Guide for Tolerance Compatibility in Concrete Construction

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This guide lists industry-standard tolerances and presents recommendations for mitigating tolerance conflicts related to embedded items, elevator cores and hoistways, openings in slabs and walls, manufactured couplers and splicing systems for reinforcing bars, stairs, cladding systems, infill wall systems, surface accessibility components, finish floor coverings, and expansion joints. Evaluating tolerance compatibility can be challenging due to the variety of materials, products, and elements that interface with, or connect to, concrete construction. Failure to accommodate these varying tolerances could have a significant impact on construction quality, cost, and schedules. Architects and engineers can use these guide recommendations to accommodate individual material, product, and element tolerances at their interface with concrete construction. Contractors can use these guide recommendations to mitigate tolerance conflicts during the construction phase.

The materials, processes, quality control measures, and inspections described in this document should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI Certifications or equivalent.

Keywords: construction; embedded items; foundation; reinforced concrete; specification; tolerance; tolerance compatibility.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Evaluating tolerance compatibility at the interface between concrete and other building systems is challenging because materials, products, and elements that connect to the concrete often have tolerances that differ from those for concrete. Coordinating these different tolerances early in the project reduces problems that can impact quality, cost, and schedule during construction.

Architects and engineers can use the recommendations in this guide to accommodate individual material, product, and element tolerances at their interface with concrete construction. Contractors can use the recommendations in this guide to mitigate tolerance conflicts during the construction phase. To assist the architect, engineer, and contractor, this guide lists industry-standard tolerances and presents recommendations for mitigating tolerance conflicts related to embedded items, elevator cores and hoistways, openings in slabs and walls, manufactured couplers and splicing systems for reinforcing bars, stairs, cladding systems, infill wall systems, surface accessibility components, finish floor coverings, and expansion joints. This guide does not list all concrete or industry tolerances or all potential tolerance conflicts.

1.2—Scope

Tolerances for concrete construction from ACI 117 and other industry standards developed by trade and standards-writing organizations are discussed. Tolerances and suggested methods of mitigating tolerance conflicts for common concrete construction procedures and typical construction materials that interface with or connect to concrete elements are described. This guide is not intended to apply to special structures, such as nuclear reactors and containment vessels, bins, prestressed circular structures, thin shell structures, and single-family residential construction. Construction projects may require tolerances that are less or more stringent than contained in this guide.

1.3—Unit conversions

Hard conversions are used throughout this guide. Where individual trade or standards-writing organizations have established a specific SI equivalent to inch-pound units, the value determined by the organization is used. The equivalent SI units for the same inch-pound unit from different sources could be different. Use the units and tolerances specified in the construction documents. If the drawings are in one system of measurement and the tolerances are in another, a soft conversion is acceptable but should not exceed the published tolerance.

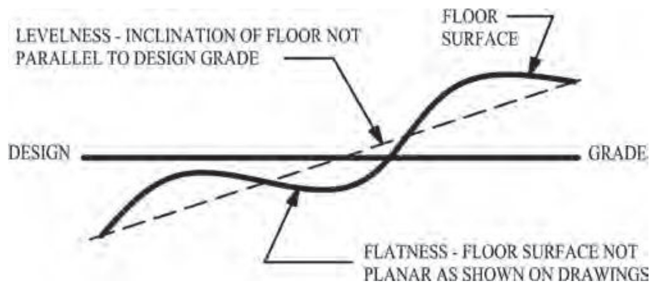

Fig. 2.1—Flatness and levelness.

CHAPTER 2—DEFINITIONS

2.1—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," http://www.concrete.org/Tools/ConcreteTerminology.aspx. Definitions provided herein complement that resource.

anchor bolt—Refer to ACI Concrete Terminology. See **rod, anchor**.

assembly tolerance—overall tolerance for the assembly of components.

bearing devices—shop-attached base and bearing plates; loose base and bearing plates; and leveling devices, such as leveling plates, leveling nuts and washers, and leveling screws.

component tolerance—permitted deviation for a single component.

curtain wall—cladding system installed on the exterior of the primary building structure and carrying no loads other than its self-weight, wind, or seismic loads.

datum—ideal geometric point, line, or plane used to define the location or orientation of a constructed work.

envelope tolerance—boundary defining the permitted deviation for any accumulation of tolerances on a feature, component, or assembly.

erection tolerance—permitted deviation in the orientation or location of a component resulting from its erection or installation.

