Precision and Bias for SAM and Resistivity Test Methods

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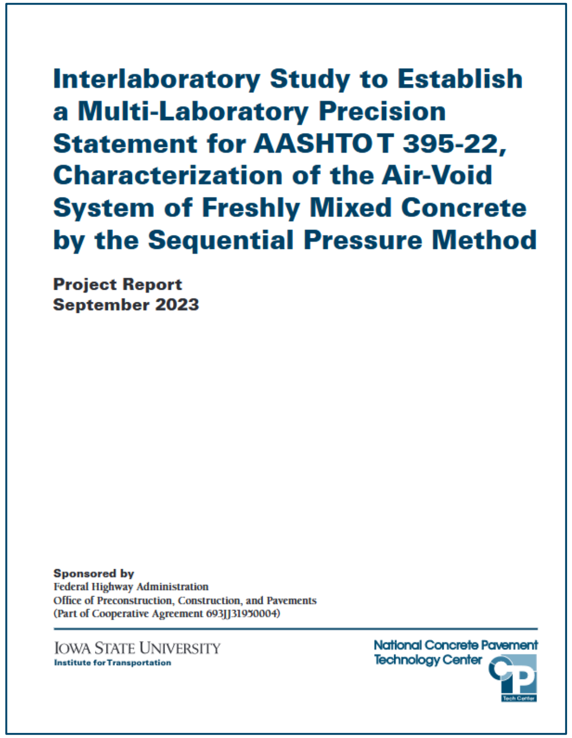
Outline

- Overview & Acknowledgments
- Introduction to Precision & Bias
- Interlaboratory Studies & Results
  - Resistivity
  - SAM

Overview

- Two interlaboratory studies conducted in 2022-24 through CP Tech Center’s cooperative agreement with FHWA
- Full reports are available on the CP Tech Center website



Interlaboratory Study to Establish a Multi-Laboratory Precision Statement for AASHTO T 395-22, Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method

Project Report
September 2023

Sponsored by
Federal Highway Administration
Office of Preconstruction, Construction, and Pavements
(Part of Cooperative Agreement 693JJ31950004)

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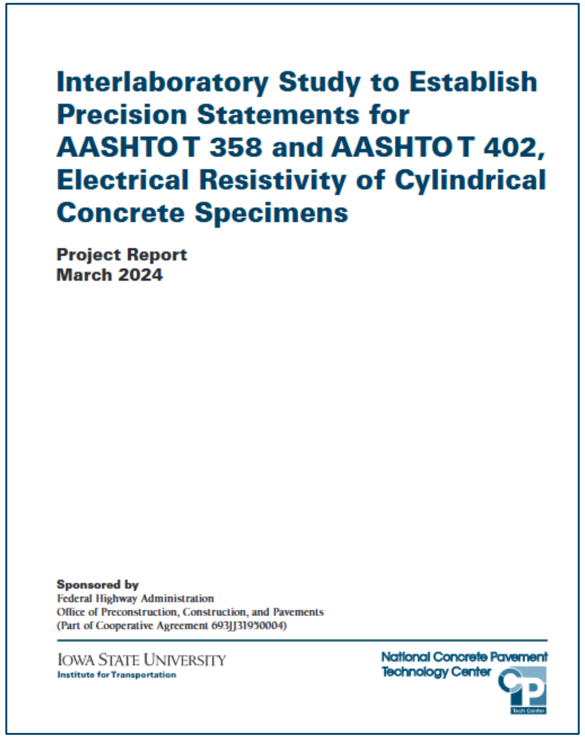

Interlaboratory Study to Establish Precision Statements for AASHTO T 358 and AASHTO T 402, Electrical Resistivity of Cylindrical Concrete Specimens

Project Report
March 2024

Sponsored by
Federal Highway Administration
Office of Preconstruction, Construction, and Pavements
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Overview

- Go to “Resources” > “FHWA Cooperative Agreement Resources”

About the research

The purpose of this cooperative agreement is to further an ongoing concrete pavement technology program, which includes the deployment and transfer of new and innovative technologies and strategies to advance concrete pavements and improve pavement performance. A list of the recent deliverables is available here.

