

ACI 117.1R-14

Guide for Tolerance Compatibility in Concrete Construction

Reported by ACI Committee 117



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Guide for Tolerance Compatibility in Concrete Construction

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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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Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

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ACI 117.1R-14 was adopted and published August 2014.

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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

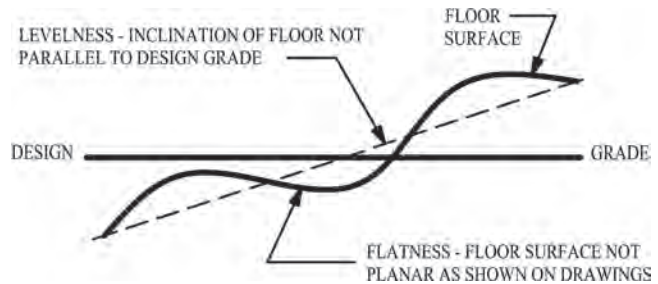


Fig. 2.1—Flatness and levelness.

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.

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 $0.54/1.41$

= 38 percent). Thus, the relative positional accuracy in the [National Society of Professional Surveyors \(2002\)](#) provides reasonable measurement accuracy.

3.4.5 Establish a clear protocol for measurement and acceptance of the toleranced feature, component, or assembly to avoid misunderstandings of tolerance requirements.

3.4.6 Because a building undergoes movements with age, timing may be an important factor in the measurement of a variation. The timing of the measurement should be discussed when measurement protocol and tolerance acceptance are established.

3.4.7 Dimensional changes in materials will occur due to temperature variation; this will affect tolerances. [AISC 303](#) requires dimension to be corrected to 70°F (21°C). ACI and other organizations are silent on the need to correct for temperatures in the measurement process. This effect should be discussed when the measurement protocol and tolerance acceptance are established.

CHAPTER 4—CREATING TOLERANCE COMPATIBILITY

4.1—Steps toward tolerance compatibility

To create tolerance compatibility, the architect/engineer can use three basic steps on any project to create tolerance compatibility (4.1.1 through 4.1.3).

4.1.1 *Gather tolerance information*

4.1.1.1 Tolerance information comes from codes and standards, industry organizations, manufacturers, designers, users, and contractors. This guide provides common industry tolerances for cast-in-place concrete and the variety of materials, products, and elements that interface with or connect to concrete construction. Some tolerances are unpublished and should be obtained directly from the manufacturers and contractors.

4.1.1.2 Tolerances are typically necessary to ensure the functioning, performance, aesthetics, quality, or assembly of a component. Preferred practice is to ask manufacturers, fabricators, and contractors for the tolerance of interfacing products specified to determine the requirements for proper function, dimensional variations that impact installation, and any space or clearance required for installation. The architect/engineer should identify what is required for the constructed element. This could include plumbness; levelness; flatness; a clear envelope; or the location of an edge, surface, or point. The purpose for the tolerance should be understood and the specifier aware of the four different tolerances: 1) component; 2) erection; 3) envelope; and 4) assembly.

4.1.1.3 Published tolerances are subject to interpretation. To avoid misunderstandings of tolerance requirements, the architect/engineer, contractors, and other interested parties should establish a clear protocol for measurement and acceptance of the toleranced feature, component, or assembly.

4.1.2 *Evaluate tolerance information*—Systematically analyze tolerance information for conflicts.

4.1.2.1 First, identify multiple tolerances for the same interface or component. For example, the [Maple Flooring](#)

[Manufacturers Association \(2005\)](#) and [ACI 302.1R](#) require different concrete flatnesses for the installation of wood flooring; and [AISC 360](#) and [ACI 117](#) have different tolerance specifications for location of anchor bolts and weld plates.

4.1.2.2 Second, identify tolerances required by interfacing components that are inconsistent with the cast-in-place concrete tolerances specified by ACI 117. Some tolerances required for interfacing components cannot be achieved using standard cast-in-place concrete practices. The gap in tolerance compatibility between the concrete and interfacing components could require additional work or rework, such as grinding a floor slab or applying a leveling compound. Differences should be identified and an appropriate solution found. For example, ASCC Position Statement #6 ([ASCC 2003](#)), with reference to conflicting floor flatness tolerances, recommends providing an allowance in the contract documents for any necessary grinding or leveling to ensure tolerance compatibility between the concrete and floor finishes.

4.1.2.3 Finally, to ensure the tolerance system is compatible, investigate how the identified tolerances combine and interact by evaluating various deviation scenarios.

4.1.3 *Generate solutions that create tolerance compatibility*

4.1.3.1 Once tolerance conflicts are identified, select an appropriate mitigation strategy to address them. A variety of mitigation strategies for dealing with tolerance conflicts are used regularly. For example, common strategies to create tolerance compatibility include the use of filler materials such as caulk, floor leveling compounds, and grout; adjustable structural connections; suitable clearances; and custom fabricating parts based on as-built dimensions of in-place construction. Successful application of the specific solutions included in this guide is job-dependent. Strategies on which solutions are based, however, can be generalized to apply to any job.

4.1.3.2 Finding the best solution depends on the nature of the incompatibility, design flexibility, manufacturing processes, construction techniques, and the inspection process. In general, better solutions for creating tolerance compatibility in terms of safety, cost, schedule, and quality are generated through collaboration with project participants. General strategies can be as simple as a design modification of the connection or interface. They should be implemented during the design phase of a project, and some can also be implemented during the procurement, shop drawing, and field construction phases. In general, lower overall project costs are achieved by implementing mitigating strategies in the early stages of the project cycle.

4.2—More restrictive tolerances

4.2.1 Specifying more restrictive tolerances is often the easiest way to create tolerance compatibility. This option, however, is rarely the most economical or practical solution for tolerance incompatibility problems. ACI 117 states that specification of more restrictive tolerances often results in an increase in material cost and construction time. The difficulty in specifying a tighter tolerance is choosing one that can be realistically achieved, even with the increased cost. [AISC 822](#) warns that choosing a more restrictive tolerance

as a solution is a risk to the project. Common law principles require a contractor to complete a contract agreement regardless of the extra costs or difficulties encountered in the process. If, however, the specified tolerance proves to be so impracticable that it is impossible to meet, the contractor should seek a change order to provide an alternative solution. The rationale frequently used by the courts for excusing the contractor on the basis of impossibility is that the contract contains an implied condition that performance, as contemplated by the contracting parties, is possible at the time performance is due (Sweeney et al. 1997).

4.2.2 The AISC perspective on specifying more restrictive tolerances is shown in an excerpt from **AISC 822**:

Designers can specify special steel frame tolerances to limit the amount of tolerance that must be addressed in the design and detailing of the façade systems and attachments. However, it is unreasonable to disregard the realities of construction practices. The AISC *Code of Standard Practice (AISC 360)* defines tolerances for the steel frame that have been developed through long-standing usage as practical criteria. Although many frames are erected well within these tolerances, requiring more stringent tolerances should only be considered for exceptional situations, and based on consultation with fabricators and erectors local to the project. In the event that this is attempted and the design otherwise has no recourse to accommodate greater tolerances, there is a real risk to the project, as the probability of exceeding these tolerances is significant and the consequences to the project schedule and budget can be severe. Alternatively, the components of the wall will have to follow the frame, and this may compromise the appearance. Fortunately, a balance can be achieved by providing for the tolerances in the configuration of the attachment details.

Providing for the tolerances in the configuration of the attachment details is a viable solution to the problem. Refer to the Commentaries to Sections 7.5.1 and 7.13.3 of **AISC 360** for more information on restrictive tolerances.

4.3—Tolerance limit considerations

4.3.1 Basis for tolerances—**ACI 117** defines tolerances as the permitted deviation from a specified dimension, location, or quantity. Tolerances define the acceptable deviations for allowances within design and size. The choice of tolerances reflects the economic balance between the cost of improving accuracy and accommodating deviations in the design. Not all tolerances are based on the same statistical confidence level. **CSA A23.1/A23.2** provides concrete tolerances that are plus or minus the value stated at a 90 percent confidence level, allowing for an expected 10 percent deviation out of tolerance and required rework. For a normal distribution, the 90 percent confidence level represents an area calcu-

lated as the mean ± 1.64 times the standard deviation. **BS 5606** recommends that the tolerance represent 95 percent of the expected variation or the mean ± 2.0 times the standard deviation.

In the United States, many standards organizations and manufacturers do not provide a confidence level for many of their stated tolerances. Because of this, it is common to assume that the stated tolerances represent 99.7 percent of the expected variation or ± 3.0 standard deviations.

4.3.2 Consequences of choosing a tolerance—Details that accommodate the **CSA A23.1/A23.2** 90 percent tolerance confidence limits still require correction of 10 percent of the work, on average. Likewise, choosing a 95 percent or 99.7 percent tolerance value still requires corrective work for 5 percent and 0.3 percent of the work, respectively. Understanding the amount of corrective work required is a function of the confidence level of the tolerance chosen.

4.3.3 Combining tolerances—**ACI 117** provides position, location, and plan dimension tolerances, making it necessary to combine them for a length dimension tolerance. For example, if the nominal plan clear dimension between the top concrete floor surface of Level 5 and bottom elevation of Level 6 slab is 8 ft 0 in. (2440 mm), the **ACI** elevation tolerance of the top surface of a shored concrete slab is $\pm 3/4$ in. (± 20 mm). The elevation tolerance of the ceiling of the upper concrete floor is $\pm 3/4$ in. (± 20 mm). What is the possible clear dimension based on these tolerances?

To obtain the constructed clear dimension, the extreme values of the tolerances are added in each direction: $+3/4 + 3/4 = +1-1/2$ in. and $-3/4 - 3/4 = -1-1/2$ in., and then these combined tolerances are added or subtracted to the nominal plan clear dimension. Thus, the constructed clear dimension could be 8 ft 0 in. $\pm 1-1/2$ in. or from 7 ft 10-1/2 in. to 8 ft 1-1/2 in. This methodology is used in a **CRSI EDR40**.

Under certain conditions, however, the tolerances can be combined to provide a more realistic and smaller estimate. Adding the tolerances together provides the largest tolerance estimate and likely overestimates the combined tolerance. For example, if a floor were to be at the extreme tolerance value $+3/4$ in. ($+20$ mm), the ceiling above it should be at the extreme tolerance value $-3/4$ in. (-20 mm). It is unlikely, however, that both extremes would occur at the same location. If the floor and ceiling tolerance are measured independently and randomly, there is a 50 percent chance that an underestimate of the floor tolerance will be accompanied by an overestimate of the ceiling tolerance. Clearly, the probability that both the floor and ceiling tolerance will be at the extreme is fairly small. Therefore, adding the two tolerances together overestimates the probable combined tolerance (**Taylor 1982**).

A probability-based estimate of the combination of the two tolerances is based on the assumptions that the ceiling and floor tolerances are independent and governed by a normal (bell-shape) distribution. The better estimate can be made by squaring the numbers, adding the squares, and then taking the square root as shown

$$\text{combined tolerance} = \sqrt{\text{floor}^2 + \text{ceiling}^2} = \sqrt{\frac{3^2}{4} + \frac{3^2}{4}} = 1.06 \text{ or } 1\text{-}1/8 \text{ in. (in.-lb)}$$

$$\text{combined tolerance} = \sqrt{\text{floor}^2 + \text{ceiling}^2} = \sqrt{20^2 + 20^2} = 28 \text{ mm (SI)} \quad (4.3.3)$$

Note that this combined tolerance is approximately 25 percent less than the larger combined tolerance estimate. If the 3/4 in. (20 mm) tolerance was based on a 99.7 percent confidence level (± 3 standard deviations on either side of the mean), the combined tolerance of 1-1/8 in. (28 mm) would have the same confidence level. Thus, the most probable estimate of the constructed clear height is 7 ft 10-7/8 in. to 8 ft 1-1/8 in. (2412 to 2468 mm). Based on the properties of a normal distribution, the following constructed clear heights in Table 4.3.3 could be estimated.

Equation (4.3.3) is not always applicable in the situation presented because it reflects the possibility that an overestimate of the floor tolerance can be offset by an underestimate in the ceiling tolerance. There are tolerances and measurements where this is not possible. For example, consider the sum of the measurements of two lengths, x and y , with the same steel tape. The steel tape is being used at a temperature that differs from the temperature for which the tape length was calibrated. If the temperature correction is unknown, the tape may be measuring shorter or longer than the calibrated length; if too long, x and y are underestimated and if too short, x and y are overestimated. Thus, there is no possibility for the cancellations that are justified using the square root of the sum of the squares. The error in tape measuring is considered systematic. Most measurements are subject to random and systematic errors. Systematic errors are often hard to evaluate and more difficult to detect. Measurements are typically set up to ensure that systematic errors are small compared with random ones, allowing for the statistical treatment of measurements.

4.3.4 Steel frame and concrete wall connection example—

Connections between the steel frame and embedded plates in the concrete wall have historically been an industry problem.

The AISC 822 location tolerance at the exterior is +1 in. (+25 mm) toward the building column line and -2 in. (-50 mm) away from the established building column line. This increases to +2 in. (+50 mm) and -3 in. (-75 mm) above the first 20 stories at the rate of 1/16 in. (1.5 mm) per story. The AISC 822 plumb tolerance is 1/500 of the column between column splice points. The plumb tolerance limits the magnitude of location change within each building story. AISC 822 expects that the embedded plate in the concrete wall “Shall be limited to a magnitude that is consistent with the tolerances that are specified in Section 7.13 for the erection of Structural Steel.” Regardless of whether the steel is +1 in. (+25 mm) toward the building line or -2 in. (-50 mm) away from it, AISC 822 requires the connection plate in the concrete wall located where it can receive the steel consistent with the tolerances specified for the structural steel erection. The ACI 117 location tolerance for walls under 83 ft 4 in. (25.4 m) in height is ± 1 in. (± 25 mm) from the plan location. Above 84 ft 4 in. (25.4 m), this increases to ± 6 in. (± 150

Table 4.3.3—Clear height estimates based on properties of normal distribution

Shortest clear height	Largest clear height	Probability
7 ft 10-1/2 in. (2400 mm)	8 ft 1-1/2 in. (2480 mm)	Overestimates
7 ft 10-7/8 in. (2412 mm)	8 ft 1-1/8 in. (2468 mm)	99.7 percent (3 standard deviation)
7 ft 11-1/4 in. (2420 mm)	8 ft 3/4 in. (2460 mm)	95 percent (2 standard deviation)
7 ft 11-5/8 in. (2430 mm)	8 ft 3/8 in. (2450 mm)	68 percent (1 standard deviation)

Table 4.3.4—Combination of ACI and AISC tolerances

Clear- ance	AISC 822 tolerance	ACI 117 tolerance	Adding directly	SRSS 99.7 percent	SRSS 95 percent	SRSS 90 percent
Longer	+1 in. (+25 mm)	-1 in. (-25 mm)	2 in. (50 mm)	1.41 in. (36 mm)	0.94 in. (24 mm)	0.60 in. (15 mm)
Shorter	-2 in. (-50 mm)	+1 in. (+25 mm)	3 in. (75 mm)	2.24 in. (57 mm)	1.49 in. (38 mm)	0.95 in. (24 mm)
		Total	5 in. (125 mm)	3.65 in. (93 mm)	2.43 in. (62 mm)	1.55 in. (39 mm)

mm) at the rate of 1/1000 times the height above the top of the foundation. Similar to AISC 822, ACI 117 has a plumb tolerance of 3/8 in. over 10 ft (10 mm over 3 m) that limits the amount of location change within each story. ACI 117 provides embed plate tolerances that are with respect to the wall tolerances. AISC 822 and ACI 117 location and plumb tolerances and requirements for location of the embed plates have fundamental incompatibilities. These incompatibilities must be resolved by the architect/engineer design team in the construction documents, or in the field by the constructors. The most reasonable way to deal with the steel and concrete tolerances is for the architect/engineer to design an adjustable connection that allows for both tolerances (Suprenant and Malisch 2009); otherwise, the contractors in the field will be making more expensive field connection adjustments. Table 4.3.4 shows the combination of AISC 822 and ACI 117 location tolerances using direct addition and using the square root of the sum of the squares, with the assumption being that the individual tolerances are independent, random, and governed by a normal distribution. The combination of tolerances is used to consider the desired magnitude of adjustment of the connection between the steel frame and concrete wall. The direct addition provides a larger estimate of the connection movement than the square root of the sum-of-the-squares method (SRSS). The architect/engineer needs to assess the cost of connection fabrication required for each design to address the adjustment shown in Table 4.3.4. The required adjustment should accommodate movement toward and away from the support. There should be a combination of fabrication cost and a small amount of field adjustment time that will optimize total project cost. In buildings 10 stories or less, experience has shown that

a connection capable of moving on the order of $\pm 9/16$ in. (± 14.5 mm) is satisfactory for many buildings to avoid field modifications.

AISC 822 discusses connection design in Chapter 4 and offer advice to the structural steel designer:

Although unlikely, it is possible that the tolerances of each assembled component will vary to the maximum value allowed and combine in the same direction. Statistical research on the distribution of variations for each component and each source is not readily available to the designer. This information would be required for the designer to quantify the risk of exceeding a selected accumulated tolerance. Therefore, the designer does not know how the sum of the specified tolerances compares with the distribution of actual accumulated variations. Although it is not uncommon for designers to detail for an amount of accumulated variation that is less than the sum of the tolerances, they do so with an undetermined amount of risk.

A square root of the sum of the squares (SRSS) approach is one method designers use to combine the individual tolerances that results in a number less (sometimes significantly less) than the absolute sum. There is no basis in statistical theory for this. For the case of façades supported on steel frames, the absolute value of tolerance of the steel frame is large compared with material, fabrication, and erection tolerances of the other components. This dominates the total for which designers must account. Thus, using an SRSS approach essentially means designers are optimistically assuming that the required adjustability to account for accumulated tolerance will not be much greater than that needed for the frame alone.

Designers must use judgment and understand the consequences when selecting an attachment strategy that cannot accommodate the accumulated tolerances based on the sum of the maximums for the individual components. Given the difference in magnitude between the tolerances for frame erection relative to tolerances for other components, designers should, as a minimum, account for the entire frame erection tolerance and use judgment for what additional amount is warranted. Alternatively, designers can consider the effect on the appearance and performance of the wall if it were to follow the as-built line of the steel frame. This is often the necessary approach for tall buildings.

AISC 822 provides advice regarding the architect/engineer's design of façade connections to structural steel frames. The total direct addition of the sum of all the tolerances is proven effective. The cost of this approach, however, is the owner's. AISC 822 does not address the issue where codes

and standards include tolerances based on 90 or 95 percent confidence limits.

Although AISC 822 states there is no basis in statistical theory for the SRSS approach for combining individual tolerances, the statistical basis for the SRSS method can be found in **Ang and Tang (1975)** and **Walpole and Myers (1972)**.

ISO 3443-1 states "Randomly occurring induced deviations may with advantage be treated according to statistical principles, so that account can be taken of the relative probability of small and large values, and may be expressed in terms of the standard deviation, as a measure of variability."

In addition, **ACI 214R** uses the SRSS methodology to combine independent variations from normal distributions. The steel frame-concrete wall connection example provides a basis for evaluating the design strategies described in **Chapter 5** for the variety of tolerances for materials, products, and elements that interface or connect to concrete construction.

4.4—Coordinating architectural layouts with structural framing

The way tolerances are noted in construction documents should clearly communicate the intent, the desired end product, and the priority of function for various specified items. In 4.4.1, keeping the block flush with the concrete beam may be higher priority than the typical block wall tolerances. Tolerance compatibility meetings are a good forum for establishing compatibility solutions.

4.4.1 Masonry below concrete beams—Architectural drawings often show a nominal 8 in. (200 mm) thick concrete block wall under an 8 in. (200 mm) thick concrete beam. This is shown in Fig. 4.4.1, where there are two issues:

- 1) The block wall is actually 7-5/8 in. (190 mm) thick, with a corresponding dimensional product tolerance
- 2) The concrete beam has both location and dimension tolerances

In spite of these issues, some architect/engineer's drawings present the expectation that the block wall will be flush with the concrete beam on both faces. In reality, it may not be flush with either face of the beam. Concrete contractors and masonry contractors each lay out and construct the concrete beam in accordance with their tolerances. Typically, there is no additional layout requirement for the masonry contractor to install the concrete block wall flush with a beam face.

Concrete beams and concrete block walls are often used to isolate stairwells where there is an architectural finish on one side of the block wall, but not on the side exposed in the stairwell. Constructing the block wall flush to the face of the concrete beam on the finish side avoids furring or patching the block wall or having to grind the concrete beam to match. The architect/engineer should note when the concrete block wall should be flush with the beam side and on which side.

Dimensioning with actual sizes instead of nominal ones could clarify the desired outcome. With the added requirement, masonry contractors should proceed with their layout to match the concrete wall with the desired face of the concrete beam. The concrete beam, however, could be out of location or of a width that prevents the masonry wall

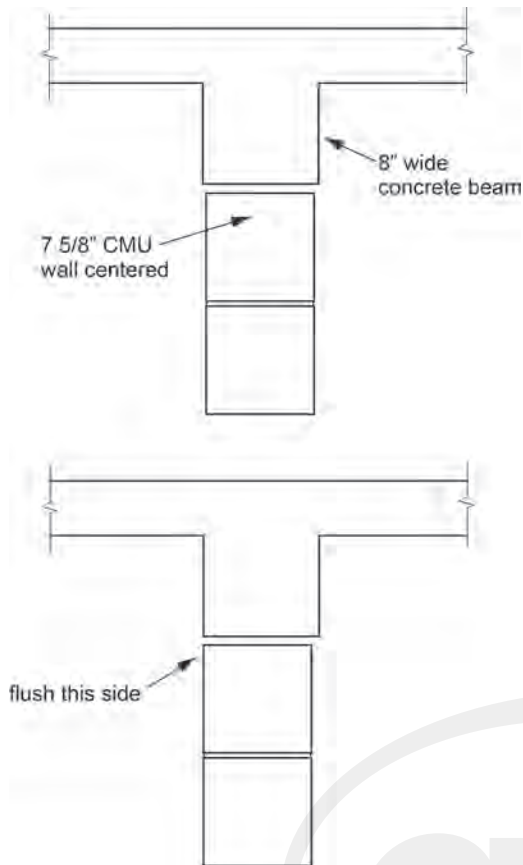


Fig. 4.4.1—Alignment of masonry wall beneath concrete beam.

from being constructed flush with the concrete beam face and within the masonry tolerances. In this case, the architect/engineer should decide if it is more important to have the masonry wall flush with the concrete beam or to have the masonry wall to be constructed within tolerances.

4.4.2 Installation of interior partitions—This section illustrates the need for coordination when establishing compatibility. Product installers often survey the floor elevation before erecting partitions. For example, the results of 54 elevation measurements relative to the theoretical plan elevation are shown in Fig. 4.4.2. The partitions have a height adjustment that allows for $\pm 3/8$ in. (± 10 mm). One option for the installer is to set the partition height off the highest floor elevation of $+3/4$ in. ($+20$ mm). Installers are not responsible for the concrete floor elevations and usually do not have surface preparation in their scope of work. With the partition height adjustment of $\pm 3/8$ in. (± 10 mm), the partitions can accommodate floor elevations from $3/4 - 3/8 = +3/8$ in. ($20 - 10 = +10$ mm) to $3/4 + 3/8 = +1-1/8$ in. ($20 + 10 = +30$ mm) above the theoretical plan elevation. Remedial work and leveling material is required for floor portions less or more than $+3/8$ in. ($+10$ mm) with respect to the theoretical plan elevation, which encompasses approximately 90 percent of the floor area.

Installers can choose to set the partition height at the theoretical plan elevation. The height adjustment would accommodate all floor elevations between $-3/8$ in. (-10 mm) and

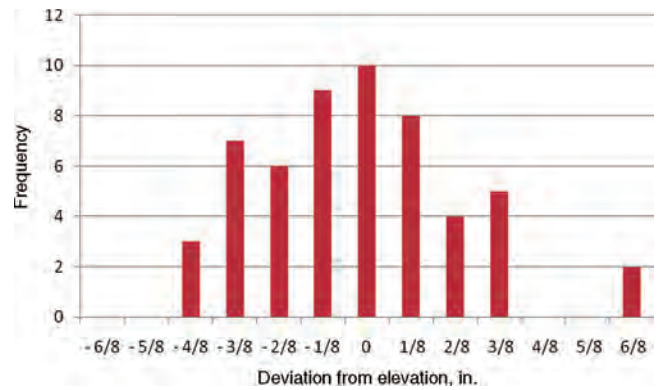


Fig. 4.4.2—Difference between theoretical and actual slab elevation. (Note: Units in inches; 1 in. = 25.4 mm.)



Fig. 4.4.3—Variations of concrete frame and masonry infill surface that is to receive plaster.

$+3/8$ in. ($+10$ mm), which encompass approximately 90 percent of the floor area. Remedial work in this case requires grinding approximately 4 percent and leveling approximately 6 percent of the floor area. Setting the partition height at the theoretical plan elevation would be the better choice, but that decision should not be left in the hands of the partition installer if the partition installer is not responsible for the cost of grinding, leveling, or both.

During the construction phase, construction managers or general contractors should coordinate trades so that the layout of each trade is accomplished within tolerance and with minimal remedial work. When the partition installer's floor elevation measurements are within the concrete contractor's elevation tolerance of $\pm 3/4$ in. (± 20 mm), remedial work would still be required, but the amount of remedial work varies dramatically with the layout choices of each installer.

