Understanding ACI 117 Construction Tolerances and Tools

Honoring Bruce Suprenant Concrete Construction Contributions

San Francisco, CA

April 4, 2023

Michael Ahern, PE

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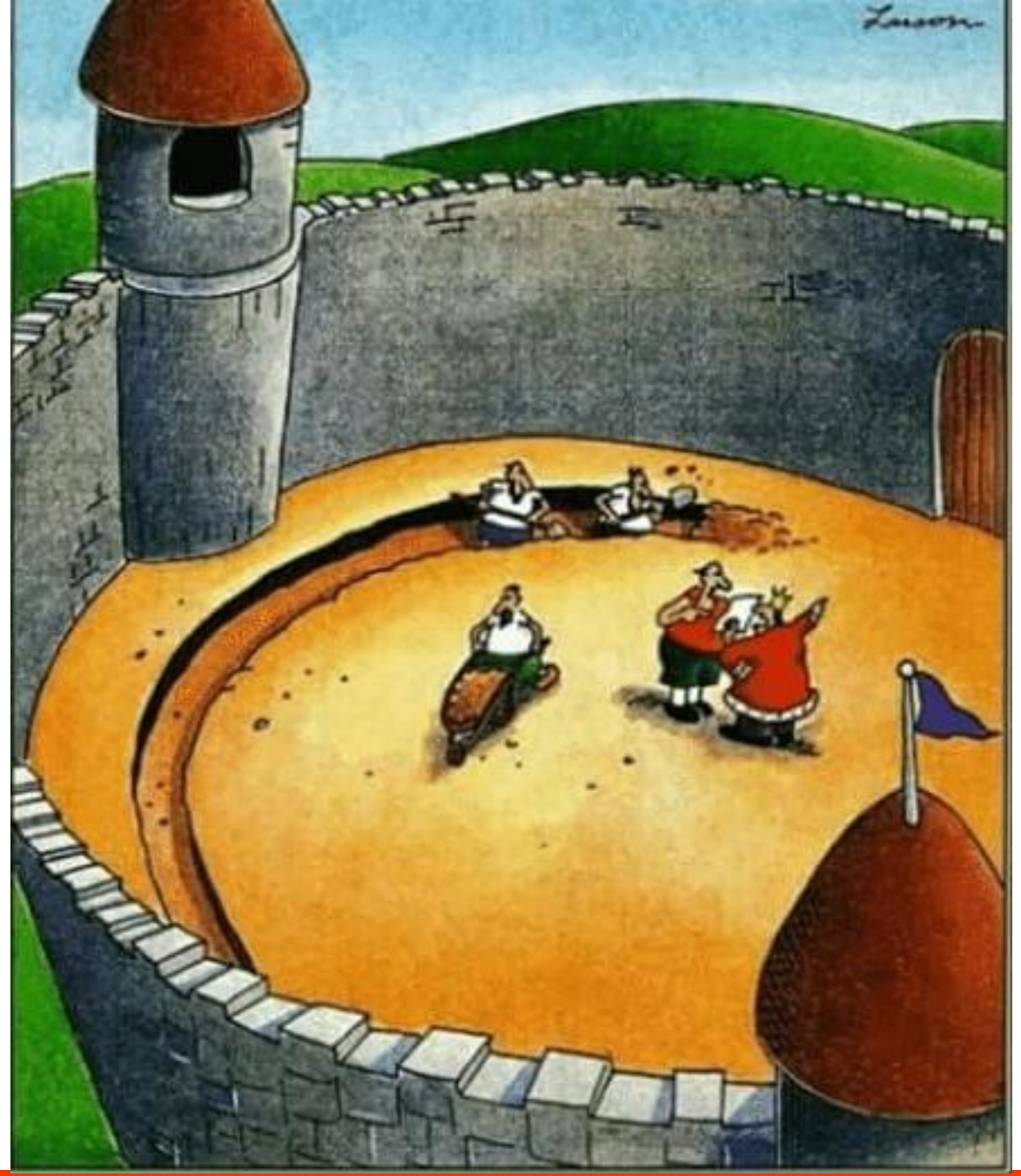
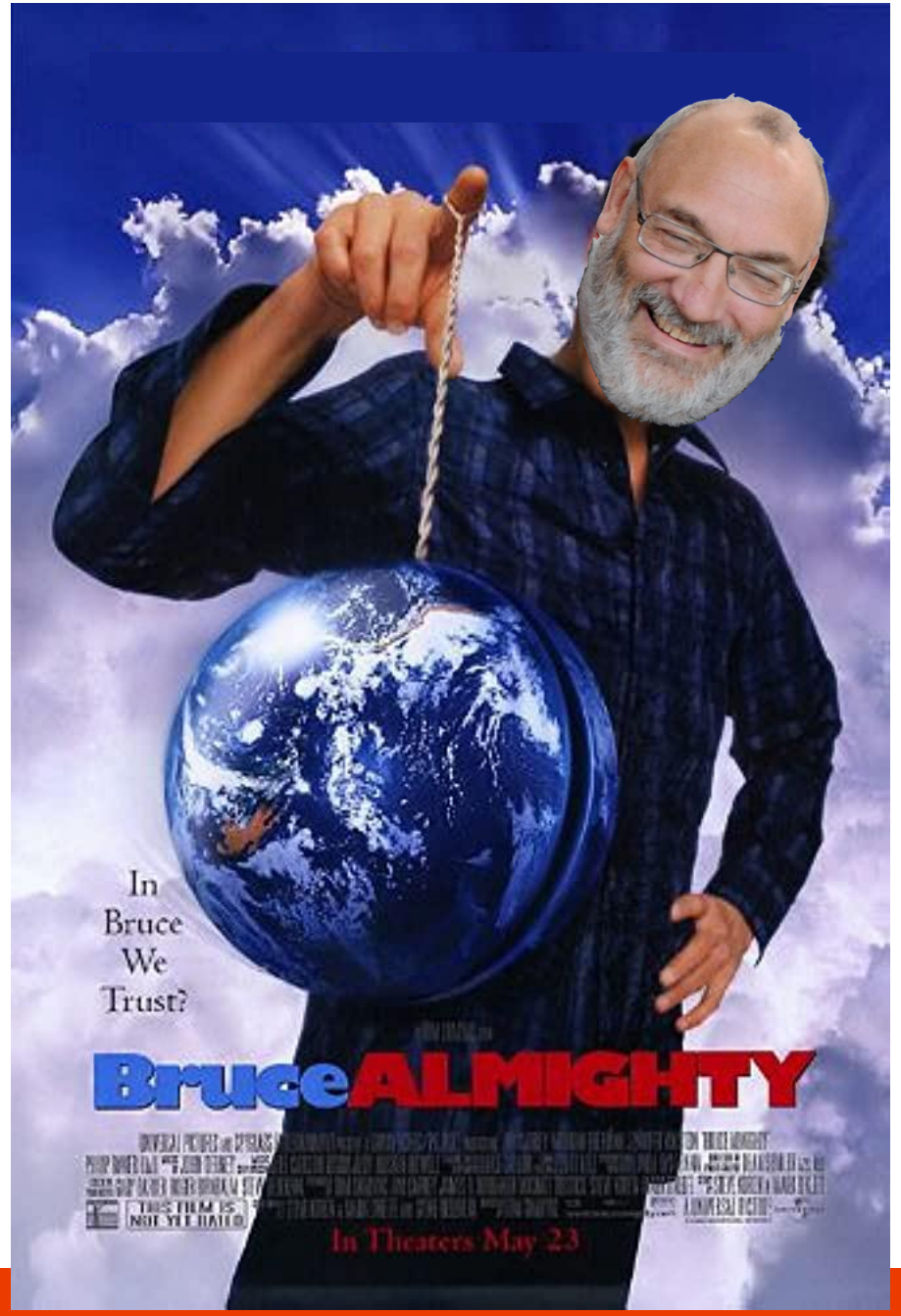
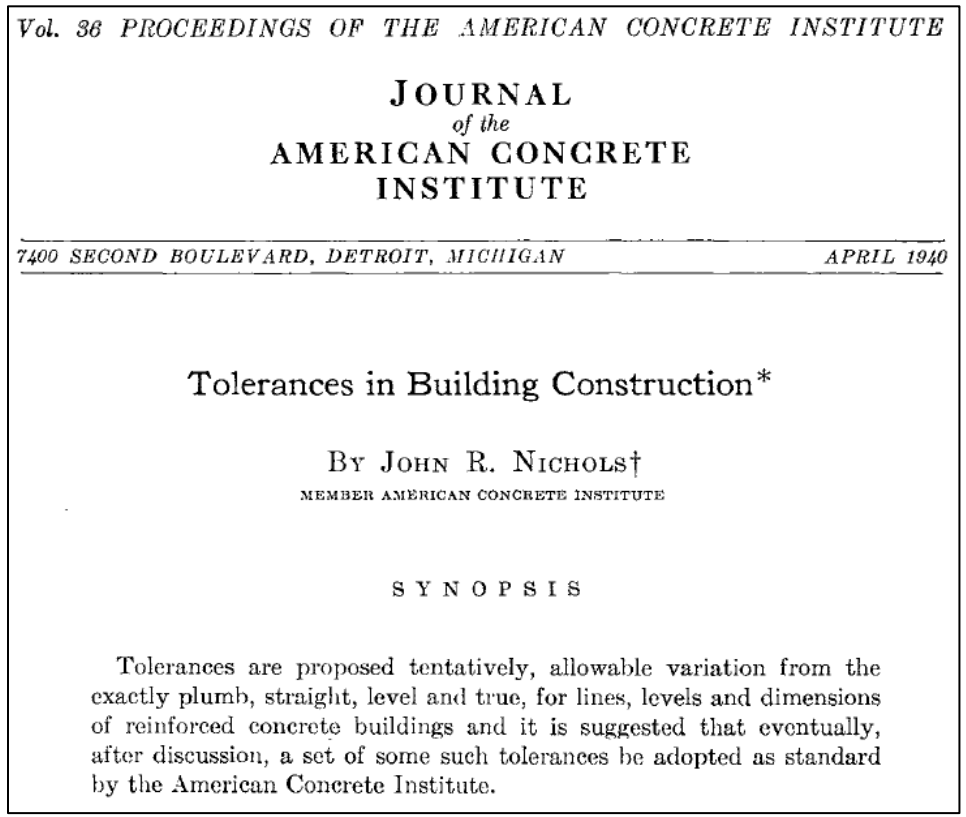