PROJECT DELIVERABLES BY TYPE

Click the toggle arrows below to view project deliverables by publication type.

- ▸ **Guides & Manuals**
- ▸ **Tech Summaries**
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- ▸ **Case Studies**
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☐ Guide/Manual ☐ Tech Summary ☐ Tech Brief ☐ Case Study ☐ One-Pager ☐ Report ☐ Spreadsheet ☐ Video ☐ White Paper

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2024	Integrating Alternative Supplementary Cementitious Materials into Next Generation Paving	Tech Brief
2024	Concrete Pavement with Portland-Limestone Cement, Coal Ash, Optimized Aggregate Gradations, and Recycled Concrete Aggregate in Colorado	Case Study
2024	Concrete Pavement with Optimized Aggregate Gradation, Coal Ash, and Slag Cement in Illinois	Case Study

RESEARCH PARTNERS

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ADDITIONAL TRAINING BY FORMAT

The CP Tech Center provides concrete pavement training promoting best practices (including with new tools/methodologies) as follows:

- Webinars/videos
- Guides/manuals
- NC² MAP tech briefs, etc.
- “Lunch & Learn” slides
- NC² States’ Q&A Listserv
- Concrete Infrastructure Research Database of in-progress and recently completed concrete pavement/bridge deck research
- Research reports
- External training resources

Acknowledgments

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Precision & Bias

- The objectives of this work were to provide data to prepare precision and bias statements for AASHTO test methods for SAM and resistivity
- Two forms of measurement error:
    - Precision = random error
    - Bias = systematic error

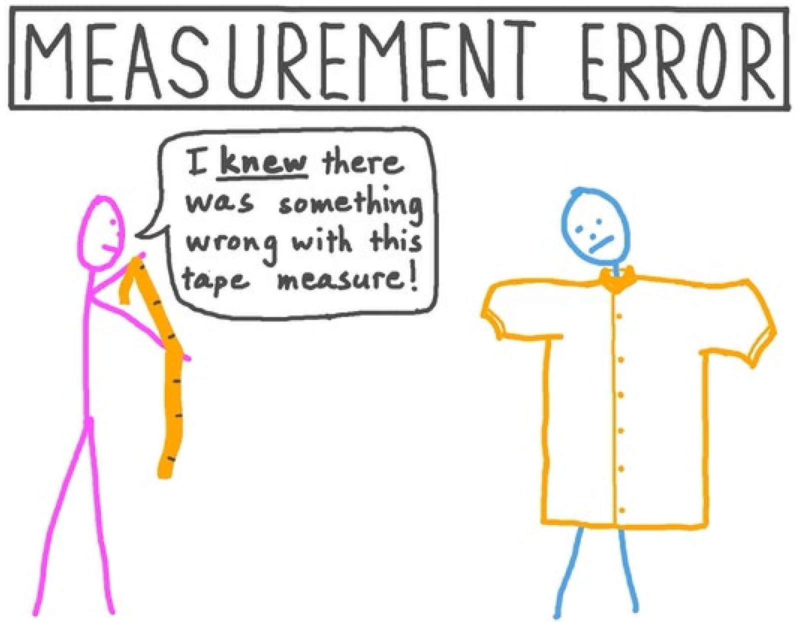


Image: Nagwa

Sources of Variability in Test Results

- Operator
  - Clarity of test method
  - Completeness of test method
  - Differences in operator technique
- Apparatus
  - Tolerances
  - Calibration
- Environment
- Sample
  - Sampling process
  - Handling
- Time

Precision

- Precision ≠ Accuracy!