4.4.3 Masonry infill in concrete frame—Two-coat direct-applied plaster is often specified as an exterior finish over cast-in-place concrete frame with concrete block masonry infill. **ASTM C926** indicates that the nominal total thickness of two coats over unit masonry is $1/2$ in. (12.5 mm), and for cast-in-place concrete it is $3/8$ in. (9.5 mm). This coating thickness is not large enough to handle the individual tolerances for concrete or masonry. Figure 4.4.3 illustrates the

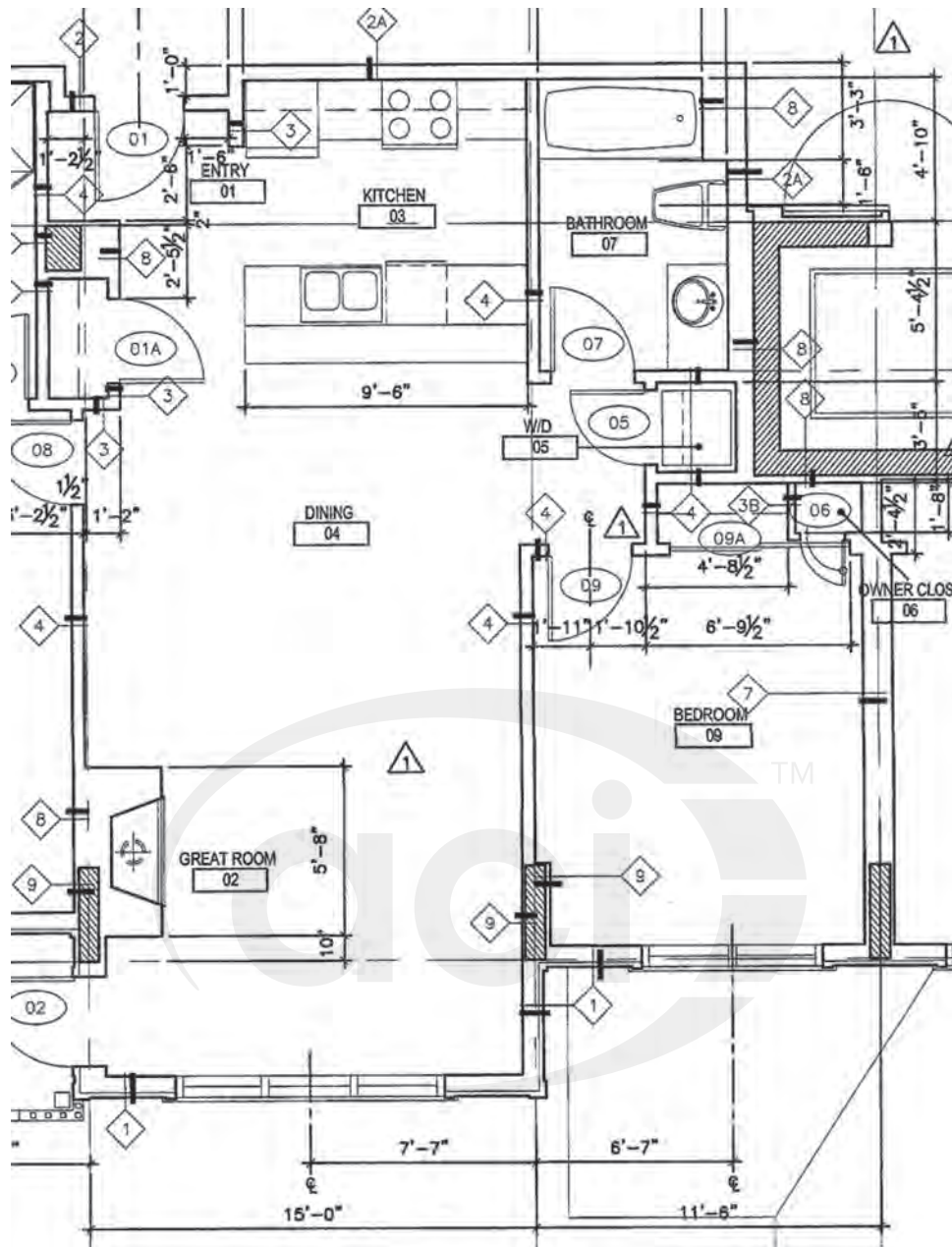


Fig. 4.4.4—Architectural floor plan.

difficulty in placing a thin coating over a concrete frame with masonry infill. The architect can direct the masonry contractor to lay out and construct the block infill to be flush with the concrete frame edges (column faces and slab edges), as long as it can be accomplished within the allowed masonry tolerances. This strategy helps to resolve the exterior finish issue, but does not address any potential interior finish issues.

4.4.4 Superimposing architectural drawings over structural drawings—This section presents an example that requires investigating all tolerances for adjacent, interfacing, and connected components; evaluating how they work as a system and coordinating to identify and apply multiple strategies to achieve compatibility, including trade sequencing. One method used to anticipate tolerance compatibility

issues with varying architectural finishes is superimposing the architectural floor plan over the structural plan. As an example, the structural framing is a concrete flat plate with columns and walls. Figure 4.4.4 shows the architectural plan with concrete columns and walls (cross-hatched). The balcony deck is concrete; bathrooms, kitchen, and entry way have tile floors; and the other rooms are carpeted. Using this layout as an aid, consider how the cabinets will be leveled and transitions made among the tile, carpet, and concrete floor finishes. The concrete floor high spots will be at the columns and walls, unless there is residual camber, and the structural deflection will cause low spots between the supporting vertical elements. Gaps that vary in height along the length below doors are always an issue. Check for orientation and swing of the door relative to the deflected slab.

Table 4.5—Estimated structural movements

Structural movements						
During construction, the structure will undergo normal types of movement and deflection. The following are estimates for the structure. Architectural finishes and nonstructural components must be detailed to accommodate these movements.						
A	Midpanel vertical slab deflection	Initial	3 months	6 months	12 months	24 months
	Corner panel	–3/4 in.	–1-1/2 in.	–1-5/8 in.	–1-3/4 in.	–2 in.
	Edge panel	–1/2 in.	–1 in.	–1-1/8 in.	–1-1/4 in.	–1-3/8 in.
	Interior panel	–3/8 in.	–3/4 in.	–7/8 in.	–1 in.	–1-1/8 in.
B	Edge vertical deflection	Initial	3 months	6 months	12 months	24 months
	Corner panel	–1/4 in.	–1/2 in.	–5/8 in.	–5/8 in.	–5/8 in.
	Edge panel	–1/8 in.	–1/4 in.	–1/4 in.	–3/8 in.	–3/8 in.
	Cantilever balcony slab (slab span parallel to framing span)	+1/8 in.	+1/4 in.	+1/4 in.	+3/8 in.	+3/8 in.
C	Post-tensioning	Initial	3 months	6 months	12 months	24 months
	Perimeter edge horizontal	0 in.	–3/4 in.	–7/8 in.	–1 in.	–1-1/8 in.
	Perimeter column tilt	0 in.	–3/4 in.	–7/8 in.	–1 in.	–1-1/8 in.
D	Window/door header deflection	Initial	3 months	6 months	12 months	24 months
	Openings in walls	–1/8 in.	–1/4 in.	–3/8 in.	–1/2 in.	–1/2 in.
	Slab-to-slab openings	See midpanel vertical slab deflections above.				
E	Column shortening	Not applicable to this building.				
	Individual column					
	Difference between columns					
F	Foundation settlement	Not applicable for this building.				
	Individual column					
	Difference between columns					

Notes:

1. Deflection estimates are for dead load plus construction load (estimated at 50 percent design live load).
2. In accordance with ACI 435R-95, “Control of Deflection in Structures,” deflections are estimated within a range of 20 to 40 percent accuracy.
3. Long-term deflection multipliers based on ACI 318-08, Chapter 9, Section 9.5.2.5.
4. Deflection: downward is minus (–) and upward is plus (+).

Coordinate the layout of all finish trades to balance tolerances, reduce the remedial work (grinding and leveling), and limit the cost and schedule impact.

4.5—Communicating information

Implementing strategies for tolerance compatibility often requires estimates of building structural movement during and after construction. A few architects/engineers provide information regarding anticipated structural movements in the structural notes on the drawings. An example of useful information for the architect/engineer and contractors is shown in Table 4.5.

Tolerances are not set for the purpose of accommodating deflection of the structural elements. When dimensioning or detailing attachments or connections, movement of the building should be considered in addition to the allowed construction tolerances. Nonstructural elements are typically detailed by the architect. For example, the estimated amount of deflection is required when developing details for interior partitions or in determining the connection detail of steel studs to the concrete ceiling. Note in Table 4.5 that

after 3 months, the initial deflections can double. This is an important consideration when formulating a strategy to achieve tolerance compatibility. The values in Table 4.5 are examples and do not pertain to any specific job. The architect/engineer should provide the values or other pertinent information for each specific project.

CHAPTER 5—TOLERANCES AND METHODS OF ACCOMMODATING TOLERANCES

Evaluating tolerance compatibility is difficult due to the variety of materials, products, and elements that interface with or connect to concrete construction. Failure to accommodate these different tolerances can have a significant impact on project cost and schedules. Architects/engineers and contractors can use the recommendations in this guide to accommodate individual material, product, and element tolerances at the interface with concrete construction. To assist the architect/engineer and contractor, Chapter 5 reviews industry-standard tolerances and presents strategies for accommodating tolerance conflicts related to work with embedded items, elevator cores and hoistways, open-

Table 5.1.1.1.1—Industry tolerances for anchor rods, column base plates, and related foundations

Item (Fig. 5.1.1.1.1)	AISC 303 tolerances	ACI 117 tolerances
1. Dimension between centers of any two anchor rods in a group	$\leq 1/8$ in. (≤ 3 mm)	—
2. Dimension between centers of adjacent anchor rod groups	$\leq 1/4$ in. (≤ 6 mm)	—
3. Elevation of tops of anchor rods	$\pm 1/2$ in. (± 13 mm)	$\pm 1/2$ in. (± 13 mm)
4. Accumulated variation between centers of anchor rod groups	$\leq 1/4$ in. per 100 ft (≤ 2 mm per 10,000 mm); 1 in. (25 mm) maximum	—
5. Variation in dimension from center of anchor rod group to column line	$\leq 1/4$ in. (≤ 6 mm)	—
6. Centerline of individual anchor rods from specified location	—	3/4 in. (19 mm) and 7/8 in. (22 mm) diameter bolts: $\pm 1/4$ in. (± 6 mm) 1 in. (25 mm), 1-1/4 in. (32 mm), and 1-1/2 in. (38 mm) diameter bolts: $\pm 3/8$ in. (± 10 mm) 1-3/4 in. (44 mm), 2 in. (51 mm), and 2-1/2 in. (64 mm) diameter bolts: $\pm 1/2$ in. (± 13 mm)
7. Position of base plate holes	$\pm 1/8$ in. (± 3 mm)	—
8. Top of concrete foundation	—	+1/2 in. (+13 mm), -2 in. (-50 mm)
9. Top surface of drilled piers	—	+1 in. (+25 mm), -3 in. (-75 mm)
10. Elevation of bearing devices	$\pm 1/8$ in. (± 3 mm)	—

ings 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.

Design and construction strategies: This guide provides recommendations for both design and construction strategies to accomplish tolerance compatibility. These strategies are usually distinguishable and separate, but sometimes overlap both design and construction. For example, shop drawing review is both a design and construction strategy, but can only take place during construction when the shop drawings are created.

Specifying more restrictive tolerances: Note that for the items listed in each section it is possible to specify more restrictive tolerances for any trade(s), or for any manufactured products as a design strategy. Architect/engineers who choose to consider that as a design strategy should refer to the discussion in 4.2.

5.1 Embedded items

5.1.1 Anchor rods and column base plates

5.1.1.1 Discussion

5.1.1.1.1 The tolerances given in Table 5.1.1.1.1 represent current industry standards developed by ACI and AISC. Because there have been conflicting standards in the past and coordinating foundations, anchor rods, and steel construction has been an ongoing issue, industry organizations such as ACI, ASCC, and AISC have been meeting to discuss them in hopes of finding solutions to the problems. An early recommendation was provided in a position statement by ASCC (2004a). Currently, ACI 117, ASCC (2004a), and AISC 303 recommend larger anchor rod holes than those commonly used in the past. These larger holes are recommended to accommodate various tolerance requirements.

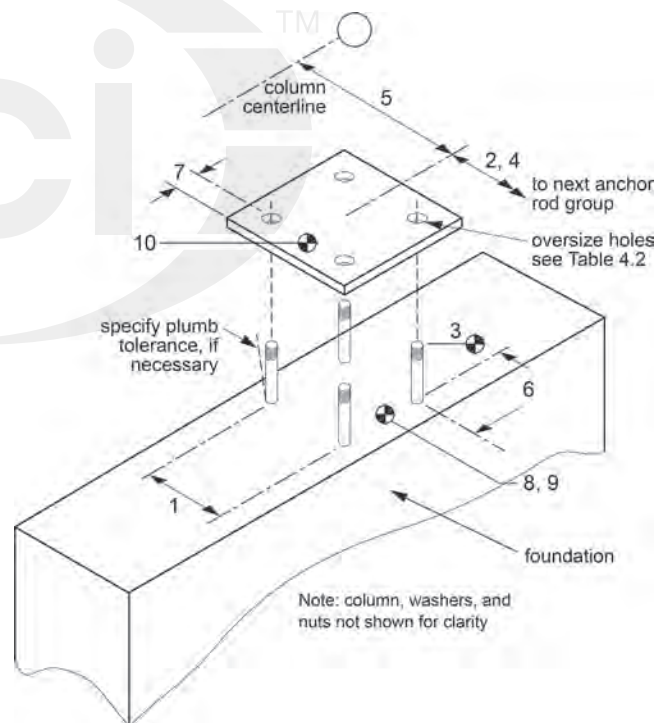


Fig. 5.1.1.1.1—Anchor rod and column base plate tolerances.

5.1.1.1.2 AISC 303, Section 7.5.2, requires that anchor rods be installed “with their longitudinal axis perpendicular to the theoretical bearing surface” with no tolerance for this installation required.

5.1.1.1.3 The design and construction strategies presented in 5.1.1.2 and 5.1.1.3 are for mislocated anchor bolts. Suggested solutions for anchor bolts placed too low or high are given in Putkey (1993).

Table 5.1.1.2.2—Suggested hole sizes in base plates for rods

Bolt size, in. (mm)	Hole size, in. (mm)*
3/4 (19)	1-5/8 (41)
7/8 (22)	1-3/4 (44)
1 (25)	1-13/16 (46)
1-1/4 (32)	2-1/16 (52)
1-1/2 (38)	2-5/16 (59)
1-3/4 (44)	2-3/4 (70)
2 (51)	3-1/4 (83)
2-1/2 (64)	3-3/4 (95)

*Hole sizes are based on statistical analysis as outlined in Suprenant (2006).

5.1.1.2 Design strategies

5.1.1.2.1 The suggestions given herein include those developed by industry groups including ACI, ASCC, AISC, and others (Suprenant 2006; Suprenant and Malisch 2009).

5.1.1.2.2 Consider providing oversized holes that allow for a tolerance of 1/8 in. (3 mm) for steel fabrication and erection and a 1/4 to 1/2 in. (6 to 13 mm) tolerance for anchor rod placement. Note that the 1/8 in. (3 mm) dimension was determined by a statistical combination of the tolerances needed to position the hole, make it, and match the plate to the rods. Suggested hole sizes for various bolt diameters are shown in Table 5.1.1.2.2. The hole sizes for 3/4 in. (19 mm) and 7/8 in. (22 mm), bolts are slightly larger than AISC 325 recommendations. The current hole sizes recommended by AISC 325 for 3/4 in. (19 mm) and 7/8 in. (22 mm) bolt sizes are 1-5/16 in. (33 mm) and 1-9/16 in. (40 mm), respectively. For hole sizes that are larger than AISC 325 recommendations, washer sizes and thicknesses are subject to review by the architect/engineer.

5.1.1.2.3 ACI 117 contains elevation and location tolerances for the centerline of individual anchor rods. Where the location tolerance does not result in an anchor rod that is sufficiently plumb, consider specifying a plumb tolerance for anchor rods and an envelope tolerance (Fig. 5.1.1.1.1).

5.1.1.2.4 The architect/engineer should review the concrete and steel specification tolerance requirements to clarify conflicts.

5.1.1.2.5 Consider specifying or approving drilling holes and bonding the anchor rods in the hardened concrete with epoxy or high-strength grout. This strategy may not be appropriate for heavily reinforced concrete with holes that are difficult to locate or to drill without damaging the reinforcement. Tolerances in Table 5.1.1.1.1 apply to post-installed anchors.

5.1.1.3 Construction strategies

5.1.1.3.1 To position, secure, and align anchor rods within a group, it is helpful to use templates, either steel or plywood, for each base plate or piece of anchored equipment. Orientation of the vertical element can be scribed on the template. The concrete contractor might consider ordering anchor rods with two nuts. The bottom nut should be clear to move below the planned elevation by at least 3/4 in. (19 mm) to allow for adjustment, which might require extra thread. To avoid out-

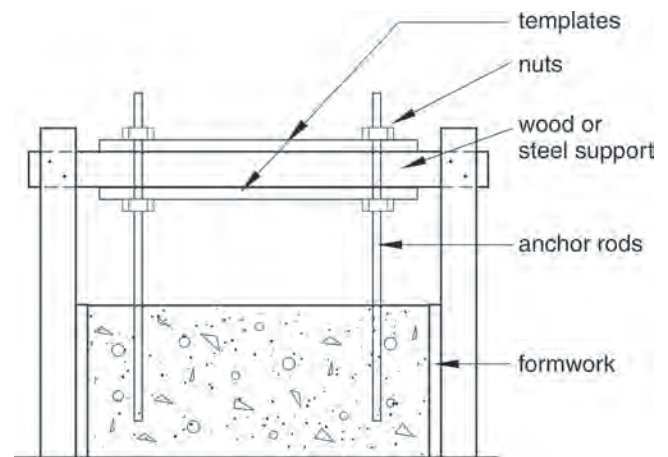


Fig. 5.1.1.3.2—Anchor rod placement.

of-plumb alignment for anchor rods that extend above the concrete, two templates can be used. Where two templates are used, one template may be close to the concrete face and one near the top of the anchor rods. If two template plates are used, consider specifying four nuts. In all cases, the template should be designed to support the weight of the anchor rods without deflecting. These nuts are only to be used to secure the template to the rods and not for temporary support of a column. Refer to AISC 303 for methods of supporting a column and base plate with pregrouted plates, leveling nuts, or shims.

5.1.1.3.2 When a single plate for large bolt groups is impractical, consider using two templates to sandwich the support member spanning the forming. This technique may require longer rods for forming considerations. This suggestion is not intended to reduce the embedment of the rods (Fig. 5.1.1.3.2). Any templates supported from the forms may move as concrete is placed in the forms. If the forms are not rigid enough to maintain the anchor bolt position during concrete placement, then support the anchor bolts independently from the forms. This type of detail only needs to be reviewed by the architect/engineer if the contractor wants to use longer bolts.

5.1.1.3.3 When circumstances require close coordination, consider having the installing contractor of the work requiring anchor rods confirm the as-built horizontal and vertical locations before commencing fabrication of base plates. This is only practical for a small number of anchor rods and activities that are not on the critical path. A more practical solution is to specify or approve drilling holes and bonding the anchor rods in the hardened concrete with epoxy.

5.1.1.3.4 For individual anchor rods, sleeves that permit rod adjustment after the concrete has hardened may be used. The sleeve should be filled with grout after the final positioning of the rod. The use of sleeves should be approved by the engineer.

5.1.1.3.5 When conflicts in the location between the rods and the reinforcing steel occur, consider: a) moving the reinforcing steel so that it still meets the tolerance; b) moving

Table 5.1.2.1.1—Industry tolerances for various embedded items

Item (Fig. 5.1.2.1.1)	Industry tolerances	ACI 117 tolerances
1. Anchor channels, horizontal and vertical deviation to centerline of assembly	Some channel manufacturers suggest tolerances as small as $\pm 1/8$ in. or $\pm 1/4$ in. (± 3 mm or ± 6 mm)	± 1 in. (± 25 mm)
2. Anchor channels, surface of assembly from specified plane	—	$\pm 1/2$ in. per 12 in. with a minimum tolerance of $1/4$ in. (± 13 mm per 300 mm with a minimum tolerance of 6 mm) when assembly dimension is 12 in. (300 mm) or smaller; $\pm 1/2$ in. (± 13 mm) when assembly dimension is greater than 12 in. (300 mm)
3. Weld plates, horizontal and vertical deviation in location	The variation in location of these items shall be limited to a magnitude that is consistent with the tolerances that are specified in 7.13 for the erection of the structural steel (AISC 303)	± 1 in. (± 25 mm)
4. Weld plates, surface of assembly from specified plane	—	$\pm 1/2$ in. per 12 in. with a minimum tolerance of $1/4$ in. (± 13 mm per 300 mm with a minimum tolerance of 6 mm) when assembly dimension is 12 in. (300 mm) or smaller; $\pm 1/2$ in. (± 13 mm) when assembly dimension is greater than 12 in. (300 mm)
5. Edge-of-slab inserts, horizontal and vertical deviation to centerline of assembly	—	± 1 in. (± 25 mm)
6. Stud rails, horizontal and vertical deviation to centerline of assembly	—	± 1 in. (± 25 mm)
7. Stud rails, surface of assembly from specified plane	—	± 1 in. (± 25 mm)
8. Sleeves, edge location of openings	—	$\pm 1/2$ in. (± 13 mm)
9. Ledgers and bollards	—	—
10. Davits/stabilizing anchors	—	—
11. Stair nosings	$\pm 3/8$ in. (± 9.5 mm) maximum variation between largest and smallest riser (IBC 2009)	$\pm 3/16$ in. (± 5 mm) maximum variation between adjacent risers or treads
12. Reglets, horizontal and vertical deviation to centerline of assembly	—	± 1 in. (± 25 mm)
13. Clear distance from embedded item to nearest reinforcement	—	The greater of the bar diameter or 1 in. (25 mm)

the reinforcing even though it is out of tolerance; or c) oversizing the holes in the base plates and using a welded washer to secure the rod. Options b) and c) are subject to review by the architect/engineer.

5.1.1.3.6 If concrete has already been cast around anchor rods and alternative solutions are not available, remedial action could include the following:

a) For rods slightly out of plumb, the contractor could chip out a small amount of concrete behind the bolt and bend it into position.

b) For rods misplaced by less than one diameter, field cutting corresponding holes in the base plate may be considered.

All methods for realignment or base plate modification should be approved by the architect/engineer. **The Code of Federal Regulations, 29-CFR Chapter XVII**, Section 1926.755(B) for column erection stability, states:

a) “Anchor rods (anchor bolts) shall not be repaired, replaced, or field modified without the approval of the project structural engineer of record.”

b) “Prior to the erection of a column, the controlling contractor shall provide written notification to the steel erector if there has been any repair, replacement or modification of the anchor rods (anchor bolts) of that column.”

5.1.1.3.7 Subject to architect/engineer review, when anchor rods are incorrectly placed by at least one rod diameter, it may be better to cut them off flush with the foun-

ation, drill new holes in the correct position, and set new rods with epoxy. For rods misplaced by less than one rod diameter, it may be better to field cut (enlarged or slotted) the corresponding holes in the base plate. If a bolt is proposed to be cut, however, the architect/engineer must review the proposal per 29-CFR Chapter XVII, Section 1926.752(a)(2), especially with regard to the embedment depth of the new rod compared to the original one.

5.1.1.3.8 Subject to architect/engineer review, the contractor may consider cutting the base plate off the column and rewelding it with an American Welding Society (AWS)-approved process or a modified base plate to the column to correct an out-of-tolerance condition.

5.1.2 Other embedded items

5.1.2.1 Discussion

5.1.2.1.1 Embedded items, as listed in Table 5.1.2.1.1, include any fabrication or assembly cast into concrete for the subsequent attachment of other construction items or as an integral part of the concrete element. Typically, there are no industry standards for the manufacture of most embedded items, including anchor channels, edge-of-slab inserts, weld plates, stud rails, sleeves, ledgers, bollards, davits and stabilizing anchors, stair nosings, and reglets. Whereas the International Window Cleaning Association, **IWCA I-14.1**, sets the industry standard for davits and stabilizing anchors, it does not include tolerances for their manufacture or posi-

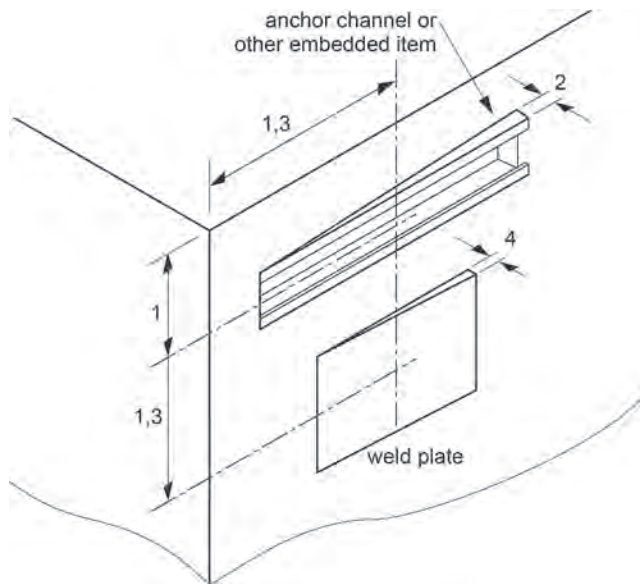


Fig. 5.1.2.1.1—Embedded items placement.

tioning. **ACI 117** tolerances for the location and placement of embedded items are shown in Table 5.1.2.1.1.

5.1.2.1.2 Generally, tolerance incompatibility can arise in two areas:

- 1) In the placement and positioning of embedded items that may create problems for subsequent construction
- 2) In conflicts between concrete reinforcement and the anchors of embedded items

Installation of embedded items and their studs should be coordinated with the reinforcement installation to ensure proper placement.

5.1.2.1.3 As a general strategy to enhance tolerance compatibility, consider using embedment shop drawings for coordination and review by all applicable trades. Coordinate embed requirements with concrete tolerances.

5.1.2.2 Design strategies

5.1.2.2.1 If there is a conflict between the anchors of an embedded item and the reinforcing bars, the embedded item may typically be made larger or longer. This allows new stud locations to provide for anchoring while allowing for adjusting the position of the embedded item around reinforcing bars.

5.1.2.2.2 **AISC 303** states that weld plates and other embedded items should be located and set by the owner's designated representative for construction, in accordance with an approved embedment drawing. Variations in location should be limited to a magnitude that is consistent with the tolerances specified for the erection of structural steel.

5.1.2.2.3 Oversized weld plates should be detailed to accommodate required returns on the weld, to accommodate conflicts between the plate studs and reinforcing steel, and to allow for vertical and lateral adjustment of attached items. Verify **AWS D1.1/D1.1.M** requirements for minimum distance from the edge of the fillet weld and weld plate. In shear walls or other heavily reinforced walls, multiple studs on a weld plate may conflict in several places with rein-

forcing steel, laps, or couplers. An oversized dimension of 4 in. (100 mm) is suggested for weld plates in heavily reinforced walls, although smaller or larger dimensions could be appropriate depending on project conditions. Verify required size of weld plates during the design phase. Coordinate stud locations with design location of reinforcing steel to enable proper placement.

5.1.2.2.4 Unless project conditions dictate otherwise, consider using weld plates rather than anchor bolts for concrete wall ledgers. This allows for adjustments in the ledger to accommodate the differing changes in position of concrete and steel.

5.1.2.2.5 Because **AISC 303** does not state a particular dimensional tolerance for weld plates, consider using **ACI** tolerances for embedment placement and reference **ACI 117** in all applicable sections of the specifications. Design adjustable connections to connect structural steel to concrete.

5.1.2.2.5 Specify, or approve the use of, setting holes in weld plates.

5.1.2.2.6 Accurate placement of reglets—grooves in a concrete wall to receive flashing—may be necessary for practical or aesthetic reasons. If so, the architect/engineer should consider the appropriate tolerances in the contract documents.

5.1.2.3 Construction strategies

5.1.2.3.1 A preconstruction tolerance meeting should be held to determine the accuracy required for setting embedded items if a tolerance smaller than ± 1 in. (± 25 mm) is required (**ACI 117**).

5.1.2.3.2 Consider using at least two setting holes in embed weld plates when setting embeds to vertical formwork. Consider using small machine screws instead of nails for fastening embeds to vertical formwork. This can result in improved flushness and embed positioning.

