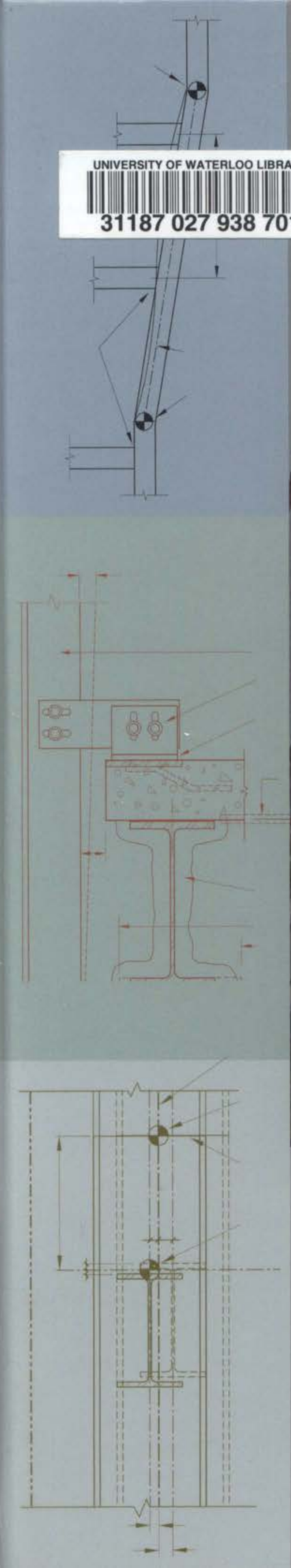

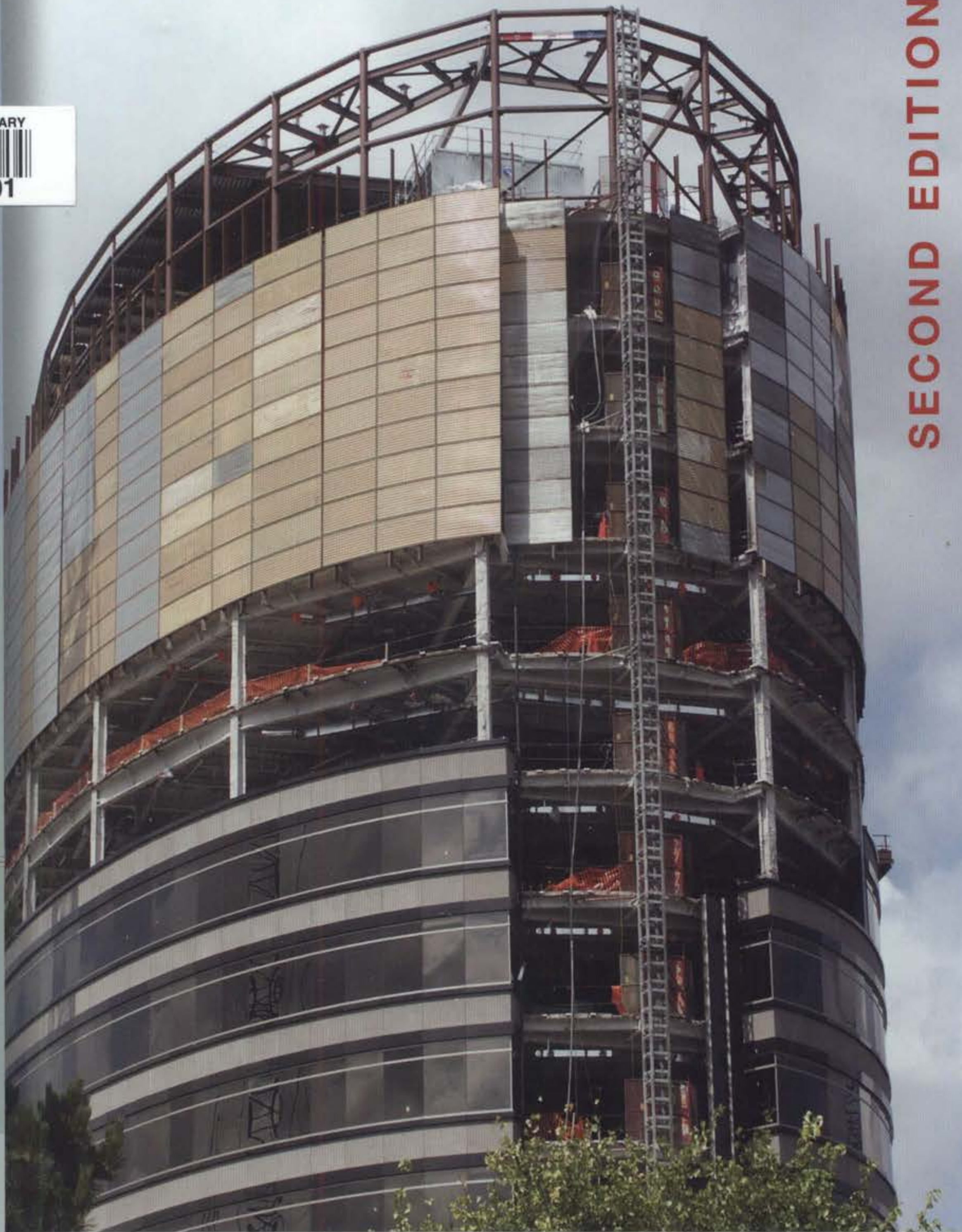

SECOND EDITION

HANDBOOK OF Construction Tolerances

David Kent Ballast, AIA, CSI

99.95

Handbook of Construction Tolerances

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Handbook of Construction Tolerances

Second Edition

David Kent Ballast

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Acknowledgments

For the Second Edition

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Introduction

Introduction to the Second Edition

The *Handbook of Construction Tolerances* provides architects, engineers, contractors, interior designers, lawyers, and others involved in the construction industry with a single-source reference to the thousands of industry-standard tolerances for the manufacture, fabrication, and installation of construction materials and components. The information it contains can be used to aid in design and detailing, to write better specifications, to establish what normal practice and standard of care are, to aid in construction supervision, and to settle disputes.

The current edition of this book updates and expands features in the first edition. The industry tolerances found in the first edition have been updated if they have changed. New sections have been added on right-of-way construction, autoclaved aerated concrete, tilt-up concrete panels, interior stone wall cladding, structural insulated panels, decorative architectural glass, laminated architectural flat glass, and bent glass. Finally, a new Part 3 has been added on measurement. Topics in this part include measuring devices and the methods of measurement, the uncertainty of measurement in construction, and how the designer can effectively document and enforce tolerances on a project. These topics have seldom been covered as related to building construction and are especially important when considering the task of measuring for compliance with Americans with Disabilities Act (ADA) accessibility regulations and other building codes. Compliance with tolerances can only be achieved when correct measurement protocols are used.

Interestingly, there are still many construction tolerances that do not exist as industry standards. Although many can be derived from combined individual and accumulated tolerances, the various trade associations need to continue work on setting realistic and enforceable standards for both tolerances and uniform measurement protocols. This is especially the case in the areas of accessibility and code compliance.

As in the first edition, both customary U.S. units (also called English or inch-pound units) and Système Internationale (SI) units are used in this book. Generally, the customary U.S. unit is used first, with the SI unit in parentheses. However, when a trade association or standards-writing organization uses SI units as the preferred measurement, the SI units are given first, with the customary U.S. unit in parentheses.

As before, equivalent SI units may not be consistent throughout the book. In this book SI units developed by a trade association, code-writing body, standards organization, or other reference are printed as developed by that group. For example, one organization may convert 1/4 in. to 6.4 mm, while another group may use 6 mm as the equivalent SI dimension. When a soft conversion has been made from a U.S. customary unit, the equivalent SI dimension is generally rounded off to the nearest millimeter for dimensions under 1 in., to the nearest 5 mm for larger dimensions, or to the nearest tenth of a meter when meters are used.

David Kent Ballast

Introduction to the First Edition

In the construction industry, all materials are assumed to have specific dimensions and the locations of construction elements are dimensioned on the drawings to a theoretically exact position relative to one or more datum points. Of course, in reality all dimensions and positions of installed materials vary somewhat. The acceptable amount of this variation is the tolerance of the material or installed position of the material. For some materials, such as shop-fabricated windows, the variation may be so slight as to be insignificant. For other materials, such as cast-in-place concrete, the allowable tolerance may be in an order of magnitude of several inches and may adversely affect the installation of other components. While some materials can be custom-cut and fit at the job site, others come from the factory in a fixed size and must be attached to previously a constructed frame. All of the materials must be fit together to satisfy the functional requirements of the building while being reasonably economic to build.

The construction industry is unique in that tolerances range from thousandths of an inch for many manufactured items to several inches for many field installed components. Each range of tolerances is important in its own right, and the architect and contractor must know what tolerances apply for any given situation. Then the tolerances must be accommodated with adequate clearances between adjacent elements and with adjustable connections or appropriately sized joints.

Acceptable construction tolerances have become established over a long time. Some are simply considered standard practice based on years of field experience about what is practical and readily achievable. Many are based on standards that specific industries have published and reflect what each industry agrees is reasonable as a balance between ease of construction, quality, and cost. Because of this evolution, there are innumerable tolerances that architects, engineers, suppliers, fabricators, and contractors must know about and accommodate to build well.

For the first time, the *Architect's Handbook of Construction Tolerances* assembles the thousands of industry-standard and standard-practice tolerances for the manufacture, fabrication, and installation of hundreds of construction assemblies, from structural steel to ceramic tile, and shows how dimensional variations must be accommodated in today's buildings. Whether you are an architect, interior designer, contractor, or specification writer, you will find this book invaluable for designing and detailing, establishing what normal practice is, settling disputes in the field, and writing more accurate specifications.

Because current construction techniques require using a combination of factory-built and site-built components assembled in complex ways, it is more important than ever that you understand what normal tolerances are, how they can accumulate during construction, and how you can plan for them before they cause trouble. Too often, when the reality of tolerances are ignored, the results can include costly field modifications, delays, design compromises, or even failure of a building component. This book arms you with the knowledge you need to help avoid these kinds of problems on your projects.

Part 1 of this book includes all types of material and assembly tolerances, from structural concrete and masonry to finish components like architectural woodwork and ceilings. Each material, fabrication, installation, or erection tolerance is shown graphically, making it easy to quickly pull out exactly what you need. In addition, you will find guidance on how one material tolerance relates to another and how dimensional variations should be accounted for in design and construction. Among the many tolerance data you will find, this handbook

- Shows what variation to expect when architectural precast concrete comes from the plant
- Lays out guidelines for concrete, asphalt, and pedestrian paving
- Gives the standards for cast-in-place concrete construction
- Explains how to anticipate dimensional differences for structural steel construction and how to provide for attachment of other construction materials to the steel frame
- Blocks out the basic requirements for unit masonry including concrete block, brick, and even terra cotta
- Presents the tolerances for exterior stone cladding and illustrates how to detail it to structural framing
- Demonstrates the fine points of accommodating interior material tolerances of finishes such as stone, paneling, ceilings, and more
- Organizes what you need to know for detailing fine cabinetry and other woodwork
- Identifies the variances involved with aluminum curtain wall construction
- Sets forth the generally accepted limits for gypsum wallboard construction including glass-reinforced gypsum
- Illustrates the tolerances for ceramic and quarry tile so you know what kinds of finish installations to expect
- Provides the basic data for flooring materials such as terrazzo, stone, and wood
- Discusses the degree of perfection you can expect with various types of glazing materials
- Gives guidelines for how to get the most from decorative and ornamental metals for high-quality interior detailing
- Illustrates the variations common with wood and metal door and frame construction and installation
- Shows the common dimensional variations of windows and their installation, including wood, steel, and aluminum products
- Illustrates how to accommodate combinations of tolerances commonly found in building construction such as masonry veneer on a steel or concrete frame and precast concrete on a steel frame
- Provides suggested details for particularly troublesome material and assembly tolerances that are often overlooked

The information about each tolerance follows an identical format to help speed your research. First, a drawing shows the material or installed assembly with the pertinent dimensional variation allowed by an industry standard or by common practice. Next, on the facing page, there is a brief written description about the essential facts concerning the component shown and the tolerances involved. The applicable industry standard organization and relevant standard number are listed in case you want to do more research. After this, there is a brief discussion of the tolerances and how they can be accommodated with proper detailing and construction methods. Finally, cross-references to related sections in the book are included so you can coordinate the assembly of several materials, if necessary.

Part 2 of this book addresses the all-important subject of accumulated dimensional variations. These occur when seemingly minor tolerances build on one another or when several materials are combined in such a way that normally acceptable small variations add up to a large difference. Knowing how this can occur and how you can plan for it will minimize many field problems. Dozens of detail drawings show how typical assemblies are put together to accommodate common tolerances.

Because tolerances can vary so much, always discuss them with the supplier, fabricator, contractor, and installer to determine acceptable amounts for a specific application. Then include the tolerances in the specifications. In the field, contractors often do not build to the theoretical tolerances given in industry standards (or even know them) so they should be listed in each section of the specifications, especially when they are critical or serve as the basis for subsequent finish work. In some cases, the required tolerances may be more stringent that industry standards, so unless they are clearly spelled out in the specifications, the contractor may build to the less exacting dimension.

Throughout this book both English and SI units are used. In most cases, the English measurement or unit is given first with the equivalent SI unit in parentheses. The equivalent SI unit may not be consistent in all parts of the book. For example, 1/4 inch may be considered 6.4 mm in some places, while it may be 6 mm in others. This is because in some cases the equivalent SI unit is a mathematical conversion using standard conversion factors and rounded off, while in other cases the SI equivalent is the standard adopted by a particular trade association or testing agency and published to a specific degree of accuracy. These published SI tolerances have been reproduced without adjusting them for consistency with nonstandardized SI units. As the United States slowly converts to the metric system, more and more tolerances will be published in both systems.

Whether you are involved with the design, construction, or evaluation of buildings, you will find this book a valuable addition to your reference collection. It will give you an easy-to-use guide to the thousands of construction tolerances currently in use and help you avoid countless detailing problems.

How SI Units Are Used in this Book

This edition of the *Handbook of Construction Tolerances* includes equivalent measurements, using the Système Internationale (SI), in the text and illustrations. However, the use of SI units for construction and book publishing in the United States is problematic. This is because the building construction industry in the United States (with the exception of federal construction) has generally not adopted the metric system, as it is commonly called. Equivalent measurements of customary U.S. units (also called English or inch-pound units) are usually given as *soft* conversions using standard conversion factors. This always results in a number with excessive significant digits. When construction is done using SI units, the building is designed and drawn according to *hard* conversions, where planning dimensions and building products are based on a metric module from the beginning. For example, studs are spaced 400 mm on center to accommodate panel products that are manufactured in standard 1,200-mm widths.

During the transition to Système Internationale units in the United States, code-writing bodies, federal laws (such as the ADA), product manufacturers, trade associations, and other construction-related industries typically still use the customary U.S. system and make soft conversions to develop SI equivalents. Some manufacturers produce the same product using both measuring systems. Although there are industry standards for developing SI equivalents, there is no consistency for rounding off when conversions are made. For example, the International Building Code shows a 152-mm equivalent when a 6-in. dimension is required. The ADA Accessibility Guidelines shows a 150-mm equivalent for the same dimension.

For the purposes of this book, the following conventions have been adopted.

Throughout this book, the customary U.S. measurements are given first and the SI equivalents follow in parentheses. In the text, the unit suffixes for both systems, such as ft or mm, are shown. In the illustrations, the number values and U.S. unit suffixes are given first (in., ft., etc.) and the SI value after that in parentheses but *without* units if the number is in millimeters but *with* the unit if it is meters or some other unit except millimeters. This follows standard construction practice for SI units on architectural drawings; a number is understood to be in millimeters unless some other unit is given. The exception to this convention occurs when a number is based on an international standard or product. In this case, the primary measurement is given first in SI units with the U.S. equivalent in parentheses. The unit suffix is shown for *both* in the text as well as in the illustrations to avoid confusion.

When there is a ratio or some combination of units where it might be confusing, unit suffixes are used for all numbers; for example, 6 mm/3 m.

When a standards-writing organization or a trade association gives dual units for a particular measurement, those numbers are used exactly as they come from the source. For example, one group might use 6.4 mm as the equivalent for 1/4 in., while another organization might use 6 mm.

When an SI conversion is used by a code agency, such as the International Building Code (IBC or published in another regulation, such as the *ADA Accessibility Guidelines* (ADAAG), the SI equivalents used by the issuing agency are printed in this book. For example, the IBC uses a 152-mm equivalent when a 6-in. dimension is required, while the ADAAG gives a 150-mm equivalent for the same dimension.

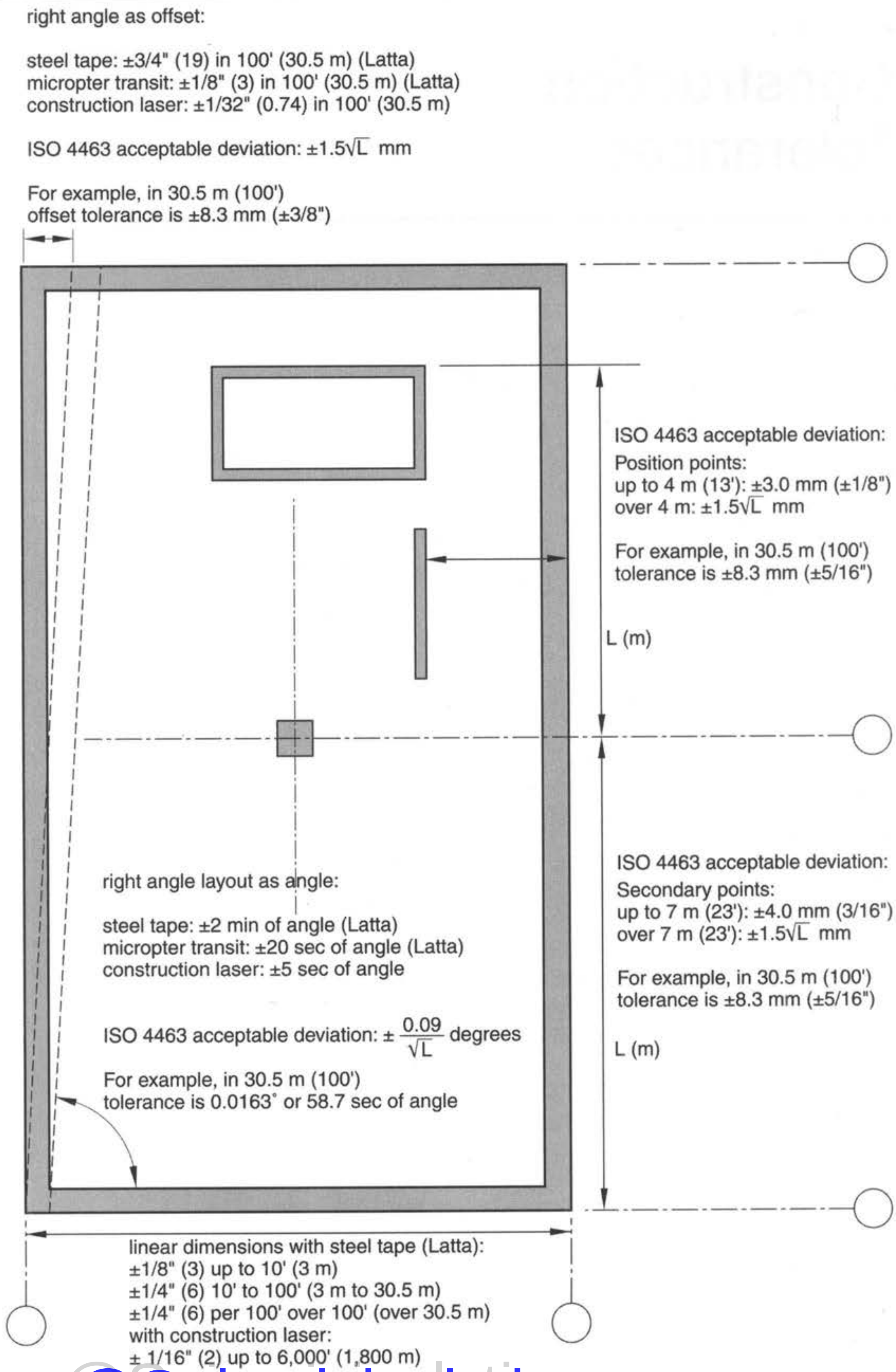
If a specific conversion is not otherwise given by a trade association or standards-writing organization, when converted values are rounded, the SI equivalent is rounded to the nearest millimeter for numbers under a few inches unless the dimension is very small (as for small tolerances like 1/16 in.), in which case a more precise decimal equivalent is given.

For dimensions over a few inches, the SI equivalent is rounded to the nearest 5 mm and to the nearest 10 mm for numbers over a few feet. When the dimension exceeds several feet, the number is rounded to the nearest 100 mm.

Part 1

Construction Tolerances

Figure 1–1 Horizontal building layout



Chapter 1

Building Layout and Sitework

1–1 Horizontal Building Layout

Description

One of the first sources of inaccuracies in building construction is the establishment of horizontal and vertical referencing systems for the layout of a building and subsequent marking of lines and benchmarks for horizontal and vertical dimensions as construction proceeds. Layout is dependent on the accuracy of the instruments used, as well as on environmental conditions and the skill of the people doing the layout. This section includes some of the horizontal layout accuracies possible with various instruments, assuming the surveyor uses a normal degree of skill. This section also gives accuracy standards given in three publications. Refer to sections on specific materials for industry standard tolerances for each specific material. Refer to Chapter 17 for more information on the accuracy of measuring instruments and methods of measurement.

With currently available surveying equipment, it is possible to lay out a building and monitor construction with a high degree of accuracy, in many cases much higher than is generally required for most construction. Because of this fact and because there are few standards for general building layout, the architect and engineer should clearly state in the specifications what tolerances are required, recognizing that higher degrees of accuracy generally will result in higher costs.

References

Latta, J. K. "Inaccuracies in Construction," *Canadian Building Digest* 171, April 1975. In *Canadian Building Digests*, 151–200 (Ottawa, ON: Institute for Research in Construction, National Research Council Canada, 1989.

Model Standards of Practice (Gaithersburg, MD: National Society of Professional Surveyors, 2003) www.acsm.net/nsps/modelstandards.html.

NIST Handbook 44-2003, Section 5.52 (Gaithersburg, MD: National Institute of Standards and Technology) http://ts.nist.gov/ts/htdocs/230/235/h442003.htm.

Product literature: Faro Technologies, Inc. (www.faro.com), Leica Geosystems (www.leica-geosystems.com), Topcon Positioning Systems (www.topcon.com), and Trimble (www.trimble.com).

ISO 4463-1, *Measurement Methods for Buildings—Setting Out and Measurement—Part 1: Planning and Organization, Measuring Procedures, Acceptance Criteria*, November 1 (Geneva, Switzerland: International Organization for Standardization, 1989.

Allowable Tolerances

Although there are no generally accepted standards that are widely used for building layout in the United States, one international standard and one U.S. model standard may be used to gauge what is realistically possible for most building construction and layout of site elements. These standards may be used to guide the development of specifications for individual building projects or to determine a reasonable standard in the absence of specific project requirements.

International standard ISO 4463-1, *Measurement Methods for Building—Setting Out and Measurement*, describes procedures for establishing a survey grid, relating it to a building site, and establishing building layout and control points based on property boundaries and major survey control points. It gives guidance on measurement methods and acceptance criteria (tolerances) for various stages of the process, which includes the primary system, the secondary system, and position points. The primary system is connected to the official control system (national, municipal, or other higher-order coordinate system) and normally covers the entire site. The secondary system is that structural or other grid reference system that is used for the erection of a particular building. Position points mark the location of individual elements in the building, both horizontally and vertically. The standard gives acceptance criteria for distance measurement, angle measurement, plumbing, and the establishment of levels. The ISO acceptance criteria are shown in Figure 1-1 for secondary and position points and in Figure 1-1.1 for primary positioning. For building construction, the accuracy of individual building layout (secondary points) and position points within a building are, in most cases, more important than the exact position of the building on the site. The acceptable values in ISO 4463-1 are for general layout and not specific materials. In this standard, the tolerance level is typically given in terms of the length being measured.

For the structural grid or reference grid of a building, ISO 4463 suggests that a reasonable linear dimension tolerance can be ±4.0 mm (±3/16 in.) for distances up to 4 m (13 ft.) and ±1.5 mm for distances over 4 m (13 ft.), where *L* is the length in meters. For position points, ISO 4463 suggests that a reasonable tolerance can be ±3.0 mm (±1/8 in.) for distances up to 4 m (13 ft.) and ±1.5 mm for distances over 4 m (13 ft.) where *L* is the length in meters. These numbers are very close to the linear accuracies published by the Institute for Research in Construction (IRC) in 1975 (Latta).

For right angle layout, ISO 4463 suggests that a reasonable angular tolerance can be ±degrees, where *L* is the length in meters of the shorter side of the angle. In a 30.5-m (100-ft.) length, this translates to a tolerance of approximately 1 minute of angle (0.0163°). This is well within the accuracy standards of transits as well as construction lasers. Viewed in terms of an offset over a length of 30.5 m (100 ft.), ISO 4463 suggests an allowable tolerance of ±8.3 mm (±3/8 in.). Again, this is well within the capabilities of a standard transit as published by the IRC in 1975 and is easily accomplished with construction lasers.

In the United States, the National Society of Professional Surveyors (NSPS) publishes model standards that are intended to be used as guidelines for those individual state associations, professional registration boards, state surveying agencies, and others who have the authority of set standards. Section D of these model standards is for construction layout surveys and the recommended positional accuracies are given in Table 1-2 in Section 1-6.

The NSPS standard for building offset stakes is ±10 mm (0.03 ft.) for horizontal positional accuracy. Positional accuracy in this standard is given at the 95 percent confidence level. This means, for example, that if a 200-ft. (61-m) distance is measured 100 times, the measurement will be between 199.97 ft. and 200.03 ft. (60.09 m to 61.0 1m) 95 times out of 100. Refer to Chapter 18 for a discussion of expressing the uncertainty of measurement.

Construction lasers and other electronic devices can measure distances, angles, and plumb with a high degree of accuracy. The exact accuracy level depends on the specific manufacturer's device, the calibration of the equipment, the conditions under which the equipment is used, whether or not a prism is employed, and, of course, the skill and diligence of the surveyor. Refer to Chapter 17 for a discussion of electronic distance measuring devices. The numbers given in Figure 1-1 are derived from several manufacturers' product literature and represent what can reasonably be expected when these devices are used correctly under ideal conditions.

While more precise construction laser equipment is commonly used for commercial construction, many contractors still use more traditional equipment for residential and small commercial projects. The expected degree of accuracy when using steel tapes and transits is also shown in Figure 1-1.

The dimensional accuracy for a 100-ft. (30.5-m) steel tape depends on the amount of sag, temperature, tension, and angle of use. The National Institute of Standards and Technology (NIST) sets tolerances for metal tapes as shown in Table 1-1. For typical situations and when sag is minimized, the tolerances shown in Figure 1-1 can be expected. If higher accuracy is required, a laser should be used or steel tapes with correction factors included for temperature and other variables.

Table 1-1 Maintenance and acceptance tolerances, in excess and in deficiency, for metal tapes

Nominal interval from zero, ft (m)	Tolerance, in (mm)
6 or less (1.8 m)	1/32 (0.8)
7 to 30, inclusive (2.1 m to 9.1 m)	1/16 (1.6)
31 to 55, inclusive (9.4 m to 16.8 m)	1/8 (3.2)
56 to 80, inclusive (17.1 m to 24.4 m)	3/16 (4.8)
81 to 100, inclusive (24.7 m to 30.5 m)	1/4 (6.4)

Note: SI units added

Source: NIST Handbook 44-2003, Section 5.52, Table 2

Right angles for many buildings, such as houses and small commercial structures, can be laid out with a steel tape measuring a 3:4:5 triangle. When greater accuracy is required, a transit or construction laser should be used.

Related Sections

1–2 Vertical Building Layout
1–6 Grading and Sitework
17–1 Measuring Devices
18–2 Expressing Uncertainty

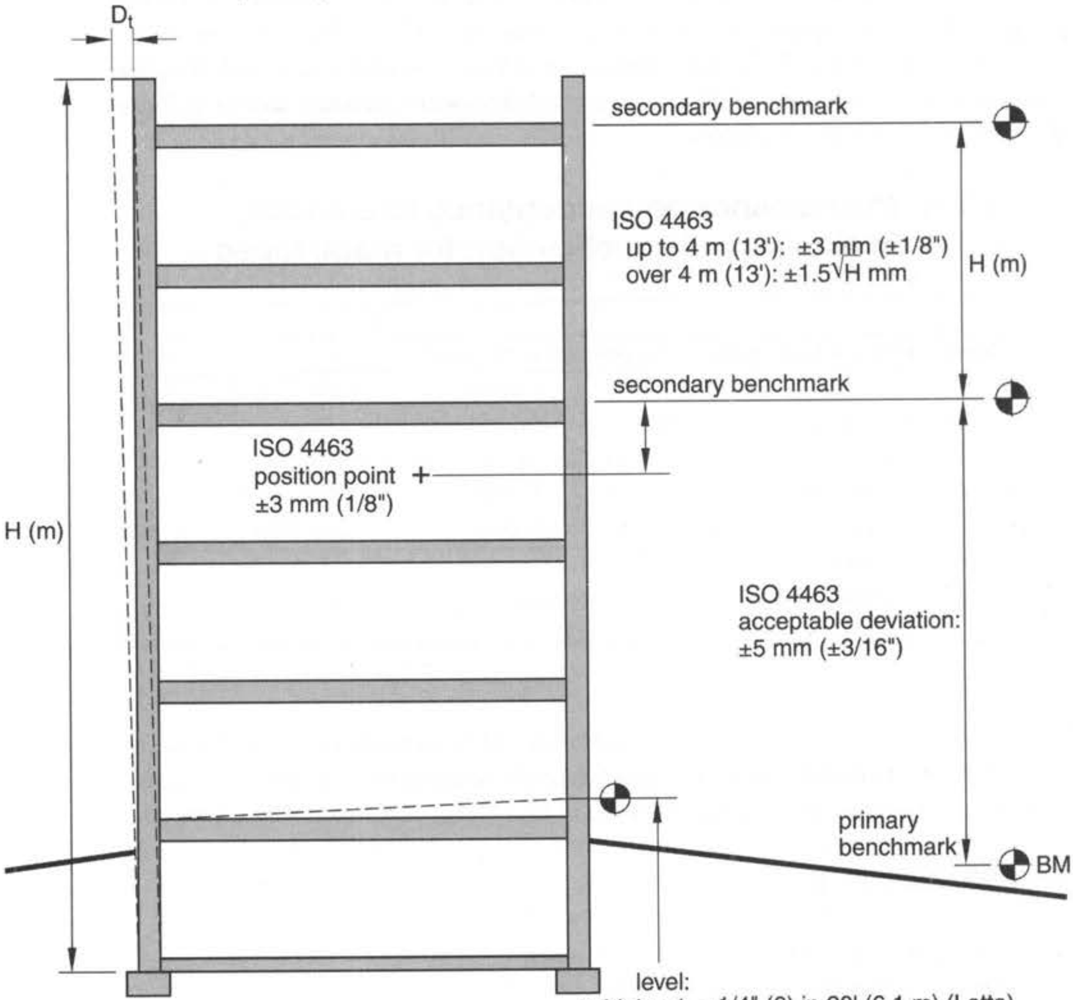
Figure 1–2 Vertical building layout

Accuracy in plumbness: (Latta)
spirit level: ±1/4" (6) in 10' (3 m)
plumb bob: ±1/8" (3) in 10' (3 m)
transit: ±1/8" (3) in 100' (30.5 m)
optical plumbing device: ±1/16" (1.6) in 100' (30.5 m)

SmartTool: ±1/32" (0.8) in 2' (600) or 0.1°
laser plumb: ±1/32" (0.8) in 100' (30.5 m)

ISO 4463 acceptable deviation from plumb:
for heights up to 4 m (13'): $D_t = \pm 3$ mm (1/8")
for heights greater than 4 m: $D_t = \pm 1.5\sqrt{H}$ mm

For example, in 30.5 m (100')
tolerance is ±8.3 mm (±5/16")



level:
spirit level: ±1/4" (6) in 20' (6.1 m) (Latta)
water level: ±1/8" (3) in 30' (9.1 m) (Latta)
optical level: ±1/8" (3) in 200' (61 m) (Latta)
precise level: ±1/16" (1.6) in single sight (Latta)

SmartTool: ±1/32" (0.8) in 2' (600) or 0.1°
optical level: ±1/32" (0.8) in 100' (30.5 m)
digital level: ±1.5 mm in 1 km (1/16" in 3280')
laser level: ±1/16" (1.6) in 100' (30.5 m)

1-2 Vertical Building Layout

Description

After the horizontal form and dimensions of a building are established, the next source of inaccuracy is setting elevations, plumbing vertical elements, and maintaining levels. These are dependent on the accuracy of the instruments used as well as on environmental conditions and the skill of the people doing the layout. This section includes some of the layout accuracies possible in establishing elevations, plumb, and level with various instruments, assuming the surveyor uses a normal degree of skill.

The tolerances shown in other sections of this book for plumb and level for individual construction materials and assemblies are often more or less accurate than those shown in this section. Refer to individual sections for more specific information on industry standards for specific materials. Refer to Chapter 17 for more information on the accuracy of measuring instruments and methods of measurement.

References

"Inaccuracies in Construction," J. K. Latta, *Canadian Building Digest* 171, April 1975. In *Canadian Building Digests*, 151–200 (Ottawa, ON: Institute for Research in Construction, National Research Council Canada, 1989).

Model Standards of Practice (Gaithersburg, MD: National Society of Professional Surveyors, 2003) www.acsm.net/nsps/modelstandards.html.

NIST Handbook 44-2003, Section 5.52 (Gaithersburg, MD: National Institute of Standards and Technology) http://ts.nist.gov/ts/htdocs/230/235/h442003.htm.

Product literature: Faro Technologies, Inc. (www.faro.com), Leica Geosystems (www.leica-geosystems.com), Topcon Positioning Systems (www.topcon.com), and Trimble (www.trimble.com).

M-D Building Products. SmartTool® digital inclinometer. www.mdteam.com

ISO 4463-1, *Measurement Methods for Buildings—Setting Out and Measurement—Part 1: Planning and Organization, Measuring Procedures, Acceptance Criteria*, November 1 Geneva, Switzerland: International Organization for Standardization, 1989.

Allowable Tolerances

As with horizontal layout, there are no generally accepted standards for vertical layout. The numbers given in Figure 1-2 for tolerances are based on ISO 4463 and research done by the Institute for Research in Construction (Latta). However, with construction lasers and laser levels, optical levels, and digital levels, higher degrees of accuracy are possible. For example, some manufacturers' digital levels can achieve an accuracy of ±1.5 mm per kilometer if used according to the manufacturer's recommendations. Single-measurement optical levels can be accurate to ±0.8 mm in 30 m (±1/32 in. in 100 ft.). The required tolerances should be clearly stated in the specifications based on the level of accuracy required by the project.

For less exacting applications, spirit levels and plumb bobs are often used for residential and small commercial buildings. The typical accuracies for these instruments are also shown in Figure 1-2.

For establishing slopes and checking for level, digital inclinometers are now commonly used. The accuracy for a digital inclinometer (SmartTool) is 0.1 degree (approximately ±1/16 in. in 4 ft. or1.6 mm in 1,200 mm). They are available in 2-ft. and 4-ft. lengths. Because local variations of flatness are possible, large slabs and ramps should be checked with a transit or construction laser to establish overall level or slope.

The NSPS standard for building offset stakes is ±10 mm (0.03 ft.) for vertical positional accuracy. Positional accuracy in this standard is given at the 95 percent confidence level, as described in Section 1-1.

Related Sections

1–1 Horizontal Building Layout
1–6 Grading and Sitework
17–1 Measuring Devices
18–2 Expressing Uncertainty

1–3 Concrete Paving

Description

Concrete paving includes drives, parking surfaces, and other site paving. In many cases, tight tolerances for exterior paving for vehicles is not critical. However, when existing building and site elevations require minimum slopes for drainage (usually ¼ in. per ft. or 6 mm per 300 mm), the tolerances shown in this section should be specified. When ponding of water might create hazards in any situation, these tolerances should also be specified.

Industry Standards and Recommendations

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Farmington Hills, MI: American Concrete Institute, 2006).

NCHRP Project 20-07/Task 167, *An Analysis of the Draft ADA Guidelines for Accessible Rights-of-Way*, David Kent Ballast, June (Washington, DC: Transportation Research Board, National Cooperative Highway Research Program, 2004).

Standard Specifications and Supplements (Washington, DC: American Association of State Highway and Transportation Officials, 1998) http://fhwapap04.fhwa.dot.gov/nhswp/servlet/LookUpCategory

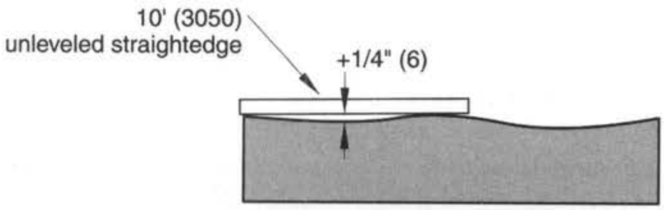
UFGS Section 02752, *Portland Cement Concrete Pavement for Roads and Site Facilities*, and UFGS Section 02754, *Concrete Pavements for Small Projects*. United Facilities Guide Specifications, August 2004 (Washington, DC: National Institute of Building Sciences, 2004) www.ccb.org/docs/ufgshome.

Allowable Tolerances

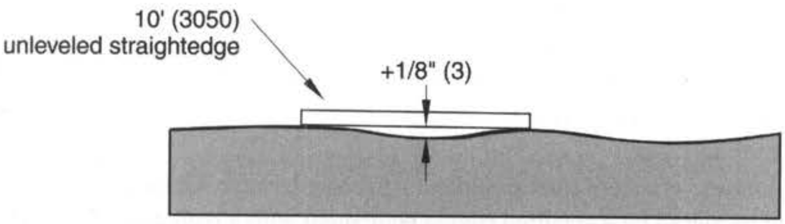
The only industrywide tolerances for paving on a construction site are published by the American Concrete Institute (ACI) as shown in Figure 1-3(a), (b), and (c). For highway work, state and local departments of transportation (DOTs) often give allowable tolerances in their model specifications or contract requirements. The tolerances by ACI are for vertical deviations of surfaces below an unleveled straightedge resting on high spots. Slope tolerances are not included in the ACI document.

Guide specifications for concrete pavement published as part of the Unified Facilities Guide Specifications (UFGS) for military facilities state that roads and streets should have a tolerance of ±5 mm (3/16 in.) in the longitudinal direction and ±6.5 mm (¼ in.) in

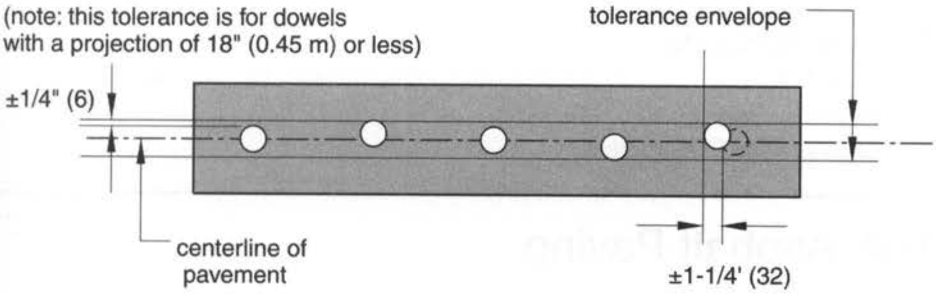
Figure 1–3 Concrete paving



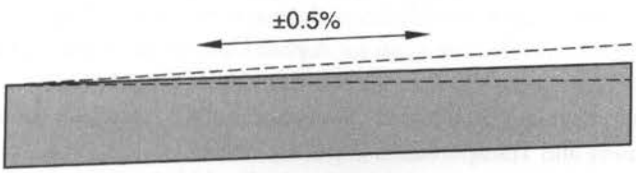
(a) mainline pavements in transverse direction (ACI)



(b) mainline pavements in longitudinal direction (ACI)



(c) lateral placement and alignment of dowels (ACI)



(d) suggested slope tolerance for concrete paving the transverse direction when measured with a straightedge. Interestingly, in Section 02754, no length of straightedge is specified, and in Section 02752, a 4-meter (12-ft.) straightedge is required. For other surfaces, such as parking areas, the suggested tolerance is ±6.5 mm (¼ in.) in both directions.

A research report for the Transportation Research Board suggested an allowable slope tolerance for concrete of ±0.5 percent, as shown in Figure 1-3(d). The same research report surveyed state and city departments of transportation and found that the allowable tolerances for roadway slope ranged from a low of 0 percent to a high of 5 percent, with an average of 0.6 percent. However, the suggested slope tolerance did not indicate the length over which the slope should be measured or in what locations slope should be measured. See Chapter 17 for discussions on measuring slopes and the flatness of surfaces.

For highway paving, the American Association of State Highway and Transportation Officials (AASHTO) publishes the AASHTO Standard Specifications and Supplements. In Section 501 for Portland Cement Concrete Pavement, the specifications require a surface test that limits surface defects to ±5 mm under a 3-m straightedge placed at random locations. (Section 501 [L]1). This is very close to the commonly used ¼-in. deviation under a 10-ft. straightedge.

When necessary, concrete road pavement, highway barriers, curbs and gutters, and sidewalks can be placed by specialized paving equipment with a high degree of precision. Slope tolerances of ±0.13 percent can be achieved for roads and sidewalks using automated equipment guided by stringlines, lasers, or global positioning system (GPS) devices. They are made by a number of manufacturers. However, this equipment is commonly used only for very long runs of highways or sidewalks.

Related Sections

1–4 Asphalt Paving
1–5 Pedestrian Paving
1–7 Right-of-Way Construction

1–4 Asphalt Paving

Description

Asphalt paving includes drives and parking surfaces. Like concrete paving, asphalt paving tolerances are not always critical if sufficient slope is built into the paving for drainage. However, when a minimum drainage slope of ¼ in. per ft. (6 mm per 300 mm) is required, the tolerances shown in this section should be specified.

Recommendations

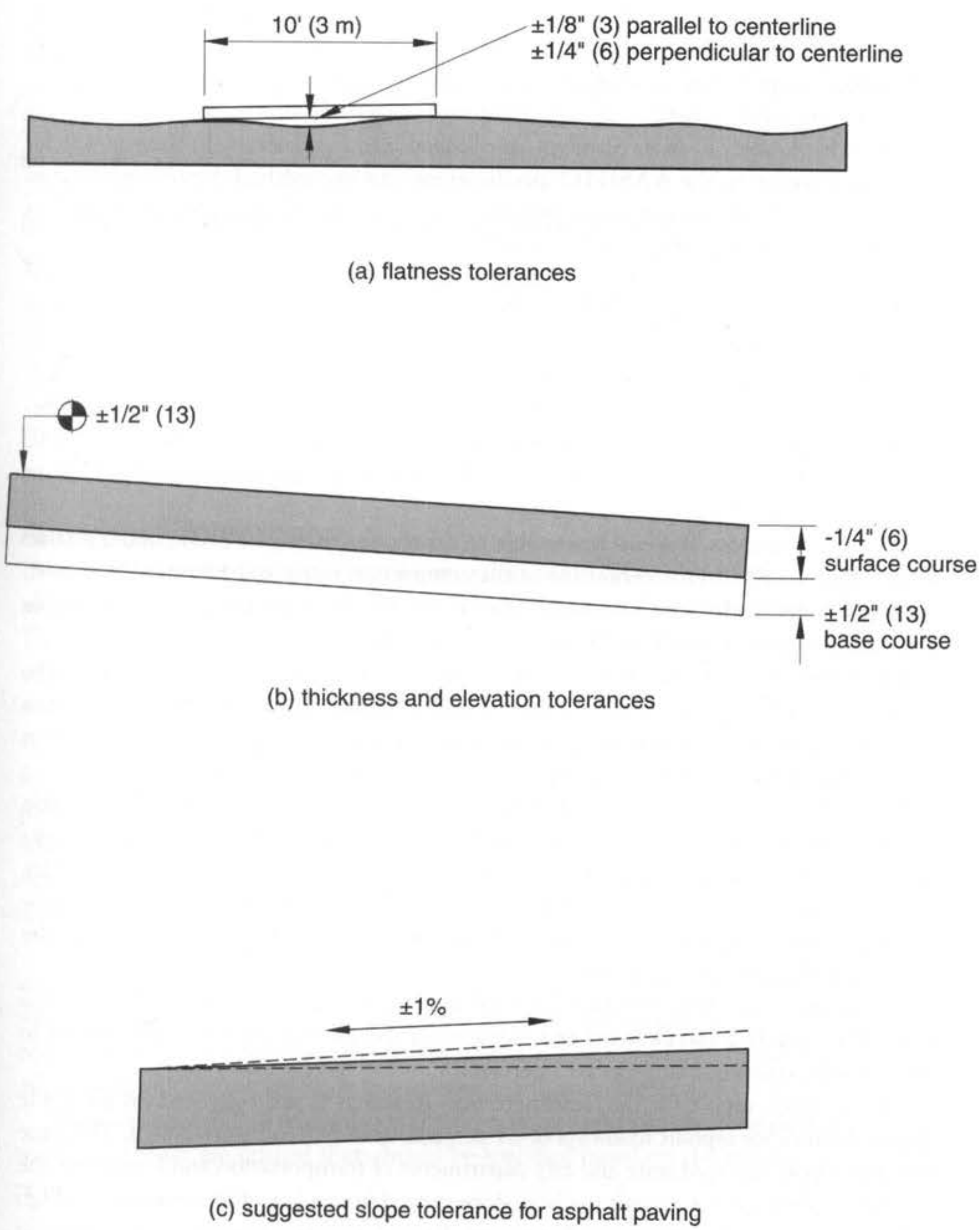
NCHRP Project 20-07/Task 167, *An Analysis of the Draft ADA Guidelines for Accessible Rights-of-Way*, David Kent Ballast, June (Washington, DC: Transportation Research Board, National Cooperative Highway Research Program, 2004).

SS-1: *Model Construction Specifications for Asphalt Concrete and Other Plant-Mix Types*, November (Lexington, KY: Asphalt Institute, 1984) Out of print.

Standard Specifications and Supplements (Washington, DC: American Association of State Highway and Transportation Officials, 1998) http://fhwapap04.fhwa.dot.gov/nhswp/servlet/LookUpCategory

UFGS Section 02742, *Hot Mix Bituminous Pavement*. United Facilities Guide Specifications, August 2004 (Washington, DC: National Institute of Building Sciences, 2004) www.ccb.org/docs/ufgshome.

Figure 1–4 Asphalt paving



Allowable Tolerances

There are currently no industry tolerances for asphalt paving. The Asphalt Institute (AI) previously had tolerances as part of its *Model Construction Specifications*. This document is no longer in print and the Asphalt Institute no longer establishes tolerances. However, in the last edition of the printed volume, the recommended tolerances were ±⅛ in. (3) parallel to the centerline of the compaction roller and ±¼ in. (6) perpendicular to the centerline as measured under a 10-ft. (3-m) straightedge. See Figure 1-4(a). These previously published tolerances suggest what one trade organization deemed reasonable.

The previous AI tolerances are consistent with suggested limits on surface smoothness published by AASHTO in its *Standard Specifications and Supplements*. In Section 401 for plant mix pavements, the AASHTO specifications give two methods for testing surfaces. The first method calls for surfaces to be tested with a 3-m (10-ft.) straightedge at random locations. Variations greater than 3 mm to 5 mm (⅛ in. to 3/16 in.) are to be corrected.

Guide specifications for hot-mix bituminous pavement published as part of the Unified Facilities Guide Specifications (UFGS) for military facilities states that the unevenness of leveling and binder courses should not vary more than 6 mm in 3 m (¼ in. in 10 ft.) and that unevenness of the wearing course should not vary more than 3 mm in 3 m (⅛ in. in 10 ft.).

Research done for the Transportation Research Board found that the state and city departments of transportation surveyed reported tolerances ranging from a low of ⅛ in. in 10 ft. (3 mm in 3 m) to a high of 2 in. in 10 ft. (50 mm in 3 m) with an average of 0.37 in. in 10 ft. (9.4 mm in 3 m).

From these sources, it seems reasonable to expect a tolerance of ±⅛ in. under a 10 ft. straightedge parallel to the centerline of the compaction roller and ±¼ in. under a 10 ft. straightedge perpendicular to the centerline. If smoothness is not critical, it is preferable to specify a tolerance of ±/4 in. (6 mm) in both directions.

The variation of actual elevation from spot elevations shown on the drawings should be within ±½ in. (13 mm). See Figure 1-4(b). This is consistent with the Asphalt Institute's former recommendations as well as the specification language in the UFGS specification and research done for the Transportation Research Board.

For thickness tolerances, the UFGS specification states that the maximum allowable deficiency at any point should not be more than 6 mm (¼ in.) less than the stated thickness. Previous master specifications suggested a base course thickness tolerance of ±½ in. (13 mm). Both the previous Asphalt Institute's model specifications and UFGS specification state that the average thickness should not be less than the thickness stated on the drawings and in the specifications.

There are no industry-standard slope tolerances for asphalt pavement, although the AASHTO *Standard Specifications and Supplements* specify that asphalt pavers be set to maintain the transverse slope at ±0.1 percent.

The research report for the Transportation Research Board suggested an allowable slope tolerance for asphalt roadways of ±1 percent, as shown in Figure 1-4(c). The same research report surveyed state and city departments of transportation and found that the allowable tolerances for asphalt roadway slope ranged from a low of zero percent to a high of 5 percent, with an average of 0.83 percent. As with concrete pavement, the suggested slope tolerance did not indicate the length over which the slope should be measured or in what locations slope should be measured. See Chapter 17 for discussions on measuring slopes and the flatness of surfaces.

Related Sections

1–3 Concrete Paving
1–5 Pedestrian Paving
1–7 Right-of-Way Construction

1–5 Pedestrian Paving

Description

This section includes paving of concrete, asphalt, and concrete steps. For safety reasons, pedestrian paving should be constructed to close tolerances to avoid ponding and freezing of water; to prevent water buildup, which could damage the paving; and to drain water away from the building and other important site structures. This is especially important because pedestrian paving is normally shown at low slopes, from ¼ in. per ft. (6 mm per 300 mm) to ½ in. per ft. (13 mm per 300 mm). There are currently no industry tolerances for concrete pavers, brick pavers, stone, or wood walkways.

Industry Standards and Recommendations

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Farmington Hills, MI: American Concrete Institute, 2006).

NCHRP Project 20-07/Task 167, *An Analysis of the Draft ADA Guidelines for Accessible Rights-of-Way*, David Kent Ballast, June (Washington, DC: Transportation Research Board, National Cooperative Highway Research Program, 2004).

SS-1: *Model Construction Specifications for Asphalt Concrete and Other Plant-Mix Types*, November (Lexington, KY: Asphalt Institute, 1984) Out of print.

Allowable Tolerances

Tolerances for pedestrian paving are shown in Figure 1-5. The tolerance for concrete sidewalk flatness is based on an ACI standard, which is ±¼ in. in 10 ft. (±6 mm in 3,050 mm). There are no ACI standards for slope deviation, but a Transportation Research Board report suggested a slope tolerance for concrete sidewalks of ±1 percent for running slopes and ±0.5 percent for sidewalk cross-slopes.

Tolerances for concrete steps are also based on ACI standards and are ±³⁄₁₆ in. (5 mm) for riser height and ±³⁄₁₆ in. (5 mm) for tread width as shown in Figure 1-5(b). The International Building Code allows a ⅜-in. (9.5 mm) variation between the highest and lowest extremes of risers and treads within any flight of stairs. The *Americans with Disabilities Act Accessibility Guidelines* (ADAAG) only states that treads and risers must be of uniform dimension.

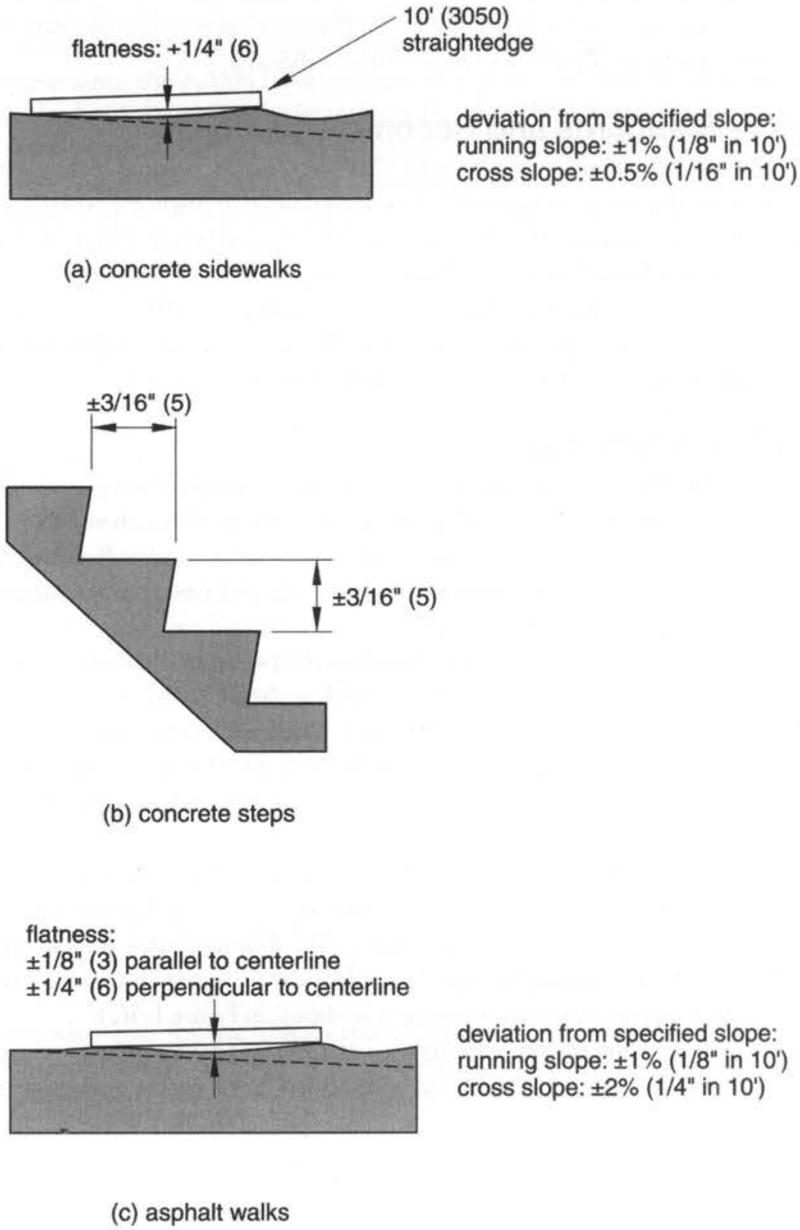
Tolerances for asphalt walks are based on the Asphalt Institute's previous model specifications, which are no longer published. However, as with asphalt paving, it suggests what one trade organization deemed reasonable. The Transportation Research Board report suggested a slope tolerance for asphalt sidewalks of ±1 percent for running slopes and ±0.5 percent for asphalt sidewalk cross-slopes as shown in Figure 1-5(c).

There are no standard tolerances for brick, concrete unit pavers, stone paving, or wood walks, so if these are critical they should be specified based on the requirements of the project.

Related Sections

1–3 Concrete Paving
1–4 Asphalt Paving
1–7 Right-of-Way Construction

Figure 1–5 Pedestrian paving



1-6 Grading and Sitework

Description

Although grading tolerances are not always critical, they can affect drainage away from a building, the appearance of ground cover material at the building line, and the final appearance of finish landscaping. Because of its nature, soil grading cannot be very accurate and is subject to the skills of the people grading as well as natural forces such as rain, snow, and freeze-thaw cycles. This section includes some of the various recommended tolerances for grading.

Industry Recommendations

ISO 4463-1, *Measurement Methods for Buildings—Setting Out and Measurement—Part 1: Planning and Organization, Measuring Procedures, Acceptance Criteria*, November 1 (Geneva, Switzerland: International Organization for Standardization, 1989).

Model Standards of Practice; Section D, NSPS Model Standards for Construction Layout Surveys (Gaithersburg, MD: National Society of Professional Surveyors, 2003) www.acsm.net/nsps/modelstandards.html.

2005 Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys (Washington, DC: American Land Title Association /American Congress on Surveying and Mapping, 2005) www.acsm.net/ALTA2005.pdf.

UFGS Section 02730, *Earthwork*. United Facilities Guide Specifications, October 2004 (Washington, DC: National Institute of Building Sciences, 2004) www.ccb.org/docs/ufgshome.

Landscape Specification Guidelines, 5th ed. (Rockville, MD: Landscape Contractors Association, 2000).

SPECTEXT® Section 02211, *Rough Grading*, July (Baltimore: Construction Sciences Research Foundation, 1989).

SPECTEXT Section 02923, *Landscape Grading*, July (Baltimore: Construction Sciences Research Foundation, 1989).

Allowable Tolerances

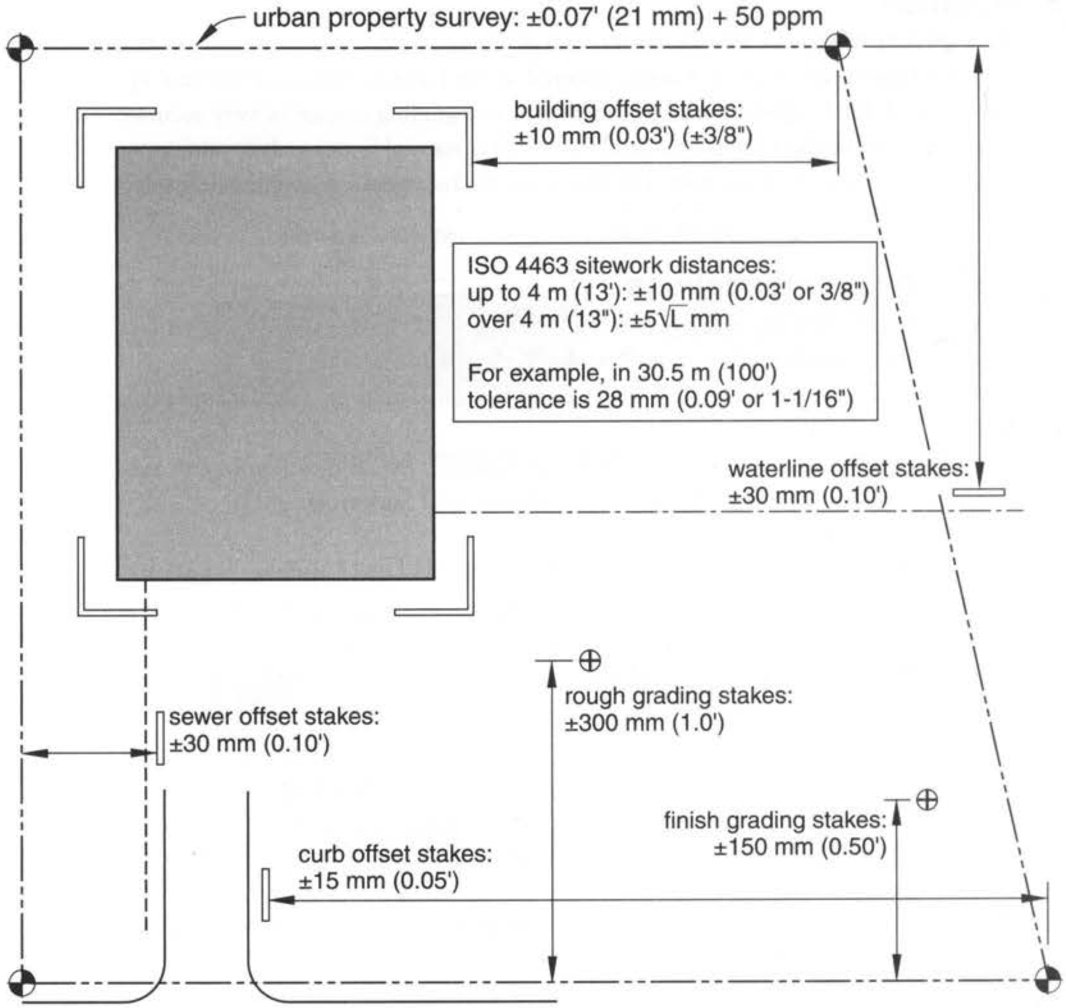
There are several sources for recommended tolerances for rough and finish grading as well as the horizontal position of various elements on a building site. The National Society of Professional Surveyors publishes the *Model Standards of Practice*, which includes guidelines for the horizontal and vertical relative positional accuracy of stake placement to mark the location of proposed fixed works. These are shown in Table 1-2 and in Figure 1-6.

In addition, the NSPS Model Standards includes accuracy standards for property surveys based on the intended use of the land. These are shown in Table 1-3.

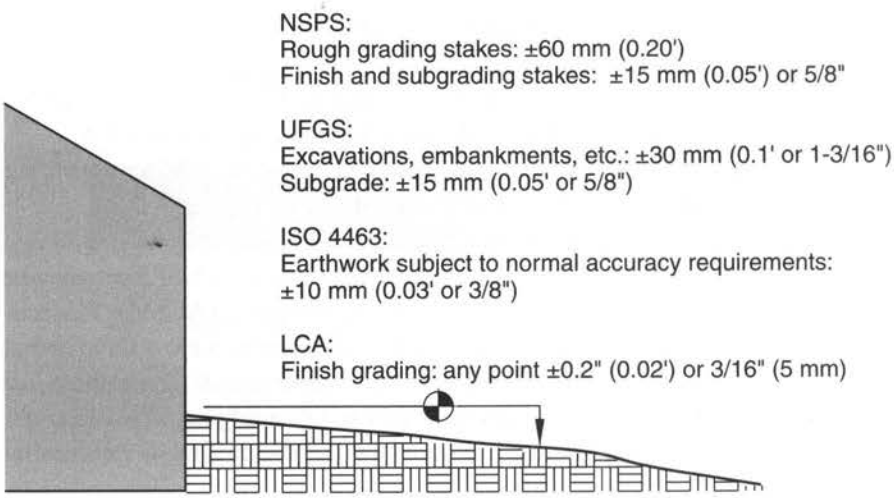
Another U.S. standard is the *Accuracy Standards for ALTA/ACSM Land Title Surveys*, published by the American Land Title Association (ALTA) and the NSPS as a member organization of the American Congress on Surveying and Mapping (ACSM). This standard is used by professional surveyors for the execution of property surveys (land boundaries). It allows a relative positional accuracy for measurements controlling land boundaries on ALTA/ACSM land title surveys of 0.07 ft. (20 mm) plus 50 parts per million (ppm). The NSPS *Model Standards of Practice* adopts this standard for its classification of urban surveys.