Precision

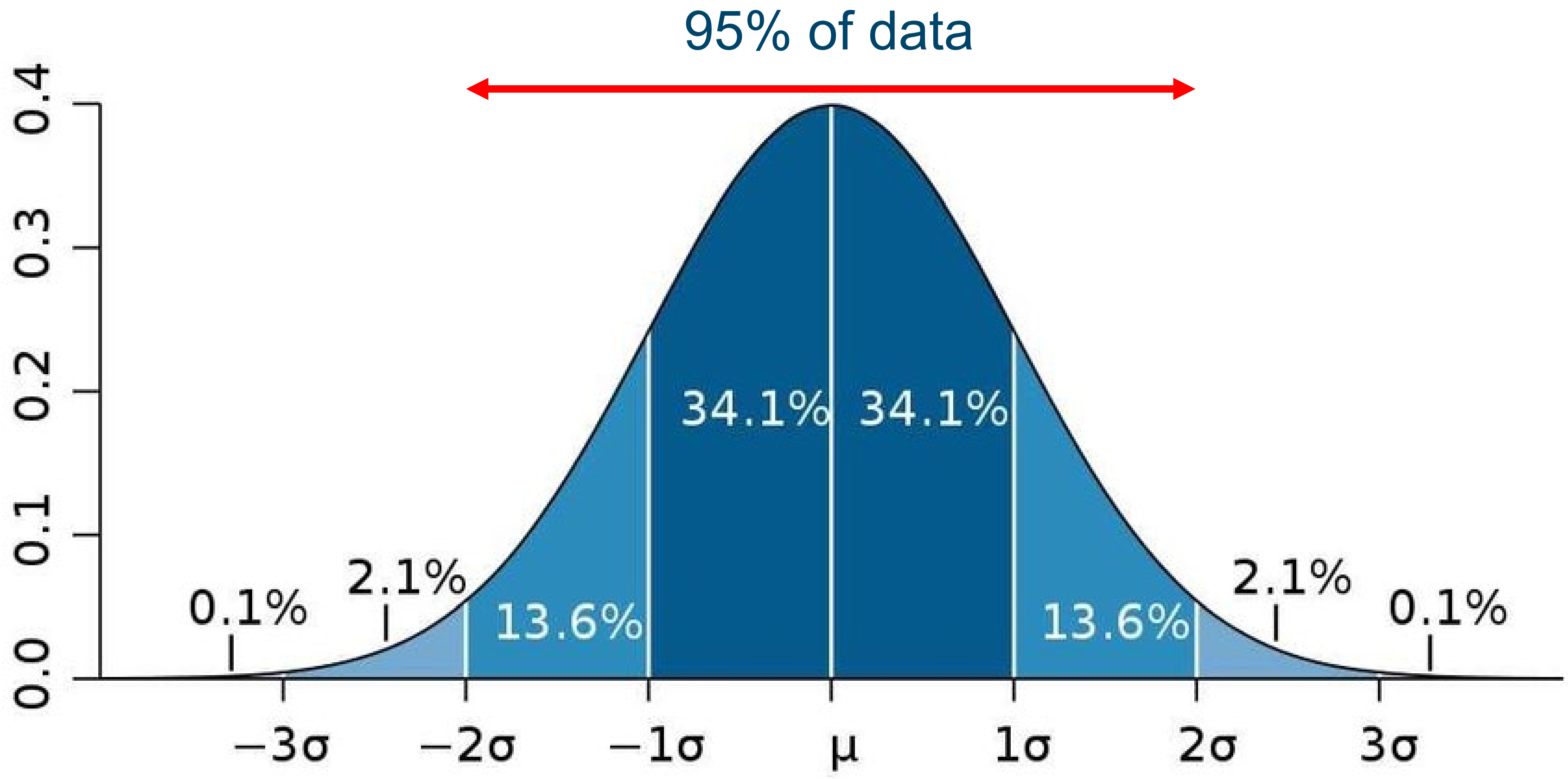
- "The closeness of agreement between independent test results obtained under stipulated conditions" (ASTM E177)
- Expressed in terms of the standard deviation or the coefficient of variation of the test results

$$\sigma = \sqrt{\frac{\sum (X_i - \bar{X})^2}{(N-1)}}$$

$$COV(\%) = 100\left(\frac{\sigma}{\bar{\bar{X}}}\right)$$

Precision

- Precision statements also report a difference limit that describes the maximum acceptable difference between 2 test results



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Precision

- If a test method requires more than two test results (i.e. you're averaging three or more test results), instead of a difference limit, the precision statement instead reports a maximum acceptable range between the highest and lowest result