Suddenly, a heated exchange took place between the king and the moat contractor.



- 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



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INSTITUTE

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Tolerances in Building Construction*

By John R. Nichols†
MEMBER AMERICAN CONCRETE INSTITUTE

SYNOPSIS

Tolerances are proposed tentatively, allowable variation from the exactly plumb, straight, level and true, for lines, levels and dimensions of reinforced concrete buildings and it is suggested that eventually, after discussion, a set of some such tolerances be adopted as standard by the American Concrete Institute.

"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

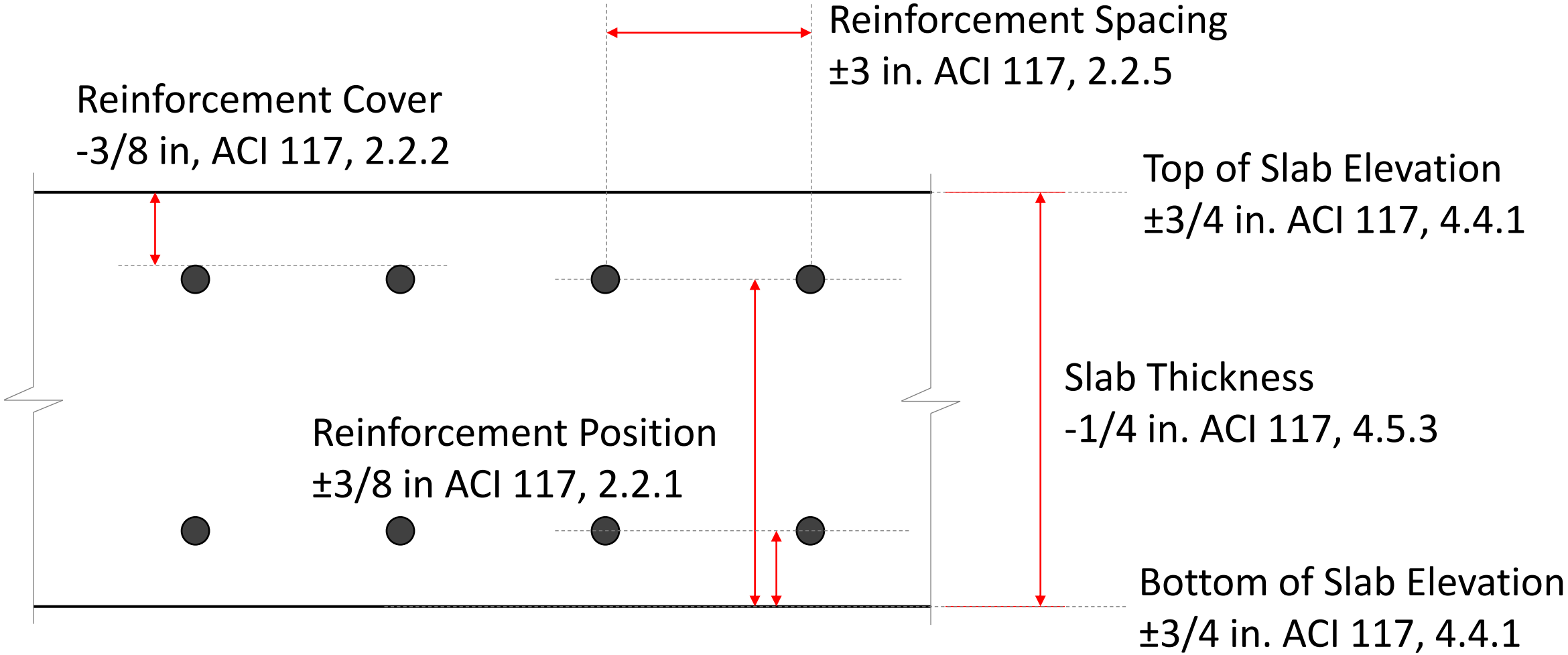
Need for Tolerances

- Imperfection is expected by the structural building codes
- "The purposes of the strength reduction factor ϕ 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)

Tolerance Definition and References

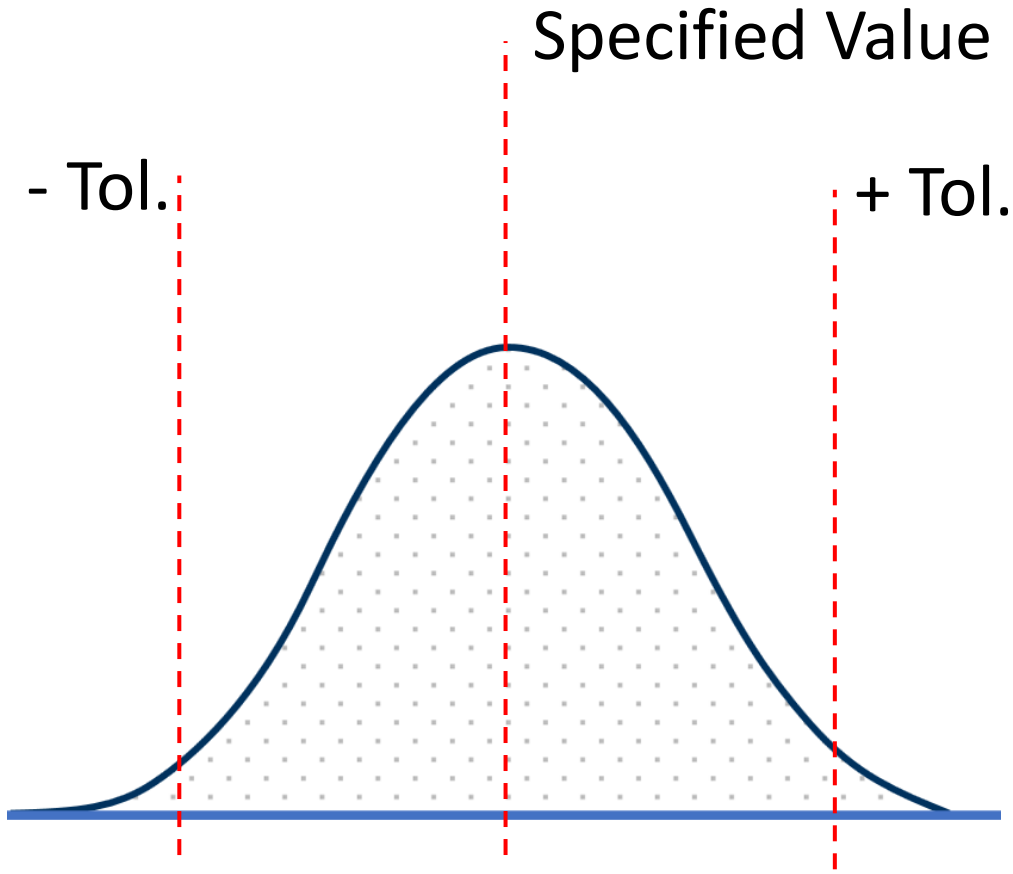
- According to the American Concrete Institute (ACI), a “tolerance” is the permitted deviation from a specified dimension, location, or quantity.
- Common reference for concrete tolerances is *Specification for Tolerances for Concrete Construction and Materials* by ACI Committee 117
- Specification is 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



