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

A round robin study was conducted to prepare precision estimates for AASHTO T148, "Measuring Length of Drilled Concrete Cores." Six drilled concrete cores with varying dimensions and surface roughness were obtained from the Long-Term Pavement Performance test sections of Federal Highway Administration. The cores were delivered to 11 laboratories, where the length of each core was measured using a 3-point caliper described in AASHTO T148. The measurements were carried out at nine different locations at the center and along the circumference of the cores. A complete set of measurements was repeated five times by each laboratory for the purpose of determining repeatability precision estimates. The collected data were analyzed according to ASTM E691, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a test method". The following are the findings from the analysis of the collected data:

- The variability of the measurements significantly increases as the length of the cores reaches the limits of the 3-point caliper measuring range described in AASHTO T148. This was indicated by the highest repeatability standard deviation of the 12" length core and highest reproducibility standard deviation of 4" length core.

- The repeatability standard deviation increases with the increase in surface roughness of the cores as was indicated by higher variability of one of the 4" diameter cores that had more surface irregularities than the other 4" diameter cores. However, the variability was not statistically significant and the within-laboratory variability of all 4" diameter cores could be combined.

- The variability of the measurements was found to be the same for cores with the same diameter (4" or 6") and significantly different for cores with different diameters (4" and 6"). Therefore, the standard deviations of the measurements of the same diameter cores were combined to prepare two sets of precisions for 4" and 6" diameter cores.

4.2 Recommendations

The measurement of length of drilled concrete cores is an important aspect of a pavement construction process. Currently, there are no precision estimates that would define the accuracy requirements for length measurements following AASHTO T148. Therefore, it is recommended that the precision statement in Appendix C, which is prepared based on analysis of the data collected through a round robin study to be published in AASHTO T148.

REFERENCES

1. AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing (Part 2A – Tests), Twenty-Ninth Edition, American Association of State Highway and Transportation Officials, Washington, DC. 2009.

2. ASTM Book of Standards, Vol. 04.02, Concrete and Aggregates, West Conshohocken, PA, 2009.

3. ASTM Standards on Precision and Bias for Various Applications, Fifth Edition, West Conshohocken, PA, 1997.

APPENDIX A- INSTRUCTIONS AND DATASHEET FOR AASHTO T148 ROUND ROBIN STUDY

Instructions to the Participants of the Round Robin Study for Developing Precision Estimates for AASHTO T148," Measuring Thickness of Concrete Elements Using Drilled Concrete Cores"

Please follow the instructions below to measure length of the supplied concrete cores:

1. Follow AASHTO T148 (ASTM C 174) to measure length of each of the six concrete cores. Record the measurements to the nearest 0.1 mm as "Trial 1" in the provided work sheet.
2. For each of the six cores, repeat the length measurements 4 more times. Record the measurements to the nearest 0.1 mm as "Trial 2", Trial 3", "Trial 4", " Trial 5" in the provided work sheet.

Note 1: It is important to conduct one complete set of measurements on all six cores before performing the next round of measurements.

Note 2: For each round of measurements, place the core in the apparatus in complete random position to avoid repeating the measurements in the same locations as the previous rounds of measurements.

AMRL Round Robin Study for Determining Precision Estimates of AASHTO T148

Data Sheet for Length Measurements of Concrete Cores (to the nearest 0.1 mm)

Core ID	Trail #	Center Point	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	Position 7	Position 8
LT 523	Trial 1									
LT 523	Trial 2									
LT 523	Trial 3									
LT 523	Trial 4									
LT 523	Trial 5									
LT 425	Trial 1									
LT 425	Trial 2									
LT 425	Trial 3									
LT 425	Trial 4									
LT 425	Trial 5									
LT 1119	Trial 1									
LT 1119	Trial 2									
LT 1119	Trial 3									
LT 1119	Trial 4									
LT 1119	Trial 5									
LT 755	Trial 1									
LT 755	Trial 2									
LT 755	Trial 3									
LT 755	Trial 4									
LT 755	Trial 5									
LT 2894	Trial 1									
LT 2894	Trial 2									
LT 2894	Trial 3									
LT 2894	Trial 4									
LT 2894	Trial 5									
LT 659	Trial 1									
LT 659	Trial 2									
LT 659	Trial 3									
LT 659	Trial 4									
LT 659	Trial 5									