TABLE 1 Maximum Acceptable Range of Test Results[A]

Number of Test Results	Multiplier of Standard Deviation or Coefficient of Varitation[B]
2	2.8
3	3.3
4	3.6
5	3.9
6	4.0
7	4.2
8	4.3
9	4.4
10	4.5

[A] A test result can be a single determination or the average of two or more determinations as defined in the test method.
[B] Values were obtained from Table A7 of "Order Statistics and Their Use in Testing and Estimation," Vol 1, by Leon Harter, Aerospace Research Laboratories, United States Air Force.

Source: AASHTO C670

Types of Precision

- Repeatability, or single-operator precision
  - Variability of a large group of test determinations by the same operator on the same material within a short time interval
- Reproducibility, or multi-laboratory precision
  - The variability of a group of test results obtained by different laboratories on the same material

Example Precision Statement

- AASHTO T 22 (Compressive Strength of Concrete Cylinders)
  - Single-operator precision:

	Coefficient of Variation[a]	Acceptable Range[a] of Individual Cylinder Strengths	
		2 Cylinders	3 Cylinders
150 × 300 mm (6 × 12 in.)			
Laboratory conditions	2.4%	6.6%	7.8%
Field conditions	2.9%	8.0%	9.5%
100 × 200 mm (4 × 8 in.)			
Laboratory conditions	3.2%	9.0%	10.6%

[a] These numbers represent respectively the (1s) and (d2s) limits as described in ASTM C670.

Example Precision Statement

- AASHTO T 22 (Compressive Strength of Concrete Cylinders)
  - Multilaboratory precision:

11.1.3. *Multilaboratory Precision*—The multilaboratory coefficient of variation for compressive strength test results of 150-by-300-mm (6-by-12-in.) cylinders has been found to be 5.0 percent; therefore, the results of properly conducted tests by two laboratories on specimens prepared from the same sample of concrete are not expected to differ by more than 14 percent of the average (see Note 16). A strength test result is the average of two cylinders tested at the same age.

Note 16—The multilaboratory precision does not include variations associated with different operators preparing test specimens from split or independent samples of concrete. These variations are expected to increase the multilaboratory coefficient of variation.

Bias

- “The difference between the expectation of the test results and an accepted reference value” (ASTM E177)