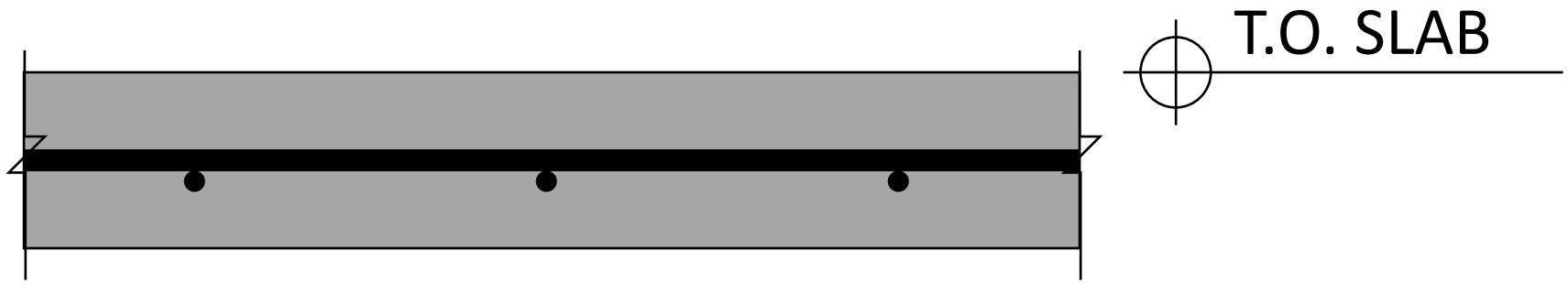
Tolerances Are Not Cumulative

- "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



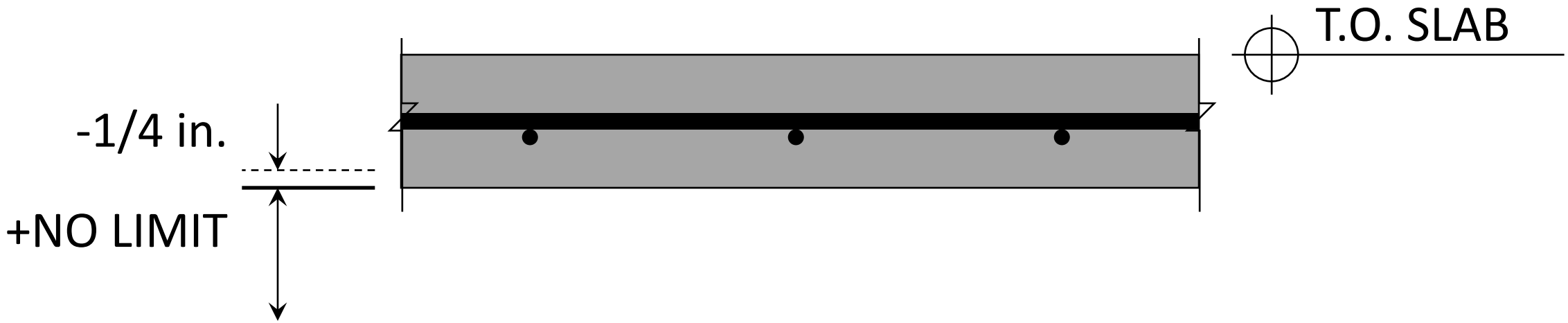
Example: Slab Section

- 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)



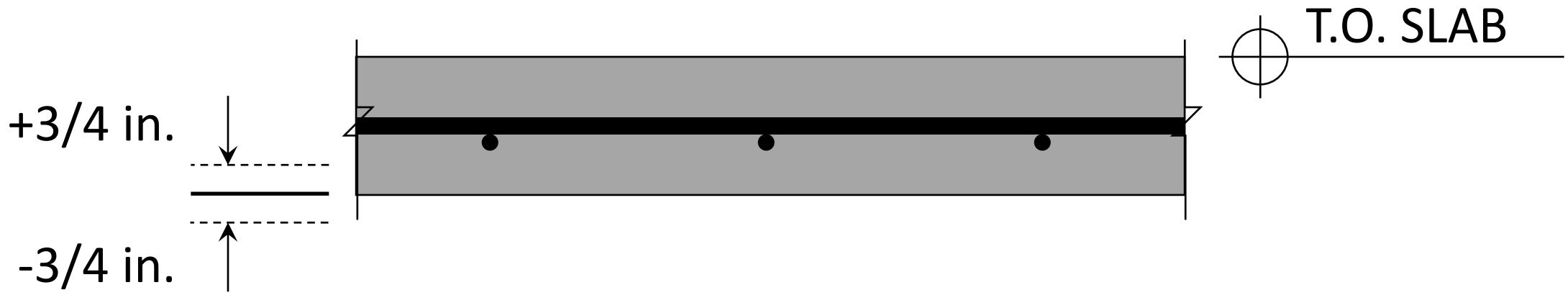
Example: Slab Section

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



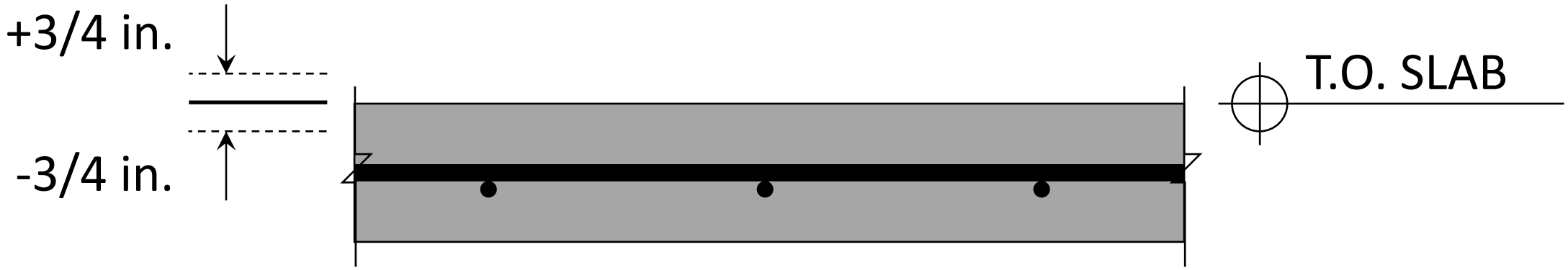
Example: Slab Section

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



Example: Slab Section

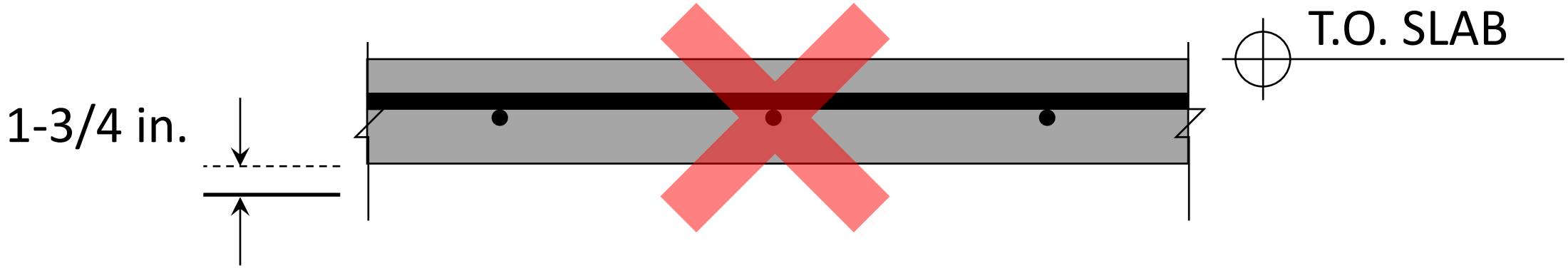
- Deviation from elevation, top of slab (ACI 117-10, Section 4.4.1): +/- 3/4 in.
- Measured before removal of supporting shores