Guide specifications for earthwork published as part of the Unified Facilities Guide Specifications (UFGS) for military facilities states that the degree of finish for graded

Figure 1–6 Grading and sitework



(a) Sitework positional accuracy (NSPS)



(b) Grading elevations

areas be within 30 mm (0.1 ft. or 1 3/16 in.) of the grades and elevations shown. Requirements for subgrade preparation call for elevations to not vary more than 15 mm (0.05 ft. or 5/8 in.) from the established grade and cross section.

The *Landscape Specification Guidelines*, published by the Landscape Contractors Association, suggests the landscape contractor not proceed with final work until the finish grading of topsoil has been uniformly graded to within 0.2 in. (about 3/16 in. or 5 mm).

International standard ISO 4463-1 gives general allowable deviations for sitework distances and elevations regardless of the site element being placed. These are also shown in Figure 1-6.

There are other recommended tolerances for rough and finish grading. Previous SPECTEXT master specifications suggested the topsoil be within 1/2 in. (13 mm) of specified elevations. For rough grading, SPECTEXT master specifications suggested a tolerance of ±0.1 ft. or 1 3/16 in. (30 mm).

Related Sections

1–5 Pedestrian Paving
1–7 Right-of-Way Construction

1–7 Right-of-Way Construction

Description

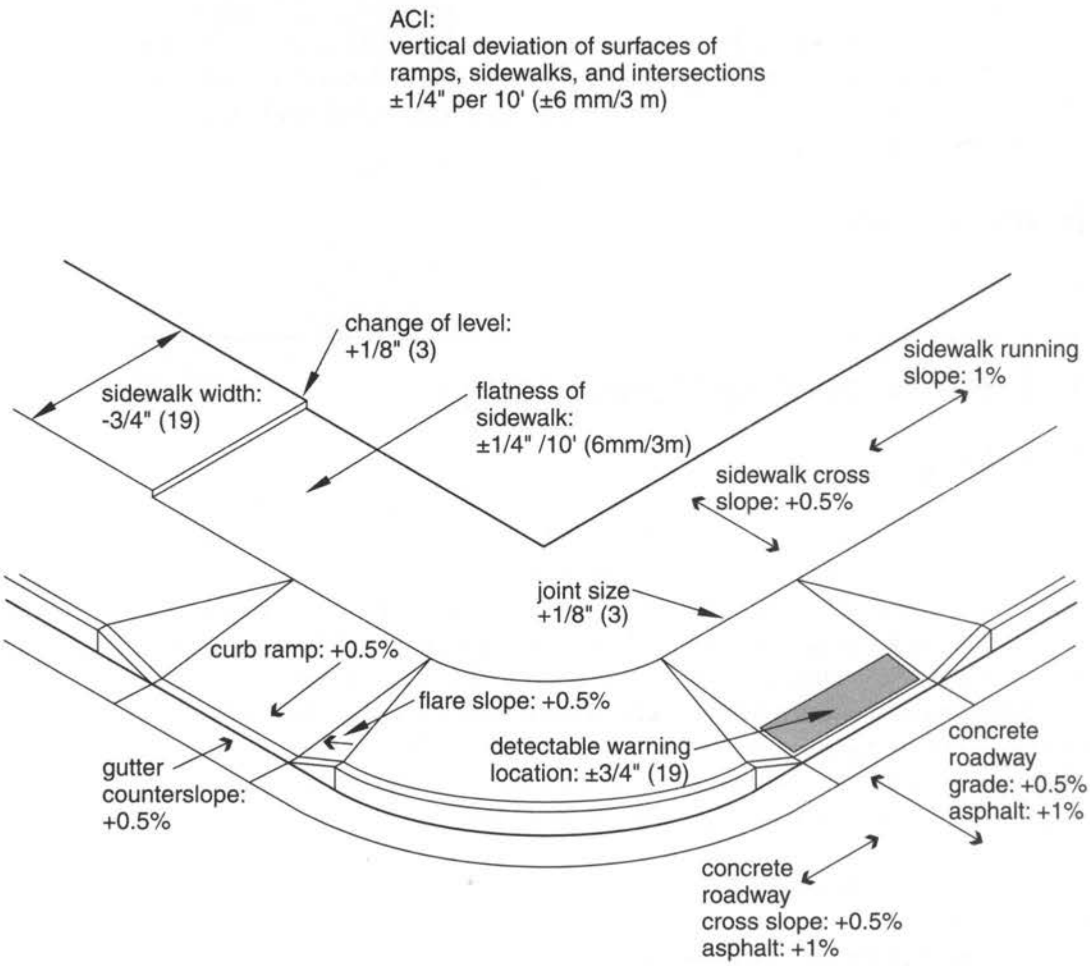
Right-of-way construction consists of streets, highways, sidewalks, curb ramps, bus stops, and other structures that are accessible by the public outside the borders of private property. The Federal Highway Administration (FHA), AASHTO, and state and local departments of transportation (DOTs) all have standards for various components of right-of-way construction, but few have standards for tolerances. In most cases the tolerance standards relate to roadway smoothness, surface flatness of sidewalks, and curb alignment. Allowable deviations from dimensions and slopes on design drawings and in specifications are typically left to the discretion of the field inspector of the local DOT.

In most cases, tolerances are not a critical part of right-of-way construction, given the nature and use of the construction and the variables related to climate exposure, maintenance, and the heavy wear and tear that exterior elements are subjected to. Where tolerances *are* becoming an increasingly important issue is in the area of accessibility for disabled users.

At this writing, the U.S. Access Board had issued revised draft guidelines for accessible public rights-of-way, but they had not been issued as a final rule, nor had the Department of Justice adopted them as law. In the meantime, current right-of-way construction that is funded wholly or in part with federal monies is subject to requirements of various existing federal laws and generally makes reference to the technical requirements of the current ADAAG. Individual state laws may also apply. In addition, most local and state departments of transportation have requirements and guidelines for accessibility to meet ADA guidelines.

The draft guidelines for rights-of-way as well as the revised ADAAG both state that "all dimensions are subject to conventional industry tolerance except where the requirement is stated as a range with specific minimum and maximum end points." (Section R103.1.1 of the draft rights-of-way guidelines and Section 3.2 of the revised ADAAG and). However, the advisory in the revised ADAAG states that where a requirement is a minimum or maximum dimension that does not have two specific minimum and maximum end points, tolerances may apply.

Figure 1–7 Right-of-way construction



Note: recommended roadway tolerances are given in the direction of pedestrian/wheelchair travel and are opposite of terminology for the roadway; that is, pedestrian roadway cross slope is the running slope of the roadway.

Note: suggested tolerances, not industry standards. See text.

Table 1–2 Relative positional accuracies

Site elements	Horizontal positional accuracy *mm*	Horizontal positional accuracy *ft*	Vertical positional accuracy *mm*	Vertical positional accuracy *ft*
Rough grading stakes	±300	±1.0	±60	±0.02
Subgrade red head stakes	±150	±0.50	±15	±0.05
Finish grade blue top stakes	±150	±0.50	±15	±0.05
Building offset stakes	±10	±0.03	±10	±0.03
Sewer offset stakes	±30	±0.10	±10	±0.03
Waterline offset stakes	±30	±0.10	±30	±0.10
Hydrant offset stakes	±30	±0.10	±15	±0.05
Street lights	±60	±0.20	±30	±0.10
Curb offsets	±15	±0.05	±10	±0.03

Positional accuracy is given at the 95 percent confidence level

Source: Used with permission from National Society of Professional Surveyors

Table 1–3 Relative positional accuracies for land title surveys

Classification of survey	Acceptable Relative Positional Accuracy
Urban	0.07 ft (21 mm) plus 50 ppm
Suburban	0.13 ft (40 mm) plus 100 ppm
Rural	0.26 ft (79 mm) plus 200 ppm

Positional accuracy is given at the 95 percent confidence level
ppm: parts per million
Source: Used with permission from National Society of Professional Surveyors

There are very few industry standard tolerances for right-of-way construction. Although tolerances exist for architectural construction, it is not generally appropriate to apply these to exterior work.

Industry Recommendations

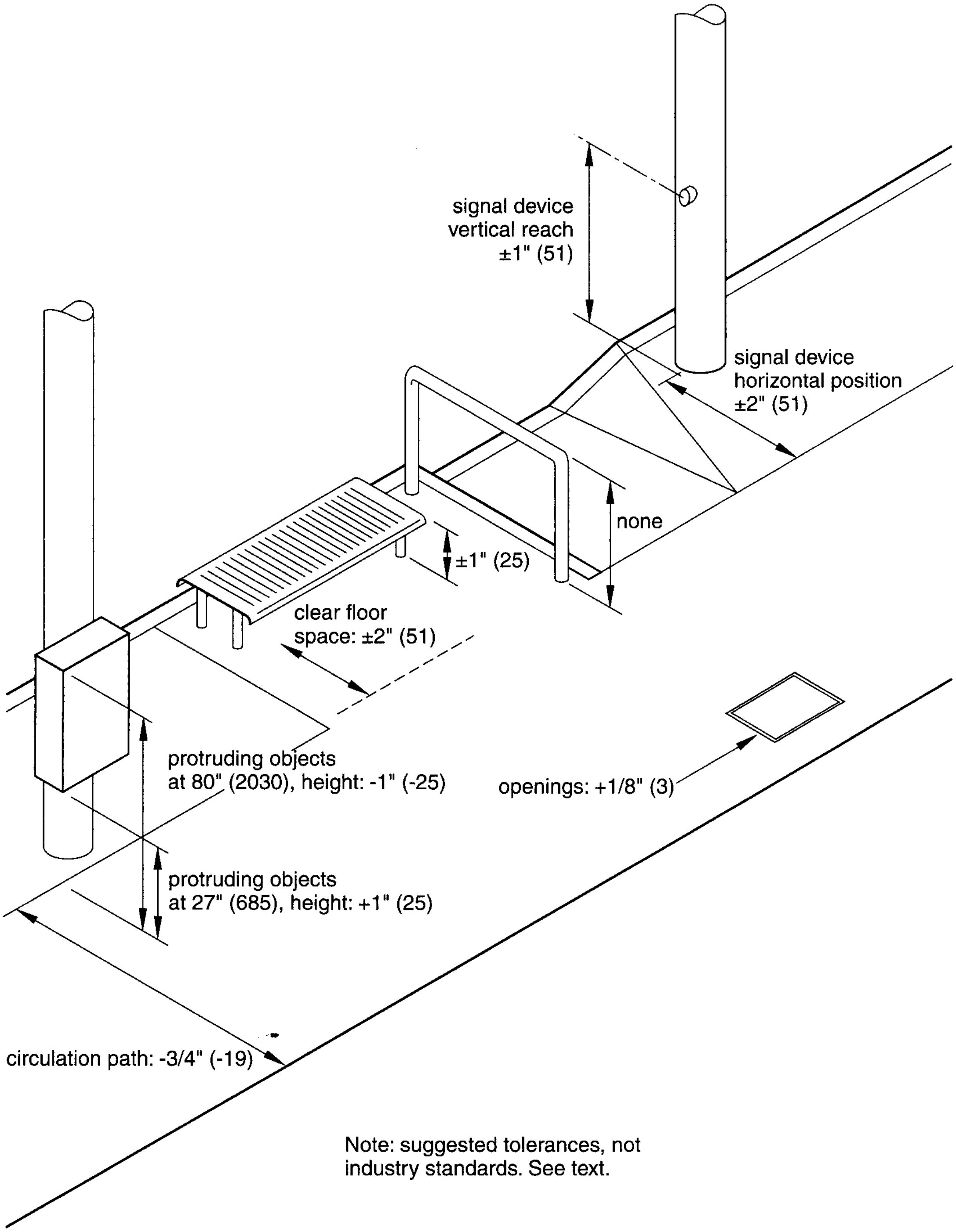
Accessible Rights-of-way: A Design Guide, November (Washington, DC: U.S. Architectural and Transportation Barriers Compliance Board, 1999).

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Farmington Hills, MI: American Concrete Institute, 2006).

Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines, July 23 (Washington, DC: U.S. Architectural and Transportation Barriers Compliance Board, 2004) www.access-board.gov/ada-aba/index.htm

NCHRP Project 20-07/Task 167, *An Analysis of the Draft ADA Guidelines for Accessible Rights-of-Way*, David Kent Ballast, June (Washington, DC: Transportation Research Board, National Cooperative Highway Research Program, 2004).

Figure 1–7.1 Right-of-way construction



Note: suggested tolerances, not industry standards. See text.

Table 1–4 Recommended tolerances for right-of-way construction

Element surveyed	Final suggested tolerance
Roadway grade (cross slope)-Concrete	+0.5%
Roadway grade cross slope (running grade)-Concrete	+0.5%
Sidewalk running slope	+1%
Sidewalk cross slope	+0.5%
Flatness (smoothness) of sidewalks	±¼"/10' (±6 mm/3 m)
Curb ramp slope, main ramp	+0.5%
Curb ramp, flare slope	+0.5%
Curb ramp gutter counterslope	+0.5%
Widths of sidewalks and other paving	±¾" (±19 mm)
Elevation points of construction	±0.5" (±13 mm)
Concrete joint size	+⅛" (3 mm)
Concrete stairs (riser and tread)	± ⅛" (±3 mm) riser, ±¼" (±6 mm) tread
Placement of detectable warning surfaces	± ¾" (±19 mm)
Installation of metal handrails and guardrails	±½" (±13 mm)
Horizontal placement of poles, controls, signs, etc.	±2" (±50 mm)
Vertical placement of handrails, controls, signs, etc.	±1" (±25 mm) None for handrail height.
Street furniture–horizontal placement	±2" (±50 mm)
Street furniture–vertical placement	±1" (±25 mm)
Size of gaps at rail crossings	±¼" (±6 mm) light rail and passenger train tracks
Flushness of surfaces at rail crossings	±¼" (±6 mm)
Asphalt roadway grade	+1%
Asphalt roadway grade cross slope	+1%
Asphalt sidewalk running slope	+1%
Asphalt sidewalk cross slope	+0.5%
Asphalt flatness (smoothness) of sidewalks	±¼"/10' (±6 mm/3 m)
Asphalt curb ramp slope, main ramp	+0.5%
Asphalt curb ramp, flare slope	+0.5%
Asphalt curb ramp gutter counterslope	+0.5%
Asphalt widths of sidewalks and other paving	±¾" (±19 mm)
Asphalt elevation points of construction	±½" (±13 mm)
Change of level	+⅛" (+3 mm)

Source: An Analysis of the Draft ADA Guidelines for Accessible Rights-of-Way

Publication No. FHWA-EP-01-027, *Designing Sidewalks and Trails for Access, Part II of II: Best Practices Design Guide*, Beneficial Designs, Inc. (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, 2001).

Revised Draft Guidelines for Accessible Public Rights-of-Way, November 23 (Washington, DC: U.S. Architectural and Transportation Barriers Compliance Board, 2005) www.access-board.gov/prowac/draft.htm.

Allowable Tolerances

The only industry standard tolerances for right-of-way construction are for mainline pavements, ramps, sidewalks, and intersections published by the ACI. Refer to Section 1-3 for ACI paving tolerances. For ramps and sidewalks, ACI tolerances state that the vertical deviation of a surface as measured below an unleveled 10-ft. (3-m) straightedge shall not exceed ¼ in. (3 mm).

In the publication, *Designing Sidewalks and Trails for Access, Part II of II: Best Practices Design Guide*, it is suggested that curb ramps be specified at 7.1 percent ±1.2 percent tolerance. This is intended to give a maximum slope of 8.33 percent (1:12) as required by the ADAAG.

For specific tolerances for highway and road smoothness, the local DOT responsible for construction should be consulted.

There are currently no industry standards for other tolerances of the various elements that are part of right-of-way construction. The recommendations given in this section are based on a report summarizing research conducted for the National Cooperative Highway Research Program of the Transportation Research Board. For this research, state and city departments of transportation were surveyed to determine if they had standards for tolerances and if not, what they believed were reasonable tolerances for the items listed in the questionnaire. Additionally, recently completed right-of-way construction was measured to determine if actual construction met the requirements of the ADAAG and if not, how close actual construction came to meeting the requirements. The information was evaluated to determine what could reasonably be expected of right-of-way construction using today's standard construction techniques, tools, equipment, and work crews. Requirements by individual state or local departments of transportation may vary.

Some of the suggested tolerances developed by the author of this report are shown in Figures 1-7 and 1-7.1 and detailed in Table 1-4. These are not endorsed by the Transportation Research Board.

Related Sections

1–3 Concrete Paving
1–4 Asphalt Paving
1–5 Pedestrian Paving
20–4 Tolerances and Accessibility

Chapter 2

Concrete

2–1 Reinforcement Placement for Flexural Members

Description

This section includes some of the typical tolerances for rebar placement for cast-in-place beams and other flexural members. Refer to ACI 117 for a complete listing of all placement tolerances and for fabrication of individual pieces of reinforcing steel.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

In reinforcement placement, a tolerance envelope is created by two limitations: the maximum reduction on concrete cover or clear distance between the rebar and forms and the reduction in distance between reinforcement. The clear distance between side forms or formed soffits is shown in Figure 2-1(a) and given in Table 2.1. However, the specified concrete cover cannot be reduced more than ⅜ in. (10 mm) for members 12 in. (305 mm) or less in dimension or more than ½ in. (13 mm) for members over 12 in. In any case, the reduction in cover cannot exceed one-third of the specified concrete cover. For soffits, the reduction in cover cannot exceed ¼ in. (6 mm). The distance between reinforcement is shown in Figure 2.1(b), but the distance cannot be less than the greater of the bar diameter or 1 in. (25 mm) for unbundled bars.

Table 2–1 Clear distance tolerance to side forms and soffits

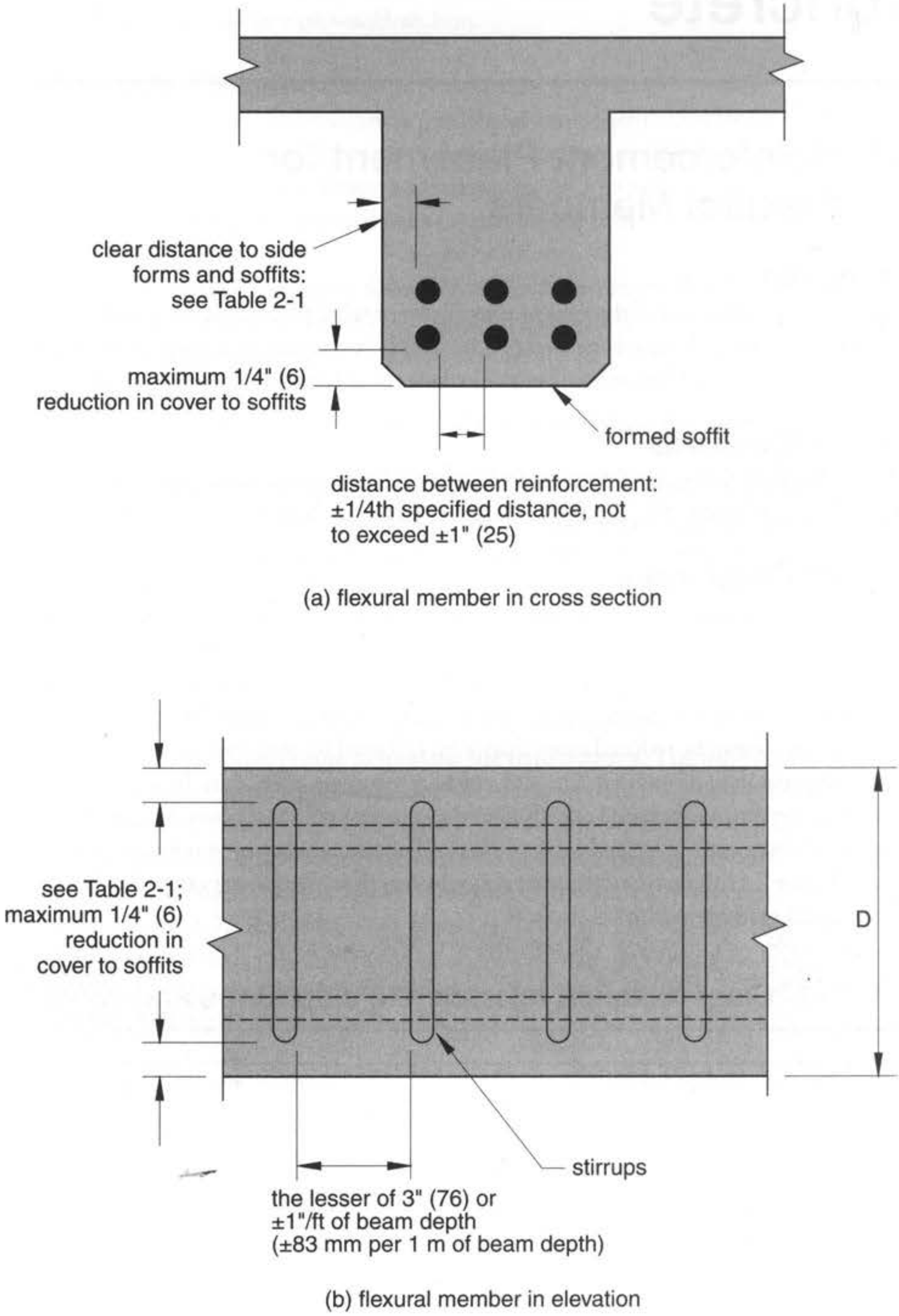
Member size, inches (mm)	Tolerance, inches (mm)
4 inches (101) or less	±¼ (6)
Over 4 inches (101) but not over 12 inches (305)	±⅜ (10)
Over 12 inches (305)	±½ (13)

Source: Compiled from information in ACI 117

Related Sections

2–2 Reinforcement Placement in Walls and Columns

Figure 2–1 Reinforcement placement for flexural members



2-2 Reinforcement Placement in Walls and Columns

Description

Reinforcement placement for cast-in-place walls and columns follows many of the same requirements as for flexural members. Refer to ACI 117 for a complete listing of all placement tolerances and for fabrication of individual pieces of reinforcing steel.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

As with flexural members, placement tolerances for walls and columns depend on the specified clear cover and the spacing between individual members. The clear-distance tolerances given in Table 2.1 apply to walls and columns. As with flexural members, the specified cover cannot be reduced more than ⅜ in. (10 mm) for members 12 in. (305 mm) or less in dimension or more than ½ in. (13 mm) for members over 12 in. In any case, the reduction in cover cannot exceed one-third of the specified concrete cover. The spacing of reinforcement in walls (other than ties) shown in Figure 2-2(a) cannot exceed ±3 in. (76 mm) except that the total number of bars cannot be less than that specified. For columns, the distance between reinforcement is shown in Figure 2-2(b), but the distance cannot be less than the greater of the bar diameter or 1 in. (25 mm) for unbundled bars.

For bar laps and embedded length, there is no positive tolerance; that is, bars may overlap or be embedded more than specified by any amount but not less than shown in Figures 2-2(c) and (d).

Related Sections

2–3 Reinforcement Placement for Flexural Members

2–3 Reinforcement Placement of Prestressing Steel

Description

Prestressing steel includes tendons used for reinforcement of precast, prestressed concrete sections. Simple precast reinforcing steel placement tolerances are governed by ACI 117.

Industry Standards

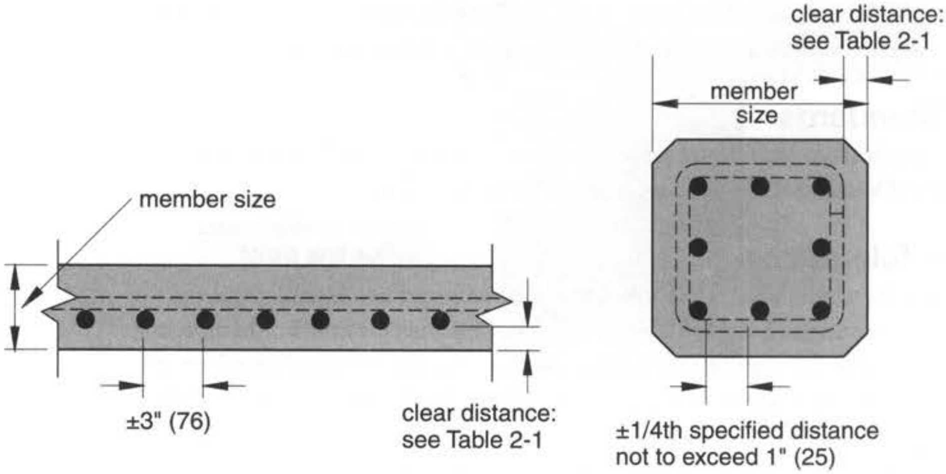
MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

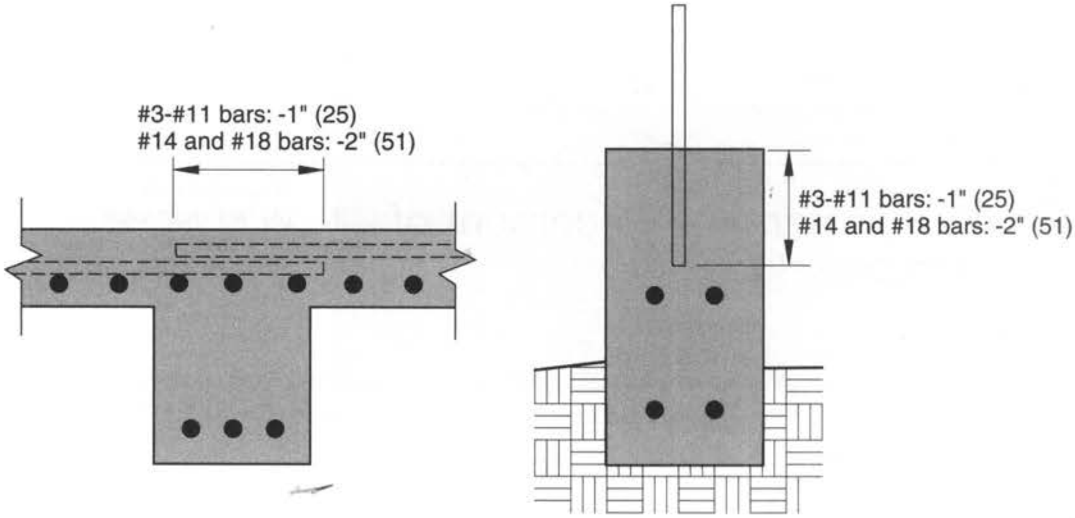
Lateral and vertical placement tolerances for prestressing steel and prestressing steel ducts are shown in Figure 2-3. ACI 117 sets tolerances based on member depth, while the Precast/Prestressed Concrete Institute sets tolerances based on member type.

Figure 2–2 Reinforcement placement in walls and columns



(a) walls

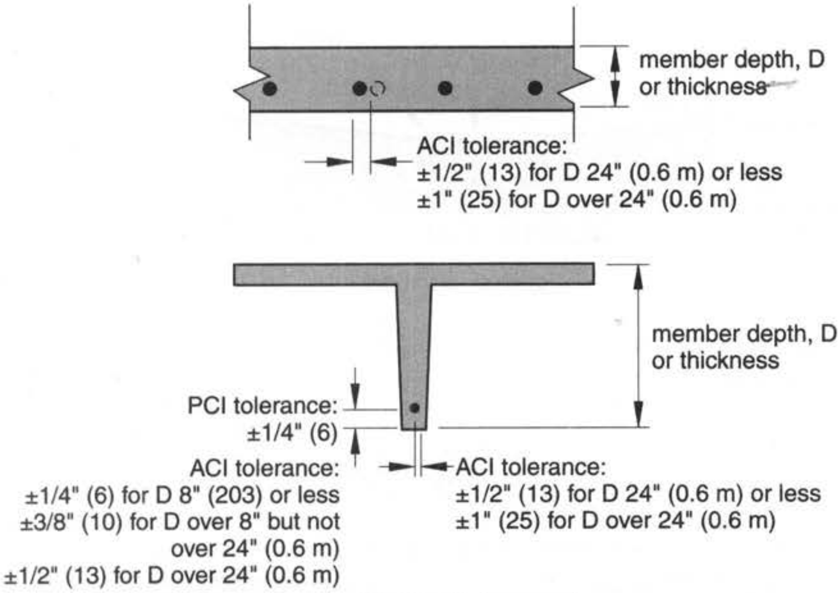
(b) columns



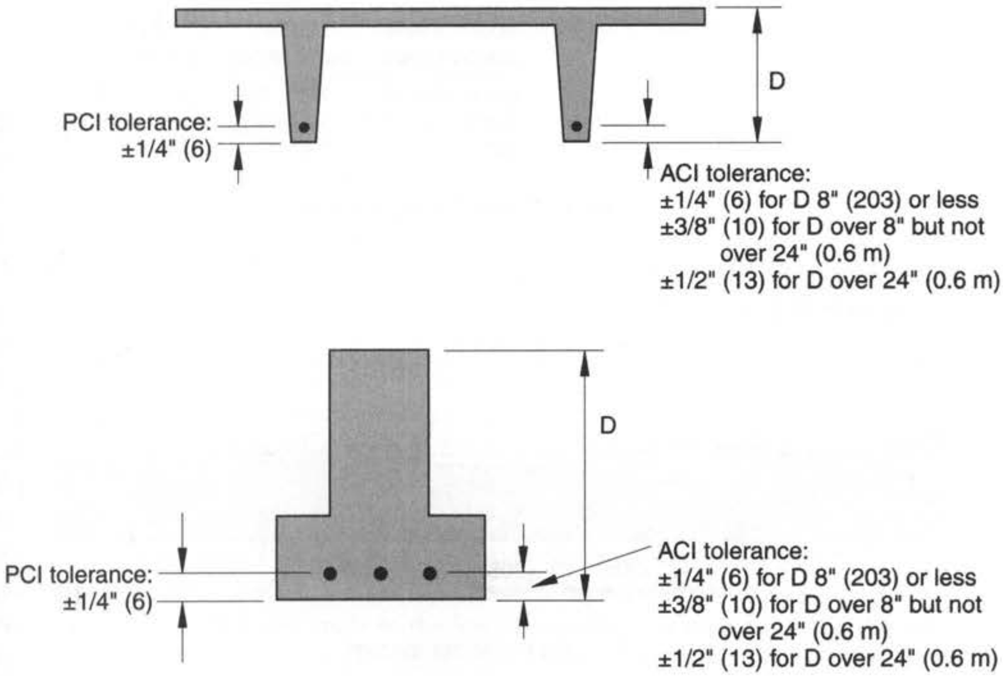
(c) bar laps

(d) embedded length

Figure 2–3 Reinforcement placement of prestressing steel

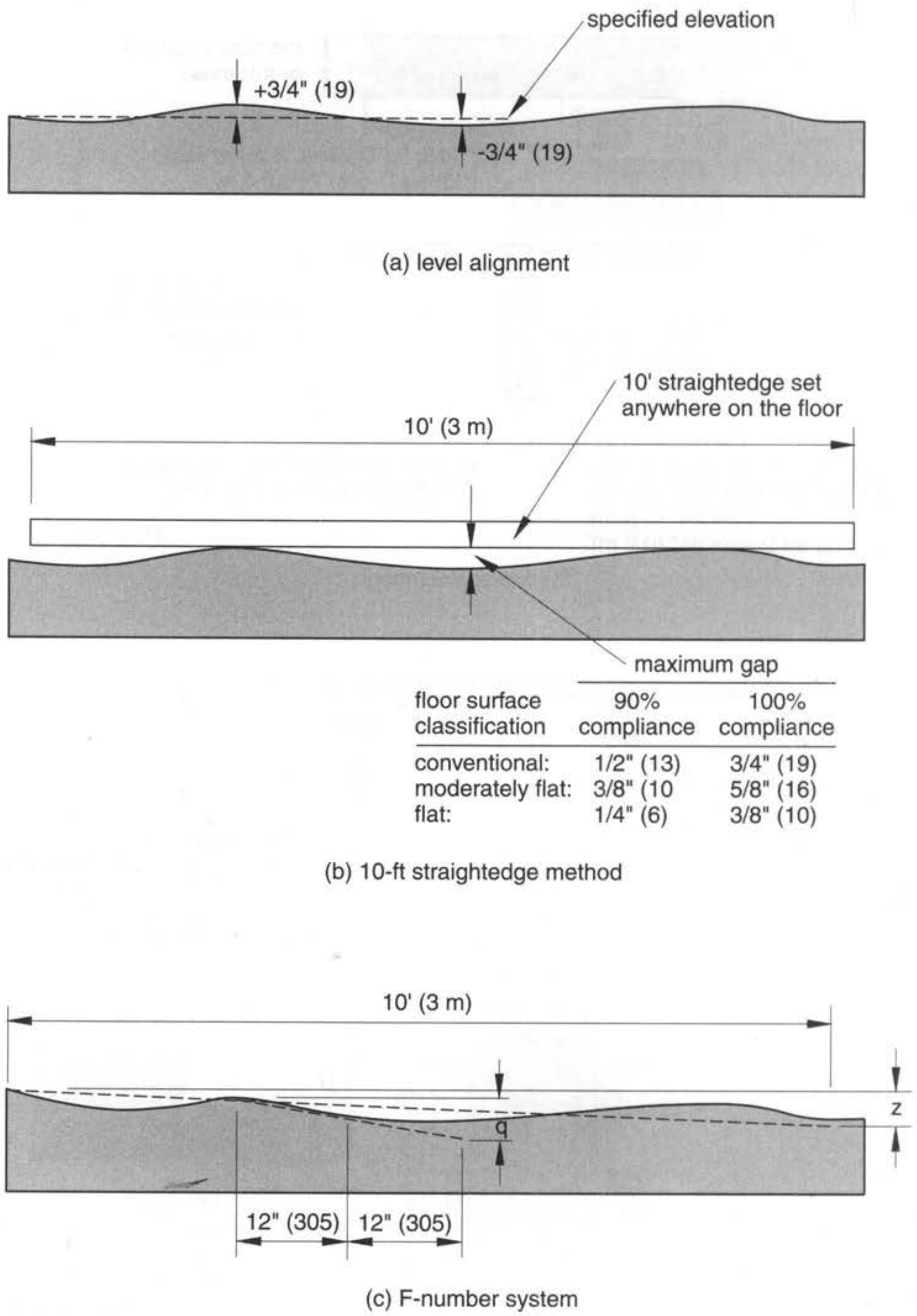


(a) lateral placement



(b) vertical placement

Figure 2–4 Concrete slabs on grade



floor surface classification	maximum gap 90% compliance	maximum gap 100% compliance
conventional:	1/2" (13)	3/4" (19)
moderately flat:	3/8" (10	5/8" (16)
flat:	1/4" (6)	3/8" (10)

The Precast/Prestressed Concrete Institute recommends that the position of tendons be ±¼ in. (6 mm) for individual tendons and ±½ in. (13 mm) for bundled tendons for prestressed sections such as single tees, double tees, beams, spandrels, columns, ribbed wall panels, insulated wall panels, and tee joists.

Related Sections

2–1 Reinforcement Placement for Flexural Members
2–2 Reinforcement Placement in Walls and Columns

2–4 Concrete Slabs on Grade

Description

Both slabs on grade and elevated slabs are subject to two tolerances. One is the overall tolerance above and below the specified elevation, and the other is the flatness and levelness of the floor finish. Flatness is the degree to which the surface approximates a plane. Levelness is the degree to which the surface parallels horizontal. For a complete discussion of the F-numbering system, refer to ACI 302.1R-89, *Guide for Concrete Floor and Slab Construction*, and ACI Compilation No. 9, *Concrete Floor Flatness and Levelness*.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

ASTM E 1155-96 (Reapproved 2001), *Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers* (West Conshohocken, PA: American Society for Testing and Materials, 2001).

Allowable Tolerances

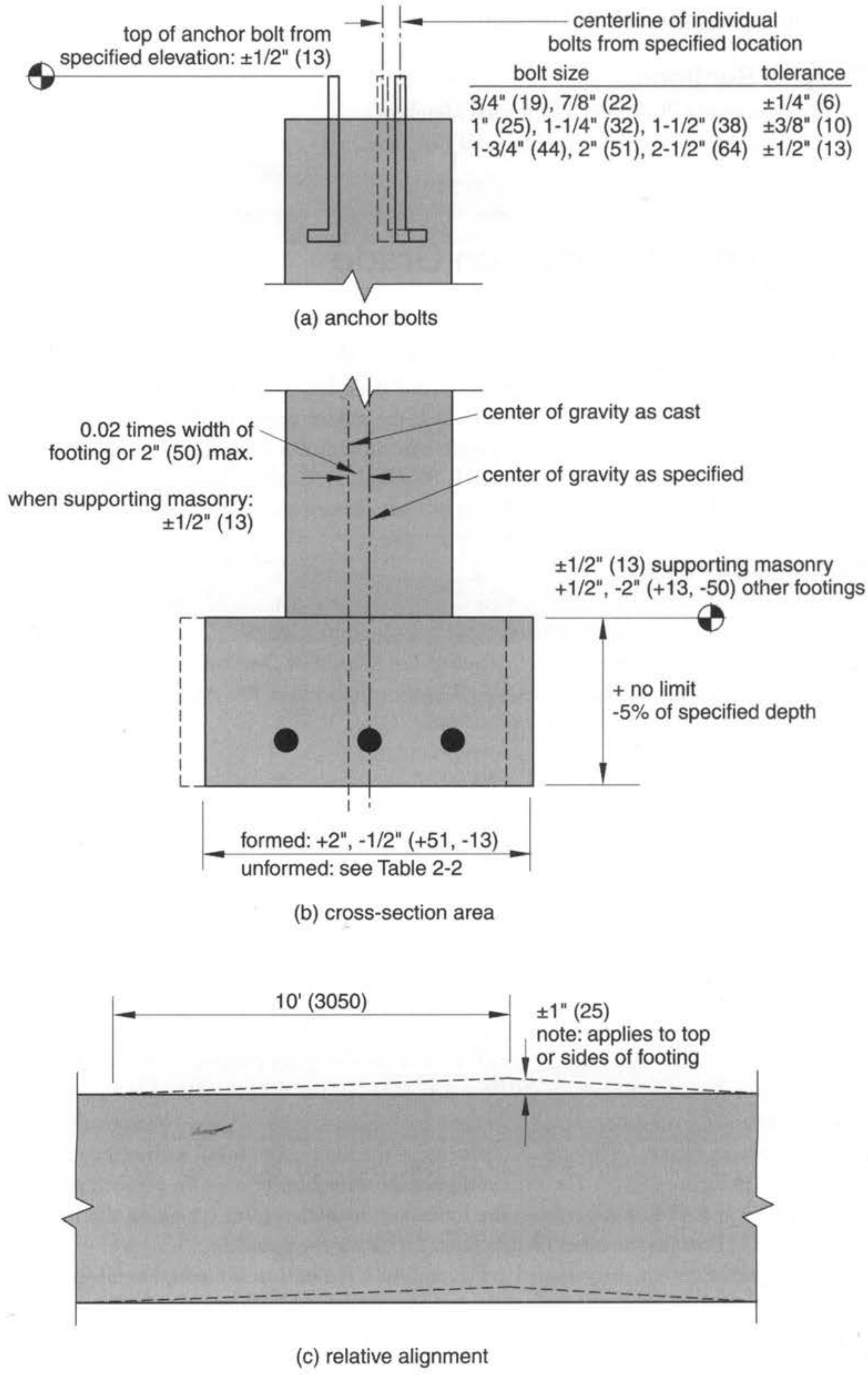
Level alignment tolerance is shown in Figure 2-4(a). This means that over the entire surface of a concrete slab, all points must fall within an envelope ¾ in. (19 mm) above or below the theoretical elevation plane.

Random-traffic floor finish tolerances may be specified either by the traditional 10-ft. straightedge method, shown in Figure 2-4(b), or by the F-number system. A third method, the Waviness Index, is an optional method of specifying floor surfaces. Refer to Section 17-5 for more information on the Waviness Index.

If the 10-ft. straightedge method is used, there are three floor classifications: conventional, moderately flat, and flat. For a surface to meet the requirements of one of these three classifications, a minimum of 0.01 times the area of the floor measured in ft.^{2} (0.1 times the area in m^2) must be taken. Ninety percent of the samples must be within the first column shown in Figure 2-4(b) and 100 percent of the samples must fall within the second column in Figure 2-4(b). The orientation of the straightedge must be parallel, perpendicular, or at a 45-degree angle to the longest construction joint bounding the test surface. ACI 117 details the other requirements for taking the samples.

The F-number system, diagrammed in Figure 2-4(c), is a statistical method to measure and specify both the local flatness of a floor within adjacent, 12-in. intervals (the F_F number) and the local levelness of a floor (the F_L number) over a 10-ft. (3,050-mm) distance. The higher the F_F or F_L number, the flatter or more level the floor. To determine if a floor falls within the tolerances of a particular F_F and F_L number, measurements must be taken

Figure 2-5 Footings and anchor bolts



according to the procedure set forth in ASTM E1155-87. In most cases, a sophisticated instrument must be used that can take the measurements and perform the calculations necessary for determining the F-numbers. Although there is no direct correlation, an F_{F50} roughly corresponds to a ⅛-in. (3.2-mm) gap under a 10-ft. straightedge. For other approximate correlations, refer to Table 17-3.

For slabs on grade, the F-numbering system works well. However, to determine the F-numbers, measurements must be taken within 72 hours of floor installation and, for suspended slabs, before shoring and forms are removed. Therefore, for suspended slabs specified levelness of a floor may be compromised when the floor deflects when the shoring is removed and loads applied.

ACI 117 gives requirements for five classes of floors that can be specified: conventional, moderately flat, flat, very flat, and super-flat. To meet the requirements for whatever class of floor is specified, the procedures of ASTM E1155 must be followed and the test results must meet certain overall flatness (SOF_F) values and specified overall levelness (SOF_L) values. In addition, minimum local values for flatness and levelness must also be achieved. These are ⅗ of the SOF_F and SOF_L values. For example, a "conventional"" floor must have an SOF_F of 20 and an SOF_L of 15, while a "super-flat" floor must have an SOF_F of 60 and an SOF_L of 40. Refer to ACI 117 for detailed requirements.

Refer to Chapter 17 for more information on measurement methods and proposed protocols for both flat and sloped surface measurement.

Related Sections

1–3 Concrete Paving
1–7 Right-of-Way Construction
2–8 Cast-in-Place Sectional Tolerances
17–5 Measuring Flatness, Level, and Smoothness

2-5 Footings and Anchor Bolts

Description

Footings include continuous-spread footings and pad footings. They include foundations poured in forms or directly against the soil. Anchor bolts (or anchor rods, as they are called in the steel industry) are typically set by the foundation contractor.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

The allowable tolerances for horizontal deviation of anchor bolts from their specified location depend on the size of the anchor bolt and are shown in Figure 2-5(a). These possible deviations are provided for by oversizing the hole diameters in steel base plates as recommended by the AISC *Manual of Steel Construction*. Refer to Section 14-2.

Tolerances for footings include lateral and level alignment as well as cross-sectional dimensions and relative alignment of the length along the sides and tops. As shown in Figure 2-5(b), lateral alignment depends on the width of the footing in the least dimension based on the center of gravity of the footing as specified and as cast. For unformed footings, the horizontal cross-sectional dimension depends on the specified width of the footing and is given in Table 2-2.

Table 2–2 Horizontal dimension tolerance for footings cast against soil

Specified width of footing	Tolerance, inches (mm)
2 ft (0.6 m) or less	+3, -½ (+76, -13)
Greater than 2 ft (0.6 m)	+6, -½ (+152, -13)

Source: Compiled from information in ACI 117.

The sides and top of footings may slope at a rate not to exceed 1 in. in 10 ft. (25 mm in 3,050 mm), as shown in Figure 2-5(c). Note that thickness tolerance and the top elevation tolerance cannot be combined to give a tolerance greater than formed top surface tolerance.

Related Sections

2–6 Piers
2–17 Precast Pilings
3–6 Steel Column Erection Tolerances
14–2 Accumulated Steel Frame Tolerances

2–6 Piers

Description

This section includes drilled piers of three categories. Category A includes unreinforced shafts extending through materials offering no or minimal lateral restraint, such as water, normally consolidated organic soils, or soils that might liquefy during an earthquake. Category B includes unreinforced shafts extending through materials offering lateral restraint, which are soils other than those in Category A. Category C is for reinforced shafts.

Proposed revisions to ACI 117 would change the allowable deviation from plumb for Category A piers to a maximum of 1.5 percent of the shaft length. Refer to the latest edition of ACI 117 for current tolerances.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

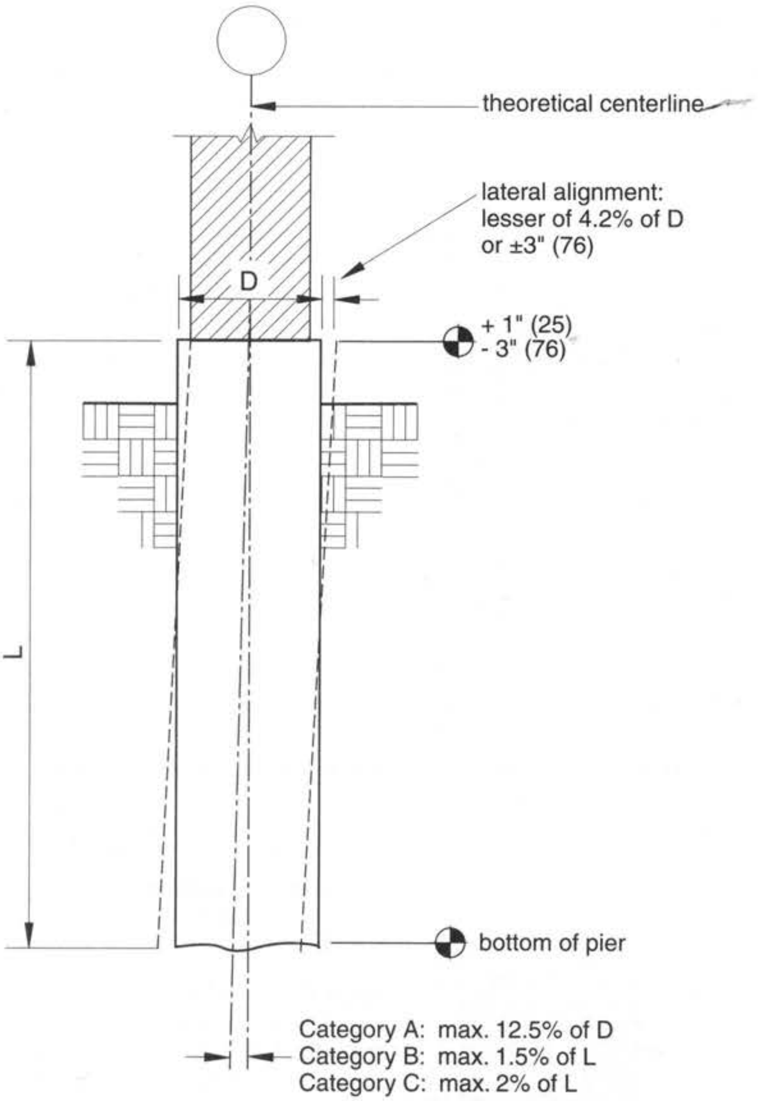
Allowable Tolerances

Tolerances for drilled piers are shown in Figure 2-6. Note that vertical alignment tolerances depend on either the diameter of the pier or its length depending on the category.

Related Sections

2–5 Footings
2–17 Precast Pilings

Figure 2–6 Piers



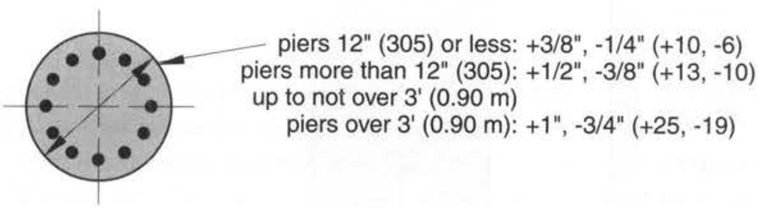
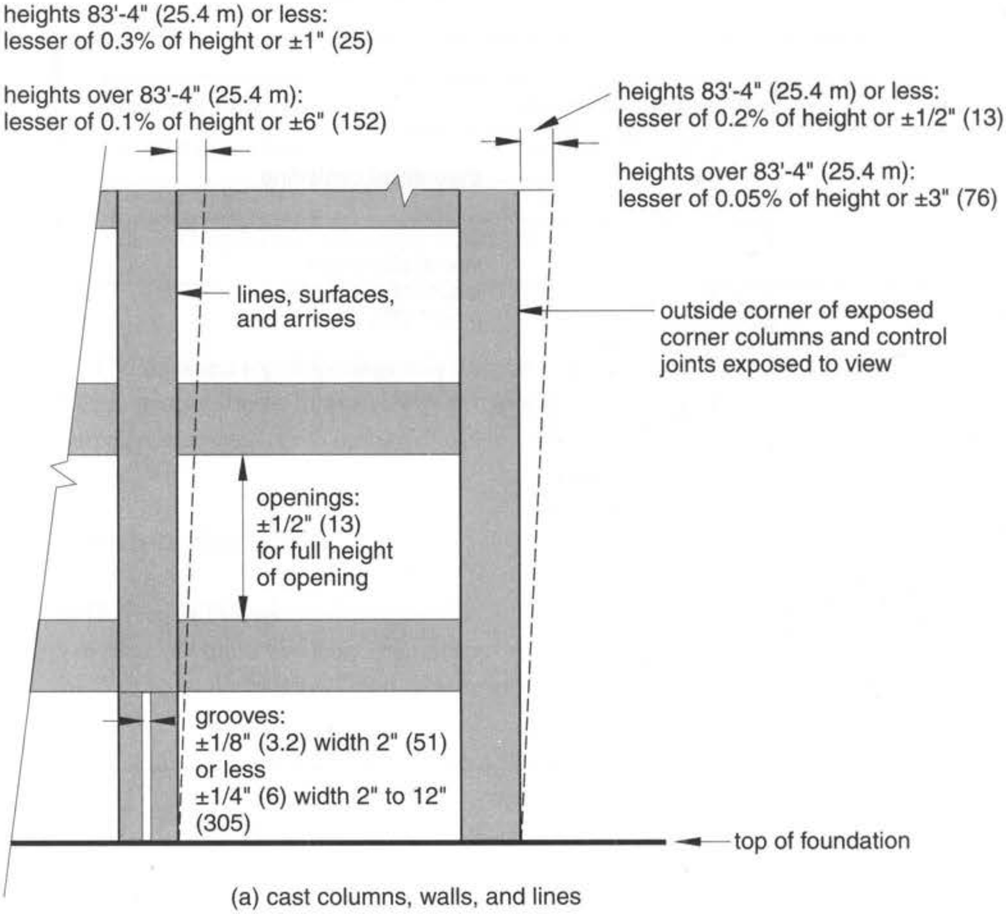
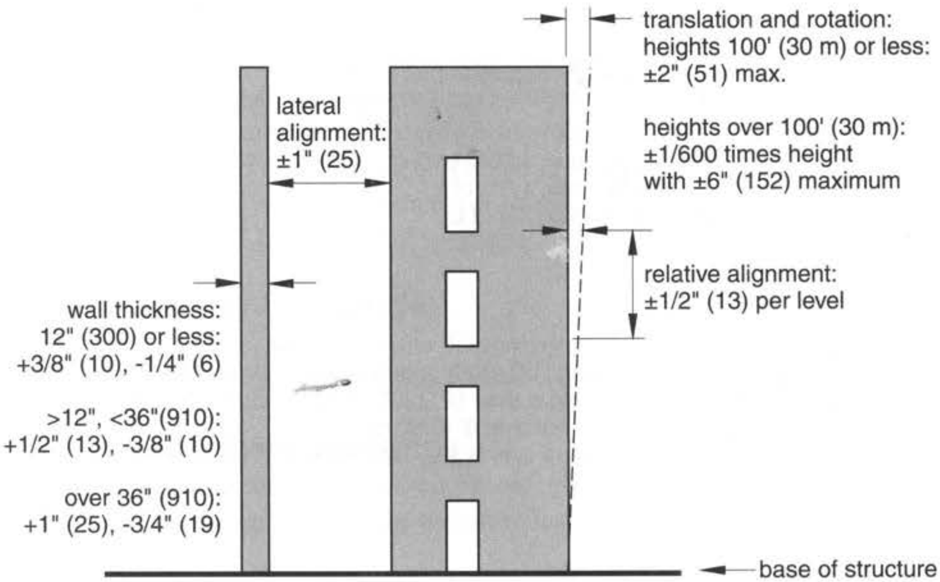


Figure 2–7 Cast-in-place plumb tolerances



(a) cast columns, walls, and lines



(b) slip-formed elements

2–7 Cast-in-Place Plumb Tolerances

Description

This section includes tolerances for both cast-in-place and vertically slip-formed elements. It includes visible elements, such as exposed columns, grooves, and expansion joints, as well as plumb tolerances for concealed column edges, walls, and slab edges.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

Vertical alignment tolerances (plumb) depend on the height of the structure above the top of the foundation and the location of the line in question. These conditions are shown in Figure 2-7(a). Note that the vertical tolerance for exterior corner columns and interior lines also applies to the edges of concealed suspended slabs to which other building elements may be attached.

For slip-formed structures shown in Figure 2-7(b), rotation is the twisting of a structure based on a fixed point at the base, while translation is the change in horizontal position perpendicular to the original position of the structure at the base. The lateral alignment tolerance of ±1 in. (25 mm) is between adjacent elements.

Related Sections

2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan

2–8 Cast-in-Place Sectional Tolerances

Description

This section includes dimensional tolerances for cast-in-place concrete elements. It includes elevation tolerances as well as cross-sectional tolerances for elements such as columns, beams, walls, and slabs.

Industry Standards

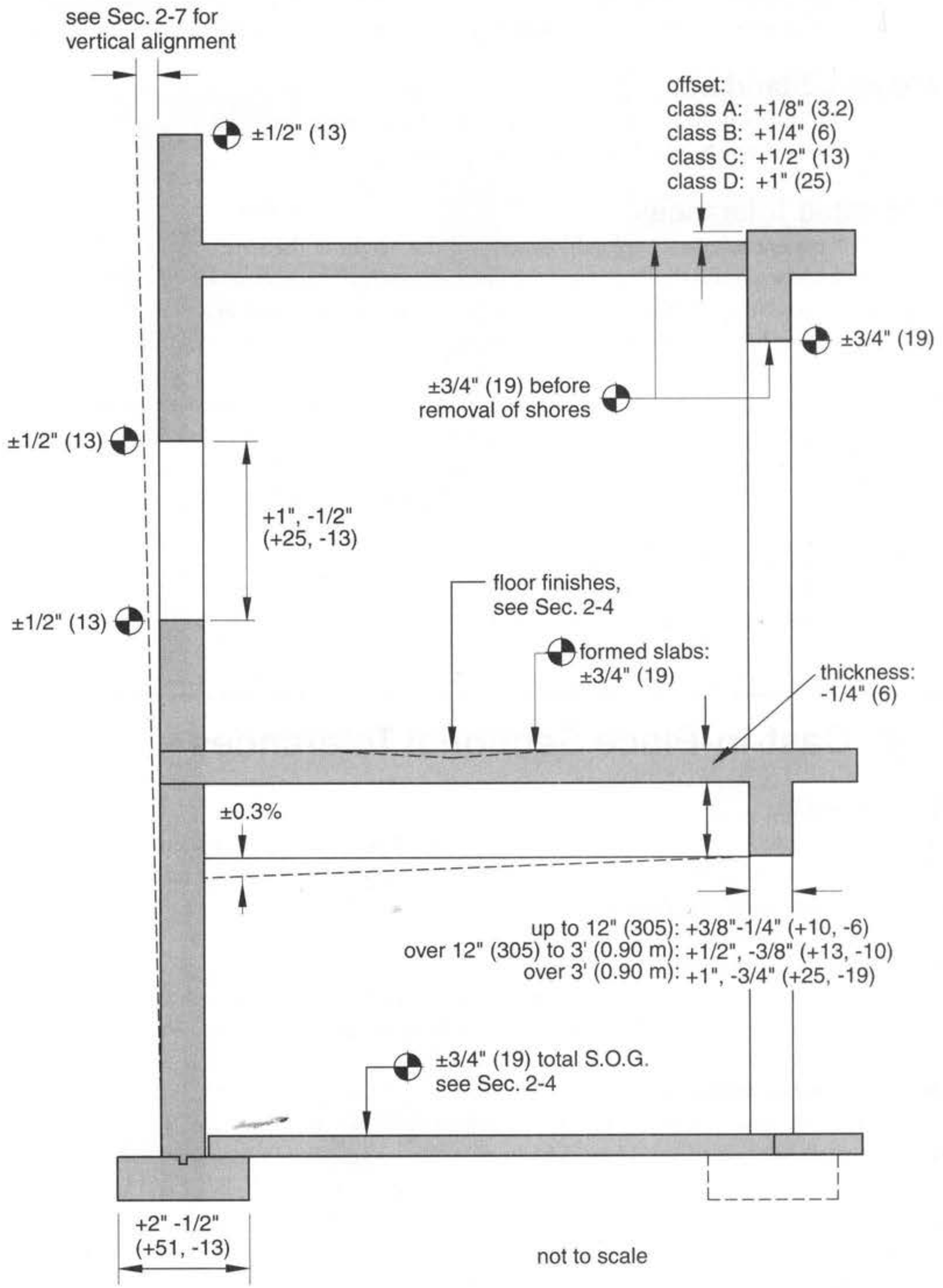
ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

The various sectional tolerances are shown diagrammatically in Figure 2-8. The level alignment tolerance of ±½ in. (13 mm) for lintels, sills, and parapets also applies to horizontal grooves and other lines exposed to view. Offsets listed as Class A, B, C, and D are for adjacent pieces of formwork facing material. Note that the level alignment of the top surface of formed slabs and for other formed surfaces is measured *before* the removal of shoring. There is no requirement for slabs on structural steel or precast concrete. The tolerance for a top of wall is ±¾ in. (19 mm).

For slabs on grade, the tolerance is –⅜ in. (–10 mm) for the average of all samples and –¾ in. (–19 mm) for an individual sample. The minimum number of samples that must be taken is one per 10,000 ft.^{2} (929 m^2).

Figure 2–8 Cast-in-place sectional tolerances



Related Sections

2–4 Concrete Slabs on Grade
2–5 Footings
2–7 Cast-in-Place Plumb Tolerances
2–9 Cast-in-Place Concrete Elements in Plan

2–9 Cast-in-Place Concrete Elements in Plan

Description

This section includes lateral dimensional tolerances for cast-in-place concrete construction. It includes location tolerances for elements such as columns and walls as well as opening tolerances.

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).

Allowable Tolerances

Tolerances for lateral alignment of cast-in-place building elements are shown in Figure 2-9. The cross-section dimensions apply to columns, beams, piers, and walls.

Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Section Tolerances

2–10 Cast-in-Place Stairs

Description

The American Concrete Institute's tolerances for cast-in-place concrete only require adjacent risers and treads to be within a listed tolerance. However, the International Building Code requires that the tolerance between the largest and smallest riser or tread cannot exceed ⅜ in. (9.5 mm).

Industry Standards

ACI 117-06, *Specifications for Tolerances for Concrete Construction and Materials and Commentary* (Detroit, MI: American Concrete Institute, 2006).
International Building Code, 2006, Section 1009.3.2 (Country Club Hills, IL: International Code Council, Inc., 2003).

Allowable Tolerances

Current ACI tolerances only give allowable variations in height and width between adjacent risers and treads, respectively, as shown in Figure 2-10. Previous versions of ACI 117 also limited the total rise in a flight of stairs to ±⅛ in. (3.2 mm) and the total run to ±¼ in. (6 mm), but these tolerances are no longer included as part of ACI 117. If the elevation of the top surfaces of formed slabs is ±¾ in. (19 mm), as stated in Section 2-8, there could be a maximum difference of 1 ½ in. (38 mm) beyond what is shown on the drawings. This could require riser heights to be adjusted to match actual floor-to-floor heights.