5.1.2.3.3 Subject to architect/engineer review, weld plates incorrectly set (beyond permissible tolerance) below the surface of the concrete may be corrected by welding a new plate on top of the existing plate. For plates incorrectly set (beyond permissible tolerance) above the surface of the concrete, the plate may be cut out and the concrete chipped out to the proper depth for the plate. A new plate may be drilled and plug-welded to the existing anchor studs.

5.1.2.3.4 For stud rails, consider using shop drawings reflecting color-coded stud rail delineation. Also consider laying out and installing stud rails before reinforcement placement. Inspect and adjust stud rails after reinforcement placement. If stud rails or reinforcement cannot be placed within tolerances, a review by the architect/engineer is necessary.

5.1.2.3.5 The contractor should consider using sleeves in concrete floors that do not protrude above the surface of concrete floors. Concrete place-and-finish crews routinely obtain better flatness tolerances when sleeves are level with or slightly below, by approximately 1/4 in. (6 mm), the finished concrete surface. Contractors should consider placing this item in their standard contract terms, obtaining prior approval by the architect/engineer and coordinating this practice in advance with the affected trades. It is worth noting that flush sleeves allow water to flow from floor to floor, which is why raised sleeves are specified by Mechan-

Table 5.2.1.1—Industry and ACI tolerances for elevator cores and hoistways

Item (Fig. 5.2.1.1)	NEII-1 tolerances	ACI 117 tolerances
1. Hoistway plumb, cast-in-place	± 1 in. (± 25 mm) in the first 100 ft (30.5 m); tolerance increase for each additional 10 ft (3 m): $\pm 1/32$ in. (± 0.8 mm) maximum of 2 in. (50 mm)	For heights less than or equal to 83 ft 4 in. (25.4 m): the lesser of 0.3 percent times the height above the top of the foundation or ± 1 in. (± 25 mm); For heights greater than 83 ft 4 in. (25.4 m): the lesser of 0.1 percent times the height above the top of the foundation or ± 6 in. (± 150 mm)
2. Deviation from plumb and twist, slipformed, 100 ft (30 m) or less	—	$\pm 1/2$ in. (± 13 mm) per level; ± 2 in. (± 50 mm) maximum
3. Deviation from plumb and twist, slipformed, more than 100 ft (30 m)	—	$\pm 1/2$ in. (± 13 mm) per level; $\pm 1/600$ times the height; ± 6 in. (± 150 mm) maximum
4. Horizontal and vertical deviation to centerline of embedded items, cast-in-place	—	± 1 in. (± 25 mm)
5. Size of embedded plates, slipformed construction	—	+2 in. (+75 mm), -0 in. (-0 mm)
6. Horizontal deviation to edges of openings, sleeves, and embedments, slipformed	—	For elements 12 in. (300 mm) and smaller: ± 1 in. (± 25 mm); For elements greater than 12 in. (300 mm): ± 2 in. (± 50 mm)
7. Concrete rough openings	Note: Make rough openings 12 in. (300 mm) wider than the elevator door clear opening width and 6 in. (150 mm) higher than the elevator door clear opening height	-1/2 in. (-13 mm), +1 in. (+25 mm)
8. Depth (thickness) of concrete entrance walls	Increase the depth of the hoistway door space by 1 in. (25 mm) on the outside of the shaft to compensate for normal field variations	For thicknesses 12 in. (300 mm) or less: +3/8 in. (+10 mm), -1/4 in. (-6 mm); For thicknesses 12 to 36 in. (300 to 900 mm): +1/2 in. (+13 mm), -3/8 in. (-10 mm)
9. Edge location of all openings, cast-in-place	—	$\pm 1/2$ in. (± 13 mm)
10. Edge location of door or walk-through openings, slipformed	—	+1-1/2 in. (+40 mm), -1/4 in. (-6 mm)
11. Edge location of other openings and sleeves, slipformed	—	+1 in. (+25 mm), -0 in. (-0 mm)
12. Pits and sumps: horizontal deviation in location of edge	—	$\pm 1/2$ in. (± 13 mm)
13. Depth of pit, formed slabs or slab-on-ground	—	$\pm 3/4$ in. (± 20 mm)
14. Machine room edge location of all openings	—	$\pm 1/2$ in. (± 13 mm)
15. Machine room formed opening width	—	+1 in. (+25 mm), -1/2 in. (-13 mm)

ical/Electrical/Plumbing/Fire Engineer. Alternatively, flush sleeves with sleeve extension couplings can also be specified.

5.1.2.3.6 Positioning bollards is a function of the opening width required by the design. When the clear spacing between bollards is critical, consider the position tolerance when casting in-place bollards or locating sleeves. For suspended slabs, consider using embedded base plates and welding the bollard to the base plate after the slab has deflected or using a through-bolt method. If the bollard is connected to the slab before deflection, the bollard will rotate as the slab deflects, changing its position.

5.1.2.3.7 For davits and stabilizing anchors, the contractor can request weld plate locations from the manufacturer in the form of a shop drawing to confirm the location of weld plates. Consider using setting hardware such as nuts, washers, and template depth gauges for setting of stabilization anchors.

5.2—Elevator cores and hoistways

5.2.1 Discussion

5.2.1.1 Hoistway tolerance requirements for plumb for cast-in-place surfaces set by the National Elevator Industry,

Inc.—**NEII-1**—are tighter than those established by **ACI 117**, as shown in Table 5.2.1.1. For example, NEII-1 requires a tolerance of ± 1 in. (± 25 mm) for the first 100 ft (30.5 m) instead of ± 1 in. (± 25 mm) for the first 83 ft 4 in. (25.4 m) set by ACI 117. The NEII-1 limits the total tolerance for taller structures to ± 2 in. (50 mm), whereas ACI allows a ± 6 in. (150 mm) tolerance.

5.2.2 Design strategies

5.2.2.1 ASCC (2004b) recommends that the architect/engineer considers adding a minimum of 2 in. (50 mm) to the minimum elevator plan dimensions provided by the elevator manufacturer. Elevator requirements should be coordinated with concrete alignment tolerances (Fig. 5.2.1.1). Note that oversizing the shaft may increase the cost of guide and counterweight rail installations.

5.2.2.2 Consider following NEII-1 recommendations to dimension concrete rough openings 12 in. (300 mm) wider than the clear opening width and 6 in. (150 mm) higher than the clear opening height. Any additional dimensions should be clearly shown in the drawings and not be added by the contractor. The clear opening width and height are

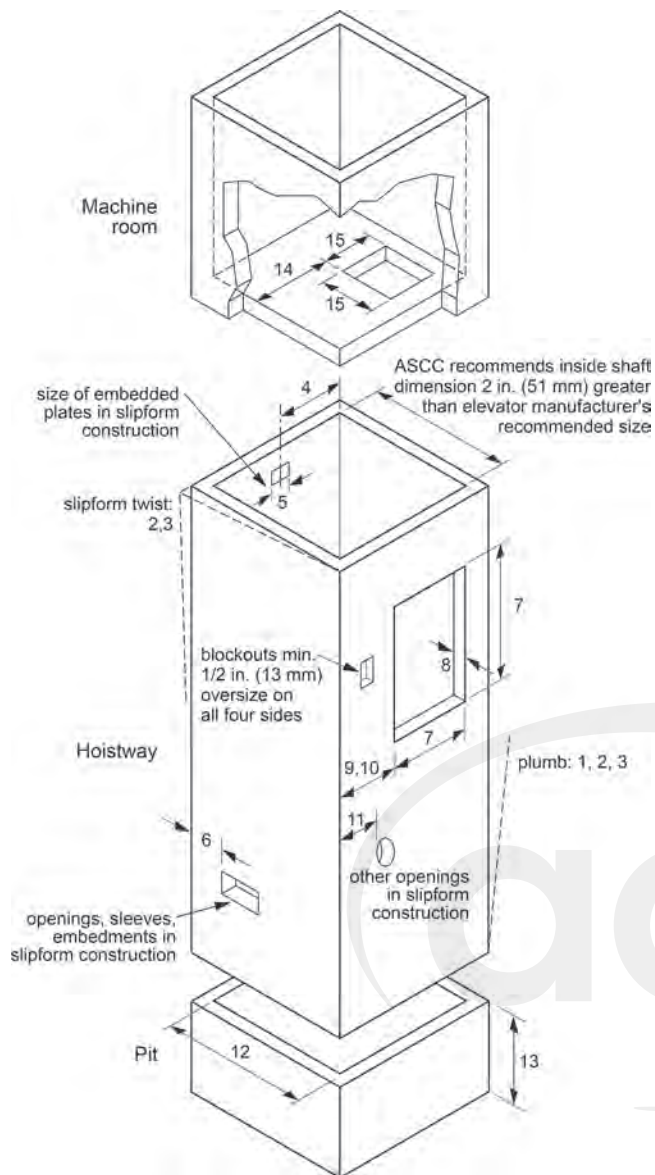


Fig. 5.2.1.1—Elevator cores and hoistways.

the dimensions to the finish elevator frame. Rough opening requirements should be confirmed with the elevator manufacturer. For exposed concrete shafts, the size of rough openings should be tightly controlled during construction.

5.2.2.3 Confirm requirement for pit sizes, sump sizes, and machine room openings with the elevator manufacturer.

5.2.2.4 Coordinate shop drawings of hoistways, pits, machine rooms, and embeds with the requirements of other trades. Coordinate embed requirements with concrete tolerances. The architectural, structural, and elevator shop drawings should be reviewed for dimensional consistency.

5.2.2.5 Requirements of back boxes for call buttons and hall lanterns should be confirmed with the elevator manufacturer. Blockouts for back boxes should be a minimum of 1/2 in. (13 mm) larger than the boxes on all four sides.

5.2.3 Construction strategies

5.2.3.1 Use appropriate layout techniques to ensure that centerlines of openings follow a plumb line through the

elevator shaft. Additionally, when projecting survey control onto a new construction level, the contractor should confirm that this control is consistent with control established on lower levels.

5.2.3.2 Use a shaft formwork system that ensures dimensional consistency, squareness, and plumbness.

5.2.3.3 Hold a preconstruction tolerance meeting to determine the accuracy required setting embedded items if a tolerance smaller than ± 1 in. (± 25 mm) is required (ACI 117).

5.2.3.4 Hold a preconstruction tolerance meeting to determine the accuracy required for pit and sump sizes, and machine room openings if it differs from ACI tolerances. The concrete tolerance of $\pm 1/2$ in. (± 13 mm) should be used.

5.2.3.5 For slipform construction, hold a preconstruction tolerance meeting among the concrete contractor, construction manager, elevator manufacturer, and elevator installer.

5.3—Openings in slabs and walls

5.3.1 Openings for metal stairs, escalators, and miscellaneous elements

5.3.1.1 Discussion

5.3.1.1.1 Concrete openings are required for a variety of elements such as metal stairs; escalators; mezzanines; louvers; roof hatches; and mechanical, electrical, and plumbing services. Openings for precast stairs, doors, and windows are discussed in 5.3.2 and 5.3.3. Because each type of element may require a different concrete tolerance, the architect/engineer, contractor, subcontractors, and suppliers should determine what tolerances have to be maintained (Table 5.3.1.1.1).

5.3.1.1.2 For cast-in-place concrete, the tolerance for any edge of the opening is $\pm 1/2$ in. (± 13 mm). These ACI 117 tolerances are for openings that are enclosed in a wall or slab (openings in an element). Clear space between floors has an elevation tolerance of $\pm 3/4$ in. (± 20 mm) on each floor. This space is not considered an opening.

5.3.1.2 Design strategies

5.3.1.2.1 Metal stairs—Consider providing a minimum 1 in. (25 mm) design clearance between the concrete opening and edge of the metal stair. This allows for concrete tolerances, metal stair oversize tolerance, and installation clearance. Verify specific project details and adjust opening size as required (Fig. 5.3.1.2.1). Consider providing an oversized or adjustable closure plate at the bottom and top landings for a connection to the concrete openings. For systems that provide for grouted sills at the top and bottoms of flights, coordinate with the stair fabricator. Consider providing oversized weld plates or embedded angles for support connections as required by stair fabricator.

5.3.1.2.2 Escalators—Verify the manufacturing and installation tolerances of escalators with the manufacturer. Escalator manufacturers suggest a rough opening 2 in. (50 mm) larger than the physical width of the escalator to allow for variations in the construction within specified tolerances.

5.3.1.2.3 Mezzanines—For mezzanines, consider the expected deflection that might affect the installation of all materials, products, and mechanical, electrical, and plumbing services that are located below.

Table 5.3.1.1.1—ACI tolerances and recommendations for openings

Item (Fig. 5.3.1.1.1)	NAAMM AMP 510 recommendations	NEII-1 recommendations	ACI 117 tolerances
1. Edge location of all openings	—	—	±1/2 in. (±13 mm)
2. Formed openings	—	—	+1 in. (+25 mm), -1/2 in. (-13 mm)
3. Edge location for openings 12 in. (300 mm) or smaller	—	—	±1/2 in. (±13 mm)
4. Clearance between metal stairs and framing or wall surface	Requires 1/4 in. (6 mm) minimum	—	—
5. Clearance between top riser and edge of rough opening	1-1/2 in. (38 mm)	—	—
6. Openings for escalators	—	Openings 2 in. (50 mm) wider than escalator	—
7. Concrete slab elevation	—	—	±3/4 in. (±20 mm)

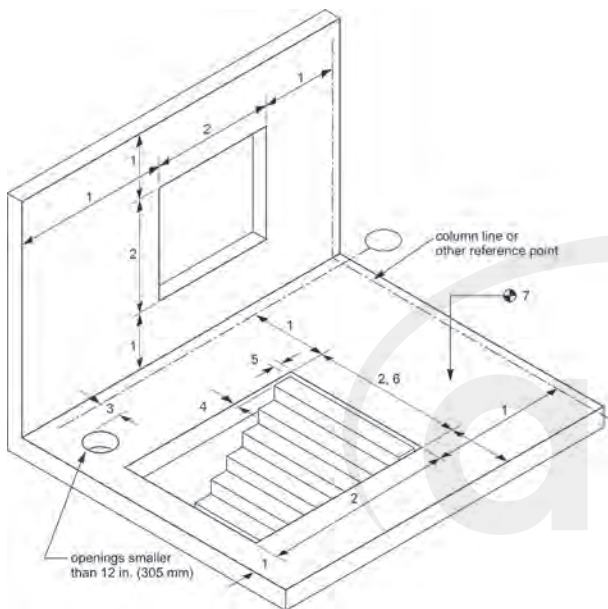


Fig. 5.3.1.1.1—Tolerances for concrete openings.

5.3.1.2.4 Louvers—For louvers installed within a concrete opening, most manufacturers require an opening size 1/2 in. (13 mm) larger than the louver assembly, 1/4 in. (6 mm) on each side. Because standard ACI 117 tolerances allow for a -1/2 in. (-13 mm) undersize dimension for total formed opening width (1/4 in. [6 mm] each side), the total concrete opening width and height for a louver assembly should be 1 in. (25 mm) larger than the louver assembly to allow for a 1/2 in. (13 mm) clearance on each side. Design details at each edge should provide for adjustable fit from 1/4 to 1 in. (6 to 25 mm). Required tolerances for louvers depend on the method of installation, which would be totally within the concrete opening or installed with a flange. Verify installation method with approved shop drawings.

5.3.1.2.5 Roof hatches—In most cases, accommodating roof hatches with concrete tolerances presents few problems because they are typically surface mounted on the roof deck. Roof hatch positions provide a utilitarian function and are usually out of sight from the building occupants.

With a maximum oversize concrete opening tolerance of +1 in. (+25 mm), the flanges of most roof hatches can still

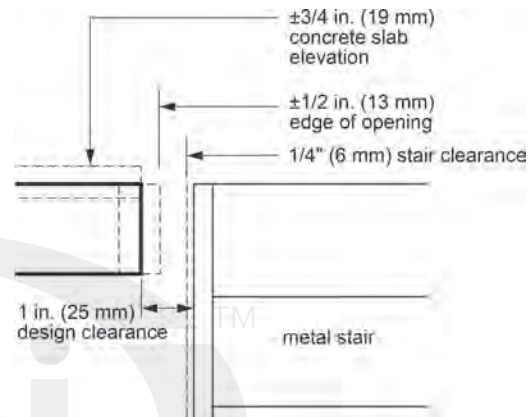


Fig. 5.3.1.2.1—Metal stairs in concrete opening.

be attached to the roof assembly. Inside finish dimensions of the hatch can then be matched with through-roof finishes, if required. With a maximum undersize concrete opening tolerance of -1/2 in. (-13 mm), a 1/4 in. (6 mm) mismatch between inside dimensions of the through-roof finishes with the inside dimension of the hatch may not pose a problem. In critical situations, confirm the inside dimension of the roof hatch with shop drawings, manufacturer's literature, and ACI 117 concrete tolerances.

5.3.1.2.6 Mechanical, electrical, and plumbing services—Tolerance requirements for openings in walls should also include provisions for deflection requirements of mechanical, electrical, and plumbing services and seismic movement. Design opening size to accommodate expansion and contraction, especially of large-diameter piping and ducts.

5.3.1.3 Construction strategies

5.3.1.3.1 For openings required for stairs and other items, a preconstruction tolerance meeting should be held to determine the accuracy required for opening sizes if they conflict with ACI 117 tolerances for edge locations, concrete opening sizes, and slab elevations. Mechanical, electrical, and plumbing service requirements should be confirmed, located, and laid out by each specialty contractor.

5.3.2 Openings for precast stairs

5.3.2.1 Discussion

5.3.2.1.1 For precast concrete, product tolerances and secondary control surface tolerances are additive. For precast

Table 5.3.2.1.1—Industry and ACI tolerances for precast stairs

Item (Fig. 5.3.2.1.1)	PCI MNL 135 tolerances	ACI ITG-7 tolerances
1. Overall length of stair	±1/2 in. (±13 mm)	±1/2 in. (±13 mm)
2. Overall width of stair	±3/8 in. (±10 mm)	±3/8 in. (±10 mm)
3. Overall height of stair	±1/4 in. (±6 mm)	±1/4 in. (±6 mm)
4. Variation from specified plan end squareness or skew	±1/8 in. per 12 in. (±3 mm per 300 mm); ±1/2 in. (±13 mm) maximum	±1/8 in. per 12 in. (±3 mm per 300 mm); ±1/2 in. (±13 mm) maximum
5. Variation from specified elevation end squareness or skew	±1/4 in. (±6 mm)	±1/2 in. (±13 mm)
6. Location of embedments	±1 in. (±25 mm)	±1 in. (±25 mm)
7. Tipping and flushness of embedments	±1/8 in. (±3 mm)	—
8. Location of inserts for structural connections	±3/8 in. (±10 mm)	±3/8 in. (±10 mm)
9. Individual riser height	±3/16 in. (±5 mm)	—
10. Deviation from specified depth	±1/4 in. (±6 mm)	±1/4 in. (±6 mm)
11. Erection tolerance for plan location from building datum	±1/2 in. (±13 mm)	Maximum 1/2 in. (13 mm)
12. Differential elevation of landing as erected, pre-topped landings	±1/4 in. (±6 mm)	±1/4 in. (±6 mm)
13. Differential elevation of landing as erected, topping added later	± 3/8 in. (±10 mm)	±3/8 in. (±10 mm)

stairs, the primary control surface for a stair unit is the top of the landing. Therefore, other surfaces are secondary control surfaces. For a complete description of precast tolerances, refer to **ACI ITG-7** and **PCI MNL 135** (Table 5.3.2.1.1).

5.3.2.1.2 For cast-in-place concrete, the tolerance for any edge of slab opening size is ±1/2 in. (±13 mm).

5.3.2.2 Design strategies

5.3.2.2.1 For horizontal placement, precast stairs placed in a cast-in-place opening require accommodation for a ±1/2 in. (±13 mm) cast-in-place plan location tolerance of the opening, a ±3/16 in. (±5 mm) product tolerance of the stair (assuming half of the ±3/8 in. [±10 mm] total product tolerance), and a ±1/2 in. (±13 mm) erection tolerance for the stair unit. For stairs placed next to cast-in-place beams or columns, an additional 1/2 in. (13 mm) should be provided to account for a ±1 in. (±25 mm) horizontal tolerance for those elements (Fig. 5.3.2.2.1).

5.3.2.2.2 Consider providing a minimum 1-1/2 in. (40 mm) horizontal design clearance between a cast-in-place opening and a precast stair unit, and providing a minimum 2 in. (50 mm) horizontal design clearance between a cast-in-place beam, column, or wall and a precast stair unit (Fig. 5.3.2.2.1). Any open gap between the precast stairs and cast-in-place concrete opening may need to be protected by a railing or toe plate or another detail as determined by the architect/engineer if the open gap presents an issue for foot traffic.

5.3.2.2.3 Consider providing a connection adjustment that allows for a minimum as-built gap of 5/16 in. (8 mm) and a maximum as-built gap of 2-11/16 in. (68 mm).

5.3.2.2.4 For vertical placement, precast stairs placed in a cast-in-place opening require accommodation for a ±3/4 in. (±20 mm) cast-in-place slab elevation tolerance, a ±1/4 in. (±6 mm) erection tolerance for the stair unit using the landing as the primary control surface, and a maximum riser

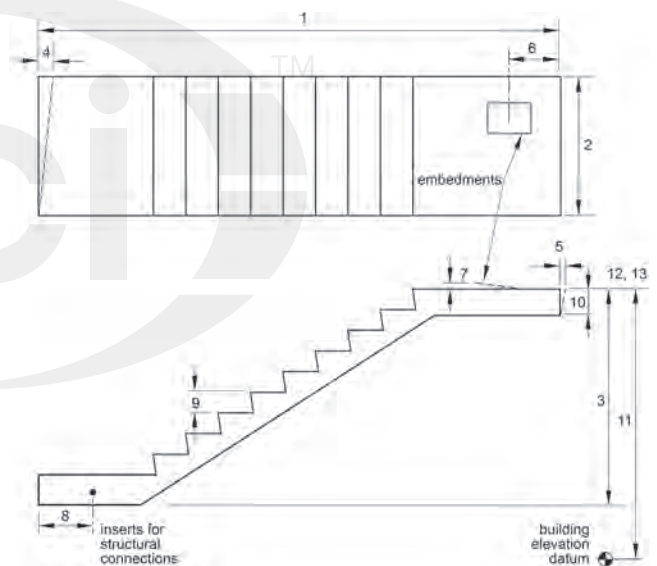


Fig. 5.3.2.1.1—Precast concrete stair tolerances.

height variation between the smallest and largest riser in a flight defined by the applicable code, commonly ±3/8 in. (±10 mm). Slab deflection or excess concrete placed on steel decking may increase the deviation of the top of the slab elevation beyond 3/4 in. (20 mm), depending on the position of the opening relative to beam lines.

5.3.2.2.5 The architect/engineer should consider developing details for precast stairs set on cast-in-place concrete that include provisions for stair adjustment as well as the use of a finish topping to allow exact alignment of the precast stairs with the finish floor elevations.

5.3.2.3 Construction strategies

5.3.2.3.1 The methods of accommodating vertical placement depend on the connection types used and whether or

not topping is used. Verify clearances and adjustable connections required for specific project details.

5.3.2.3.2 As a means of managing precast stair erection tolerances, precast stair elements can be designed and produced so that they are erected in advance of the casting of their respective floor levels and landings. If the stair element is set to elevation, prior to the casting of the floor level and the intermediate landing, the slabs can be placed and finished so as to be flush with the stair.

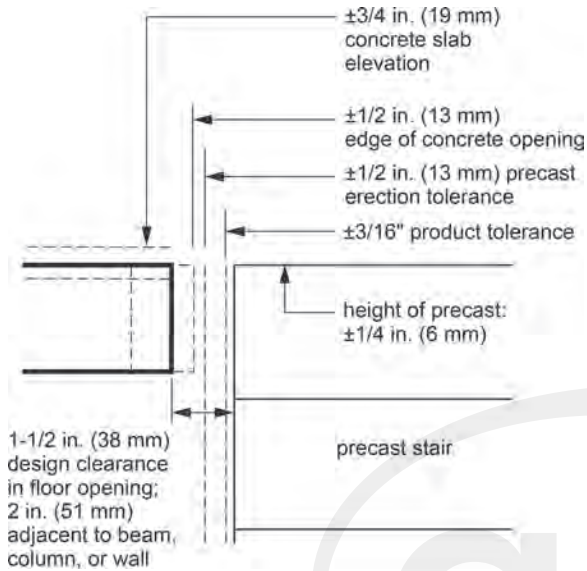


Fig. 5.3.2.2.1—Precast stairs in concrete opening.

5.3.3 Openings for doors and windows

5.3.3.1 Discussion

5.3.3.1.1 Installation of doors, windows, and storefronts is usually accommodated by varying the size of the sealant joint. Undersized openings, however, may not allow sufficient clearance for the proper proportioning of the sealant joint. The plumb of the jambs is also critical for the proper installation and functioning of the doors. Therefore, undersized openings need to be avoided. Oversized openings can be accommodated with a wider sealant joint and the limiting oversize tolerance may be determined by aesthetics and by the minimum required sealant joint.