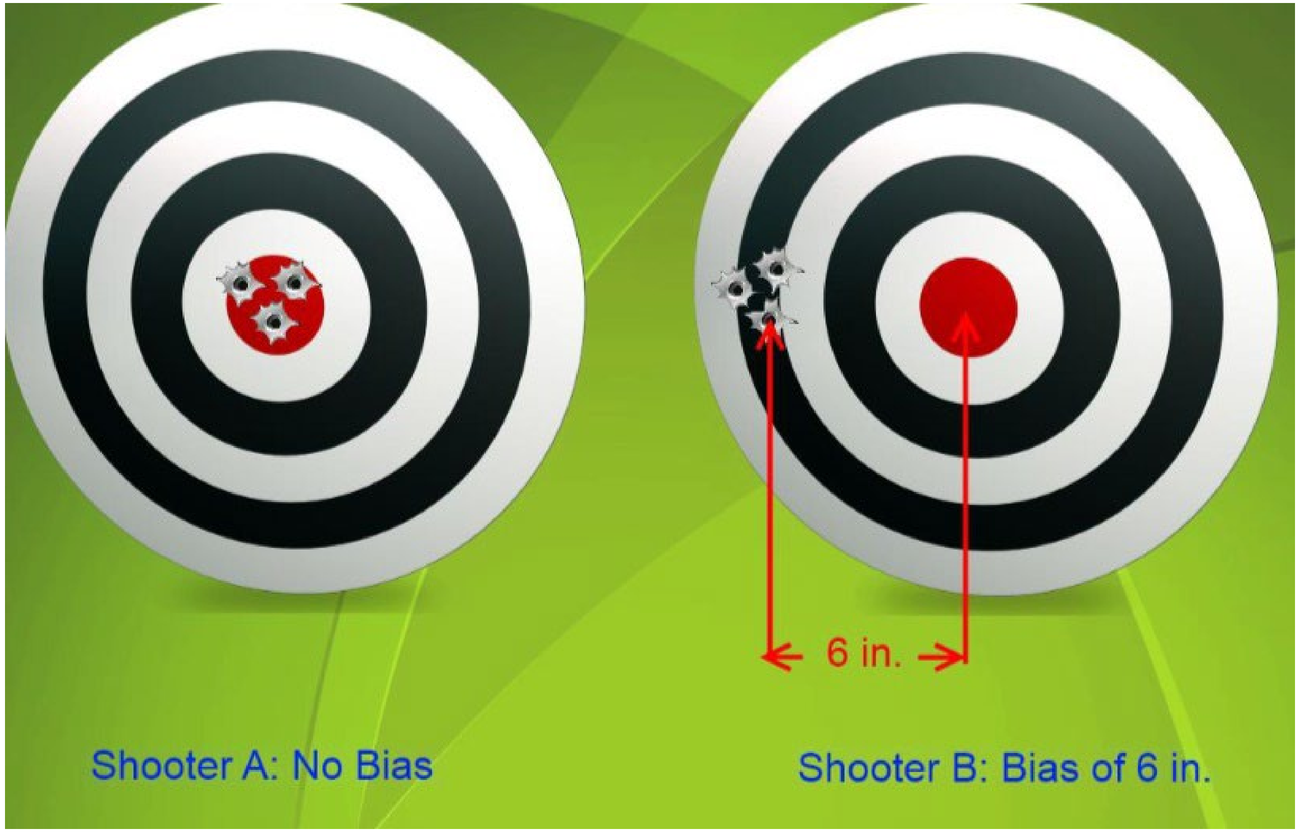


Image: AASHTO

Bias

- It's not always possible to establish the bias of a test method
- Requires a certified reference material with an accepted reference value for the measured property
- Expressed as a difference from the accepted reference value within a 95% confidence interval

$$t = \frac{\bar{X} - X_r}{\frac{\sigma}{\sqrt{N}}}$$

$$(\bar{X} - X_r) + t_{\alpha/2}\frac{\sigma}{\sqrt{N}}$$

Example Bias Statement

- AASHTO T 178 (Portland Cement Content of Hardened Concrete)

12.2.5. *Maleic Acid Procedure*—The bias of the maleic acid procedure is dependent upon the composition of the concrete for reasons stated in Section 12.1.3. Based on the mean values from the interlaboratory test program described under Precision, the values determined should be within –10 to +4 kg/m^3 (–17 to +6 lb/yd^3) of the actual values.

- AASHTO T 22 (Compressive Strength of Concrete Cylinders)
  - “Because there is no accepted reference material, no statement on bias is being made”

Test Methods

- Resistivity
  - AASHTO T 358 (surface resistivity)
  - AASHTO T 402 (uniaxial resistance test)
  - For both test methods, established:
    - Single-operator precision
    - Multi-laboratory precision
    - Bias

Test Methods

- SAM, AASHTO T 395 (sequential pressure method for air content)
  - Established multi-laboratory precision
  - Note that it's not possible to determine single-operator precision or to determine bias

Surface & Uniaxial Resistivity

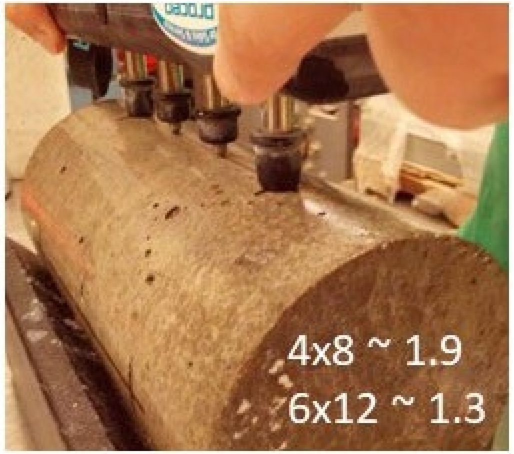
- Interlaboratory study divided into 5 phases (A-E)
  - Phases A & B identified participating labs and delivered training tools
  - Phase C: determine single-operator variability
  - Phase D: determine multi-laboratory variability
  - Phase E: final report