APPENDIX B- LENGTH OF DRILLED CONCRETE CORES AND COMPUTED ASTM E691 STATISTICS

Table B-1- Length measurements (mm) of six concrete cores in the round robin study and their computed statistics according to ASTM E 691

	6" x 12"	6" x 6"	6" x 8"	4" x 9"	4" x 7"	4" x 4"	X_bar						S						h						k					
Lab No	LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523	LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523	LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523	LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523	LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523
1	312.87	150.93	202.35				312.80	151.41	202.24				0.17	0.44	0.19				-0.77	-0.68	-0.74				0.15	0.59	0.25			
	312.9	151.2	202.07																											
	312.5	151.4	202.13																											
	313.0	152.1	202.13																											
	312.8	151.4	202.52																											
2	322.02	150.14	203.06	228.46	175.68	120.93	320.07	151.13	202.92	228.29	176.78	121.52	3.42	1.11	0.56	0.81	1.01	0.66	1.75	-0.79	-0.33	-0.28	-0.42	2.59	3.06	1.50	0.73	2.20	1.33	1.52
	321.2	152.4	202.35	227.19	175.97	121.07																								
	321.7	152.0	202.92	228.88	176.67	121.50																								
	321.5	151.3	203.76	229.16	177.52	121.50																								
	314.0	149.9	202.49	227.75	178.08	122.63																								
3	320.04	159.17	206.30	233.68	184.29	112.89	320.18	158.89	207.21	233.51	184.23	112.83	0.37	0.49	1.15	0.25	0.67	0.13	1.79	2.38	2.29	2.77	2.62	0.81	0.33	0.66	1.52	0.68	0.88	0.29
	319.8	158.9	207.43	233.68	183.73	112.89																								
	320.7	159.2	205.74	233.68	185.14	112.89																								
	320.3	158.0	208.28	233.40	184.57	112.89																								
	320.0	159.2	208.28	233.12	183.44	112.61																								
4	313.97	151.27	202.35	228.18	177.38	106.68	313.69	151.78	202.72	228.64	177.60	106.88	0.28	0.61	0.41	0.41	0.34	0.16	-0.47	-0.52	-0.45	-0.07	-0.08	-0.41	0.25	0.82	0.53	1.10	0.45	0.37
	313.7	152.3	202.21	228.32	178.08	106.82																								
	313.4	151.7	203.06	229.08	177.52	106.82																								
	313.4	152.5	203.06	229.02	177.24	107.10																								
	314.0	151.1	202.92	228.60	177.80	106.96																								
5	312.25	151.61	202.21	228.20	176.22	106.93	312.96	151.99	202.57	228.11	176.79	106.78	0.45	0.46	0.33	0.11	0.35	0.23	-0.72	-0.44	-0.54	-0.38	-0.41	-0.43	0.40	0.62	0.43	0.29	0.46	0.53
	313.3	151.8	202.30	228.04	177.01	106.91																								
	312.8	151.8	202.61	228.09	176.70	106.40																								
	313.2	152.8	203.00	227.98	177.07	106.71																								
	313.2	152.0	202.75	228.23	176.95	106.93																								
6	313.27	151.13	203.91	228.18	176.25	106.54	313.63	151.89	202.52	228.18	176.45	106.37	0.24	1.20	1.66	0.10	0.26	0.38	-0.49	-0.48	-0.57	-0.34	-0.55	-0.52	0.21	1.62	2.19	0.27	0.34	0.87
