Economic Effects on Construction of Uncertainty in Test Methods

Toy Poole
U.S. Army Corps of Engineers
August 2005
Selected Examples

- CRD-C 114 - F/T dur of aggregates
- ASTM C 78 – flex beam
- ASR testing
- Curing compound testing
- Heat of hydration testing
Test Method Uncertainty

- Within-laboratory variation
  - Operator
  - Equipment
- Between-laboratory variation
- Simple bias
- Material-dependent bias
ASTM

- Requires precision and bias statement
  - Within laboratory - repeatability
  - Between laboratory – reproducibility
- d2s – based on std dev
- d2s% - based on CV
d2s

- Maximum difference among a set of determinations in 95% of cases
- For duplicate determinations,
  - \( d2s = 2.8s \), or 2.8*CV
- For triplicate determinations,
  - \( d2s = 3.3s \), or 3.3*CV
- Multipliers for larger sets in ASTM C 670
Example – ASTM C 138
Density of Concrete

• Within-lab std dev = 0.65 lb/ft³
  – d2s (n=2) = 1.85 lb/ft³
  – d2s (n=3) = 2.15 lb/ft³

• Between-lab std dev = 0.82 lb/ft³
  – d2s (n=2) = 2.31 lb/ft³
CRD-C 114
Durability of Aggregates to Cycles of Freezing and Thawing

• Acceptance testing of concrete aggregate
• Based on ASTM C 666
  – Air-entrained concrete
  – Results reported as a Durability Factor 0 – 100%
  – 100% Specifications typically 50 – 75%
• No reported precision estimate
CRD-C 114
Durability of Aggregates to Cycles of Freezing and Thawing

- Significant between-laboratory disagreements
- Changes in use of durability factor specifications
Mather 1954

Durability Factor, %

Laboratory

SAD  SPD  MRD  NPD  ORD  WES  SWD
Precision CRD-C 114

- Standard deviation among labs
  - 19.3%
- d2s among labs
  - 54%
Economic Consequences of Rejection

- Hauling distance to secondary source
- 10 mi of 4 lane highway
  - 120,000 yd³ of concrete at $0.15/ton/mi
  - 25 mi haul = $450,000
  - 50 mi haul = $900,000
ASTM C 78
Flexural Strength

• Basis for acceptance of mix design
• CV = 7% between laboratory
• At 650 psi
  – d2s ~ 125 psi
Economic Consequences

- Delays over mixture acceptance
- Add extra 100 lb/yd$^3$ to insure compliance
- 10 mi of 4 Lane
- \$1,000,000 in cement cost
ASTM C 150 – Low Alkali

Graph showing the relationship between the expansion of cement and its alkali content. The x-axis represents the alkali content of cement (% as Na₂O) ranging from 0.0 to 2.0, while the y-axis represents the expansion (%), ranging from 0.0 to 1.0. The spread of the data points is indicated by error bars, which represent the standard deviation among 6 aggregates.
ASR Testing

![Graph showing correlation between mortar (C 1260) and concrete (C 1293) percentages.]
AAR Cost Factors

• Rejection of acceptable aggregate
  – Short term $$

• Acceptance of inadequate aggregate
  – Long term $$
ASTM C 156 – TM for Curing Compounds
ASTM C 156

- Typical limit: 0.55 kg/m²
- Typical production: 0.45 - 50 kg/m²
- Between Lab Std dev = 0.07 kg/m²
- Between Lab d2s = 0.20 kg/m²

Error > Safety Margin!!
C 156 Cost Factors

- User – producer disputes
- Over conservative specification
  - High solids materials
  - Difficult to apply
- May not perform
- Little testing by Federal Gov’t
ASTM C 186
Heat of Hydration of Hydraulic Cement
ASTM C 186
Heat of Hydration of Hydraulic Cement

- Between Lab std dev = 4 cal/g
- d2s = 11 cal/g
- Represents ~1,000 psi strength difference
- Target strength = 1500 psi, 3 days
- Specification limit = 1000 psi, 3 days
Cost Issues

- Uniformity in Strength Gain
  - Weekly variation ~1,000 psi
- Uncertainty in Form Removal