Figure 2–9 Cast-in-place concrete elements in plan

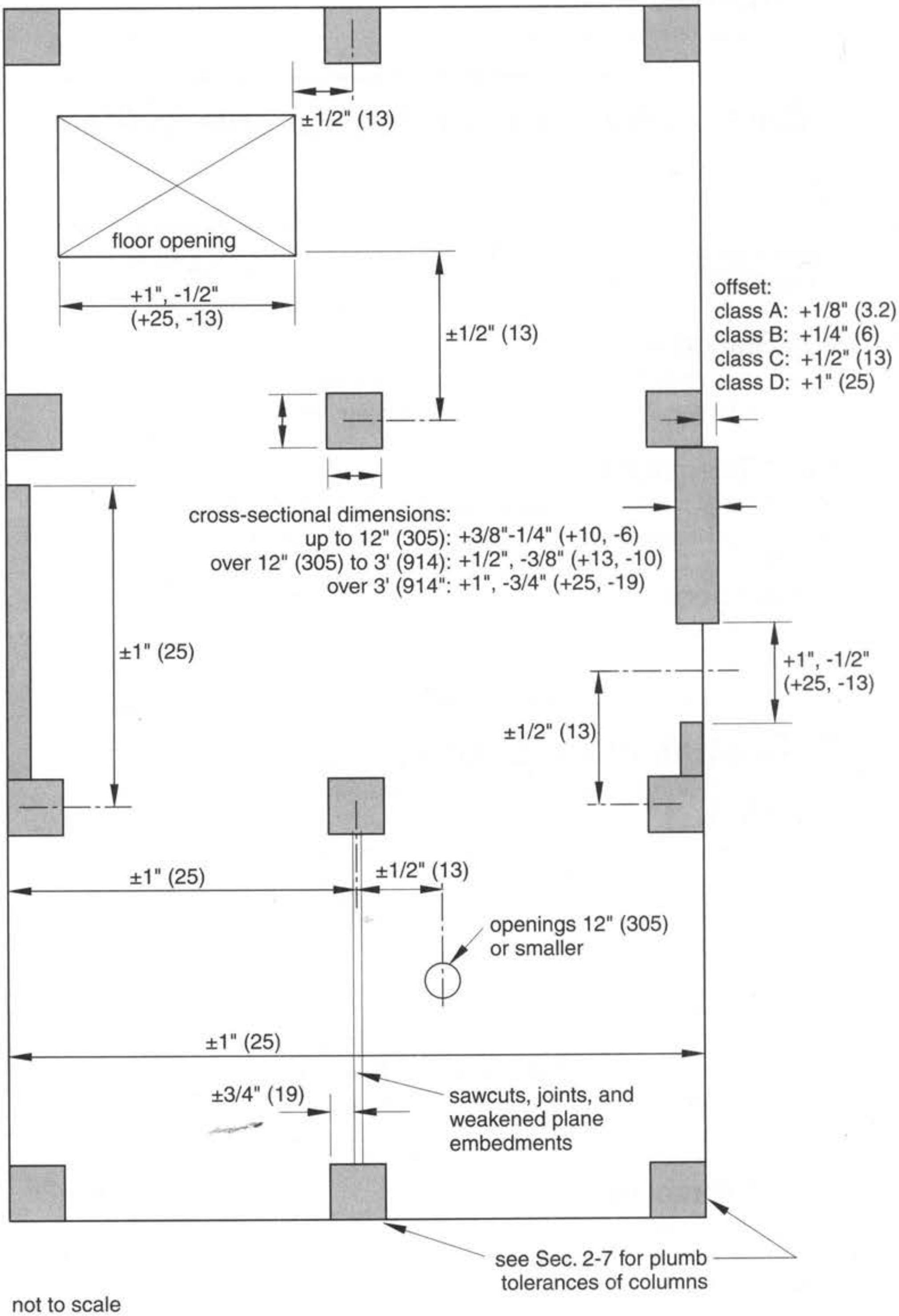
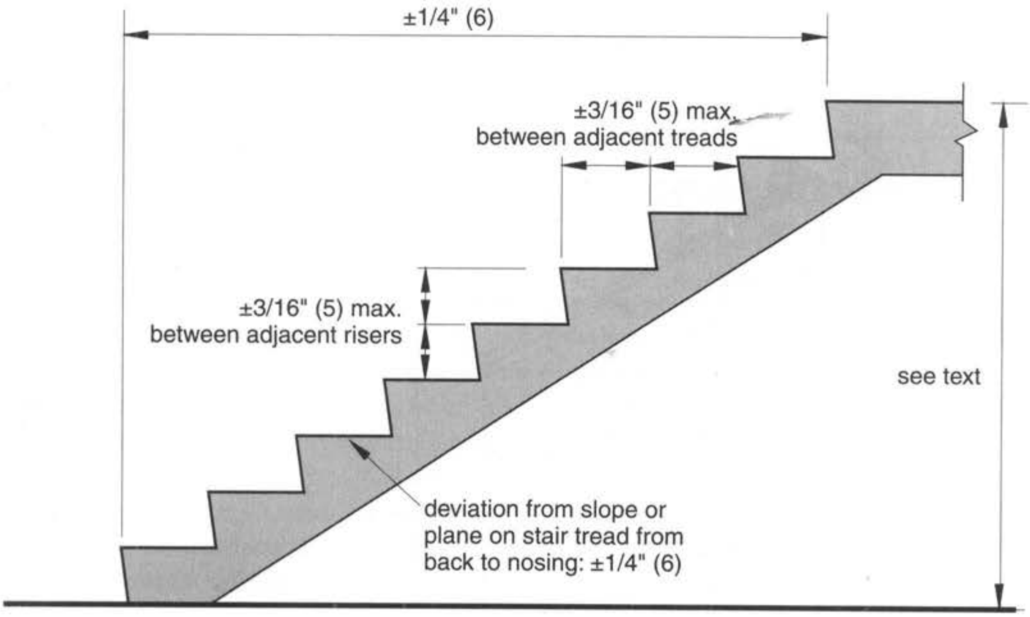


Figure 2–10 Cast-in-place stairs



Related Sections

2–8 Cast-in-Place Section Tolerances
2–9 Cast-in-Place Concrete Elements in Plan
2–16 Precast Stairs

2–11 Glass-Fiber-Reinforced Concrete Panels

Description

Glass-fiber-reinforced concrete (GFRC) applies to products manufactured with a cement/aggregate slurry reinforced with alkali-resistant glass fibers. GFRC panels are typically used for exterior cladding, column covers, and interior finish panels. They can be manufactured with or without a face mix of conventional concrete with decorative aggregates. When a face mix is used GFRC panels have the same appearance as standard precast concrete panels. Panels are normally ⅜ to ½ in. (10 to 13 mm) thick not including any exposed aggregate or veneer finish, if used.

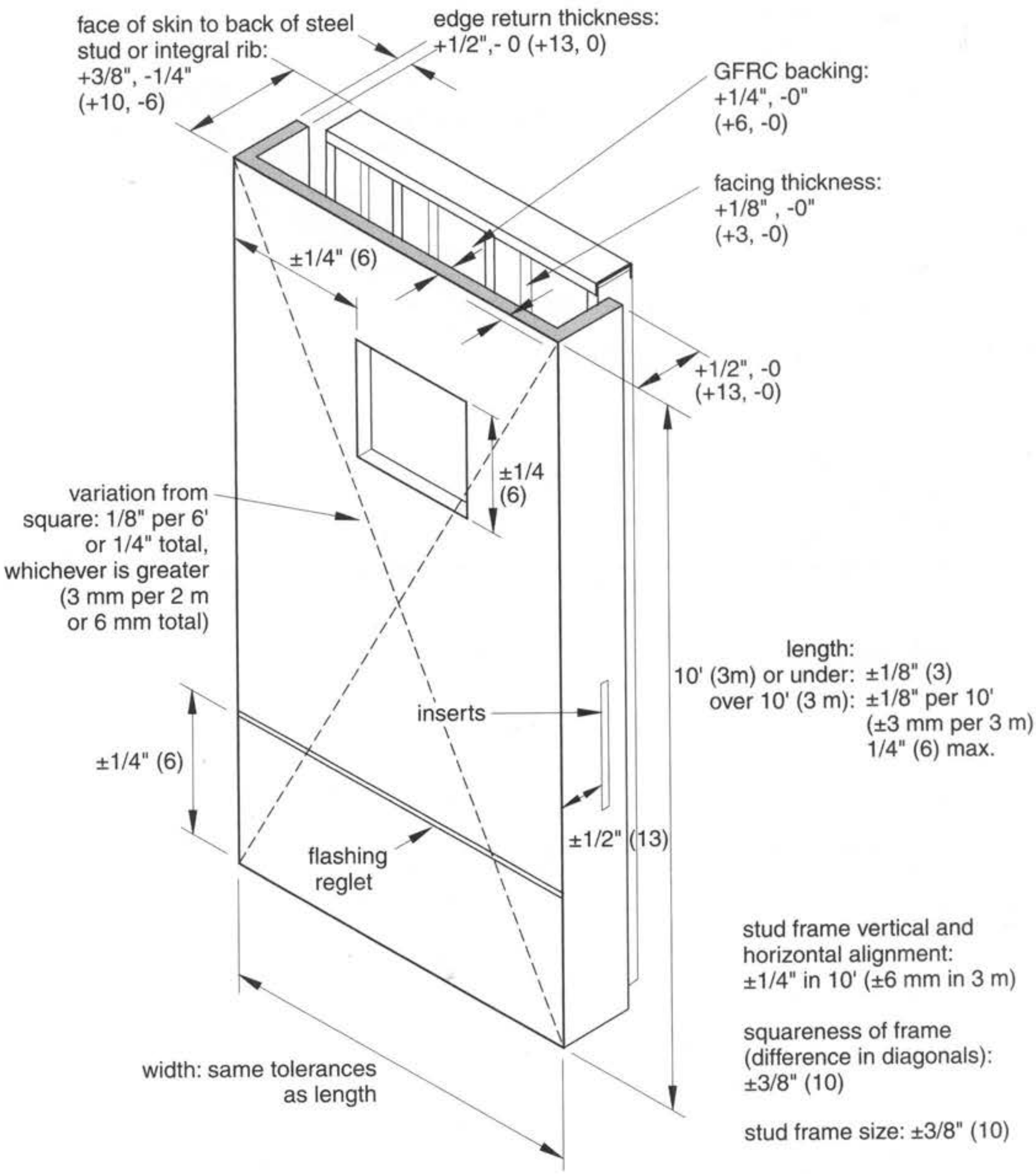
Industry Standards

MNL-128-01, *Recommended Practice for Glass Fiber Reinforced Concrete Panels*, 4th ed. (Chicago: Precast/Prestressed Concrete Institute, 2001).

Allowable Tolerances

Most of the tolerances for glass-fiber-reinforced concrete panel manufacturing are shown in Figure 2-11. Where tolerances for thickness are shown, increased tolerances should be allowed at a change in plane, a radius section, stiffening ribs, and similar construction elements. Generally, manufacturing tolerances can be compensated for during erection by

Figure 2–11 Glass-fiber-reinforced concrete panels



making adjustments in the clearance space, and joints and by forcing out minor variations in bow and warpage during attachment of the panel to the supporting framework. See the *Recommended Practice for Glass Fiber Reinforced Concrete Panels* for a complete listing and discussion of GFRC panel tolerances.

Related Sections

2–28 Glass-Fiber-Reinforced Concrete Panel Erection

2–12 Architectural Precast Concrete Panels

Description

This section includes tolerances for plant-cast and precast prestressed concrete panels commonly used as exterior cladding. The tolerances shown are some of the most common with which architects are concerned. Manufacturing tolerances (sometimes referred to as product tolerances) must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

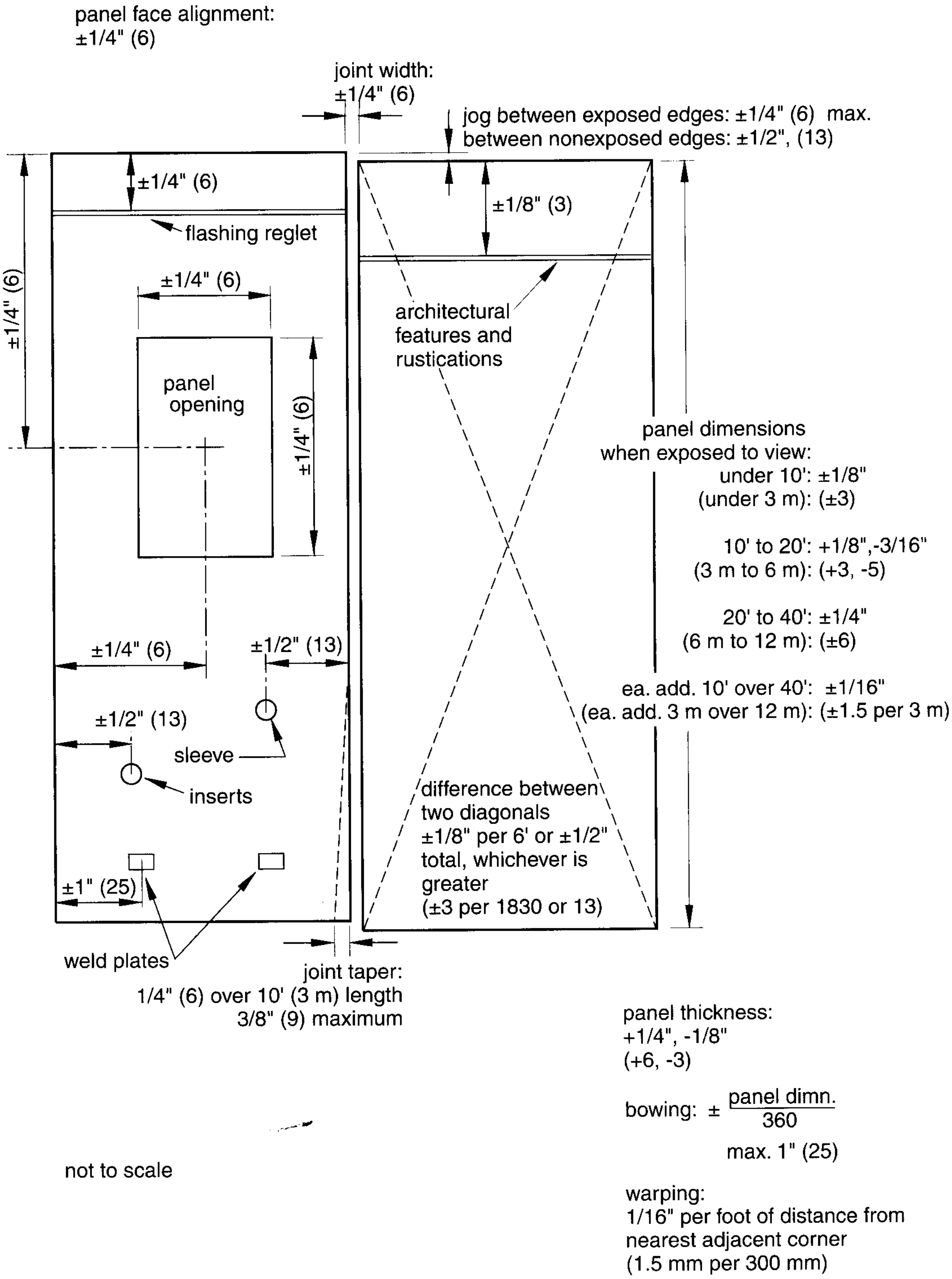
Allowable Tolerances

Some of the primary casting tolerances for flat panels are shown in Figure 2-12. Other tolerances exist for items such as haunch dimensions and positions, hidden blockouts, and other inserts. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing. The bowing tolerances refer to the overall out-of-planeness that can occur in one direction along a length of panel or in two directions. Warping, on the other hand, refers to the variation of one corner from adjacent corners. The difference between diagonals applies to major openings as well as the panel itself.

Related Sections

2–13 Precast Ribbed Wall Panels
2–14 Precast Insulated Wall Panels
2–26 Precast Structural Wall Panel Erection
2–27 Precast Architectural Wall Panel Erection
2–30 Tilt-Up Concrete Panels
Chapter 13 Precast Concrete Systems

Figure 2–12 Architectural Precast Concrete Panels



2–13 Precast Ribbed Wall Panels

Description

This section includes tolerances for plant-cast and site-cast precast and precast, prestressed concrete ribbed wall panels. These are similar to double tees but have a slightly different configuration.

Manufacturing tolerances (sometimes referred to as product tolerances) must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Many of the tolerances for ribbed wall panels are shown in Figure 2-13. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±⅛ in. per 12 in. (±3 mm per 300 mm). Bowing is limited to the length of the member divided by 360. Differential bowing between adjacent panels of the same design is limited to ±½ in. (13 mm). Warping cannot exceed 1/16 in. per ft. (1.5 mm per 300 mm) of the distance from the nearest adjacent corner. The local smoothness of any surface is ±¼ in. per 10 ft. (6 mm per 3 m).

The tolerance for the tipping and flushness of plates as well as tendon location is ±¼ in. (6 mm). Inserts for structural connections are located within ±½ in. (13 mm).

Related Sections

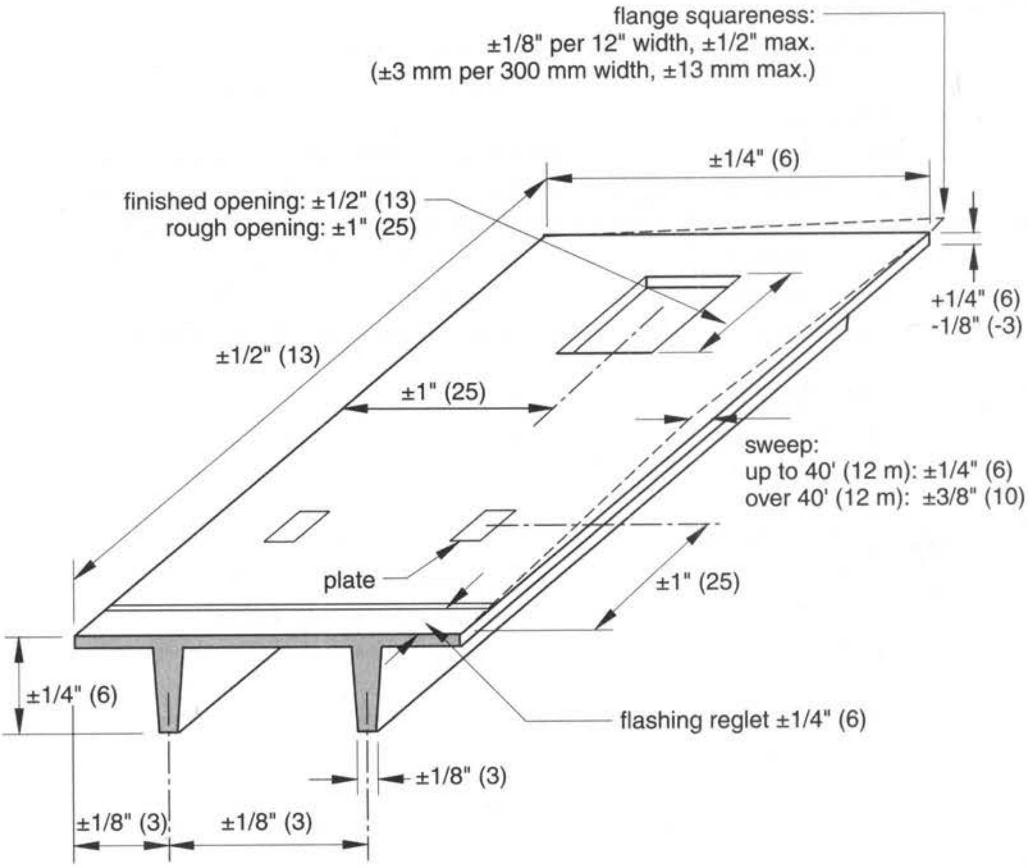
2–12 Architectural Precast Concrete Panels
2–20 Prestressed Double Tees
2–26 Precast Structural Wall Panel Erection
Chapter 13 Precast Concrete Systems

2–14 Precast Insulated Wall Panels

Description

This section includes tolerances for multi-wythe wall panels used in single-story structures. The manufacturing tolerances (sometimes referred to as product tolerances) shown here must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Figure 2–13 Precast ribbed wall panels



Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Many of the tolerances for insulated wall panels are shown in Figure 2-14. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±⅛ in. per 12 in. (±3 mm per 300 mm). Bowing is limited to the length of the member divided by 360. Differential bowing between adjacent panels of the same design is limited to ±½ in. (13 mm). Warping cannot exceed 1/16 in. per ft. (1.5 mm per 300 mm) of the distance from the nearest adjacent corner. The local smoothness of any surface is ±¼ in. per 10 ft. (6 mm per 3 m).

The tolerance for the tipping and flushness of plates as well as tendon location is ±¼ in. (6 mm). Inserts for structural connections are located within ±½ in. (13 mm).

Related Sections

2–12 Architectural Precast Concrete Panels
2–26 Precast Structural Wall Panel Erection
Chapter 13 Precast Concrete Systems

Figure 2–14 Precast insulated wall panels

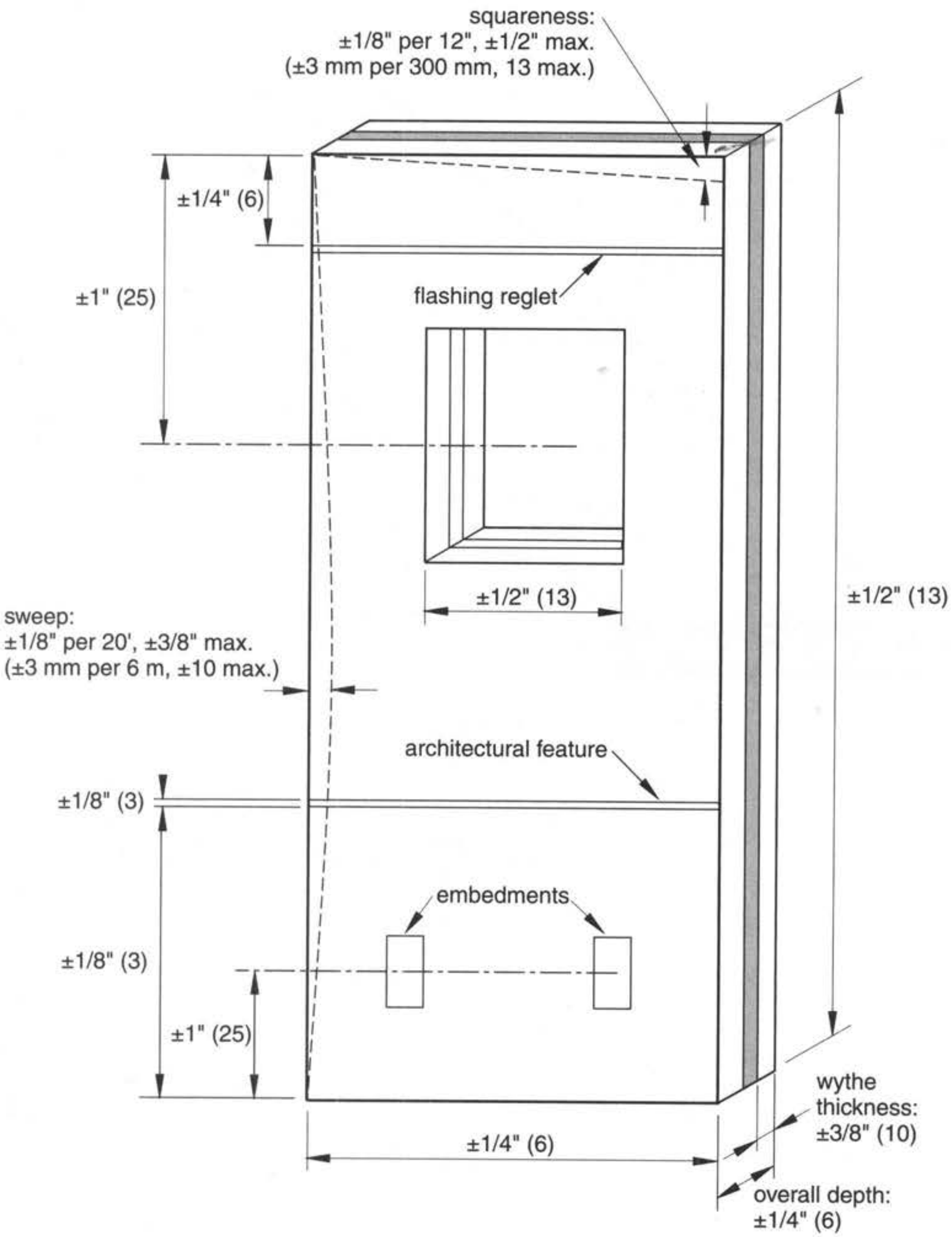
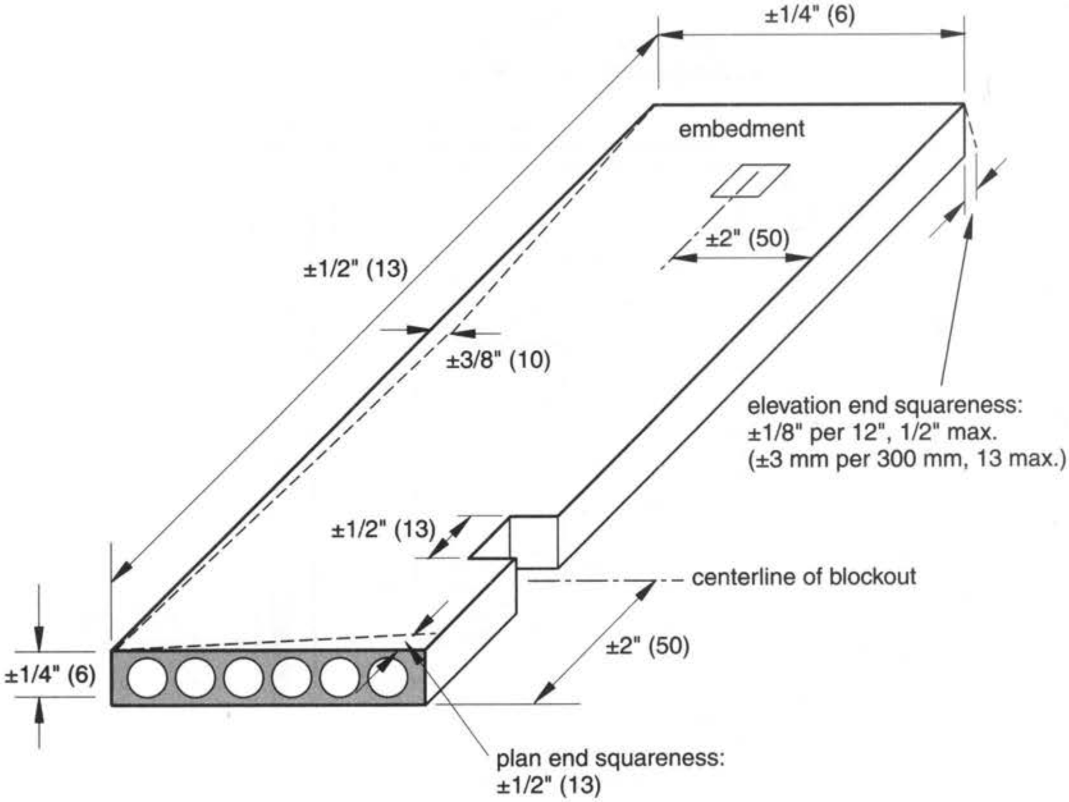


Figure 2–15 Hollow-core slabs



$$\text{bow} = \frac{\text{length}}{360} \text{ maximum}$$

2–15 Hollow-Core Slabs

Description

This section includes tolerances for cored slabs used for floor and roof construction. Manufacturing tolerances (sometimes referred to as product tolerances) must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Many of the tolerances for hollow-core slabs are shown in Figure 2-15. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±½ in. (13 mm). When differential camber between adjacent members of the same design is critical, the amount of tolerance should be verified with the producer. The local smoothness of any surface is ±¼ in. in 10 ft. (6 mm per 3 m). However, this does not apply to the top deck surface that is to receive a topping or other visually concealed surface. The tolerance for the tipping and flushness of plates is ±¼ in. (6 mm).

Related Sections

2–18 Prestressed Concrete Beams
2–25 Precast Floor and Roof Member Erection
Chapter 13 Precast Concrete Systems

2–16 Precast Stairs

Description

Precast stairs may be part of a larger precast building or may be incorporated into a cast-in-place concrete structure or a composite structure of steel and concrete. The applicable fabrication and erection tolerances of the base structure must be coordinated with the tolerances in this section to ensure that code maximums for variance of riser heights are not exceeded.

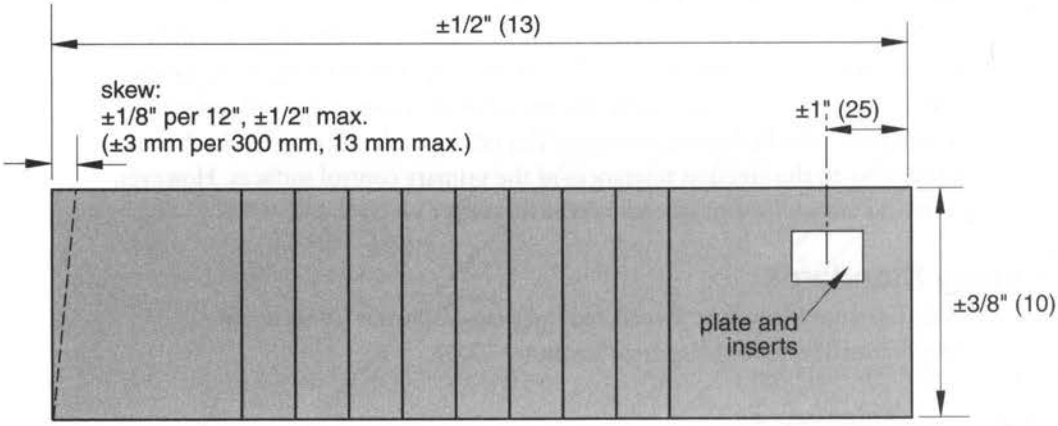
Industry Standards

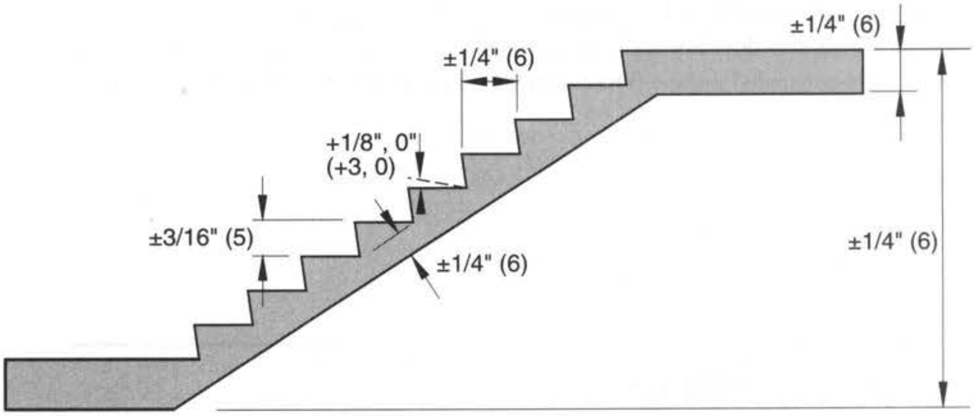
MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Overall tolerances and individual step tolerances are shown in Figure 2-16. In addition, the maximum difference between two risers is ±¼ in. (6 mm). These step tolerances are within the Uniform Building Code's requirement that the largest tread run (or riser height) within any flight not exceed the smallest tread (or riser) by more than ⅜ in. (10 mm).

Figure 2–16 Precast stairs





The square tolerance for the entire assembly (the difference in length of the two diagonals) is ±¼ in. per 6 ft. with a ½-in. maximum (±6 mm per 1.8 meters, with a 13-mm maximum variance). The position of inserts for structural connections must fall within ⅜ in. (10 mm) of the specified location.

Related Sections

2–10 Cast-in-Place Stairs
2–25 Precast floor and Roof Member Erection
Chapter 13 Precast Concrete Systems

2–17 Precast Pilings

Description

This section includes tolerances for both solid and hollow pilings. The dimensions illustrated are for round-, square-, and octagonal-shaped pilings.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

The primary tolerances are shown in Figure 2-17. Note that the length tolerance of ±1 in. (25 mm) is smaller than is often necessary. In many instances, a tolerance of +6 in. (150 mm) and –2 in. (50 mm) is acceptable.

For hollow pilings, the wall thickness has a tolerance of +½ in. and –¼ in. (plus 13 mm, minus 6 mm). Smoothness tolerance is ±¼ in. in 10 ft. (6 mm in 3 meters).

Related Sections

2–5 Footings
2–6 Piers

2–18 Prestressed Concrete Beams

Description

This section includes tolerances for rectangular, T-shaped, and L-shaped beams. Manufacturing tolerances (sometimes referred to as product tolerances) must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Figure 2–17 Precast pilings

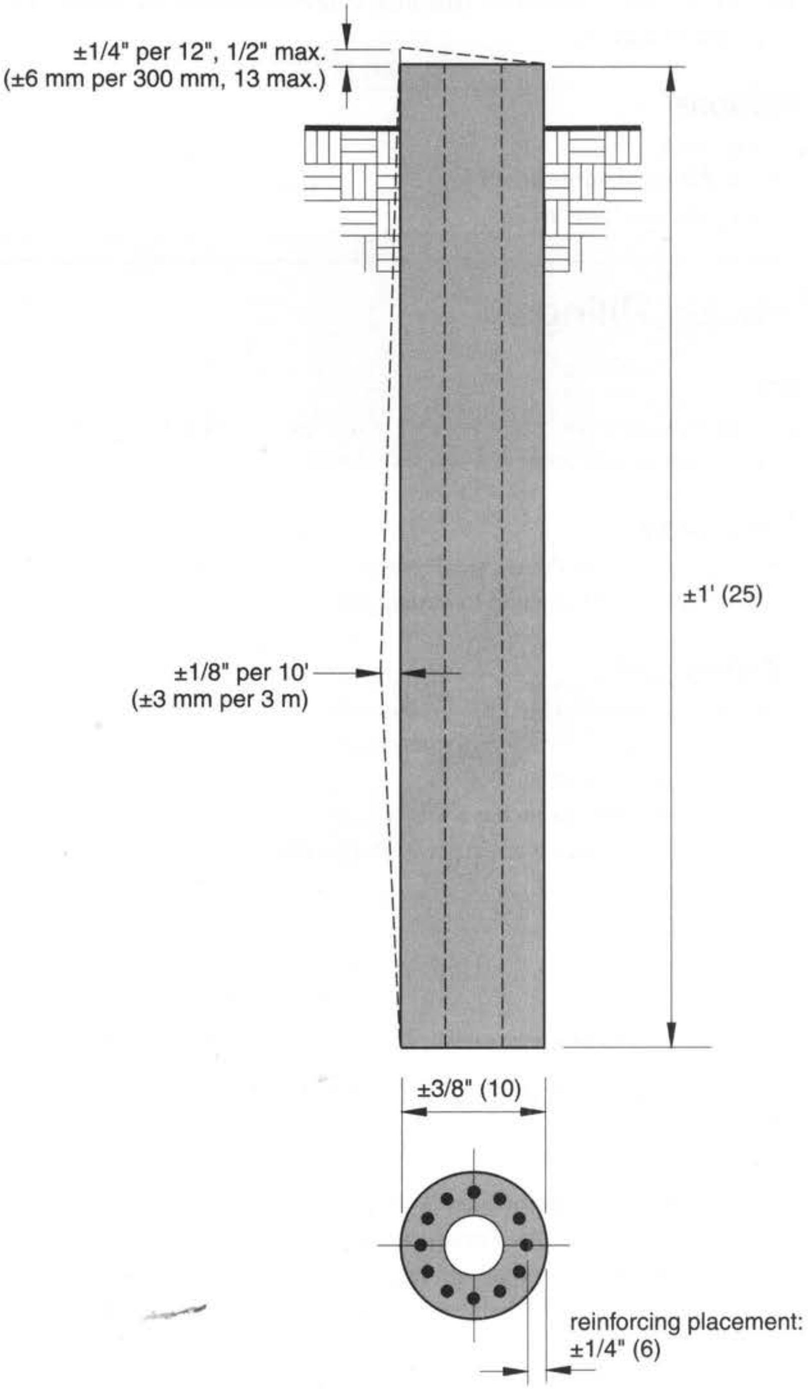
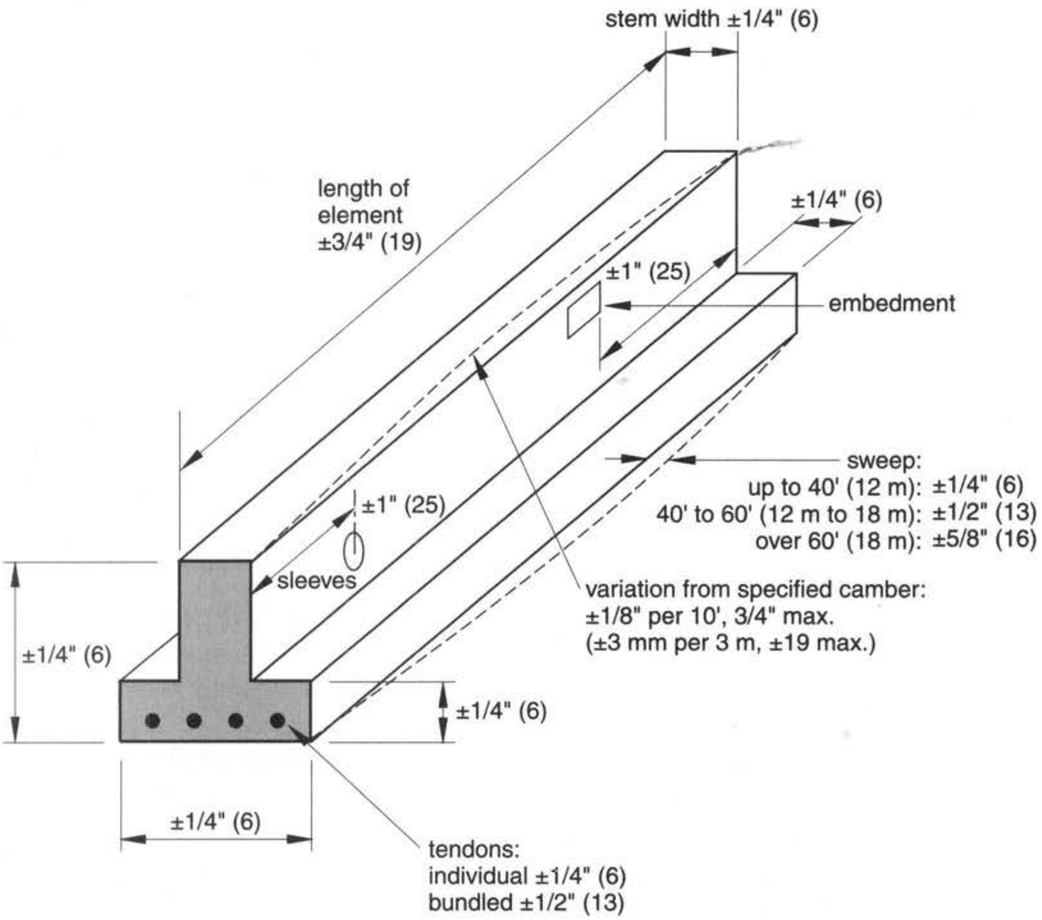


Figure 2–18 Prestressed concrete beams



Allowable Tolerances

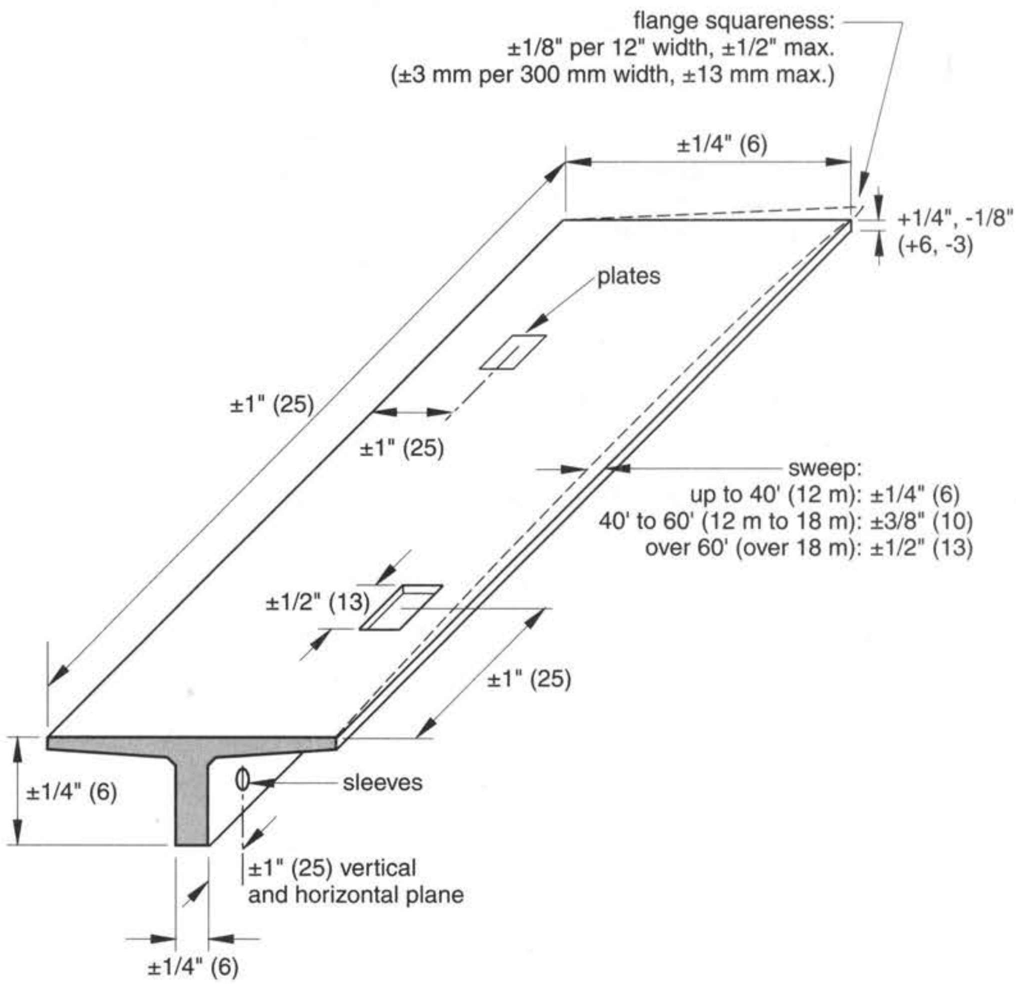
Many of the tolerances for precast beams are shown in Figure 2-18. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±⅛ in. per 12 in. of depth, with a ½-in. maximum (±3 mm per 300 mm of depth, 13-mm maximum). Camber variation from the design camber is ±⅛ in. per 10 ft., with a ¾-in. maximum (±3 mm per 3 meters, with a 19-mm maximum). However, for members with a span-to-depth ratio approaching or exceeding 30, this camber tolerance may not apply. If camber tolerances must be controlled with such span-to-depth ratios premium production measures may be required. Specific job requirements should be verified with the producer.

Plate position tolerance is ±1 in. (25 mm) for miscellaneous plates and ½ in. (13 mm) for bearing plates. The tolerance for the tipping and flushness of miscellaneous plates is ±¼ in. (6 mm), and for bearing plates it is ±⅛ in. (3 mm). Inserts for structural connections are located within ±½ in. (13 mm).

Smoothness of any surface must be within ¼ in. in 10 ft. (6 mm in 3 meters), except that surface requirements do not apply to top surfaces left rough to receive a topping.

Figure 2–19 Prestressed single tees



Related Sections

2–19 Prestressed Single Tees
2–20 Prestressed Double Tees
2–21 Precast Columns
2–24 Precast Beam and Spandrel Erection
Chapter 13 Precast Concrete Systems

2–19 Prestressed Single Tees

Description

This section includes tolerances for single tees as commonly used for floor and roof structure. The manufacturing tolerances (sometimes referred to as product tolerances) shown here must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction*(Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Many of the tolerances for single tees are shown in Figure 2-19. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±⅛ in. per 12 in. of depth, with a ½-in. maximum (±3 mm per 300 mm of depth, 13-mm maximum) for depths greater than 24 in. (600 mm). For depths 24 in. (600 mm) or less, the end squareness tolerance is ±¼ in. (±6 mm). Camber variation from the design camber is ±¼ in. per 10 ft., with a ¾-in. maximum (±6 mm per 3 meters, with a 19-mm maximum). However, for members with a span-to-depth ratio, approaching or exceeding 30, this camber tolerance may not apply. If camber tolerances must be controlled with such span-to-depth ratios premium production measures may be required. Specific job requirements should be verified with the producer. Differential camber between adjacent members of the same design is ±¼ in. per 10 ft., with a ¾-in. maximum (6 mm per 3 meters, 19-mm maximum).

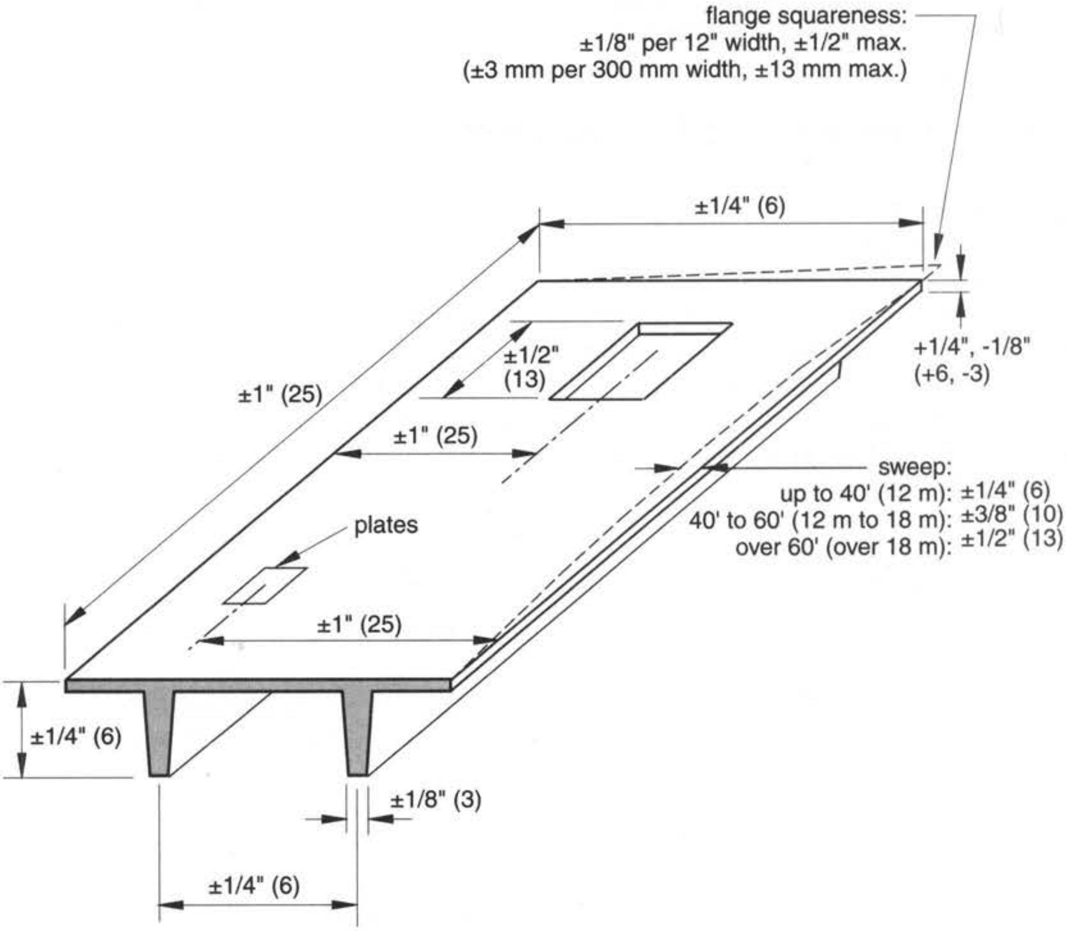
Plate position tolerance is ±1 in. (25 mm) for miscellaneous plates and ½ in. (13 mm) for bearing plates. The tolerance for the tipping and flushness of miscellaneous plates is ±¼ in. (6 mm), and for bearing plates it is ±⅛ in. (3 mm). Inserts for structural connections are located within ±½ in. (13 mm).

Smoothness of any surface must be within ¼ in. in 10 ft. (6 mm in 3 meters), except that surface requirements do not apply to top surfaces left rough to receive a topping.

Related Sections

2–18 Prestressed Concrete Beams
2–20 Prestressed Double Tees
2–25 Precast Floor and Roof Member Erection
Chapter 13 Precast Concrete Systems

Figure 2–20 Prestressed double tees



2–20 Prestressed Double Tees

Description

This section includes tolerances for double tees as commonly used for floor and roof structures. The manufacturing tolerances (sometimes referred to as product tolerances) shown here must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Many of the tolerances for double tees are shown in Figure 2-20. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±⅛ in. per 12 in. of depth, with a ½-in. maximum (±3 mm per 300 mm of depth, 13-mm maximum) for depths greater than 24 in. (600 mm). For depths 24 in. (600 mm) or less the end squareness tolerance is ±¼ in. (±6 mm). Camber variation from the design camber is ±¼ in. per 10 ft., with a ¾-in. maximum (±6 mm per 3 meters, with a 19-mm maximum). However, for members with a span-to-depth ratio approaching or exceeding 30, this camber tolerance may not apply. If camber tolerances must be controlled with such span-to-depth ratios, premium production measures may be required. Specific job requirements should be verified with the producer. Differential camber between adjacent members of the same design is ±¼ in. per 10 ft., with a ¾-in. maximum (6 mm per 3 meters, 19-mm maximum).

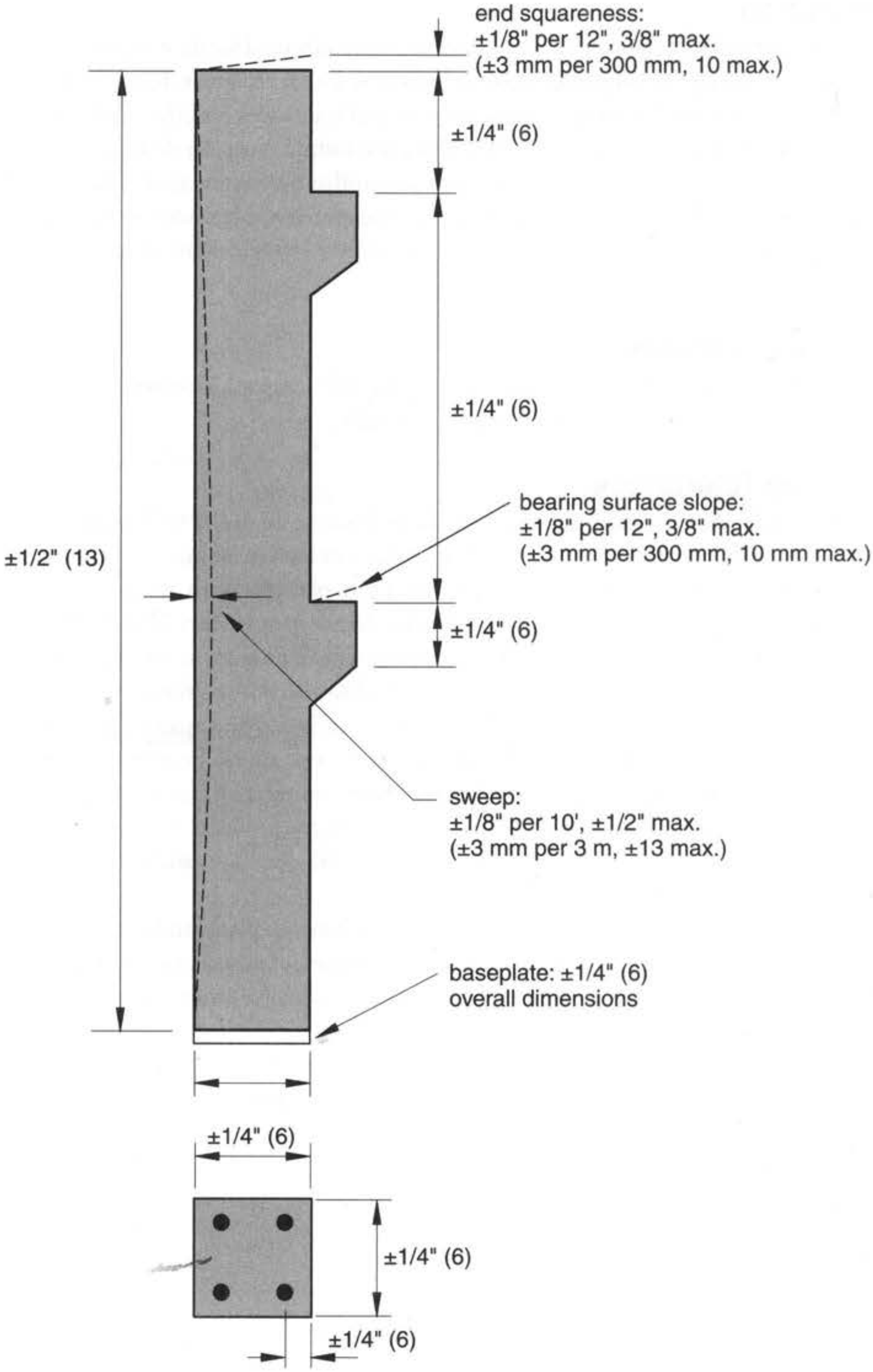
Plate position tolerance is ±1 in. (25 mm) for miscellaneous plates and ½ in. (13 mm) for bearing plates. The tolerance for the tipping and flushness of miscellaneous plates is ±¼ in. (6 mm), and for bearing plates it is ±⅛ in. (3 mm). Inserts for structural connections are located within ±½ in. (13 mm).

Smoothness of any surface must be within ¼ in. in 10 ft. (6 mm in 3 meters), except that surface requirements do not apply to top surfaces left rough to receive a topping.

Related Sections

2–18 Prestressed Concrete Beams
2–19 Prestressed Single Tees
2–25 Precast Floor and Roof Member Erection
Chapter 13 Precast Concrete Systems

Figure 2–21 Precast columns



2–21 Precast Columns

Description

This section includes tolerances for precast concrete columns commonly used to support precast beams or other structural members. The manufacturing tolerances shown here must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Many of the tolerances for precast columns are shown in Figure 2-21. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing. Note that the tolerances for the size and position of haunches are not cumulative. Plate position tolerance is ±1 in. (25 mm). The tolerance for the tipping and flushness of plates is ±¼ in. (6 mm). Inserts for structural connections are located within ±½ in. (13 mm). Smoothness of any surface must be within ¼ in. in 10 ft. (6 mm in 3 meters), except that surface requirements do not apply to visually concealed surfaces.

Related Sections

2–23 Precast Column Erection
Chapter 13 Precast Concrete Systems.

2–22 Precast Tee Joists or Keystone Joists

Description

This section includes tolerances for tee joists and keystone joists. The manufacturing tolerances (sometimes referred to as product tolerances) shown here must be coordinated with erection tolerances and tolerances for other building systems for a successful project. During construction, one surface is usually designated as the primary control surface, the location of which is controlled during erection. The product tolerances given in this section are *not* additive to the erection tolerances of the primary control surfaces. However, product tolerances are additive to secondary control surface erection tolerances.

Industry Standards

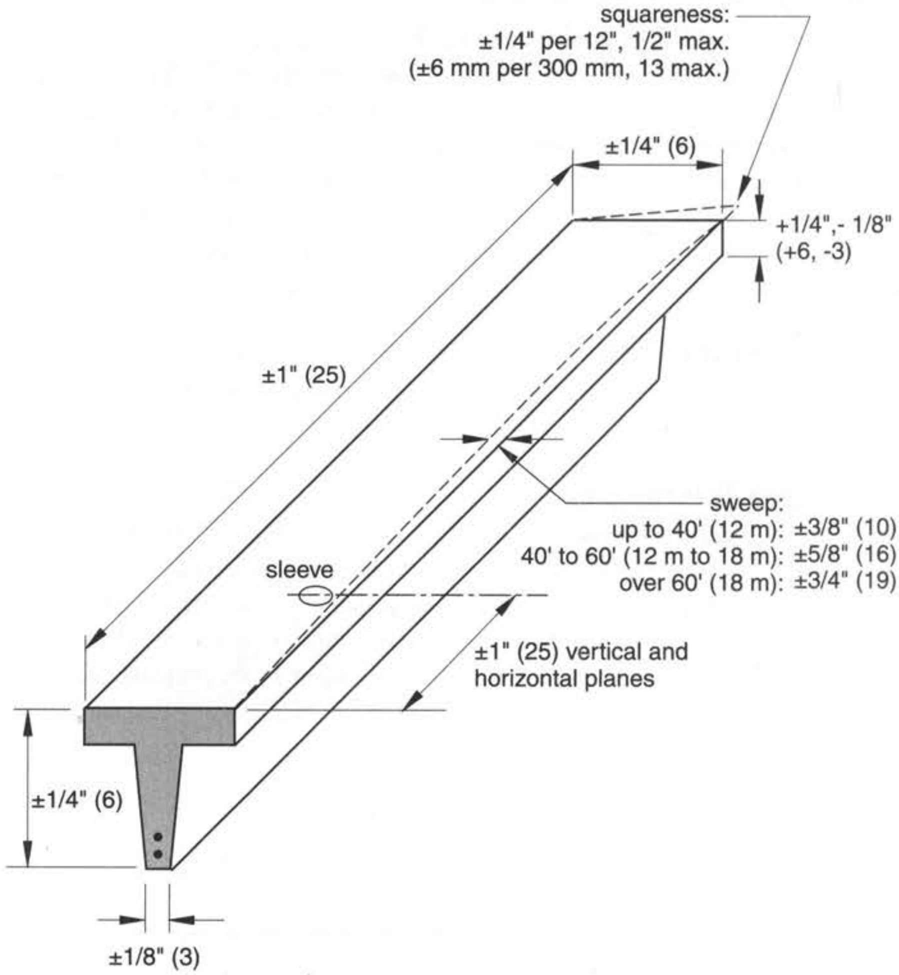
MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

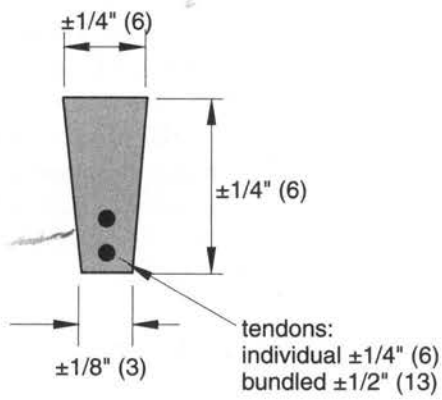
Many of the tolerances for tee and keystone joists are shown in Figure 2-22. Refer to *Tolerance Manual for Precast and Prestressed Concrete Construction* for a complete listing.

The variation from end squareness is ±¼ in. per 12 in., with a ½-in. maximum (±6 mm

Figure 2–22 Precast tee joists or keystone joists



(a) precast tee joist



(b) precast keystone joist

per 300 mm of depth, 13-mm maximum). Camber variation from the design camber is ±¼ in. per 10 ft., with a ¾-in/ maximum (±6 mm per 3 m, with a 19-mm maximum). However, for members with a span-to-depth ratio approaching or exceeding 30, this camber tolerance may not apply. If camber tolerances must be controlled with such span-to-depth ratios, premium production measures may be required. Specific job requirements should be verified with the producer. For some types of combined precast and cast-in-place construction, these tolerances may not be required.

Plate position tolerance is ±1 in. (25 mm) for miscellaneous plates and ½ in. (13 mm) for bearing plates. The tolerance for the tipping and flushness of miscellaneous plates is ±¼ in. (6 mm), and for bearing plates it is ±⅛ in. (3 mm). Inserts for structural connections are located within ±½ in. (13 mm).

Smoothness of any surface must be within ¼ in. in 10 ft.. (6 mm in 3 meters), except that surface requirements do not apply to top surfaces left rough to receive a topping.

Related Sections

2–18 Prestressed Concrete Beams
2–19 Prestressed Single Tees
2–20 Prestressed Double Tees
2–24 Precast Beam and Spandrel Erection
Chapter 13 Precast Concrete Systems.

2–23 Precast Column Erection

Description

The tolerances given in this section are recommended tolerances rather than strict standards. They are reasonable variations that can be expected in most situations. However, because precast erection is subject to many variables and some situations are visually more critical than others, tolerances should be reviewed with the precast supplier before finalizing specifications. To minimize costs, the tolerances in this section can be increased where the members will be covered with other finish material or in structures where visual appearance is not critical.

The erection tolerances shown in this section must be coordinated with manufacturing tolerances and tolerances for other building systems to which the precast system is connected. The erection tolerances are based on the primary control surfaces, which are the surfaces that are controlled during erection. The erection tolerances are *not* additive to the product tolerances given in previous sections. However, erection tolerances are additive to the product tolerances for secondary control surfaces.

The erection tolerances shown in this section are primarily for precast element to precast element.

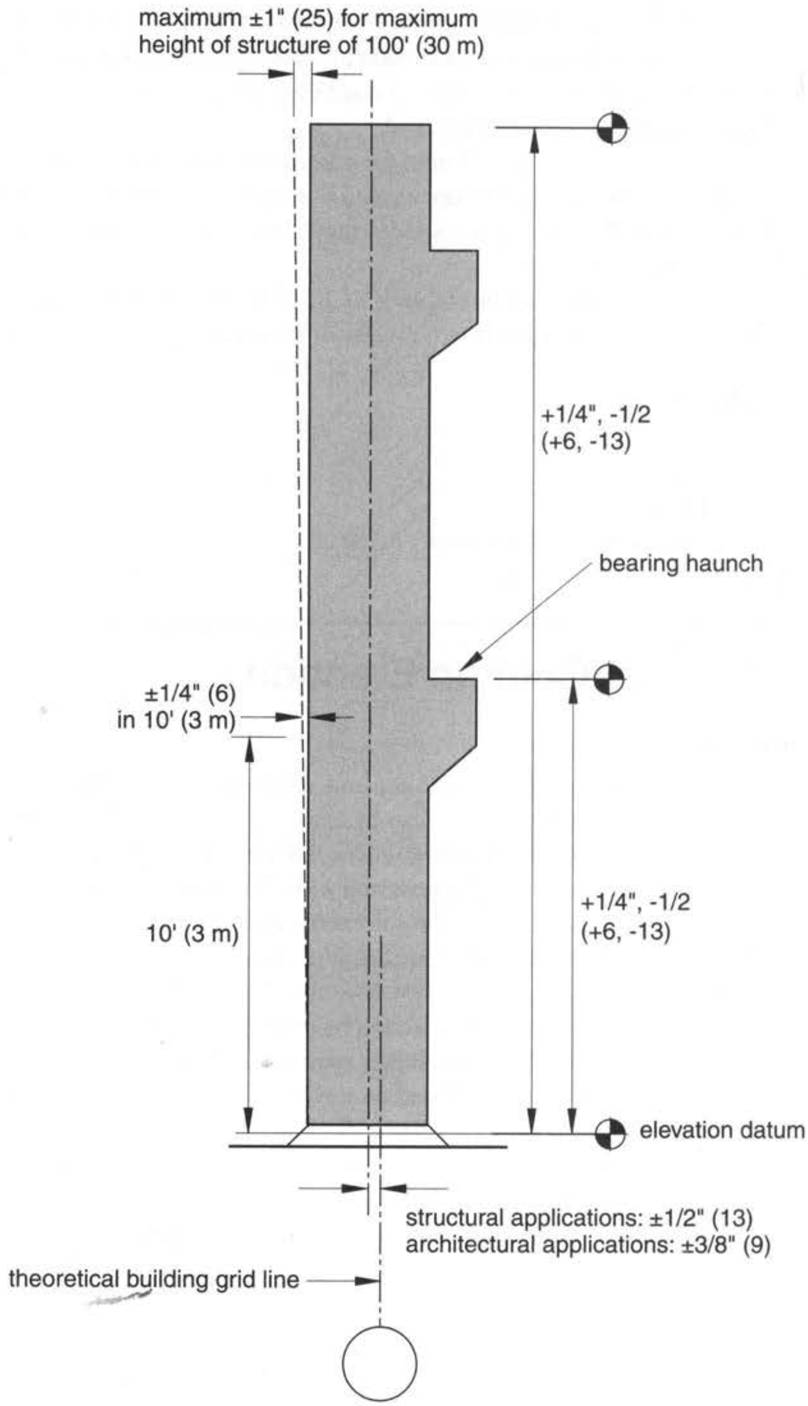
Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Tolerances for precast column erection are shown in Figure 2-23. Note that the tolerance in placement from the theoretical building grid line is for the plan location so it applies to two directions. In addition, the maximum jog in the alignment of matching edges is ±¼ in. (6 mm) for architectural exposed edges and ±½ in. (13 mm) for visually non-critical edges.