fabrication tolerance—permitted deviation from the specified dimensions or shape for a manufactured product.

feature—geometric aspect of an element, such as a surface, edge, line, centerline, median plane, corner, or center point.

flatness—deviation of a surface from a plane. (Fig. 2.1)

levelness—deviation of a line or surface from a horizontal line or surface. (Fig. 2.1)

location tolerance—permitted deviation in position relative to a datum.

nominal—stated or expressed, but not necessarily corresponding exactly to the real value.

orientation tolerance—permitted angular deviation relative to a datum.

oversize(d)—of a size larger than the specified or usual size.

random error—measured value that, if repeated, is different than the previous value.

shape tolerance—permitted deviation from an ideal feature.

shoes (for glass railings)—U-shaped base that is anchored to the floor to receive glass railing.

systematic error—measured value of error, also known as measurement bias, that remains constant with each measurement.

tolerance—permitted deviation from a specified dimension, location, or quantity.

CHAPTER 3—TOLERANCE COORDINATION AND RESPONSIBILITY

3.1—Tolerance coordination meetings

A preconstruction tolerance coordination meeting that includes the owner, general contractor, construction manager, architect/engineer, concrete contractor, and all other subcontractors whose work will interface with concrete construction elements is strongly recommended. Attendees should address the anticipated tolerance compatibility questions and conflicts applicable to their work so that tolerance issues are identified and resolved before concrete construction. Resolution of tolerance issues after contract award may result in changes having to be made to the contract terms, which may affect one or more of the parties involved. This document is written primarily for the traditional design-bid-build project delivery method. Other project delivery methods may allow for earlier tolerance coordination

3.2—Responsibilities

3.2.1 On most projects, the architect/engineer is responsible for coordinating tolerances for the construction, as shown in the following excerpts from documents published by the American Concrete Institute and American Society of Concrete Contractors.

a) ACI 347—"The engineer/architect should be responsible for coordinating the tolerances for concrete work with the tolerance requirements of other trades whose work adjoins the concrete construction".

b) ACI 117—"*Compatibility*—Designers are cautioned to use finish and architectural details that are compatible with the type and anticipated method of construction. Finish and architectural details used should be compatible with the concrete tolerances which are achievable."

c) ASCC Position Statement #18 (ASCC 2004b)—"Contractors coordinate their own work, but they aren't responsible for adjusting tolerances or ensuring that tolerances for the work of other trades are compatible with their own work. Only the design professional can decide which tolerances are reasonable and compatible."

d) Guidelines for Authorities and Responsibilities in Concrete Design and Construction (ACI Committee on Responsibility in Concrete Construction 2005)—"The Design Professional should specify tolerances where appropriate in the contract documents as well as any special or unusual requirements that are necessary."

Specialized concrete construction or construction procedures thus require the design professional to include specialized tolerances. The ACI Responsibility Committee also indicates that:

> The design professional must always take overall design responsibility for the safety and proper performance of the completed structure; but it can be appropriate to delegate certain aspects of engineering design to specialty engineers working for the constructor or subcontractors. When any of this design work involves engineering (as opposed to simply detailing), it should be done under the control of an engineer who is licensed in the state of the project and who takes responsibility for such work.
>
> The Specialty Engineer employed by the constructor should perform design services that are subject to the review and approval of the Design Professional. This review and approval will not relieve the Constructor and his Specialty Engineer of their design responsibility.

Such specialty engineers might also be involved in assisting with tolerance coordination and compatibility between different elements or products.

3.2.2 It is critical that the architect/engineer account for tolerance requirements in the contract documents and develop details that provide for the required clearances and adjustability between concrete and other construction elements. When specific industry standard tolerances do not exist, the architect/engineer should coordinate with individual manufacturers and the general contractors, as required, to develop details that provide for individual and accumulated tolerances. Additional industry standard construction tolerances are found in the *Handbook of Construction Tolerances* (Ballast 2007).

3.2.3 Methods of mitigating tolerance conflicts should include the effects of deflection, creep, drying shrinkage, or other possible sources of long-term dimensional changes in concrete. If building movement caused by deflection, shrinkage, creep, or other sources affects the space allowed for tolerance variations of the structure during construction, the architect/engineer should specify unique requirements to mitigate these effects in the contract documents. Other ACI documents, including ACI 209R, 209.1R, 209.2R, 435R, and 435.8R, may be of assistance in determining anticipated movement in the structure and interfacing materials during construction.