5.3.3.1.2 **ACI 117** tolerances for wall openings allow for a +1 in. (+25 mm) oversize tolerance and a -1/2 in. (-13 mm) undersize tolerance for opening width or height. This allows for an inward variation of 1/4 in. (6 mm) at each jamb, and an outward variation of 1/2 in. (13 mm) at each jamb and at the head. Because tolerances for doors and windows are tightly controlled, as indicated in Table 5.3.3.1.2, the opening sizes of concrete and plumb and level tolerances are usually the critical factors in tolerance compatibility. For example, consider a hollow metal door. The Steel Door Institute (**SDI 117**) tolerances allow for an oversize door tolerance of 1/16 in. (1.6 mm). In the worst case, this requires the sealant joint to accommodate a 5/16 in. (8 mm) undersize variation at both jambs and a 9/16 in. (14 mm) undersize variation at the head. Plumb tolerances, however, could create problems if the concrete opening is undersized and out of plumb. Conversely, when openings are constructed with allowable

Table 5.3.3.1.2—Industry and ACI tolerances for door and window openings

Item (Fig. 5.3.3.1.2)	Industry tolerances	ACI 117 tolerances
1. Edge location of all openings	—	$\pm 1/2$ in. (± 13 mm)
2. Formed openings	—	+1 in. (+25 mm), -1/2 in. (-13 mm)
3. Concrete opening plumb	—	$\pm 1/2$ in. (± 13 mm)
4. Standard hollow metal door frames, width and height	+1/16 in. (+1.6 mm), -1/32 in. (-0.8 mm) (SDI 117)	—
5. Standard hollow metal door frame depth	$\pm 1/16$ in. (± 1.6 mm) (SDI 117)	—
6. Standard hollow metal door frame face width	$\pm 1/32$ in. (± 0.8 mm) (SDI 117)	—
7. Detention hollow metal door frames, overall height	$\pm 3/64$ in. (± 1.2 mm) (HMMA 863)	—
8. Detention hollow metal door frames, overall width	+1/16 in. (+1.6 mm), -1/32 in. (-0.8 mm) (HMMA 863)	—
9. Detention hollow metal door frame depth and frame width	$\pm 1/32$ in. (± 0.8 mm) (HMMA 863)	—
10. Hollow metal glazed openings, overall width and height	+1/16 in. (+1.6 mm), -1/32 in. (-0.8 mm) (SDI 117)	—
11. Hollow metal glazed openings, frame depth	$\pm 1/16$ in. (± 1.6 mm) (SDI 117)	—
12. Hollow metal glazed openings, face frame width	$\pm 1/32$ in. (± 0.8 mm) (SDI 117)	—
13. Steel windows	$\pm 1/16$ in. (± 1.6 mm) (Manufacturers' typical tolerances)	—
14. Aluminum doors and windows, overall height and width	Dimensions 72 in. (1830 mm) and under: $\pm 1/16$ in. (± 1.6 mm) Dimensions between 72 in. (1830 mm) and 144 in. (3660 mm): $\pm 1/8$ in. (± 3 mm) Dimensions over 144 in. (3660 mm): $\pm 3/16$ in. (± 4.5 mm) (AAMA/WDMA/CSA 101/I.S. 2/A440)	—
15. Storefronts, erection tolerance: difference in length of diagonals of any rectangular opening	Maximum 1/8 in. (3 mm) (GANA 2008)	—
16. Storefronts, erection tolerance: variation in plumb or level	$\pm 1/8$ in. in 12 ft (± 3 mm in 3660 mm); $\pm 1/4$ in. (± 6 mm) in any single run (GANA 2008)	—
17. Storefronts, erection tolerance: floor level under door	$\pm 1/16$ in. (± 1.65 mm) (GANA 2008)	—

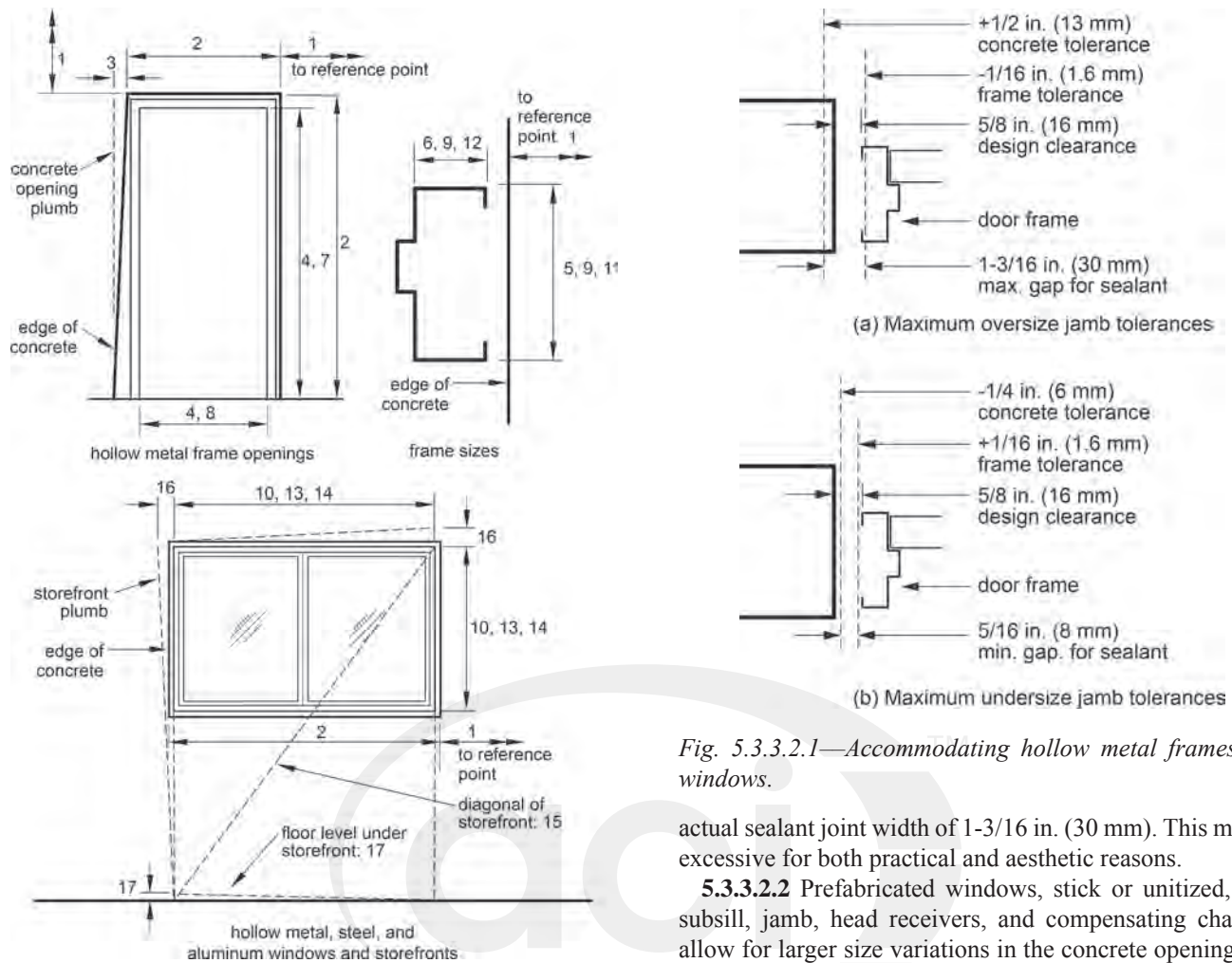


Fig. 5.3.3.1.2—Door and window tolerances.

oversized tolerances, the width of the sealant joint may be excessive for aesthetic reasons.

5.3.3.1.3 Note that **ACI 117** does not consider doors or windows that are installed from floor to ceiling as an opening tolerance. The elevation tolerance for the slab floor and ceiling or beam above is $\pm 3/4$ in. (± 20 mm). Details for doors and windows in a wall opening typically will need to be modified for the elevation tolerances and deflection of the slabs/beams.

5.3.3.1.4 Note that although there are no industry standards specifically for hollow metal glazed openings, **SDI 117** may be used, as **ANSI A250.8** refers to frames as including transoms, sidelights, and interior glazed panels.

5.3.3.2 Design strategies

5.3.3.2.1 If **ACI 117** door and window tolerances are used, a minimum design clearance of $5/8$ in. (16 mm) should be detailed at each jamb and a $7/8$ in. (22 mm) design clearance detailed at the head (Fig. 5.3.3.2.1). If the maximum $5/16$ in. (8 mm) variation occurs as described in 5.3.3.1.2, this provides for a $5/16$ in. (8 mm) sealant joint. If the concrete opening is oversized by the allowed 1 in. (25 mm), or $1/2$ in. (13 mm) at each jamb, however, and the door is undersized by $1/16$ in. (1.6 mm) at each jamb and a $5/8$ in. (16 mm) clearance is detailed on the drawings, this results in an

Fig. 5.3.3.2.1—Accommodating hollow metal frames and windows.

actual sealant joint width of $1-3/16$ in. (30 mm). This may be excessive for both practical and aesthetic reasons.

5.3.3.2.2 Prefabricated windows, stick or unitized, with subsill, jamb, head receivers, and compensating channels allow for larger size variations in the concrete opening than for single-piece windows. Compensating channels may be provided at the head, jambs, or both. The architect/engineer may consider using existing concrete tolerances for these types of windows. These tolerances may apply to the height only if compensating channels are used at the head and to the width if channels are used at the jambs.

5.3.3.2.3 Prefabricated windows without compensating channels are usually accommodated by varying the size of the sealant joint. Undersized openings, however, may not allow sufficient clearance for the proper proportioning of the sealant joint. Therefore, undersized openings need to be tightly restricted. Oversized openings can be accommodated with sealant and the limiting tolerance may be determined by aesthetics.

5.3.3.2.4 Large coiling doors, truck doors, rolling grills, and similar special doors mounted to the face of a concrete wall can be accommodated with existing concrete opening tolerances of +1 in. (+25 mm) and $-1/2$ in. (-13 mm). Large coiling doors, truck doors, rolling grills, and similar special doors installed within the concrete opening may require tighter tolerances. A minimum $1/2$ in. (13 mm) clearance should be detailed at each jamb. Verify door tolerances with the manufacturer.

5.3.3.2.5 Storefront systems installed in openings in concrete walls may be field measured before fabrication and include a head receiver/channel to accommodate structural deflection as well as opening height tolerance. To accommo-

Table 5.4.1.1—Industry and ACI tolerances for reinforcing bar placement and splicing systems

Item (Fig. 5.4.1.1)	Manufacturers' tolerances	ACI 117 tolerances
1. Placement of non-prestressed reinforcement, measured from form surface	—	When member depth (or thickness) is: 4 in. (100 mm) or less: $\pm 1/4$ in. (± 6 mm) Over 4 in. (100 mm) and not over 12 in. (300 mm): $\pm 3/8$ in. (± 10 mm) Over 12 in. (300 mm): $\pm 1/2$ in. (± 13 mm)
2. Splice sleeves	Provides for bar misalignment: No. 5 and No. 6 bar sleeves: $\pm 5/16$ in. (± 8 mm) Larger than No. 6 bar: $\pm 1/2$ in. (± 13 mm)	—

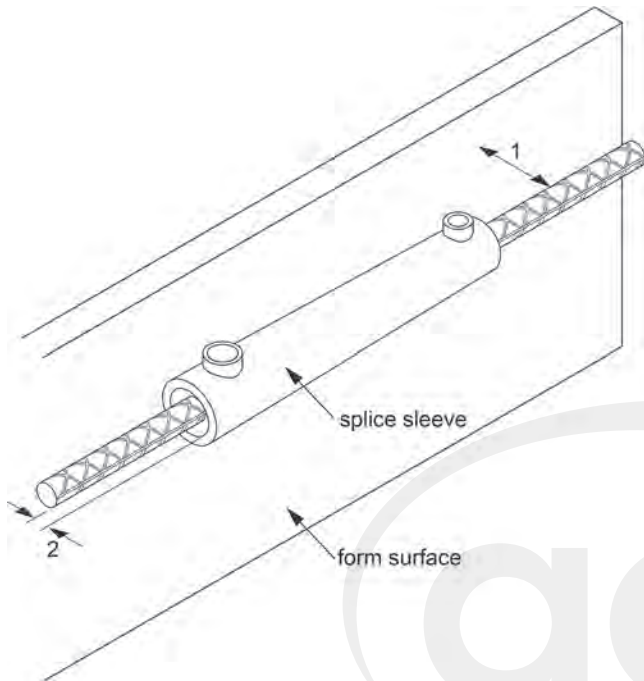


Fig. 5.4.1.1—Couplers and splicing systems for reinforcing bars.

date deflection and vertical tolerances, opening size should be at least 1 in. (25 mm) higher than the storefront system. Verify anticipated deflection with the architect/engineer and size the head receiver/channel accordingly.

5.3.3.2.6 For sliding glass doors, consider oversizing the opening height and providing a slider curb that is cast after the floors are set and the shoring is removed. Because the floor will deflect, do not specify a constant curb height but rather specify an elevation at the top of curb. Note that a slider curb will affect accessibility and can only be used in some circumstances.

5.3.3.3 Construction strategies

5.3.3.3.1 Openings can best be formed directly by fabricating a blockout for the opening to the correct size and placing it according to the opening centerline. These blockouts need to have a structural capacity equal to the formwork in which they are being installed.

5.3.3.3.2 Hollow metal doors and windows may also be fabricated after field measurement of the concrete opening. While this reduces the requirement for tight tolerances, field measuring has implications for scheduling and added cost. Tolerances of the concrete opening using this approach should be set by architectural and aesthetic considerations and incorporated into the contract documents.

5.4—Manufactured couplers and splicing systems for reinforcing bars

5.4.1 Discussion

5.4.1.1 Although there are no industry standards for the manufacture and placement of reinforcing bar couplers and splicing systems, manufacturers of splice sleeves provide for bar misalignment on the wide (field) end of the sleeves, as indicated in Table 5.4.1.1. ACI 117 has established placement tolerances for the fabrication and placement of reinforcing bar. Refer to ACI 117 for a complete listing of ACI tolerances. In most cases, slight misalignment of reinforcing bar is not a problem when couplers are used because the bars can be connected before fixing in place.

5.4.2 Design strategies

5.4.2.1 The position of manufactured couplers depends on the accuracy of the reinforcing steel placement. For cast-in-place concrete matching one end of reinforcing bar to the next with a manufactured coupler usually poses few problems. The minimum concrete cover should be increased to account for the size of the coupler.

5.4.2.2 Because splice sleeves are designed to accommodate bar misalignment tolerances, as shown in Table 5.4.1.1, verify tolerances for other aspects of precast connections, such as column plan location and panel jog. If splice sleeve misalignment exceeds limits of other tolerances, consider remedial action as described in 5.4.3.3, 5.4.3.4, and 5.4.3.5.

5.4.3 Construction strategies

5.4.3.1 For footing/column connections, consider using matching templates for the location of column reinforcement and splice sleeve placement or consider placing splice sleeves in the footing.

5.4.3.2 Subject to review by the architect/engineer, consider making field adjustments as suggested by the manufacturer in 5.4.3.3, 5.4.3.4, and 5.4.3.5.

5.4.3.3 For misalignment in plan location if the bar is within a bar diameter of the correct position, consider drilling a hole similar to the diameter of the bar on the side to which it needs to be moved. The bar may be bent over such that it is in the proper position at the base and a steel wedge may be inserted to hold the position. The bar may then be bent back to vertical, pivoting at the wedge. Epoxy or grout the hole around the wedge. Minimum bend diameters should conform to requirements given in ACI 301 based on bar size. This solution should be approved by architect/engineer, especially with regard to the embedment depth of the new rod/bolt compared with the original rod/bolt.

5.4.3.4 For misalignment in plan location, if the bar is more than a bar diameter away, consider cutting it off and

Table 5.6.1.1.1—Tolerances for curtain walls and storefronts

Item (Fig. 5.6.1.1.1)	Industry tolerances	ACI tolerances
<i>Curtain walls</i>		
1. Position of components from location shown on the drawings	±1/8 in. (±3 mm) (AAMA MCWM-1)	—
2. Maximum offset alignment between two identical members end to end	1/16 in. (2 mm) (Unified Facilities Guide Specifications 2011)	—
3. Maximum variation from plane	1/8 in. per 12 ft (3 mm per 3600 mm); Maximum 1/2 in. (13 mm) in any length (Unified Facilities Guide Specifications 2011)	—
4. Maximum variation in diagonal length within any rectangular opening	1/8 in. (3 mm) recommended (GANA 2008)	—
5. Maximum variation of mullions from plumb or horizontal	±1/8 in. in 12 ft (±3 mm in 3660 mm) or ±1/4 in. (±6 mm) in any single run recommended (GANA 2008)	—
6. Maximum out-of-plane offset between horizontal and vertical glazing members	1/32 in. (0.8 mm) recommended (GANA 2008)	—
7. Deviation from plumb of concrete framing for building heights less than or equal to 83 ft 4 in. (25.4 m)	—	The lesser of 0.3 percent times the height above the top of foundations or up to a maximum of ±1 in. (±25 mm) (ACI 117)
8. Deviation from plumb or concrete framing for building heights over 83 ft 4 in. (25.4 m)	—	The lesser of 0.1 percent times the height above the foundation or 6 in. (150 mm) (ACI 117)
9. Elevation of formed floor slabs before removal of shoring	—	±3/4 in. (±20 mm) (ACI 117)
10. Elevation of concrete floor slabs on structural steel or precast	—	No requirement (ACI 117)
11. Elevation of concrete slab on ground	—	±3/4 in. (±20 mm) (ACI 117)
12. Top surface of foundations	—	+1/2 in. (+13 mm), -2 in. (-50 mm) (ACI 117)
13. Location of embedded anchors	—	±1 in. (±25 mm) (ACI 117)
<i>Storefronts</i>		
14. Difference in length of diagonals of any rectangular opening as erected	Maximum 1/8 in. (3 mm) recommended (GANA 2008)	—
15. Variation in plumb or level as erected	±1/8 in. in 12 ft (±3 mm in 3660 mm) or ±1/4 in. (±6 mm) in any single run recommended (GANA 2008)	—
16. Maximum out-of-plane offset between horizontal and vertical glazing members	1/32 in. (0.8 mm) recommended (GANA 2008)	—
17. Deviation of floor level under swinging doors	±1/16 in. (±1.5 mm) recommended (GANA 2008)	—
18. Deviation from plumb of masonry wall	—	±1/4 in. in 10 ft (±6.4 mm in 3.05 m) ±3/8 in. in 20 ft (±9.5 mm in 6.10 m) (ACI 530/530.1)

drilling a hole to epoxy anchor a new bar in the correct location. Choose an epoxy anchoring system that develops the ultimate strength of the reinforcing bar. However, capacity may be lost by cutting the rod/bolt. This solution should be approved by the architect/engineer, especially with regard to the embedment depth of the new rod/bolt compared with the original rod/bolt.

5.4.3.5 Heat bending for misaligned bars may also be considered. Properly apply heat before bending if required based on ambient temperature, bar diameter, or grade of steel. Follow guidelines published in **ACI 318**, R7.3 and **CRSI EDR 12** for field bending embedded bars. This solution should be approved by the architect/engineer.

5.5—Cast-in-place stairs

5.5.1 Discussion

5.5.1.1 This section includes tolerances for items attached to, or that are part of, a concrete stair. Refer to **5.3.1** for

prefabricated steel stair requirements. Follow guidelines given in **5.3.1.1** for opening tolerances in concrete for metal stairs. Refer to **5.3.2** for precast stair tolerances.

5.5.1.2 There are no industry standards for the manufacture or placement of shoes for glass railings. Some manufacturers work to a tolerance of ±1/8 in. (±3 mm) for glass size. Required tolerance for placement should be verified with the manufacturer and the approved shop drawings.

5.5.2 Design strategies

5.5.2.1 The architect/engineer may consider including in the specifications a requirement that the floor covering installer include an appropriate allowance in bids for grinding, patching, or using self-leveling flooring products over the structural stair to bring surfaces into compliance.

5.5.2.2 Consider specifying oversize sleeves to accommodate fabricated handrails and posts. The contractor may then grout, as required. A minimum grout space of 1/2 in. (13 mm) is suggested.

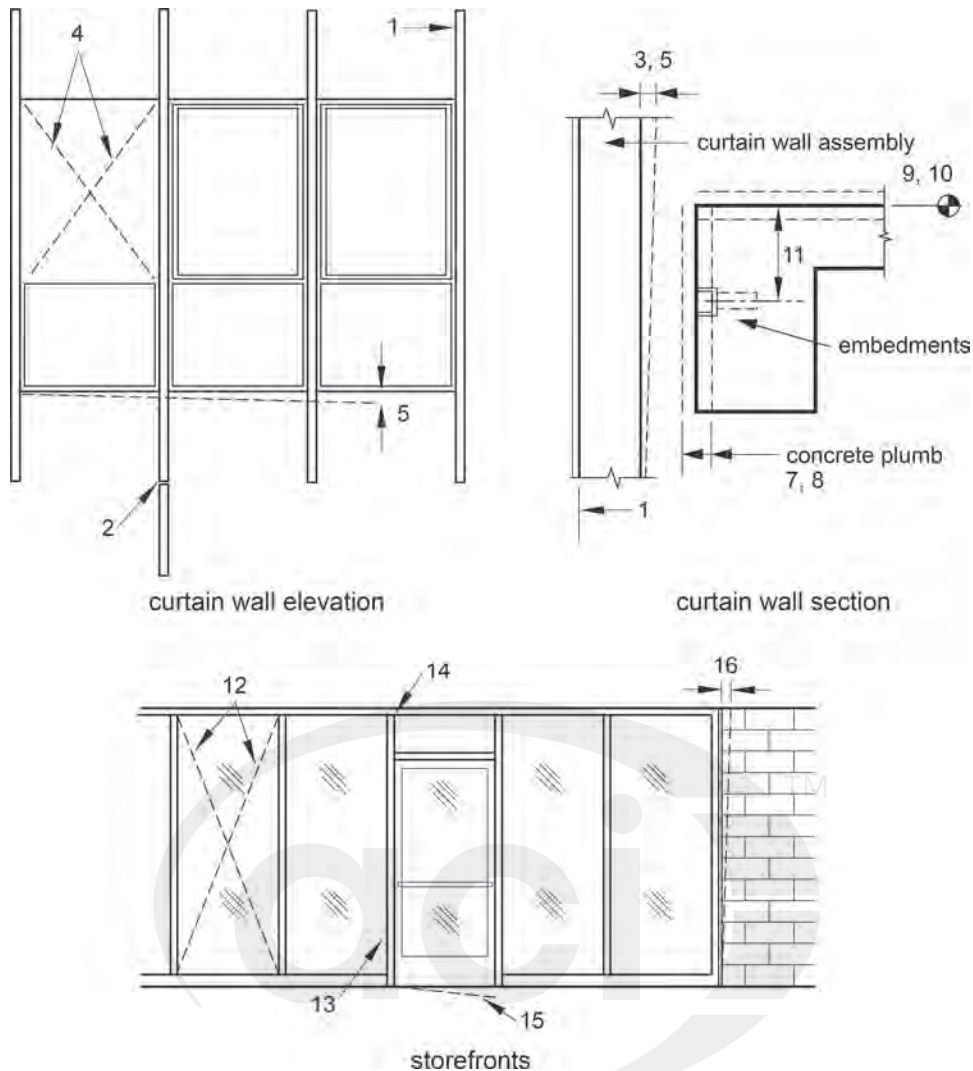


Fig. 5.6.1.1.1—Curtain walls and storefront tolerances.

5.5.3 Construction strategies

5.5.3.1 For handrail posts and glass handrails, a preconstruction meeting should be held to determine required tolerances for placement of sleeves and shoes.

5.5.3.2 As an alternate to using sleeves, consider core drilling after the stairs have been cast and the handrails have been fabricated. The contractor should carefully coordinate reinforcing bar placement with handrail post locations to avoid coring through reinforcing bars.

5.5.3.3 Consider providing oversized plates to allow for lateral adjustment.

5.5.3.4 If weld plates are used, the posts may be cut as required to level guards and to set the handrails at the correct slope.

5.6—Cladding systems

5.6.1 Curtain walls and storefronts

5.6.1.1 Discussion

5.6.1.1.1 There are no industry standard fabrication tolerances for aluminum curtain walls or storefront systems. A curtain wall is commonly identified as a cladding system

spanning continuously outside of the primary structure. Storefront window walls and entrances are deemed to be cladding systems that span in between the primary structural elements. Each manufacturer establishes its own fabrication tolerances. Recommended installation tolerances are shown in Table 5.6.1.1.1 and Fig. 5.6.1.1.1.

5.6.1.1.2 Specific tolerances for curtain walls will vary depending on the system type and application. Curtain wall in-place tolerances should be defined in the curtain wall specifications and shop drawings. Due to the curtain wall system spanning outside of the structure and the adjustability of the system, it is not as susceptible to top-of-concrete tolerances as compared with storefront entrances that span between openings.

5.6.1.1.3 There are no standard installation tolerances for storefronts and entrances; these will vary depending on the specific storefront and entrance system and application. Recommended installation tolerances are shown in Table 5.6.1.1.1 and Fig. 5.6.1.1.1.

5.6.1.1.4 Dimensional tolerances for aluminum shapes are specified in [ANSI H35.2](#). Because the dimensional toler-

ances for aluminum shapes are so small, they are insignificant compared to fabrication, installation, and construction tolerances and do not need to be considered. Therefore, as the product is delivered to the fabricating plant or the job site, they normally do not affect fabrication or installation.

5.6.1.2 Design strategies

5.6.1.2.1 To construct metal curtain walls on a concrete frame within a tolerance of $\pm 1/8$ in. (± 3 mm) for length, width, and plumb, there should be provisions for adjustment in three directions (Fig. 5.6.1.2.1). The curtain wall system should be designed to accommodate ACI 117 tolerances and other interfacing building components. Refer to AAMA CWG-1 and AAMA MCWM-1 for more information on curtain wall design and installation.

5.6.1.2.2 Variations in the concrete frame can be more easily accommodated with adjustable connections if the curtain wall extends totally outside the concrete frame in a construction zone of its own.

5.6.1.2.3 As stated in AAMA CWG-1, “The clearance necessary for installation of curtain walls will depend on the wall design ... In no case, however, should the actual clearance provided be less than 2 in. (50 mm).” Perimeter fire containment required between the concrete frame and the back of the curtain wall is designed to accommodate the variation in gap sizes between the frame and the curtain wall within the limits of tested assemblies. For buildings higher than 166 ft 8 in. (50.8 m) (ACI 117 plumb tolerance of 0.1 percent equals 2 in. [50 mm]) where the frame exceeds tolerances, the curtain wall may be installed out of plumb, following the line of the frame along the height of the building, subject to engineering review. Accommodating tolerances greater than 2 in. (50 mm) with adjustable curtain wall connectors becomes more difficult and expensive.

5.6.1.2.4 There are several commonly used methods for installing curtain walls on concrete frames. These include using slotted bolt holes, serrated angles, T-shaped clips, clip angles welded to embedded plates, and shims. The exact method used depends on the type of curtain wall used, structural requirements, recommendations of the curtain wall manufacturer, and other construction details, such as the interface with interior finishes.

5.6.1.2.5 Consider providing a connection detail that accommodates the expected variations in vertical dimension between concrete floors. This includes tolerances for the elevation of the floor slab as well as possible deflection when shoring is removed.

5.6.1.2.6 Post-tensioned slabs present additional concerns. These types of slabs that support curtain walls will almost always shorten by a measurable dimension after the tendons are stressed. Calculations can be made to estimate the final slab edge location (PTI DC20.7). Experience has demonstrated that movements of 1 in. in 100 ft (25 mm in 30 m) are common (Aalami and Barth 1989; Allred 2005; Bondy 1989; Suprenant and Malisch 2009). In larger buildings, movements in excess of 1 in. (25 mm) can occur and should be reviewed with the architect/engineer. Therefore, tolerances required for post-tensioned slabs could be greater than for non-prestressed slabs.

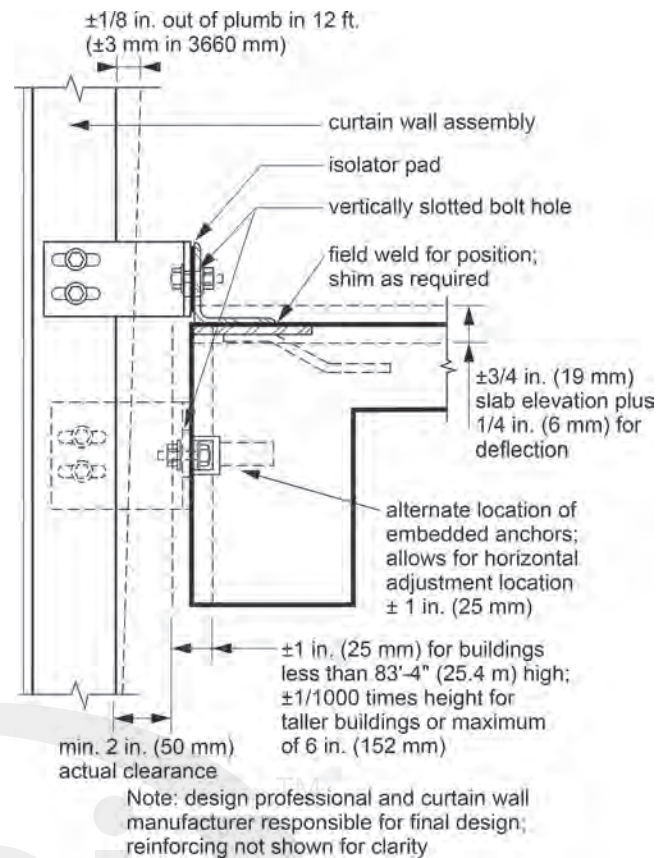


Fig. 5.6.1.2.1—Accommodating curtain walls.