Figure 2–23 Precast column erection



Related Sections

2–21 Precast Columns
2–24 Precast Beam and Spandrel Erection
Chapter 13 Precast Concrete Systems

2–24 Precast Beam and Spandrel Erection

Description

The tolerances given in this section are recommended tolerances rather than strict standards for beam erection. They are reasonable variations that can be expected in most situations. However, because precast erection is subject to many variables and some situations are visually more critical than others, tolerances should be reviewed with the precast supplier before finalizing specifications. To minimize costs, the tolerances in this section can be increased where the members will be covered with other finish material or in structures where visual appearance is not critical.

The erection tolerances shown in this section must be coordinated with manufacturing tolerances and tolerances for other building systems to which the precast system is connected. The erection tolerances are based on the primary control surfaces, which are the surfaces that are controlled during erection. The erection tolerances are *not* additive to the product tolerances given in previous sections. However, erection tolerances are additive to the product tolerances for secondary control surfaces.

The erection tolerances shown in this section apply to precast elements attached to other precast elements, to cast-in-place concrete or masonry, and to steel members.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

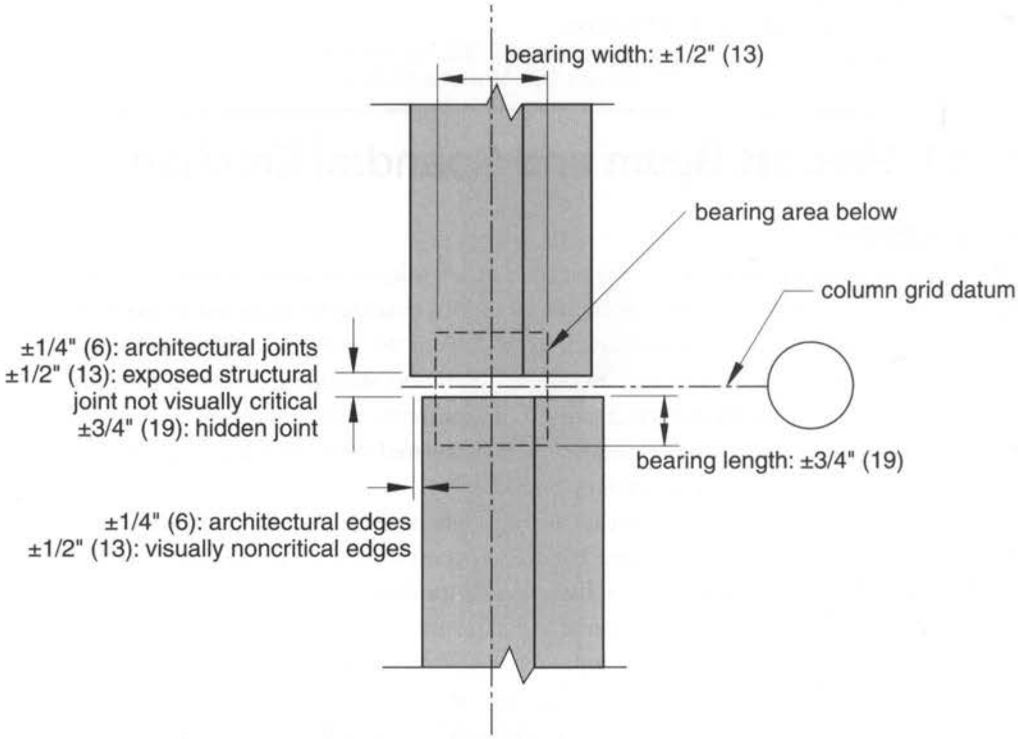
Allowable Tolerances

Tolerances for beam erection are shown in Figure 2-24. When a precast beam is placed on a steel column, the 1-in. (25-mm) tolerance still applies, but it is measured from the centerline of the steel support structure. Joint width is the width of the space between ends of abutting members.

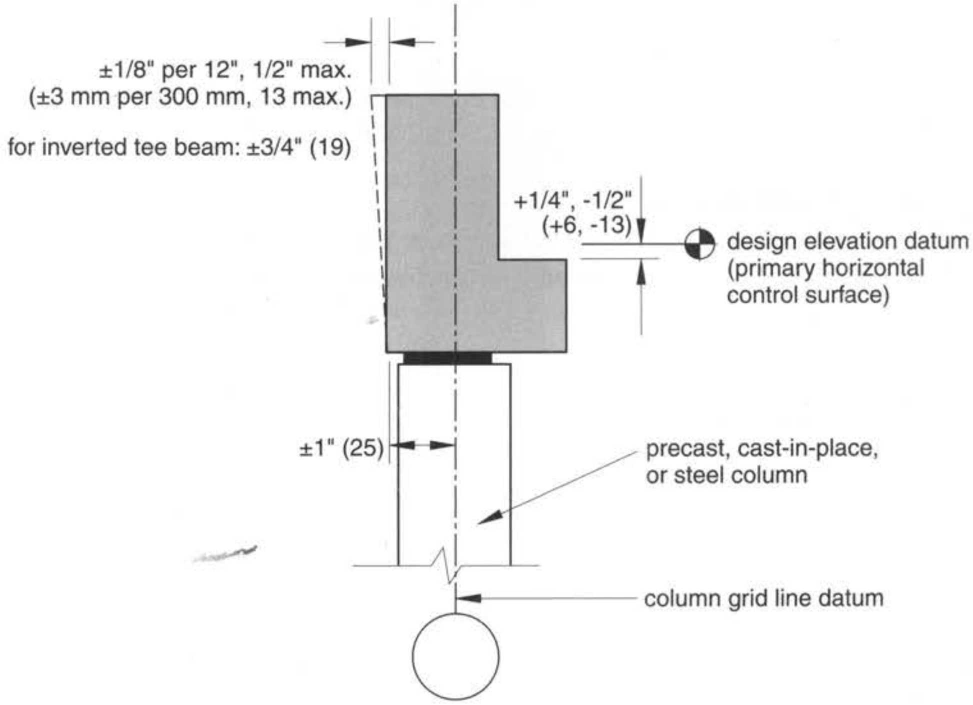
Related Sections

2–18 Precast Concrete Beams
2–21 Precast Columns
Chapter 13 Precast Concrete Systems

Figure 2–24 Precast beam and spandrel erection



(a) plan view



(b) section view

2–25 Precast Floor and Roof Member Erection

Description

The tolerances given in this section are recommended tolerances rather than strict standards for floor and roof members. They are reasonable variations that can be expected in most situations. However, because precast erection is subject to many variables and some situations are visually more critical than others, tolerances should be reviewed with the precast supplier before finalizing specifications. To minimize costs, the tolerances in this section can be increased where the members will be covered with other finish material or in structures where visual appearance is not critical.

The erection tolerances shown in this section must be coordinated with manufacturing tolerances and tolerances for other building systems to which the precast system is connected. The erection tolerances are based on the primary control surfaces, which are the surfaces that are controlled during erection. The erection tolerances are *not* additive to the product tolerances given in previous sections. However, erection tolerances are additive to the product tolerances for secondary control surfaces.

The erection tolerances shown in this section apply to precast elements attached to other precast elements, to cast-in-place concrete or masonry, and to steel members.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Tolerances for floor and roof members are shown in Figure 2-25. When a precast floor or roof member is placed on a steel beam, the 1-in. (25-mm) tolerance from the end of the member to the building grid still applies, but it is measured from the centerline of the steel support structure. When hollow-core slabs are used, the differential bottom elevation of exposed slabs is ±¼ in. (96 mm). In addition, the bearing length (in the direction of the floor or roof member span) is ±¾ in. (19 mm) and the bearing width is ±½ in. (13 mm).

Related Sections

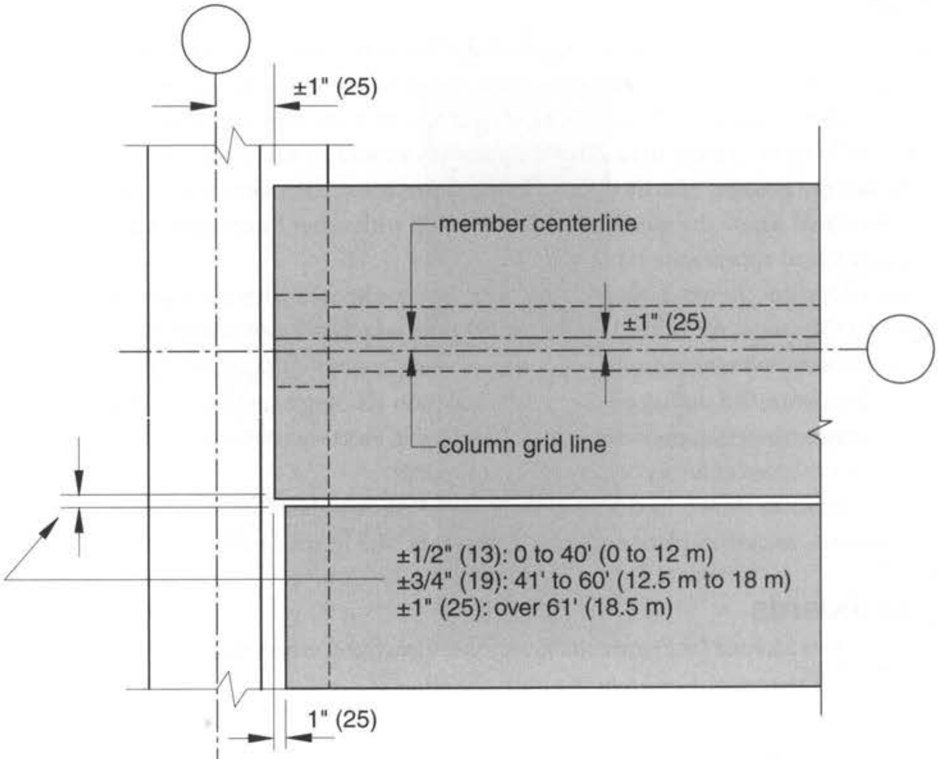
2–15 Hollow-Core Slabs
2–19 Prestressed Single Tees
2–20 Prestressed Double Tees
2–24 Precast Beam and Spandrel Erection
Chapter 13 Precast Concrete Systems

2–26 Precast Structural Wall Panel Erection

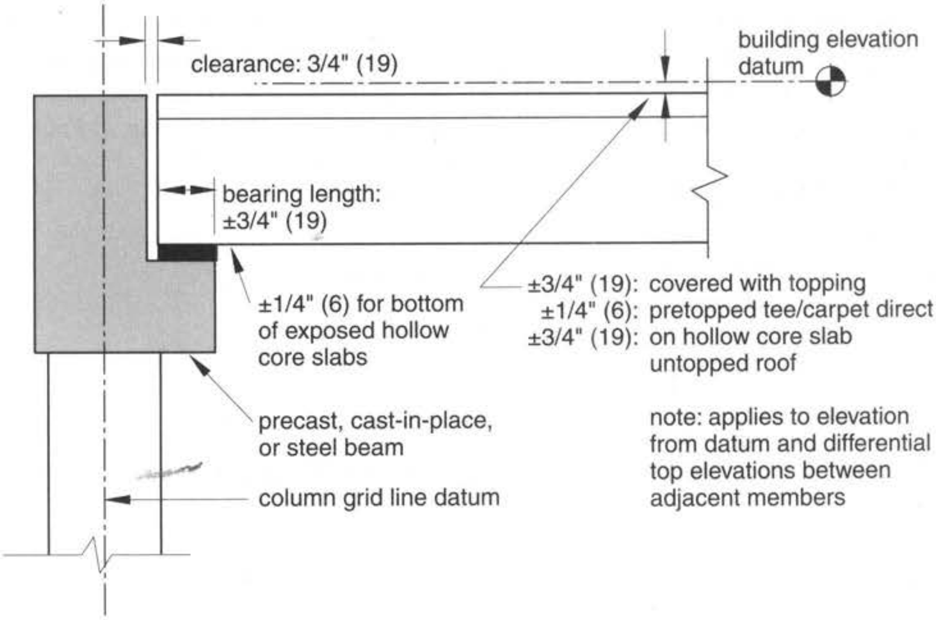
Description

The tolerances given in this section are recommended tolerances rather than strict standards. They are reasonable variations that can be expected in most situations. However, because precast erection is subject to many variables and some situations are visually more critical than others, tolerances should be reviewed with the precast supplier before finalizing specifications. To minimize costs, the tolerances in this section can be increased where the members will be covered with other finish material or in structures where visual appearance is not critical.

Figure 2–25 Precast floor and roof member erection



(a) plan view



(b) section view

The erection tolerances shown in this section must be coordinated with manufacturing tolerances and tolerances for other building systems to which the precast system is connected. The erection tolerances are based on the primary control surfaces, which are the surfaces that are controlled during erection. The erection tolerances are *not* additive to the product tolerances given in previous sections. However, erection tolerances are additive to the product tolerances for secondary control surfaces.

The erection tolerances shown in this section apply to precast elements attached to other precast elements, to cast-in-place concrete or masonry, and to steel members.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

Tolerances for the erection of precast structural wall panels are shown in Figure 2-26. When a precast panel is placed on a steel beam, the ½-in. (13-mm) tolerance still applies, but it is measured from the centerline of the steel support structure. Tolerances for the distance from the building elevation datum to the top of the panel are listed in Table 2-3. Note that the tolerances for the plan location and maximum plumb can increase ⅛ in. (3 mm) per story for buildings over 100 ft. (30 meters) high up to a maximum out-of-plumb of 2 in. (50 mm). Differential bowing between adjacent members of the same design is limited to ±½ in. (13 mm).

Related Sections

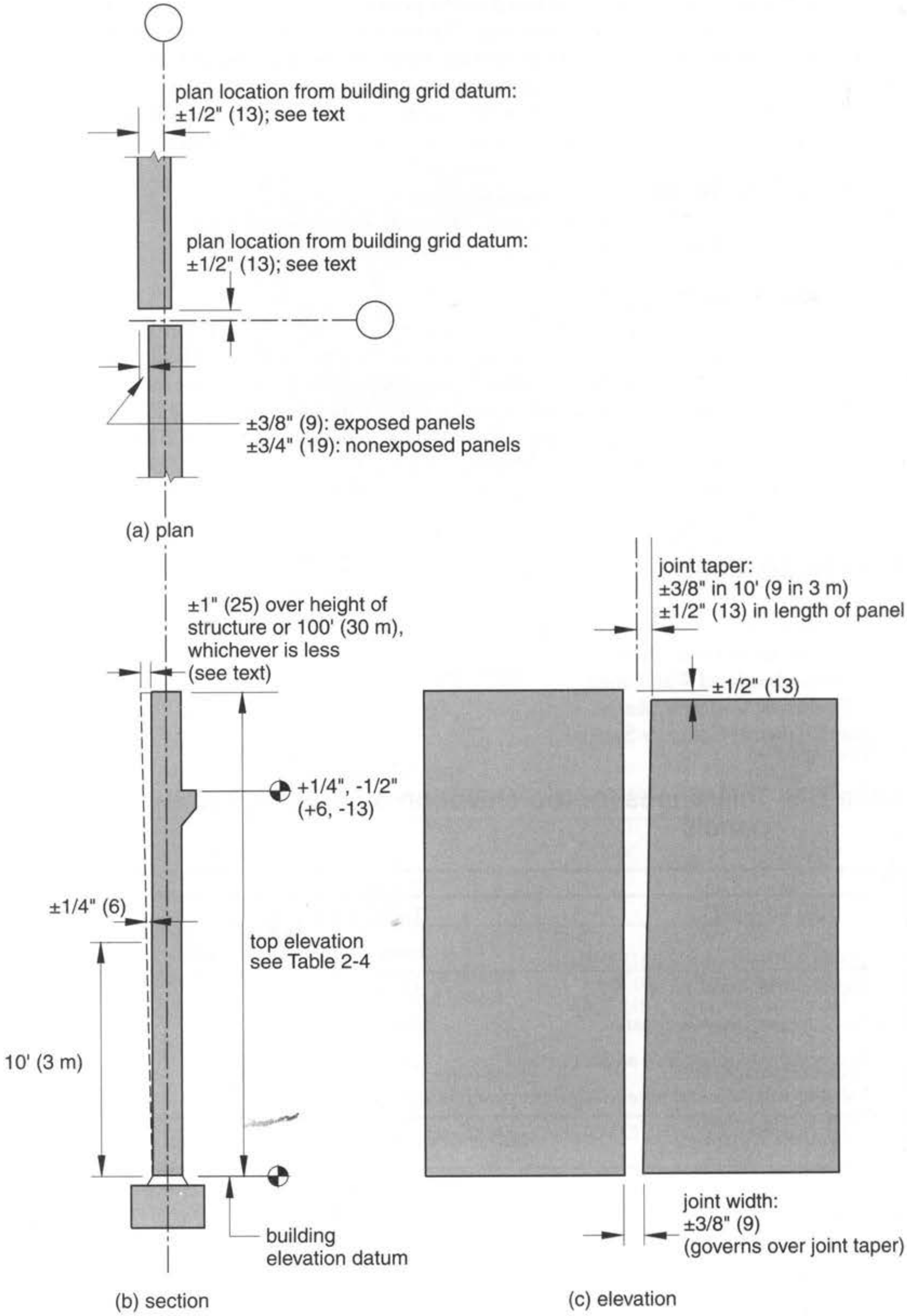
2–5 Footings
2–12 Architectural Precast Concrete Panels
2–13 Precast Ribbed Wall Panels
2–14 Precast Insulated Wall Panels
2–18 Prestressed Concrete Beams
Chapter 13 Precast Concrete Systems

Table 2-3 Tolerances for top elevation of structural wall panels

Type of panel	Tolerance, top elevation from nominal top elevation
Exposed individual panel	±½" (13 mm)
Nonexposed individual panel	±¾" (19 mm)
Exposed panel relative to adjacent panel	±½" (13 mm)
Nonexposed panel relative to adjacent panel	±¾"(19 mm)

Source: Compiled from MNL 135-00, Precast/Prestressed Concrete Institute

Figure 2–26 Precast structural wall panel erection



2-27 Precast Architectural Wall Panel Erection

Description

The tolerances given in this section are for precast panels where appearance is a primary concern. They are recommended tolerances rather than strict standards and include reasonable variations that can be expected in most situations. However, because precast erection is subject to many variables and some situations are visually more critical than others, tolerances should be reviewed with the precast supplier before finalizing specifications. To minimize costs, the tolerances in this section can be increased where the members will be covered with other finish material or in structures where visual appearance is not critical.

The erection tolerances shown in this section must be coordinated with manufacturing tolerances and tolerances for other building systems to which the precast system is connected. The erection tolerances are based on the primary control surfaces, which are the surfaces that are controlled during erection. The erection tolerances are *not* additive to the product tolerances given in previous sections. However, erection tolerances are additive to the product tolerances for secondary control surfaces.

The erection tolerances shown in this section apply to precast elements attached to other precast elements, to cast-in-place concrete or masonry, and to steel members.

Industry Standards

MNL 135-00, *Tolerance Manual for Precast and Prestressed Concrete Construction.* (Chicago: Precast/Prestressed Concrete Institute, 2000).

Allowable Tolerances

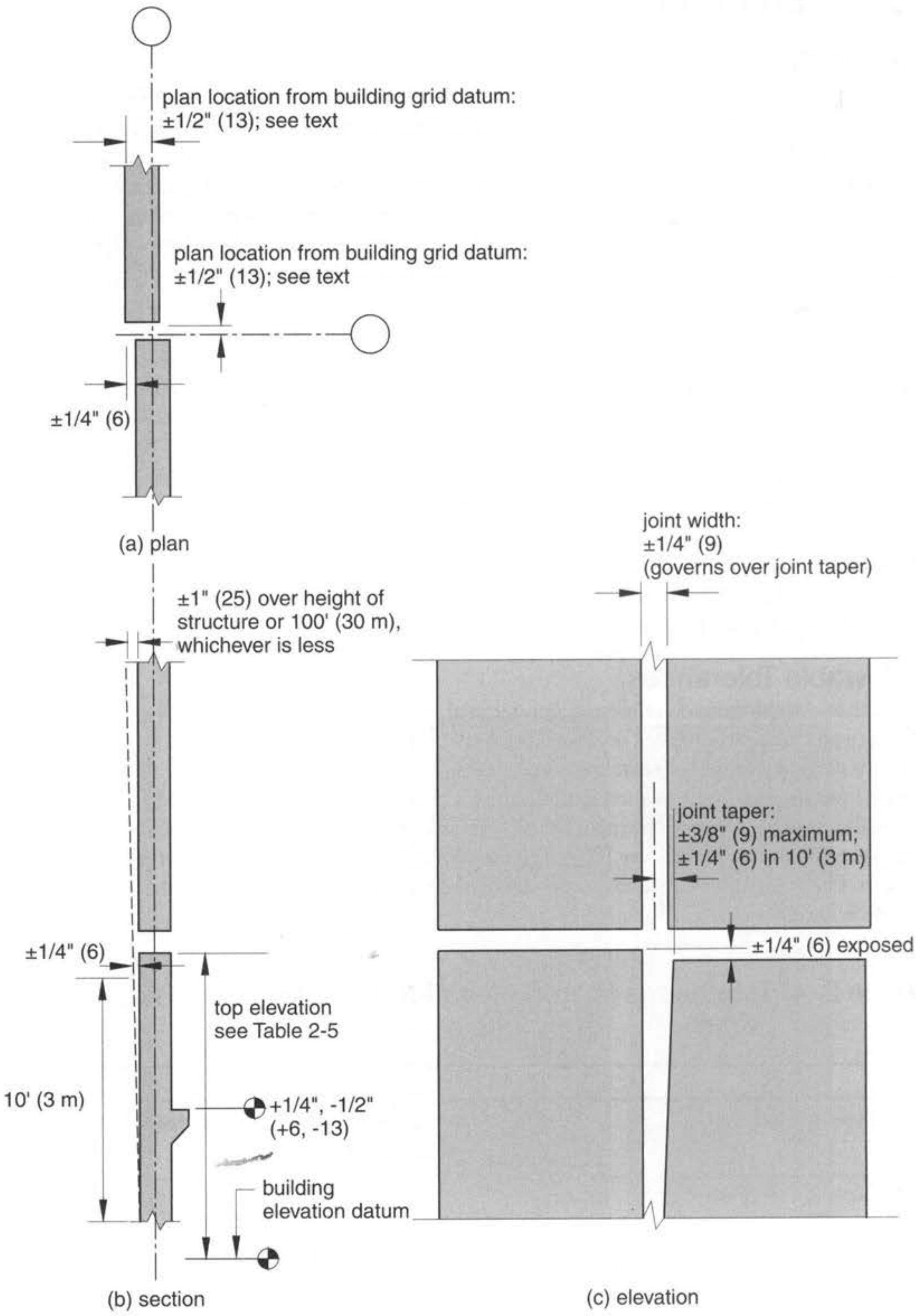
Tolerances for the erection of precast architectural wall panels are shown in Figure 2-27. When a precast panel is placed on a steel beam, the ½-in. (13-mm) tolerance still applies, but it is measured from the centerline of the steel support structure. Tolerances for the distance from the building elevation datum to the top of the panel are listed in Table 2-4. Note that the tolerances for the plan location and maximum plumb can increase ⅛ in. (3 mm) per story for buildings over 100 ft. (30 meters) high up to a maximum out-of-plumb of 2 in. (50 mm). Differential bowing or camber between adjacent members of the same design is limited to ±¼ in. (6 mm).

Table 2-4 Tolerances for top elevation of architectural wall panels

Type of panel	Tolerance, top elevation from nominal top elevation
Exposed individual panel	±¼" (6 mm)
Nonexposed individual panel	±½" (13 mm)
Exposed panel relative to adjacent panel	±¼" (6 mm)
Nonexposed panel relative to adjacent panel	±½" (13 mm)

Source: Compiled from MNL 135-00, Precast/Prestressed Concrete Institute

Figure 2–27 Precast architectural wall panel erection



Related Sections
2–5 Footings
2–12 Architectural Precast Concrete Panels
2–18 Prestressed Concrete Beams
Chapter 13 Precast Concrete Systems

2–28 Glass-Fiber-Reinforced Concrete Panel Erection

Description
Glass-fiber-reinforced concrete (GFRC) panels, described in Section 2-11, are normally attached to a stiffening assembly of metal studs. The stiffeners are then attached to the building structure. As long as sufficient clearance and adequate adjustable fasteners are provided, GFRC panels can be installed to fairly tight tolerances.

Industry Standards
MNL-128-01, *Recommended Practice for Glass Fiber Reinforced Concrete Panels*, 4th ed. (Chicago: Precast/Prestressed Concrete Institute, 2001).

Allowable Tolerances
Guideline tolerances for GFRC panels are shown in Figure 2-28. Because GFRC panels have some flexibility, some of the bowing and warpage can be compensated for during installation. It is important that tolerances for the structural frame are stated in the specifications and held during construction in order to achieve the GFRC tolerances shown here.

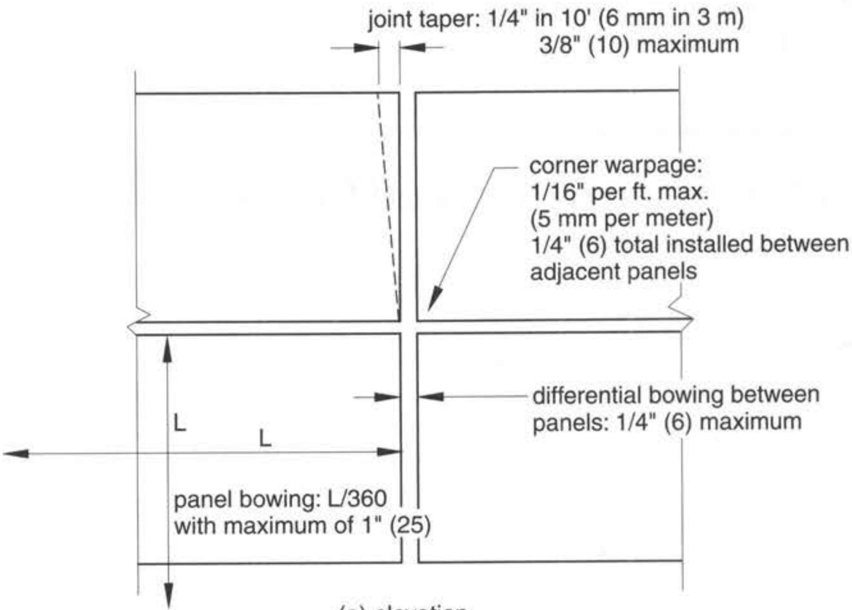
Clearances between the GFRC panels and the supporting structure are important and should be maintained. At least 1 in. (25 mm) should be maintained between a GFRC panel and steel fireproofing, but 1 ½ in. (38 mm) is preferred. If no fireproofing is used, 1 ½- to 2- in. (38- to 51-mm) clearance should be detailed in tall, irregular structures. For precast concrete, 1 ½-in. (38-mm) clearance is preferred with 1 in. (25 mm) as the minimum. A clearance of 2 in. (51 mm) between GFRC panels and cast-in-place concrete is preferred, with 1 ½ in. (38 mm) as the minimum. Clearance between columns and GFRC covers should be at least 2 in. (51 mm) with 3 in. (76 mm preferred).

Related Sections
2–11 Glass-Fiber-Reinforced Concrete Panels

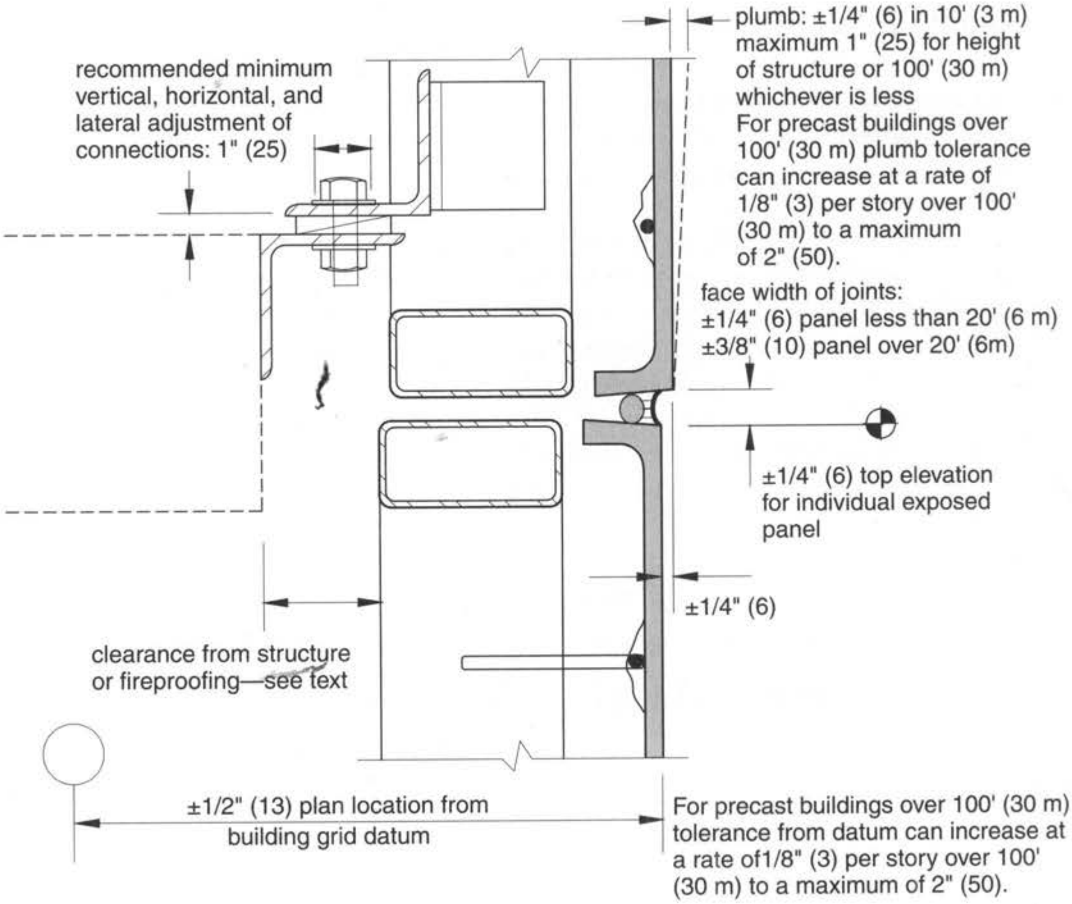
2–29 Autoclaved Aerated Concrete

Description
Autoclaved aerated concrete (AAC) is a precast, low-density, cementitious, manufactured building product made by mixing portland cement, lime, silica sand or recycled fly ash, water, and aluminum powder or paste and pouring the mixture into a mold. The reaction between the aluminum and concrete causes microscopic bubbles to form, expanding the concrete to about five times its original volume. The concrete is cut to size and form and steam-cured in a pressurized chamber.

Figure 2–28 Glass-fiber-reinforced concrete panel erection

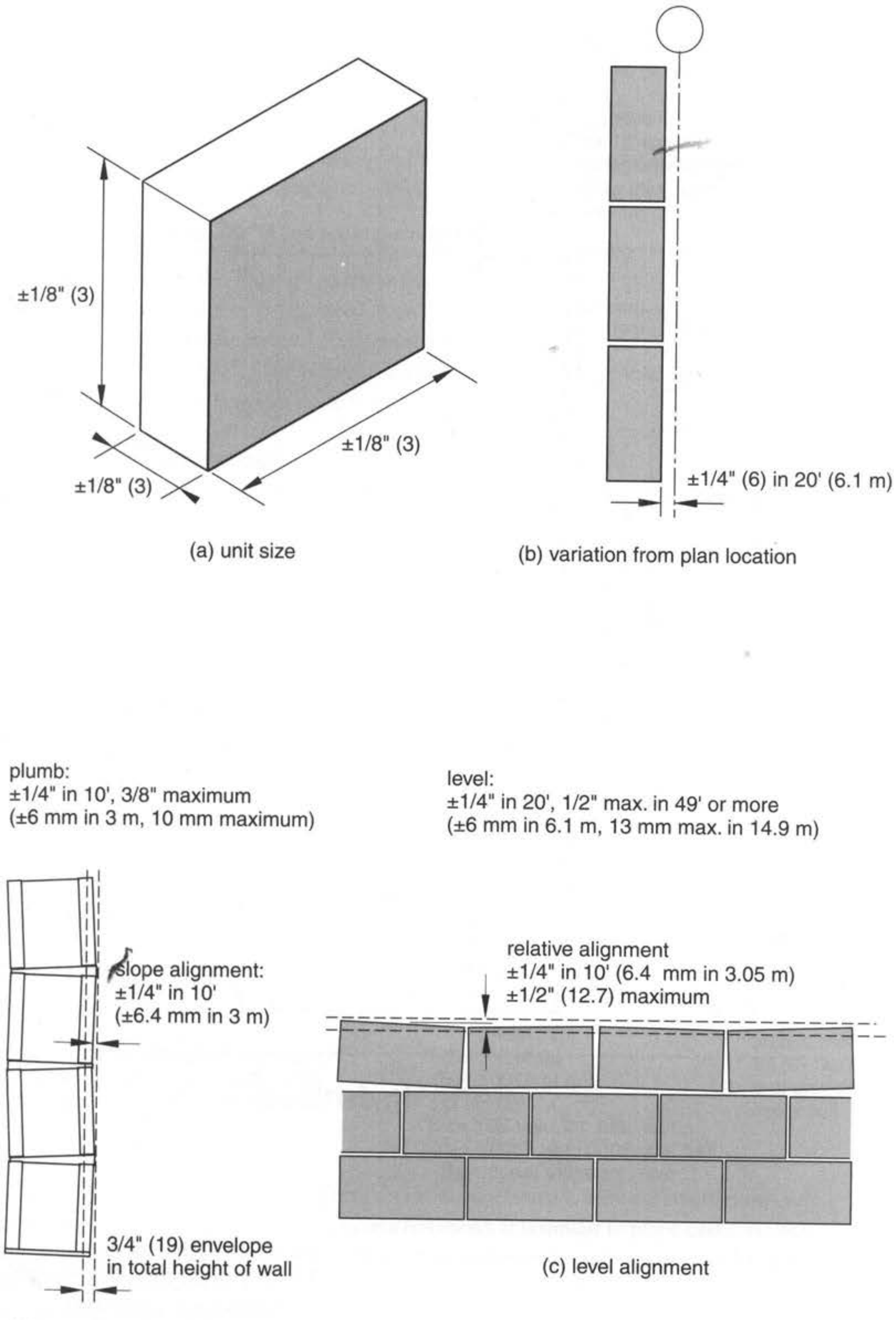


(a) elevation



(b) section

Figure 2–29 Autoclaved aerated concrete



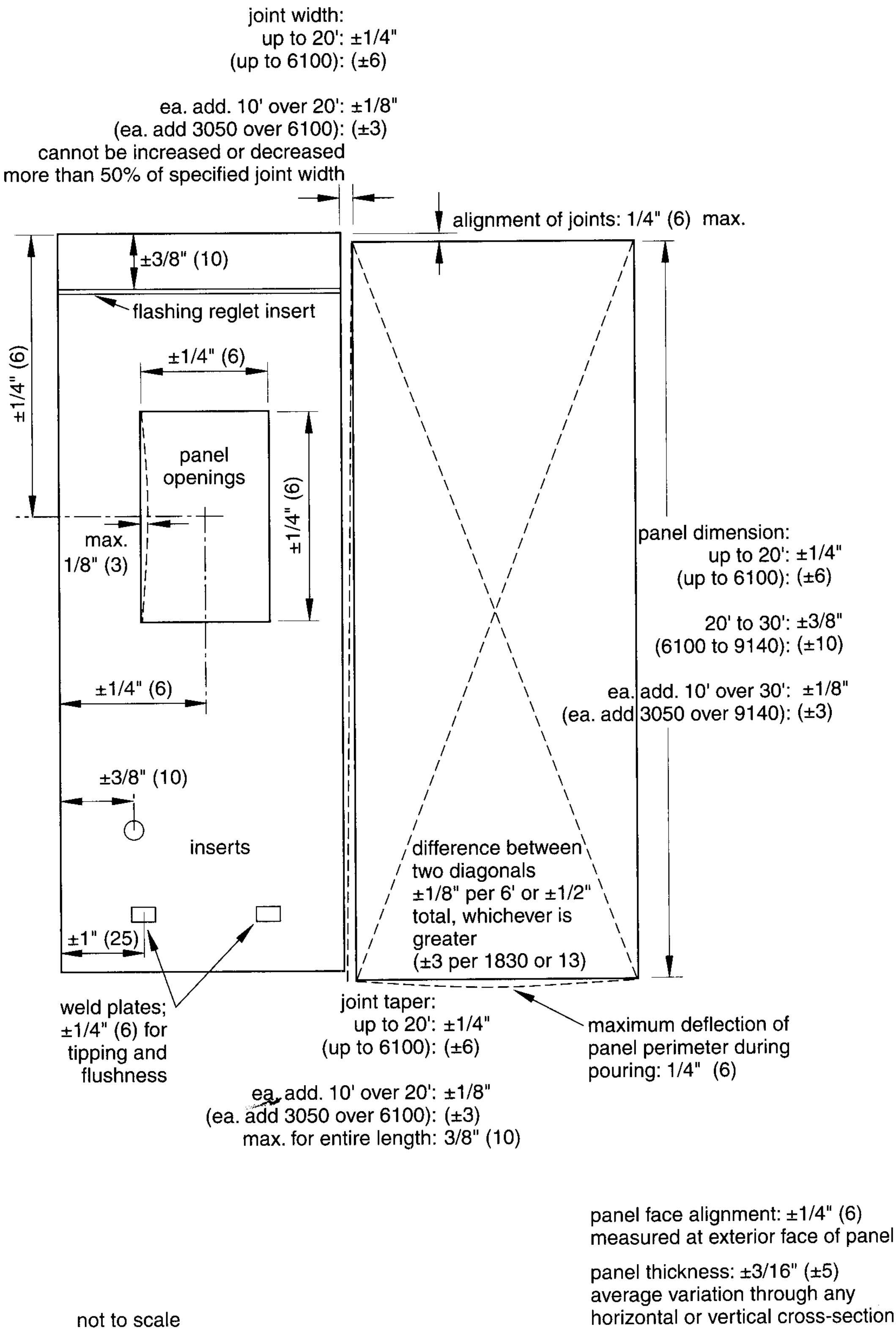
(a) unit size

(b) variation from plan location

(a) vertical alignment

(c) level alignment

Figure 2–30 Tilt-up concrete panels



The resultant product can be used in non-load-bearing and load-bearing applications and is lightweight and fire-resistant, and has good insulation properties. It is commonly formed into blocks and panels. Panels are available in thicknesses of 3 in. to 16 in. (76 mm to 403 mm), 24 in. (608 mm) wide, and up to 20 ft. (6.1 m) long. AAC can be cut with conventional saws and tools.

Industry Standards and Recommendations

ASTM C 1386-98, *Standard Specification for Precast Autoclaved Aerated Concrete (PAAC) Wall Construction Units* (Philadelphia, PA: American Society for Testing and Materials, 1998).

ASTM C 1555-03a, *Standard Practice for Autoclaved Aerated Masonry* (Philadelphia, PA: American Society for Testing and Materials, 2003).

04225 Guide Specification, Autoclaved Aerated Concrete Units. (Autoclaved Aerated Concrete Product Association, 2005. www.aacpa.org.

ACI 530.1-02/ASCE 6-02/TMS 602-02, *Specifications for Masonry Structures* (Farmington Hills, MI: American Concrete Institute, 2002).

Allowable Tolerances

ASTM C 1386 requires that unit dimensions of width, height, and length shall not differ by more than ⅛ in. (3 mm) from the specified dimensions. When field cutting is necessary, ASTM C 1555 requires the tolerances also be ±⅛ in. (3 mm). Tolerances for larger wall and roof planks should be verified with the individual manufacturer.

The guide specifications from the AACPA give three tolerances for laying up an AAC wall:

- Maximum variation from plumb: ¼ in. in 10 ft., 0 in.; not exceeding ⅜ in. in 20 ft., 0 in. (6 mm in 3 m; not exceeding 9 mm in 6.1 m)
- Maximum variation from level: ¼ in. in 20 ft., 0 in.; not exceeding ½ in. in 49 ft., 0 in. or more (6 mm in 6.1 m; not exceeding 13 mm in 15 m)
- Maximum variation in linear building line from location indicated: ¼ in. in 20 ft., 0 in. (6 mm in 6.1 m)

ASTM C 1555 requires that walls be laid according to the *Specification for Masonry Structures* (Part 3—Execution), ACI 530.1, which requires a slightly different level alignment, as shown in Figure 2-29(c).

Related Sections

4–3 Concrete Unit Masonry Construction

2–30 Tilt-Up Concrete Panels

Description

Tilt-up construction involves casting concrete wall panels in a horizontal position on-site and tilting them into place after the concrete has cured. It is similar to plant-cast concrete except that the panels are cast in the field. Casting and erection tolerances must be coordinated with tolerances for the structural frame and other building components, such as windows and doors. Joints must be designed to allow for the given tolerances as well as expected building movement.

Industry Standards

The Tilt-Up Concrete Association's Guideline Specifications (Mount Vernon, IA: The Tilt-Up Concrete Association, 2002).

Allowable Tolerances

The tolerances shown in Figure 2-30 have been developed by the Tilt-Up Concrete Association (TCA) and are given in Section 1.6 of the *TCA Guildeline Specifications*. The dimensions of the finished panels, at the time of erection in the structure, must conform to these tolerances unless otherwise specified or approved by the project architect or engineer. The tolerances for joint width, joint taper, and panel alignment must also conform to these tolerances unless otherwise specified or approved by the project architect or engineer. Refer to the *Guideline Specifications* for acceptable surface defects for various grades of site-cast panels.

Related Sections

2–12 Architectural Precast Concrete Panels
Chapter 13 Precast Concrete Systems

Chapter 3

Steel

3–1 Mill Tolerances for W and HP Shapes

Description

Figure 3-1 illustrates some of the allowable variations in cross-sectional size and straightness of standard rolled W and HP shapes, commonly used for columns. A *W shape* is a doubly symmetric, wide-flange shape used as a beam or column whose inside flange surfaces are substantially parallel. An *HP shape* is a wide-flange shape generally used as a bearing pile whose flanges and webs are of the same nominal thickness and whose depth and width are essentially the same. The tolerances shown are those that most affect architectural detailing and coordination with other materials. Tolerances for web thickness and web depth are not included. Refer to ASTM A6/A6M for a complete listing of all tolerances for various steel shapes in both U.S. customary units and SI units.

Industry Standards

AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

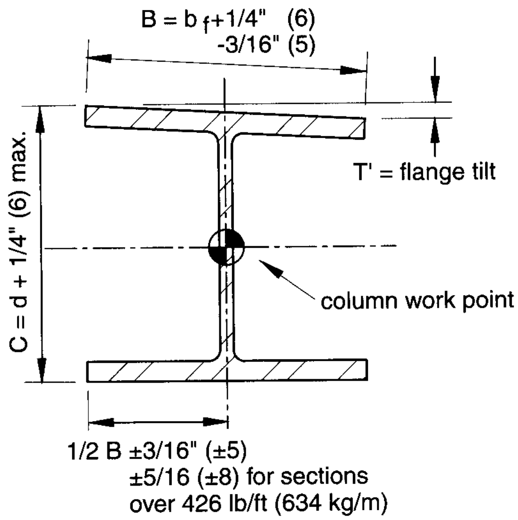
Allowable Tolerances

In addition to the tolerances shown in the drawing, Table 3-1 gives the allowable variations in camber, sweep, and length. Camber is the deviation in straightness parallel to the web. Sweep is the deviation in straightness parallel to the flanges.

When beams are specified with camber AISC (American Institute of Steel Construction) 303 fabrication, tolerances are slightly different than those required by ASTM A6/A6M. When beams are received from the mill by the fabricator with 75 percent of the specified camber, no further cambering is required. Otherwise, the maximum variation in camber depends on the length of the member. For beams equal to or less than 50 ft. (15 m), the maximum variation is -0, +½ in. (13 mm). For beams longer than 50 ft. (15 m), the maximum variation is –0, +½ in. (13 mm), plus ⅛ in. (3 mm) for each additional 10 ft. (3 m) or fraction thereof.

AISC 303 requires that inspection of camber be done in the fabricator's shop in the unstressed condition. Camber cannot be inspected in the field because of various factors, including the release of stresses over time, the effects of the dead weight of the member, the restraint caused by end conditions in the erected state, and the effects of additional dead load.

Figure 3–1 Mill tolerances for W and HP shapes

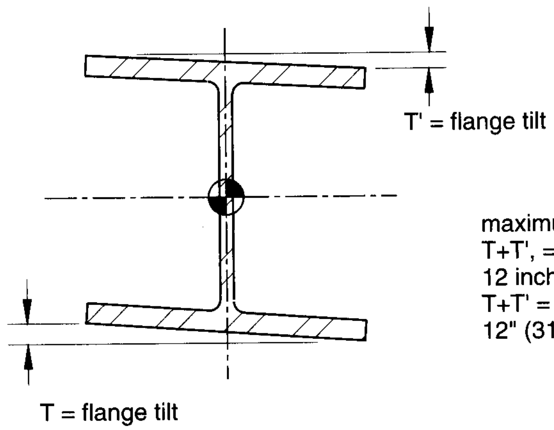


b_f = flange width as published in the *Manual of Steel Construction*

d = flange depth as published in the *Manual of Steel Construction*

B = flange width in inches (mm)

C = maximum depth at any cross section



maximum flanges out of square, T+T', = 1/4" (6) for sections 12 inches (310) deep and under and T+T' = 5/16" (8) for sections over 12" (310) deep.

Table 3–1 Permissible variation in camber and sweep for W and HP shapes

Sizes	*Length*	Permissible variation, in. (mm) *Camber*	*Sweep*
Flange width less than 6 in. (150 mm)	Any	$\frac{1}{8}" \times \frac{L, ft.}{5}$ (2 mm x L, m)	$\frac{1}{8}" \times \frac{L, ft.}{5}$ (2 mm x L, m)
Flange width equal to or greater than 6 in. (150 mm)	Any	$\frac{1}{8}" \times \frac{L, ft.}{10}$ (1 mm x L, m)	
Certain sections used as columns[a]	45 ft. (14 m) and under	$\frac{1}{8}" \times \frac{L, ft.}{10}$ with ⅜ in. max (1 mm x L, m with 10 mm max.)	
	Over 45 ft. (14 m)	$\frac{3}{8}$ in. + $\left(\frac{1}{8}" \times \frac{L, ft. - 45}{10}\right)$ (10 mm + [1 mm x (L, m - 14m)])	

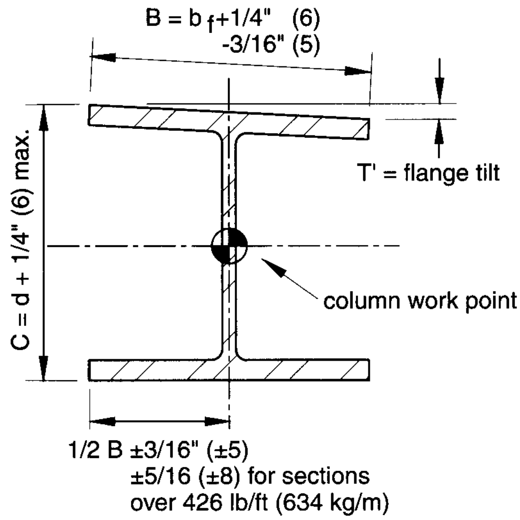
[a] *Sections include W 8 x 31 and heavier, W 10 x 49 and heavier, W 12 x 65 and heavier, W 14 x 90 and heavier. (200 mm deep, 46.1 kg/m and heavier; 250 mm deep, 73 kg/m and heavier; 310 mm deep, 97 kg/m and heavier; 360 mm deep, 116 kg/m and heavier)*

For other sections specified in the order for use as columns, the permitted variation is subject to negotiation with the manufacturer.

Related Sections

3–2 Mill Tolerances for Length of W and HP Shapes
3–3 Mill Tolerances for S and M Shapes and Channels
3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
14–1 Accumulated Column Tolerances

Figure 3–2 Mill tolerances for length of W and HP shapes

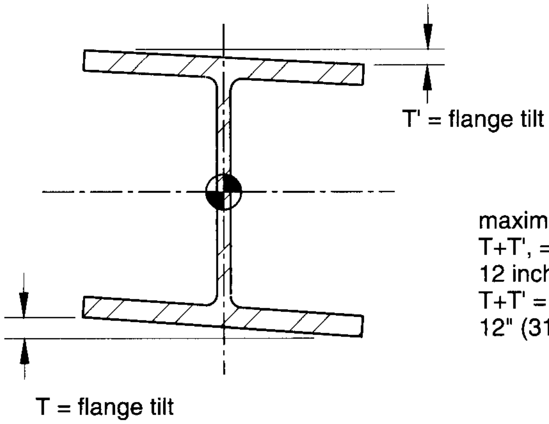


b_f = flange width as published in the *Manual of Steel Construction*

d = flange depth as published in the *Manual of Steel Construction*

B = flange width in inches (mm)

C = maximum depth at any cross section



maximum flanges out of square, T+T', = 1/4" (6) for sections 12 inches (310) deep and under and T+T' = 5/16" (8) for sections over 12" (310) deep.

3–2 Mill Tolerances for Length of W and HP Shapes

Description

These tolerances are a continuation of Section 3-1 and include allowable variations in length and end squareness for both unmilled and milled sections. Milled shapes are commonly used for columns.

Industry Standards

AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

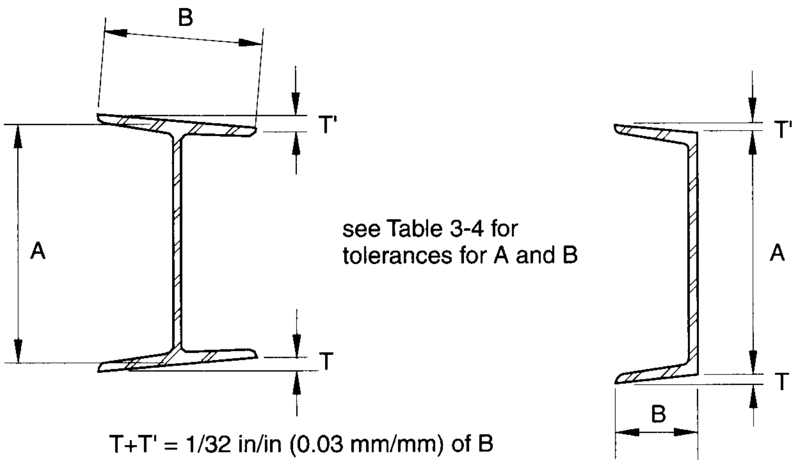
Allowable tolerances are shown in Tables 3-2 and 3-3, as illustrated in Figure 3-2. For W and HP shapes used for bearing piles, the permitted length tolerances are +5 in. (125) and –0 in. Note that AISC 303 fabrication tolerances limit fabricated length variation to $\pm\frac{1}{16}$ in. (2 mm) for members equal to or less than 30 ft. (9,000 mm) and to ±⅛ in. (3 mm) for members greater than 30 ft. (9,000 mm). For members that have both ends finished for contact bearing, the tolerance of $\frac{1}{32}$ in. (1 mm) is the same as in ASTM A6/A6M.

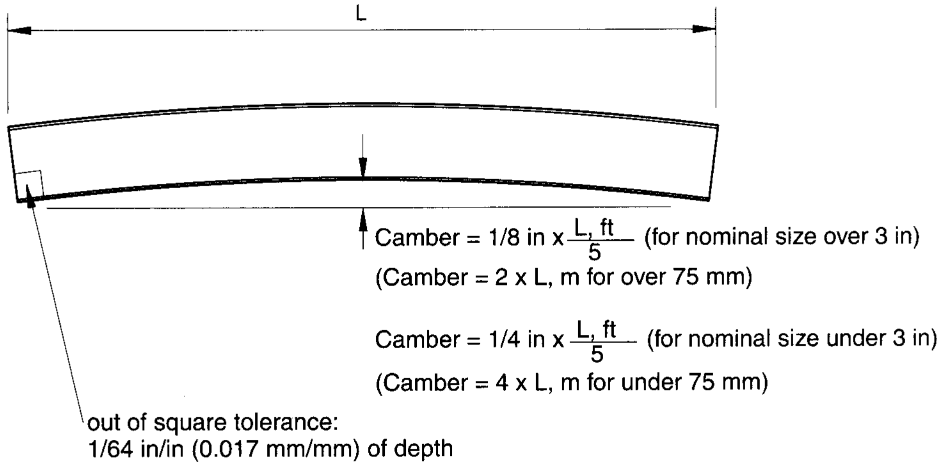
Table 3–2 Permissible variation in length for W and HP shapes

	Permissible variation from specified length, in. (mm)			
	30 ft. (9 m) and under		***Over 30 ft. (9 m)***	
W shapes	**Over**	**Under**	**Over**	**Under**
Beams 24 in. (610) and under	⅜ (10)	⅜ (10)	⅜ (10 mm) plus $\frac{1}{16}$ (1 mm) for each additional 5 ft. (1 m) or fraction thereof	⅜ (10)
Beams over 24 in. (610) and all columns	½ (13)	½ (13)	½ (13 mm) plus $\frac{1}{16}$ (1) for each additional 5 ft. (1 m) or fraction thereof	½ (13)

Source: ASTM A6/A6M. *Copyright ASTM International. Reprinted with permission.*

Figure 3–3 Mill Tolerances for S and M shapes and channels





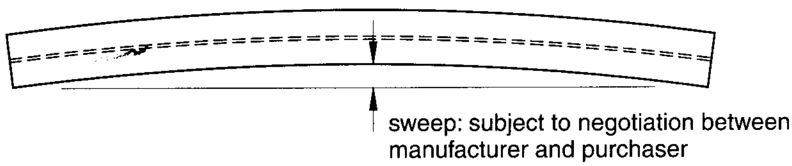


Table 3–3 Permissible variations for length and squareness for milled shapes

	Milled both ends			Milled one end		
	Length, in. (mm)		*End out of square, max., in. (mm)*	*Length, in. (mm)*		*End out of square, max., in. (mm)*
	Over	*Under*		*Over*	*Under*	
Depth: 6 to 36 in. (150 to 920 mm) Length: 6 to 70 ft. (2 to 21 m)	1/32 (1)	1/32 (1)		1/32 (1)	1/4 (6) 1/4 (6)	1/32 (1)

Length variation and out-of-square variation are additive.
Length is measured along centerline of web.
Source: ASTM A6/A6M. Copyright ASTM International. Reprinted with permission.

Related Sections
3–1 Mill Tolerances for W and HP Shapes
3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
14–1 Accumulated Column Tolerances
14–2 Accumulated Steel Frame Tolerances

3–3 Mill Tolerances for S and M Shapes and Channels

Description
Figure 3-3 illustrate some of the allowable variations in cross-sectional size and straightness of standard rolled S, M, and channel shapes. The tolerances shown are those that most affect architectural detailing and coordination with other materials. Tolerances for web thickness and web depth are not included.

Industry Standards
ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling*. (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances
In addition to the tolerances shown in the drawings, Tables 3-4 and 3-5 give the allowable variations in cross-sectional sizes and length.

Table 3–4 Permissible variation in cross sectional shapes for S, M, C, and MC shapes

Shape	Nominal size, in. (mm)	A, depth, in. (mm)		B, flange width, in. (mm)	
		Over	Under	Over	Under
S and M	3 to 7, inclusive (75 to 180)	3/32 (2)	1/16 (2)	1/8 (3)	1/8 (3)
	Over 7 to 14 inclusive (180 to 360)	1/8 (3)	3/32 (2)	5/32 (4)	5/32 (4)
	Over 14 to 24, inclusive (360 to 610)	3/16 (5)	1/8 (3)	3/16 (5)	3/16 (5)
C and MC	Over 1½ to 3, exclusive (40 to 75)	1/16 (2)	1/16 (2)	1/16 (2)	1/16 (2)
	3 to 7, inclusive (75 to 180)	3/32 (3)	1/16 (2)	1/8 (3)	1/8 (3)
	Over 7 to 14, inclusive (180 to 360)	1/8 (3)	3/32 (3)	1/8 (3)	5/32 (4)
	Over 14 (360)	3/16 (5)	1/8 (3)	1/8 (3)	3/16 (5)

Source: ASTM A6/A6M. Copyright ASTM International. Reprinted with permission.

Table 3–5 Permissible variation in length for S, M, and channel shapes

	Allowable variation from specified length, in. (mm)											
	Over 10 to 20 ft (Over 3 to 6 m) inclusive		Over 20 to 30 ft. (Over 6 m to 9 m) inclusive		Over 30 to 40 ft. (9 to 12 m) inclusive		Over 40 to 50 ft. (12 to 15 m) inclusive		Over 50 to 65 ft. (15 to 20 m) inclusive		Over 65 ft. (20 m)	
	Over	*Under*	*Over*	*Under*	*Over*	*Under*	*Over*	*Under*	*Over*	*Under*	*Over*	*Under*
S, M, and channels	1 1/2 (38)	0	1 3/4 (45)	0	2 1/4 (57)	0	2 3/4 (70)	0	2 3/4 (70)	0	No requirements	

Note: tolerances apply to sections with greatest cross sectional dimension 3" (75 mm) and over. Refer to ASTM A6/A6M for other tolerances.
Source: ASTM A6/A6M. Copyright ASTM International. Reprinted with permission.

Related Sections

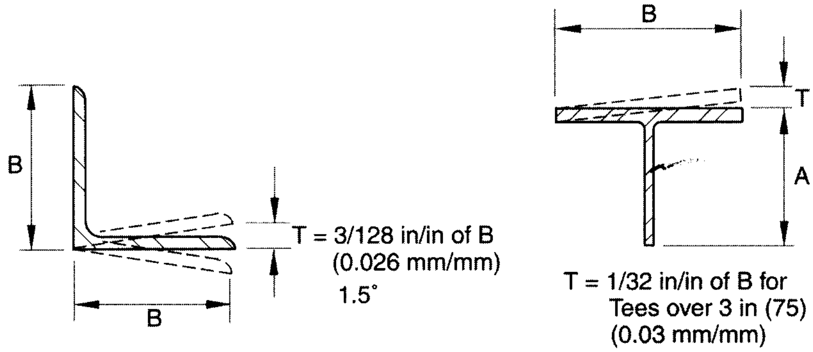
3–7 Location of Exterior Steel Columns in Plan
14–1 Accumulated Column Tolerances
14–2 Accumulated Steel Frame Tolerances

3–4 Mill Tolerances for Structural Angles and Tees

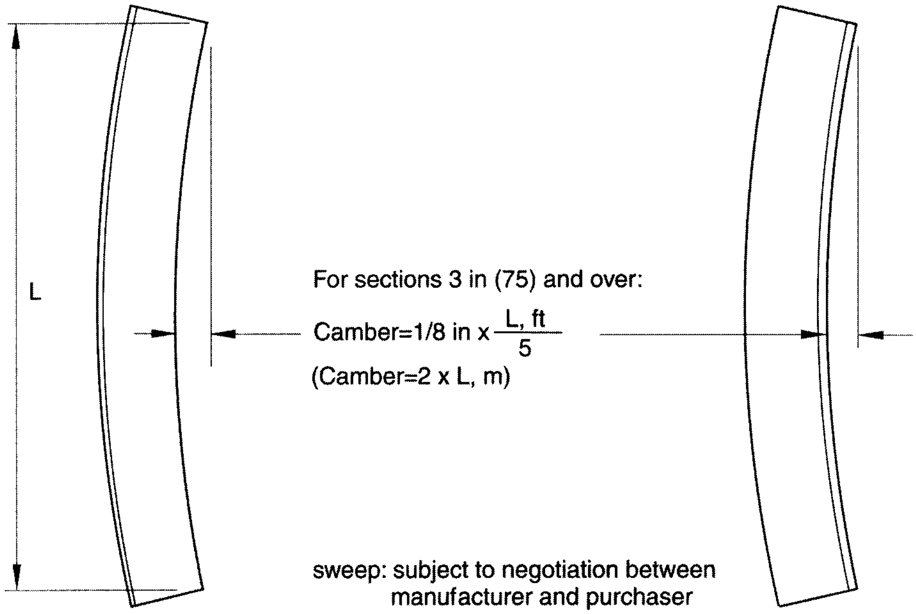
Description

This section includes information for rolled tees and structural-size angles. There are additional tolerances for bar-size angles, which include those with legs less than 3 in. (75 mm). Refer to ASTM A6/A6M for information on these smaller angles and for tee sections.

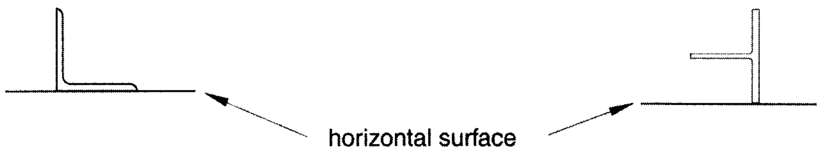
Figure 3–4 Mill tolerances for structural angles and tees



(a) cross-sectional tolerances



(b) sweep and camber tolerances



(c) position for measuring camber

Table 3–6 Permissible variation in sizes for angles and tees

Nominal size[1], in. (mm)	Variation in depth of tee, A, in. (mm)		Variation in length of angle leg, or width of tee, B, in. (mm)	
	Over, A	Under, A	Over, B	Under, B
Angles				
Over 2 to 3, exclusive (50 to 75)	—	—	1/16 (2)	1/16 (2)
3 to 4, inclusive (75 to 100 incl.)	—	—	1/8 (3)	3/32 (2)
Over 4 to 6, inclusive (Over 100 to 150)	—	—	1/8 (3)	1/8 (3)
Over 6 (Over 150)	—	—	3/16 (5)	1/8 (3)
Tees				
1 1/4 (30) and under	3/64 (1)	3/64 (1)	3/64 (1)	3/64 (1)
Over 1 1/4 to 2, inclusive (30 to 50)	1/16 (2)	1/16 (2)	1/16 (2)	1/16 (2)
Over 2 to 3, exclusive (50 to 75)	3/32 (2)	3/32 (2)	3/32 (2)	3/32 (2)
3 to 5, inclusive. (75 to 125)	3/32 (2)	1/16 (2)	1/8 (3)	1/8 (3)
Over 5 to 7, inclusive (125 to 180)	3/32 (2)	1/16 (2)	1/8 (3)	1/8 (3)

[1] *For angles with unequal legs the longer leg determines the classification.*
Source: ASTM A6/A6M. Copyright ASTM International. Reprinted with permission.