Mixtures

- Two mixtures prepared in Corvallis, OR for Phases C & D
  - Mixture 1: low electrical resistivity (poor quality)
    - 500 lbs/cy OPC (no SCMs)
    - 0.52 w/cm
  - Mixture 2: high electrical resistivity (good quality)
    - 750 lbs/cy total cementitious content
      - 30% slag
      - 4% silica fume
    - 0.37 w/cm

Phase C

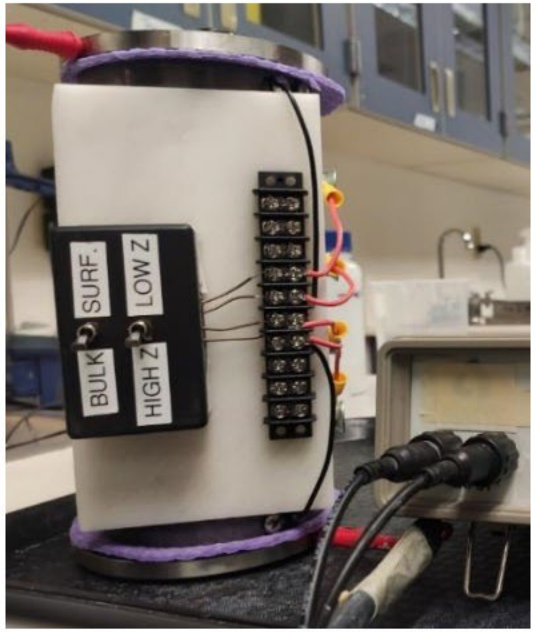
- 4x8 cylinders cured and conditioned at Oregon State
  - AASHTO T 358 (Surface): saturated lime solution
  - AASHTO T 402 (Uniaxial):
    - Simulated pore solution
    - Sealed conditioning
- Cylinders tested at Oregon State at 42 days to determine single-operator precision