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 (ACI117-10, Section 4.4.1)
  - -3/4” Deviation from elevation, formed surface (ACI 117-10, Section 4.4.2)

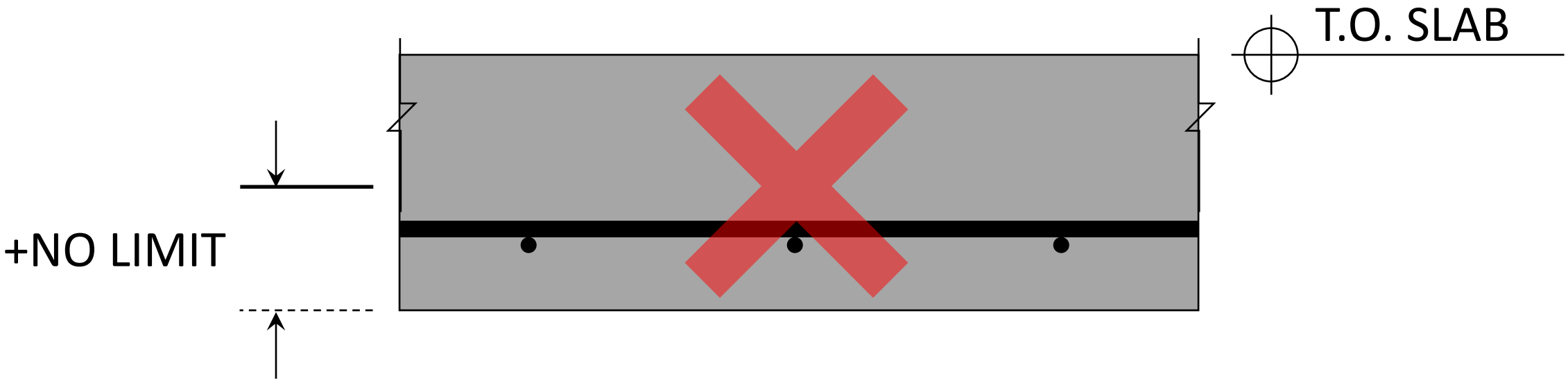
  - -1-3/4 in. Total



Example: Slab Section

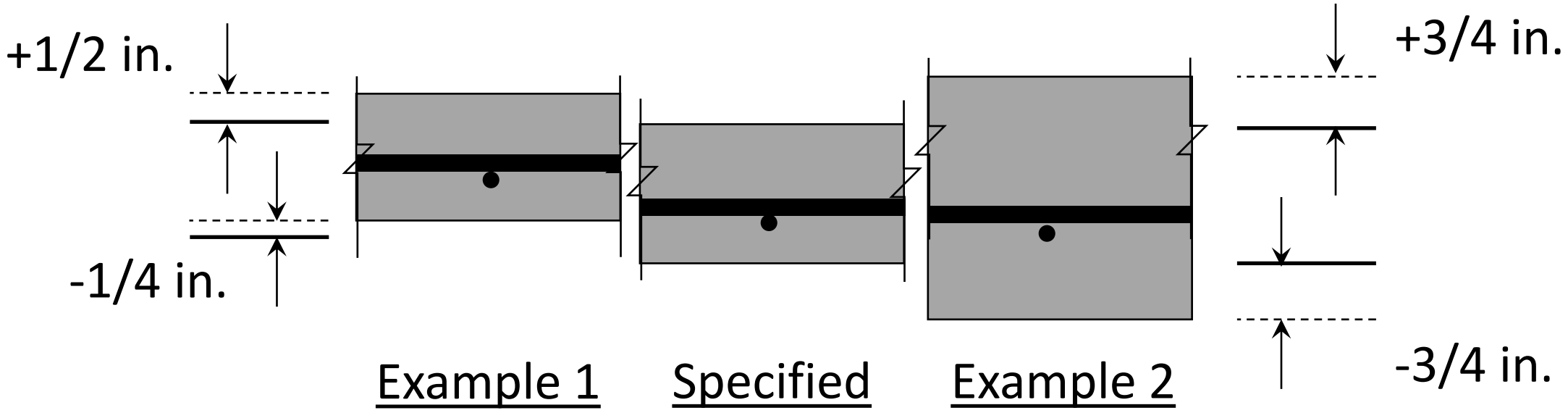
- Tolerances are not cumulative, plus tolerance not:
  - +N.L. Thickness of suspended slabs (ACI 117-10, Section 4.5.3)
  - +3/4” Deviation from elevation, top of slab (ACI117-10, Section 4.4.1)
  - +3/4” Deviation from elevation, formed surface (ACI 117-10, Section 4.4.2)

  - +N.L. Total

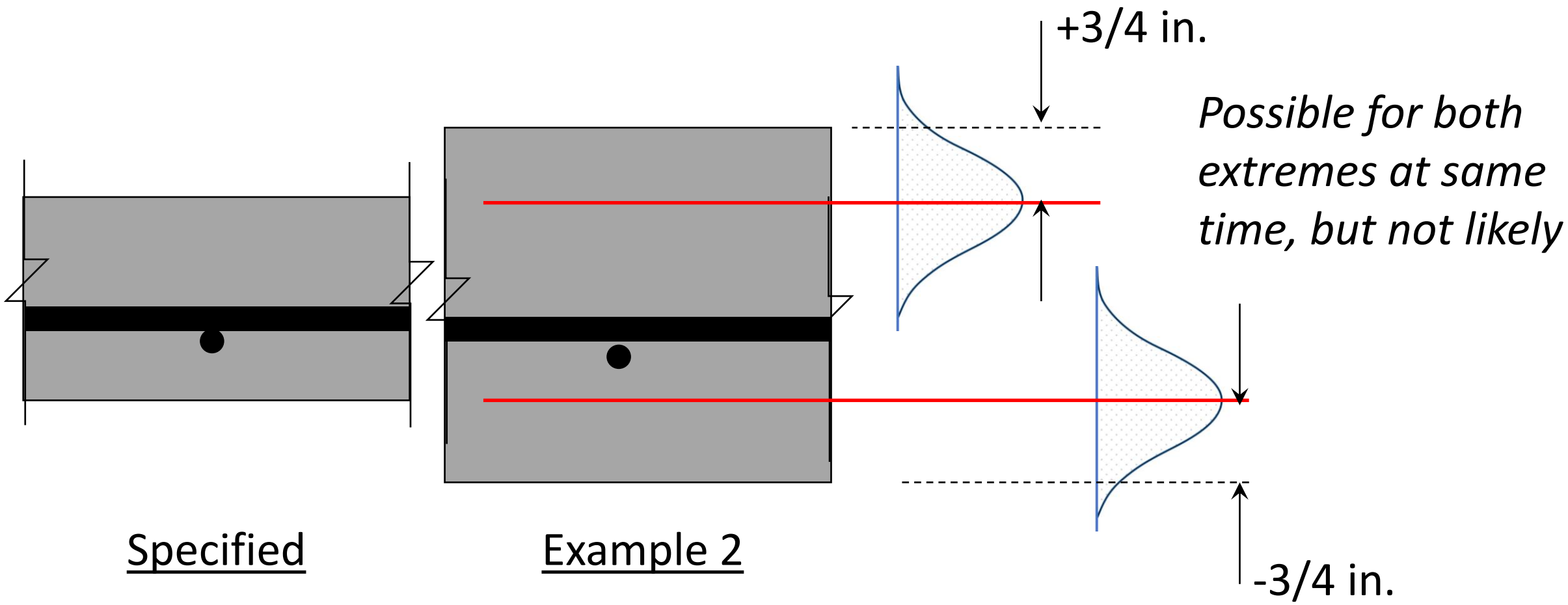


Example: Slab Section

- 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



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)