Table 3–7 Permissible variation in length for angles and tees

Nominal. size, in. (mm)	Variation from specified length, in. (mm)							
	5 to 10 ft. excl. (1.5 to 3 m)		10 to 20 ft. excl. (3 to 6 m)		20 to 30 ft. incl. (6 to 9 m)		Over 30 to 40 ft. incl. (9 to 12 m)	
	Over	*Under*	*Over*	*Under*	*Over*	*Under*	*Over*	*Under*
Under 3 (75)	5/8 (16)	0	1 (25)	0	1 1/2 (38)	0	2 (51)	0
3 (75) and over	1 (25)	0	1 1/2 (38)	0	1 3/4 (45)	0	2 1/4 (57)	0

Source: ASTM A6/A6M. Copyright ASTM International. Reprinted with permission.

Industry Standards

ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

Allowable variations in angle and tee sizes are shown in Table 3-6, as illustrated in Figure 3-4. Length tolerances for sizes up to 40 ft. (12.2 m) are shown in Table 3-7. Ends-out-of-square tolerance for angles is 3/128 in. (0.026 mm) per in. of leg length (1½°).

3–5 Mill Tolerances for Pipe and Tubing

Description

This section includes information for structural pipe and tubing that are commonly used for columns in residential and light commercial construction. In most cases, the allowable mill tolerances are small enough that problems with architectural detailing are not encountered. The relatively large mill tolerances for length are adjusted at the fabricating plant to more precise measurements if necessary.

Industry Standards

ASTM A500, *Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes* (West Conshohocken, PA: American Society for Testing and Materials, 2003).

ASTM A618/A618M, *Standard Specification for Hot-formed Welded and Seamless High-Strength Low-Alloy Structural Tubing* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

Allowable Tolerances

In addition to the tolerances shown in Figure 3-5, allowable tolerances in length for both round and rectangular tubing are shown in Table 3-8.

The dimensional tolerances, A, for square and rectangular tubing vary with the largest outside dimension but never exceed 1 percent for sections over 5 ½ in. (139.7 mm). Because this is only about 1⁄16 in. (1.6 mm) for a 6-in. section, it seldom presents a problem for architectural detailing.

Table 3–8 Length tolerances for pipe and tubing

	22 ft. (6.7 m) and under		Over 22 ft. (6.7 m)	
	Over	*Under*	*Over*	*Under*
Length tolerance for specified lengths, in. (mm)	1/2 (12.7)	1/4 (6.4)	3/4 (19.0)	1/4 (6.4)

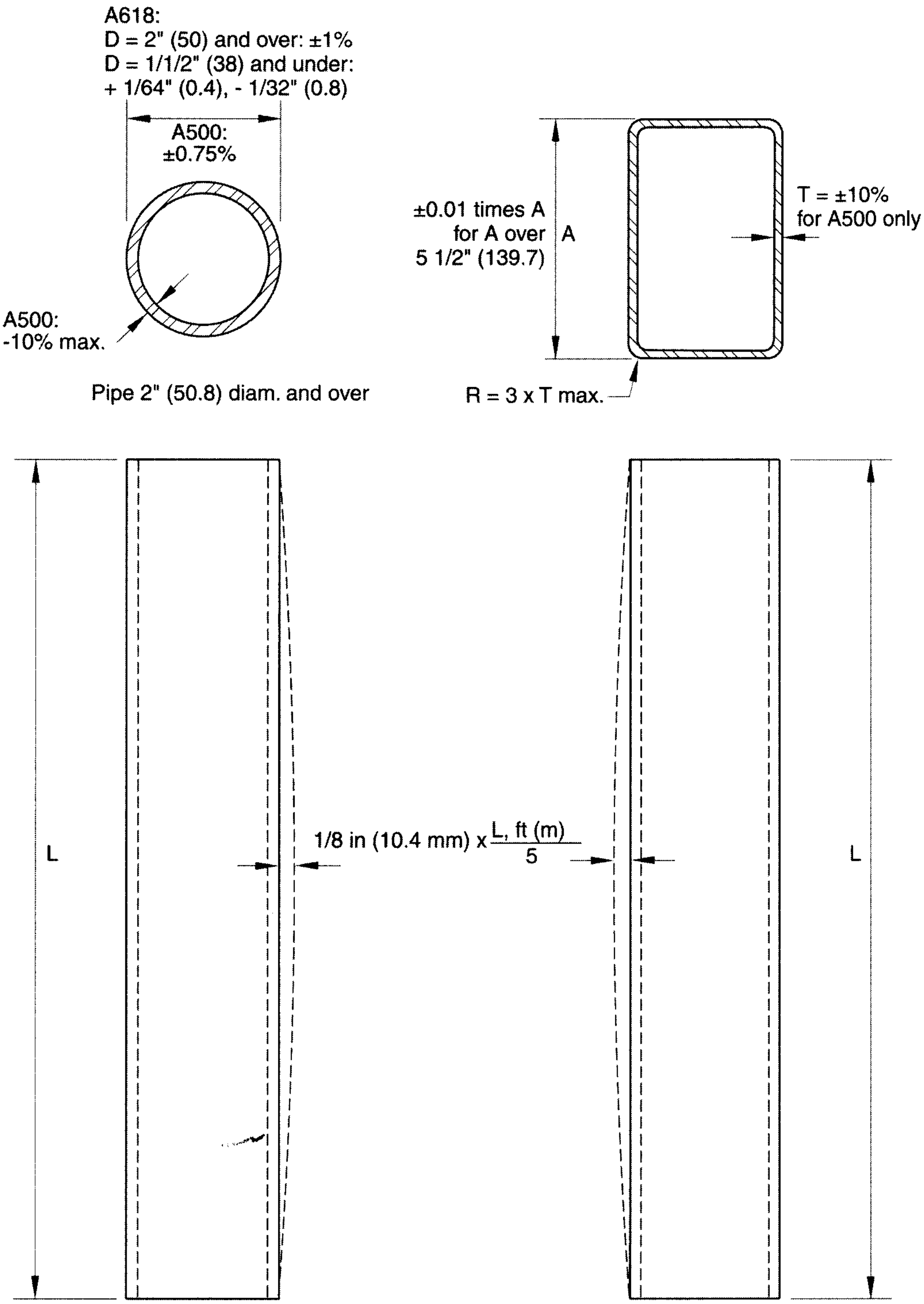
Source: ASTM A500. Copyright ASTM International. Reprinted with permission.

Table 3–9 Twist tolerances for square and rectangular tubing

Specified dimension of the longest side, in. (mm)	Maximum twist in the first 3 ft. (1 m) and in each additional 3 ft.
1 1/2 (38.1) and under	0.050 in. (1.39)
Over 1 1/2 (38.1) to 2 1/2 (63.5), incl.	0.062 in. (1.72)
Over 2 1/2 (63.5) to 4 (101.6), incl.	0.075 in. (2.09)
Over 4 (101.6) to 6 (152.4), incl.	0.087 in. (2.42)
Over 6 (152.4) to 8 (203.2), incl.	0.100 in. (2.78)
Over 8 (203.2)	0.112 in. (3.11)

Source: ASTM A500. Copyright ASTM International. Reprinted with permission.

Figure 3–5 Mill tolerances for pipe and tubing



Twist tolerances for square and rectangular tubing are measured by placing one end of the section on a flat surface and measuring the height that either corner, at the opposite end of the section, extends above the surface. These tolerances are summarized in Table 3-9.

Related Sections

3–7 Exterior Steel Columns in Plan

3–6 Steel Column Erection Tolerances

Description

Figure 3-6 illustrates some of the erection tolerances permitted by the AISC for the plumbness of columns and attached spandrel beams. Along with the mill tolerances and plan tolerances shown in Sections 3-1, 3-2, 3-7, and 3-8, this diagram permits realistic detailing of the attachment of other materials, such as exterior cladding, to a steel frame. However, AISC 303 states that the accumulated mill and fabrication tolerances cannot cause erection tolerances to be exceeded. Some of the methods by which accumulated tolerances can be accommodated are shown in Chapter 14.

Figure 3-6 shows the permissible envelope within which the working points of columns can fall. When misalignment of beams is caused by an acceptable variation in column alignment, the beams are considered acceptable as well. The *working point of a column* is the actual center of the column at each end of the column as shipped. The *working point of a beam* is the actual centerline of the top flange at each end. The member *working line* is a straight line that connects the member working points.

Industry Standards

AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

Allowable Tolerances

A column is considered plumb if the deviation of the working line of the column from true plumb does not exceed 1:500. However, for individual exterior columns, AISC standard practices limit the total variation to 1 in. (25 mm) toward the building line and 2 in. (50 mm) away from the building line up to the twentieth floor and a maximum deviation of 1/16 in. (2 mm) per floor above the twentieth floor up to a maximum of 2 in. (50 mm) toward and 3 in. (75 mm) away from the building line.

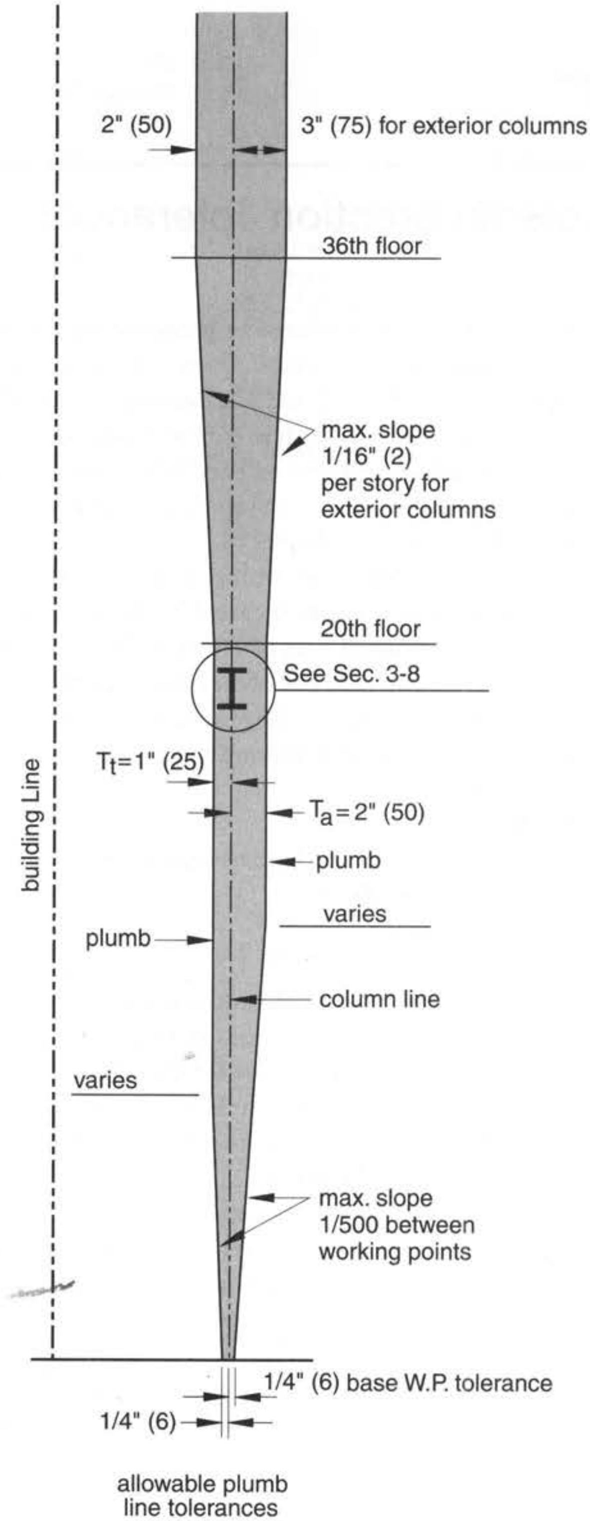
Although tolerances for anchor bolt placement are not the responsibility of the fabricator or the erector, the AISC code requires that the center-to-center dimension between adjacent anchor bolt groups and from the established column line not vary by more than 1/4 in. (6 mm). The center-to-center distance between any two bolts within an anchor bolt group cannot vary by more than 1/8 in. (3 mm).

For members with both ends finished for contact bearing, a fabrication variation of no more than 1/32 in. (1 mm) in the overall length of columns is permitted.

Related Sections

2–5 Footings and Anchor Bolts
3–1 Mill Tolerances for W and HP Shapes
3–2 Mill Tolerances for Length of W and HP Shapes

Figure 3–6 Steel column erection tolerances



3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
3–10 Elevator Shaft Tolerances
Chapter 14, Steel Frame Systems

3–7 Location of Exterior Steel Columns in Plan

Description

In addition to individual column tolerances for plumb, a row of columns must fall within specified limits. This determines the alignment of the total length of a building and the alignment of individual beams between columns. Figure 3-7 shows the tolerances for this alignment as well as permissible alignment for members with field splices.

Industry Standards

AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

Allowable Tolerances

The working points at the tops of exterior columns in a single-tier building or the working points of exterior columns at any splice level for multitier buildings must fall within a horizontal envelope parallel to the building line. This is shown diagrammatically in Figure 3-7(a). For each column, the working points must also fall within the envelope shown in Figure 3-6. This horizontal envelope is 1½ in. (38 mm) wide for buildings up to 300 ft (91 m) long and is increased ½ in. (13 mm) for each 100 ft (30 m) but cannot exceed 3 in. (75 mm).

The horizontal location of this 1½-in. (38-mm) envelope does not necessarily have to fall directly above or below the adjacent envelope but must be within the allowable 1:500 tolerance in plumbness for columns, as shown in Figure 3-6.

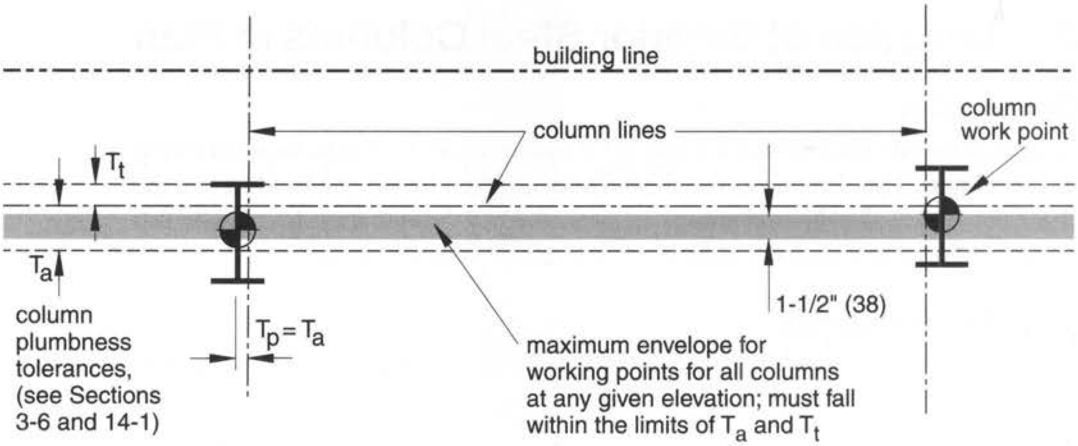
If the alignment of the columns is within acceptable limits, any single piece beam connected to them is considered in acceptable alignment. However, if the horizontal member consists of two or more splices, the field-fabricated member is considered acceptable if the misalignment does not exceed 1:500 between adjacent members. This is shown diagrammatically in Figure 3-7(b) for a beam between two columns. The same 1:500 misalignment tolerance applies to field-spliced vertical members.

For cantilevered members, alignment is checked by extending a straight line from the working point at the member's supported end and comparing it with the working line of the cantilevered member. If the misalignment is equal to or less than 1/500 of the distance from the supported end to the free end, the member is considered aligned, level, or plumb, depending on the direction of the cantilever.

Related Sections

3–1 Mill Tolerances for W and HP Shapes
3–2 Mill Tolerances for Length of W and HP Shapes
3–6 Steel Column Erection Tolerances
3–8 Beam/Column Connections
14–1 Accumulated Column Tolerances
Chapter 14, Steel Frame Systems

Figure 3–7 Location of exterior steel columns in plan

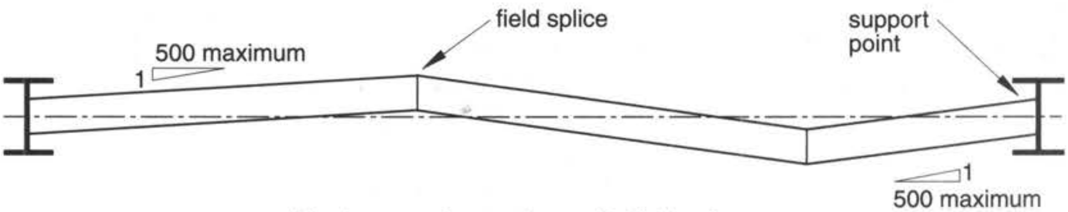


T_a = Tolerance away from building line

T_t = Tolerance toward building line

T_p = Tolerance parallel to building line (see Section 14-1)

(a) tolerances for columns with continuous intermediate beams



(b) tolerances for members with field splices

3–8 Steel Beam/Column Connections

Description

As stated in Section 3-7, horizontal alignment of beams is considered acceptable when the ends are connected to columns that fall with acceptable tolerances. This section describes acceptable variations in both horizontal and vertical placement of beams and tolerances of individual columns between floors.

Industry Standards

AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

Allowable Tolerances

Figure 3-8(a) illustrates how the horizontal position of an individual beam work point must fall within the allowable column tolerances shown in Figure 3-6. In addition, the allowable vertical tolerance is determined by measuring from the upper column splice line to the theoretical beam work point. This distance cannot be greater than 3/16 in. (5 mm) or less than 5/16 in. (8 mm).

As shown in Figure 3-8(b), the variation in straightness for straight compression must be equal to or less than 1/1,000 of the axial length between points that are to be laterally supported. This is a fabrication tolerance as given in AISC 303. For curved members, the variation from the theoretical curve must be equal to or less than the variation in sweep that is required for an equivalent straight member of the same length as specified in ASTM A6/A6M. Refer to Sections 3-2 and 3-3.

Related Sections

3–1 Mill Tolerances for W and HP Shapes
3–2 Mill Tolerances for Length of W and HP Shapes
3–3 Mill Tolerances for S and M Shapes and Channels
3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–10 Elevator Shaft Tolerances
Chapter 14, Steel Frame Systems

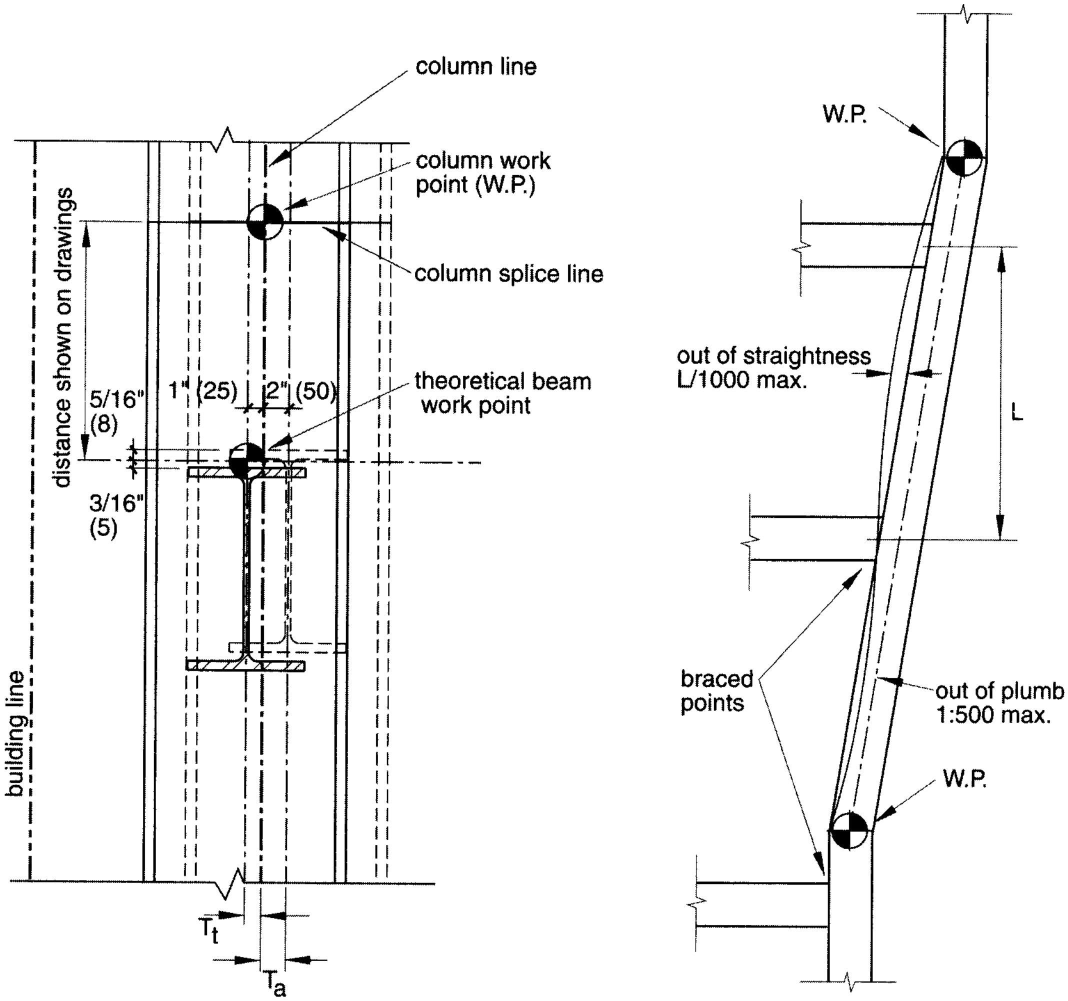
3–9 Architecturally Exposed Structural Steel

Description

Architecturally exposed structural steel (AESS) is steel subject to normal view by pedestrians or occupants of a building. It includes, but is not limited to, weathering steel. Because it is clearly visible, AESS is subject to closer tolerances than standard structural steel that is hidden from view.

The individual members that must conform to AESS, tolerances must be clearly identified on the drawings so the fabricator knows which pieces must meet the more stringent requirements.

Figure 3–8 Steel beam/column connections



(a) beam to column connection tolerances (b) allowable tolerances between floors

Industry Standards

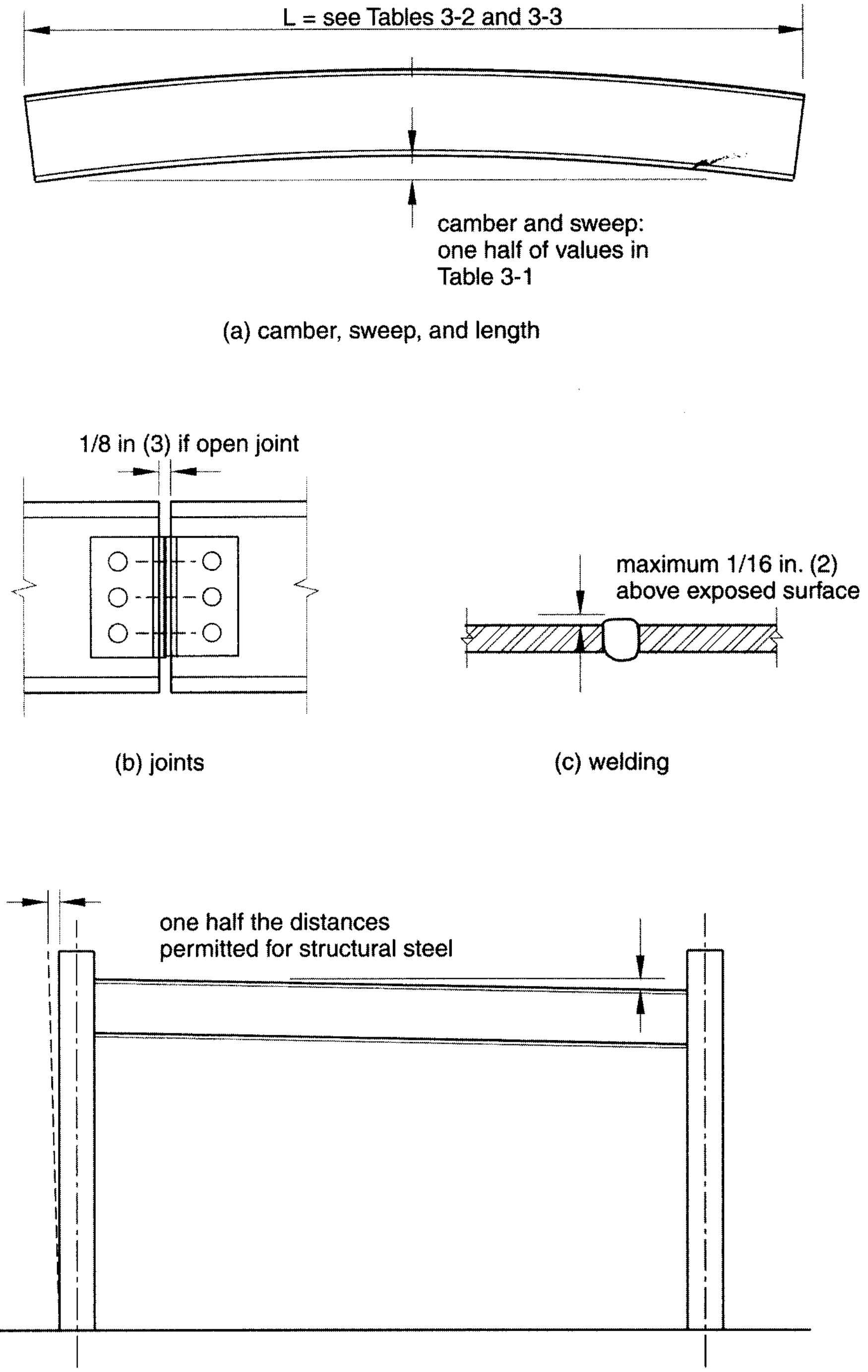
AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

ASTM A6/A6M, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

Mill tolerances for out-of-square, out-of-parallel, depth, width, and symmetry are the same as those for other structural steel shapes. Length tolerances are given in Tables 3-2 and 3-3. Camber and sweep tolerances are one-half those given in Table 3-1. See Figure 3-9(a).

Figure 3–9 Architecturally exposed structural steel



(a) camber, sweep, and length

(b) joints

(c) welding

(d) erection

As indicated in Figure 3-9(b), all miters, copes, and butt cuts in exposed surfaces are made with uniform gaps of ⅛ in. (3 mm) if the designer wants open joints or in reasonable contact if designed without gaps. Butt and plug welds cannot project more than 1⁄16 in. (2 mm) above any exposed surface. If grinding or finishing is required, it must be specifically included in the contract documents.

Erection tolerances are one-half those for structural steel as described in Sections 3-6, 3-7, and 3-8. However, the designer is responsible for providing adjustable connections between AESS and any other structural steel or masonry or concrete supports.

Related Sections

3–1 Mill Tolerances for W and HP Shapes
3–2 Mill Tolerances for Length of W and HP Shapes
3–3 Mill Tolerances for S and M Shapes and Channels
3–4 Mill Tolerances for Structural Angles and Tees
3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
Chapter 14, Steel Frame Systems

3–10 Elevator Shaft Tolerances

Description

Because guide rails of elevators must be adjusted to extremely close tolerances, the structural framing to which they are attached must be built to a tolerance closer than other construction. Because tolerances required by the National Elevator Industry, Inc. (NEII) are more stringent you may want to include the closer tolerances in the specifications if recommended by the elevator supplier rather than rely on AISC standard tolerances.

Industry Standards

AISC 303-05, *Code of Standard Practice for Steel Buildings and Bridges* (Chicago: American Institute of Steel Construction, Inc., 2005).

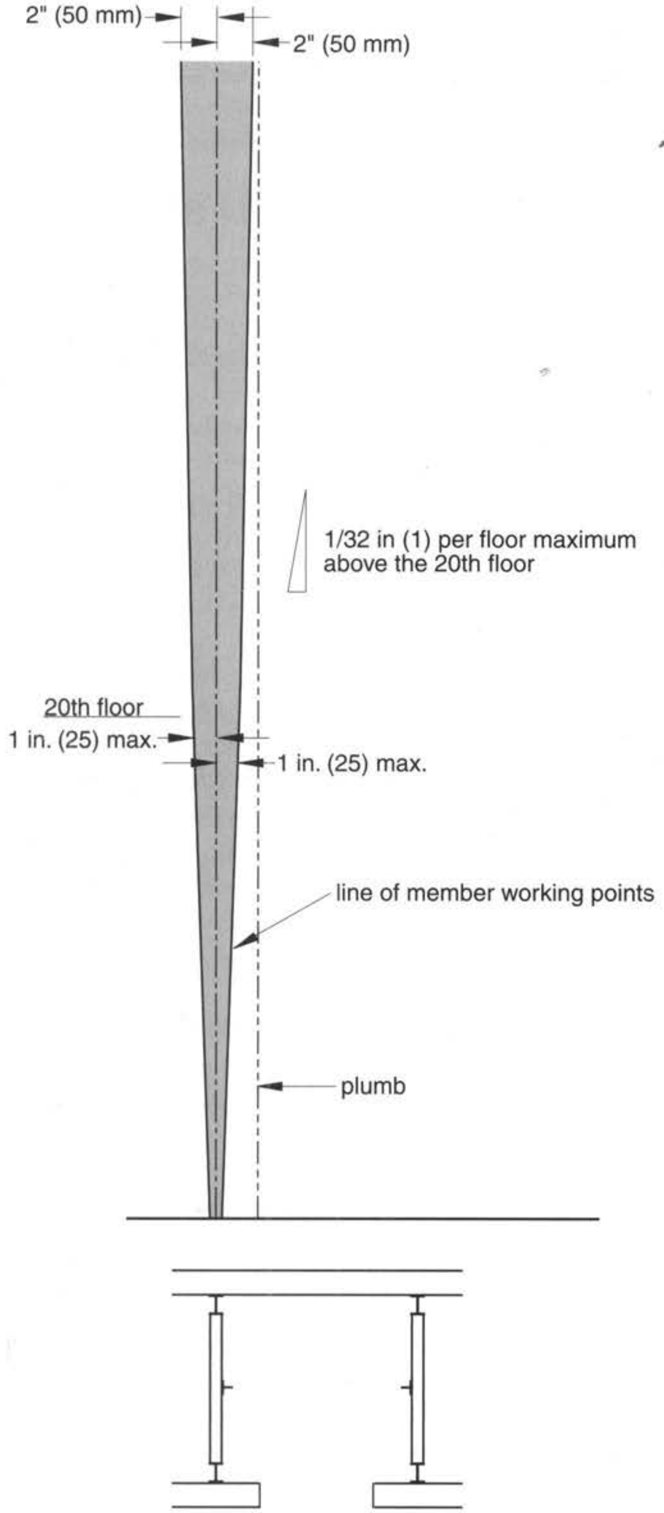
Building Transportation Standards and Guidelines (Salem, NY: National Elevator Industry, Inc.)

Allowable Tolerances

The AISC Code of Standard Practice requires the member working points of columns adjacent to elevator shafts to be displaced no more than 1 in. (25 mm) from the established column line in the first 20 stories, as shown in Figure 3-10. Above the twentieth floor, the displacement can be increased 1⁄32 in. (1 mm) for each additional story up to a maximum of 2 in. (50 mm).

However, hoistway tolerances by the NEII are slightly more stringent. They require a clear hoistway plumb from top to bottom with variations not to exceed 1 in. (25 mm) at any point in the first 100 ft. (30.5 m). Above that, the tolerance may increase 1⁄32 in. (0.8 mm rather than 1 mm, as AISC uses the SI conversion) for each additional 10 ft. (3 m), up to a maximum displacement of 2 in. (50 mm).

Figure 3–10 Elevator shaft tolerances



When entrance walls are constructed of reinforced concrete, the NEII requires that the depth of the hoistway door space be increased by 1 in. (25 mm) to compensate for normal field variations. Further, concrete rough openings should be 12 in. (300 mm) wider than the clear opening width and 6 in. (150 mm) higher than the clear opening height.

Related Sections

3–1 Mill Tolerances for W and HP Shapes
3–2 Mill Tolerances for Length of W and HP Shapes
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
Chapter 14, Steel Frame Systems

Chapter 4

Unit Masonry

4–1 Concrete Unit Masonry Manufacturing

Description

The information in this section includes concrete building brick and similar solid units, standard hollow load-bearing and non-load-bearing concrete block, and prefaced concrete block. The tolerances are measured from the standard, or actual, size of the concrete block units, whether modular or nonmodular, rather from the nominal sizes of the blocks. The actual sizes of concrete bricks are the manufacturers' designated dimensions. The actual size of modular concrete bricks is usually $\frac{3}{8}$ in. (10 mm) less than the nominal dimension (the width of one mortar joint). The actual size of nonmodular building bricks is usually $\frac{1}{8}$ in. to $\frac{1}{4}$ in. (3.2 to 6.4 mm) less than the nominal dimension. Standard concrete blocks are $\frac{3}{8}$ in. (10 mm) less than the nominal dimension. See Figure 4-1.

Industry Standards

ASTM C55, *Standard Specification for Concrete Brick* (West Conshohocken, PA: American Society for Testing and Materials, 2003).

ASTM C90, *Standard Specification for Hollow Loadbearing Concrete Masonry Units.* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

ASTM C129, *Standard Specification for Nonloadbearing Concrete Masonry Units.* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

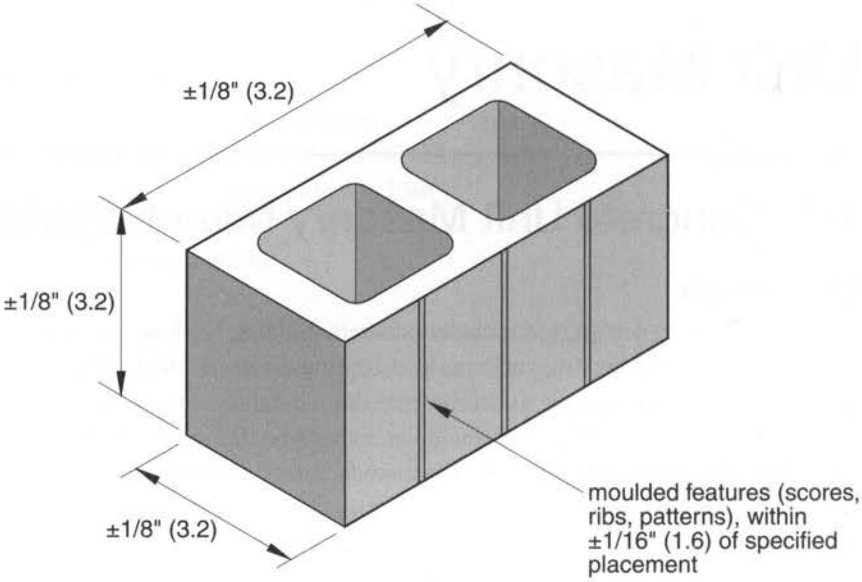
ASTM C744, *Standard Specification for Prefaced Concrete and Calcium Silicate Masonry Units.* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

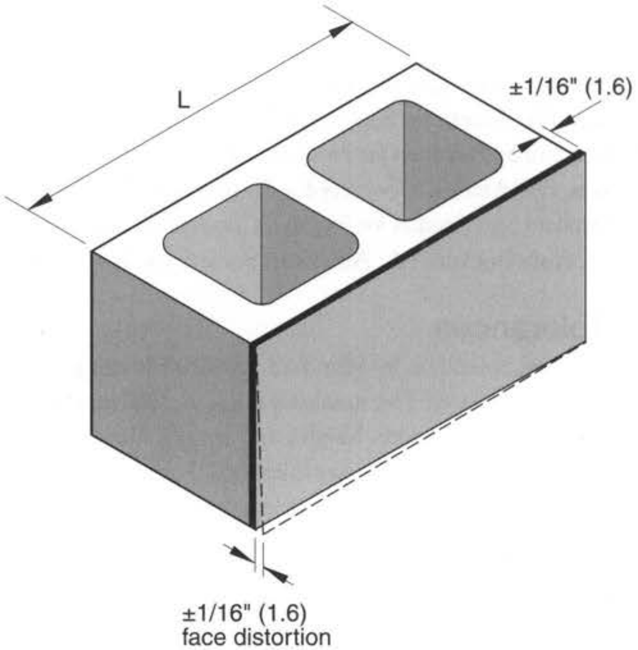
Allowable dimensional tolerance for standard non-load-bearing and load-bearing concrete masonry units based on ASTM standards is $\pm\frac{1}{8}$ in. (3.2 mm) from the standard (actual) dimension. This includes width, height, and length. However, in practice, units are usually manufactured to a $\frac{1}{16}$-in. (1.6-mm) tolerance. For non-load-bearing concrete masonry units, the face shell thickness cannot be less than $\frac{1}{2}$ in. (13 mm). For concrete building brick, the tolerance is also $\pm\frac{1}{8}$ in. (3.2 mm) in width, height, and length from the standard (actual) dimension.

Concrete masonry units used for prefaced block must meet the tolerances described in the preceding text. In addition, the total variation in finished face dimensions of prefaced units cannot exceed $\pm\frac{1}{16}$ in. (1.6 mm) between the largest and smallest unit in any lot of each size. The distortion of the plane and edges of the face of prefaced units from the corresponding plane and edges of the concrete masonry unit cannot exceed $\frac{1}{16}$ in. (1.6 mm).

Figure 4–1 Concrete unit masonry manufacturing



(a) standard concrete masonry block or brick



(b) prefaced concrete masonry unit

Related Sections

4-2 Concrete Unit Masonry Reinforcement Placement
4-3 Concrete Unit Masonry Cnstruction

4–2 Concrete Unit Masonry Reinforcement Placement

Description

Reinforced concrete unit masonry is often used for walls, columns and pilasters, lintels, and beams. The placement of the reinforcing is critical to the strength and performance of these construction elements and can affect the placement of other embedded items, such as electrical boxes, plumbing, and structural fasteners. The American Concrete Institute prescribes allowable variations in reinforcement placement. The International Building Code references the ACI code for its requirements.

Industry Standards

ACI 530.1/ASCE 6/TMS 602, *Specifications for Masonry Structures* Detroit, MI: American Concrete Institute, 2005).

Allowable Tolerances

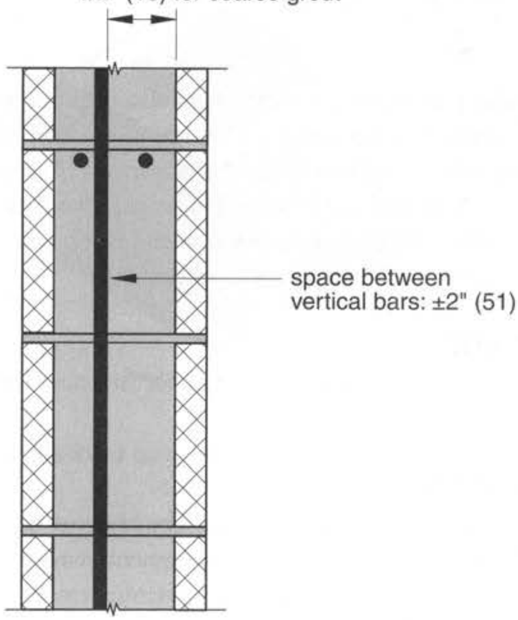
Joint standards of the American Concrete Institute, The Masonry Society, and the American Society of Civil Engineers for reinforcement placement in masonry are shown in Figures 4-2(a) and (b). Tolerances for the placement of reinforcement in walls and flexural elements depend on *d*, the distance from the compression face of the wall or flexural member to the centroid of the reinforcement. See Figure 4-2(b) and Table 4-1. When two parallel bars are within the same cell, the clear distance between the bars must be greater than or equal to the diameter of the bars and not less than 1 in. (25 mm). Longitudinal spacing must be within 2 in. (51 mm) of the required location.

Table 4–1 ACI masonry reinforcement placement tolerances

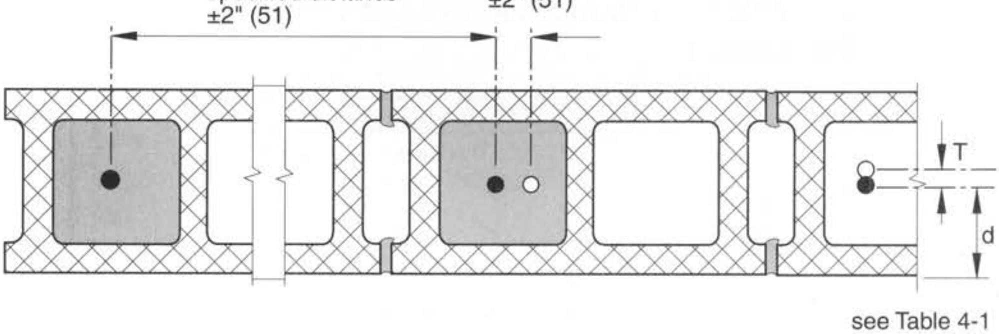
d	Placement tolerance, T
d ≤ 8" (203)	± ½" (12.7)
8" (203) ≤ d ≤ 24" (610)	±1" (25.4)
d > 24" (610)	± 1¼" (32)

Source: ACI 530.1/ASCE 6/TMS 602.

Figure 4–2 Concrete unit masonry reinforcement placement



(a) ACI tolerance standards



(b) ACI requirements

Figure 4–3 Concrete unit masonry construction

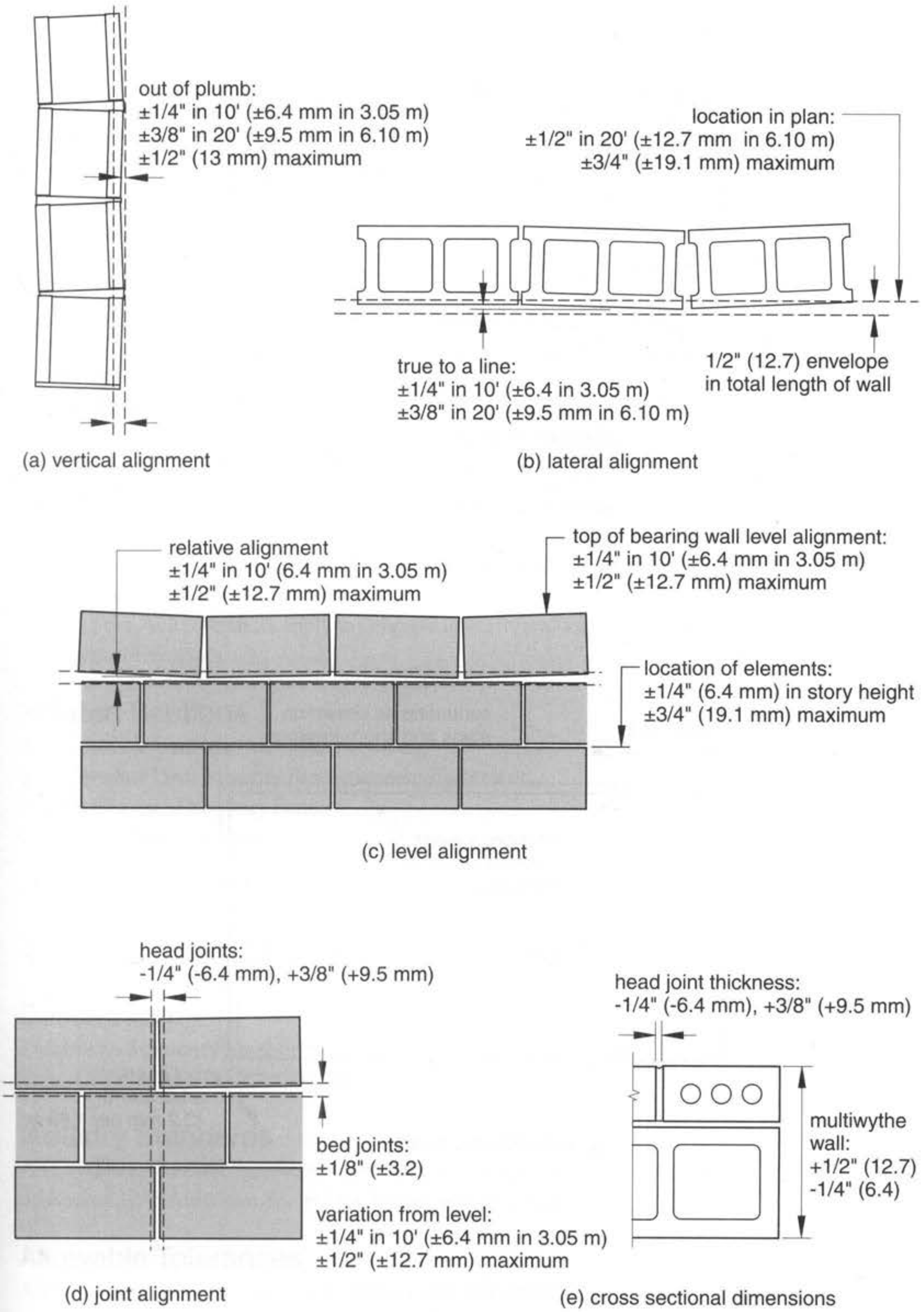
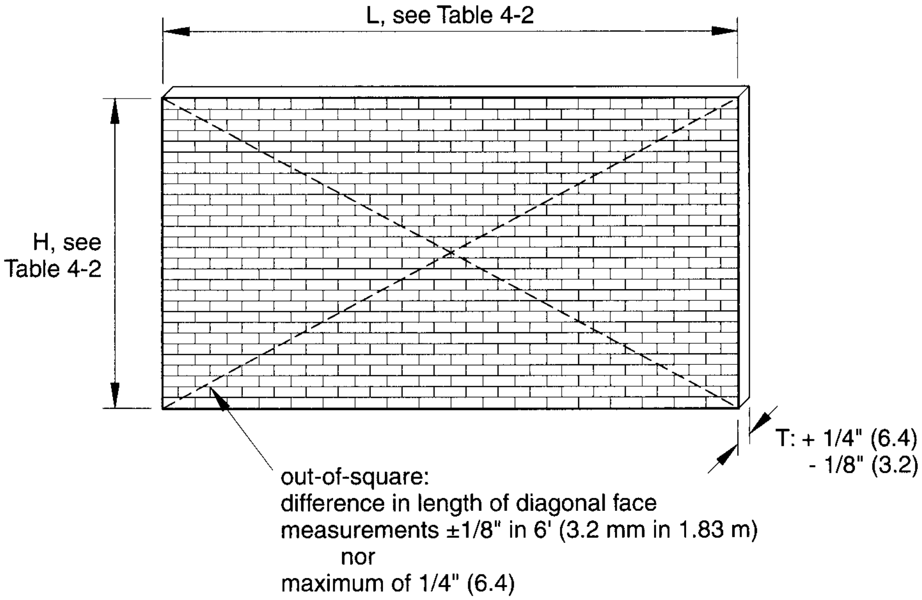
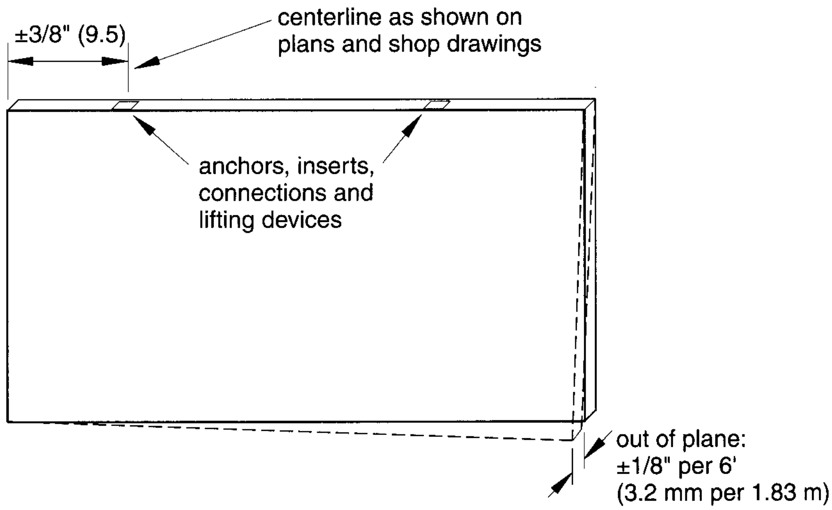


Figure 4–4 Prefabricated masonry panels



(a) dimensional tolerances



(b) warpage and inserts

Related Sections
4–1 Concrete Unit Masonry Manufacturing
4–3 Concrete Unit Masonry Construction
4–4 Prefabricated Masonry Panels

4–3 Concrete Unit Masonry Construction

Description
This section describes tolerances for laying up standard concrete unit masonry walls, either single wythe or multiple wythe.

Industry Standards
ACI 530.1/ASCE 6/TMS 602, *Specifications for Masonry Structures* (Detroit, MI: American Concrete Institute, 2005).

Allowable Tolerances
The tolerance for concrete unit masonry as given in ACI 530.1 and the National Concrete Masonry Association are shown in Figure 4-3. In addition, the alignment of columns and walls and the alignment of a wall interrupted by a floor slab is ±½ in. (13 mm) for bearing walls and ±¾ in. (19 mm) for nonbearing walls. The ACI 530.1 tolerances for a collar joint, grout space, or cavity width are –¼ in. (6.4 mm) and +⅜ in. (9.5 mm).

All of the ACI tolerances apply to concrete masonry walls as well as brick and other types of masonry.

Related Sections
4–1 Concrete Unit Masonry Manufacturing
4–2 Concrete Unit Masonry Reinforcement Placement
4–4 Prefabricated Masonry Panels
Chapter 15, Masonry Systems

4–4 Prefabricated Masonry Panels

Description
Prefabricated masonry panels include shop-fabricated assemblies made from concrete units masonry, brick, or structural clay tile.

Industry Standards
ASTM C901, *Standard Specification for Prefabricated Masonry Panels* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances
ASTM tolerance specifications only relate to the fabrication of load-bearing and non-load-bearing panels, as shown in Figure 4-4. Erection tolerances are generally required to conform to ACI standards as described in Section 4-3. Dimensional tolerances depend on the size of the panel and are listed in Table 4-2.

Table 4-2 Dimensional tolerances of prefabricated masonry panels

size of panel, L or H	tolerance
10' or under (3.05 m or under)	±1/8" (±3.2 mm)
10' to 20' (3.05 m to 6.1 m)	+1/8", –3/16" (+3.2 mm, -4.8 mm)
20' to 30' (6.096 m to 9.144 m)	+1/8", –1/4" (+3.2 mm, - 6.4 mm)

For each additional 10' (3.05 mm): ±1/16" (1.6 mm)
Source: ASTM C 901. Copyright ASTM International. Reprinted with permission.

Related Sections

4.1 Concrete Unit Masonry Manufacturing
4.2 Concrete Unit Masonry Reinforcement Placement
4-5 Brick Manufacturing
4-7 Glazed Structural Clay Facing Tile
Chapter 15, Masonry Systems

4–5 Brick Manufacturing

Description

This sections covers four categories of brick. The first category, *facing brick*, is available in three types: FBS, FBX, and FBA. Only types FBS and FBX have manufacturing tolerances established by ASTM specifications. The other three categories are building brick, hollow brick, and thin veneer brick units. *Building brick* is a solid-clay masonry unit used where external appearance is not a concern. *Hollow brick* is clay masonry whose net cross-sectional solid area is less than 75 percent of its gross cross-sectional area. *Thin brick veneer* is a clay masonry unit with a maximum thickness of 1¾ in. (44 mm).

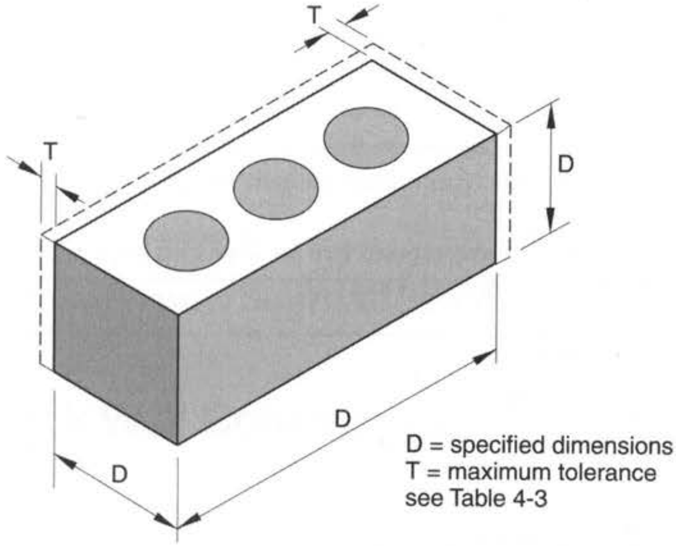
Industry Standards

ASTM C62, *Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale)*. (West Conshohocken, PA: American Society for Testing and Materials, 2004).

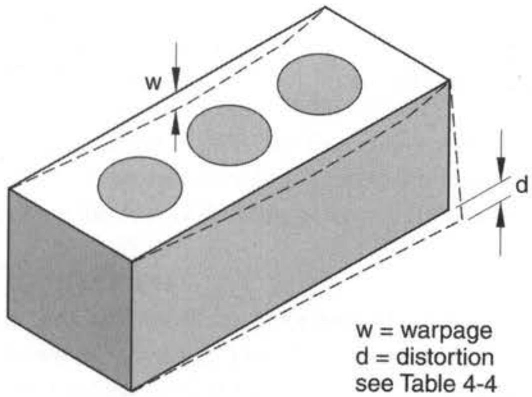
ASTM C216, *Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

ASTM C652, *Standard Specification for Hollow Brick (Hollow Masonry Units Made from Clay or Shale)* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

Figure 4–5 Brick manufacturing



(a) dimensional tolerances



maximum out-of-square dimension:
FBX brick: 3/32" (2.4)
FBS brick: 1/8" (3.2)

(b) warpage and distortion tolerances

ASTM C1088: *Standard Specification for Thin Veneer Brick Units Made from Clay or Shale* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

ASTM manufacturing tolerances apply to each of the four categories of brick mentioned previously. Although there are several types of brick in each of the four categories, only two types in each category (except building brick) have established manufacturing tolerances. These are listed in Table 4-3 and shown diagrammatically in Figure 4-5(a). The tolerances for each of the four categories are the same. Distortion tolerances are shown in Table 4-4. Tolerances for other types of brick in each category must be specified by the purchaser.

Out-of-square tolerances of the exposed face for Type FBS brick is ±⅛ in. (3.2 mm), and for Type FBX brick, it is ±3/32 in. (2.4 mm).

Related Sections

4–6 Brick Wall Construction
4–7 Glazed Structural Clay Facing Tile

Table 4–3 Brick manufacturing dimension tolerances

Specified dimension, inches (mm)	Maximum variation from specified dimension, inches, (mm)	
	Facing brick, Type FBX Hollow brick, Type HBX Thin veneer brick, Type TBX	Facing brick, Type FBS & Building brick Hollow brick, Types HBS and HBB Thin veneer brick, Type TBS
3 and under (76 and under)	1/16 (1.6)	3/32 (2.4)
Over 3 up to and including 4 (76 to 102 inclusive)	3/32 (2.4)	1/8 (3.2)
Over 4 up to and including 6 (102 to 152 inclusive)	1/8 (3.2)	3/16 (4.8)
Over 6 up to and including 8 (152 to 203 inclusive)	5/32 (4.0)	1/4 (6.4)
Over 8 up to and including 12 (203 to 305 inclusive)	7/32 (5.6)	5/16 (7.9)
Over 12 up to and including 16 (305 to 406 inclusive)	9/32 (7.1)	3/8 (9.5)

Source: Compiled from ASTM C 62, C 216, C 652, and C 1088. Copyright ASTM International. Reprinted with permission.

Table 4–4 Brick distortion tolerances

Maximum dimension, inches (mm)	Maximum permissible distortion, inches, (mm)	
	Facing brick, Type FBX Hollow brick, Type HBX Thin veneer brick, Type TBX	Facing brick, Type FBS Hollow brick, Type HBS Thin veneer brick, Type TBS
8 and under (203 and under)	$^{1}/_{16}$ (1.6)	$^{3}/_{32}$ (2.4)
Over 8 up to and including 12 (203 to 305 inclusive)	$^{3}/_{32}$ (2.4)	$^{1}/_{8}$ (3.2)
Over 12 up to and including 16 (305 to 406 inclusive)	$^{1}/_{8}$ (3.2)	$^{5}/_{32}$ (4.0)

Source: Compiled from ASTM C 216, C 652, and C 1088. Copyright ASTM International. Reprinted with permission.

4–6 Brick Wall Construction

Description

This section describes tolerances for laying up standard brick walls, either single wythe or multiple wythe. The same standards apply to brick walls as apply to concrete masonry walls.

Industry Standards

ACI 530.1/ASCE 6/TMS 602, *Specifications for Masonry Structures*. (Detroit, MI: American Concrete Institute, 2005).

Technical Notes on Brick Construction, Technical Note 11C, *Guide Specifications for Brick Masonry*, Part 4 (Reston, VA: The Brick Industry Association, 1998).

UFGS Section 04200, *Masonry*. United Facilities Guide Specifications, April (Washington, DC: National Institute of Building Sciences, 2005) www.ccb.org/docs/ufgshome.

Allowable Tolerances

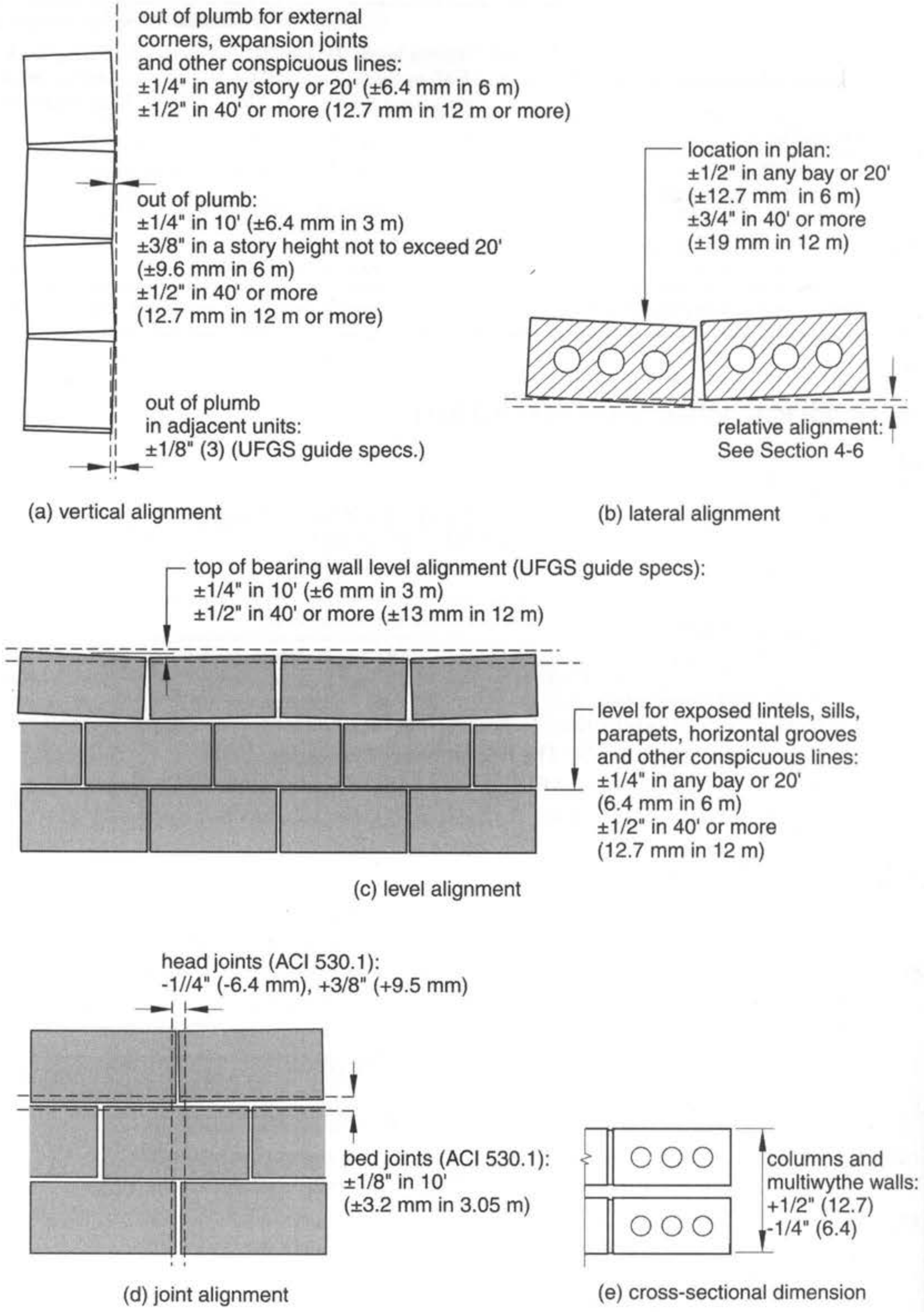
The tolerances in the *Guide Specifications for Brick Masonry* of the Brick Industry Association (BIA) are shown in Figure 4-6. The BIA document states that the tolerances are for protecting the structural integrity of the masonry elements and may not be adequate for establishing tolerances associated with aesthetics or visual requirements.

The BIA tolerances are nearly identical to the requirements for masonry construction given in ACI 530.1, with only slight differences in metric conversions and the length over which a tolerance is given. However, some tolerances are not given in the BIA *Guide Specifications*. Refer to Section 4-3 for ACI tolerances. All of the ACI tolerances apply to brick walls as well as concrete masonry walls and other types of masonry construction.

Required tolerances given in UFGS Section 04200 generally conform to the BIA guidelines except for the following:

- Variation from plumb in columns, walls, and arrises in adjacent masonry units: ±⅛ in. (3 mm).
- Variation from level for bed joints and tops of bearing walls, in 10 ft. (3 m): ±¼ in. (6 mm).
- Variation from level for bed joints and tops of bearing walls, in 40 ft. (12 m) or more: ±½ in. (13 mm).

Figure 4–6 Brick wall construction



Note: tolerances shown are based on BIA guidelines unless otherwise noted.

Related Sections

4–3 Concrete Unit Masonry Construction
4–4 Prefabricated Masonry Panels
4–5 Brick Manufacturing
14–5 Detailing for Brick on Steel
15–2 Detailing Brick And Concrete Masonry Systems

4–7 Glazed Structural Clay Facing Tile

Description

Structural clay facing tile is load-bearing clay tile having a finish consisting of ceramic glazed fused to the body at above 1,500°F (665°C). Tolerance standards established by ASTM C126 also apply to facing brick and other solid masonry units that have a ceramic glazed finish.