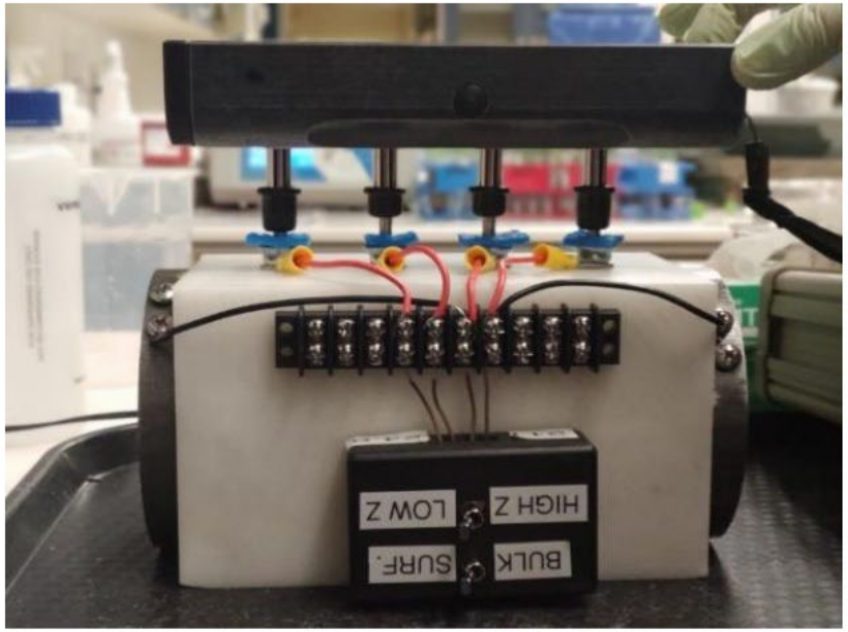


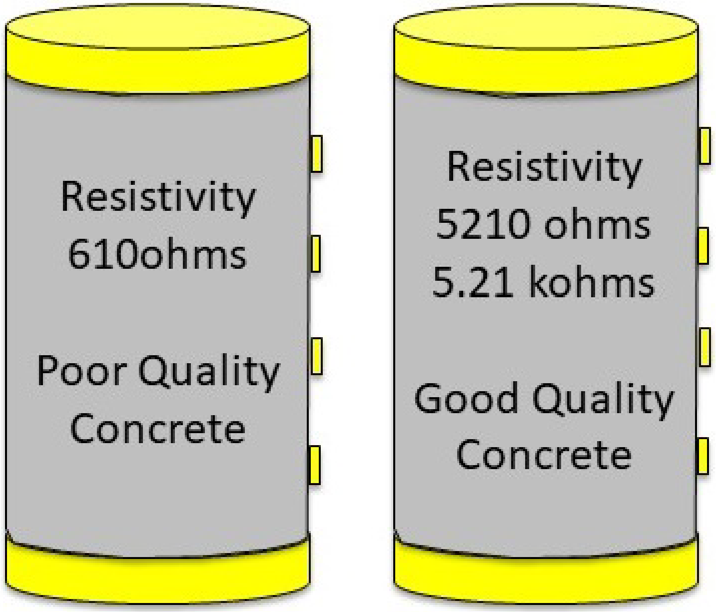
Images: Oregon State University

Phase C

- A verification device was used to determine single-operator bias for both test methods
  - Geometry matched that of a 4x8 cylinder
  - Consisted of two circuits with known impedance/resistivity







Images: Oregon State University

Phase D

- 4x8 cylinders cast and demolded at Oregon State, and shipped in sealed conditions within 72 hours to the participating laboratories
- Cylinders tested at each laboratory at 56 days to determine multi-laboratory precision
- Verification devices sent to the participating laboratories for determination of multi-laboratory bias

Resistivity Results

- AASHTO T 358 (Surface)
  - Precision:

Precision Indices		Coefficient of Variation (%)	Maximum Acceptable Difference between Two Operators' Results, d2s (%)
Verification Device	Single-Operator	0.2	0.4
	Multi-Laboratory	0.5	1.3
Concrete Specimens	Single-Operator	5.8	16.1
	Multi-Laboratory	10.9	30.5

  - Bias:
    - "The bias of the test method is found with 95% confidence to lie between -1.8% and -2.0%"

Resistivity Results

- AASHTO T 402 (Uniaxial)
  - Precision:

Precision Indices		Coefficient of Variation (%)	Maximum Acceptable Difference between Two Operators Results, d2s (%)
Verification Device	Single-Operator	0.2	0.5
	Multi-Laboratory	2.1	5.8
Concrete Specimens, Conditioning Option A[1]	Single-Operator	3.3	9.2
	Multi-Laboratory	13.0	36.5
Concrete Specimens, Conditioning Option B[2]	Single-Operator	3.4	9.5
	Multi-Laboratory	11.3	31.7

[1] Conditioning in pore solution
[2] Sealed sample conditioning

  - Bias
    - “The bias of the test method is found with 95% confidence to lie between 2.0% and 2.4%”