3.2.4 The architect/engineer and contractor should examine specific ways of applying information in this guide to develop individual methods of mitigating tolerance conflicts in each building project. Methods for ensuring tolerance compatibility should preferably be developed during the design phase prior to bidding or contract negotiation.

3.3—Review and approval

3.3.1 Implementation of the options suggested in this guide for dealing with tolerance compatibility is subject to architect/engineer review or approval. The ACI Committee on Responsibility in Concrete Construction (2005) explains the difference between review and approval, and the responsibility involved, as follows:

> There are a few areas in concrete design and construction where it is logical for the design professional to "review" a constructor's submittal rather than "approve" it. For example, these guidelines recommend giving the constructor ample control over 'means and methods' and total control over job safety. But certain means, methods, and sequences, such as forming flat plate floors, can affect safety or performance of the completed structure. Most constructors prefer design professional input on forming while still retaining control of how and when it is done. Most design professionals want to provide input but do not want to approve the detailed construction methods. In this case, the engineer can review the constructor's forming plans with the expectation that questions or concerns will be resolved prior to commencing work. In this area, the constructor's responsibility (means, methods, sequences) and the design professional's responsibility (completed structure performance) overlap and differences should be settled in the spirit of partnering.
>
> To clarify responsibilities in overlapping areas, one approach is a clear statement in the contract documents which identifies submittals that are for information only and those that require formal approval.

3.3.2 Contract documents should clearly state how tolerance adjustments are processed during construction. They should differentiate between submittal approvals or submittal reviews. Submittal approvals involve tolerance coordination or changes in the contract documents to ensure tolerance compatibility. Submittal reviews describe the proposed means and methods for accomplishing tolerance coordination.

3.4—Measurements

3.4.1 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 (PCI MNL 135). This allows for a reasonable construction variation. The specifier of a tolerance should consider the method(s) that will be used to verify compliance when establishing the tolerance. For example, there is a precision difference between core samples used to verify the thickness of a concrete slab and measurements made using an impact echo device for the same purpose. When considering a destructive versus nondestructive method, it may be preferable to use a nondestructive approach and accept the lesser precision. In this case, the tolerance range will need to be expanded. This compromise has the benefit of not involving a repair and requiring less time. The accuracy of the impact echo device should provide the confidence needed to the entities concerned that the thickness requirement has been met within acceptable variation. This example shows that verification of a tolerance should be considered at the time the tolerance is specified, as well as taking into consideration the functional and aesthetic basis of the tolerance range. This item should be considered during the preconstruction tolerance compatibility meeting, as the methods of verification involve time, reliability, and expense.

3.4.2 Measurements used for specification compliance should be rounded in accordance with ASTM E29.

3.4.3 Initial layout of the project and proper maintenance of primary and secondary control points throughout construction are critical for tolerance coordination and compatibility. Contractors should follow the "Model Standards of Practice, Section D" for Construction Layout Surveys (National Society of Professional Surveyors 2002), including relative positional accuracy for setting the location of proposed fixed works. The model outlines the surveyor's responsibilities, monument establishment procedures, data presentation requirements, and specific relative positional accuracy for the placement of stakes or other materials used to mark the location of proposed fixed works.

3.4.4 The National Society of Professional Surveyors (2002), Section G, indicates that the relative positional accuracy listed in Section D represents the uncertainty of the location of any point in a survey relative to any other point in the same survey at the 95 percent confidence level. The relative positional accuracy, therefore, is also the accuracy of the distance between all points on the same survey. For example, the horizontal positional accuracy for building offset stakes is listed as ±0.03 ft or ±0.36 in. (±9 mm). The National Society of Professional Surveyors (2002) table footnote in Section D indicates this is at a 95 percent confidence level. Without specific information, specified tolerances are usually assumed to be at a 99.7 percent confidence level. Thus, the measurement precision should equal the confidence level. At a 99.7 percent confidence level, the horizontal relative positional accuracy for building offset stakes should be ±0.045 ft or ±0.54 in. (±14 mm). ACI 117 specifies a horizontal deviation from location (for example, edge of slab on ground) as ±1 in. (±25 mm). The relative positional accuracy—that is, the distance between two points in accordance with ACI 117—would be either:

a) ±2 in. (±50 mm) by direct addition

b) ±1.41 in. (±36 mm) by using the square root of the sum of squares. The ratio of the measured precision to tolerance is approximately one-third (0.54/2.00 = 27 percent or 0.54/1.41