5.6.1.2.7 In multistory buildings, storefronts, window walls, and similar aluminum-glazed wall systems that extend from the top of one concrete slab to the bottom of the slab above, the horizontal location of slab edges is usually not as critical as it is with curtain wall systems. The edge of the slab is left exposed or covered with a metal panel. In many cases, the tolerance for the horizontal location of slab edge will be governed by aesthetic concerns only. Subsill, head, and jamb flashings should be accommodated.

5.6.1.2.8 For storefront systems, the tolerances of slab elevations and slab thicknesses can usually be accommodated with shimming within the top channel if used to accommodate deflection of the slab above. ACI 117 tolerances for the top of the slab should be accommodated with the design of the storefront system. In addition, the possible variation in cross-sectional dimensions of a slab or beam above the storefront should be accommodated in the design of the storefront system.

When the storefront system includes a metal panel or similar architectural covering piece for the slab edge, dimensions should accommodate the potential deflected shapes of the slabs. Slip joints or other accommodations for allowing slab movements over the life of the structure are usually necessary.

5.6.1.2.9 Sufficient clearance should be provided between the storefront system and adjacent construction to allow for minor tolerances of the storefront system as well as the adjacent construction.

Table 5.6.2.1.1—Precast concrete cladding tolerances—nonstructural architectural panels

Item (Fig. 5.6.2.1.1)	PCI MNL 135 tolerances	ACI ITG-7 tolerances
1. Length and width at the face exposed to view	Under 10 ft: $\pm 1/8$ in. (Under 3 m: ± 3 mm) 10 to 20 ft: $+1/8$ in., $-3/16$ in. (3 to 6 m: $+3$ mm, -5 mm) 20 to 40 ft: $\pm 1/4$ in. (6 to 12 m: ± 6 mm) Each additional 10 ft over 40 ft: $\pm 1/16$ in. (3 m over 12 m: ± 1.5 mm)	Under 10 ft: $\pm 1/8$ in. (Under 3 m: ± 3 mm) 10 to 20 ft: $+1/8$ in., $-3/16$ in. (3 to 6 m: $+3$ mm, -5 mm) 20 to 40 ft: $\pm 1/4$ in. (6 to 12 m: ± 6 mm) Each additional 10 ft over 40 ft: $\pm 1/16$ in. (3 m over 12 m: ± 2 mm)
2. Panel thickness	$+1/4$ in. ($+6$ mm), $-1/8$ in. (-3 mm)	$+1/4$ in. ($+6$ mm), $-1/8$ in. (-3 mm)
3. Panel face alignment	$\pm 1/4$ in. (± 6 mm)	$\pm 1/4$ in. (± 6 mm)
4. Joint width	$\pm 1/4$ in. (± 6 mm)	$\pm 1/4$ in. (± 6 mm)
5. Joint taper	$1/4$ in. over 10 ft, $3/8$ in. maximum (6 mm over 3 m, 10 mm maximum)	$1/4$ in. over 10 ft, $3/8$ in. maximum (6 mm over 3 m, 10 mm maximum)
6. Panel opening location	$\pm 1/4$ in. (± 6 mm)	$\pm 3/4$ in. (± 20 mm)
7. Opening size	$\pm 1/4$ in. (± 6 mm)	$\pm 3/4$ in. (± 20 mm)
8. Location of weld plates	± 1 in. (± 25 mm)	± 1 in. (± 25 mm)
9. Location of sleeves and inserts	$\pm 1/2$ in. (± 13 mm)	$\pm 1/2$ in. (± 13 mm)
10. Bowing (out-of-plane)	\pm Panel dimension/360, maximum of 1 in. (25 mm)	\pm Panel dimension/360, maximum of 1 in. (25 mm)
11. Warping (variation of one corner from adjacent corners)	$1/16$ in. per 1 ft (1.5 mm per 300 mm) of distance from adjacent corner	$1/16$ in. per 1 ft (1.5 mm per 300 mm) of distance from nearest adjacent corner
12. Difference in length between two diagonals	$\pm 1/8$ in. per 6 ft or $1/2$ in. total, whichever is greater (± 3 mm per 1830 mm or 13 mm total)	$\pm 1/8$ in. per 6 ft or $1/2$ in. total, whichever is greater (± 3 mm per 1830 mm or 13 mm total)
13. Position of flashing reglet from top of panel	$\pm 1/4$ in. (± 6 mm)	$\pm 1/4$ in. (± 6 mm)
14. Position of architectural features and rustications	$\pm 1/8$ in. (± 3 mm)	$\pm 1/8$ in. (± 3 mm)
15. Jog between exposed edges	$\pm 1/4$ in. (± 6 mm)	$\pm 1/4$ in. (± 6 mm)
16. Plan location of panel face from building grid datum	$\pm 1/2$ in. (± 13 mm)	$\pm 1/2$ in. (± 13 mm)
17. Top elevation of panel from building elevation datum	Exposed individual panels: $\pm 1/4$ in. (± 6 mm) Exposed panel relative to adjacent panel: $\pm 1/4$ in. (± 6 mm)	Exposed individual panels: $\pm 1/4$ in. (± 6 mm) Exposed panel relative to adjacent panel: $\pm 1/4$ in. (± 6 mm)
18. Elevation of haunch from building elevation datum	$+1/4$ in., $-1/2$ in. ($+6$ mm, -13 mm)	$+1/4$ in., $-1/2$ in. ($+6$ mm, -13 mm)
19. Deviation from plumb	$\pm 1/4$ in. (6 mm) in 10 ft (3 m); maximum of ± 1 in. (± 25 mm) over height of structure or 100 ft (30 m), whichever is less	$\pm 1/4$ in. (± 6 mm) in 10 ft (3 m); maximum of ± 1 in. (± 25 mm) over height of structure or 100 ft (30 m), whichever is less
20. Length of columns	$\pm 1/2$ in. (± 13 mm)	$\pm 1/2$ in. (± 13 mm)
21. Deviation from plumb of concrete frame for heights less than or equal to 83 ft 4 in. (25.4 m)	—	The lesser of 0.3 percent times the height above the top of foundations or up to a maximum of ± 1 in. (± 25 mm).
22. Deviation from plumb or concrete framing for building heights over 83 ft 4 in. (25.4 m)	—	The lesser of 0.1 percent times the height above the foundation or 6 in. (150 mm)
23. Elevation of formed floor slabs before shoring removal	—	$\pm 3/4$ in. (± 20 mm)
24. Location of embedments	—	± 1 in. (± 25 mm)

5.6.1.3 Construction strategies

5.6.1.3.1 A preconstruction tolerance meeting should be held to discuss the potential problems with suspended slabs and cladding systems. The meeting should include the architect/engineer, concrete contractor, general contractor or construction manager, cladding contractor, and all contractors and trades whose work will come into contact with the concrete surface or façade. Issues that should be discussed include slab deflection, building settlement, plumbness tolerances, elevation tolerances, embed tolerances, connec-

tion details, camber, and others as required by the individual project.

5.6.1.3.2 At each level, provide the curtain wall contractor with the original horizontal and vertical control points that were given to the concrete contractor.

5.6.1.3.3 If the curtain wall extends outside the concrete frame, the working surface of the curtain wall (façade line) can be determined after careful survey measurements of the in-place concrete frame at the floor edges and exterior columns (5.6.1.2.2).

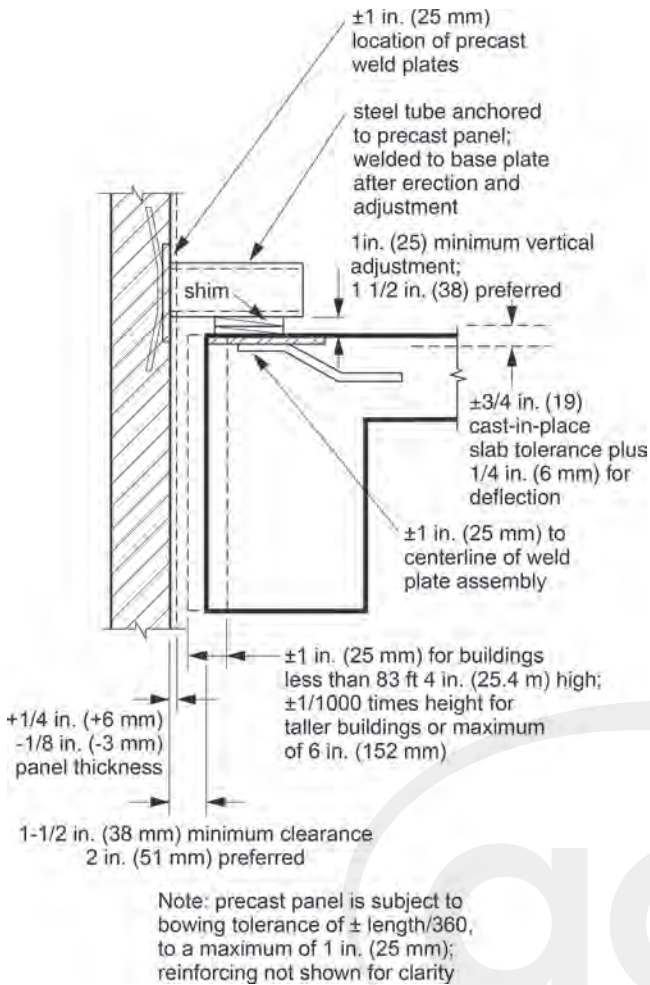


Fig. 5.6.2.2.1—Accommodating precast panels.

5.6.2.2.3 When precast panels or their connectors rest on a cast-in-place corbel, continuous ledge, or a wall, provide a minimum vertical adjustment of 3/4 in. (± 19 mm).

5.6.2.2.4 Post-tensioned slabs that support curtain walls present additional concerns because the slabs will usually shorten by a measurable dimension after the tendons are stressed. Calculate the estimated final slab edge location (PCI MNL 120). Experience indicates movements of 1 in. in 100 ft (25 mm in 30 m) are common (Aalami and Barth 1989; Allred 2005; Bondy 1989; Suprenant and Malisch 2009). In larger buildings, movements in excess of 1 in. (25 mm) can occur and should be reviewed with the structural engineer. As a result, tolerances required for post-tensioned slabs could be greater than those for non-prestressed slabs.

5.6.2.2.5 Joint width of precast panels should be designed to provide for expected movement and sealant capability, as well as a minimum joint width of 1/2 in. (13 mm) if the tolerances for panel size and installed top-of-panel elevation are applied.

5.6.2.2.6 Precast columns can be set on cast-in-place footings in several ways. Two of the most common are shown in Fig. 5.6.2.2.6. In both cases, a minimum vertical design clearance of 2 in. (51 mm) should be provided. Refer also to detailing suggestions for column-to-footing connections in PCI MNL 135.

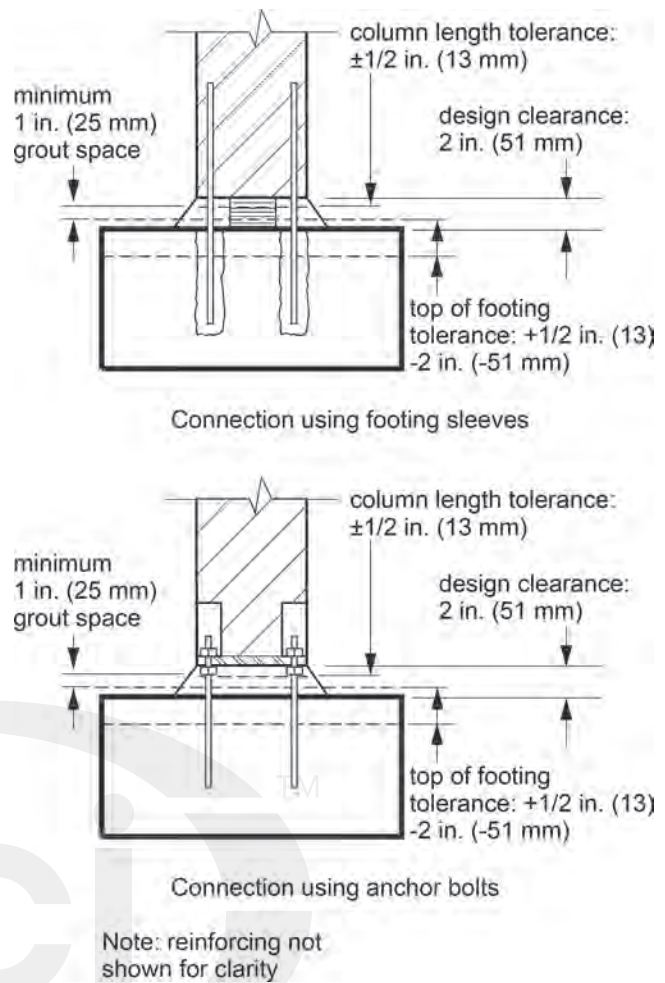


Fig. 5.6.2.2.6—Accommodating precast columns on footings.

5.6.2.3 Construction strategies

5.6.2.3.1 The precast contractor should be given the original horizontal and vertical control points provided to the concrete contractor by the general contractor. Control points should be provided at each level.

5.6.3 Glass fiber-reinforced concrete cladding panels

5.6.3.1 Discussion

5.6.3.1.1 Glass fiber-reinforced concrete (GFRC) panels are products manufactured with a cement/aggregate slurry reinforced with glass fibers and normally attached to a structural assembly of metal studs. The industry standard tolerances listed in Table 5.6.3.1.1 and shown in Fig. 5.6.3.1.1a and b are only a small portion of those found in PCI MNL 128. PCI MNL 128 should be consulted for specific requirements for the various types of GFRC elements and methods of attachment to the building structure.

5.6.3.1.2 GFRC panels are normally attached to an assembly of metal studs, which are, in turn, attached to the building structure with clip angles, shims, and other adjustable fasteners. Tolerances for the structural frame should be stated in the specifications to achieve the installed tolerances as published by the Precast/Prestressed Concrete Institute. As long as sufficient clearance and adjustable fasteners are provided, GFRC panels can be installed to fairly tight tolerances.

Table 5.6.3.1.1—GFRP panel tolerances

Item (Fig. 5.6.3.1.1a and b)	PCI MNL 128 tolerances	ACI tolerances
1. Length and width	Under 10 ft (3 m): $\pm 1/8$ in. (± 3 mm); Over 10 ft (3 m): $\pm 1/8$ in. (± 3 mm) per 10 ft (3 m); Maximum: 1/4 in. (6 mm)	—
2. Panel thickness, face to back of steel framing	+3/8 in., -1/4 in. (+10 mm, -6 mm)	—
3. Edge return depth	+1/2 in., -0 in. (+13 mm, -0 mm)	—
4. Panel face alignment	1/4 in. (6 mm) maximum	—
5. Joint width	Panels less than 20 ft (6 m): $\pm 1/4$ in. (± 6 mm) Panels over 20 ft (6 m): $\pm 3/8$ in. (± 10 mm)	—
6. Joint taper	1/4 in. in 10 ft (6 mm in 3 m) Maximum: 3/8 in. (10 mm)	—
7. Panel opening location	$\pm 1/4$ in. (± 6 mm)	—
8. Opening size	$\pm 1/4$ in. (± 6 mm)	—
9. Location of inserts	$\pm 1/2$ in. (± 13 mm)	—
10. Bowing (out-of-plane)	Bowing shall not exceed $L/240$ unless it can be shown that the member can meet erection tolerances using connection adjustments.	—
11. Warping of corners	Maximum permissible warpage of one corner out of the plane to the other three shall be 1/16 in. per ft (5 mm per m) of the distance from the nearest adjacent corner, unless it can be shown that the member can meet the erection tolerances using connection adjustments.	—
12. Position of flashing reglets	$\pm 1/4$ in. (± 6 mm)	—
13. Steel stud frame vertical and horizontal alignment	$\pm 1/4$ in. (± 6 mm) in 10 ft (3 m)	—
14. Steel stud frame size	$\pm 3/8$ in. (± 10 mm)	—
15. Squareness of steel stud frame, difference in diagonals	Maximum: 3/8 in. (10 mm)	—
16. Differential bowing between panels	Maximum: 1/4 in. (6 mm)	—
17. Deviation of outside face in plan location from building datum	$\pm 1/2$ in. (± 13 mm) For precast buildings over 100 ft (30 m), tolerance from datum can increase at a rate of 1/8 in. (3 mm) per story over 100 ft (30 m) to a maximum of 2 in. (50 mm)	—
18. Variation from square	1/8 in. per 6 ft or 1/4 in. total, whichever is greater (3 m per 2 m or 6 mm total)	—
19. Plumb	$\pm 1/4$ in. (± 6 mm) in 10 ft (3 m) with a of 1 in. (25 mm) for height of structure or 100 ft (30 m) whichever is less; For precast buildings over 100 ft (30 m), plumb tolerance can increase at a rate of 1/8 in. (3 mm) per story over 100 ft (30 m) to a maximum of 2 in. (50 mm)	—
20. Installed elevation of top of individual exposed panels	$\pm 1/4$ in. (± 6 mm)	—

5.6.3.2 Design strategies

5.6.3.2.1 The following clearances between the building structure and the back of the supporting frame should be shown in the contract documents:

- Cast-in-place concrete: 1-1/2 in. (38 mm) minimum, 2 in. (50 mm) preferred
- Precast concrete: 1 in. (25 mm) minimum, 1-1/2 in. (38 mm) preferred
- Concrete columns: 2 in. (51 mm) minimum, 3 in. (76 mm) preferred

5.6.3.2.2 Provide adjustable connections and details with a minimum vertical, horizontal, and lateral adjustment of ± 1 in. (± 25 mm) (Fig. 5.6.3.1.1a). When panels span two floors, the detailing should accommodate the elevation for both floor slabs as well as differential deflection between floors.

5.6.3.3 Construction strategies

5.6.3.3.1 The GFRC contractor should be provided and use the original horizontal and vertical control points provided

to the concrete contractor. Control points should be provided at each level.

5.6.3.3.2 Compensation for bowing and warpage of GFRC panels can be accommodated during installation by taking advantage of the inherent flexibility of the panels.

5.6.4 Clay masonry cladding and concrete masonry unit (CMU) backup

5.6.4.1 Discussion

5.6.4.1.1 Tolerances for clay masonry construction are established with **BIA 11C** and **ACI 530/530.1**. A number of these tolerances are shown in Table 5.6.4.1.1 and are illustrated in Fig. 5.6.4.1.1.

5.6.4.1.2 Clay masonry and CMU backup walls typically consist of a reinforced, structural concrete block wall with brick veneer tied together with metal ties or horizontal reinforcement. In exterior walls, the cavity between the two wythes should be a recommended width of 2 in. (50 mm), exclusive of insulation or other components. Because

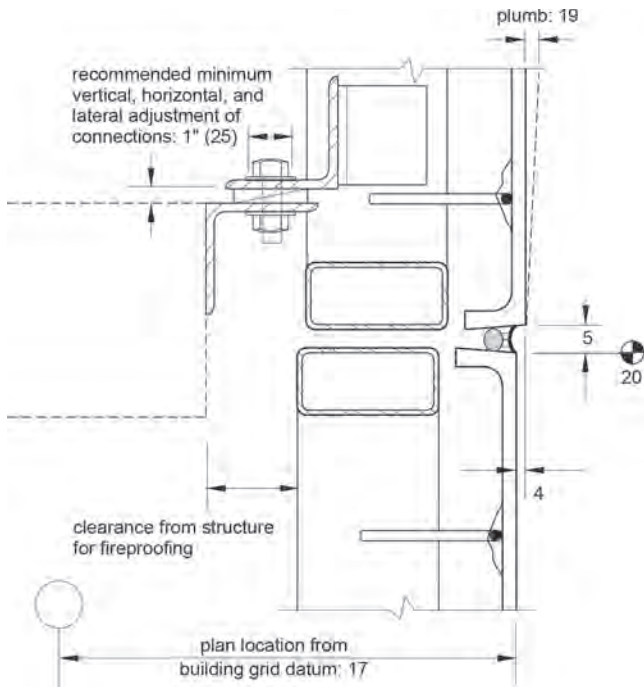


Fig. 5.6.3.1.1a—GFRC panel installation.

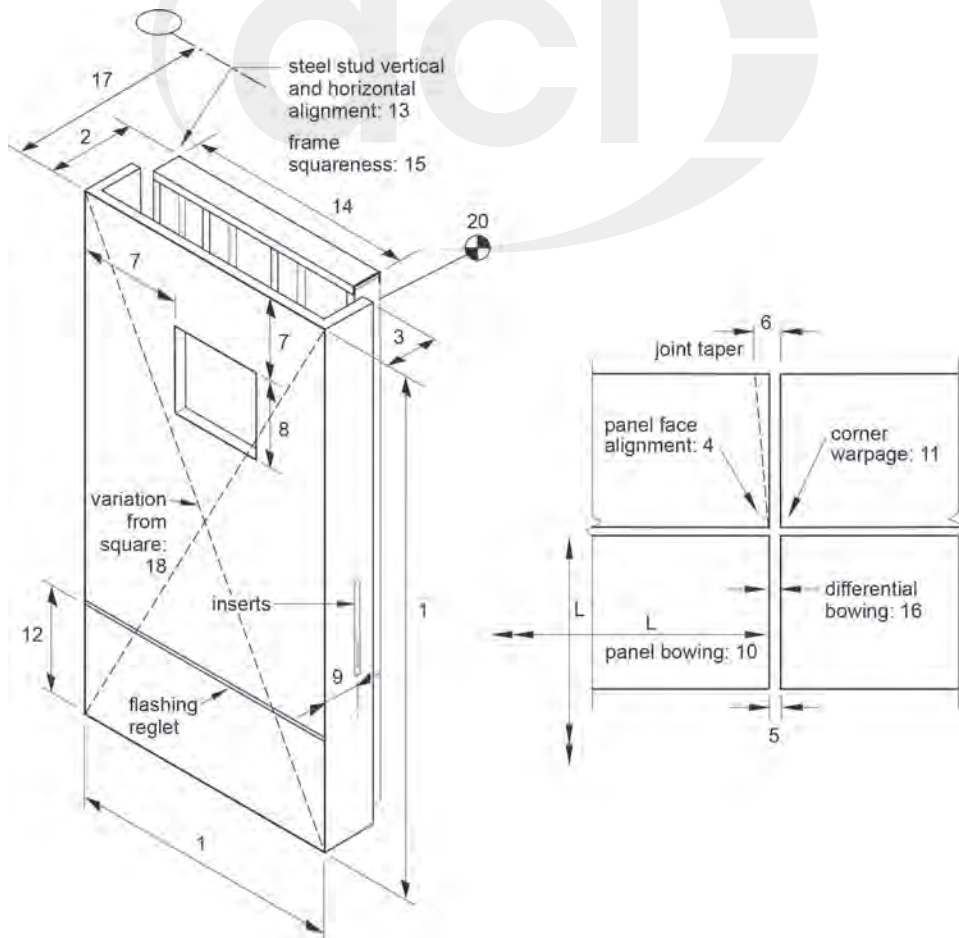


Fig. 5.6.3.1.1b—GFRC panels.

the clear cavity width is so large relative to masonry tolerances, variations in the size of the clay masonry or the CMU backup can be accommodated in the cavity.

5.6.4.2 Design strategies

5.6.4.2.1 When a masonry wall passes in front of the edge of a concrete slab, the connection detail should be designed to allow for the positional tolerance of the slab. This tolerance might vary depending on whether the slab is non-prestressed or post-tensioned. Post-tensioned slabs may have a greater inward tolerance, in the direction away from the outside of the buildings, than mild reinforced, non-prestressed slabs.

5.6.4.2.2 Exterior clay masonry backed up with cast-in-place concrete walls requires the same cavity width as CMU backup walls (2 in. [50 mm]). Dovetail slot anchors are commonly used to tie the masonry to the concrete and can accommodate coursing position and minor tolerances of the masonry and concrete. Insulation and vapor/air retarders are placed next to the concrete backup wall as with CMU backup walls.

5.6.5 Brick veneer/steel stud cladding

5.6.5.1 Discussion

5.6.5.1.1 There are no industry standard tolerances for combined brick veneer on steel stud backup walls. Standards for brick construction as indicated in Table 5.6.5.1.1 apply to the brick. Although there are no industry standards for the installation of exterior metal studs used as backing, [ASTM](#)

Table 5.6.4.1.1—Clay masonry wall tolerances with CMU backup

Item (Fig. 5.6.4.1.1)	BIA 11C tolerances	ACI 530/530.1 tolerances
1. Total width of multi-wythe construction	+1/2 in. (+12.7 mm), -1/4 in. (-6.4 mm)	+1/2 in. (+12.7 mm), -1/4 in. (-6.4 mm)
2. Face plane alignment	Within a 1/2 in. (12.7 mm) envelope along total height of wall	—
3. Variation in vertical slope	Maximum of ±1/4 in. in 10 ft (±6.4 mm in 3 m)	—
4. Maximum variation from plumb for vertical lines and surfaces of columns, walls, and arises	±1/4 in. in 10 ft (±6.4 mm in 3 m); ±3/8 in. (±9.6 mm) in a story height not to exceed 20 ft (6 m); ±1/2 in. in 40 ft (±12.7 mm in 12 m) or more	±1/4 in. in 10 ft (±6.4 mm in 3.05 m); ±3/8 in. (±9.6 mm) in a story height not to exceed 20 ft (6.10 m); ±1/2 in. in 40 ft (±12.7 mm in 12 m) or more
5. Maximum variation from plumb for external corners, expansion joints, and other conspicuous lines	±1/4 in. in any story or 20 ft (6.4 in any story or 6 m) maximum; ±1/2 in. in 40 ft (±12.7 mm in 12 m) or more	—
6. Level for exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines for brick wythe	±1/4 in. (±6.4 mm) in any bay or 20 ft (6 m); ±1/2 in. in 40 ft (±12.7 mm in 12 m) or more	±1/4 in. (±6.4 mm) in any bay or 10 ft (3.05 m); ±1/2 in. (±12.7 mm) maximum
7. Maximum variation from plan location of related portions of columns, walls, and partitions	±1/2 in. (±12.7 mm) in any bay or 20 ft (6 m); ±3/4 in. (±19 mm) in 40 ft (12 m) or more	—
8. Width of head joints	—	-1/4 in. (-6.4 mm), +3/8 in. (+9.5 mm)
9. Width of bed joints	—	±1/8 in. in 10 ft (±3.2 mm in 3.05 m)
10. CMU plumb tolerances	—	±1/4 in. in 10 ft (±6.4 mm in 3.05 m) ±3/8 in. in 20 ft (±9.6 mm in 6.10 m) ±1/2 in. (±12.7 mm) maximum

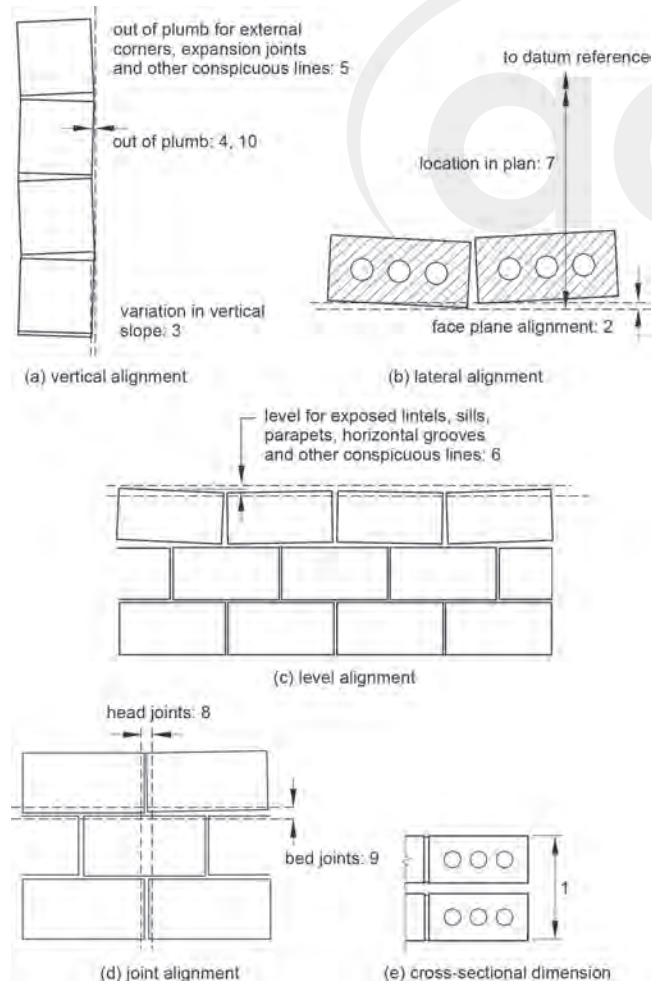


Fig. 5.6.4.1.1—Clay masonry wall tolerances with CMU backup.