There are two grades: S grade (select) is for use with relatively narrow mortar joints, and SS grade (select sized or ground edge) is for use where the variation of face dimensions must be very small. There are various types and core configurations, but tolerances depend on which of the two grades is specified.

Industry Standards

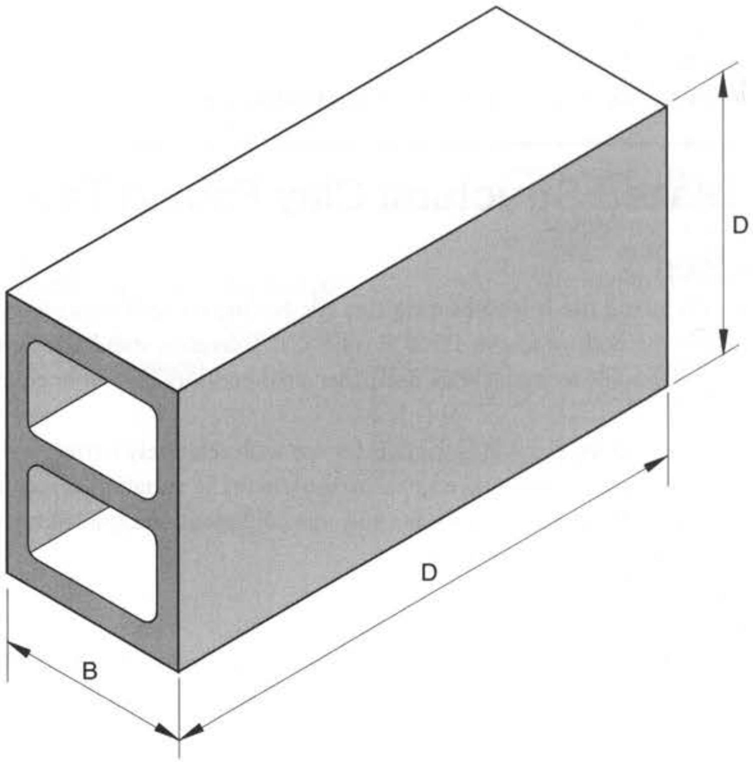
ASTM C126, *Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units.* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Table 4–5 Face dimension tolerances for glazed clay facing tile

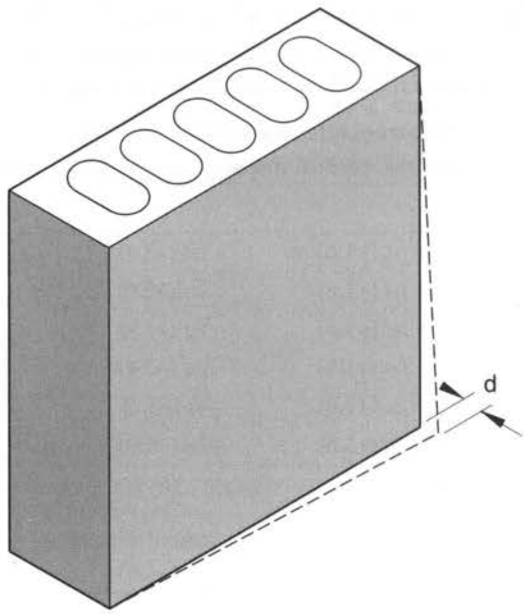
Specified face dimension, D, in, mm	Maximum difference between any unit and the specified dimension, in, (mm)[a]		Maximum difference between largest and smallest unit in one lot, in, (mm)
Grade S units			
2 3/8 (60.3)	+1/16 (+1.6)	–3/32 (–2.4)	3/32 (2.4)
3 3/4 (95.3)	+1/16 (+1.6)	–3/32 (–2.4)	3/32 (2.4)
5 1/16 (128.6)	+1/16 (+1.6)	–3/32 (–2.4)	3/32 (2.4)
5 3/4 (146.1)	+1/16 (+1.6)	–3/32 (–2.4)	3/32 (2.4)
7 3/4 (196.9)	+1/16 (+1.6)	–1/8 (–3.2)	3/32 (4.0)
11 3/4 (198.5)	+1/16 (+1.6)	–5/32 (–4.0)	3/32 (4.8)
Grade SS units			
7 3/4 (196.9)	+1/16 (+1.6)	–1/16 (–1.6)	3/32 (2.4)
15 3/4 (400.1)	+1/16 (+1.6)	–1/16 (–1.6)	3/32 (2.4)

[a] *When a unit has a dimension more than 1/4 in (6.4 mm) greater than shown, its tolerance is the same as for the next larger dimension.*
Source: ASTM C 126. Copyright ASTM International. Reprinted with permission.

Figure 4–7 Glazed structural clay facing tile



(a) dimension tolerances



(b) distortion tolerances

Table 4–6 Bed depth (thickness) tolerances for glazed clay facing tile

Specified bed depth (thickness), B, in (mm)	Maximum difference between any unit and the specified dimension, in, (mm)[a]		Maximum difference between largest and smallest unit in one lot, in, (mm)[b]
Type I, single faced units			
$1^3/_4$ (44.5)	$+^1/_8$ (+3.2)	$-^1/_8$ (−3.2)	$^1/_8$ (3.2)
$3^3/_4$ (95.3)	$+^1/_8$ (+3.2)	$-^3/_{16}$ (−4.8)	$^3/_{16}$ (4.8)
$5^3/_4$ (146.0)	$+^1/_8$ (+3.2)	$-^1/_4$ (−6.4)	$^1/_4$ (6.4)
$7^3/_4$ (196.9)	$+^1/_8$ (+3.2)	$-^5/_{16}$ (−7.9)	$^5/_{16}$ (7.9)
Type II, two-faced units			
$3^3/_4$ (95.3)	$+^1/_8$ (+3.2)	$-^1/_8$ (−3.2)	$^1/_8$ (3.2)
$5^3/_4$ (146.0)	$+^1/_8$ (+3.2)	$-^1/_8$ (−3.2)	$^1/_8$ (3.2)

[a] *When a unit has a dimension more than $^1/_4$ in (6.4 mm) greater than shown, its tolerance is the same as for the next larger dimension.*

[b] *Lot size is determined by agreement between purchaser and the seller.*

Source: ASTM C 126. Copyright ASTM International. Reprinted with permission.

Table 4–7 Distortion tolerances for glazed clay facing tile

Specified face dimensions, D, (height x length) inches, (mm)[1]	Grade	Maximum distortion, d, inches (mm)
$2^3/_8 \times 7^3/_4$ (60.3 × 196.9)	S	$^1/_{16}$ (1.6)
$5^1/_{16} \times 7^3/_4$ (128.6 × 196.9)	S	$^1/_{16}$ (1.6)
$5^1/_{15} \times 11^3/_4$ (128.6 × 196.9)	S	$^1/_{16}$ (1.6)
$3^3/_4 \times 11^3/_4$ (95.3 × 298.5)	S	$^1/_{16}$ (1.6)
$5^3/_4 \times 11^3/_4$ (146.1 × 298.5)	S	$^1/_{16}$ (1.6)
$7^3/_4 \times 11^3/_4$ (196.9 × 298.5)	S	$^5/_{32}$ (4.0)
$7^3/_4 \times 15^3/_4$ (196.9 × 400.1)	SS	$^3/_{32}$ (2.4)

Source: ASTM C 126. Copyright ASTM International. Reprinted with permission.

Allowable Tolerances

Tolerances are established for face dimensions, *D*; bed-depth dimension (thickness), *B*; and distortion tolerances, *d*, as shown in Figure 4-7. Tables 4-5 through 4-7 give the tolerances based on the size of the unit used.

Related Sections

4–8 Facing, Load-Bearing, and Non-Load-Bearing Clay Tile

4–8 Facing, Load-Bearing, and Non-Load-Bearing Clay Tile

Description

Tile conforming to ASTM C34 and C56 is used for concealed walls and partitions, furring, backup tile, and fireproofing. Load-bearing facing tile conforming to ASTM C212 is used for exposed exterior and exterior walls and partitions where low absorption and high stain resistance are required.

Industry Standards

ASTM C34: *Standard Specification for Structural Clay Load-bearing Wall Tile* (West Conshohocken, PA: American Society for Testing and Materials, 2003).

ASTM C56: *Standard Specification for Structural Clay Non-load-bearing Tile.* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

ASTM C212: *Standard Specification for Structural Clay Facing Tile.* (West Conshohocken, PA: American Society for Testing and Materials, 2000).

Allowable Tolerances

As shown in Figure 4-8(a), the tolerance for tile conforming to ASTM C34 and C56 is only ±3 percent of the specified dimension. Tolerances for structural clay facing tile depend on the type and are illustrated in Figure 4-8(b) and detailed in Tables 4-8 and 4-9.

Related Sections

4–7 Glazed Structural Clay Facing Tile

Table 4–8 Clay facing tile manufacturing dimension tolerances

Specified dimension, in , (mm)	Maximum variation from specified dimension, in, (mm)	
	Type FTX	*Type FTS*
3 and under (76.2 and under)	1/16 (1.6)	3/32 (2.4)
Over 3 up to and including 4 (76.2 to 101.6 inclusive)	3/32 (2.4)	2/16 (3.2)
Over 4 up to and including 6 (101.6 to 152.4 inclusive)	2/16 (3.2)	3/16 (4.7)
Over 6 up to and including 8 (152.4 to 203.2 inclusive)	5/32 (4.0)	4/16 (6.4)
Over 8 up to and including 12 (203.2 to 304.8 inclusive)	7/32 (5.6)	5/16 (7.9)
Over 12 up to and including 16 (304.8 to 406.4 inclusive)	9/32 (7.1)	6/16 (9.5)

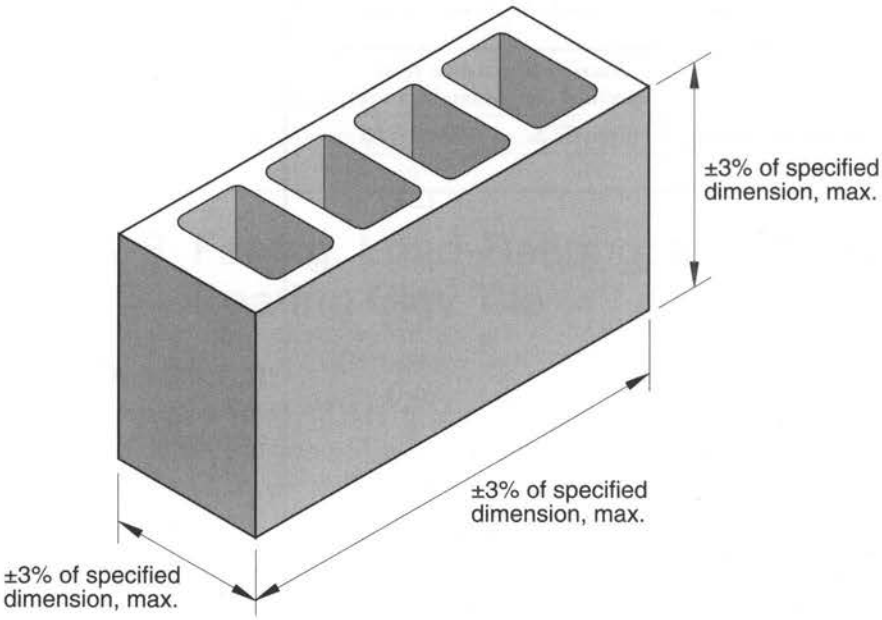
Source: ASTM C212. Copyright ASTM International. Reprinted with permission.

Table 4–9 Clay facing tile distortion tolerances

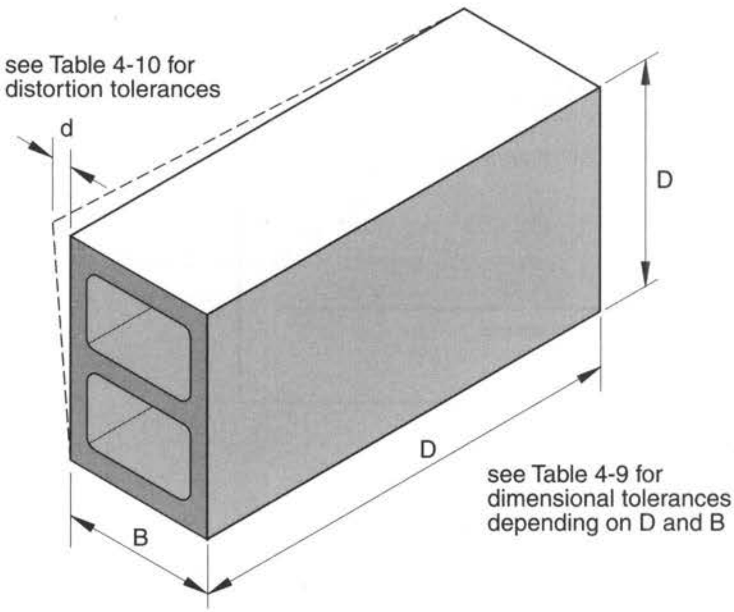
Maximum dimension, in, (mm)	Maximum permissible distortion, in, (mm)	
	Type FTX	*Type FTS*
8 and under (203.2 and under)	3/32 (2.4)	4/32 (3.2)
Over 8 up to and including 12 (203.2 to 304.8 inclusive)	4/32 (3.2)	6/32 (4.8)
Over 12 up to and including 16 (304.8 to 406.4 inclusive)	6/32 (4.8)	8/32 (6.4)

Source: ASTM C212. Copyright ASTM International. Reprinted with permission.

Figure 4–8 Facing, Load-Bearing, and Non-Load-Bearing Clay Tile



(a) load-bearing and non-load-bearing structural clay tile



(b) structural clay facing tile

4–9 Terra Cotta Manufacturing and Erection

Description

Terra cotta is made by machine extrusion, by mold pressing, or by hand carving. Machine-extruded terra cotta is often called *ceramic veneer*. Because terra cotta is not used much, there are very few manufacturers, and each may have its own tolerances for manufacturing and installation.

Industry Standards

Public Works Specifications, *Ceramic Veneer*, AIA File No. 9, October 1961, (Architectural Terra Cotta Institute [now defunct]).

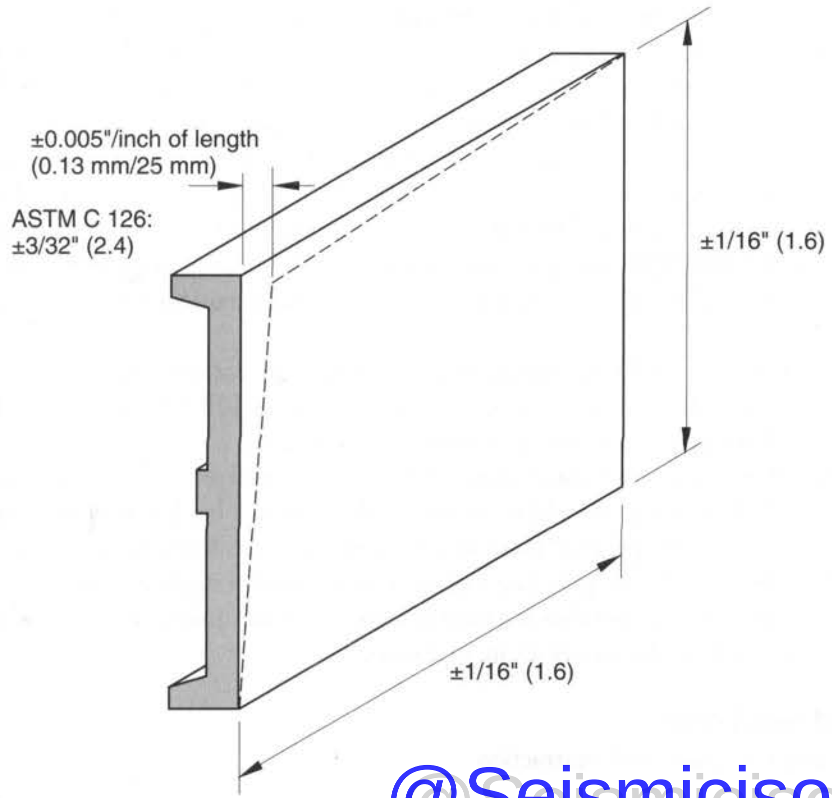
ASTM C126, *Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units*.(West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

Tolerances for machine-extruded terra cotta generally follow the requirements of ASTM C126 for type SS units. In addition, specifications developed by the Architectural Terra Cotta Institute (which are still used by one manufacturer) correspond with the ASTM requirements for finished face dimension tolerances.

However, there is a slight variance between the two specifications concerning flatness tolerances. ASTM C126 requirements for sizes less than 5¾ in. by 11¾ in. (146.1 mm by 298.5 mm) is 1/16 in. (1.6 mm). For larger sizes, the tolerance increases to 3/32 in. (2.4 mm).

Figure 4–9 Terra cotta manufacturing and erection



The 1961 specifications call for a flatness tolerance of 0.005 in. per inch of length (0.13 mm per 25 mm), as shown in Figure 4-9. Tolerances for erection and for pressed or hand-carved work should be verified with the manufacturer.

Related Sections

4–7 Glazed Structural Clay Facing Tile

4–10 Glass Block Manufacturing and Erection

Description

Glass block consists of individual masonry units made from partially evacuated hollow glass units or solid-glass units. Because glass block cannot be cut, openings must be precisely formed based on the modular unit size plus allowances for expansion joints, reinforcing, and framing.

Industry Standards

IBC, Section 2104.1.2.4, *Glass Unit Masonry* (Country Club Hills, IL: International Code Council, 2006).

ACI 530.1/ASCE 6/TMS 602, *Specifications for Masonry Structures* (Detroit, MI: American Concrete Institute, 2005).

Currently no industry standards are available for glass block manufacturing. Specific tolerances should be verified with each manufacturer and erection tolerances stated in the specifications.

Allowable Tolerances

The American Concrete Institute has established standards for joints of masonry glass units as part of ACI 530.1. The International Building Code has adopted these standards and further states that masonry shall be constructed within the tolerances stated in ACI 530.1. The International Building Code and ACI 530.1 require bed joint thickness to have a tolerance of -1/16 in (–1.6 mm) and +1/8 in. (3.2 mm). Head joints must have a thickness tolerance of ±1/8 in. (3.2 mm).

Despite the lack of manufacturing standards, most glass block is manufactured to within ±1/16 in. (1.6 mm) of the actual specified size of the unit, as shown in Figure 4-10(a). In most cases, the mortar joints can accommodate these minor variations without visible misalignment.

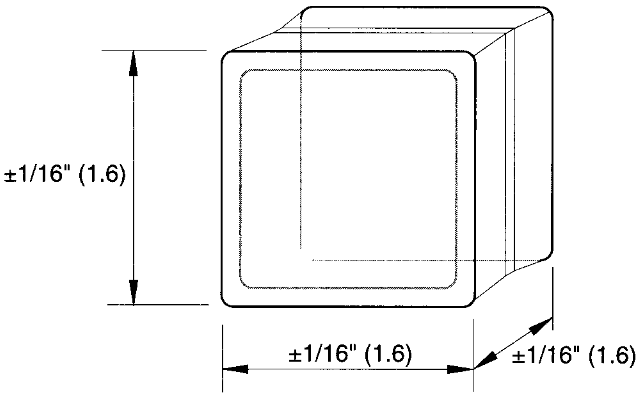
Variations in vertical and horizontal alignment between adjacent units should be specified but can be as small as ±1/32 in. (1 mm), as shown in Figure 4-10(b). Variations out of plane can be as little as ±1/16 in. (1.6 mm) between adjacent units.

No standards exist for out-of-plane tolerances for an entire wall section between framing, but it should be possible to build to the same tolerances as a brick wall or no more than ±1/8 in. in 6 ft. (3.2 mm per 1820 mm). Masonry construction tolerances given in ACI 117 and ACI 530.1 could also apply (see Section 4-3). For walls a single story high, out-of-plumb tolerances may be specified as a total of ±1/8 in. (3.2 mm). Joints should be laid 1/4 in. (6 mm) thick with a tolerance of ±1/8 in. (3.2 mm).

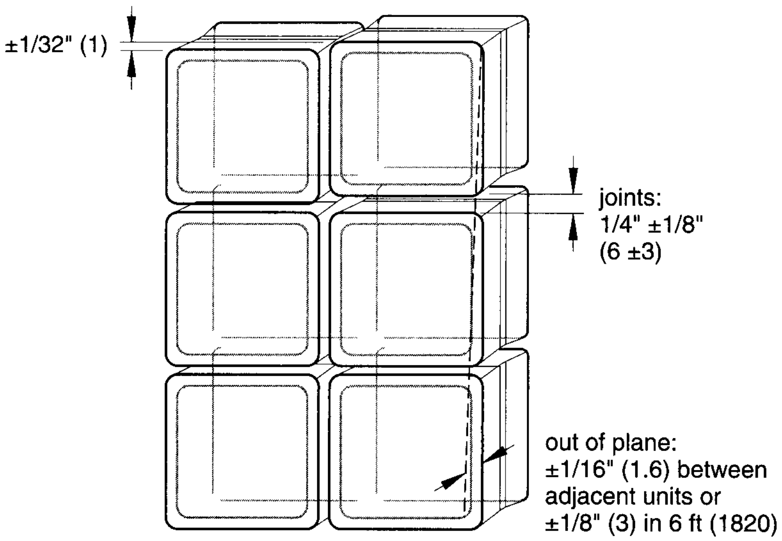
Related Sections

4–3 Concrete Unit Masonry Construction

Figure 4–10 Glass block manufacturing and erection

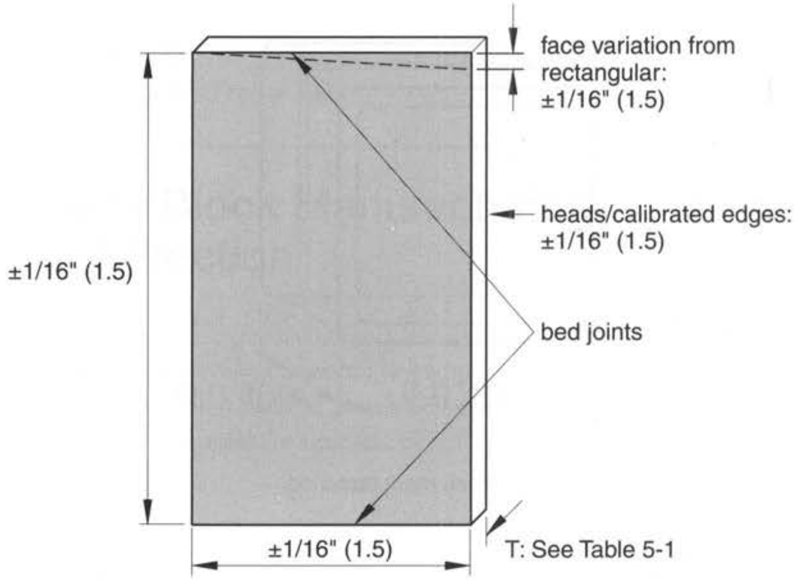


(a) glass block manufacturing

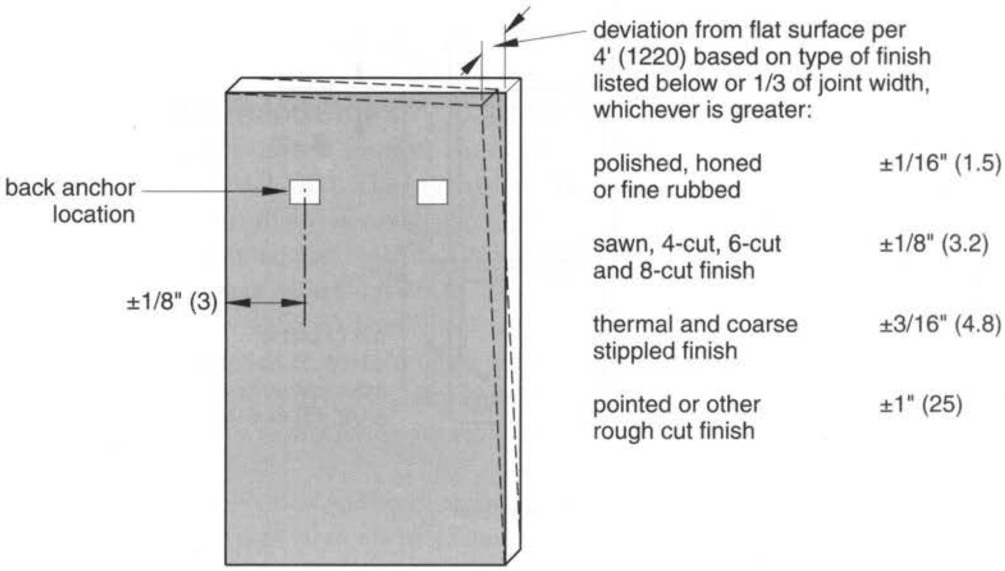


(b) glass block construction

Figure 5–1 Granite fabrication



(a) dimensional tolerances



(b) distortion tolerances

note: NBGQA specifications convert 1/16 in dimension to 1.5 mm

Chapter 5

Stone

5–1 Granite Fabrication

Description

This section includes tolerances for thick veneer granite and dimension stone. It also includes the newer, reinforced, thin granite panels.

Industry Standards

Specifications for Architectural Granite (Washington, DC: National Building Granite Quarries Association, 2006).
Dimension Stone Design Manual VI (Cleveland: Marble Institute of America, Inc., 2003).

Allowable tolerances

Maximum length and width tolerances, as shown in Figure 5-1(a), are ±1/16 in. (1.5 mm) with a maximum out-of-square tolerance of ±1/16 in. (1.5 mm). Thickness tolerances depend on the nominal thickness and are listed in Table 5-1. For quirk miters, the tolerance depends on the width of the nose. These are also shown in Table 5-1.

Flatness tolerances depend on the finish of the stone. For polished, honed, and fine rubbed finishes, flatness tolerances cannot exceed those shown in Figure 5-1(b) or one-third of the specified joint width, whichever is greater. On surfaces with other finishes, the tolerance is that shown in Figure 5-1(b) or one-half the specified joint width, whichever is greater. Flatness tolerances are determined by a 4-ft. (1,220-mm) dimension in any direction on the surface.

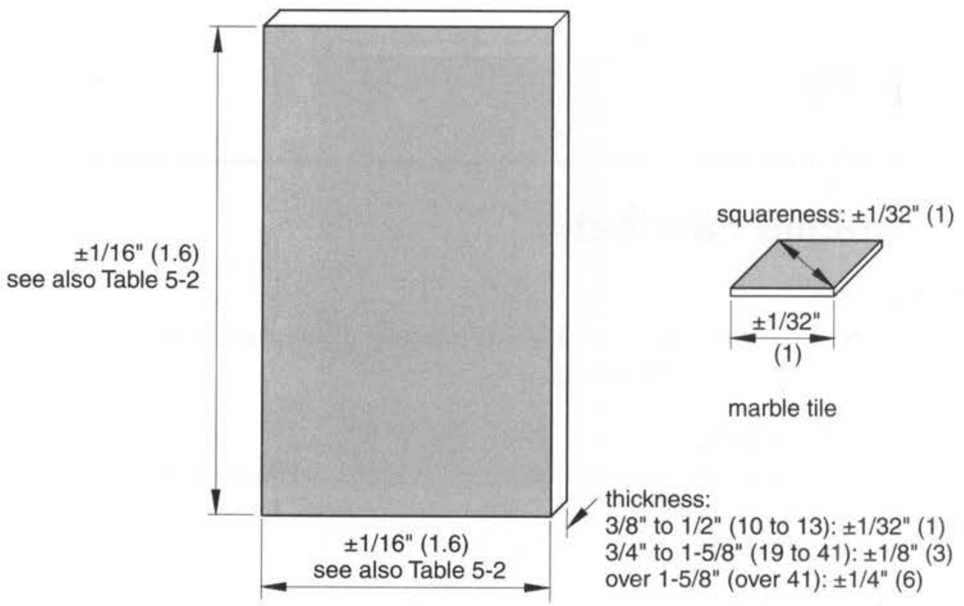
Anchors must be as shown in Figure 5-1(b) with the depth of anchor sinkages within –0 in. and +1/8 in. (3 mm). An anchor sinkage is a recess in the surface of the stone. The width and location of slots or kerfs cut into the edge of granite must be within ±1/16 in. (1.5 mm). The depth of kerfs must be within –1/16 in. (1.5 mm) or +1/8 in. (3 mm).

Table 5–1 Tolerances for granite veneer

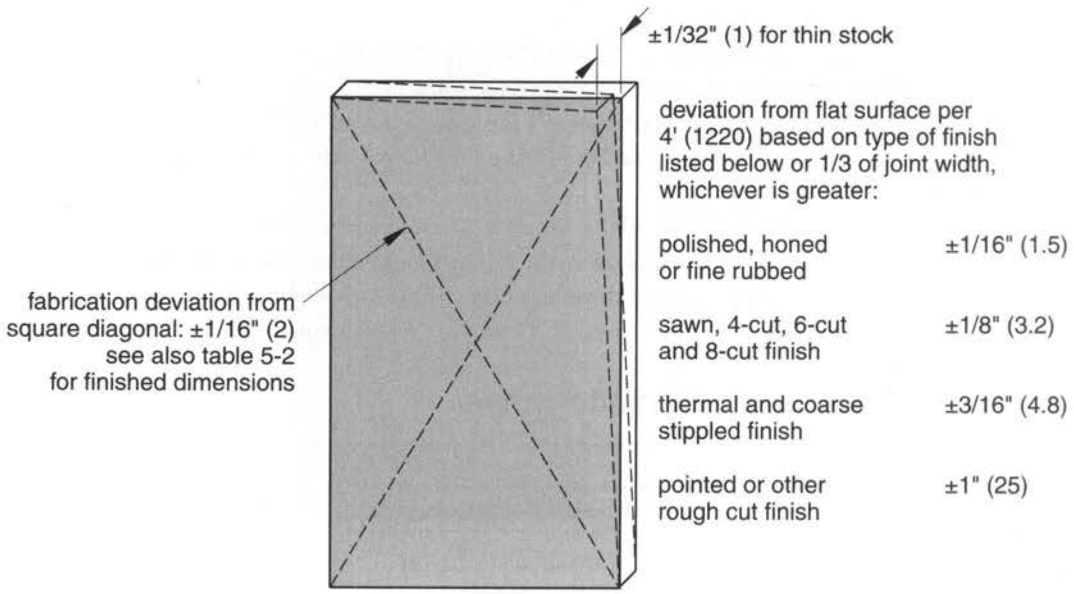
Panel thickness	Finished one face, in (mm)
3/8 or 1/2 in (10 or 13 mm)	±1/32 (0.8)
3/4 in to 1 5/8 in (20 mm to 41 mm)	±1/8 (3)
Greater than 1 5/8 in (41 mm)	±1/4 (6)
Quirk miters (width of nose)	
Up to 1/4 in (6 mm)	-0, +25% of dimension
Over 1/4 in (6 mm)	-0, +1/16 (1.5)

Source: Dimension Stone Design Manual VI. Marble Institute of America, Inc. and NBGQA Specifications

Figure 5–2 Marble Fabrication



(a) dimensional tolerances



(b) fabrication distortion tolerances

For additional tolerances on the location, size, and depth of anchor slots, holes, and kerfs, refer to the industry standards listed in this section.

Related Sections

5–4 Granite and Marble Installation
5–8 Interior Stone Wall Cladding
9–8 Stone Flooring

5–2 Marble Fabrication

Description

Marble tolerances include those for thin veneer slabs, cubic stock, and marble tile. This section does not include newer, reinforced, thin marble panels.

Industry Standards

Dimension Stone Design Manual VI (Cleveland: Marble Institute of America, Inc., 2003).

Allowable Tolerances

Dimensional fabrication tolerances are shown in Figure 5-2. Thicknesses tolerances depend on the basic panel thickness. Final finish tolerances depend on whether the panel is finished on one or both sides, as listed in Table 5-2.

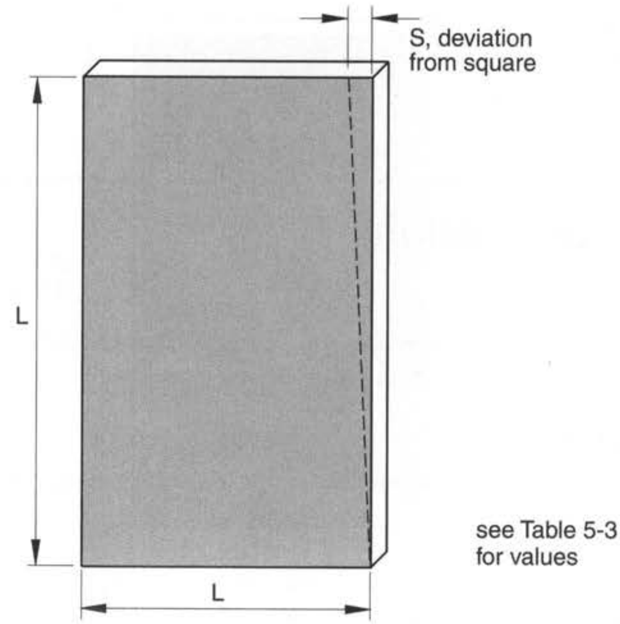
Table 5–2 Finished size tolerances for marble

Thickness (all material)*	**Finished both faces in (mm)**	**Finished one face in (mm)**
Thin Stock (3/4 in to 2 in) (2 cm to 5 cm)	+0, −1/32 (+0, −1)	±1/32 (±1)
Cubic Stock (2 in +) (5 cm+)	±1/16 (±2)	±1/8 (±4)
Stone Tile (5/8 in or less) (15 mm)		±1/64 (±0.5)
Face dimensions (all material)		
Thin Stock	+1/16, −1/32 (+2, −1)	+1/16, −1/32 (+2, -1)
Cubic Stock	±1/16 (±2)	±1/16 (±2)
Stone Tile		±1/32 (±1)
Squareness (all material)		
Thin Stock	±1/32 (±1)	±1/32 (±1)
Cubic Stock	±1/16 (±2)	±1/16 (±2)
Stone Tile		±1/32 (±1)

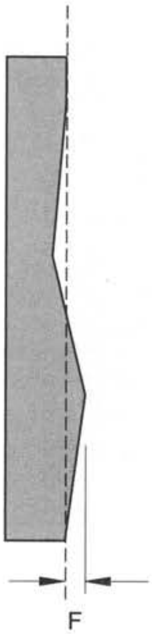
**All thicknesses are subject to gauged fabrication tolerances*

Source: Marble, Dimension Stone Design Manual VI. Marble Institute of America, Inc.

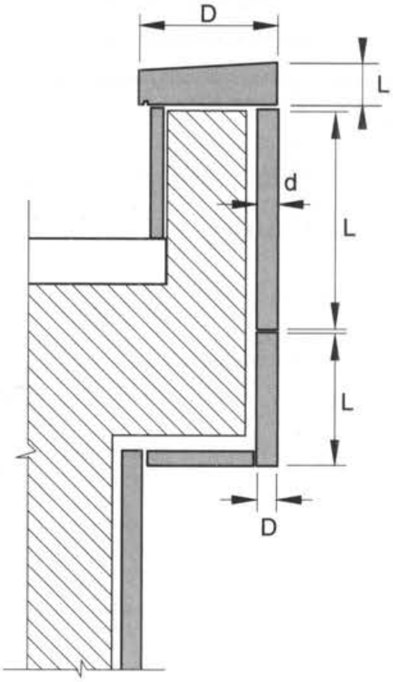
Figure 5–3 Limestone Fabrication



(a) dimensional tolerances



(b) flatness tolerances



(c) depth tolerances

Flatness tolerances depend on the finish of the stone. For polished, honed, and fine rubbed finishes, flatness tolerances cannot exceed those shown in Figure 5-2(b) or one-third of the specified joint width, whichever is greater. On surfaces with other finishes, the tolerance is that shown in Figure 5-1(b) or one-half the specified joint width, whichever is greater. Flatness tolerances are determined by a 4-ft. (1,220-mm) dimension in any direction on the surface.

Tolerances for anchors are the same as those for granite shown in Figure 5-1. For additional tolerances on the location, size, and depth of anchor slots, holes, and kerfs, refer to the industry standards listed in this section.

Related Sections

5–4 Granite and Marble Installation
5–8 Interior Stone Wall Cladding
9–8 Stone Flooring

5–3 Limestone Fabrication

Description

This section includes standard limestone construction using both single panels and shop-fabricated assemblies. Tolerances for ornately carved work should be verified with the supplier.

Industry Standards

Indiana Limestone Handbook, 21st ed. (Bedford, IN: Indiana Limestone Institute of America, Inc., 2002).

Allowable Tolerances

Common tolerances are shown in Figure 5-3 and listed in Table 5-3. Common finishes are indicated in Table 5-3, but special finishes are available that may affect the tolerance of

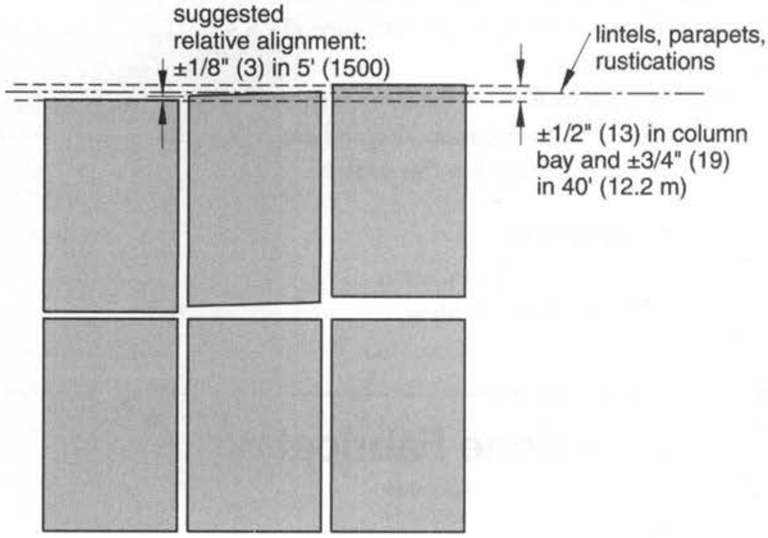
Table 5–3 Limestone fabrication tolerances

Finish type	Length, L, in (mm)	Deviation from flat surface, F, in (mm)	Critical depth, D, in (mm)	Non-critical depth, d, in (mm)	Deviation from square, S, in (mm)
Smooth machine finish	±1/16 (2)	±1/16 (2)	±1/16 (2)	±1/2 (13)	±1/16 (2)
Diamond gang finish	±1/16 (2)	±1/4 (6)	±1/8 (3)	±1/2 (13)	±1/16 (2)
Chat sawed finish	±1/16 (2)	±1/4 (6)	±1/8 (3)	±1/2 (13)	±1/16 (2)
Shot sawed finish	±1/16 (2)	±1/2 (13)	±1/4 (6)	±1/2 (13)	±1/16 (2)
Pre-assembled units[1]	±1/8 (3)	±1/8 (3)	±1/8 (3)	±1/2 (13)	±1/8 (3)
Panels over 50 ft^2 (4.6 m^2)	±1/8 (3)	±1/8 (3)	±1/8 (3)	±1/2 (13)	±1/8 (3)

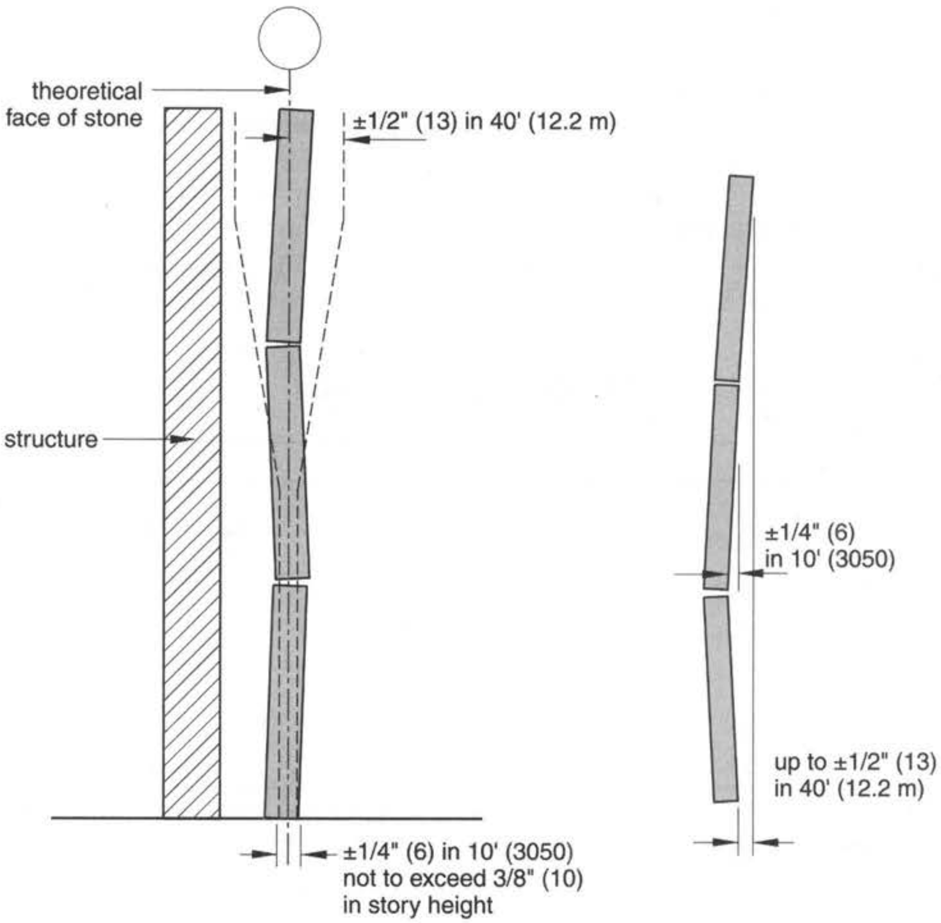
Note: In stones having one or more dimensions over 5 ft 0 in (1520 mm), and in many multiple-stone assemblies, tolerances larger than the above may be necessary. Determination of applicable tolerances will result from consultation with the stone fabricator by designers or engineers. Indiana Limestone tolerances are much smaller than those of most other materials. As a result, tolerance problems usually arise from ignorance or misuse of the tolerances allowable for other materials.

Source: Indiana Limestone Handbook, 21st ed. Indiana Limestone Institute of America, Inc. Reproduced with permission

Figure 5–4 Granite and marble Installation



(a) tolerances for level



(b) tolerances for plumb for walls and columns (c) tolerances out of plane various pieces. Preassembled units are stone assemblies consisting of two or more stones assembled at the plant using adhesives and metal accessories where required.

Related Sections

5–5 Limestone Installation
5–8 Interior Stone Wall Cladding

5–4 Granite and Marble Installation

Description

This section covers the installation of exterior granite and marble panels. Granite and marble can be installed on a variety of substrates, including steel framing, concrete, and masonry. In addition, stone can be installed on a steel grid framework anchored to other structural backup systems. The accuracy with which stone can be installed depends on the tolerance of the structural framework and the clearances between materials, as well as the amount of adjustment designed into the connections.

Industry Standards

Dimension Stone Design Manual VI (Cleveland: Marble Institute of America, Inc., 2003).

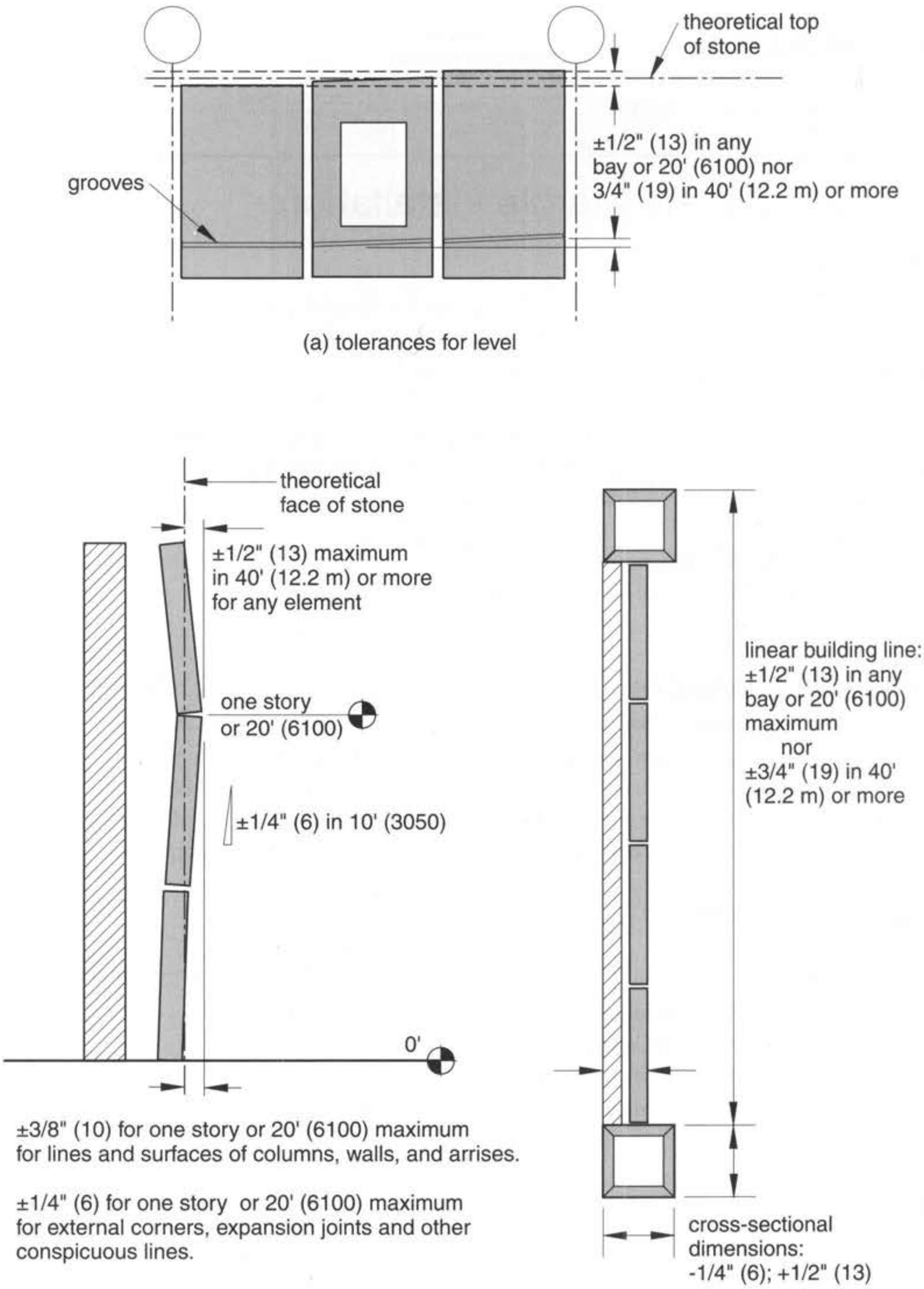
Allowable Tolerances

The installation tolerances shown in Figure 5-4 are those recommended in the *Dimension Stone Design Manual.* For exterior corners or other conspicuous lines, plumb tolerances are as shown in Figure 5-4(b), except out-of-plane tolerance cannot exceed ¼ in. (6 mm) for a story. Variation from linear building line should not exceed ½ in. (13 mm) in a column bay and ¾ in. (19 mm) in 40 ft. (12.2 m).

Related Sections

5–1 Granite Fabrication
5–2 Marble Fabrication
5–8 Interior Stone Wall Cladding
12–5 Detailing for Stone on Concrete Systems
14–6 Detailing for Stone on Steel Systems
15–3 Detailing for Stone on Masonry Backup

Figure 5–5 Limestone installation



(b) tolerances for plumb

(c) plan, and cross-sectional tolerances

5–5 Limestone Installation

Description

This section describes the allowable setting tolerances for exterior limestone regardless of the type of structural system being used. These tolerances assume that sufficient clearance and correct anchorage devices have been detailed and specified.

Industry Standards

Specifications for Cut Indiana Limestone, Section 3.3.5 (Bedford, IN: Indiana Limestone Institute of America, 2005) www.iliai.com/ilibook.pdf.

Allowable Tolerances

Tolerances for level are shown in Figure 5-5(a) and include exposed lintels, sills, parapets, horizontal grooves, and other conspicuous lines. The Indiana Limestone Institute of America (ILIA) specifications note that the stone setting tolerances are masonry industry setting tolerances, and as a production industry, the ILIA cannot and does not control them.

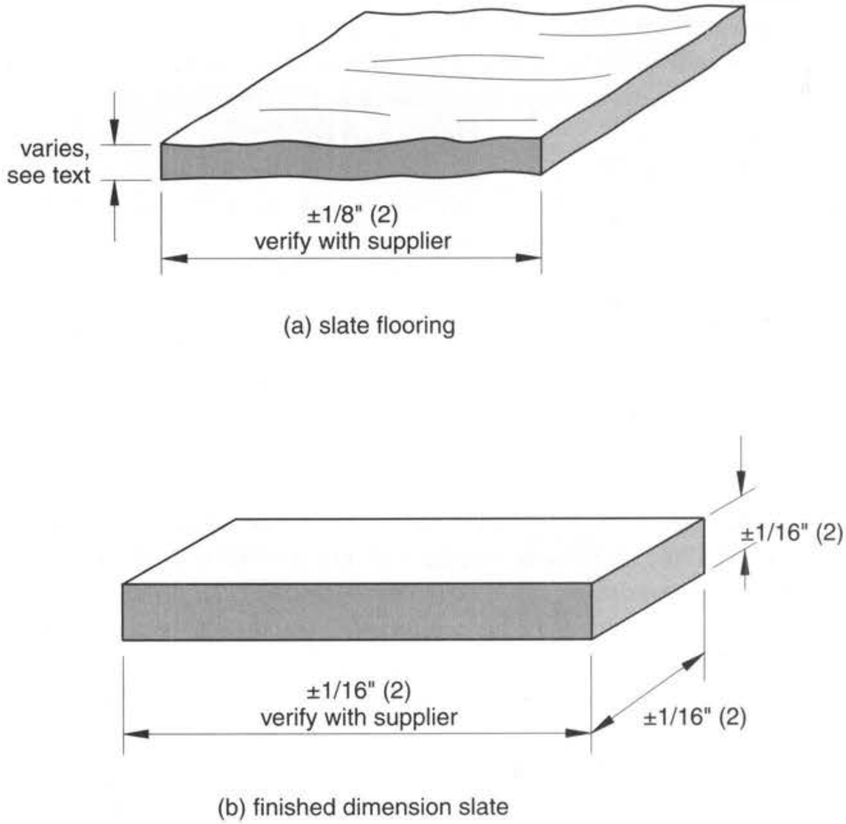
As shown in Figure 5-5(b), plumb tolerances require that deviations not exceed ¼ in. (6 mm) per any 10-ft. (3,050-mm) length, ⅜ in. (10 mm) for a single story or a 20-ft. (6,100-mm) section maximum, and ½ in. (13 mm) in 40 ft. (12.2 m) or more. For external corners, expansion joints, and other conspicuous lines, the tolerance is ± ¼ in. (6 mm) per 20 ft. (6,100 mm) and ±¾ in. (19 mm) in 40 ft. (12.2 m) or more.

For the position of limestone components shown in plan and related portions of columns, walls, and partitions, the tolerance is ±½ in. (13 mm) in any bay or 20 ft. (6,100 mm) maximum. Plan dimensions must also not vary more than ¾ in. (19 mm) total in 40 ft. (12.2 m) or more. For columns and thickness of walls, tolerances are –¼ in. (6 mm) and +½ in. (13 mm).

Related Sections

5–3 Limestone Fabrication
5–8 Interior Stone Wall Cladding
12–5 Detailing for Stone on Concrete Systems
14–6 Detailing for Stone on Steel Systems
15–3 Detailing for Stone on Masonry Backup

Figure 5–6 Fabrication and Erection Tolerances for Slate



5–6 Fabrication and Erection Tolerances for Slate

Description

Structural slate (for uses other than roofing) is used for flooring, for interior wall facing, for stair treads and risers, for windowsills, and occasionally for exterior spandrels and facings. Because slate has natural cleavage planes and is often fabricated with a natural split face, tolerances for thickness can vary widely, depending on the fabricator, job conditions, size of panel, and other variables.

Industry Standards

There are no established industry standards for slate tolerances. However, for interior wall cladding, the standards of the Marble Institute of America are often used. Refer to Section 5-8.

Allowable Tolerances

As shown in Figure 5-6, many manufacturers cut structural split face and flooring slate to within ±⅛ in. (3 mm) in length and width. Dimension stone is often finished by honing or sand rubbing to within ±1⁄16 in. (2 mm).

For natural-cleft flooring, slabs are often specified by a thickness range: ⅜ in. to ½ in., ½ in. to ⅝ in., ⅝ in. to ¾ in., and ¾ in. to 1 in. Construction details should account for this possible range of thickness, even if the bottom of the slab is gauged or smoothed.

Larger tolerances for both size and thickness may exist for imported slate.

Related Sections

5–2 Marble Fabrication
5–8 Interior Stone Wall Cladding

5–7 Cast Stone Fabrication and Erection

Description

Cast stone is an architectural precast concrete building stone manufactured from portland cement and coarse and fine aggregates to simulate natural stone. It is used for facing, trim, ornaments, columns, moldings, and copings, among other architectural elements.

Industry Standards

Standard Specification 04 72 00, *Cast Stone* (Lawrenceville, GA: The Cast Stone Institute, 2004).

Allowable Tolerances

Fabrication and erection tolerances established by the Cast Stone Institute are illustrated in Figure 5-7. The tolerances of ⅛ in. (3 mm) or length divided by 360, whichever is greater, apply to all sectional dimensions, to length, and to distortions of twist, square, and camber.

For inserts, dowel holes, flashing grooves, false joints, and similar features, the tolerance is ±⅛ in. (3 mm) on the formed sides of a unit. On the back, or unformed side, the location tolerance is increased to ±⅜ in. (10 mm).

Related Sections

12–5 Detailing for Stone on Concrete Systems
14–6 Detailing for Stone on Steel Systems

5–8 Interior Stone Wall Cladding

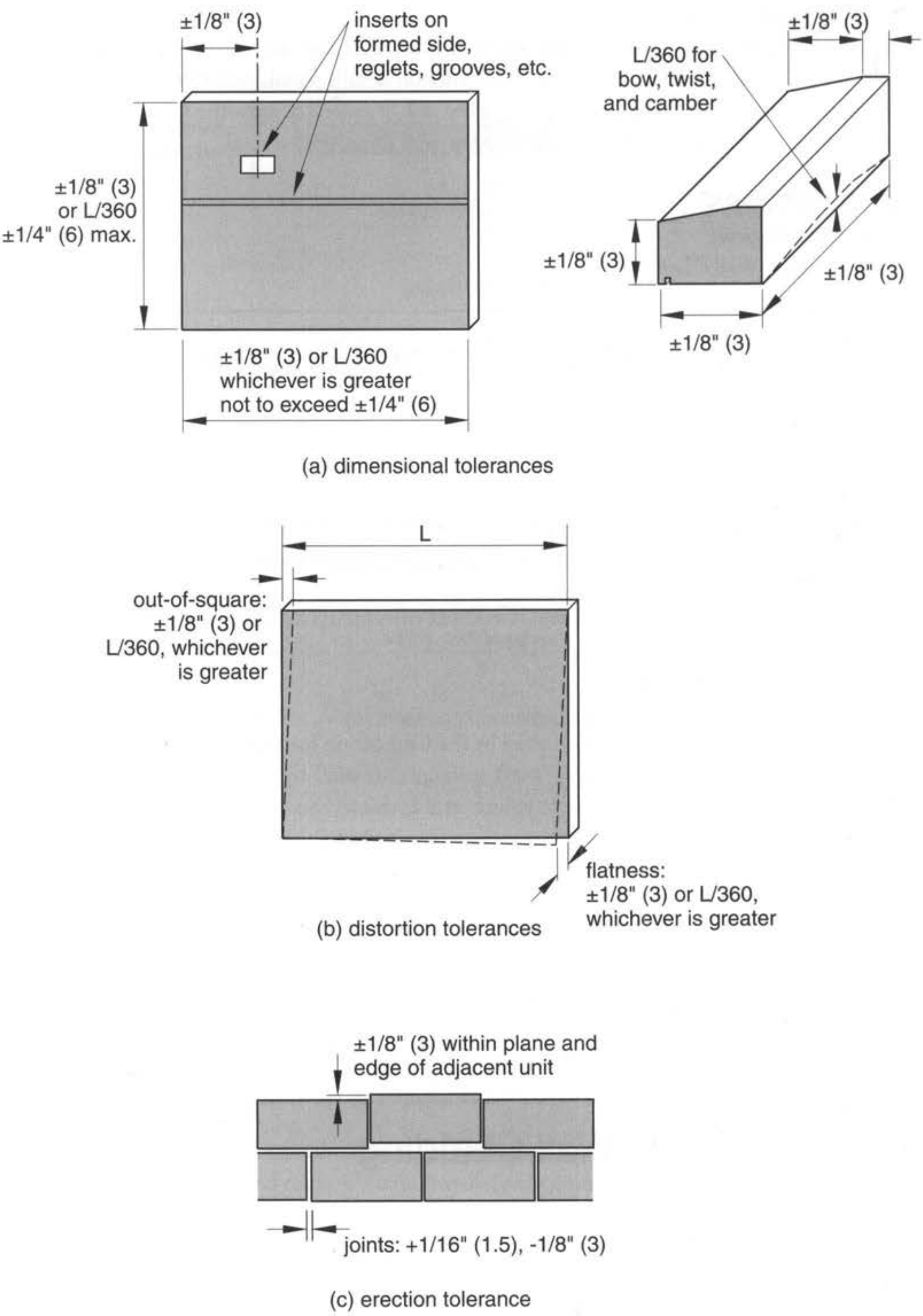
Description

This section includes the fabrication and installation of granite, marble, limestone, slate, and other quartz-based stone used for interior wall cladding.

Industry Standards

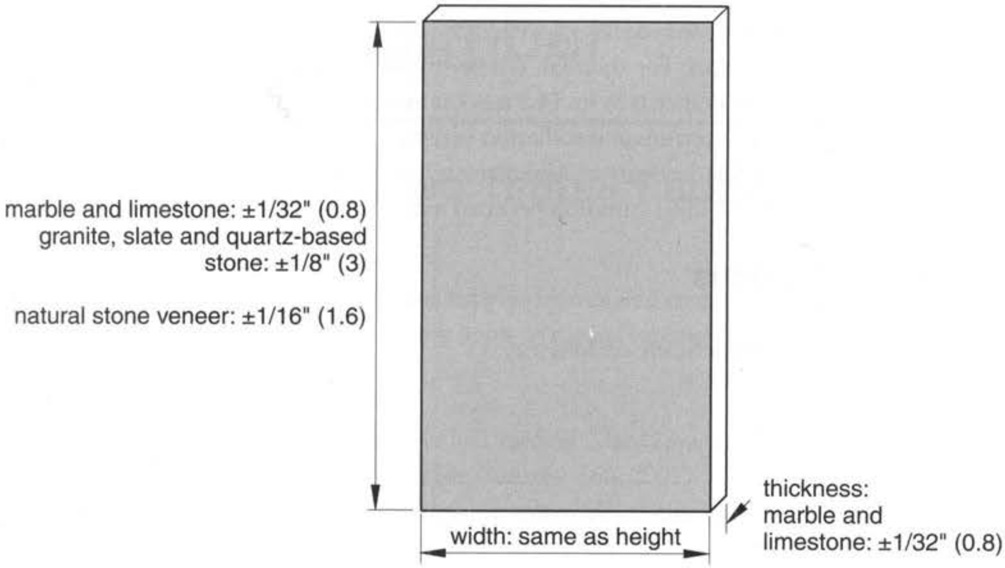
Dimension Stone Design Manual VI (Cleveland: Marble Institute of America, Inc., 2003.)

Figure 5–7 Cast stone fabrication and erection

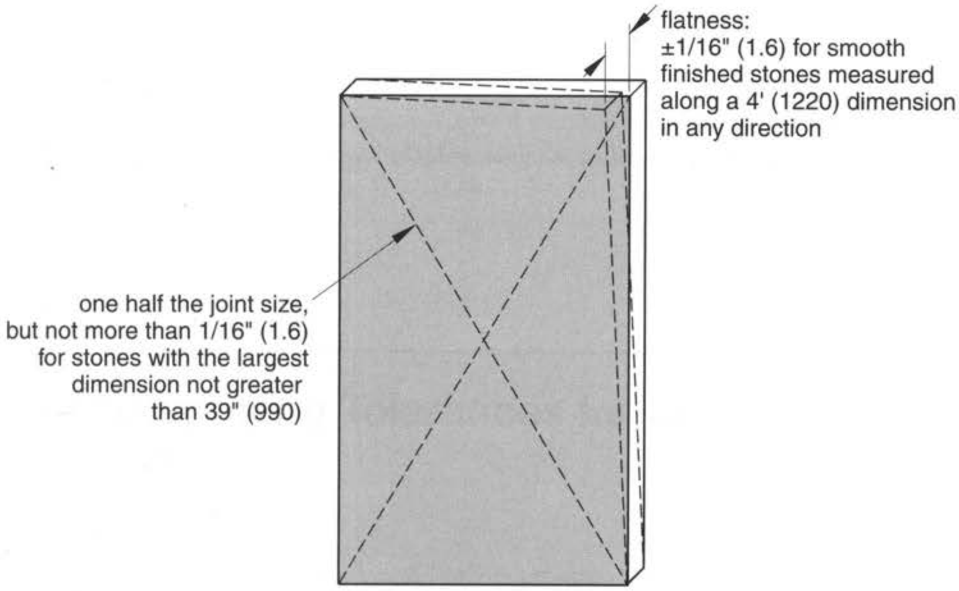


Note: maximum length of any unit shall not exceed 15 times the average thickness of the unit unless agreed by the manufacturer

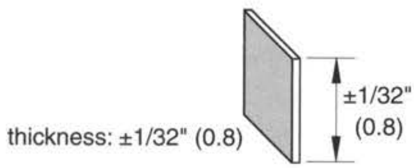
Figure 5–8 Interior stone wall cladding



(a) dimensional tolerances



(b) distortion tolerances



(c) stone tiles

Allowable Tolerances

Dimensional fabrication tolerances for interior stone are shown in Figure 5-8. Thickness tolerances as shown in Figure 5-8(a) for granite, slate, and quartz-based stone are larger than those for marble and limestone. For smooth-faced stone, the thickness tolerance is ±1⁄16 in. (0.8 mm) at exposed edges. For sawn-faced stone, the thickness tolerance is ±1⁄8 in. (3 mm) at exposed edges. For thermal, coarse-stippled finished stone and natural-cleft slate, the thickness tolerance is 3⁄16 in. (4.8 mm) at exposed edges.

