Understanding ACI 117 Construction Tolerances and Tools

Honoring Bruce Suprenant Concrete Construction Contributions

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Suddenly, a heated exchange took place between the king and the moat contractor.
- Joined ACI in 1975
- Joined ACI Committee 117 in 2001
- Over 30 different committees, often serving in a leadership position
- Winner of six ACI awards
- Author of numerous papers, including several on tolerances
  - ACI Concrete International Award in 2022 for article “Establishing Thickness Tolerances for Parking Lot Slabs”
- Author of numerous ASCC Position Statements, several on tolerances
- Co-author of the book *Tolerances for Cast-in-Place Concrete Buildings*
Need for Tolerances

“Whether the specifications call for it explicitly or not, there is implied in every set of plans that columns, walls, and arrises shall be plumb, that floors, ceilings, lintels shall be level -- or shall have the slopes indicated, in plane or other geometrical form. It is expected the structure and its parts shall correspond with the dimensions given. As a matter of fact no building is ever plumb, level, straight, and true to dimension, -- that is, not exactly. Fortunately, no building need be.”
Need for Tolerances

• No design is perfect
• No construction is perfect, and “fortunately, no building need be”
• Perfection is not the standard of care
  • Engineers (example): “perform their engineering services with no less than the skill customarily exercised by other structural engineers in similar circumstances”
  • Contractors (example): “a contractor promises (a) to use reasonable skill, care and diligence, (b) that the work will be performed in a workmanlike manner, and (c) that the work, when completed, will be reasonably fit for its intended use.”
    • Workmanlike manner is “degree of skill, efficiency and knowledge which is possessed by those of ordinary skill, competency and standing in the particular trade or business for which the contractor is employed”
• Standard is compared to your peers, not perfection
Need for Tolerances

• Imperfection is expected by the structural building codes

• “The purposes of the strength reduction factor $\phi$ are: (1) to allow for the probability of under-strength members due to variations in material strengths and dimensions, (2) to allow for inaccuracies in the design equations, (3) to reflect the degree of ductility and required reliability of the member under the load effects being considered, and (4) to reflect the importance of the member in the structure.” (Section R9.3.1)
According to the American Concrete Institute (ACI), a “tolerance” is the permitted deviation from a specified dimension, location, or quantity.

Common reference for concrete tolerances is Specification for Tolerances for Concrete Construction and Materials by ACI Committee 117.

Specification is for “typical” construction, and not all construction.
- “Tolerances in this specification are for typical concrete construction and construction procedures and are applicable to exposed concrete and to architectural concrete.” (Section 1.1.2)
- “Tolerances for specialized concrete construction that is outside the scope of this specification shall be specified in Contract Documents.” (Section 1.1.2)

“Typical” is not defined, and up to specifier to determine what is appropriate for the project.
Example – 9” Elevated Slab

- Reinforcement Cover: ±3/8 in. (ACI 117, 2.2.2)
- Reinforcement Position: ±3/8 in. (ACI 117, 2.2.1)
- Reinforcement Spacing: ±3 in. (ACI 117, 2.2.5)
- Top of Slab Elevation: ±3/4 in. (ACI 117, 4.4.1)
- Slab Thickness: -1/4 in. (ACI 117, 4.5.3)
- Bottom of Slab Elevation: ±3/4 in. (ACI 117, 4.4.1)

Tolerances Are Not Cumulative

• “Tolerances are not cumulative. The most restrictive tolerance controls.” (Section 1.2.3)
• Tolerances are independent and concurrent
• Tolerances limits are based on a normal distributed

Specified Value

- Tol. + Tol.
Example: Slab Section

- **Concrete Tolerances**
  - Thickness of suspended slabs (ACI 117-10, Section 4.5.3)
  - Deviation from elevation, top of slab (ACI 117-10, Section 4.4.1)
  - Deviation from elevation, formed surface (ACI 117-10, Section 4.4.2)

- **Reinforcement Tolerances** (ACI 117-10, Section 2)
Example: Slab Section

- Thickness of suspended slab (ACI 117-10, Section 4.5.3): -1/4 in., no plus tolerance
Example: Slab Section

- Deviation from elevation, formed surfaces (ACI 117-10, Section 4.4.2):
  +/- 3/4 in.
- Measured before removal of supporting shores
Example: Slab Section

• Deviation from elevation, top of slab (ACI 117-10, Section 4.4.1): +/- 3/4 in.
• Measured before removal of supporting shores

Specification for Tolerances for Concrete Construction and Materials (ACI 117-10(15)) and Commentary by ACI Committee 117
Example: Slab Section

• Tolerances are not cumulative, **minus tolerance not**:
  • -1/4” Thickness of suspended slabs (ACI 117-10, Section 4.5.3)
  • -3/4” Deviation from elevation, top of slab (ACI 117-10, Section 4.4.1)
  • -3/4” Deviation from elevation, formed surface (ACI 117-10, Section 4.4.2)
  • -1-3/4 in. Total
Example: Slab Section

- Tolerances are not cumulative, **plus tolerance not**:  
  - +N.L. Thickness of suspended slabs (ACI 117-10, Section 4.5.3)  
  - +3/4” Deviation from elevation, top of slab (ACI 117-10, Section 4.4.1)  
  - +3/4” Deviation from elevation, formed surface (ACI 117-10, Section 4.4.2)  
  - +N.L. Total
Example: Slab Section

• Tolerances are not cumulative, range of acceptance:
  • Example 1: thickness -1/4 in., top of slab elevation +1/2 in.
  • Example 2: top of slab elevation +3/4 in., bottom of slab elevation -3/4”
  • Both examples are within concrete tolerances, need to check reinforcement
Example: Slab Section

Possible for both extremes at same time, but not likely

Specified

Example 2

+3/4 in.