C1007 may apply. Refer to 5.6.4 for more tolerances of clay masonry construction.

5.6.5.1.2 Brick veneer with steel stud backup walls can be constructed in two basic configurations. In what is usually called the spandrel system, steel studs are supported by the slab edge or spandrel beam and the brick veneer is supported by a shelf angle attached to the studs or to separate miscellaneous structural steel elements at the plane of the studs. **BIA 11C**, however, recommends shelf angles not be supported by the steel studs directly. In the second configuration, shelf angles are anchored directly to the edge of the floor slab or spandrel beam (Fig. 5.6.5.1.1). The metal stud walls are anchored to the floor and span to the underside of the floor above. Allow for deflection above the head of the door to accommodate building movement.

5.6.5.2 Design strategies

5.6.5.2.1 A 2 in. (50 mm) air space is recommended between the back of the brick and the face of insulation or sheathing covering the veneer backup. This space provides a means to drain any water that penetrates the veneer and to redirect the water to the exterior.

5.6.5.2.2 **BIA 11C** recommends a maximum dimension of 4-1/2 in. (114 mm) for the distance between the back of the brick and the steel framing unless the anchors are designed for a greater dimension.

5.6.5.2.3 Dimensional and distortion tolerances of individual bricks are relatively minor and are accommodated within the cavity or mortar joint by varying the plane of the exterior of the brick within the construction tolerances for brick walls.

5.6.5.2.4 When using the spandrel system building frame, tolerances can be accommodated by varying the positioning of the stud, slab edge connector, or both. If the shelf angle is attached to miscellaneous structural steel elements, these

Table 5.6.5.1.1—Brick veneer on steel stud and concrete framing tolerances

Item (Fig. 5.6.5.1.1)	BIA 11C and ASTM C1007 tolerances	ACI 117 tolerances
1. Maximum deviation from plumb and level for steel studs	1/960 of span or $\pm 1/8$ in. in 10 ft (± 3 mm in 3050 mm) (ASTM C1007)	—
2. Deviation from plumb of concrete frame for heights ≤ 83 ft 4 in. (25.4 m)	—	The lesser of 0.3 percent times the height above the top of foundations or up to a maximum of ± 1 in. (± 25 mm).
3. Deviation from plumb or concrete framing for building heights over 83 ft 4 in. (25.4 m)	—	The lesser of 0.1 percent times the height above the foundation or 6 in. (150 mm)
4. Horizontal deviation of edge of concrete beam	—	± 1 in. (± 25 mm)
5. Elevation of formed floor slabs before shoring removal	—	$\pm 3/4$ in. (± 20 mm)
6. Location of embedments	—	± 1 in. (± 25 mm)
7. Maximum variation from plumb for vertical lines and surfaces of columns, walls, and arrises	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3 m); $\pm 3/8$ in. (± 9.6 mm) in a story height not to exceed 20 ft (6 m); $\pm 1/2$ in. in 40 ft (± 12.7 mm in 12 m) or more (BIA 11C)	$\pm 1/4$ in. in 10 ft (6 mm in 3 m); $\pm 3/8$ in. (± 10 mm) in a story height not to exceed 20 ft (6 m); $\pm 1/2$ in. in 40 ft (± 13 mm in 12 m) or more
8. Maximum variation from plumb for external corners, expansion joints, and other conspicuous lines	$\pm 1/4$ in. (± 6.4 mm) in any story or 20 ft (6 m) maximum; $\pm 1/2$ in. in 40 ft (± 12.7 mm in 12 m) or more (BIA 11C)	—
9. Level for exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines for brick wythe	$\pm 1/4$ in. (± 6.4 mm) in any bay or 20 ft (6 m); $\pm 1/2$ in. in 40 ft (± 12.7 mm in 12 m) or more (BIA 11C)	$\pm 1/4$ in. (± 6 mm) in any bay or 10 ft (3 m); $\pm 1/2$ in. (± 13 mm) maximum
10. Maximum variation from plan location of related portions of columns, walls, and partitions	$\pm 1/2$ in. (± 12.7 mm) in any bay or 20 ft (6 m); $\pm 3/4$ in. in 40 ft (± 19 mm in 12 m) or more (BIA 11C)	—

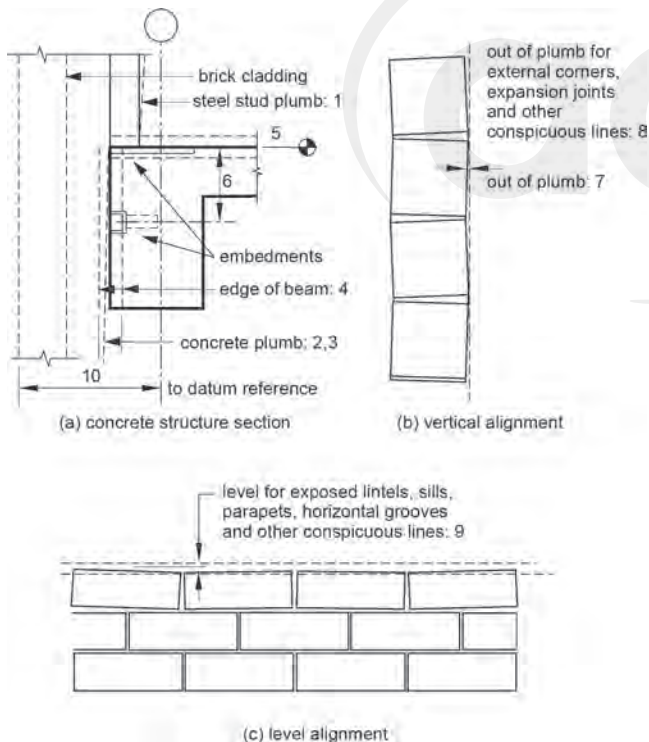


Fig. 5.6.5.1.1—Brick veneer/steel stud cladding tolerances.

items can be adjusted to position the face of the brick wall in the plane shown on the contract documents.

5.6.5.2.5 When anchoring the shelf angle (brick angle) directly to the slab edge or spandrel beam, as shown in Fig. 5.6.5.2.5, structural concrete frame tolerances can be accommodated by using wedge bolts, horizontal slotted holes in

the vertical leg of the angle, shimming behind the vertical leg of the angle, or using other adjustable anchors. The 1 in. (25 mm) shim space shown in Fig. 5.6.5.2.5 is a suggested method of dealing with concrete frame tolerances. If shim space is not available, a wider angle can be used, subject to review by the architect/engineer.

5.6.5.2.6 In most cases, using a 2 in. (50 mm) minimum cavity dimension can accommodate minor brick tolerances and a concrete building frame tolerance of ± 1 in. (± 50 mm).

5.6.5.3 Construction strategies

5.6.5.3.1 When adjusting the position of the shelf angle to accommodate frame tolerance, a minimum of $3/4$ in. (20 mm) should be maintained from the exterior face of the brick and the toe of the shelf angle to provide sufficient room for sealant and backer rod. If the space is less than $3/4$ in. (20 mm), consider the use of sealant and bond breaker tape.

A minimum bearing of two-thirds the width of the brick on the shelf angle should also be maintained. If the spandrel beam varies inward slightly, steel shims can be inserted between the angle and the concrete face. If the beam varies inward a distance too great to be accommodated with shims, a longer leg angle can be used but this may require a thicker angle and should be reviewed by the architect/engineer.

5.6.6 Concrete masonry cladding and prefabricated masonry panels

5.6.6.1 Discussion

5.6.6.1.1 Tolerances for concrete masonry construction are established by **ACI 530/530.1**. Several examples are given in Table 5.6.6.1.1 and illustrated in Fig. 5.6.6.1.1a and b.

5.6.6.1.2 Tolerances for prefabricated masonry panels (Fig. 5.6.6.1.1b) are established by **ASTM C901**. Because prefabricated masonry panels have tolerances similar to

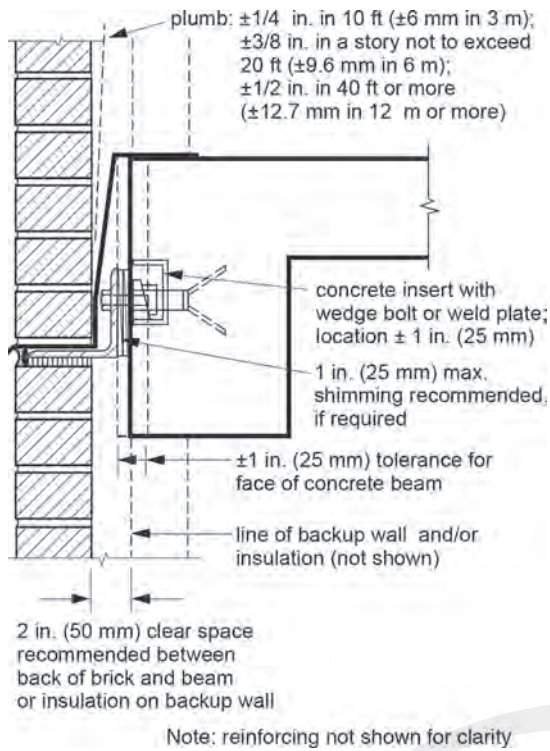


Fig. 5.6.5.2.5—Accommodating brick walls.

architectural precast concrete, the suggested clearances and adjustment allowances given in 5.6.2 can be used.

5.6.6.2 Design strategies

5.6.6.2.1 A design clearance of 1-1/2 in. (38 mm) minimum is recommended between the back of a concrete masonry wall and a concrete frame, excluding any consideration for allowances with a backup wall or insulation. This allows for a ±1 in. (±25 mm) positional tolerance of the concrete frame and tolerances for the size of the CMU, out-of-plumb tolerances, and positional tolerances.

5.6.6.2.2 When masonry walls pass in front of a concrete slab edge, design of the connection and detail should allow for the positional tolerance of the slab when connections are designed. This tolerance may vary depending on whether the slab is non-prestressed or post-tensioned. Post-tensioned slabs may require a larger tolerance in the direction away from the outside of the building than is necessary for mild reinforced, non-prestressed slabs.

5.6.6.3 Construction strategies

5.6.6.3.1 The contractor should determine tolerances with the anchor manufacturer for structural elements before construction.

5.6.7 Stone cladding

5.6.7.1 Discussion

Table 5.6.6.1.1—Concrete masonry and prefabricated masonry panel tolerances

Item (Fig. 5.6.6.1.1a and b)	ASTM C901 tolerances	ACI 530/530.1 tolerances
<i>Concrete masonry cladding</i>		
1. Total width of multi-wythe construction	—	+1/2 in. (12.7 mm), -1/4 in. (6.4 mm)
2. Face plane alignment	—	±1/4 in. in 10 ft (±6.4 mm in 3.05 m); ±3/8 in. in 20 ft (±9.5 mm in 6.10 m); ±1/2 in. (±12.7 mm) in total length of wall
3. CMU plumb tolerances	—	±1/4 in. in 10 ft (±6.4 mm in 3.05 m); ±3/8 in. in 20 ft (±9.5 mm in 6.10 m); ± 1/2 in. (±12.7 mm) maximum
4. Location in plan	—	±1/4 in. in 20 ft (±6.4 mm in 6.10 m); ±3/4 in. (±19.1 mm) maximum
5. Top of bearing wall level alignment	—	±1/4 in. in 10 ft (±6.4 mm in 3.05 m); ±1/2 in. (±12.7 mm) maximum
6. Relative alignment in any course	—	± 1/4 in. in 10 ft (±6.4 mm in 3.05 m); ±1/2 in. (±12.7 mm) maximum
7. Location of elements vertically	—	± 1/4 in. (±6.4 mm) in story height; ± 3/4 in. (±19.1 mm) maximum
8. Width of head joints	—	-1/4 in. (-6.4 mm), +3/8 in. (+9.5 mm)
9. Width of bed joints	—	±1/8 in. (±3.2 mm)
<i>Prefabricated masonry panels</i>		
10. Height and length of panels 10 ft (3.05 m) and under	±1/8 in. (±3.2 mm)	—
11. Height and length of panels 10 ft to 20 ft (3.05 m to 6.1 m)	+1/8 in. (+3.2 mm), -3/16 in. (-4.8 mm)	—
12. Height and length of panels 20 ft to 30 ft (6.096 m to 9.144 m)	+1/8 in. (+3.2 mm), -1/4 in. (-6.4 mm)	—
13. Out of square (difference between diagonal measurements)	±1/8 in. in 6 ft (±3.2 mm in 1.83 m); 1/4 in. (6.4 mm) maximum	—
14. Thickness	+1/4 in. (+6.4 mm); -1/8 in. (-3.2 mm)	—
15. Warpage (out of plane)	±1/8 in. per 6 ft (±3.2 mm per 1.83 m)	—
16. Location of anchors, inserts, and connecting devices (to centerline of imbed)	±3/8 in. (±9.5 mm)	—

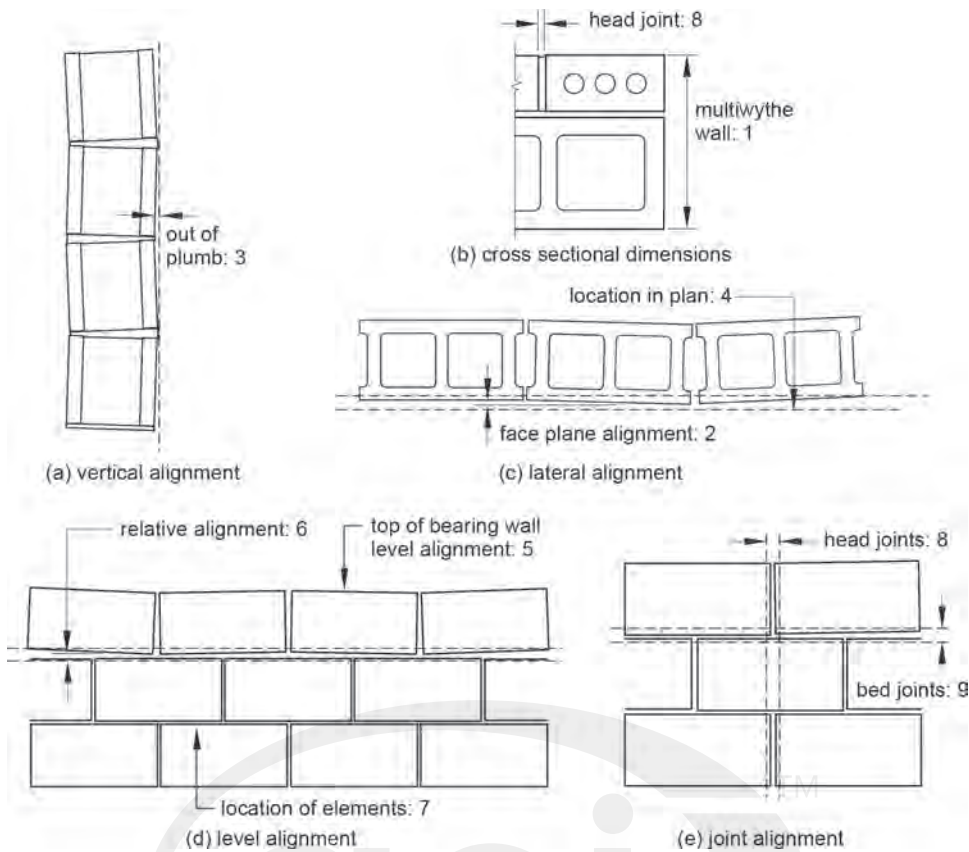


Fig. 5.6.6.1.1a—Concrete masonry tolerances.

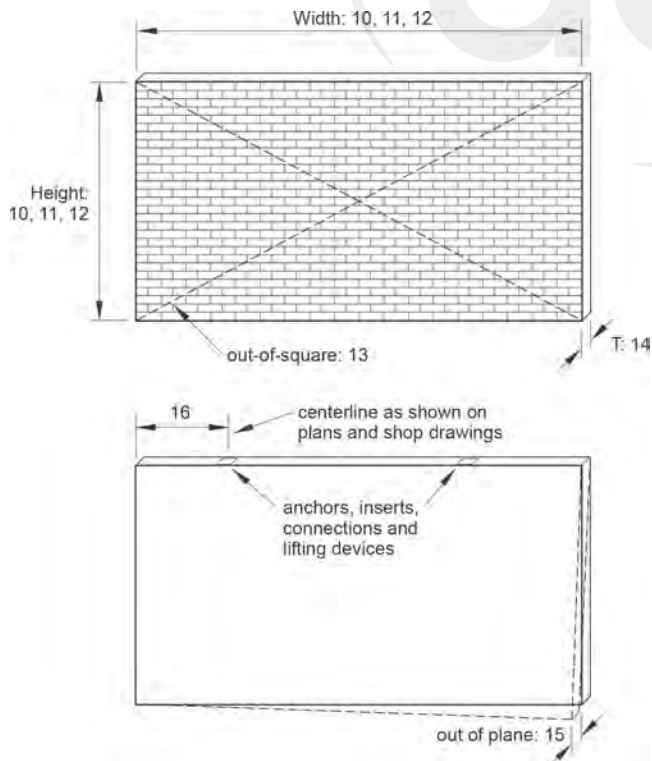


Fig. 5.6.6.1.1b—Prefabricated masonry tolerances.

5.6.7.1.1 Industry standards for fabrication and installation of stone vary slightly depending on the specific type of stone (Tables 5.6.7.1.1a through d). As with other types of curtain walls, adequate clearances and adjustable connections should be detailed when stone is attached to concrete. Industry-standard tolerances for limestone (Table 5.6.7.1.1a), granite (Table 5.6.7.1.1b), and marble (Table 5.6.7.1.1c) allow the finished face of panels to be installed slightly out of plumb to partially accommodate minor irregularities of the frame if absolutely necessary.

5.6.7.1.2 A concrete and stone veneer interface should accommodate the following elements: a ± 1 in. (± 25 mm) tolerance of the face of the concrete; the thickness tolerance of the type of stone being used; the thickness and configuration of the anchoring or supporting device; working space required for erection and fastening; and any insulation, flashing, weep tubes, or other accessories behind the stone. The worst-case scenario typically arises when the concrete frame deviates toward the outside of the structure; increased stone thickness within tolerance should be accommodated toward the structural frame (Fig. 5.6.7.1.2).

5.6.7.1.3 A variety of supports and lateral anchors are available for stone installation that should provide sufficient adjustment to maintain erection tolerances developed by the stone trade associations. Variations in vertical dimensions of a concrete frame are accommodated with adjustable concrete inserts, slotted angles, or shimming. Variations perpendicular to the building are accommodated by shim-

Table 5.6.7.1.1a—Limestone tolerances

Item (Fig. 5.6.7.1.1a)	Indiana Limestone Institute (ILI) Handbook (2007) tolerances	ACI 117 tolerances
1. Size of panels	±1/8 in. (±3 mm) for preassembled units and panels over 50 ft ² (4.6 m ²); ±1/16 in. (±2 mm) for other surface finishes	—
2. Thickness	Critical depths: ±1/8 in. (±3 mm) for most finishes Critical depths: ±1/4 in. (±6 mm) for shot sawed Noncritical depths: ± 1/2 in. (±13 mm)	—
3. Deviation from plumb	±1/4 in. in 10 ft (±6 mm in 3050 mm) ±3/8 in. (±10 mm) for one story or any 20 ft (6100 mm) section; ±1/2 in. (±13 mm) in 40 ft (12.2 m) or more	—
4. Deviation from plumb for external corners, expansion joints, and other conspicuous lines	±1/4 in. (±6 mm) for one story or 20 ft (6100 mm); ±3/4 in. (±19 mm) in 40 ft (12.2 m) or more	—
5. Horizontal position of components in plan	±1/2 in. (±13 mm) in any bay or 20 ft (6100 mm); ±3/4 in. (±19 mm) in 40 ft (12.2 m) or more	—
6. Cross-sectional dimensions	-1/4 in. (-6 mm), +1/2 in. (+13 mm)	—
7. Top of stone and grooves	±1/2 in. (±13 mm) in any bay or 20 ft (6100 mm); ±3/4 in. (±19 mm) in 40 ft (12.2 m) or more	—
8. Deviation from plumb of concrete frame for heights ≤ 83 ft 4 in. (25.4 m)	—	The lesser of 0.3 percent times the height above the top of foundations or up to a maximum of ±1 in. (±25 mm).
9. Deviation from plumb or concrete framing for building heights over 83 ft 4 in. (25.4 m)	—	The lesser of 0.1 percent times the height above the foundation or 6 in. (150 mm)
10. Horizontal deviation of edge of concrete beam	—	±1 in. (±25 mm)
11. Elevation of formed floor slabs before shoring removal	—	±3/4 in. (±20 mm)
12. Location of embedments	—	±1 in. (±25 mm)

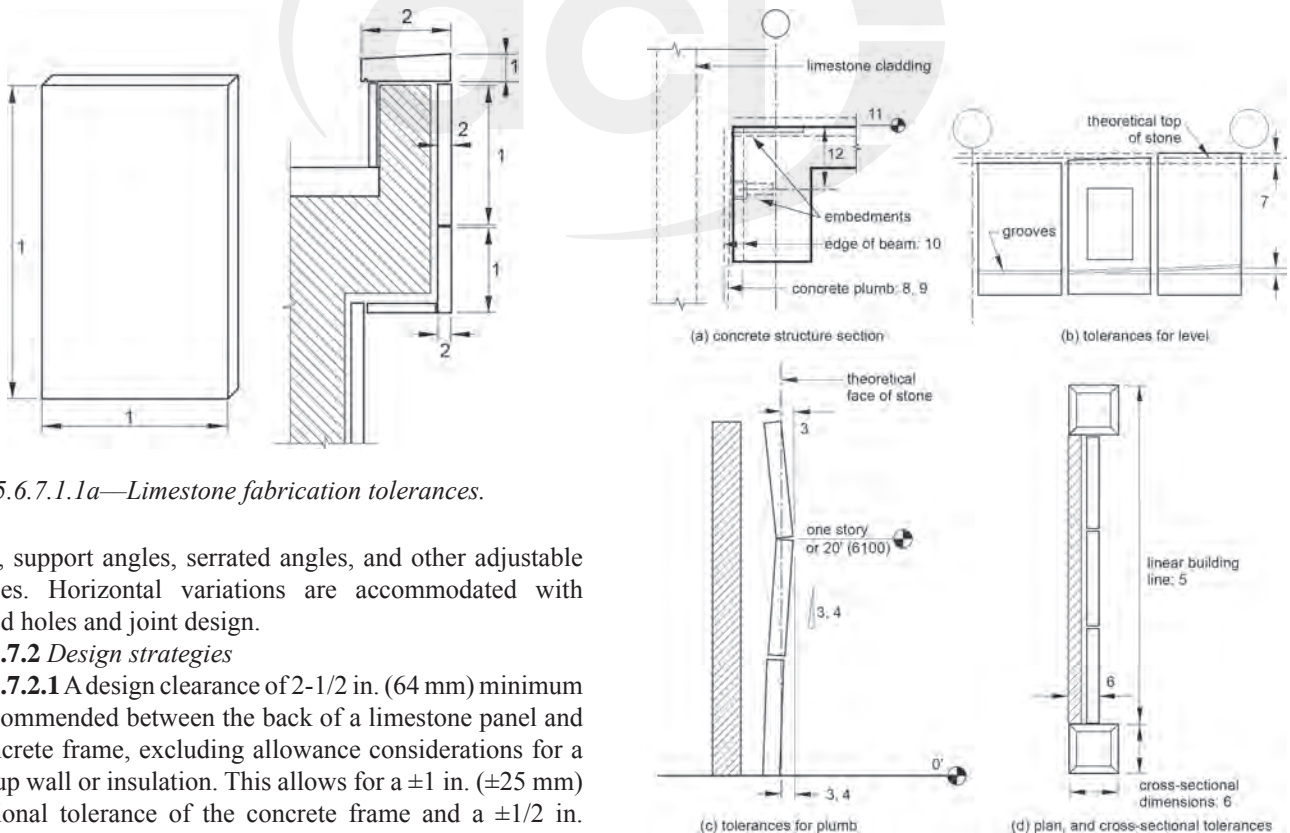


Fig. 5.6.7.1.1a—Limestone fabrication tolerances.

ming, support angles, serrated angles, and other adjustable devices. Horizontal variations are accommodated with slotted holes and joint design.

5.6.7.2 Design strategies

5.6.7.2.1 A design clearance of 2-1/2 in. (64 mm) minimum is recommended between the back of a limestone panel and a concrete frame, excluding allowance considerations for a backup wall or insulation. This allows for a ±1 in. (±25 mm) positional tolerance of the concrete frame and a ±1/2 in. (±13 mm) tolerance for noncritical panel thickness and the head of the anchor connection. Additional clearance should be added as required by specific details to accommodate thicker stone, other fastening devices, insulation, flashing, weep tubes, and other accessories behind the stone.