	313.8	151.1	202.78	228.32	176.67	105.97																								
	313.8	154.0	199.67	228.18	176.11	106.54																								
	313.7	151.3	202.78	228.04	176.53	106.82																								
	313.5	152.0	203.48	228.18	176.67	105.97																								
7	314.25	153.25	203.06	228.04	179.92	107.10	314.11	152.96	203.12	227.98	179.35	107.13	0.14	0.75	0.21	0.13	0.43	0.15	-0.32	-0.04	-0.21	-0.46	0.63	-0.36	0.13	1.01	0.28	0.34	0.57	0.35
	314.0	153.8	202.92	227.89	178.79	107.10																								
	314.3	151.8	202.92	227.89	179.07	107.39																								
	314.0	153.2	203.34	228.18	179.49	106.96																								
	314.1	152.7	203.34	227.89	179.49	107.10																								
8	313.72	153.25	201.72	228.53	177.57	105.89	314.01	152.96	202.89	228.65	177.75	106.55	0.38	0.75	0.86	0.40	0.46	0.60	-0.35	-0.04	-0.34	-0.07	-0.02	-0.48	0.34	1.01	1.13	1.08	0.60	1.38
	314.0	153.8	202.30	228.82	177.17	106.08																								
	314.4	151.8	203.20	228.00	177.65	107.09																								
	313.5	153.2	203.76	228.88	178.39	107.24																								
	314.4	152.7	203.48	229.00	177.99	106.43																								
9		154.52	204.19	228.51	175.99	107.84		155.67	205.03	228.69	176.04	108.53		1.00	0.63	0.43	1.86	0.83		1.07	0.96	-0.04	-0.72	-0.07		1.35	0.83	1.18	2.44	1.90
		155.1	205.18	228.00	178.30	109.22																								
		155.8	204.61	228.96	176.02	108.94																								
		155.8	205.46	229.00	176.71	109.22																								
		157.2	205.74	228.96	173.17	107.45																								
10	316.44	154.44	204.44	227.33	175.78	106.33	316.24	154.44	205.13	227.40	176.20	106.27	0.14	0.38	0.54	0.10	0.37	0.22	0.42	0.57	1.02	-0.79	-0.65	-0.54	0.13	0.52	0.70	0.27	0.49	0.50
	316.2	154.2	205.56	227.33	176.22	106.33																								
	316.3	154.2	204.67	227.44	176.22	106.33																								
	316.1	154.2	205.56	227.56	176.00	106.44																								
	316.1	155.1	205.44	227.33	176.78	105.89																								
11	312.89	150.44	202.33	228.53	176.56	105.78	312.58	150.53	201.69	228.17	176.87	106.07	0.25	0.31	0.42	0.27	0.18	0.32	-0.85	-1.03	-1.08	-0.34	-0.38	-0.58	0.23	0.42	0.55	0.74	0.24	0.73
	312.6	150.2	201.44	228.16	177.00	105.78																								
	312.3	150.7	201.22	227.78	177.00	106.11																								
	312.3	150.3	201.78	228.28	176.89	106.56																								
	312.8	151.0	201.67	228.11	176.89	106.11																								
							10	11	11	10	10	10	10	11	11	10	10	10	10	11	11	10	10	10	10	11	11	10	10	10

X_dbl_bar / Sx						Sr / SR						h Critical						k Critical					
315.0	153.1	203.5	228.8	177.8	108.9	1.12	0.74	0.76	0.37	0.76	0.44	2.29	2.34	2.34	2.29	2.29	2.29	1.82	1.83	1.83	1.82	1.82	1.82
2.87	2.44	1.64	1.71	2.46	4.87	3.04	2.53	1.78	1.74	2.55	4.89												