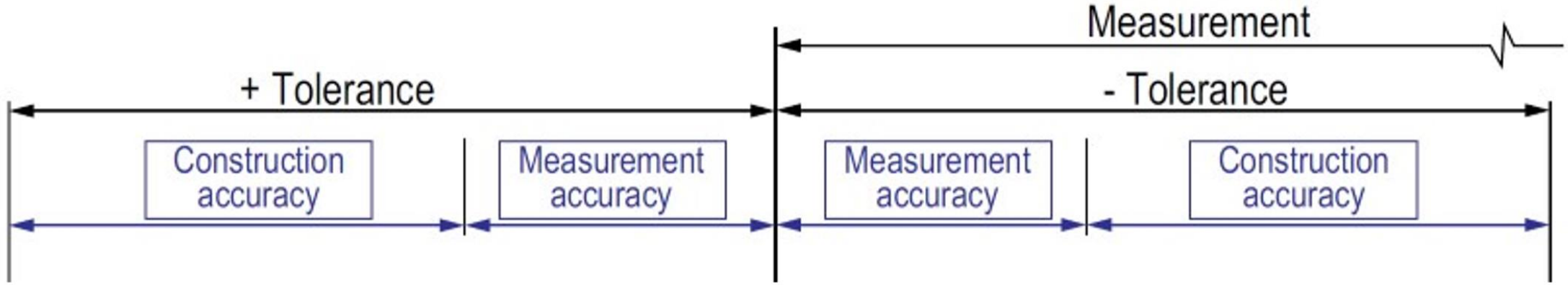


Figure provided by Bruce Suprenant

Measurement Factors

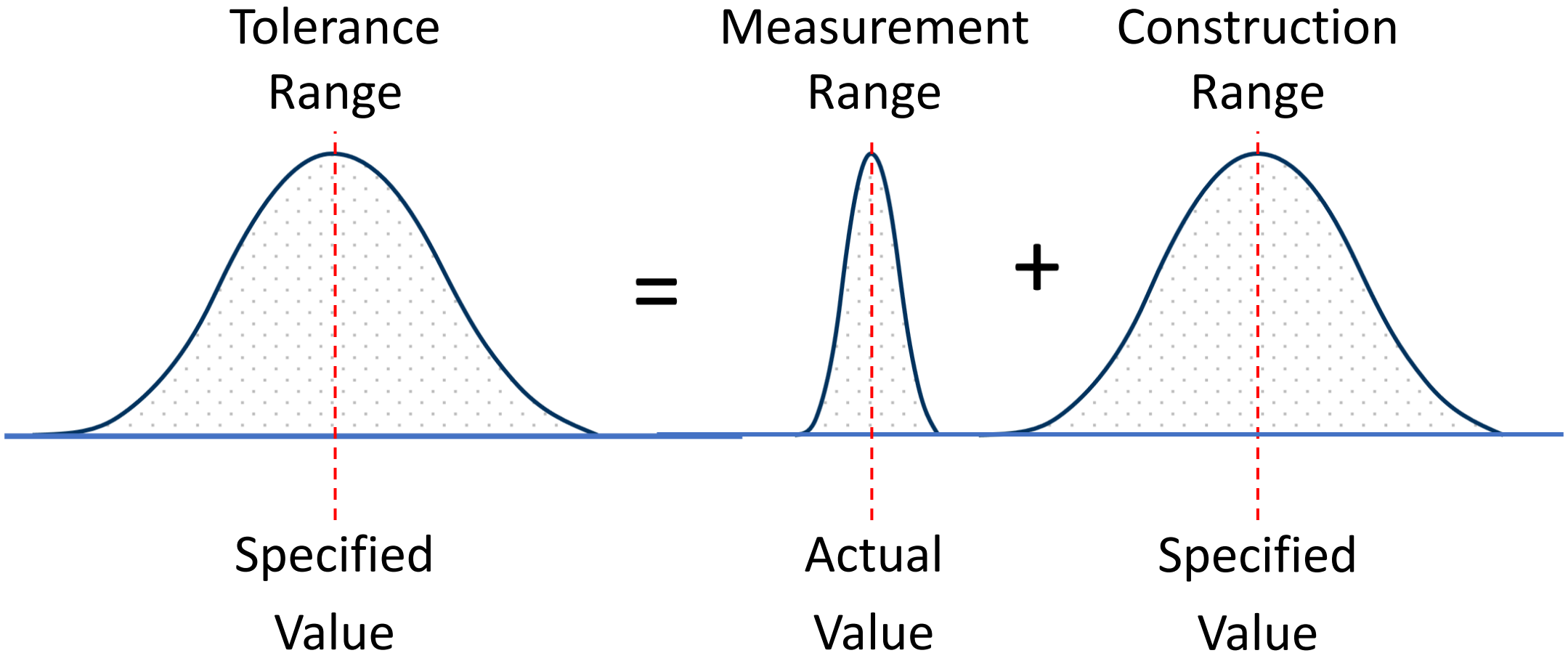
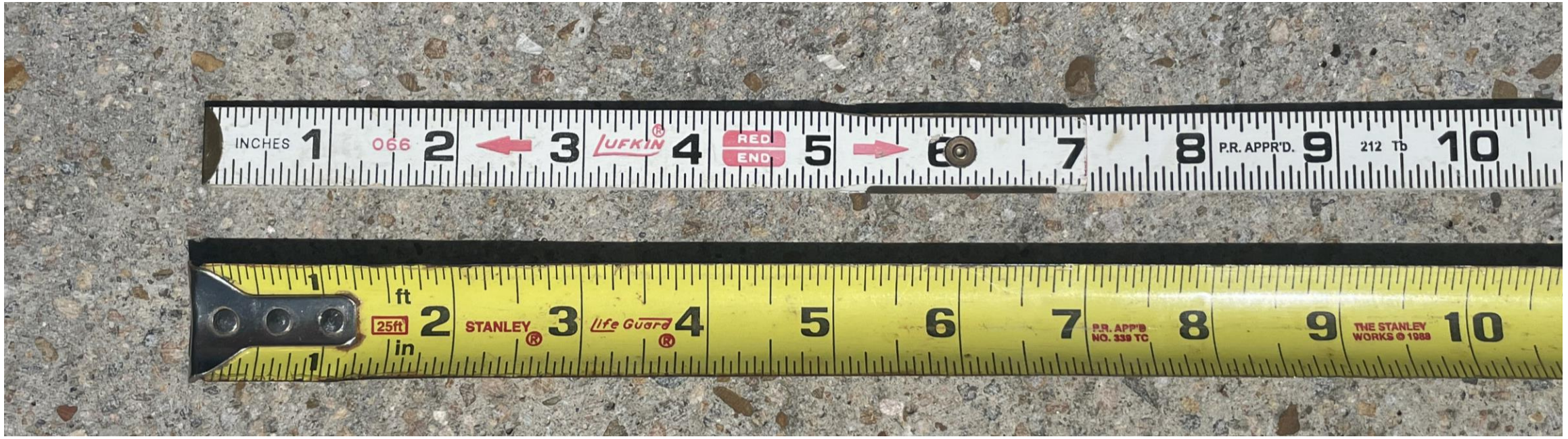