Fig. 5.6.7.1.1b—Limestone installation tolerances.

Table 5.6.7.1.1b—Granite tolerances

Item (Fig. 5.6.7.1.1c)	National Building Granite Quarries Association (2011) tolerances	Marble Institute of America (2011) tolerances
1. Length and width	±1/16 in. (1.5 mm)	—
2. Thickness	Panels 3/8 or 1/2 in. (10 or 13 mm) nominal thickness: ±1/32 in. (±0.8 mm); Panels 3/4 to 1-5/8 in. (20 to 41 mm) nominal thickness: ±1/8 in. (±3 mm); Panels greater than 1-5/8 in. (41 mm) nominal thickness: ±1/4 in. (±6 mm)	—
3. Deviation from flat surface per 4 ft (1220 mm) based on finish, or one-third the joint width, whichever is greater	Polished, honed, or fine rubbed finish: ±1/16 in. (±1.5 mm); Sawn, four, six, and eight cut: ±1/8 in. (±3.2 mm); Thermal/coarse stippled: ±3/16 in. (±4.8 mm); Pointed or other rough cut finish: ±1 in. (±25 mm)	—
4. Location of anchor plates	±1/8 in. (±3 mm)	—
5. Out-of-plane	—	±1/4 in. in 10 ft (±6 mm in 3050 mm); ±1/2 in. in 40 ft (±13 mm in 12.2 m)
6. Variation from plumb for walls and columns	—	±1/4 in. in 10 ft (±6 mm in 3050 mm); not to exceed 3/8 in. (10 mm) in story height; ±1/2 in. in 40 ft (±13 mm in 12.2 m)
7. Level line for lintels, parapets, and rustications	—	±1/8 in. in 5 ft (±3 mm in 1500 mm); ±1/2 in. (±13 mm) in column bay; ±3/4 in. in 40 ft (±19 mm in 12.2 m)

Note: Refer to Table 5.6.7.1.1a and Fig. 5.6.7.1.1c for concrete framing tolerances.

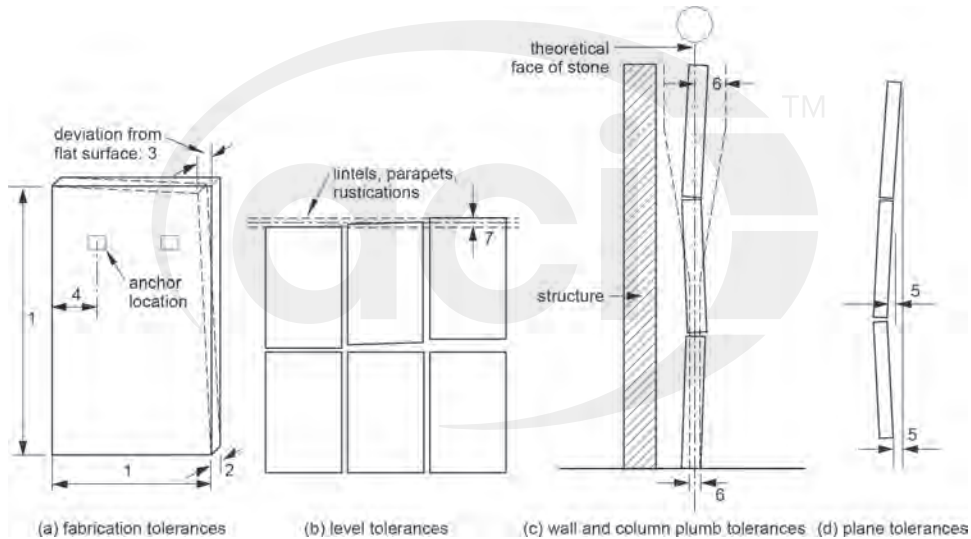


Fig. 5.6.7.1.1c—Granite tolerances.

5.6.7.2.2 A design clearance of 2 in. (50 mm) minimum is recommended between the back of a granite, marble, or cast stone panel and concrete frame, excluding allowance considerations for a backup wall or insulation. This allows for a ±1 in. (±25 mm) positional tolerance of the concrete frame and up to a 1/4 in. (6 mm) tolerance for panel thickness and the head of the anchor connection. Additional clearance should be considered (5.6.7.2.1). Recommended design clearances for granite, marble, and cast stone are slightly less than for limestone because of their slightly greater thickness and installation tolerances.

5.6.7.2.3 When suspended from a concrete frame, connectors for stone panels should allow for a minimum 1 in. (25 mm) vertical adjustment. This allows for a potential ±3/4 in. (±19 mm) variation in the elevation of the slab or spandrel beam and up to a ±1/8 in. (±3 mm) variation in the panel

length. This provides sufficient adjustment to align joints and compensates for out-of-square panels.

5.6.7.3 Construction strategies

5.6.7.3.1 For buildings over 83 ft 4 in. (25.4 m), tolerances for the concrete frame may need to be held tighter than allowed by ACI 117 as the permissible out-of-plumb variation begins to exceed ±1 in. (±25 mm).

5.6.7.3.2 Provide the stone veneer contractor with the original horizontal and vertical control points at each level that were provided to the concrete contractor by the general contractor.

5.6.8 All glass cladding

5.6.8.1 Discussion

5.6.8.1.1 There are no industry standard tolerances for all-glass window systems. Tolerances could vary with individual manufacturers. Tolerances could apply, however, for

Table 5.6.7.1.1c—Marble tolerances

Item (Fig. 5.6.7.1.1d)	MIA (2011) tolerances	ACI tolerances
1. Length and width	$\pm 1/16$ in. (± 1.6 mm)	—
2. Thickness	Panels 3/8 or 1/2 in. (10 or 13 mm): $\pm 1/32$ in. (± 0.8 mm); Panels 3/4 in. to 1-5/8 in. (20 to 41 mm): $\pm 1/8$ in. (± 3 mm); Panels greater than 1-5/8 in. (41 mm): $\pm 1/4$ in. (± 6 mm)	—
3. Deviation from flat surface per 4 ft (1220 mm) based on finish, or one-third the joint width, whichever is greater	Polished, honed, or fine rubbed finish: $\pm 1/16$ in. (± 1.5 mm); Sawn, four, six, and eight cut: $\pm 1/8$ in. (± 3.2 mm); Thermal/coarse stippled: $\pm 3/16$ in. (± 4.8 mm); Pointed or other rough cut finish: ± 1 in. (± 25 mm)	—
4. Location of anchor plates	$\pm 1/8$ in. (± 3 mm)	—
5. Out-of-plane	$\pm 1/4$ in. in 10 ft (± 6 mm in 3050 mm); $\pm 1/2$ in. in 40 ft (± 13 mm in 12.2 m)	—
6. Variation from plumb for walls and columns	$\pm 1/4$ in. in 10 ft (± 6 mm in 3050 mm); not to exceed 3/8 in. (10 mm) in story height; $\pm 1/2$ in. in 40 ft (± 13 mm in 12.2 m)	—
7. Level line for lintels, parapets, and rustications	$\pm 1/8$ in. in 5 ft (± 3 mm in 1500 mm); $\pm 1/2$ in. (± 13 mm) in column bay; $\pm 3/4$ in. in 40 ft (± 19 mm in 12.2 m)	—

Note: Refer to Table 5.6.7.1.1a and Fig. 5.6.7.1.1c for concrete framing tolerances.

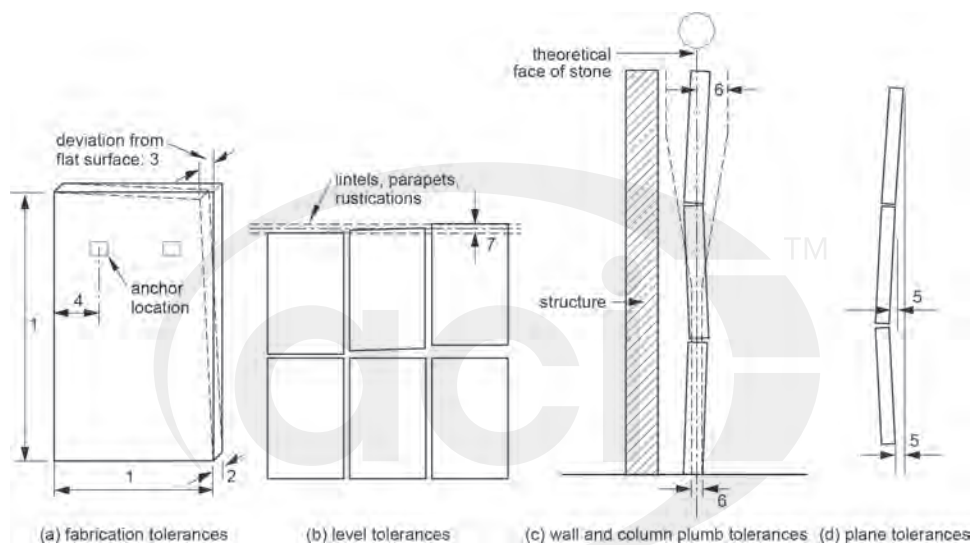


Fig. 5.6.7.1.1d—Marble tolerances.

heat-treated flat glass and sealed insulated glass units (Table 5.6.8.1.1).

5.6.8.1.2 All-glass window systems are typically anchored to structural steel or a secondary steel framing system. When the steel framing system is attached to structural concrete, accommodation of concrete tolerances can usually be made with adjustable connections. Manufacturer's glazing systems provide for adjustment of the final glass position.

5.6.8.2 Design strategies

5.6.8.2.1 The architect/engineer, in consultation with the glazing system manufacturer, should develop glazing details that can accommodate concrete tolerances. If standard concrete tolerances are problematic, more restrictive concrete tolerances should be stated in the contract documents.

5.6.8.3 Construction strategies

5.6.8.3.1 Connections should be verified with the glazing contractor and hold a preconstruction tolerance meeting to determine potential problems with tolerance compatibility.

5.6.8.3.2 The glazing contractor should be provided with and use the original horizontal and vertical control points

provided to the concrete contractor by the general contractor. Control points should be provided at each level.

5.7—Infill wall systems

5.7.1 Discussion

5.7.1.1 Infill wall systems include concrete masonry, clay masonry, light gauge metal framing, or glass block placed within a perimeter of concrete. Tolerances for these products are given in Tables 5.7.1.1a through 5.7.1.1c and are illustrated in Fig. 5.7.1.1a through 5.7.1.1c.

5.7.1.2 The International Building Code (IBC 2009) requires that all masonry be constructed with tolerances specified in ACI 530/530.1. This includes glass unit masonry.

5.7.1.3 Although there are no industry standards for installation of exterior metal studs used as backing or infill systems, ASTM C1007 recommends that studs be plumb and level within 1/960 of the span, or 1/8 in. in 10 ft (3 mm in 3050 mm).

5.7.1.4 AISI S200 for light gauge steel framing requires:

Table 5.6.7.1.1d—Cast stone tolerances

Item (Fig. 5.6.7.1.1e)	CSI Specification 04-72-00 tolerances	ACI tolerances
1. Length, width, and thickness	$\pm 1/8$ in. (± 3 mm) or $L/360$, whichever is greater	—
2. Twist, square, and camber	$\pm 1/8$ in. (± 3 mm) or $L/360$, whichever is greater	—
3. Location of weld plates, reglets, grooves, and dowel holes, front side	$\pm 1/8$ in. (± 3 mm)	—
4. Location of weld plates, reglets, grooves, and dowel holes, back side	$\pm 3/8$ in. (± 10 mm)	—

Note: Refer to Table 5.6.7.1.1a and Fig. 5.6.7.1.1c for concrete framing tolerances.

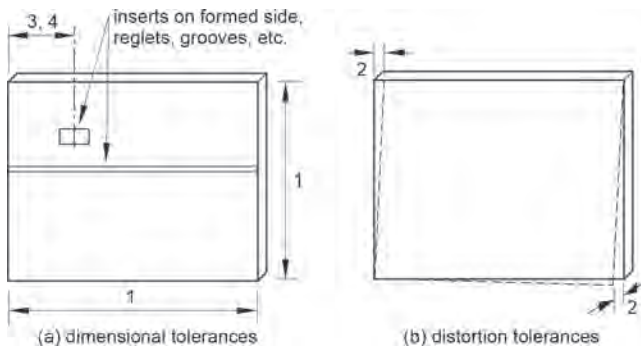


Fig. 5.6.7.1.1e—Cast stone tolerances.

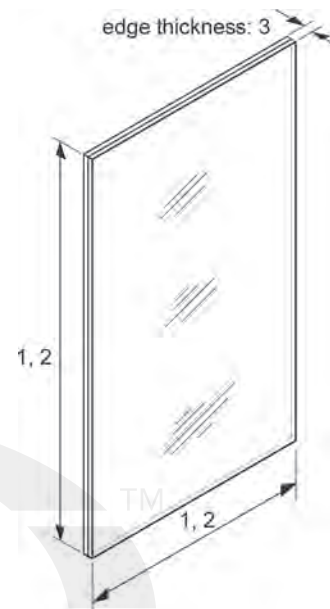
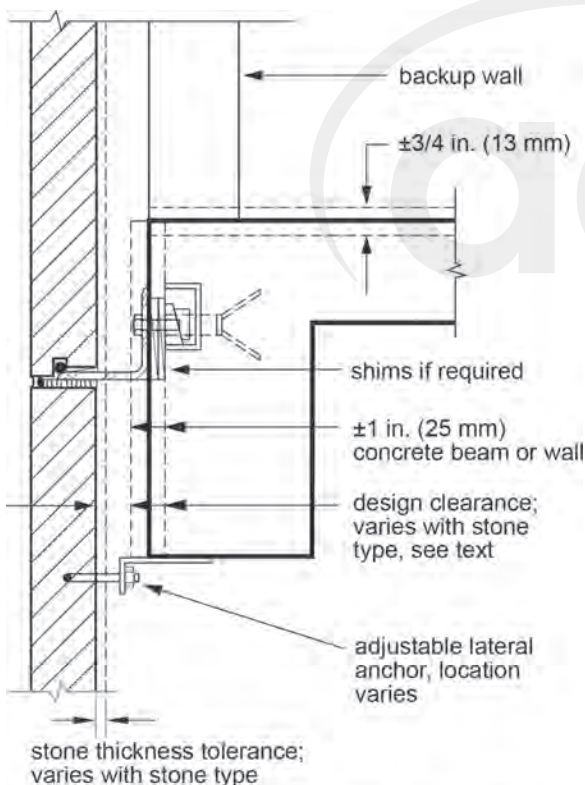


Fig. 5.6.8.1.1—Glass tolerances.



Note: insulation, flashing, and other details not shown for clarity. Support method and joint details vary.

Fig. 5.6.7.1.2—Accommodating stone veneer.

The foundation shall be level and free from defects beneath load-bearing walls. If the foundation is not level, provisions shall be made to provide a uniform

bearing surface with a maximum 1/4 in. (6.4 mm) gap between the bottom track or rim track and the foundation. This shall be accomplished through the use of load-bearing shims or grout provided between the underside of the wall bottom track or rim track and the top of the foundation wall or slab at stud or joist locations.

5.7.1.5 There are no industry standards for the size of glass block. Most glass block, however, is manufactured to within $\pm 1/16$ in. (1.6 mm) of the actual specified size. Consult individual manufacturers for specific product tolerances.

5.7.2 Design strategies

5.7.2.1 When concrete masonry units or clay masonry units are used as infill between cast-in-place concrete slabs or beams and concrete columns or walls, standard concrete tolerances should be accommodated. This includes allowance for tolerance of the concrete head and sill framing and the expected deflection and creep of the beam or slab above (Fig. 5.7.2.1).

5.7.2.2 If glass block panels are detailed with framing attached to concrete, the framing may be shimmed to provide a level and plumb opening. Gaps and shims may be covered with trim or otherwise concealed within the detail. Variations in vertical opening dimensions can be accommodated with deflection framing at the head of the panel as shown in Fig. 5.7.2.1(a). Variations in horizontal opening sizes may be

Table 5.6.8.1.1—Glass tolerances

Item (Fig. 5.6.8.1.1)	ASTM C1048 tolerances	IGMA TR-1200 tolerances
1. Length and width, tempered glass	1/2 in. (12 mm): $\pm 1/8$ in. (± 3.2 mm); 3/4 in. (19 mm): $\pm 3/16$ in. (± 4.8 mm)	—
2. Length and width, insulating glass	—	Over 30 to 60 in. (760 to 1525 mm): $+5/32$ in. ($+4.0$ mm), $-1/16$ in. (-1.6 mm); Over 60 to 84 in. (1525 to 2134 mm): $+3/16$ in. ($+4.8$ mm), $-1/16$ in. (-1.6 mm); Over 84 in. (2134 mm): consult manufacturer
3. Edge thickness, 1 in. (25 mm) glass unit	—	0.938 to 1.062 in. (23.8 to 27.0 mm)

Table 5.7.1.1a—Concrete masonry unit tolerances

Item (Fig. 5.7.1.1a)	ASTM C90 tolerances	ACI 530/530.1 tolerances
1. Overall height, width, and depth of CMU	$\pm 1/8$ in. (± 3.2 mm)	—
2. Total width of multi-wythe construction	—	$+1/2$ in. ($+12.7$ mm), $-1/4$ in. (-6.4 mm)
3. Face plane alignment	—	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3.05 m); $\pm 3/8$ in. in 20 ft (± 9.5 mm in 6.10 m); $\pm 1/2$ in. (± 12.7 mm) in total length of wall
4. CMU plumb tolerances	—	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3.05 m); $\pm 3/8$ in. in 20 ft (± 9.5 mm in 6.10 m); $\pm 1/2$ in. (± 12.7 mm) maximum
5. Location in plan	—	$\pm 1/2$ in. in 20 ft (± 12.7 mm in 6.10 m); $\pm 3/4$ in. (± 19.1 mm) maximum
6. Top of bearing wall level alignment	—	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3.05 m); $\pm 1/2$ in. (± 12.7 mm) maximum
7. Relative alignment in any course	—	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3.05 m); $\pm 1/2$ in. (± 12.7 mm) maximum
8. Location of elements vertically	—	$\pm 1/4$ in. in story height (± 6.4 mm in story height); $\pm 3/4$ in. (± 19.1 mm) maximum
9. Width of head joints	—	$-1/4$ in. (-6.4 mm), $+3/8$ in. ($+9.5$ mm)
10. Width of bed joints	—	$\pm 1/8$ in. (± 3.2 mm)

Note: Refer to Tables 5.6.7.1.1a and 5.7.1.1b and Fig. 5.6.7.1.1c and 5.7.1.1c for concrete framing tolerances.

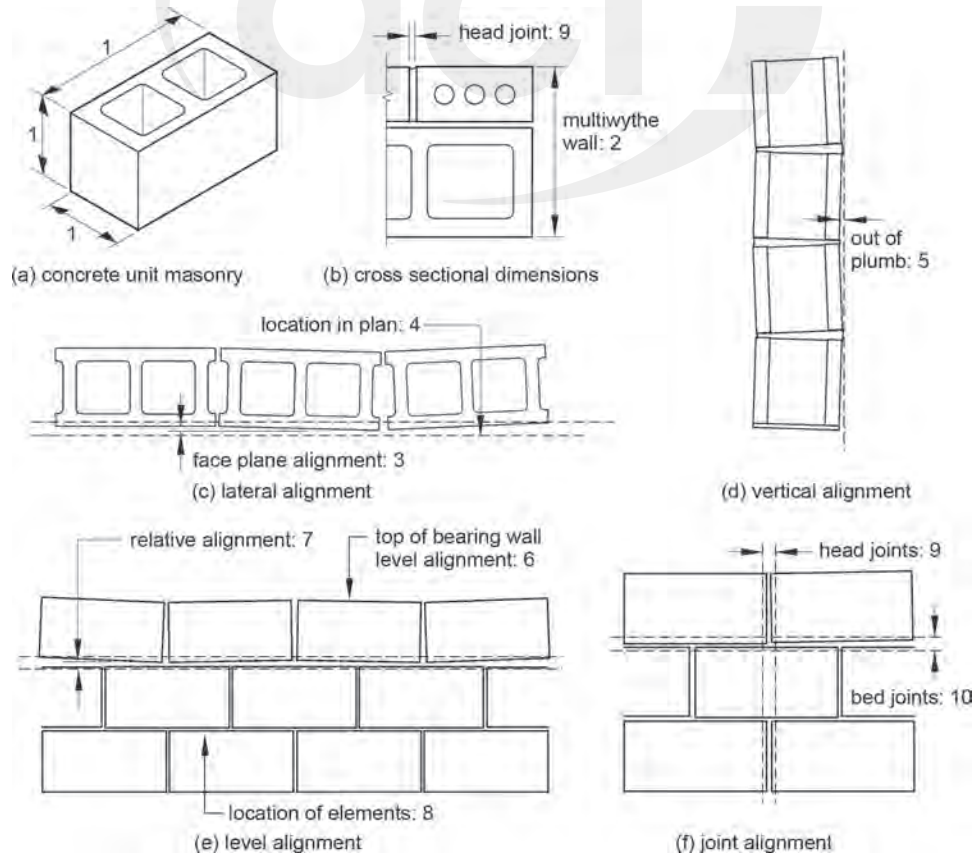


Fig. 5.7.1.1a—Concrete masonry unit tolerances.

Table 5.7.1.1b—Clay masonry unit tolerances

Item (Fig. 5.7.1.1b)	BIA 11C and ASTM C216 tolerances	ACI 530/530.1 tolerances
1. Clay masonry dimensions, FBX facing brick	Dimension 3 in. (76 mm) and under: $\pm 1/16$ in. (± 1.6 mm) (BIA 11C)	—
2. Clay masonry dimensions, FBS facing brick	Dimension 3 in. (76 mm) up to 4 in. (102 mm): $\pm 3/32$ in. (± 2.4 mm); Dimension 4 in. (102 mm) up to 6 in. (152 mm): $\pm 1/8$ in. (± 3.2 mm); Dimension 6 in. (152 mm) up to 8 in. (203 mm): $\pm 5/32$ in. (± 4.0 mm) (ASTM C216)	—
3. Clay masonry warpage and distortion	FBX, 8 in. (203 mm) and under: $\pm 1/16$ in. (± 1.6 mm); FBS, 8 in. (203 mm) and under: $\pm 3/32$ in. (± 2.4 mm) (ASTM C216)	—
4. Total width of multi-wythe construction	$+1/2$ in. ($+12.7$ mm), $-1/4$ in. (-6.4 mm) (BIA 11C)	$+1/2$ in. ($+12.7$ mm), $-1/4$ in. (-6.4 mm)
5. Face plane alignment	Within a $1/2$ in. (13 mm) envelope along total height of wall (BIA 11C)	Within a $1/2$ in. (12.7 mm) envelope along total height of wall
6. Variation in vertical slope	Maximum of $\pm 1/4$ in. in 10 ft (± 6.4 mm in 3 m) (BIA 11C)	—
7. Maximum variation from plumb for vertical lines and surfaces of columns, walls, and arrises	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3 m); $\pm 3/8$ in. (± 96 mm) in a story height not to exceed 20 ft (6 m); $\pm 1/2$ in. in 40 ft (± 12.7 mm in 12 m) or more (BIA 11C)	$\pm 1/4$ in. in 10 ft (± 6.4 mm in 3.05 m); $\pm 3/8$ in. (± 9.6 mm) in a story height not to exceed 20 ft (6.10 m); $\pm 1/2$ in. (± 12.7 mm) maximum
8. Maximum variation from plumb for external corners, expansion joints, and other conspicuous lines	$\pm 1/4$ in. (± 6.4 mm) in any story or 20 ft (6 m) maximum; $\pm 1/2$ in. in 40 ft (± 12.7 mm in 12 m) or more (BIA 11C)	—
9. Level for exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines for brick wythe	$\pm 1/4$ in. (± 6.4 mm) in any bay or 20 ft (6 m); $\pm 1/2$ in. in 40 ft (± 12.7 mm in 12 m) or more (BIA 11C)	$\pm 1/4$ in. (± 6.4 mm) in any bay or 10 ft (3.05 m); $\pm 1/2$ in. (± 12.7 mm) maximum
10. Maximum variation from plan location of related portions of columns, walls, and partitions	$\pm 1/2$ in. (± 12.7 mm) in any bay or 20 ft (6 m); $\pm 3/4$ in. (± 19 mm) in 40 ft (12 m) or more (BIA 11C)	$\pm 1/2$ in. in 20 ft (± 12.7 mm in 6.10 m); $\pm 3/4$ in. (± 19.1 mm) maximum
11. Width of head joints	—	$-1/4$ in. (-6.4 mm), $+3/8$ in. ($+9.5$ mm)
12. Width of bed joints	—	$\pm 1/8$ in. in 10 ft (± 3.2 mm in 3.05 m)
13. Deviation from plan location of concrete elements	—	± 1 in. (± 25 mm)
14. Cross-sectional dimension of columns and similar element	—	Up to 12 in. (305 mm): $+3/8$ in., $-1/4$ in. ($+9.5$ mm, -6.4 mm); Over 12 in. to 3 ft (305 to 914 mm): $+1/2$ in. ($+12.7$ mm), $-3/8$ in. (-9.5 mm)

Note: Refer to Table 5.6.7.1.1a and Fig. 5.6.7.1.1c for concrete framing tolerances.

accommodated with channel framing or other trim as shown in Fig. 5.7.2.1(b).

5.7.2.3 Where appearance and the amount of trim are important, the detail should accommodate the ACI tolerances.

5.7.3 Construction strategies

5.7.3.1 Where appearance is not important, concrete masonry units and clay masonry units can be cut to fit. Minor deviations in opening size, plumb, or level can be accommodated with variations in mortar joints subject to building code requirements.

5.7.3.2 When used as infill framing, metal studs can be cut to fit. Slip joints can be used to accommodate expected deflection. Metal framing must be installed to the tolerances required for the finish materials.

5.7.3.3 The metal framing contractor should be provided with and use the original horizontal and vertical control points provided to the concrete contractor by the general contractor. Control points should be provided at each level.

5.7.3.4 **AISI S200** requires that if the foundation is not level, a uniform bearing surface should be established through the use of load-bearing shims or grout placed between the underside of the wall bottom track or rim track and the top of the foundation wall or slab at stud or joist locations.

5.7.3.5 Because glass block cannot be cut, openings should be precisely formed based on the modular unit size plus allowances for expansion joints, reinforcement, and framing.

5.7.3.6 A common mortar joint for glass block of $1/4$ in. (6 mm) can accommodate minor variations in individual glass block size.

5.7.3.7 Concrete floor surfaces for glass block should be level and flat to within $1/4$ in. in 10 ft (6 mm in 3 m).

5.7.3.8 Concrete openings for glass block without jamb frames should be plumb to within $3/8$ in. in 10 ft (10 mm in 3 m). This is consistent with standard plumb tolerances for cast-in-place concrete. Opening dimensions for glass block

Table 5.7.1.1c—Glass unit masonry tolerances

Item (Fig. 5.7.1.1c)	IBC tolerances	ACI 530/530.1-11 tolerances
1. Size of bed joints	Refers to ACI 530/530.1	-1/16 in. (-1.6 mm), +1/8 in. (+3.2 mm)
2. Size of head joints	Refers to ACI 530/530.1	±1/8 in. (±3.2 mm)
3. Variation from plumb	Refers to ACI 530/530.1	±1/4 in. in 10 ft (±6.4 mm in 3.05 m); ±3/8 in. in 20 ft (±9.5 mm in 6.10 m); ±1/2 in. (±12.7 mm) maximum

Note: Refer to Table 5.6.7.1.1a and Fig. 5.6.7.1.1c and 5.7.1.1c for concrete framing tolerances.