Table B-2- Computed statistics of length data after elimination of outlier data

X_bar_corr						S_corr					
LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523	LT 659	LT 425	LT 755	LT 2894	LT 1119	LT 523
312.80	151.41	202.24				0.17	0.44	0.19			
FALSE	151.13	202.92	FALSE	176.78	FALSE	FALSE	1.11	0.56	FALSE	1.01	FALSE
320.18	FALSE	207.21	FALSE	FALSE	112.83	0.37	FALSE	1.15	FALSE	FALSE	0.13
313.69	151.78	202.72	228.64	177.60	106.88	0.28	0.61	0.41	0.41	0.34	0.16
312.96	151.99	202.57	228.11	176.79	106.78	0.45	0.46	0.33	0.11	0.35	0.23
313.63	151.89	FALSE	228.18	176.45	106.37	0.24	1.20	FALSE	0.10	0.26	0.38
314.11	152.96	203.12	227.98	179.35	107.13	0.14	0.75	0.21	0.13	0.43	0.15
314.01	152.96	202.89	228.65	177.75	106.55	0.38	0.75	0.86	0.40	0.46	0.60
	155.67	205.03	228.69	FALSE	FALSE		1.00	0.63	0.43	FALSE	FALSE
316.24	154.44	205.13	227.40	176.20	106.27	0.14	0.38	0.54	0.10	0.37	0.22
312.58	150.53	201.69	228.17	176.87	106.07	0.25	0.31	0.42	0.27	0.18	0.32
9	10	10	8	8	8	9	10	10	8	8	8
Corrected X_dbl_bar / Sx						Corrected Sr / SR					
314.47	152.48	203.55	228.23	177.22	107.36	0.29	0.76	0.60	0.28	0.49	0.31
2.40	1.58	1.70	0.43	1.008	2.239	2.41	1.72	1.78	0.50	1.099	2.256