Figure provided by Bruce Suprenant


INCHES
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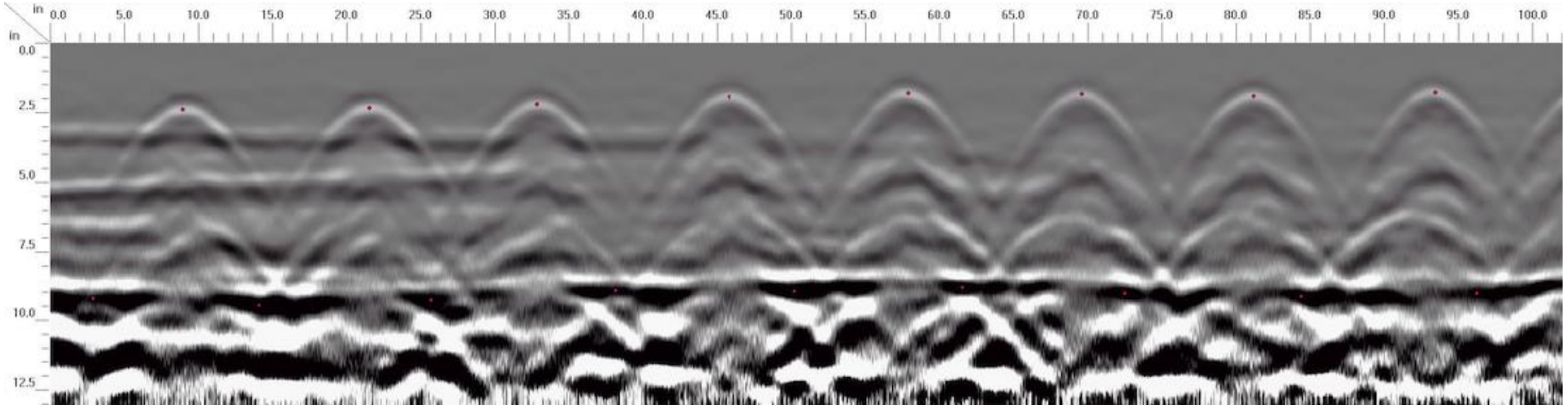
THE STANLEY WORKS © 1989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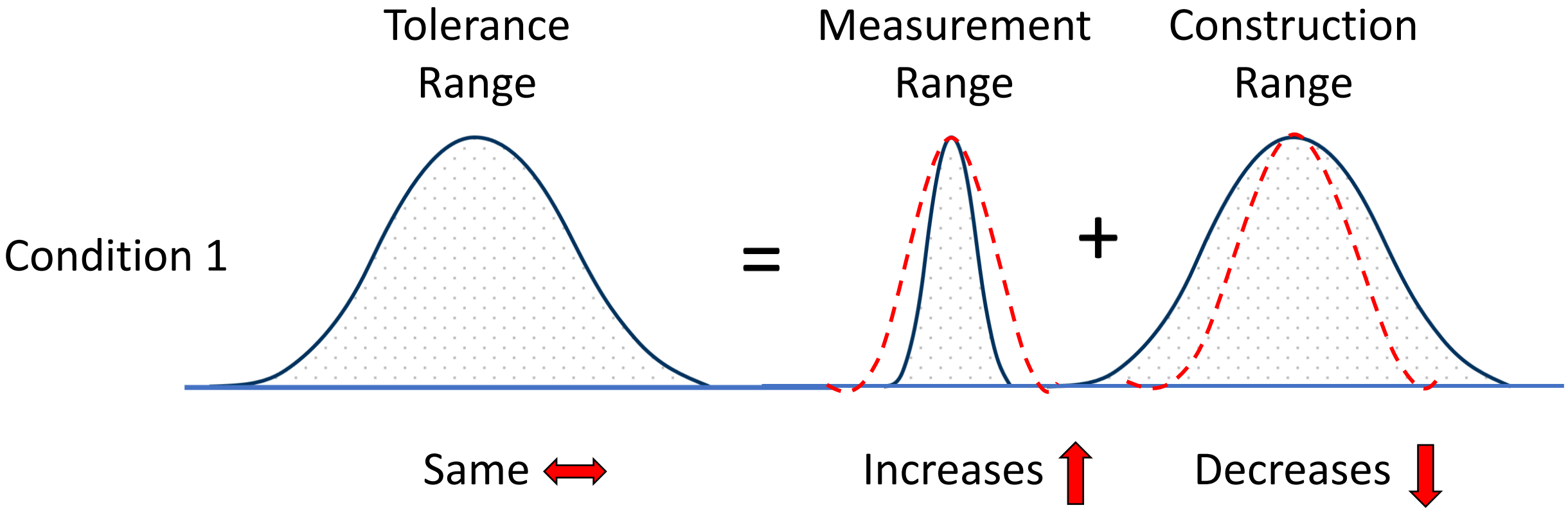
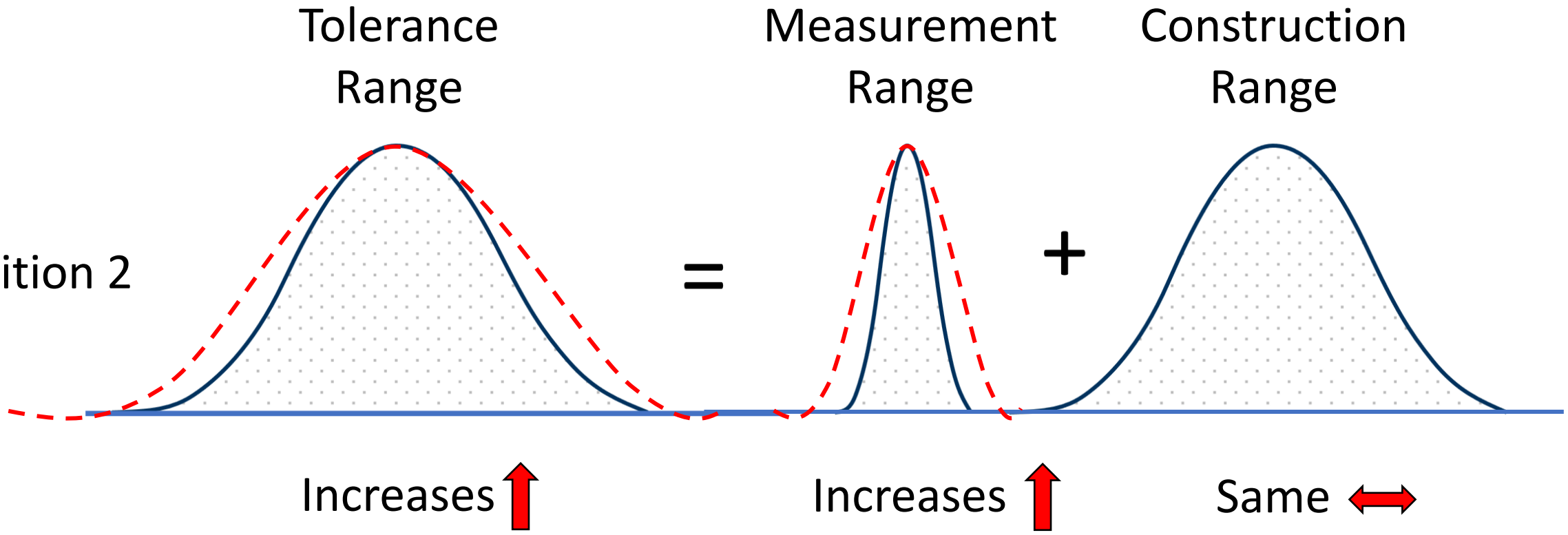
Measurement Factors