The recommended maximum installation variation for interior stone wall cladding as published by the Marble Institute of America is ±1⁄8 in. (3 mm) in 10 ft. (3,050 mm), with a maximum of 1⁄32-in. (1-mm) variation between individual stones.

Related Sections

9–8 Stone Flooring

15–4 Detailing Interior Stone on Masonry

Chapter 6

Structural Lumber

6–1 Glued Laminated Timber Fabrication

Description

The tolerances shown here are for standard glued laminated timber for either interior or exterior use. The depth tolerances do not apply to special tapered or curved shapes.

Industry Standards

AITC 113-2001, *Standard for Dimensions of Structural Glued Laminated Timber* (Centennial, CO: American Institute of Timber Construction, 2001).

ANSI/AITC A190.1-2002, *Wood Products: Structural Glued Laminated Timber* (Washington, DC: American National Standards Institute, 2002).

Allowable Tolerances

The tolerances established by the American Institute of Timber Construction (AITC) are shown in Figure 6-1 and are based on dimensions at the time of manufacture. When length dimensions are not specified as critical, the tolerances shown in the diagram do not apply. The camber or straightness tolerances are for the section at the time of manufacture without any tolerance for dead-load deflection. Camber tolerances do not apply to curved members. Squareness tolerances are for standard rectangular sections and do not apply to specially shaped sections.

Related Sections

6–6 Rough Lumber Framing

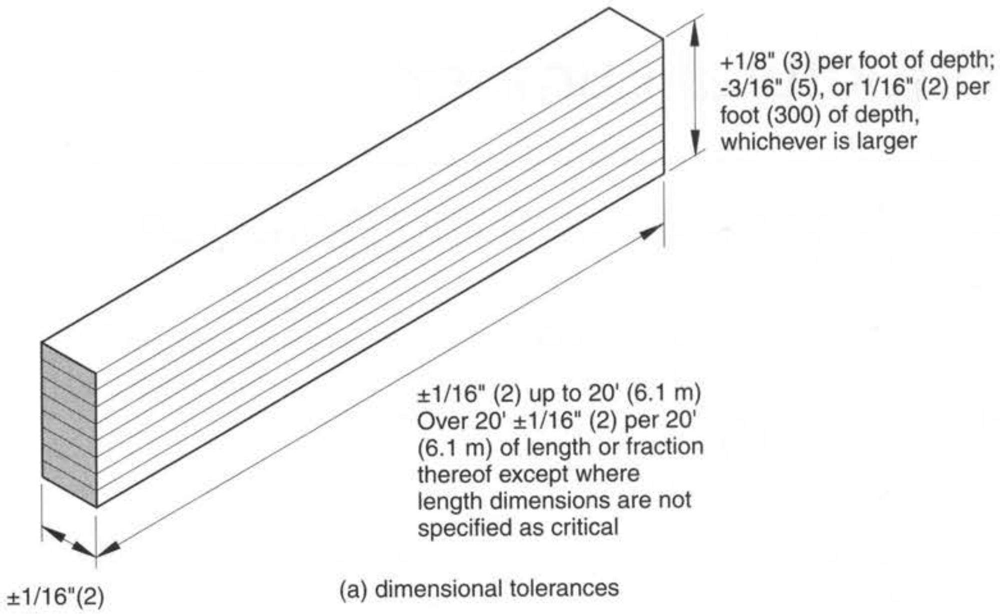
6–2 Manufacturing Tolerances for Structural Lumber

Description

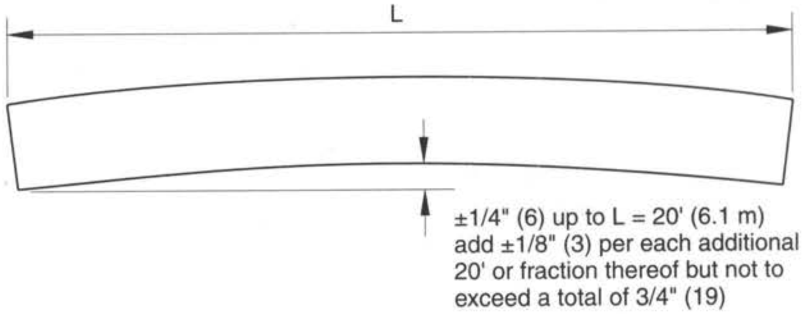
This section includes dimension lumber and timbers generally used for structural and rough framing. It does not include board lumber often used for site-built finish carpentry items.

The *American Softwood Lumber Standard* classifies dimension lumber as lumber from 2 in. (51 mm) in nominal thickness to, but not including, 5 in. (127 mm) in nominal thickness, and 2 in. or more in nominal width. Timber is lumber 5 in. or more (127 mm) nominally in the least dimension.

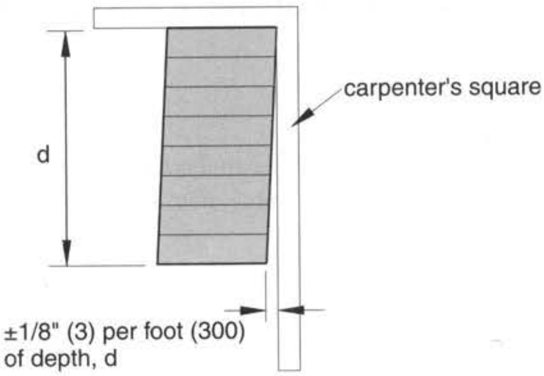
Figure 6–1 Glued Laminated Timber Fabrication



(a) dimensional tolerances

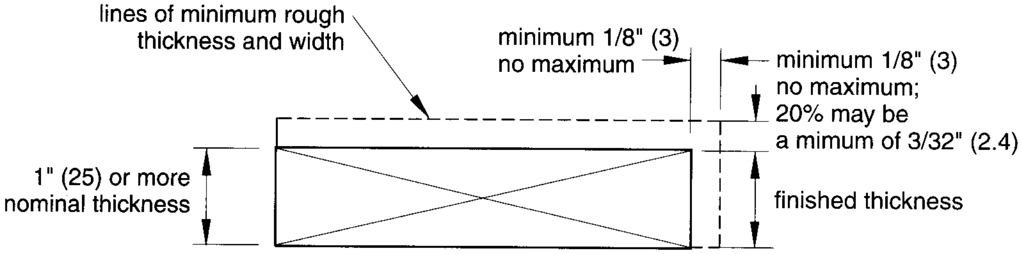


(b) camber or straightness

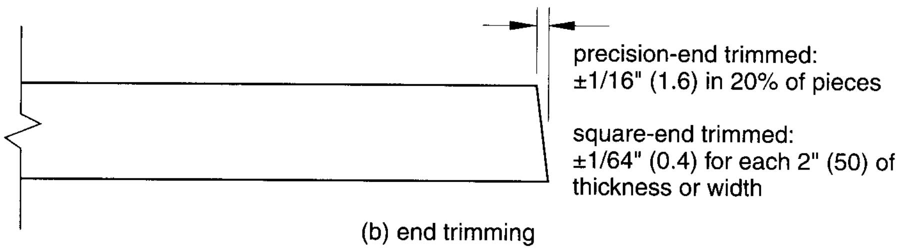


(c) squareness

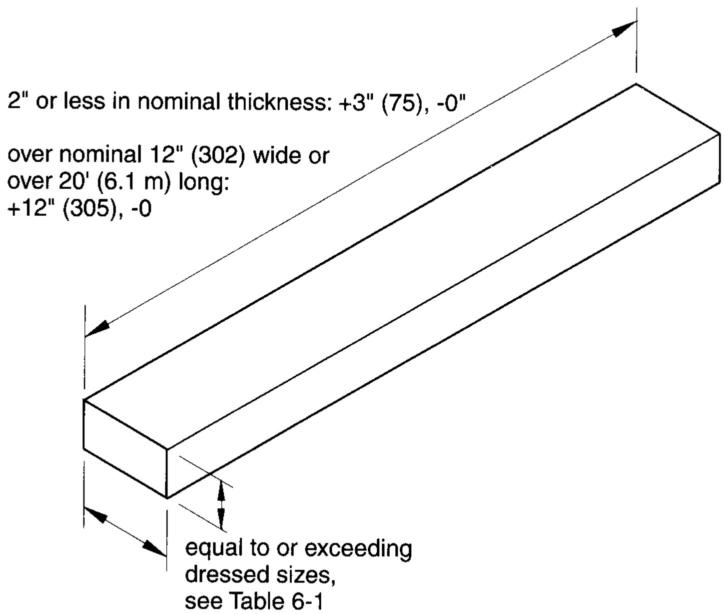
Figure 6–2 Manufacturing Tolerances for Structural Lumber



(a) rough lumber



(b) end trimming



(c) dimension lumber

Industry Standards

Voluntary Product Standard PS 20-05, *American Softwood Lumber Standard* (Gaithersburg, MD: National Institute of Standards and Technology, 2005).

Allowable Tolerances

Dimension lumber may be ordered either as dry or green lumber. *Dry lumber* is lumber that has been seasoned or dried to a moisture content of 19 percent or less, whereas *green lumber* has a moisture content greater than 19 percent. As shown in Figure 6-2(a), rough lumber size cannot be less than ⅛ in. (3.2 mm) thicker or wider than the corresponding minimum finished thickness or width, except that 20 percent of a shipment cannot be less than 3/32 in. (2.4 mm) thicker or wider.

Dressed sizes for dimension lumber must be equal to or exceed those shown in Table 6-1. These sizes are for dry lumber. Shrinkage that may occur after dressing to dry sizes can be up to 1 percent for each 4 points of moisture content below the applicable maximum or 0.7 percent for each 4 points of moisture content reduction for redwood, western red cedar, and northern white cedar. Sizes for timbers are only applicable for green lumber and are ½ in. (13 mm) smaller than the nominal dimension.

Tolerances for trimming to a given length depend on the method, either precision-end trimmed (PET) or square-end trimmed. For double-end trimmed (DET) lumber, the tolerances depend on the certified grading rules of the organization responsible for each species of lumber.

Table 6–1 Minimum sizes of dressed, dry dimension lumber

Nominal thickness, in. (mm)	Minimum actual thickness, in. (mm)	Nominal width, in. (mm)	Minimum actual width, in. (mm)
2 (50)	1½ (38)	4 (100)	3½ (89)
2½ (64)	2 (51)	6 (150)	5½ (140)
3 (76)	2½ (64)	8 (200)	7¼ (184)
3½ (89)	3 (76)	10 (250)	9¼ (235)
4 (100)	3½ (89)	12 (300)	11¼ (286)
4½ (114)	4 (102)	14 (357)	13¼ (336)

Source: Voluntary Product Standard, PS 20-05, National Institute of Standards and Technology

Related Sections

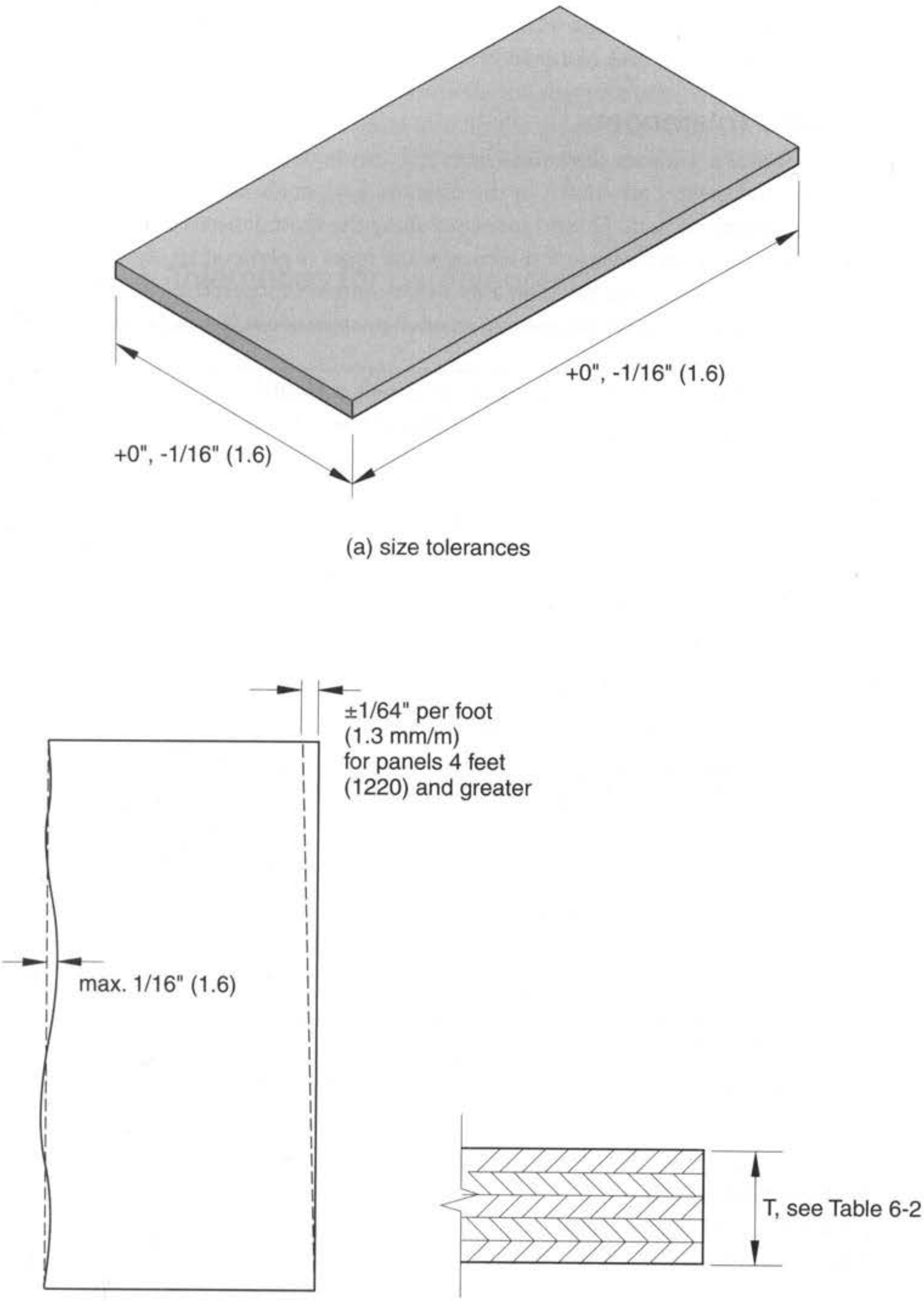
6–3 Plywood Manufacturing
6–4 Particleboard Manufacturing
7–1 Manufacturing Tolerances for Board Lumber

6–3 Plywood Manufacturing

Description

This section includes tolerances for plywood intended for construction and industrial use and that conform to U. S. Product Standard PS 1-95.

Figure 6–3 Plywood Manufacturing



(b) squareness and straightness

(c) thickness tolerances

Industry Standards

Voluntary Product Standard PS 1-95, *Construction and Industrial Plywood* (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

Voluntary Product Standard PS 2-04, *Performance Standard for Wood-Based Structural-Use Panels* (Gaithersburg, MD: National Institute of Standards and Technology, 2004).

Allowable Tolerances

Tolerances from PS 1-95 are shown in Figure 6-3. Squareness tolerances for panels 4 ft. (1,220 mm) and greater are shown in the diagram. For panels less than 4 ft. wide, the squareness tolerance is 1/16 in. (2 mm) measured along the short dimension.

Thickness tolerances for various thicknesses and types of plywood are shown in Table 6-2. Thickness tolerances are based on a moisture content of 9 percent oven dry weight and are measured with a micrometer using an anvil pressure of not less than 5 psi (34 kPa) or more than 10 psi (69 kPa).

The tolerances in PS 2-04 for structural-use panels are a little less restrictive. The PS 2-04 standards apply to plywood, waferboard, oriented strand board (OSB), structural particleboard, and composite panels. Size tolerances are +0, −1/8 in. (3.2 mm). Thickness tolerances are ±1/32 in. (0.8 mm) for panel thicknesses of 13/16 in. (20.2 mm) and less and ±5 percent of the specified thickness for thicker panels. Panels must be square within 1/64 in. per lineal foot (1.3 mm per lineal meter) of the longest side measured along the diagonals. Panel straightness is the same as in PS 1-95.

Table 6–2 Plywood thickness tolerances

Panel type	Tolerance, in (mm)
Sanded panels 3/4 in (19 mm) and less	±1/64 (0.4)
Sanded panels over 3/4 in (19 mm)	±3% of specified thickness
Unsanded, touch sanded, and overlaid panels 13/16 in (20.5 mm) and less	±1/32 (0.8)
Unsanded, touch sanded, and overlaid panels over 13/16 in (20.5 mm)	±5% of specified thickness

Source: Voluntary Product Standard, PS 1-95, National Institute of Standards and Technology

Related Sections

6–4 Particleboard Manufacturing
6–5 Fiberboard Manufacturing

6–4 Particleboard Manufacturing

Description

Particleboard is a panel product made from particles of wood and wood fibers bonded together with synthetic resins or other suitable bonding systems. There are two basic categories, one for general construction and one for flooring products. Within each category are several grades developed for various uses. In the grade designations in Tables 6-3 and 6-4, H means high density, M means medium density, LD means low density, D means decking, and PBU means underlayment.

Table 6–3 Tolerances for particleboard

	Grade tolerances, in (mm)								
	H-1	H-2	H-3	M-1	M-2	M-3	M-S	LD-1	LD-2
Length and width	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)	±0.080 (2.0)
Average panel thickness from nominal (sanded panels only)	±0.008 (0.200)	±0.008 (0.200)	±0.008 (0.200)	±0.010 (0.250)	±0.008 (0.200)	±0.008 (0.200)	±0.010 (0.250)	+0.005 –0.015 (+0.125) (–0.375)	+0.005 –0.015 (+0.125) (–0.375)

Source: ANSI A208.1-1999, Composite Panel Association

Table 6–4 Tolerances for particleboard flooring products

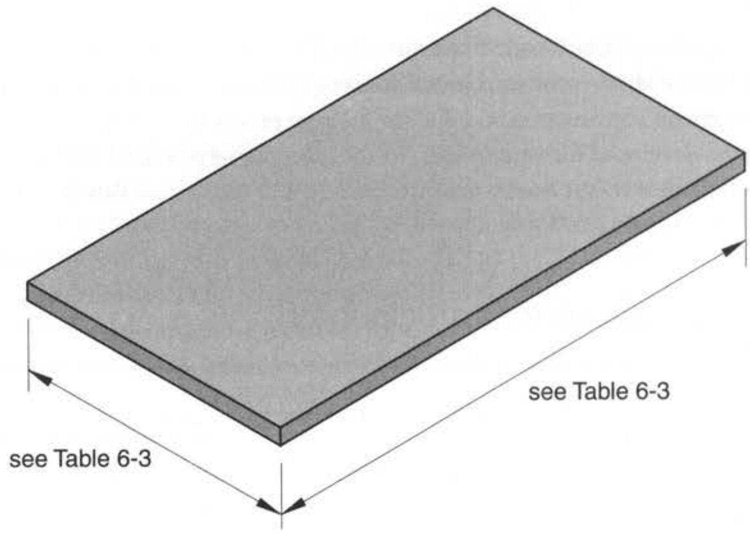
	Grade tolerances, in (mm)		
	PBU	D-2	D-3
Length and width	+0, -0.160 (+0, -4.0)	±0.080 (2.0)	±0.080 (2.0)
Average panel thickness from nominal (sanded panels only)	±0.015 (0.375)	±0.015 (0.375)	±0.015 (0.375)

Source: ANSI A208.1-1999, Composite Panel Association

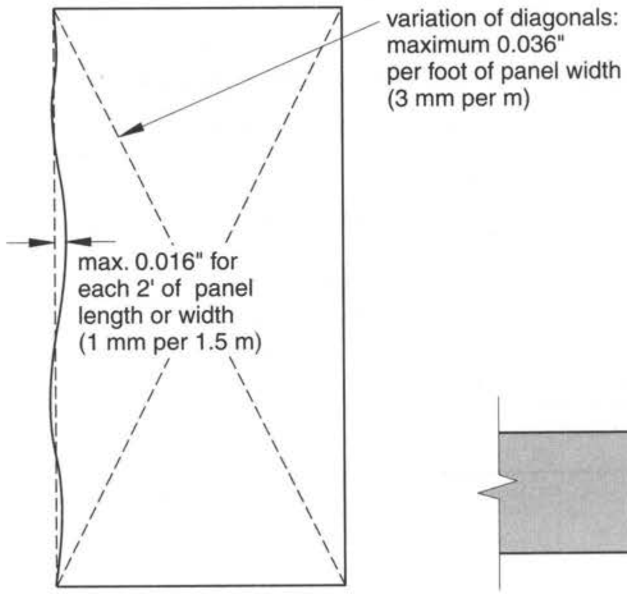
Industry Standards

ANSI A208.1-1999, *Standard for Particleboard* (Washington, DC: American National Standards Institute, 1999).

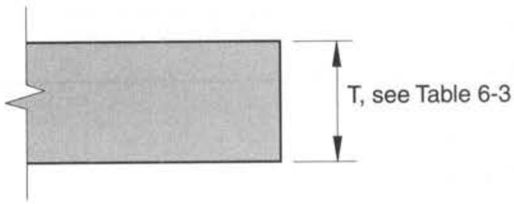
Figure 6–4 Particleboard Manufacturing



(a) size tolerances



(b) squareness and straightness



(c) thickness tolerances

Allowable Tolerances

Tolerances from ANSI (American National Standards Institute) A208.1 for squareness and straightness are illustrated in Figure 6-4. Tolerances for squareness are measured when the length and width tolerances are satisfied. Tolerances for length, width, and thickness of particleboard depend on the type and grade. The tolerances for the two categories are listed in Tables 6-3 and 6-4. The average thickness is the average of eight measurements taken at each panel corner and at the midlength of each panel edge.

The tolerances in PS 2-04 for structural-use panels are a little different. The PS 2-04 standards apply to plywood, waferboard, oriented strand board (OSB), structural particleboard, and composite panels. Size tolerances are +0, –⅛ in. (3.2 mm). Thickness tolerances are ±1/32 in. (0.8 mm) for panel thicknesses of 13/16 in. (20.2 mm) and less and ±5 percent of the specified thickness for thicker panels. Panels must be square within 1/64 in. per lineal foot (1.3 mm per lineal meter) of the longest side measured along the diagonals. Panel straightness is the same as in PS 1-95.

Related Sections

6–3 Plywood Manufacturing
6–5 Fiberboard Manufacturing

6–5 Fiberboard Manufacturing

Description

Medium-density fiberboard is a panel product made from lignocellulosic fibers bonded together with a synthetic resin or other suitable binders under heat and pressure.

Industry Standards

ANSI A208.2-2002, *Standard for MDF* (Washington, DC: American National Standards Institute, 2002).

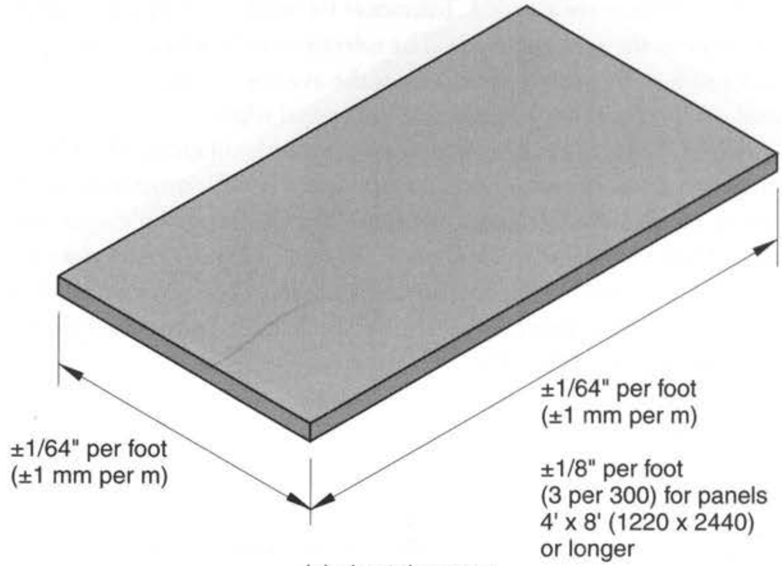
Allowable Tolerances

Tolerances for fiberboard are illustrated in Figure 6-5. For panels smaller than 4 ft. by 8 ft. (1,220 mm by 2,440 mm), the length and width tolerance is ±1/64 in. (0.4 mm) per linear ft.. The thickness tolerances shown are for surfaced panels only. The buyer and seller must agree to tolerances for unsurfaced panels.

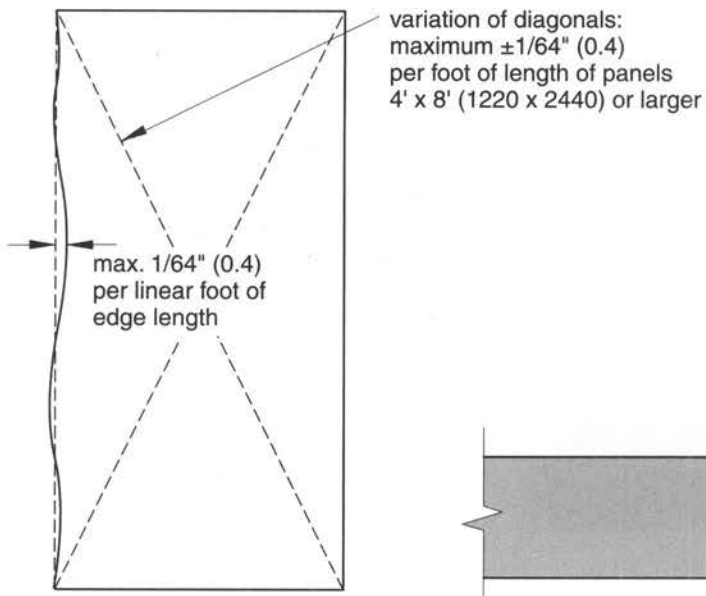
Related Sections

6–3 Plywood Manufacturing
6–4 Particleboard Manufacturing

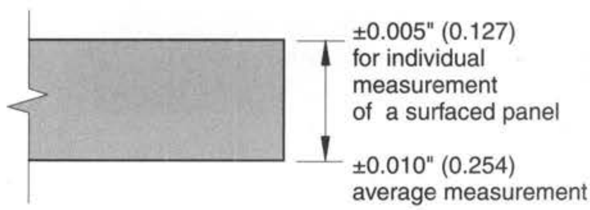
Figure 6–5 Fiberboard Manufacturing



(a) size tolerances



(b) squareness and straightness



(c) thickness tolerances

6–6 Rough Lumber Framing

Description

Rough lumber framing includes posts, beams, joists, rafters, studs, and other wood framing for residential or commercial construction. It also includes glued laminated timber and heavy timber construction.

Industry Standards

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders Remodelors™ Council, 2005).

UFGS Section 06100, *Rough Carpentry*, United Facilities Guide Specifications, May 2005 (Washington, DC: National Institute of Building Sciences, 2005) www.ccb.org/docs/ufgshome.

Allowable Tolerances

There is not a single, fixed standard for rough lumber framing tolerances. Various documents and industry practices refer to a variety of measurements. In most cases, positional tolerances of framing members of dimension lumber (less than 5 in. in nominal dimension) are not critical for the application of finish materials. A tolerance in positional tolerance of ±¼ in. (6 mm) is frequently used and is acceptable. For heavy timber construction, a tolerance of ±½ in. (13 mm) is often used.

However, plumbness tolerance is important because out-of-plumb walls and partitions can be noticeable and can affect the successful application of many finish materials. The *Residential Construction Performance Guidelines* require that walls be plumb to within ⅜ in. (10 mm) in any 32-in. (813 mm) vertical measurement. However, a smaller tolerance of ¼ in. in 10 ft. (6 mm in 3,050 mm) is often recommended for gypsum wallboard and plaster applications. For gypsum wallboard application, the maximum misalignment of adjacent framing members must not exceed ⅛ in. (3 mm).

The UFGS guide specification requires a tolerance of ¼ in. in 8 ft. (3 mm in 2,400 mm) for layout, straightness of plates and runners, plumb of studs, and true plane of framing members when the framing will be covered by finishes such as wallboard, plaster, or ceramic tile set in a mortar setting bed. When the framing will be covered by ceramic tile on a dry-set mortar, latex-portland cement mortar, or organic adhesive, the tolerances are reduced to ⅛ in. in 8 ft. (3 mm in 2,400 mm).

A tolerance of ¼ in. in 10 ft. provides a reasonable tolerance for carpenters while allowing gypsum wallboard to be installed without excessive shimming when tighter tolerances of the wallboard surface are required. For example, if a ⅛ in. in 8 ft. (3 mm in 2,440 mm) plumbness is required for a thin-set mortar application of ceramic tile, the gypsum board can be shimmed from a ¼-in. tolerance to a ⅛-in tolerance. However, most wallboard contractors prefer not to shim, so the specifier may want to require the smaller tolerance be built into the framing specifications.

Related Sections

6–2 Manufacturing Tolerances for Structural Lumber
6–7 Wood Floor Framing and Subflooring
6–9 Metal-Plate-Connected Wood Truss Erection
6–10 Prefabricated Structural Wood
9–1 Installation of Light-Gauge Framing for Gypsum Wallboard
9–5 Floor and Wall Tile

Figure 6–6 Rough Lumber Framing

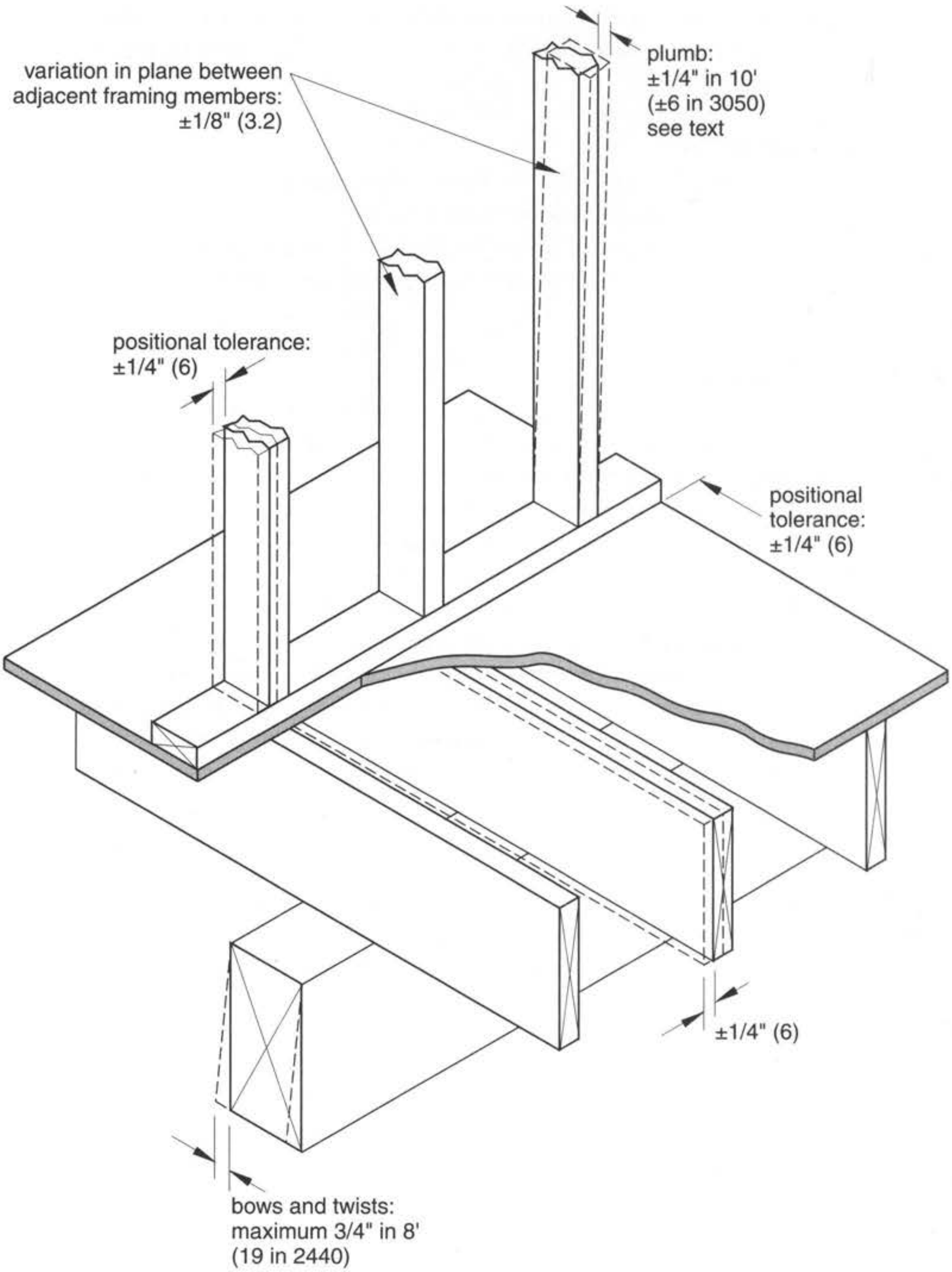
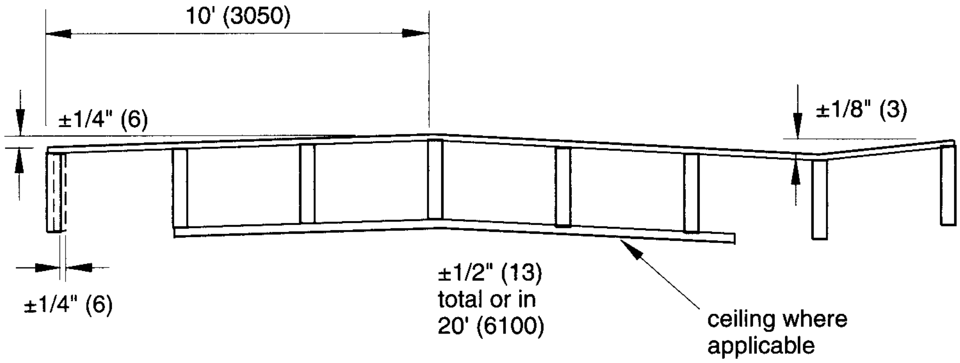
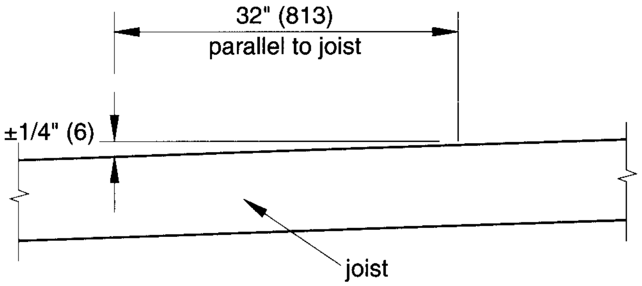


Figure 6–7 Wood Floor Framing and Subflooring



(a) perpendicular to joists



(b) parallel to joists

6–7 Wood Floor Framing and Subflooring

Description

This section includes wood floors framed with standard wood joists and covered with subflooring of plywood, particleboard, or other sheet material as a base for underlayment and other finish flooring.

Industry Standards

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders Remodelors™ Council, 2005).

UFGS Section 06100, *Rough Carpentry*, United Facilities Guide Specifications, May 2005 (Washington, DC: National Institute of Building Sciences, 2005). Available at www.ccb.org/docs/ufgshome.

GA-216, *Standard Specification for the Application and Finishing of Gypsum Board* (Washington, DC: The Gypsum Association, 2004).

Table 1604.3, "Deflection Limits" (Country Club Hills, IL: International Building Code, 2003).

Allowable Tolerances

As with rough framing, there is no single accepted tolerance for flatness of wood subfloors. In most cases, the required level depends on the type of finish surface used and other considerations, such as whether factory-built cabinets will be placed on an uneven floor, requiring shimming.

In general, a level tolerance of ±¼ in. in 10 ft. (6 mm in 3,050 mm) for new construction is a reasonable expectation and is less than the maximum allowable deflection (L/240 for dead and live load) stated by the International Building Code. It also allows for slight misalignments of supporting members. However, the *Residential Construction Performance Guidelines* state a more generous maximum out-of-level tolerance of ¼ in. in 32 in. (6 mm in 813 mm) measured parallel to the joists.

For total variation in floor level, the *Residential Construction Performance Guidelines* state a tolerance of ±½ in. (13 mm) in 20 ft. (6,100 mm).

If the floor framing is also supporting a gypsum wallboard ceiling below, the Gypsum Association requires that deflection not exceed *L*/240 of the span at full design load, where *L* is the span. In addition, the fastening surface of adjacent joists should not vary by more than ⅛ in. (3 mm).

As with other rough framing, if a smaller tolerance than those mentioned is required for finish materials, such as ceramic tile or wood flooring, it should be specified.

Related Sections

6–2 Manufacturing Tolerances for Structural Lumber
6–6 Rough Lumber Framing
6–10 Prefabricated Structural Wood
9–5 Floor and Wall Tile
9–7 Wood Flooring

6–8 Metal-Plate-Connected Wood Truss Fabrication

Description

This section includes tolerances for wood trusses fabricated in accordance with the Truss Plate Institute's quality standards. Although the standards include many details of fabrication, the tolerances shown in this section include only those that are of most interest to architects and that can affect the final appearance of a structure.

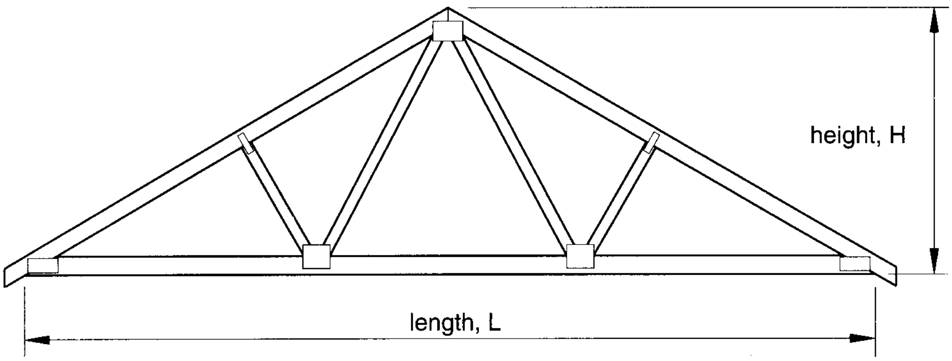
Industry Standards

ANSI/TPI 1-2002, *National Design Standard for Metal Plate Connected Wood Truss Construction* (Alexandria, VA: Truss Plate Institute, Inc., 2002).

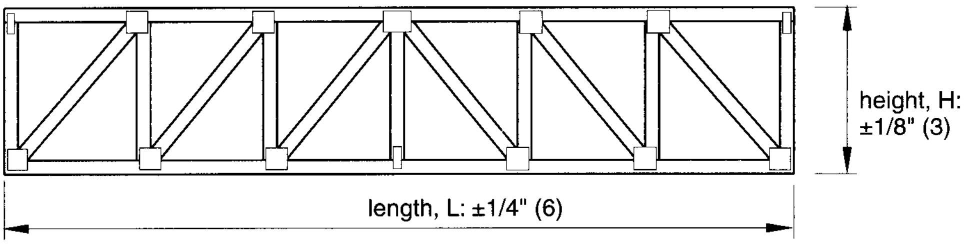
Allowable Tolerances

Overall dimensional fabrication tolerances for wood trusses are shown in Figure 6-8 and listed in Table 6-5. In addition, the Truss Plate Institute's National Design Standard includes tolerances for connector plate positioning, wood members joint tolerances, and other aspects of truss fabrication. Refer to ANSI/TPI 1 for these details.

Figure 6–8 Metal-Plate-Connected Wood Truss Fabrication



(a) pitched trusses



(b) parallel chord trusses

Note: tolerances are recommended manufacturing tolerances for finished floor truss units from design dimensions as well as for truss-to-truss variation.

Related Sections

6–9 Metal-Plate-Connected Wood Truss Erection

Table 6–5 Structural manufacturing tolerances for finished truss units

	Truss-to-truss variance Dimension of identical trusses, in (mm)	Variance from design dimensions, in (mm)
Length[a] of finished truss unit	1/2 (13)	3/4 (19)
Height[b] of finished truss unit	1/4 (6)	1/2 (13)

[a] *Length, for manufacturing tolerance purposes, is the overall length of the truss unit, excluding overhangs or extensions.*

[b] *Height, for manufacturing tolerance purposes, is the overall height of the truss unit measured from the top of the top chord to the bottom of the bottom chord at the highest point of the truss, excluding projections above the top chord and below the bottom chord, overhangs and extensions.*

Source: ANSI/TPI 1-2002, Truss Plate Institute, (www.tpinst.org). Reproduced with permission.

6–9 Metal-Plate-Connected Wood Truss Erection

Description

This section includes tolerances for wood trusses erected in accordance with the standards of the Wood Truss Council of America and the Truss Plate Institute.

Industry Standards

BCSI 1-03, *Guide to Good Practice for Handling, Installing and Bracing of Metal Plate Connected Wood Trusses*. (Madison, WI: Wood Truss Council of America and Truss Plate Institute, 2003).

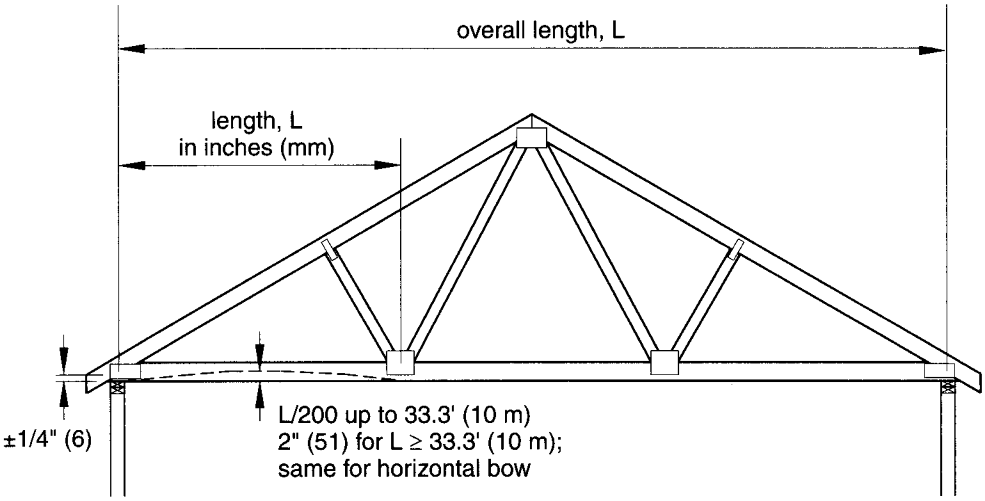
Allowable Tolerances

Placement tolerances are shown in Figure 6-9. Bow tolerances include the overall bow or the bow in any chord or panel. Vertical and horizontal placement must be within ±¼ in. (6 mm) of the placement points shown on the drawings. Special hangers or supports should be designed to accommodate this tolerance. In addition, top-chord-bearing parallel chord trusses will have a maximum gap of ½ in. (13 mm) between the inside edge of the bearing point and the first diagonal or vertical web at both ends of the truss. See Figure 6-9(c).

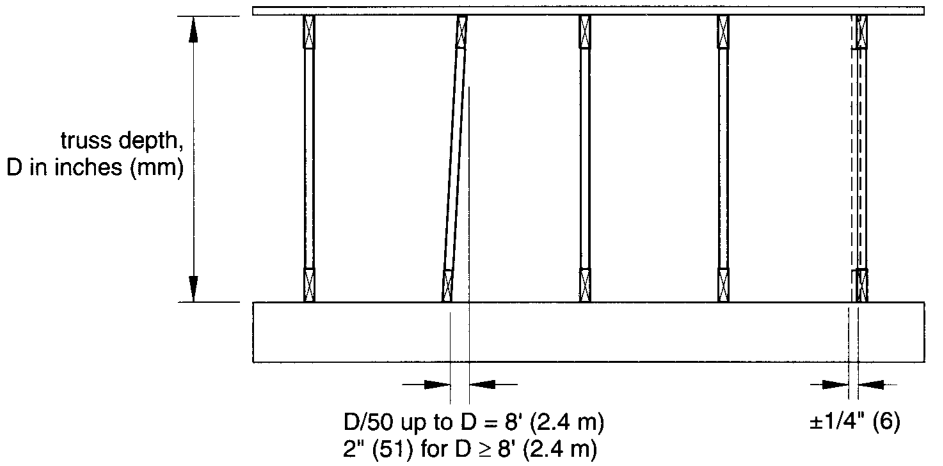
Related Sections

6–8 Metal-Plate-Connected Wood Truss Fabrication

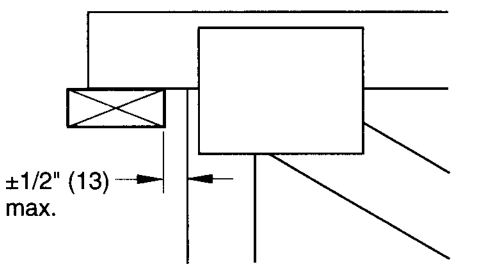
Figure 6–9 Metal-Plate-Connected Wood Truss Erection



(a) bow and vertical placement



(b) plumbness and horizontal placement



(c) tolerances for top chord bearing trusses

6–10 Prefabricated Structural Wood

Description

Prefabricated structural wood includes products such as plywood web joists, thin glued laminated framing, wood chord metal joists, or any product fabricated in the factory and composed entirely or mostly of wood products. Structural glued laminated timber is generally considered in a category by itself.

Previous Industry Guidelines

SPECTEXT Section 06151, *Wood Chord Metal Joists* (Bel Air, MD: Construction Sciences Research Foundation, 1990).

SPECTEXT Section 06196, *Plywood Web Joists* (Bel Air, MD: Construction Sciences Research Foundation, 1990).

Allowable Tolerances

There are no industry standards for the fabrication or placement of prefabricated structural wood products. Each manufacturer has its own fabricating tolerances. In critical situations, these tolerances should be verified with the manufacturer. However, the tolerances shown in Figure 6-10 are representative of several proprietary products at the time of manufacturing.

Although previous master specifications have suggested a placement tolerance of ±½ in. (13 mm), prefabricated structural wood products can usually be placed within a ¼-in. (6-mm) positional tolerance, as with rough carpentry.

Related Sections

6–1 Glued Laminated Timber Fabrication
6–6 Rough Lumber Framing

6–11 Structural Insulated Panels

Description

Structural insulated panels (SIPs) are composite building panels consisting of a core of rigid foam insulation, typically expanded polystyrene, sandwiched between two structural skins of oriented strand board. They are built in a factory and are used for floors, walls, and roofs in residential and commercial buildings.

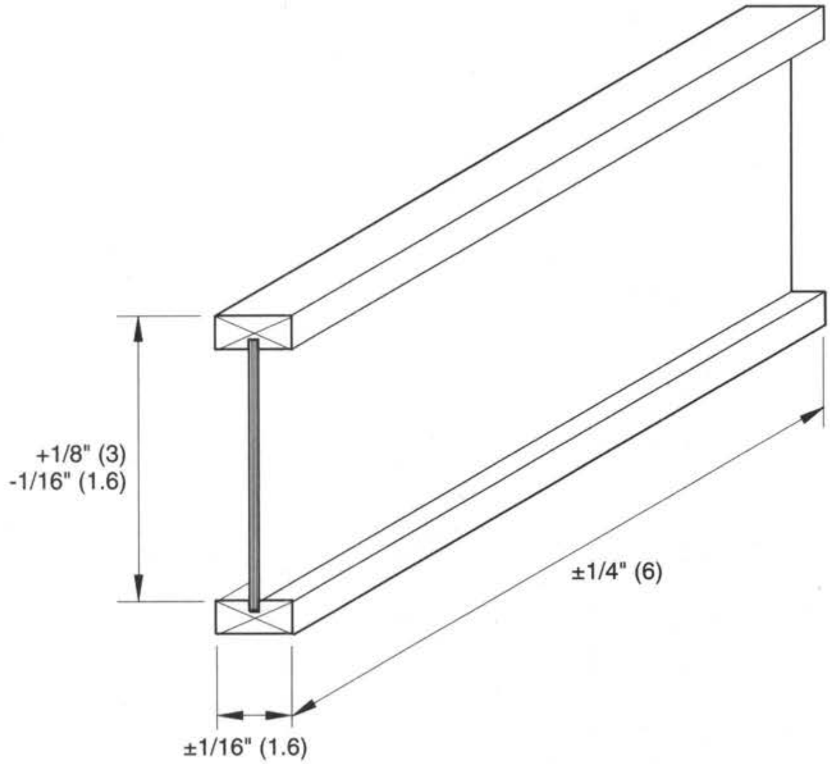
Industry Standards

There are no industry standards for structural insulated panels.

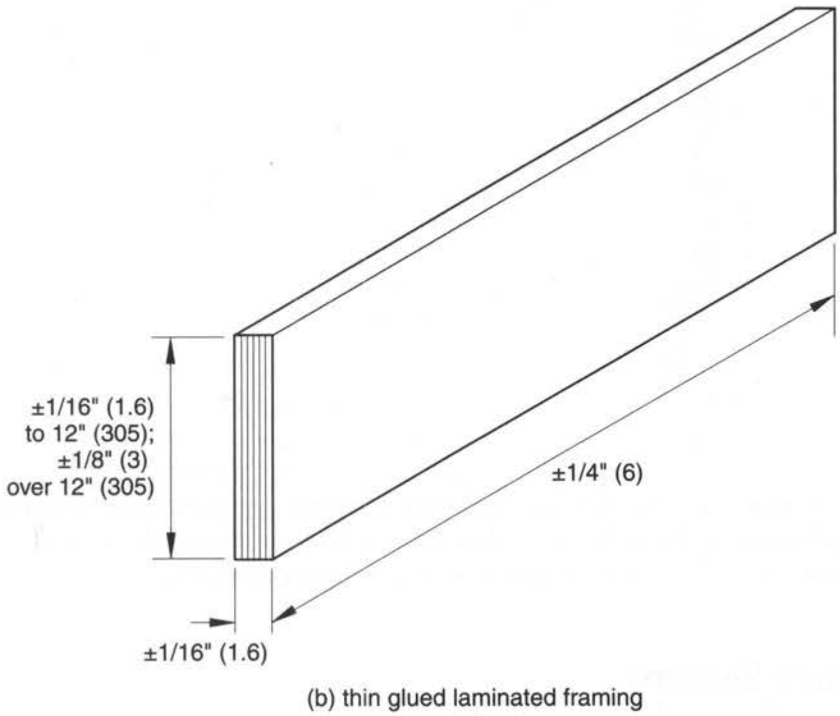
Allowable Tolerances

Currently there are no industry standards for SIPs. However, many manufacturers work with a tolerance from ±⅛ in. (3 mm) to ±¼ in. (6 mm) for size, placement, and vertical and horizontal alignment of erected panels. Some manufacturers have tighter manufacturing tolerances because they use computer numerical controlled (CNC) router technology to fabricate panels and openings in the panels. Because of the variety of fabrication and erec-

Figure 6–10 Prefabricated Structural Wood

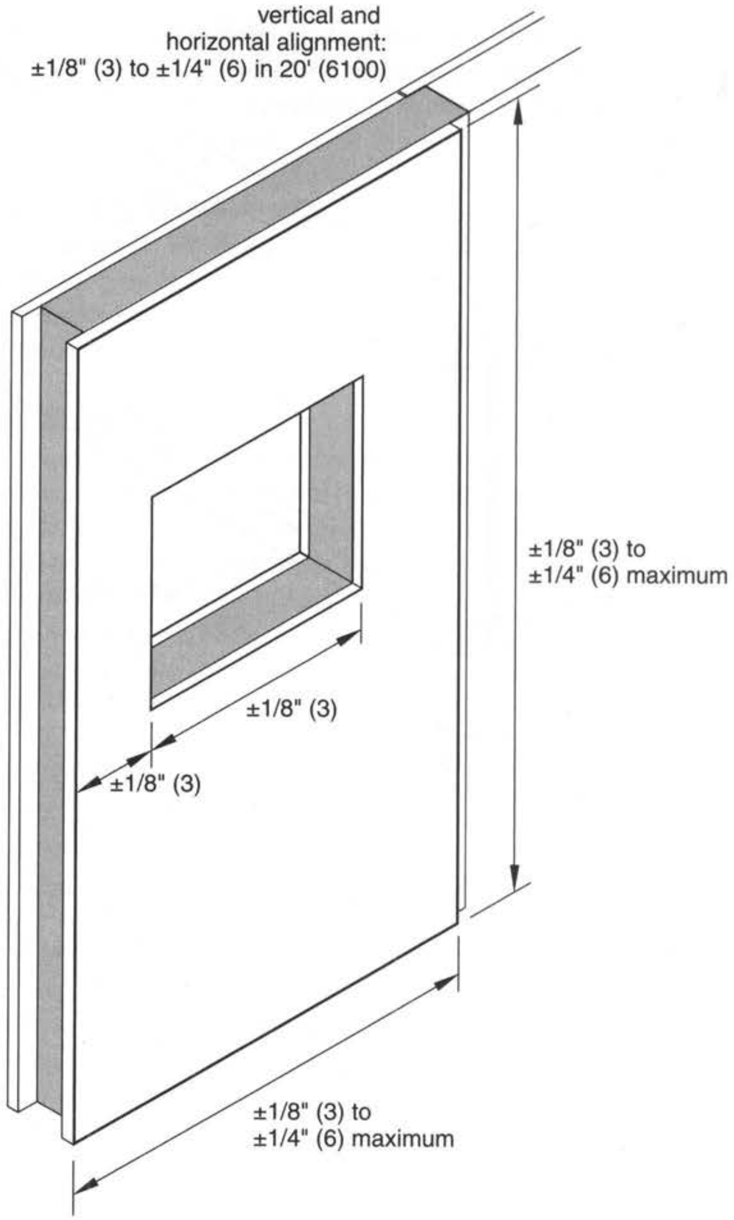


(a) plywood web joists



(b) thin glued laminated framing

Figure 6–11 Structural Insulated Panels



tion tolerances, these should be verified with the manufacturer and contractor and the required tolerances should be included in the specifications. It may also be advisable to allow for small, ⅛-in. (3-mm) expansion joints to provide clearance for minor erection tolerances.

Related Sections

6–1 Glued Laminated Timber Fabrication

6–6 Rough Lumber Framing

Chapter 7

Finish Carpentry and Architectural Woodwork

7–1 Manufacturing Tolerances for Board Lumber

Description

This section includes board lumber generally used for site-fabricated finish carpentry and miscellaneous framing and blocking for other finish carpentry or architectural woodwork. It does not include standard wood molding shapes.

The *American Softwood Lumber Standard* classifies board lumber as lumber less than 2 in. (51 mm) in nominal thickness and 2 in. or more (51 mm) in nominal width. Boards less than 6 in. (150 mm) in nominal width may be classified as strips. Southern pine board lumber is classified similarly except that boards are 1 in. (25 mm) or more in width.

Industry Standards

Voluntary Product Standard PS 20-05, *American Softwood Lumber Standard* (Gaithersburg, MD: National Institute of Standards and Technology, 2005).

Allowable Tolerances

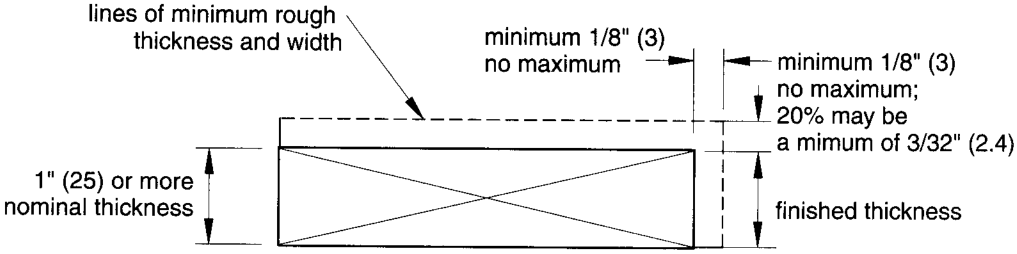
Board lumber may be ordered either as rough lumber or dressed lumber, although dressed is the most common use. As shown in Figure 7-1(a), rough lumber size cannot be less than ⅛ in. (3.2 mm) thicker or wider than the corresponding minimum finished thickness or width, except that 20 percent of a shipment cannot be less than 3/32 in. (2.4 mm) thicker or wider.

Table 7–1 Minimum sizes of dressed, dry finish, or board lumber

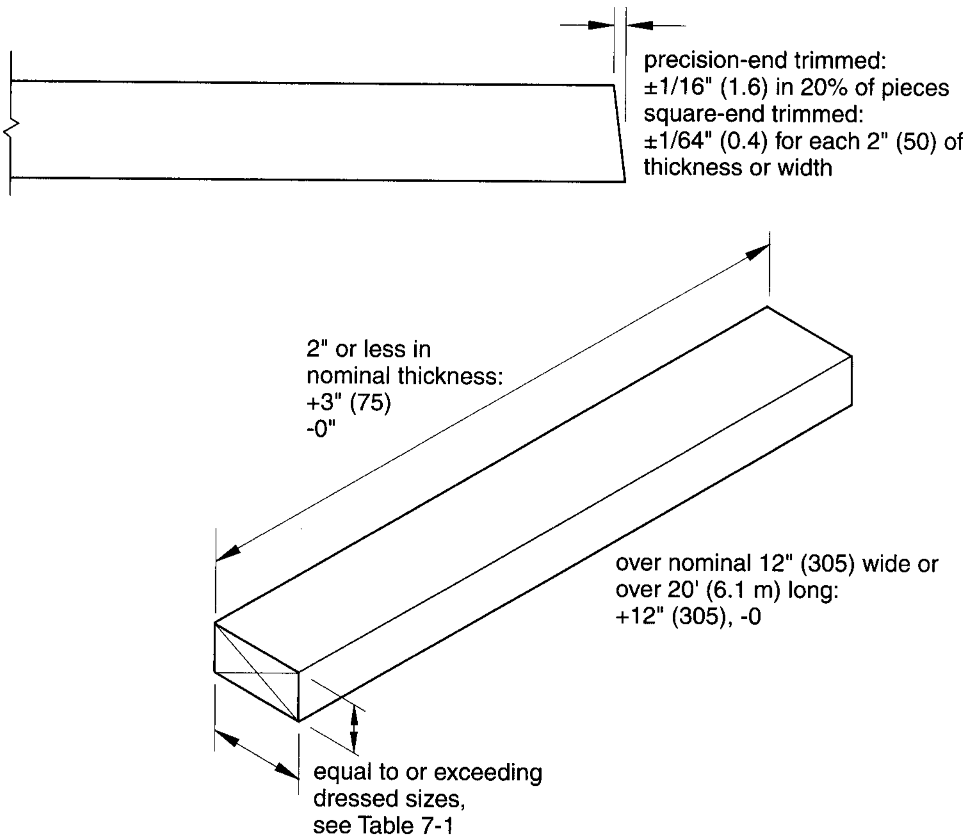
Nominal thickness, in (mm)	Minimum actual thickness, in (mm)	Nominal width, in (mm)	Minimum actual width, in (mm)
½ (13)	7/16 (11)	2 (50)	1½ (38)
⅝ (16)	9/16 (14)	3 (76)	2½ (64)
¾ (19)	⅝ (16)	4 (100)	3½ (89)
1 (25)	¾ (19)	5 (125)	4½ (114)
1¼ (32)	1 (25)	6 (150)	5½ (140)
1½ (38)	1¼ (32)	8 (200)	7¼ (184)

Source: Product Standard PS 20-05, National Institute of Standards and Technology

Figure 7–1 Manufacturing tolerances for board lumber



(a) rough lumber



(b) dressed board lumber

Dressed sizes must be equal to or exceed those shown in Table 7-1. These sizes are for dry lumber at 19 percent moisture content or less. Shrinkage that may occur after dressing to dry sizes can be up to 1 percent for each 4 points of moisture content below the applicable maximum or 0.7 percent for each 4 points of moisture content reduction for redwood, western red cedar, and northern white cedar.

Related Sections

6–2 Manufacturing Tolerances for Structural Lumber
6–3 Plywood Manufacturing
6–4 Particleboard Manufacturing

7–2 Site-Built Cabinets and Countertops

Description

For some residential and small commercial projects, cabinets and countertops are built on-site. However, in most cases, prebuilt cabinets are installed by finish carpenters. Such site-built and installed cabinets do not follow the tolerances of the Architectural Woodwork Institute described in later sections unless specifically stated in the specifications.

Few standards exist for finish carpentry work, and tolerances for construction and installation often depend on the skill of the individual worker. Two standards that are often used for residential construction are included in this section.

Industry Standards

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders Remodelors™ Council, 2005).

SPECTEXT Section 06200, *Finish Carpentry* (Bel Air, MD: Construction Sciences Research Foundation, 1990).