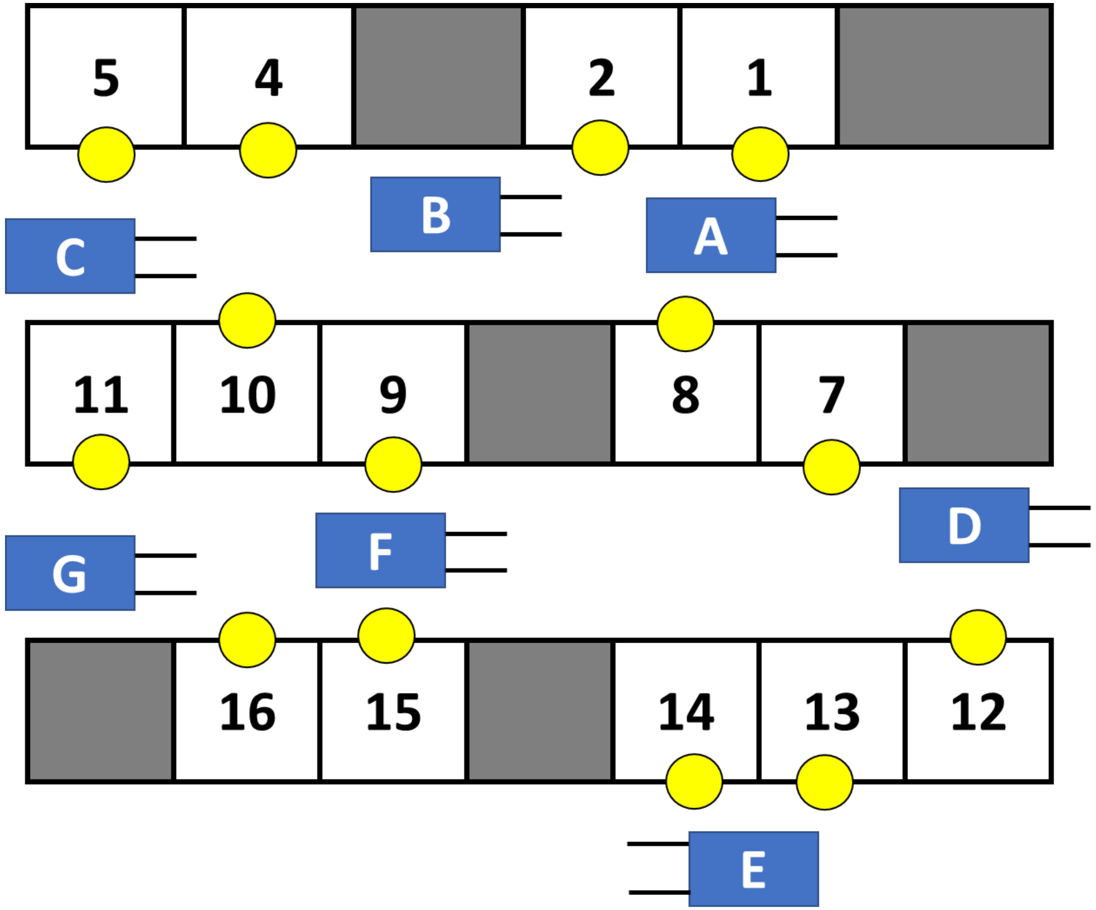
SAM

- Interlaboratory study performed over 2 days with 14 different operators at Concrete Supply, Inc. in Des Moines, IA
  - Even though everyone was at the same location, the study met the conditions for a multi-laboratory precision statement
    - Different operators and testing devices

Mixture

- Iowa DOT/SUDAS Class C-SUD paving mix
  - Optimized aggregate gradation
  - 560 lbs/cy total cementitious content
  - 20% fly ash
- Four batches of concrete (5 cy each) prepared at four target air contents ranging from 3 to 8%

Testing



Testing

Results

- Multi-laboratory Precision
  - Air Content:

Air Content (%)	Standard Deviation (%)	Acceptable Difference between Two Results [C] %
4	0.24	0.67
5	0.30	0.84
6	0.35	0.98
7	0.41	1.15
8	0.47	1.32

[A] Use interpolation to determine precision values for air contents between the values given in the table.
[B] The coefficient of variation of a single test for the volume of air was found to be 5.9%.
[C] These numbers represent the d2s limits as prescribed in ASTM C670.

Results

- Multi-laboratory Precision
  - SAM number:

SAM Number	Standard Deviation	Acceptable Difference between Two Results [C] %
0.10	0.040	0.113
0.15	0.060	0.169
0.20	0.081	0.226
0.25	0.101	0.282
0.30	0.121	0.339
0.35	0.141	0.395
0.40	0.161	0.451

[A] Use interpolation to determine precision values for SAM numbers between the values given in the table.
[B] The coefficient of variation is 40.3%.
[C] These numbers represent the d2s limits as prescribed in ASTM C670.

References

- ASTM E177: Use of the Terms Precision and Bias in ASTM Test Methods
- ASTM C670: Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials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