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

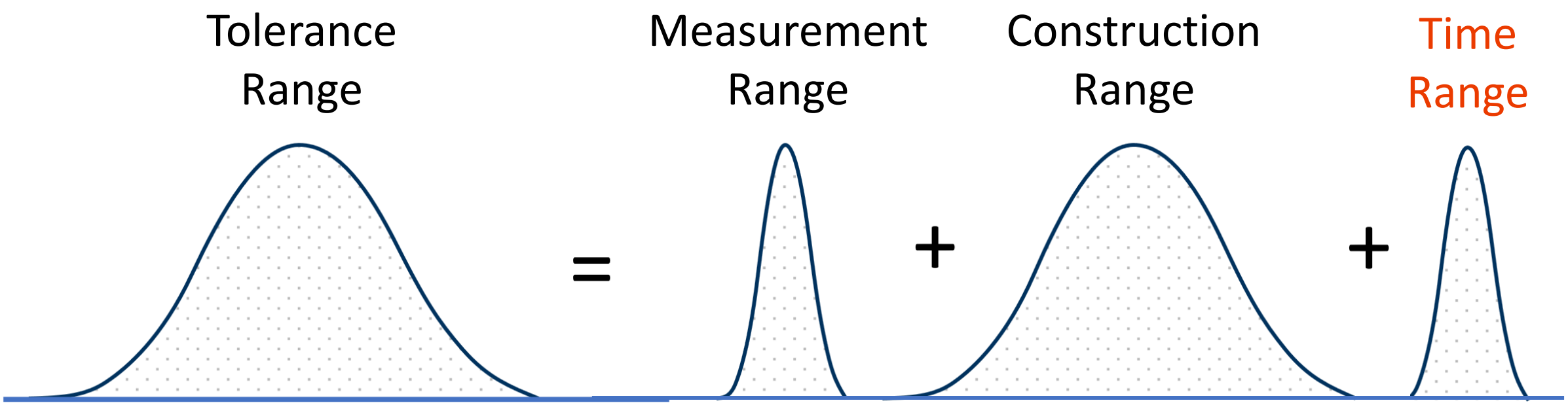
Measurement Factors



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

Figure provided by Bruce Suprenant

Measurement Factors

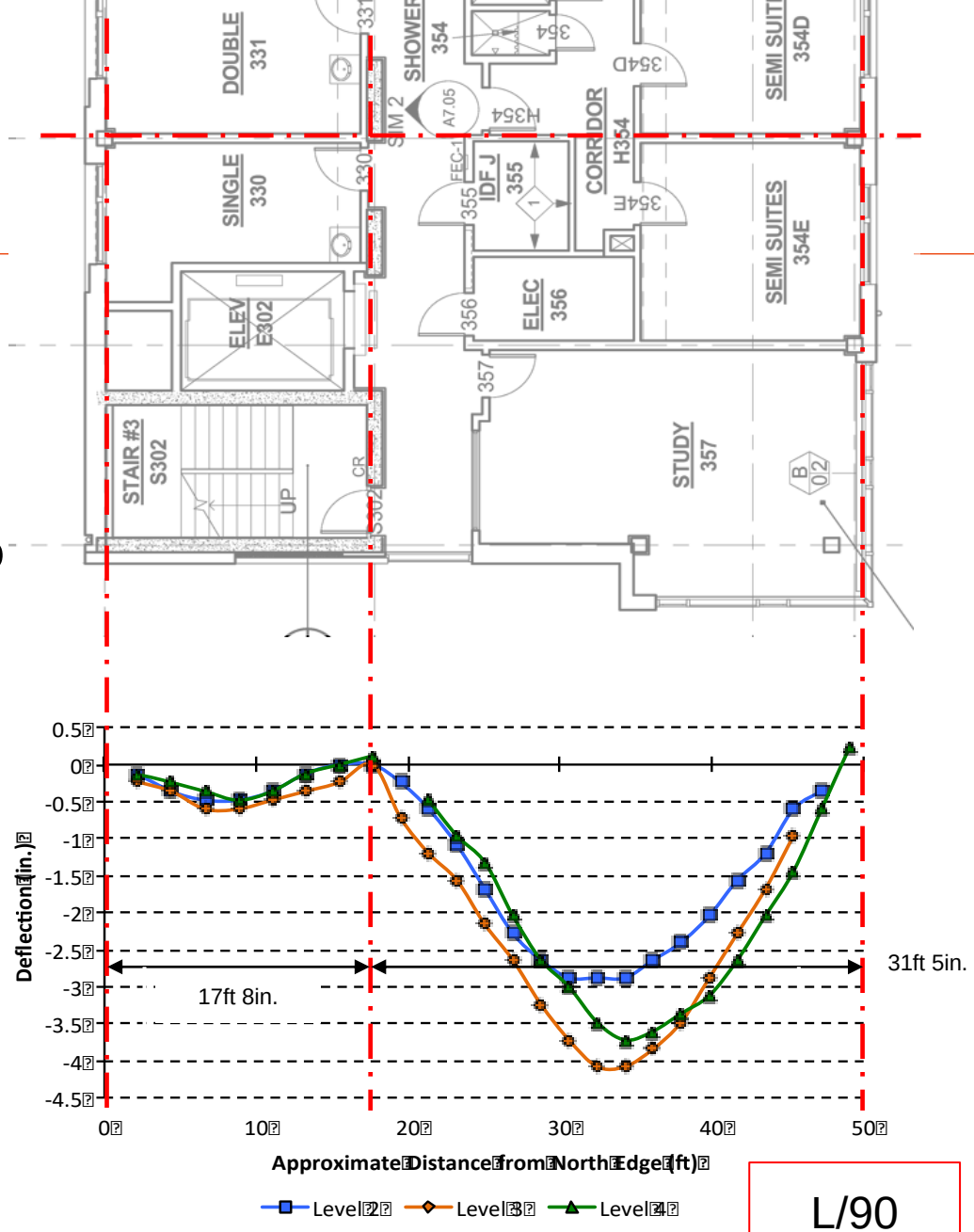


- Structures move, so when tolerances are measured for evaluation can be critical

Modified from figure provided by Bruce Suprenant

Measurement Timing

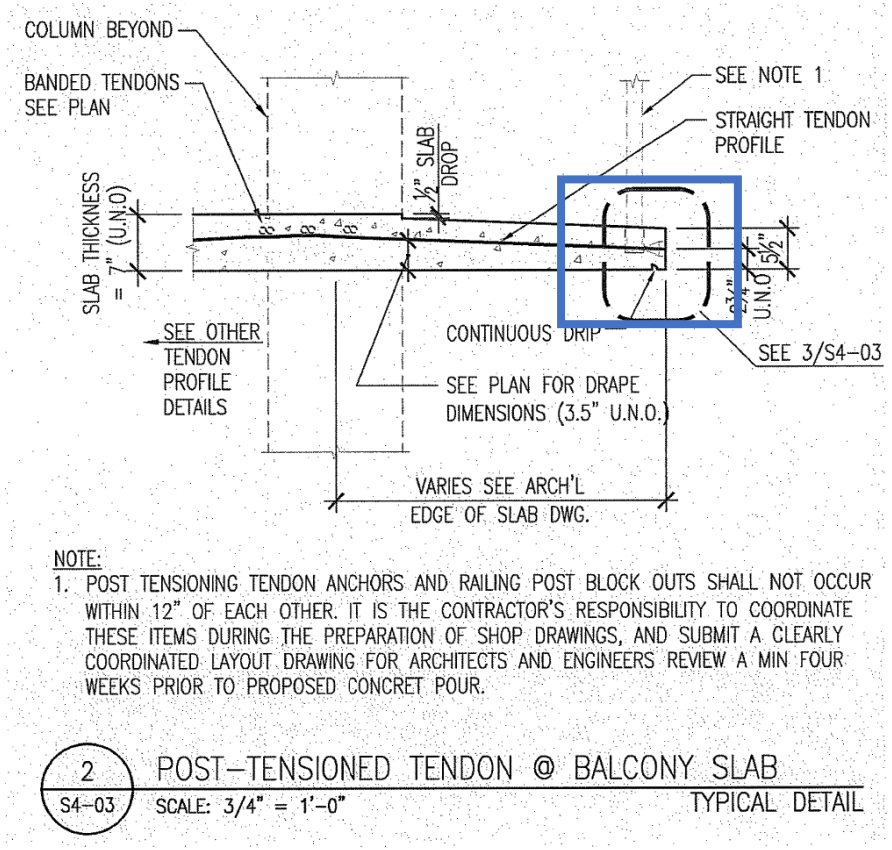
- Limited timing factors are captured by 117
  - Measuring slab flatness 72 hours after finishing operations to avoid time-depend effects
  - Measuring elevations before removing shores to avoid deflections

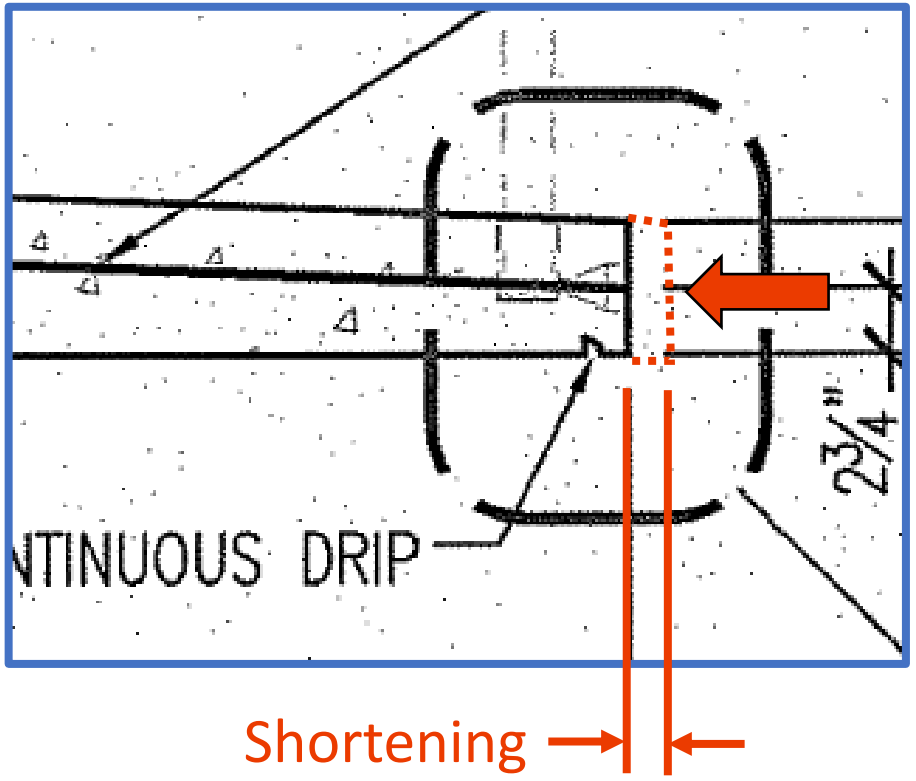


L/90

Measurement Timing

- Other timing factors are not captured by 117
  - Post-tensioning
  - Shrinkage
  - Thermal
  - Retained soil