-3/4 in.
Measurements

• "A tolerance includes the manufacturing tolerance for a product, the contractor’s ability to construct within a given variation, and the reliability with which the variation is measured. The measuring method and apparatus used to verify a tolerance should be capable of reliably measuring to one-third the value of the specified tolerance or less.” (Section 3.4.1)

• While tolerances are not cumulative, there are different factors for tolerance measurements that need to be considered together
Measurement Factors

• “A tolerance includes the manufacturing tolerance for a product, the contractor’s ability to construct within a given variation, and the reliability with which the variation is measured.” (ACI 117.1-14, 3.4.1)
Measurement Factors

Tolerance Range  =  Measurement Range  +  Construction Range

Specified Value  =  Actual Value  +  Specified Value

Figure provided by Bruce Suprenant
Measurement Factors

If measurement accuracy decreases, construction accuracy must increase to keep same tolerance range.
If measurement accuracy decreases, tolerance range must increase to keep same construction range.
Measurement Factors

• Structures move, so when tolerances are measured for evaluation can be critical

Modified from figure provided by Bruce Suprenant
Measurement Timing

- Limited timing factors are captured by 117
  - Measuring slab flatness 72 hours after finishing operations to avoid time-depend effects
  - Measuring elevations before removing shores to avoid deflections
Measurement Timing

• Other timing factors are not captured by 117
  • Post-tensioning
  • Shrinkage
  • Thermal
  • Retained soil
 Movements That Affect Tolerance Measurements

Contractors’ workmanship should be measured independently of movements

By Bruce A. Suprenant and Ward R. Malisch

Building a structure that is within tolerance is one measure of a contractor’s workmanship. As-built tolerances of a concrete-structured building’s surfaces may change during and after construction, the foundation is a result of shear or hogging deflections, potentially credible deflections, or edge deflections. Discrete expansion or compression, not settlement or heave, or a combination of these effects. Most of these movements are time-dependent and occur over a period of months or years. But when should the as-built measurements be made? 10 one time just for a consistent movement to occur: a combination of rotation, variable in numbers, and movement duration. Time is measured more than 10 years after the building was constructed. Some measurements indicated the movement was not as significant, since it is part of the tolerance, while others indicated it was a reflection on the contractor’s workmanship.

ACS 11.4.02 addresses this, but not all. Measures that affect measured values that are used to determine the tolerance value do not require a tolerance value. The article discusses how ACS 11.4.02 dealt with this issue for slopes and how the document could improve the approach for other movements.

Measuring Slab Surface Flatness and Levelness Slab surface tolerances are measured by comparing the measured surface to two mutually perpendicular, reference planes. Regardless of the method used, ACS 11.4.02, section 4.4.4 requires that slab-on-ground and suspended slab surfaces “be measured and reported within 2 years after completion of slab concrete Building operations and before removal of any support devices.” ACS 11.4.02 section 4.11.5.2, also includes the same time limit. "Tolerance tolerances and levelness shall be measured within 72 hours after completion of slab concrete Building operations and before removal of any support devices.”

"Back to Bruce"
Back to Bruce

• Raised industry awareness of tolerances
• Tolerances historian
• Applied science to the seemingly simple topic of tolerances
• Worked toward a sense of objectivity and fairness of tolerance evaluation
• Resource for the industry, committee, and many others, especially me
• Committee force multiplier

• Thank you, Bruce!
Bruce was my intro to ACI, and I personally experienced his immeasurable impact in the 5 or so years I have been involved.

Bruce freely shares knowledge and mentorship, breaks down complex issues into easy-to-understand terms, and is always ready with a quick line and a smile.

I have learned much from him, and his contributions to ACI-ASCC Committee 117 will be sorely missed.

William Paul
ACI-ASCC Committee 117
In 2007, my first ACI Convention and Tipp was the chair. Bruce and Allen Face got into a heated argument about what a minimum local should be. That was the first time for me to meet him, I just appreciate all he has done for the industry, it doesn’t matter who it benefits he fights for what is RIGHT!

David Buzzelli
ACI-ASCC Committee 117
As a design engineer I was always impressed with Bruce's ability to stand his ground, as a contractor, and yet make space for different opinions and bring forward key voices that might otherwise not be heard.

David Shook
ACI-ASCC Committee 117
Bruce demonstrated his expertise in working ‘outside the box’ by... showing up to chair an ACI committee meeting in a robe & slippers, carrying a Pina-colada left over from the night before.

Frank Salzano
ACI-ASCC Committee 117
Questions?

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