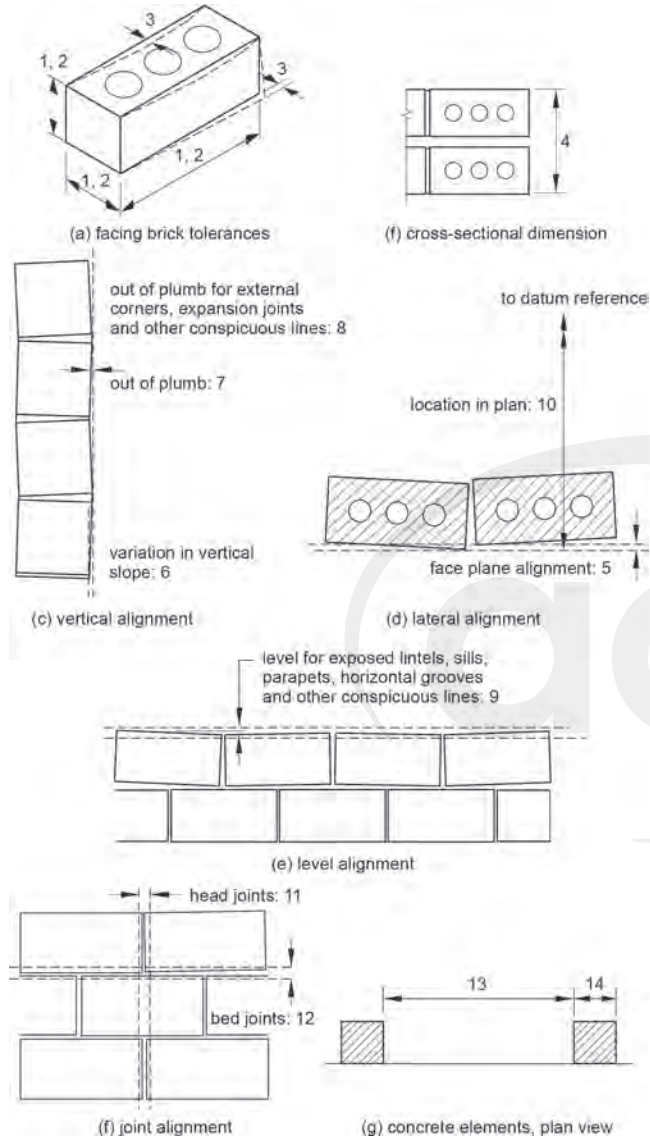


Fig. 5.7.1.1b—Clay masonry tolerances.

laid without jamb frames, as shown in Fig. 5.7.2.1(b), should be spaced within ±1/2 in. (±13 mm) of the design dimension.

5.8—Surface accessibility

5.8.1 Discussion

5.8.1.1 “Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines” (ADA/AB-AG) states that all dimensions are subject to conventional industry tolerances except where the requirement is stated as a range with specific minimum and maximum end points. Where a requirement is a minimum or a maximum dimension that

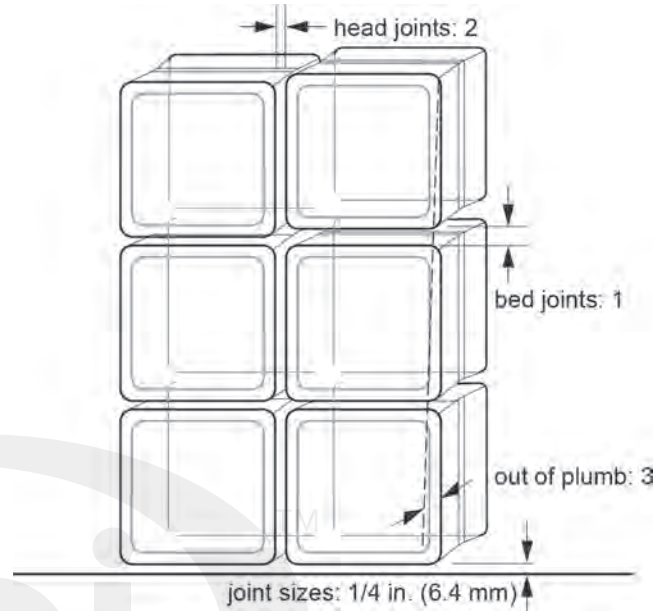


Fig. 5.7.1.1c—Glass unit masonry tolerances.

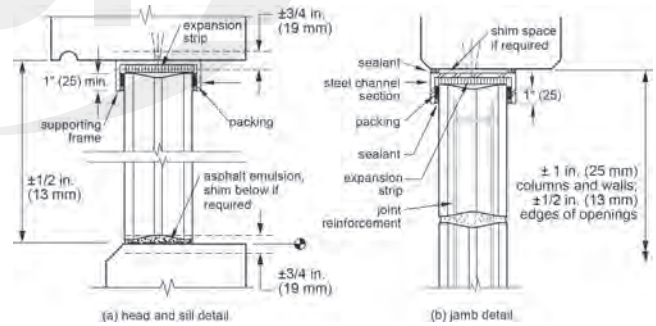


Fig. 5.7.2.1—Accommodating glass unit masonry.

does not have two specific minimum and maximum end points, tolerances may apply. The ADA/ABA-AG requirements for exterior surfaces are illustrated in Fig. 5.8.1.1 and listed in Table 5.8.1.1a.

5.8.1.2 Individual states or local jurisdictions may also have accessibility standards.

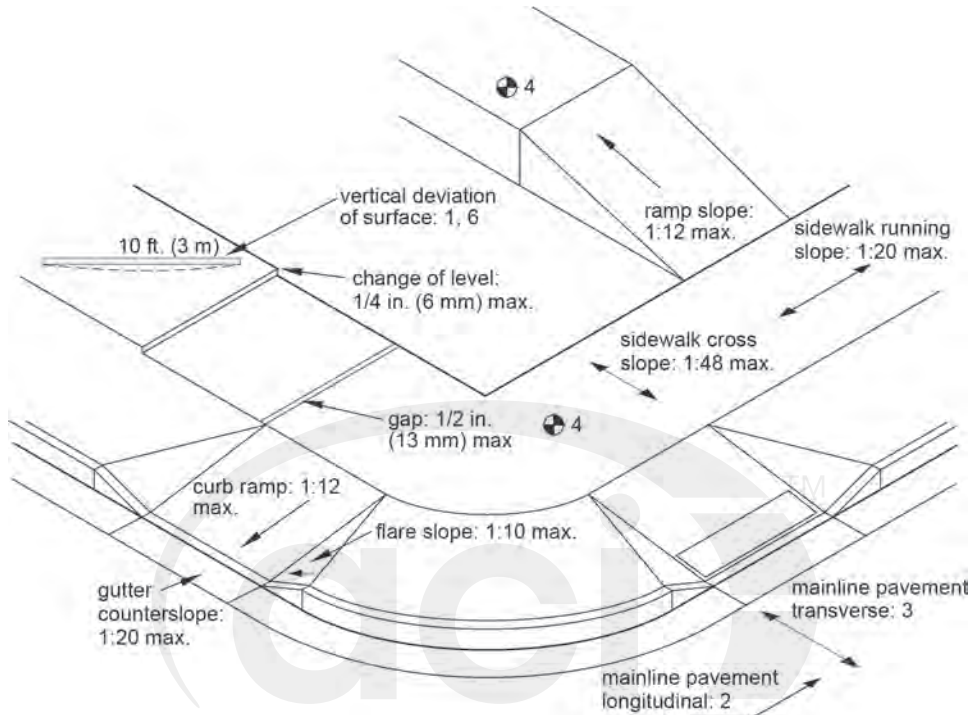
Specific requirements should be verified.

5.8.1.3 The ADA/ABA-AG requires overall slope measurement be made by the rise of the ramp over the run. There are no requirements for surface smoothness or flatness, nor is there standard protocol for measuring local slope, surface smoothness, or flatness.

5.8.1.4 ACI 117 does not specifically address standards for accessible surfaces, including flatness, smoothness, and

Table 5.8.1.1a—Tolerances related to exterior surface accessibility

Item (Fig. 5.8.1.1)	ICPI Specification 32-14-13 tolerances	ACI 117 tolerances
1. Ramps, sidewalks, and intersections: maximum gap below a 10 ft (3 m) unlevelled straightedge resting on high spots	—	1/4 in. (6 mm)
2. Top surface of slabs-on-ground	—	±3/4 in. (±20 mm)
3. Surface tolerance for interlocking concrete pavers adhesive applied to a cast-in-place concrete base, maximum gap below a 10 ft (3 m) straightedge	±3/8 in. (±10 mm)	—
4. Interlocking concrete pavers, slippage between adjacent pavers	1/8 in. (3 mm) maximum	—

*Fig. 5.8.1.1—Surface accessibility requirements and tolerances.*

ramp slope. Requirements for surface flatness of floors, sidewalks, and ramps for general use and their measurements are given in several sections of ACI 117 (Table 5.8.1.1a).

5.8.2 Design strategies

5.8.2.1 The general practice is to specify a dimension less than the required maximum (or more than the required minimum) by the amount of the expected field or manufacturing tolerance. Where ADA/ABA-AG requirements give a dimensional range, it is good practice to specify a dimension between the range.

5.8.2.2 A maximum overall design running slope for walks and other non-ramp exterior pedestrian surfaces of 1:25 (4 percent) is recommended. This allows for a potential plus construction variation of 1 percent while remaining within the ADA/ABA-AG requirements.

5.8.2.3 A maximum overall design running slope for exterior accessible ramps of 7.5 percent is recommended. This allows for a potential plus construction variation of approximately 0.8 percent and minimizes the effects of local variations without lengthening the ramp excessively.

A tolerance of +0.8 percent is generally possible with common methods of constructing concrete ramps. As an example, consider a 12 ft (3658 mm) long ramp with a

design slope of 1:12 (8.33 percent) cast between two fixed slabs with ACI elevation tolerances of ±3/4 in. (±20 mm). If one slab is high and one low, the statistical probability of the total out-of-tolerance elevations is 1-1/16 in. (27 mm) using the sum-of-the-squares method. This would give the ramp a slope of 9.07 percent—0.74 percent greater than allowed by accessibility standards. If the design slope was 7.5 percent, the out-of-tolerance slabs would define a ramp slope of slightly less than the maximum 8.33 percent and would result in an increase in length of only 16 in (406 mm) beyond the 12 ft. If possible, constructing ramps with a design slope of 7 percent allows for an even larger tolerance variation.

5.8.2.4 A maximum design cross slope for walks, accessible exterior ramps, and other pedestrian paving of 1.5 percent is recommended. This allows for a potential plus construction variation of +0.5 percent while still providing for drainage. Pervious paving may also be considered for level or nearly level surfaces.

5.8.2.5 When cast-in-place concrete is used as a subsurface for concrete pavers, brick pavers, stone, or other unit paving materials, the following design slopes are recommended:

a) Walks and other pedestrian surfaces—a maximum overall running slope of 4 percent

- b) Ramps—a maximum overall slope of 7.5 percent
- c) Cross slopes of walks and ramps—a maximum slope of 1.5 percent

5.8.3 Construction strategies

5.8.3.1 With a 1/4 in. (6 mm) maximum vertical level change, every effort should be made to avoid this amount of variation, as it presents a tripping hazard and makes the use of mobility aids more difficult than on a smooth surface. When vertical changes occur at joints and other locations, the high edge should be ground down for a length of 1 ft (0.30 m) in the direction of travel. This solution should be reviewed by the architect/engineer.

5.9—Finish floor coverings

5.9.1 Discussion

5.9.1.1 Table 5.9.1.1 lists the requirements for subsurfaces according to flooring trade organizations. Providing a concrete floor finish for suspended slabs and slabs-on-ground that is appropriate for many types of applied flooring is problematic. Ceramic tile, stone, wood, and even resilient flooring may require a finish of $F_F 35$ or higher. A finish of $F_F 35$ is approximately equivalent to a maximum gap under a 10 ft (3050 mm) straightedge of 1/4 in. (6 mm). This is considered a flat floor classification according to **ACI 117**. As shown in Table 5.9.1.1, some materials require tolerances tighter than 1/4 in. in 10 ft (6 mm in 3050 mm).

Although ACI 117 states that a flat floor classification ($F_F 35$) is the highest feasible tolerance level for suspended slabs; in practice, this is often difficult to achieve. After shoring is removed and the slab deflects, flatness will decrease (**Suprenant and Malisch 2009**).

5.9.1.2 Although there are no industry standards for several wood floor types, the tolerances shown in Table 5.9.1.1 that were previously developed by CSI are often used. These are included as guidance for the architect/engineer. The **MFMA (2005)** requires that concrete slabs for gymnasium floors be flat to a tolerance of $\pm 1/8$ in. in a 10 ft radius (± 3 mm in 3050 mm), which may be used for other types of wood flooring as well.

5.9.1.3 There are no industry standards for the required flatness of concrete floors for the installation of resinous or epoxy-coated flooring. Specific requirements for the type of installation being used should be verified with the flooring manufacturer.

5.9.2 Design strategies

5.9.2.1 Consider providing an allowance for leveling compound that can be applied after the structural concrete slab has been cast and cured and, in the case of suspended slabs, after the shoring has been removed.

5.9.2.2 The architect/engineer should consider a requirement in the contract documents for the owner to include an appropriate allowance in bids for grinding, patching, or the use of self-leveling flooring products over slabs to bring floors into compliance with flooring requirements. This accommodates concrete floors that begin within the specified flatness, but change in flatness during construction and prior to the flooring application.

Table 5.8.1.1b—ADA/ABA-AG requirements for surface accessibility

Element	Requirement
Running slope of walking surfaces	1:20, maximum (5 percent)*
Cross slope of walking surfaces	1:48, maximum (2 percent)
Accessible parking spaces and access aisles	1:48, maximum (2 percent)
Ramp slopes	1:12, maximum (8.33 percent)
Ramp cross slope	1:48, maximum (2 percent)
Curb ramps	1:12, maximum (8.33 percent)
Flared sides of curb ramps	1:10, maximum (10 percent)
Counter slopes of gutters and roads adjacent to curb ramps	1:20, maximum (5 percent)
Change in level, vertical offset	1/4 in. (6.4 mm), maximum
Openings in surface in direction of travel	1/2 in. (13 mm), maximum

*When sidewalks are adjacent to a street, the sidewalk may follow the grade of the street.

5.9.2.3 The architect/engineer should consider including the industry requirements (Table 5.9.1.1) in the specifications. Industry requirements vary slightly with the varying methods of measuring flatness. The architect/engineer should consider establishing one flatness tolerance for a project and including that in the specifications with the requirement for an allowance (5.9.2.2).

5.9.2.4 Compatibility issues for concrete floors as a substrate for finish flooring materials and other construction interfaces include the following.

5.9.2.4.1 *Curling of slabs-on-ground*—Curling is the distortion or rising up of slab corners and edges due to differences in moisture content or temperature between the top and bottom of a slab. Curling is not compatible with most floor finishes. With attention to the design mixture and addition of reinforcement, curling can be reduced. Some designers or general contractors include an allowance to grind and repair the curling should be set by the architect/engineer before bidding or contracting the concrete work.

5.9.2.4.2 *Cracking*—Cracking of slabs can be caused by applied loads. Cracking can also be caused by restrained volume change associated with drying shrinkage and thermal contraction. Cracking of grade-supported slabs can be caused by curling and subgrade settlement. Although cracking can be reduced through proper design and construction practices, some incidence of cracking is expected. Requirements for acceptable cracking based on the requirements of the floor covering should be determined by the architect/engineer and included as an owner allowance based on a price per linear foot (meter) of crack. Crack repair methods should also be specified by the architect/engineer and made part of the contract documents.

5.9.2.4.3 *Interior partitions*—Although floor slabs-on-ground and suspended slabs are within specified tolerances, they could require additional work by interior finish contractors. This is especially true for interior wall systems where gaps could require additional drywall compound, sound caulking, or other remedial work that is not the responsi-

Table 5.9.1.1—Tolerances required for various floor coverings

Finish material requirements, floor flatness	Industry tolerances	ACI tolerances
Ceramic tile floors	Portland cement beds: $\pm 1/4$ in. in 10 ft (± 6 mm in 3 m); Thin-set mortar beds: $\pm 1/4$ in. in 10 ft (± 6 mm in 3 m); Organic or epoxy adhesive: $\pm 1/16$ in. in 3 ft (± 2 mm in 1 m) (ANSI A108.1/A118/A136.1)	Maximum 1/4 in. (6 mm) gap under a 10 ft (3.0 m) straightedge
Ceramic tile walls	Portland cement beds: $\pm 1/4$ in. in 10 ft (± 6 mm in 3 m); Thin-set mortar beds: $\pm 1/4$ in. in 10 ft (± 6 mm in 3 m); Organic or epoxy adhesive: $\pm 1/8$ in. in 10 ft (± 3 mm in 3 m) (ANSI A108.1/A118/A136.1)	—
Thin-set stone tile flooring on concrete substrate	$\pm 1/8$ in. in 10 ft (± 3 mm in 3050 mm) (MIA 2011)	Maximum 1/4 in. (6 mm) gap under a 10 ft (3.0 m) straightedge
Thick stone on full mortar bed, finished surface	$\pm 1/8$ in. in 10 ft (± 3 mm in 3050 mm) (MIA 2011)	—
Strip flooring and parquet flooring (verify with manufacturer)	$\pm 1/4$ in. (6 mm) in 10 ft (3050 mm) (CSI)*	—
Cushioned or laminated wood flooring (verify with manufacturer)	$\pm 3/16$ in. in 10 ft (± 5 mm in 3050 mm) (CSI)*	—
Mastic cushioned wood flooring (verify with manufacturer)	$\pm 1/4$ in. in 10 ft (± 6 mm in 3050 mm) (CSI)*	—
Steel channel flooring (verify with manufacturer)	$\pm 1/8$ in. in 10 ft (± 3 mm in 3050 mm) (CSI)*	—
Wood gym floors	$\pm 1/8$ in. in 10 ft radius (± 3 mm in 3050 mm radius) (MFMA 2005)	—
Monolithic and thin-set terrazzo, concrete subfloor	$\pm 1/4$ in. in 10 ft (± 6 mm in 3050 mm) (NTMA 1999)	Maximum 1/4 in. (6 mm) gap under a 10 ft (3.0 m) straightedge
Polyacrylate-modified, epoxy, and epoxy-modified terrazzo, concrete subfloor	$\pm 1/8$ in. in 10 ft (± 3 mm in 3 m) (NTMA 1999)	—
Vinyl tile and resilient sheet flooring, concrete subfloor	$\pm 3/16$ in. in 10 ft (± 5 mm in 3050 mm) (ASTM F710)	—
Vinyl tile and resilient sheet flooring, concrete subfloor	—	Maximum 1/4 in. (6 mm) gap under a 10 ft (3.0 m) straightedge
Carpet, concrete subfloor	—	Maximum 3/8 in. (10 mm) gap under a 10 ft (3.0 m) straightedge

*CSI: Construction Specifications Institute, Suggested substrate tolerance in SpecGUIDE 09550 (out of print).

bility of the concrete contractor. To achieve better layout accuracy, interior finish contractors should use benchmarks provided by the general contractor rather than measuring from the concrete floor.

5.9.2.4.4 Slab thickness variations—The architect/engineer, general contractor, and concrete contractor should review **ACI 117** to become familiar with the allowable thickness tolerances and review how those tolerances might affect embeds and inserts.

5.9.2.4.5 Interior slab drainage—The architect/engineer should consider flooring details, deflection, and thickness when designing slopes to drain.

5.9.2.4.6 Doors, millwork, and cabinets—The floor flatness tolerances allowed by ACI 117 are not compatible with several finished items such as doors, millwork, and base trim. The architect/engineer should determine how doors, cabinets, and base trim will be detailed at the floor line based on expected concrete floor tolerances. For example, a pre-hung door and frame installed plumb and level over a floor that is slightly deflected could have a gap below one jamb. Base cabinets installed level over a floor should have provisions to cover the gap between the bottom of the cabinet and the floor, or the cabinet base should be scribed to the floor.

5.9.3 Construction strategies

5.9.3.1 A preconstruction tolerance meeting is recommended to discuss the potential problems with slabs and finish materials. The meeting should include the architect/engineer, concrete contractor, general contractor or construction manager, and all subcontractors whose work will come into contact with the concrete surface.

5.9.3.2 Guidance for construction of slabs-on-ground and suspended slabs is given in **ACI 302.1R**.

5.10—Expansion joints

5.10.1 Discussion

5.10.1.1 Because expansion joints vary in their type, location, and method of installation, various ACI tolerances could apply. These include edge location of openings of $\pm 1/2$ in. (± 13 mm), location of saw cuts, joints, and weakened plane embedments of $\pm 3/4$ in. (± 19 mm), or location of centerline of embedded items of ± 1 in. (25 mm). The architect/engineer, contractor, expansion joint manufacturer, and others on the project team should agree on which ACI concrete tolerances apply to expansion joints used on the project.

5.10.2 Design strategies

5.10.2.1 The architect/engineer should include in the contract documents specific requirements for tolerances related to expansion joints and their blockouts.

5.10.2.2 The architect/engineer should draw a section through the expansion joint to show the position of any post-tensioning anchor castings and surrounding reinforcement relative to the joint blockout.

5.10.3 *Construction strategies*

5.10.3.1 Verify specific requirements for expansion joint location tolerances with the contract documents and the architect/engineer.

5.10.3.2 Blockouts may be made slightly larger than required for the expansion joint. During installation, floor joints can be leveled by using a leveling grout. Verify requirements with the expansion joint manufacturer and specific project details.

CHAPTER 6—REFERENCES

American Architectural Manufacturers Association

AAMA CWG-1-89—Installation of Aluminum Curtain Walls

AAMA MCWM-1-89—Metal Curtain Wall Manual

AAMA/WDMA/CSA 101/I.S. 2/A440-05—Standard/Specification for Windows, Doors and Unit Skylights

American Concrete Institute

ACI 117-10—Specifications for Tolerances for Concrete Construction and Materials and Commentary

ACI 209R-92(08)—Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures

ACI 209.1R-05—Report on Factors Affecting Shrinkage and Creep of Hardened Concrete

ACI 209.2R-08—Guide for Modeling and Calculating Shrinkage and Creep in Hardened Concrete

ACI 214R-02—Guide to Evaluation of Strength Test Results of Concrete

ACI 301-10—Specifications for Structural Concrete

ACI 302.1R-04—Guide for Concrete Floor and Slab Construction

ACI 318-11—Building Code Requirements for Structural Concrete

ACI 347-04—Guide to Formwork for Concrete

ACI 435R-95(00)—Control of Deflection in Concrete Structures

ACI 435.8R-85(97)—Observed Deflections of Reinforced Concrete Slab Systems, and Causes of Large Deflections

ACI 530/530.1-11—Building Code Requirements and Specifications for Masonry Structures and Related Commentaries

ITG-7-09—Specification for Tolerances for Precast Concrete

American Institute of Steel Construction

AISC 303-05—Code of Standard Practice for Steel Buildings and Bridges

AISC 325-11—Steel Construction Manual, 14th edition

AISC 360-05—Specification for Structural Steel Buildings

AISC 822-08 Design Guide 22—Façade Attachments to Steel-Framed Buildings

American Iron and Steel Institute

AISI S200-07—North American Standard for Cold-Formed Steel Framing—General Provisions

American National Standards Institute

ANSI A108.1/A118/A136.1-Version 2011.1—American National Specifications for the Installation of Ceramic Tile

ANSI A250.8-03—Recommended Specifications for Standard Steel Doors and Frames

ANSI H35.2-09—Dimensional Tolerances for Aluminum Mill Products

ASTM International

ASTM C90-13—Standard Specification for Loadbearing Concrete Masonry Units

ASTM C216-13—Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)

ASTM C901-10—Standard Specification for Prefabricated Masonry Panels

ASTM C926-12—Standard Specification for Application of Portland Cement Based Plaster

ASTM C1007-11—Standard Specification for Installation of Load Bearing (Transvers and Axial) Steel Studs and Related Accessories

ASTM C1048-12—Standard Specification for Heat-Strengthened and Fully Tempered Flat Glass

ASTM E29-13—Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

ASTM F710-11—Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring

American Welding Society

AWS D.1.1/D1.1M:2004—Structural Welding Code - Steel

Brick Industry Association

BIA 11C-1998—Guide Specifications for Brick Masonry, Part 4

British Standards Institution

BS 5606:1990—Guide to Accuracy in Building

Canadian Standards Association

A23.1/A23.2-04—Concrete Materials and Methods of Concrete Construction/Methods of Test and Standard Practices for Concrete

Cast Stone Institute

CSI Specification 04-72-00-11—Standard Specifications for Architectural Cast Stone

Code of Federal Regulations (Published by Office of the Federal Register)

29-CFR Ch. XVII—Occupational Safety and Health Administration, Department of Labor

Concrete Reinforcing Steel Institute

EDR12-90 Engineering Data Report No. 12—Field Corrections to Rebars Partially Embedded in Concrete
EDR40-95 Engineering Data Report No. 40—Construction Tolerance Conflicts in Reinforced Concrete

Hollow Metal Manufacturers Association

HMMA 863-04—Guide Specifications for Stainless Steel Metal Hollow Doors and Frames

Insulated Glass Manufacturers Alliance

IGMA TR-1200-83—SIGMA Voluntary Guidelines for Commercial Insulating Glass-Dimensional Tolerances

Interlocking Concrete Pavement Institute

ICPI Specification 32-14-13:95—Interlocking Concrete Pavers Adhered to a Concrete Base

International Organization for Standardization

ISO 3443-1:1979—Tolerances for Building – Part 1: Basic Principles for Evaluation and Specification

International Code Council

IBC 2009—International Building Code

International Window Cleaning Association

IWCA I-14.1-2001—Window Cleaning Safety Standard

National Association of Architectural Metal Manufacturers

NAAMM AMP 510-92—Metal Stairs Manual

National Elevator Industry, Inc.

NEII-1-2005—Building Transportation Standards and Guidelines

Precast/Prestressed Concrete Institute

PCI MNL 128-01—Recommended Practice for Glass Fiber Reinforced Concrete Panels
PCI MNL 135-00—Tolerance Manual for Precast and Prestressed Concrete Construction
PCI MNL 120-99—Design Handbook: Precast and Prestressed Concrete

Post-Tensioning Institute

PTI DC20.7-01—Design, Construction and Maintenance of Cast-in-Place Post-Tensioned Concrete Parking Structures

Steel Door Institute

SDI 117-09—Manufacturing Tolerances, Standard Steel Doors and Frames

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