Back to Bruce

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 measurements of a concrete structural member's location are used to determine if the work is in compliance with the specified tolerances. But structural members move after the concrete has been placed. The movements[1] can be a result of short- or long-term deflection, post-tensioning, drying shrinkage, thermal expansion or contraction, soil 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? In one court case involving a condominium association, variations in member locations were measured more than 15 years after the building was constructed. If these measurements indicated the members were out of tolerance, was that a reflection on the contractor's workmanship?

ACI 117-10[2] addresses some, but not all, movements that affect measured variations that are used to determine compliance with the specified tolerances. This article describes how ACI 117-10 deals with this issue for slabs and how the document could expand this approach for other movements.

Measuring Slab Surface Flatness and Levelness

Slab surface variations are measured by F-numbers or a gap under a straightedge. F-numbers measure the slab's flatness and levelness while a gap under a straightedge measures only surface flatness. Regardless of the method used, ACI 117-10, Section 4.8.4.4, requires that slab-on-ground and suspended slab surfaces "be measured and reported within 72 hours after completion of slab concrete finishing operations and before removal of any support shores." ACI 301-16,[3] Section 11.3.5.2, also includes the same time limit: "Surface flatness and levelness shall be measured within 72 hours after [illegible] submitted to Architect/Engineer [illegible]."

Slabs-on-ground

Commentary Section R4.8.4.4 of ACI 117-10 includes one reason for this 72-hour time limit by stating that: "All slabs will shrink; joints and cracks in slabs-on-ground will curl with time, resulting in a surface that is less flat with the passage of time." ACI 302.1R-15,[4] Section 10.15.1.1, also states: "…the slab-on-ground floor surfaces change after construction as a result of shrinkage and curling." Suprenant[5] reported results of F-number surface measurements for two slabs-on-ground: one for the University of Maryland practice gym and another for

Designing for Movement

Reinforced concrete suspended slabs shored in their initial position deflect into a final position after the shoring is removed. Recognizing the effect of deflection on the serviceability of the slab, engineers sometimes specify that the initial shored position be cambered so that the desired final deflected position is obtained when the shoring is removed. This same approach can be used for other concrete elements that move after being placed in service. Engineers can specify the initial position of walls or perimeter columns for post-tensioned slabs to account for movements.

Pre-construction meetings should address how and when:

- Initial locations of key benchmarks will be measured; and
- Adjustments will be made to compensate for deflections occurring during construction.

Because calculated deflections can differ from actual deflections by as much as ±50%, contractors should provide deflection measurements to the engineer so that adjustments can be made to the initial position as the structure is constructed.

Screenshot

Everyday Issues

by Bruce A. Suprenant and Ward R. Malisch

Effect of Post-Tensioning on Tolerances

Who is responsible for slab movements that produce tolerance issues?

Screenshot

Tolerances for Cast-in-Place Concrete Buildings

A Guide for Specifiers, Contractors, and Inspectors

by Bruce A. Suprenant, PhD, PE, FACI
and Ward R. Malisch, PhD, PE, FACI

ACI AMERICAN SOCIETY OF CONCRETE CONTRACTORS
Enhancing the Capabilities of Those Who Build with Concrete

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.

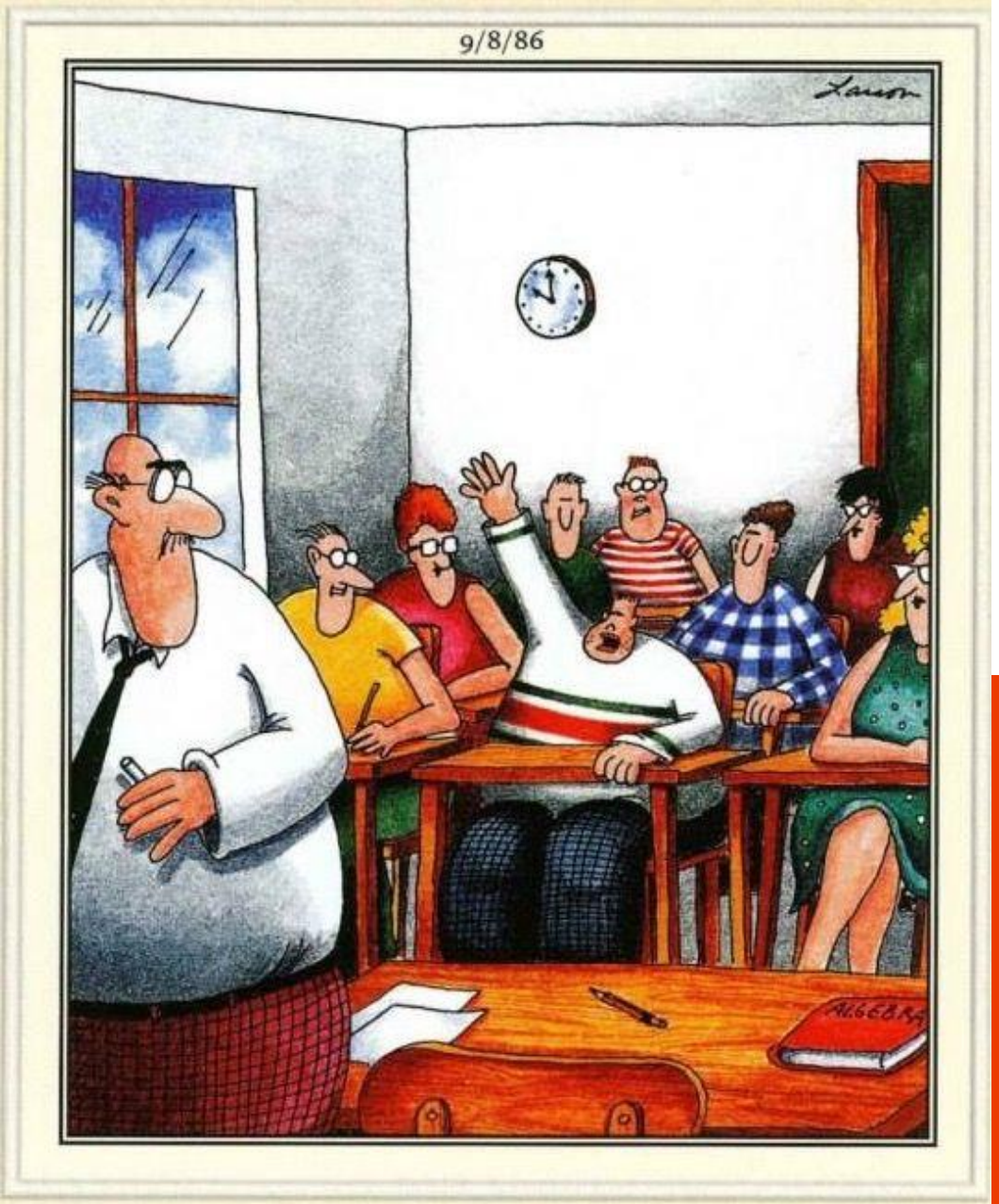
David Shook

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



"Mr. Osborne, may I be excused? My brain is full."

Questions?

Honoring Bruce Suprenant Concrete Construction Contributions

San Francisco, CA

April 4, 2023

Michael Ahern, PE

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