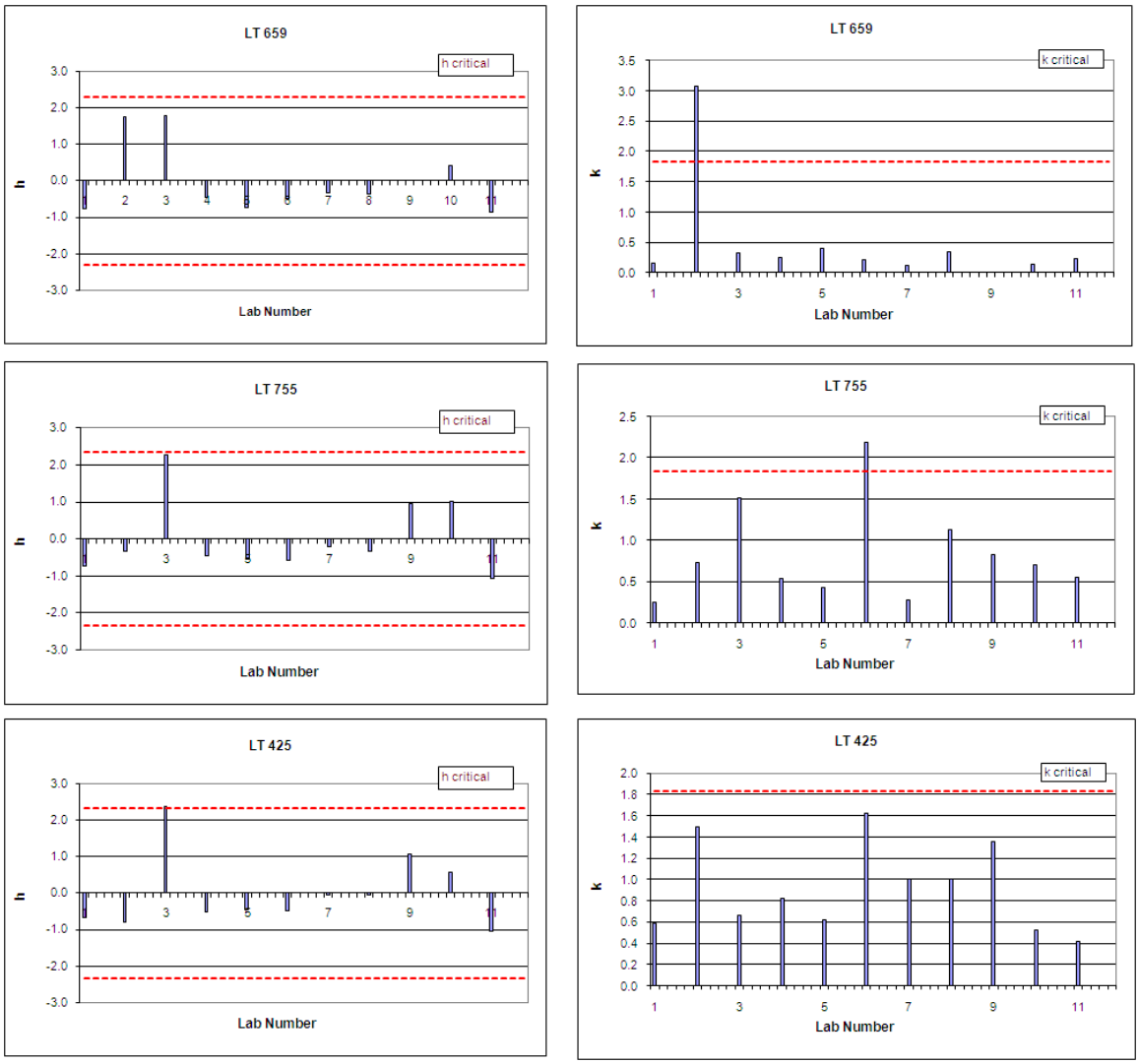

Figure B-1: h and k consistency statistics of length measurements of 6"cores

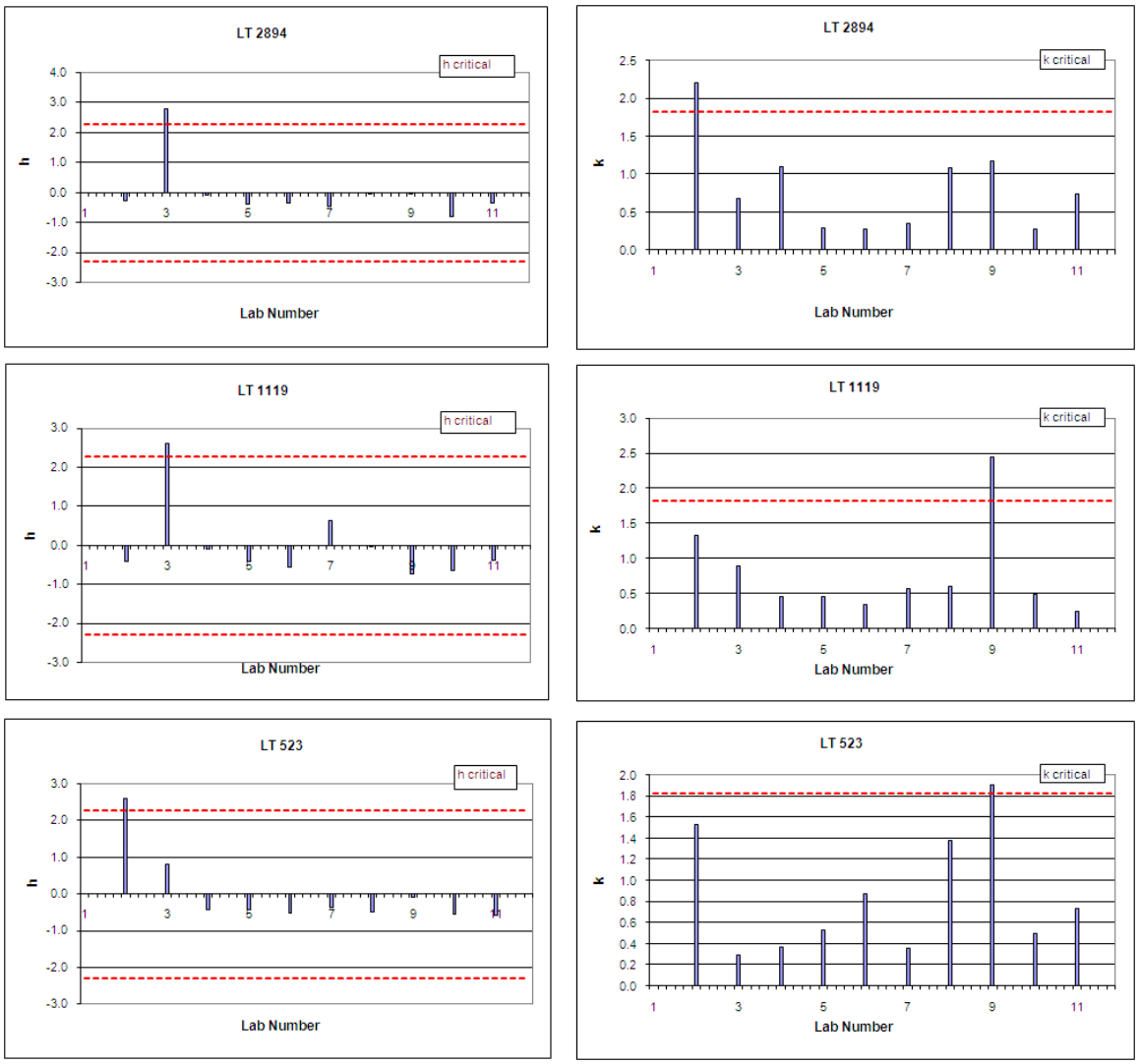

Figure B-2: h and k consistency statistics of length measurements of 4”cores

APPENDIX C- PRECISION STATEMENT FOR AASHTO T148

PRECISION STATEMENT FOR AASHTO T148, "STANDARD METHOD OF TEST FOR MEASURING LENGTH OF DRILLED CONCRETE CORES"

1 Precision and Bias

1.1 Precision - Criteria for judging the acceptability of length of drilled concrete cores obtained by this method are given as follows:

1.1.1 Single-Operator Precision (Repeatability) – The figures in Column 2 of Table 1 are the standard deviations that have been found to be appropriate for the length of drilled concrete cores. Two results obtained in the same laboratory, by the same operator using the same equipment, in the shortest practical period of time, should not be considered suspect unless the difference in the two results exceeds the single-operator limits given in Table 1, Column 3.

1.1.2 Multi-laboratory Precision (Reproducibility) – The figures in Column 2 of Table 1 are the standard deviations that have been found to be appropriate for the length of drilled concrete cores. Two results submitted by two different operators testing the same material in different laboratories shall not be considered suspect unless the difference in the two results exceeds the multi-laboratory limits given in Table 1, Column 3.

Table 1 – Precision Estimates for AASHTO T148

Property and Type Index	Standard Deviation [a] (mm)	Acceptable Range of Two Results [a] (mm)
Single-Operator precision:		
4" Diameter	0.4	1.0
6" Diameter	0.7	1.9
Multi-laboratory Precision:		
4" Diameter	0.9	2.4
6" Diameter	1.8	4.9

[a] These values represent the 1s and d2s limits described in ASTM Practice C670.

Note – The precision estimates are based on the analysis of test results from 11 laboratories participated in an AMRL round robin study. The data consisted of length measurements of six drilled concrete cylinders having diameter of 4 in. and 6 in. and height of 4" to 10". The details of this analysis are in *NCHRP Web-Only Document 165*.

1.2 Bias– No information can be presented on the bias of the procedure because no comparison with the material having an accepted reference value was conducted.