Allowable Tolerances

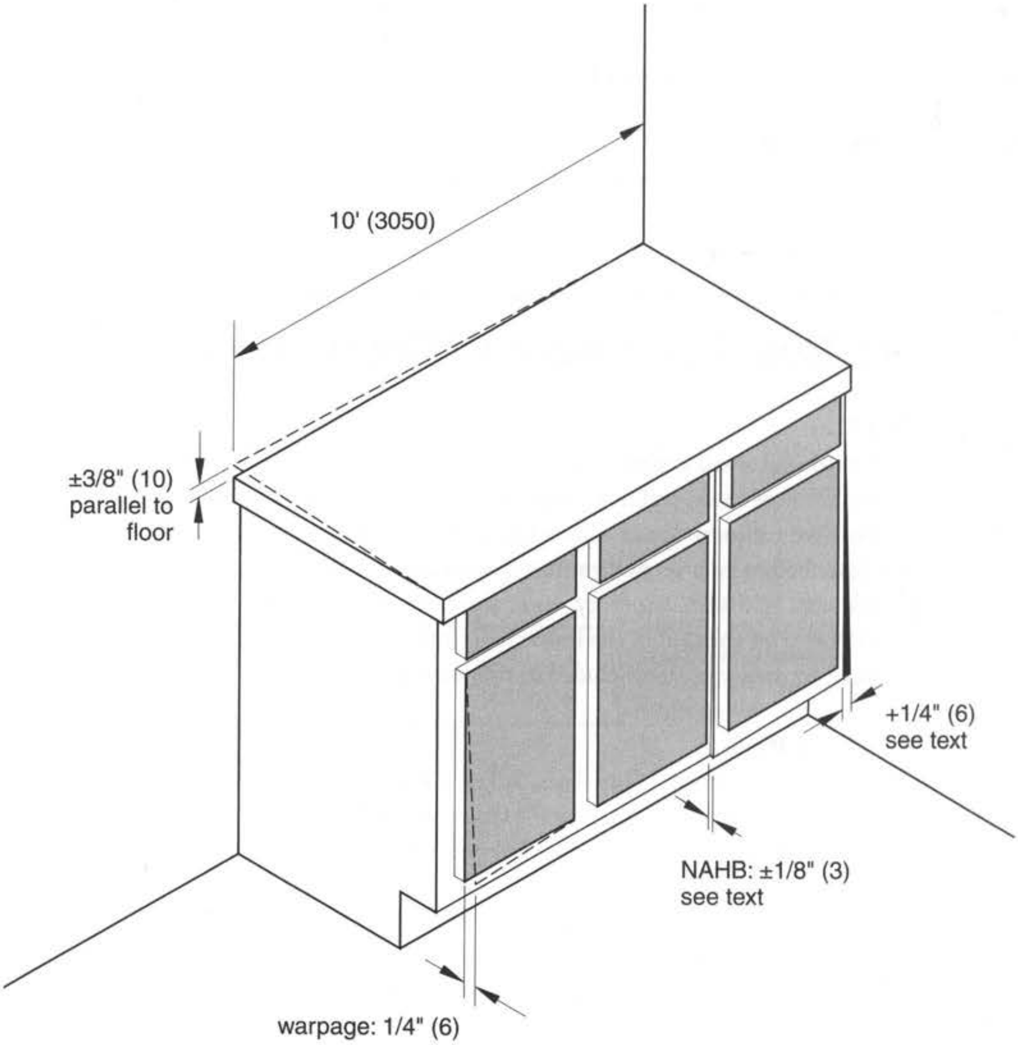
As shown in Figure 7-2, the *Residential Construction Performance Guidelines* limit gaps between cabinets and the walls or ceiling to not more than ¼ in. (6 mm). Cabinet faces can be as much as ⅛ in. (3 mm) out of line. Countertops should be not more than ⅜ in. per 10 ft. (10 mm per 3,050 mm) out of parallel with the floor. The guidelines also allow the countertop to be installed proportionately out of level if the floor is not level. However, in new construction, it is possible to shim below the base cabinets to bring a countertop level and conceal the shim space with the finish base.

The *Residential Construction Performance Guidelines* should be considered maximums, as most competent finish carpenters work to tighter limits. For example, the SPECTEXT master specifications recommend that finish carpentry be scribed when abutting other components with a maximum gap of 1/32 in. (0.8 mm). Adjacent cabinets should not be out of alignment by more than 1/16 in. (1.6 mm), nor should cabinet corners be out more than ⅛ in. (3 mm). Cabinet warpage should not exceed ¼ in. (6.4 mm) as measured from the face frame to the point of furthermost warpage.

Related Sections

7–5 Architectural Cabinets
7–6 Modular Cabinets
7–7 Countertops

Figure 7–2 Site-built cabinets and countertops



see also limits in Sections 7-5, 7-6, and 7-7

7–3 Site-Built Stairs and Trim

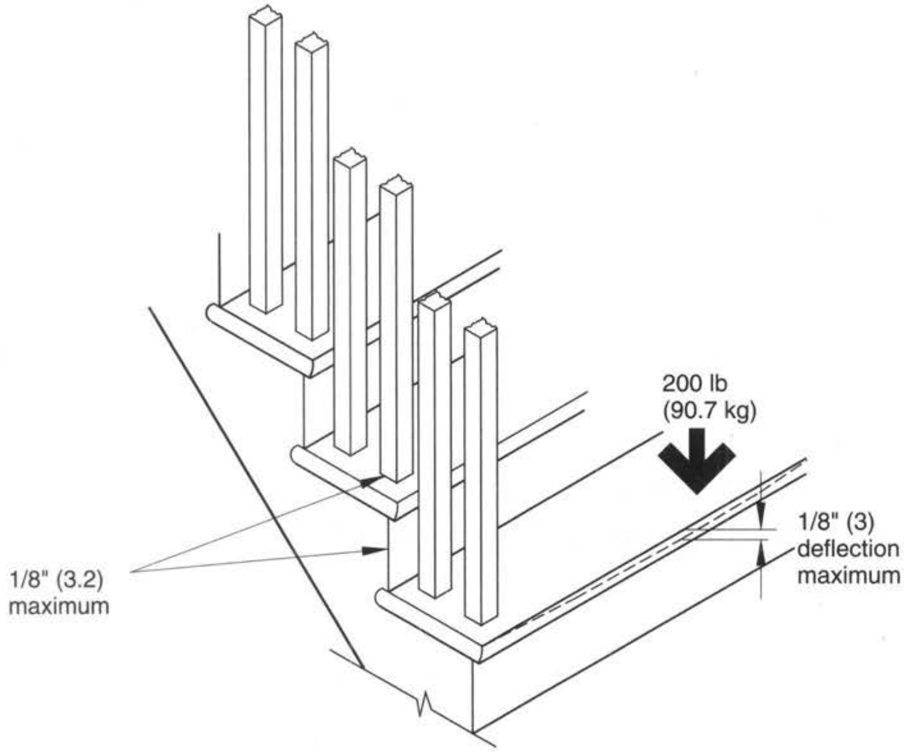
Description

This section includes woodwork build at the job site by finish carpenters. Site-built stairs and trim are commonly used in residential and small commercial projects where factory-built architectural woodwork is not required.

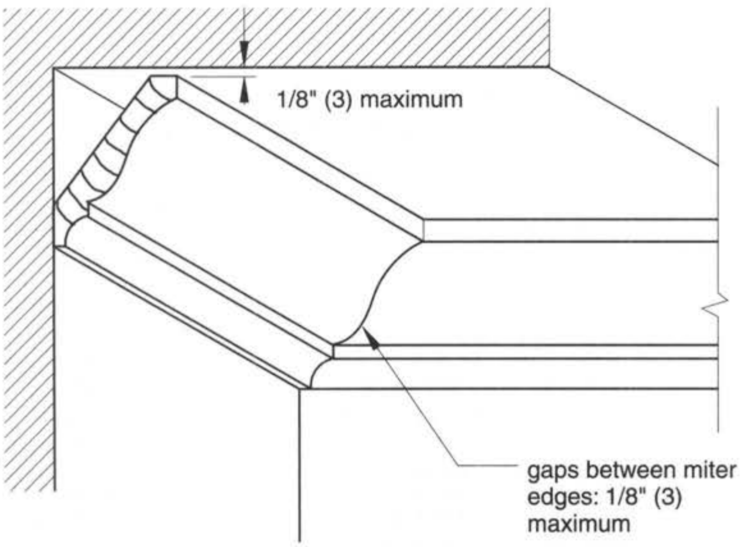
Industry Standards

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders Remodelors Council, 2005).

Figure 7–3 Site-built stairs and trim



(a) stairs



(b) trim

Allowable Tolerances

There are few standards for finish carpentry items such as stairs, shelving, and trim. Some of these are shown in Figure 7-3. The *Residential Construction Performance Guidelines* recommend that the maximum vertical deflection of interior stair treads not exceed ⅛ in. (3 mm) under a load of 200 lb. (90.7 kg). Cracks between adjoining parts that are designed to meet flush and cracks between interior stair railing parts should not exceed ⅛ in. (3 mm). For trim and moldings, openings at joints and at joints between moldings and adjacent surfaces should not exceed ⅛ in. (3 mm). Gaps at miter corners should not exceed ⅛ in. (3 mm).

As with site-built cabinets, most competent carpenters should be able to construct stairs and trim to tolerances closer to 1/16 in. (1.6 mm).

Related Sections

7–4 Standing and Running Trim
7–10 Stairwork

7–4 Standing and Running Trim

Description

Standing and running trim are shop-fabricated items such as door and window casings, base molding, and cornice molding. Standing trim is an item of fixed length installed with a single length of wood. Running trim is a continuous item requiring more than one length, such as chair rails or baseboards.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

WM 4-99, *General Requirements for Wood Moulding* (Woodland, CA: Wood Moulding and Millwork Producers Association, 1999).

Table 7–2 Tightness and flushness of plant assembled joints

	Grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
Location	**Interior**	**Exterior**	**Interior**	**Exterior**	**Interior**	**Exterior**
Miter joint	0.015 (0.4) wide by 20% of joint length	0.025 (0.6) wide by 30% of joint length	0.25 (0.6) wide by 20% of joint length	0.050 (1.3) wide by 30% of joint length	0.050 (1.3) wide by 20% of joint length	0.075 (1.9) wide by 30% of joint length
Stop/jamb interface	0.015 (0.4) x 3 (76), and no gap may occur within 72 (1829) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 60 (1524) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.050 (1.3) x 8 203), and no gap may occur within 48 (1219) of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Stop joint	0.015 (0.4)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

Maximum gap between fixed components shall be tested at points designed to join; where members connect or touch.

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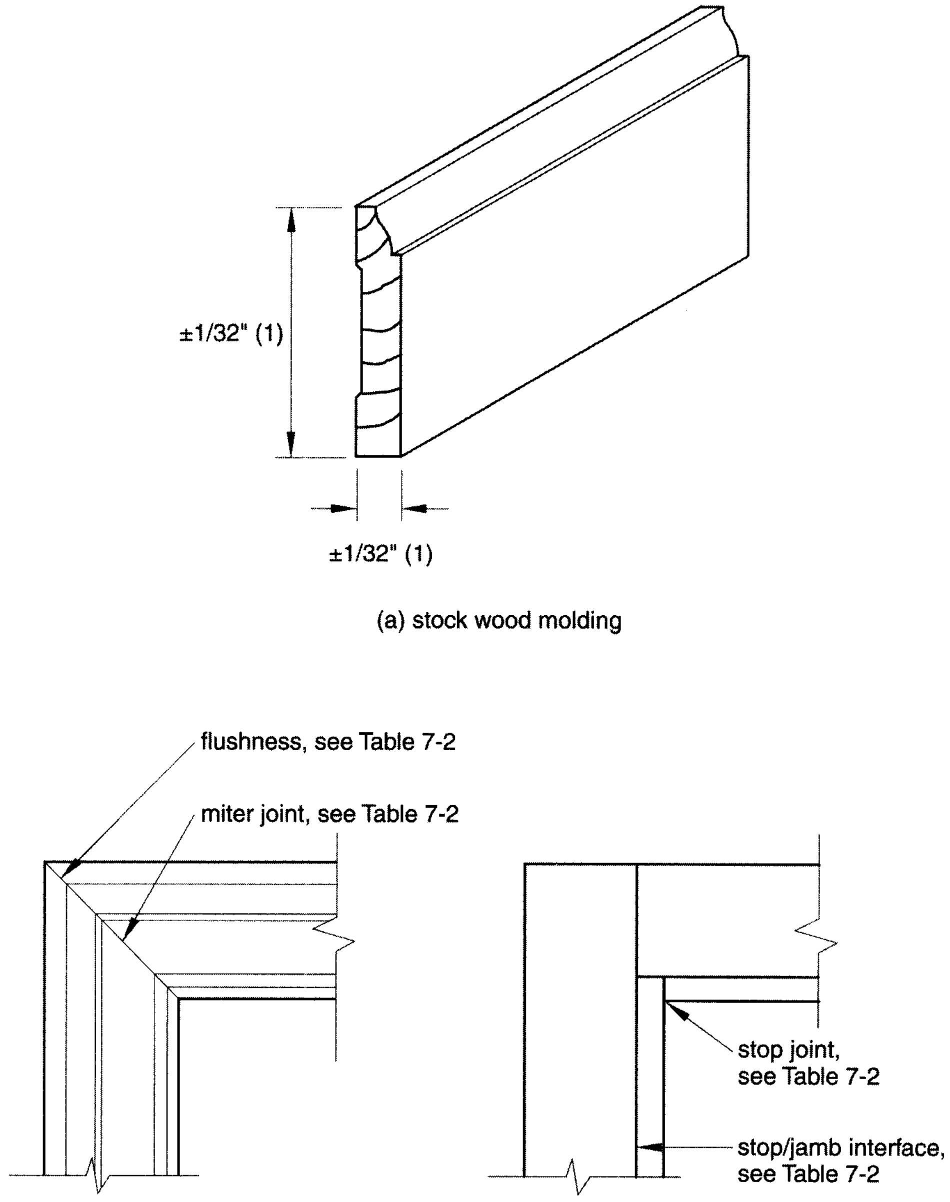
Figure 7–4 Standing and Running Trim

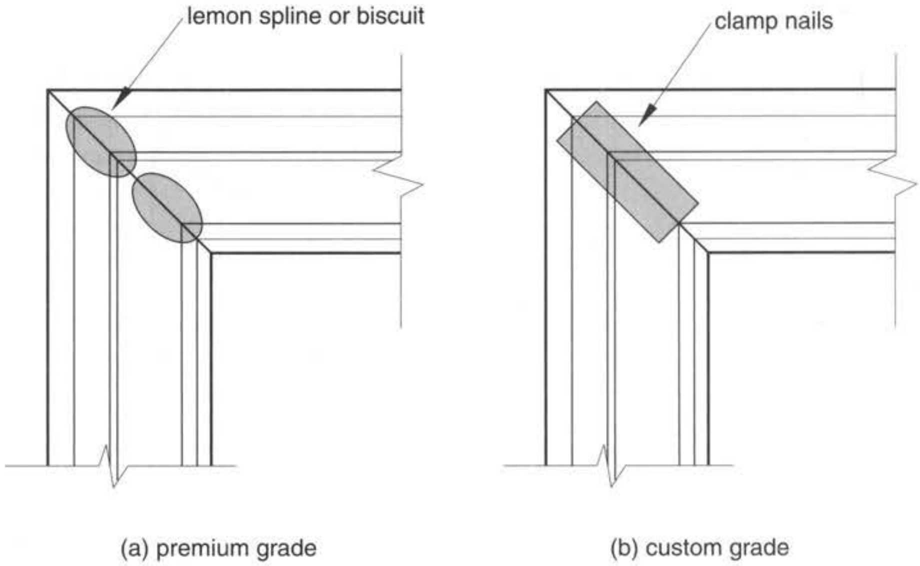


(a) stock wood molding

(b) architectural woodwork trim joints

(c) architectural woodwork jambs

Figure 7–4.1 Plant assembly of mitered joints



Allowable Tolerances

For standard stock molding made to the Wood Moulding and Millwork Producers Association standards, dimensional tolerances are ±1/32 in. (1 mm), as shown in Figure 7-4(a).

As with all tolerances for architectural woodwork built according to the Architectural Woodwork Institute (AWI) *Architectural Woodwork Quality Standards*, tolerances depend on which of the three grades is specified. Premium is the highest grade. Test locations are shown in Figures 7-4(b) and (c). Joint tolerances for plant-assembled joints are shown in Table 7-2. Methods of plant assembly of mitered joints are shown in Figure 7-4.1.

Related Sections

7–3 Site-Built Stairs and Trim
7–17 Architectural Woodwork Installation

7–5 Architectural Cabinets

Description

This section includes custom-fabricated cabinets, teller lines, desks, display cases, and similar items designed for a particular project. Items included as architectural cabinets are completely manufactured and finished in the mill shop with only minor assembly and finish touch-up on the job site. The tolerances included here are for both wood veneer and high-pressure decorative laminate (HPDL) clad cabinets.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Fabrication tolerances for the three standard AWI grades are shown in Figure 7-5. These tolerances are the same for both wood veneer and laminate clad cabinets except where noted.

The gap tolerances are for the fitting of cabinet doors, drawers, and removable panels and are subject to the size of the component, allowable warpage, hardware, and other installation variables. The gap tolerances listed are AWI-recommended targeted deviations and are subject to such variables.

Flatness tolerances shown in Figure 7-5(c) are measured diagonally after installation, and the permitted values are listed in Table 7.3. These values are per linear foot or a fraction thereof.

AWI *Quality Standards* require that cabinets be installed plumb and square for all grades and that exposed surfaces be scribed to a wall with a 1/32-in. (0.8-mm) gap tolerance for premium-grade cabinets.

Related Sections

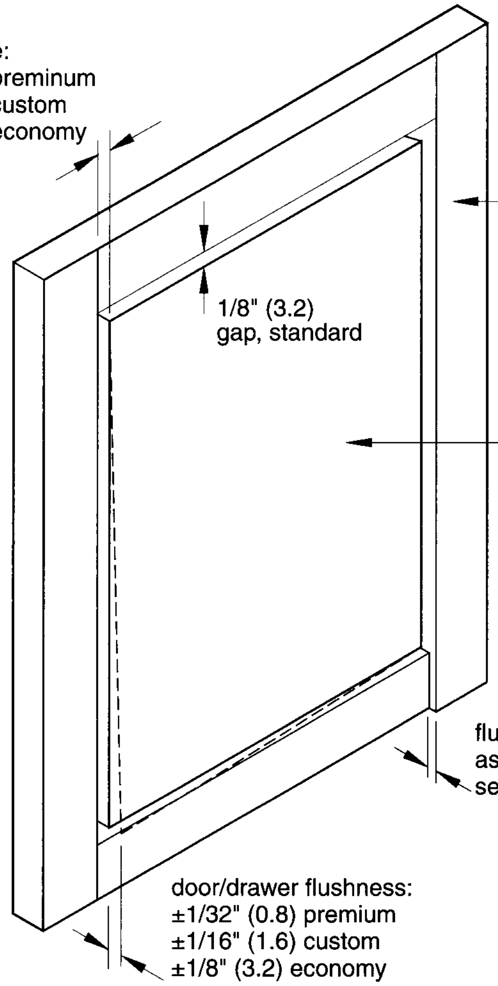
7–2 Site-Built Cabinets and Countertops
7–6 Modular Cabinets
7–7 Countertops

Table 7–3 Flushness and flatness of cabinet joints and panels

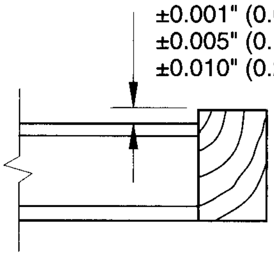
	Tolerances, in (mm)		
	Premium	**Custom**	**Economy**
Flushness, wood veneer	0.001 (0.03)	0.005 (0.13)	0.010 (0.25)
Flushness, laminate clad	0.005 (0.13)	0.010 (0.25)	0.015 (0.38)
Flatness (per linear foot)	0.027 (0.7)	0.036 (0.9)	0.050 (1.3)

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

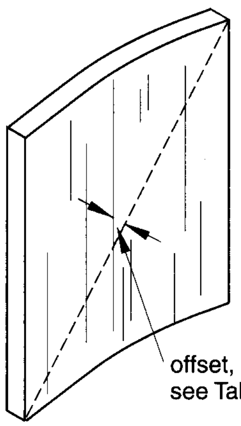
Figure 7–5 Architectural cabinets



(a) fitting tolerances



(b) edgeband tolerance



(c) flatness tolerance

7–6 Modular Cabinets

Description

Modular cabinets are mass-produced casework using a manufacturer's standard details and sizes. Modular cabinets are adapted for a particular job by using appropriate sizes and filler panels and finishing with custom countertops. The tolerances included here are for both wood veneer and high-pressure decorative laminate clad cabinets.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

ANSI/KCMA A161.1-2000, *Recommended Performance and Construction Standards for Kitchen and Vanity Cabinets*, (Potomac Falls, VA: Kitchen Cabinet Manufacturers Association, 2000).

Allowable Tolerances

The various tolerances are shown in Figure 7-6. The AWI standards do not have different tolerances for the three grades normally used; there is only one tolerance for each cabinet part.

In considering the tightness and flushness of plant assembled joints shown in Figure 7-6(b), a reasonable assessment should be made between the finished product and absolute compliance with the AWI standard. The Kitchen Cabinet Manufacturers Association standards are more stringent. For exposed exterior joints on the face of the cabinet and between stiles and rails of a framed door, a maximum gap of 0.02 in. (0.5 mm) is allowed, with the maximum length of the gap of 30 percent of the total length of the joint. Refer to ANSI/KCMA A161.1 for other gap limitations.

AWI *Quality Standards* require that doors and drawer fronts must align vertically, horizontally, and in front plane within the $\frac{5}{32}$-in. (4-mm) tolerance set in the standards. Further, cabinets must be installed plumb and square for all grades, and exposed surfaces must be scribed to a wall with a $\frac{1}{32}$-in (0.8-mm) gap tolerance, but for premium-grade cabinets only.

Related Sections

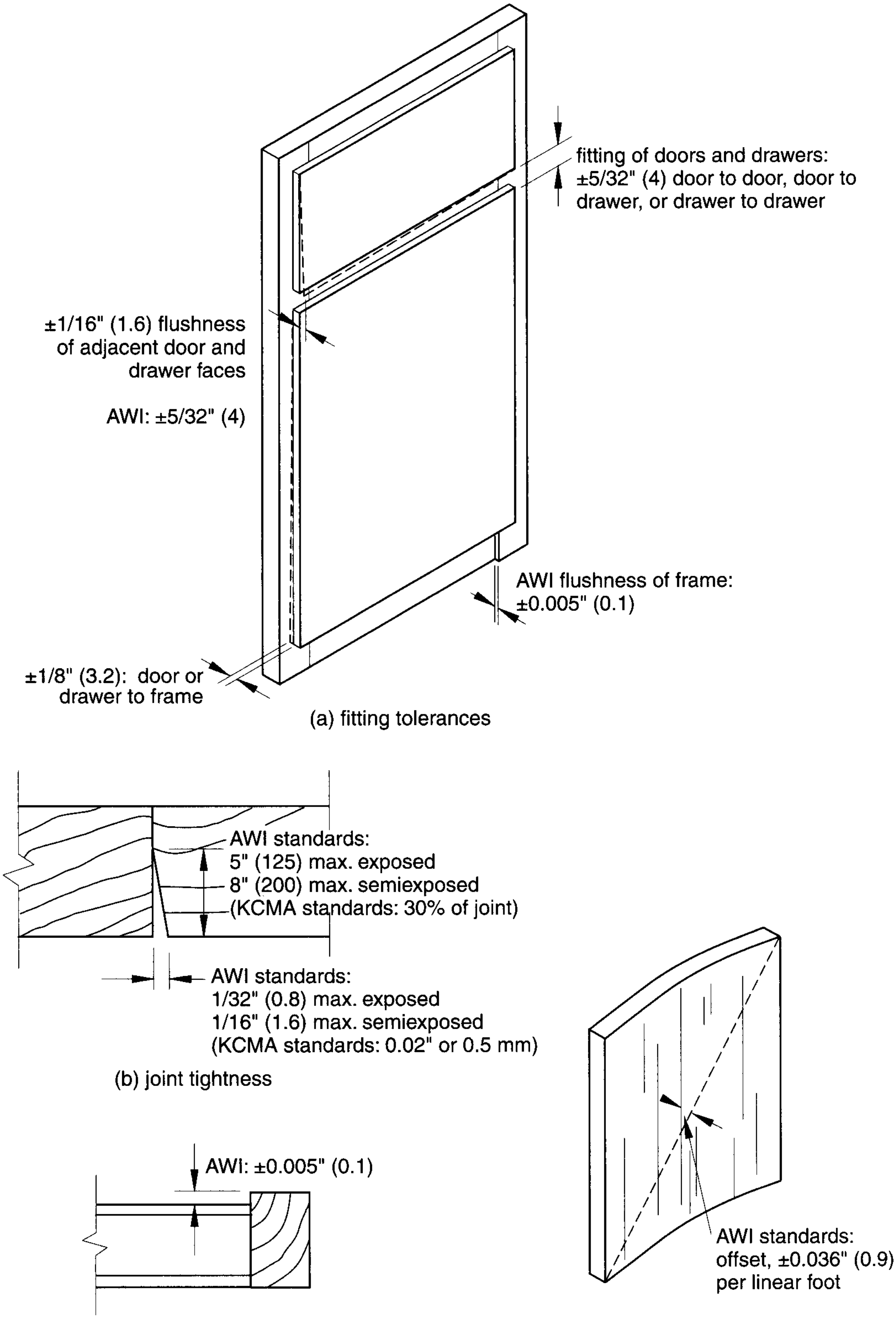
7–2 Site-Built Cabinets and Countertops
7–5 Architectural Cabinets
7–7 Countertops

7–7 Countertops

Description

The tolerances included in this section include AWI standards for countertops made with wood veneer, HPDL, post-formed HPDL, combination material tops, solid laminated tops (butcher block), and solid wood tops. Also included is solid surfacing material used for countertops.

Figure 7–6 Modular cabinets



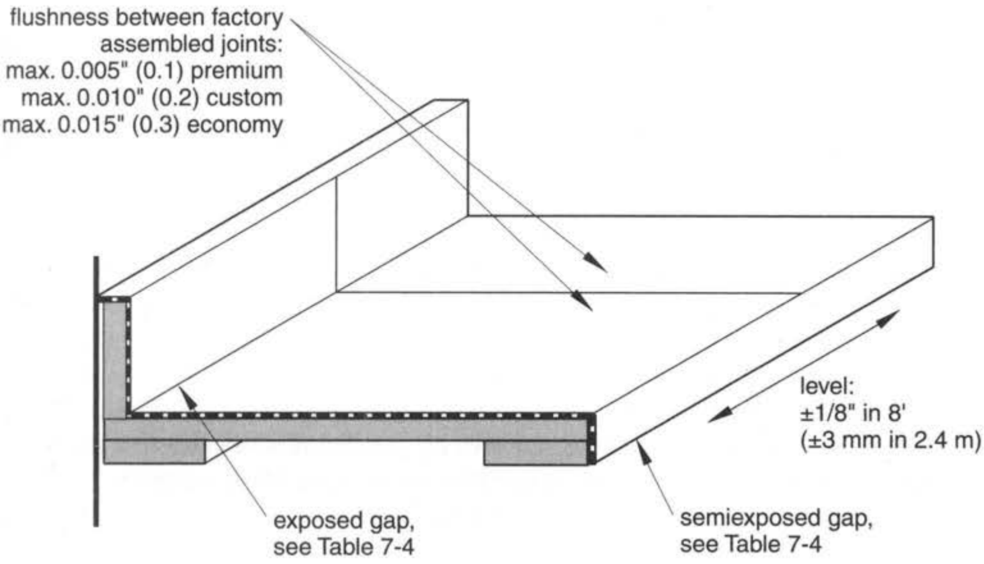
(a) fitting tolerances

(b) joint tightness

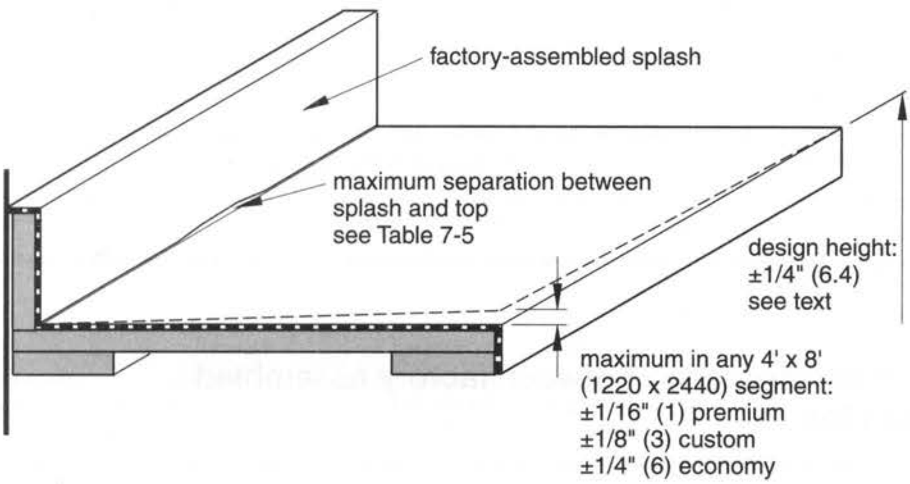
(c) edgeband tolerance

(d) flatness tolerance

Figure 7–7 Countertops



(a) joint and flushness tolerances



(b) flatness and separation tolerances

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Master Specifications, Solid Surface Materials. (Arlington, VA: International Cast Polymer Alliance, 2006) www.icpa-hq.org/professionals/mastersp.cfm.

Allowable Tolerances

Countertop tolerances are shown in Figure 7-7. When the entire countertop is factory assembled, the joint gap tolerances are as listed in Table 7.4 and shown in Figure 7-7(a). When a factory-assembled backsplash is jointed with a countertop in the field, the tolerances are as listed in Table 7.5 and shown in Figure 7-7(b).

Edges of laminate tops are eased, and there can be a maximum visible overlap of 0.005 in. (0.13 mm) for a length of not more than 1 in. (25.4 mm) in any 24-in. (610-mm) run.

AWI installation standards require that countertops be installed within ±¼ in. (6.4 mm) of the design height and within ±⅛ in. in 8 ft. (±3 mm in 2.4 m) of level and plumb. However, the AWI standards note that deviations in existing buildings and a lack of clear performance standards for framing and drywall, gaps between countertops, and backsplashes are not the responsibility of the millwork installer. These standards for design height and level also apply to solid surfacing installations.

Table 7–4 Joint tolerances for factory assembled components

Test location	AWI grade tolerances, in (mm) Premium	Custom	Economy
Maximum gap between exposed components	1/64 (0.4)	1/32 (0.8)	1/16 (1.6)
Maximum length of gap in exposed components	3 (76)	5 (127)	8 (204)
Maximum gap between semi-exposed components	1/32 (0.8)	1/16 (1.6)	1/8 (3)
Maximum length of gap in semi-exposed components	6 (152)	8 (204)	12 (305)

Note: No gap may occur within 48 in (1220 mm) of another gap (except adjustable shelf ends)

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

Table 7–5 Joint tolerance for separation between factory assembled backsplash and top

	AWI grade tolerances, in (mm) *Premium*	*Custom*	*Economy*
Maximum separation	1/64 (0.4) x 3 (76) and no more than one per 4-ft (1219-mm) section of top	1/32 (0.8) x 5 (127) and no more than one per 4-ft (1219-mm) section of top	1/16 (1.6) x 8 (203) and no more than one per 4-ft (1219-mm) section of top

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

The suggested master specifications for solid surfacing materials from the International Cast Polymer Alliance call for an allowable variation in component size of ±¼ in. (6 mm) and an allowable variation in opening location from the indicated position of ±¼ in. (6 mm).

Related Sections

7–2 Site-Built Cabinets and Countertops

7–8 Flush Paneling

Description

This section includes tolerances for both flat wood veneer paneling and HPDL paneling. Tolerances also include surface-applied moldings. For stile and rail paneling, refer to Section 7-9.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Tolerances for wood veneer flush paneling are shown in Figures 7-8(a) and 7-8.1(a) and listed in Table 7-6. Tolerances for HPDL panels are shown in Figures 7-8(b) and 7-8.1(b).

In considering the tightness and flushness of plant-assembled joints for wood veneer paneling a reasonable assessment should be made between the finished product and absolute compliance with AWI standards. For both types of paneling and all grades, AWI standards require that panel joints be plumb within 1⁄16 in. in 96 in. (1.5 mm in 2,440 mm). For premium-grade panels only, exposed surfaces that are scribed to a wall must have a 1⁄32-in. (0.8-mm) gap tolerance.

Table 7–6 Joint tolerances for factory assembled components for wood veneer paneling

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	Exterior	Interior	Exterior	Interior	Exterior
Maximum gap: test location A	0.015 (0.4) wide by 20% of joint length	0.025 (0.6) wide by 30% of joint length	0.025 (0.6) wide by 20% of joint length	0.050 (1.3) wide by 30% of joint length	0.050 (1.3) wide by 20% of joint length	0.075 (1.9) wide by 30% of joint length
Maximum gap, test location B	0.015 (0.4) x 3 (76), and no gap may occur within 72 (1829) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 60 (1524) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 48 (660) of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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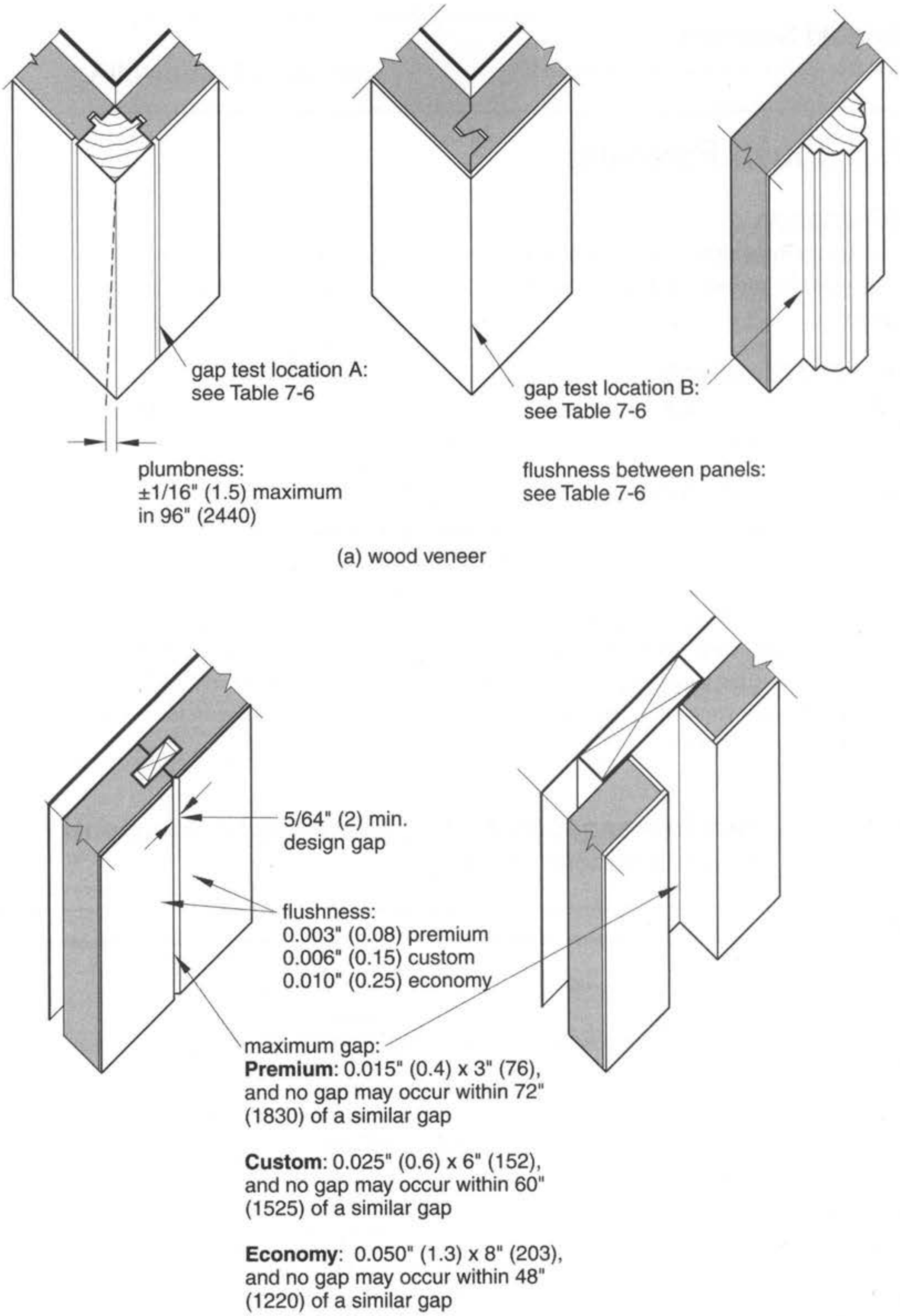
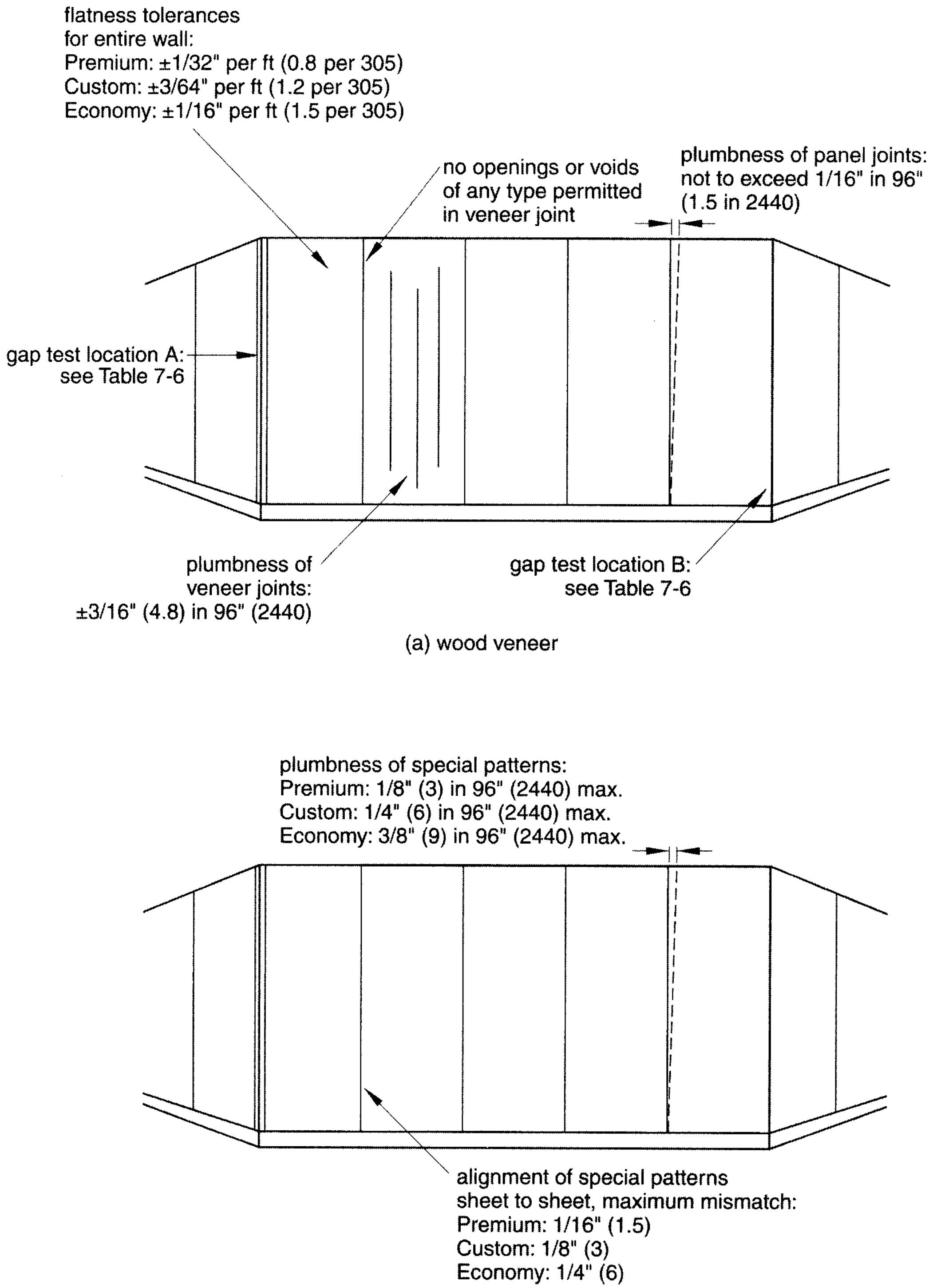
Figure 7–8 Flush paneling



(b) HPDL veneer

Figure 7–8.1 Flush paneling flatness and alignment



(a) wood veneer

(b) HPDL veneer

Related Sections

7–4 Standing and Running Trim
7–9 Stile and Rail Paneling

7–9 Stile and Rail Paneling

Description

Stile and rail paneling consists of flat or raised panels with wood veneer faces or of solid lumber, combined in a framework of stiles and rails. Surface-applied molding may also be a part of the design.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Figure 7–9 Stile and rail paneling

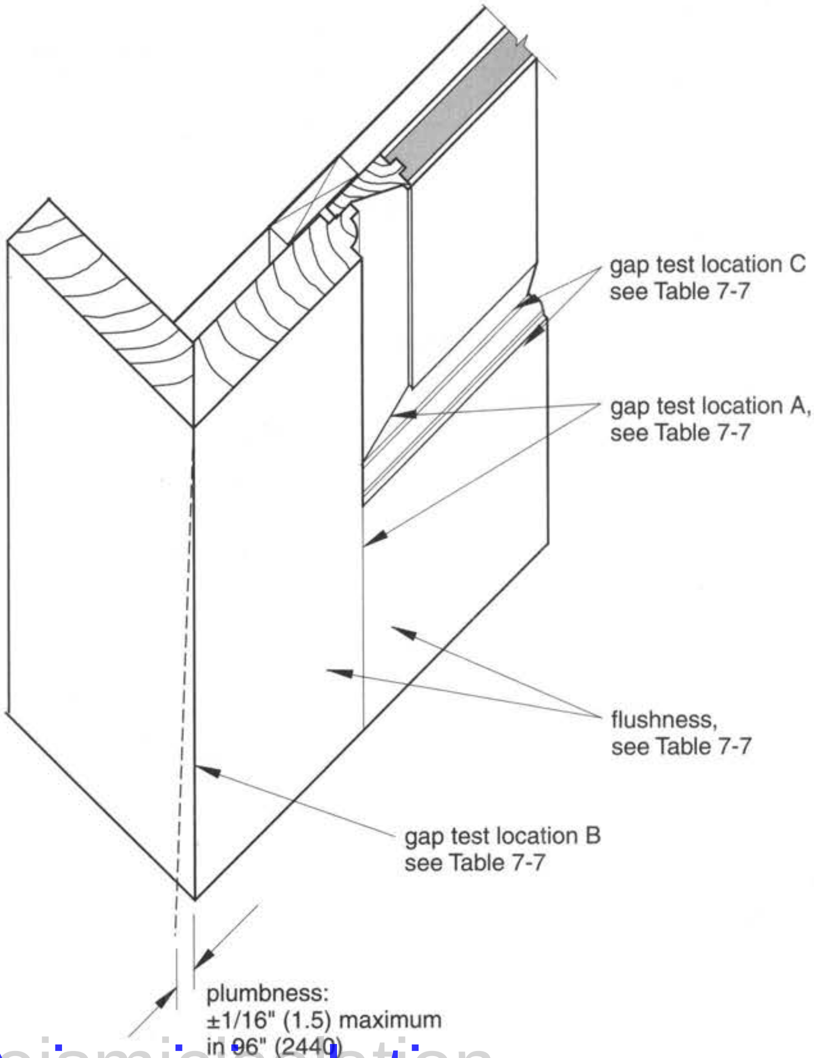


Figure 7–9.1 Stile and rail paneling joint tolerances

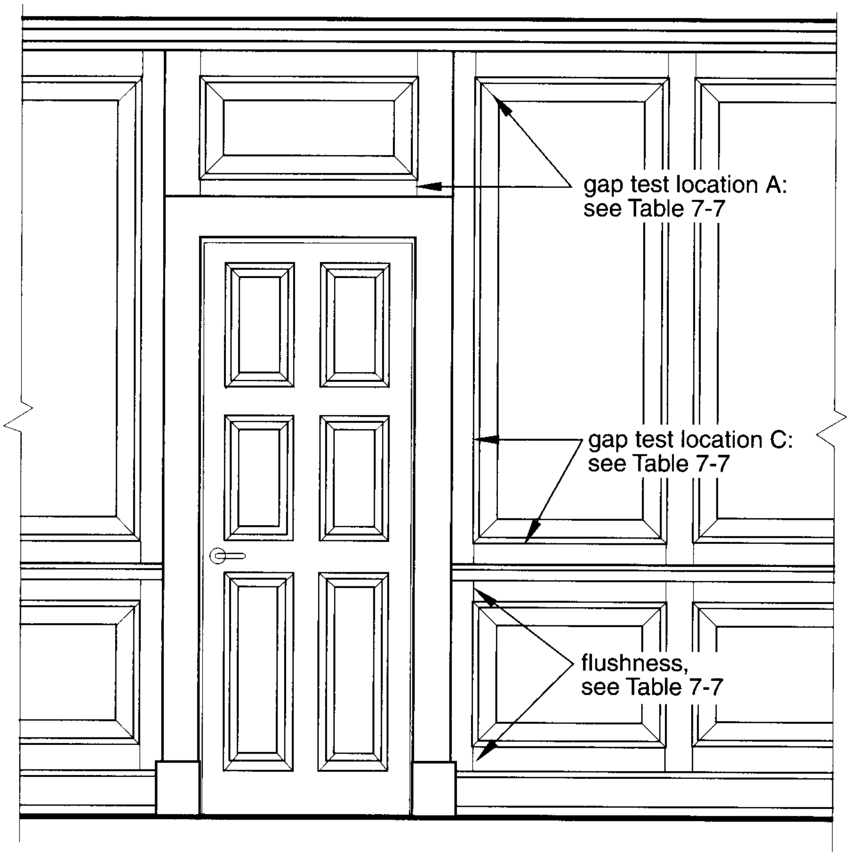


Table 7–7 Joint tolerances for factory assembled components for stile and rail paneling

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	Exterior	Interior	Exterior	Interior	Exterior
Maximum gap: test locations A	0.015 (0.4) wide by 20% of joint length	0.025 (0.6) wide by 30% of joint length	0.25 (0.6) wide by 20% of joint length	0.050 (1.3) wide by 30% of joint length	0.050 (1.3) wide by 20% of joint length	0.075 (1.9) wide by 30% of joint length
Maximum gap, test locations B	0.015 (0.4) x 3 (75), and no gap may occur within 72 (1824) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 60 (1524) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 48 (1219) of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Maximum gap, test locations C	0.015 (0.4)	0.025 (0.6)	0.25 (0.6)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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Allowable Tolerances

Tolerances for stile and rail paneling are shown in Figures 7-9 and 7-9.1 and listed in Table 7-7.

In considering the tightness and flushness of plant-assembled joints, a reasonable assessment should be made between the finished product and absolute compliance with AWI standards. For all grades of stile and rail paneling, AWI standards require that panel joints be plumb within 1/16 in. in 96 in. (1.5 mm in 2,440 mm). For premium-grade panels only, exposed surfaces that are scribed to a wall must have a 1/32-in. (0.8-mm) gap tolerance.

Related Sections

7–4 Standing and Running Trim
7–8 Flush Paneling

7–10 Stairwork

Description

This section includes tolerances for fabrication of stairs in the mill shop according to AWI *Quality Standards*.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Tolerances for stair work are listed in Table 7-8. The corresponding test locations for factory-assembled joints are shown in Figure 7-10. These tolerances apply to the stair com-

Table 7–8 Joint tolerances for factory assembled joints for stairwork

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	**Exterior**	**Interior**	**Exterior**	**Interior**	**Exterior**
Maximum gap: test location A	0.015 (0.4) wide by 20% of joint length	0.025 (0.6) wide by 30% of joint length	0.25 (0.6) wide by 20% of joint length	0.050 (1.3) wide by 30% of joint length	0.050 (1.3) wide by 20% of joint length	0.075 (1.9) wide by 30% of joint length
Maximum gap: test location B	0.015 (0.4) x 3 (76), and no gap may occur within 72 (1829) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 60 (1524) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 48 (61219of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Maximum gap: test location C	0.015 (0.4)	0.025 0.6)	0.25 (0.6)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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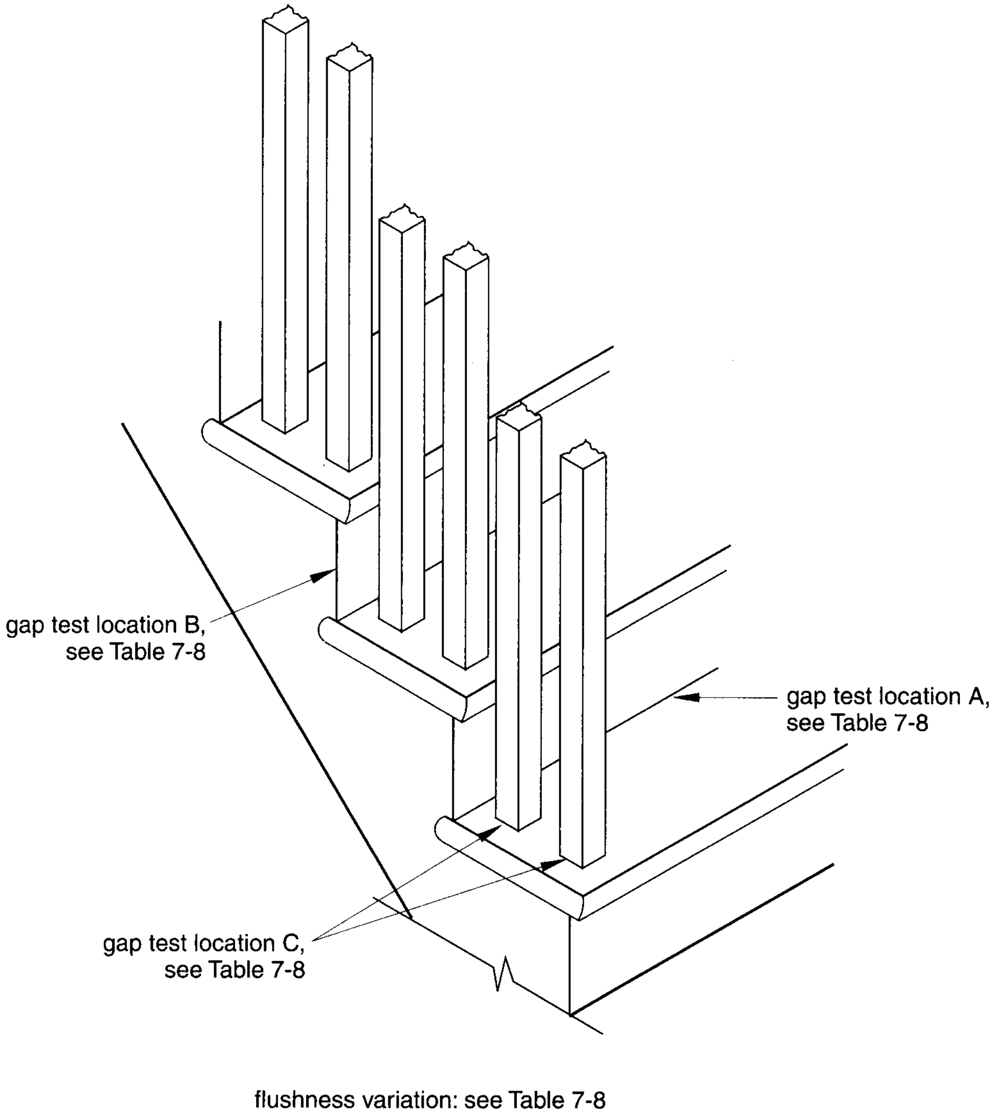
Figure 7–10 Stairwork



ponents shown in the diagram as well as for handrail joints. For premium-grade stairs only, exposed surfaces that are scribed to a wall must have a $\frac{1}{32}$-in (0.8-mm) gap tolerance.

In considering the tightness and flushness of plant-assembled joints, a reasonable assessment should be made between the finished product and absolute compliance with the AWI standard.

Related Sections

7–3 Site-Built Stairs and Trim

7–11 Frames, Jambs, and Windows

Description

This section includes components manufactured under AWI *Quality Standards* and includes frames and jambs for interior and exterior doors, sidelights, transoms, and similar elements; also included are frames, sash, and exterior trim for custom-made wood windows.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Tolerances for frames and jambs are shown in Figure 7-11(a). These only include tolerances for premium grade, as there are no plant-assembled frames and jambs in custom or economy grades. Tolerances for windows are shown in Figure 7-11(b) and listed in Table 7-9. In considering the tightness and flushness of plant-assembled joints, a reasonable assessment should be made between the finished product and absolute compliance with the AWI standard.

For both door and window frames in all grades, members must be installed plumb and level within ⅛ in. in 96 in. (3 mm in 2,440 mm).

Table 7–9 Joint tolerances for custom windows

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	**Exterior**	**Interior**	**Exterior**	**Interior**	**Exterior**
Maximum gap at test location	0.015 (0.4) by 20% of joint length	0.025 (0.6) by 30% of joint length	0.025 (0.6) by 20% of joint length	0.050 (1.8) by 30% of joint length	0.050 (1.8) by 20% of joint length	0.075 (1.9) by 30% of joint length
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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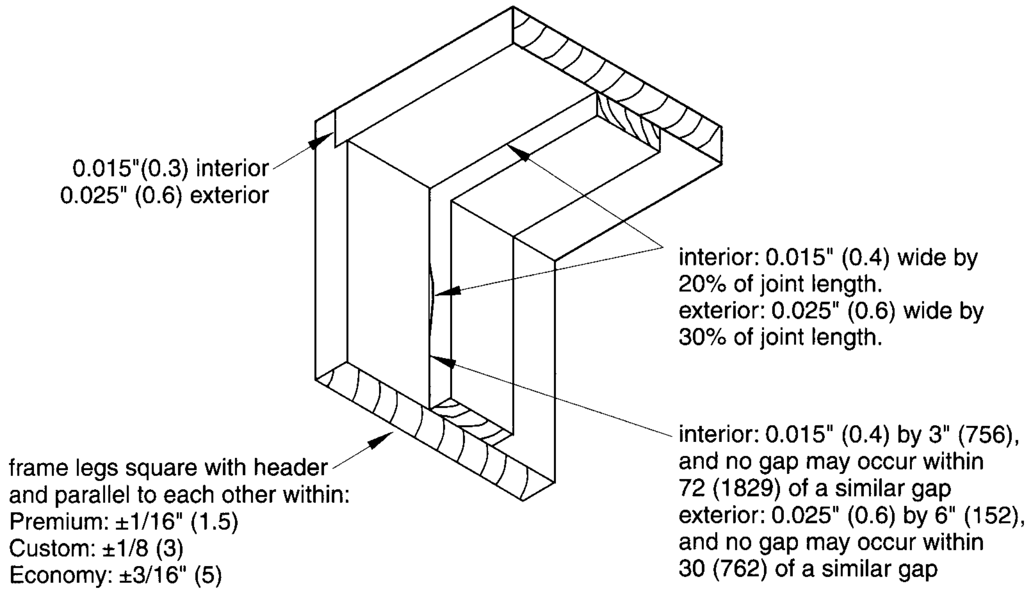
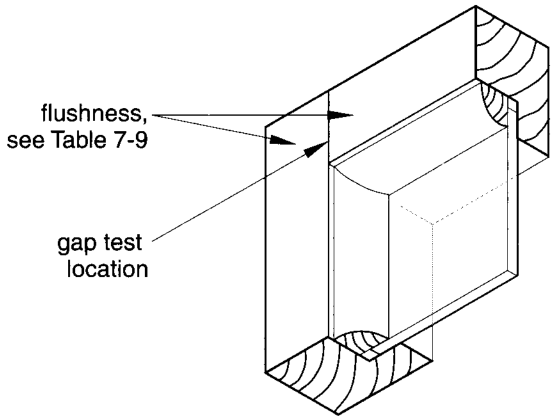
Related Sections

7–4 Standing and Running Trim
7–14 Architectural Flush Doors

Figure 7–11 Frames, jambs, and windows



(a) door frames



(b) windows

7–12 Screens

Description

This section includes custom made insect screens for windows and doors.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Tolerances for screens are shown in Figure 7-12 and listed in Table 7-10. For screens frames in all grades, members must be installed plumb and level within ⅛ in. in 96 in. (3 mm in 2,440 mm).

In considering the tightness and flushness of plant-assembled joints, a reasonable assessment should be made between the finished product and absolute compliance with the AWI standard.

Related Sections

7–11 Frames, Jambs, and Windows

Figure 7–12 Screens

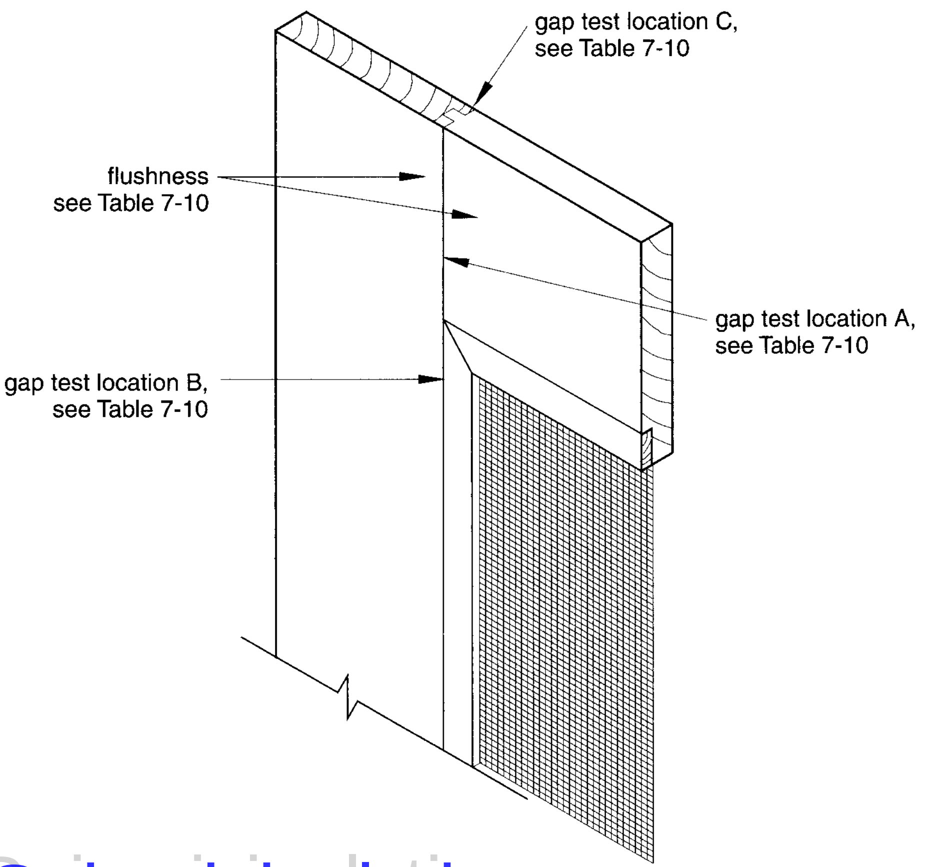


Table 7–10 Joint tolerances for screens

	AWI grade tolerances, in (mm)		
	Premium, exterior	Custom, exterior	Economy, exterior
Maximum gap: test location A	0.025 (0.6) wide by 30% of joint length	0.050 (1.3) wide by 30% of joint length	0.075 (1.9) wide by 30% of joint length
Maximum gap, test location B	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Maximum gap: test location C	0.025 (0.6)	0.050 (1.3)	0.075 (1.9)
Flushness	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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7–13 Blinds and Shutters

Description

This section includes custom-made interior and exterior blinds and shutters built with stile and rail construction.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Tolerances for blinds and shutters are shown in Figure 7-13 and listed in Table 7-11. Test locations for various types of shutters and blinds are shown in Figure 7-13.1. For both

Table 7–11 Joint tolerances for blinds and shutters

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	Exterior	Interior	Exterior	Interior	Exterior
Maximum gap: test location A	0.015 (0.4) wide by 20% of joint length	0.025 (0.6) wide by 30% of joint length	0.025 (0.6) wide by 20% of joint length	0.050 (1.3) wide by 30% of joint length	0.050 (1.3) wide by 20% of joint length	0.075 (1.9) wide by 30% of joint length
Maximum gap, test location B	0.015 (0.4) x 3 (76), and no gap may occur within 72 (1829) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 60 (1524) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 48 (1219) of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Maximum gap: test location C	0.015 (0.4)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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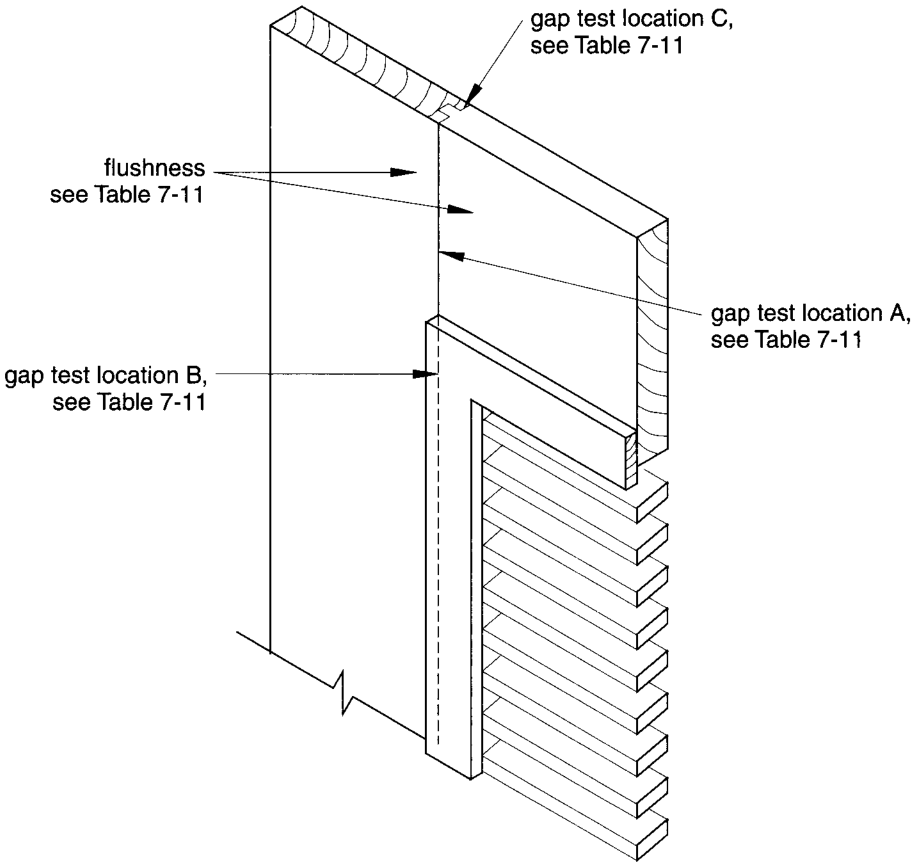
Figure 7–13 Blinds and shutters



blinds and shutters in all grades, members must be installed plumb and level within ⅛ in. in 96 in. (3 mm in 2,440 mm).

In considering the tightness and flushness of plant-assembled joints, a reasonable assessment should be made between the finished product and absolute compliance with the AWI standard.

Related Sections

7–11 Frames, Jambs, and Windows

7–14 Architectural Flush Doors

Description

This section includes flush wood doors manufactured according to AWI standards, primarily for commercial construction. Doors conforming to premium, custom, and economy grade are available. Refer to Section 11-4 for tolerances for standard flush wood doors manufactured according to Window and Door Manufacturers Association standards. However, the tolerances are very similar for both standards.

Figure 7–13.1 Blinds and shutters gap test locations

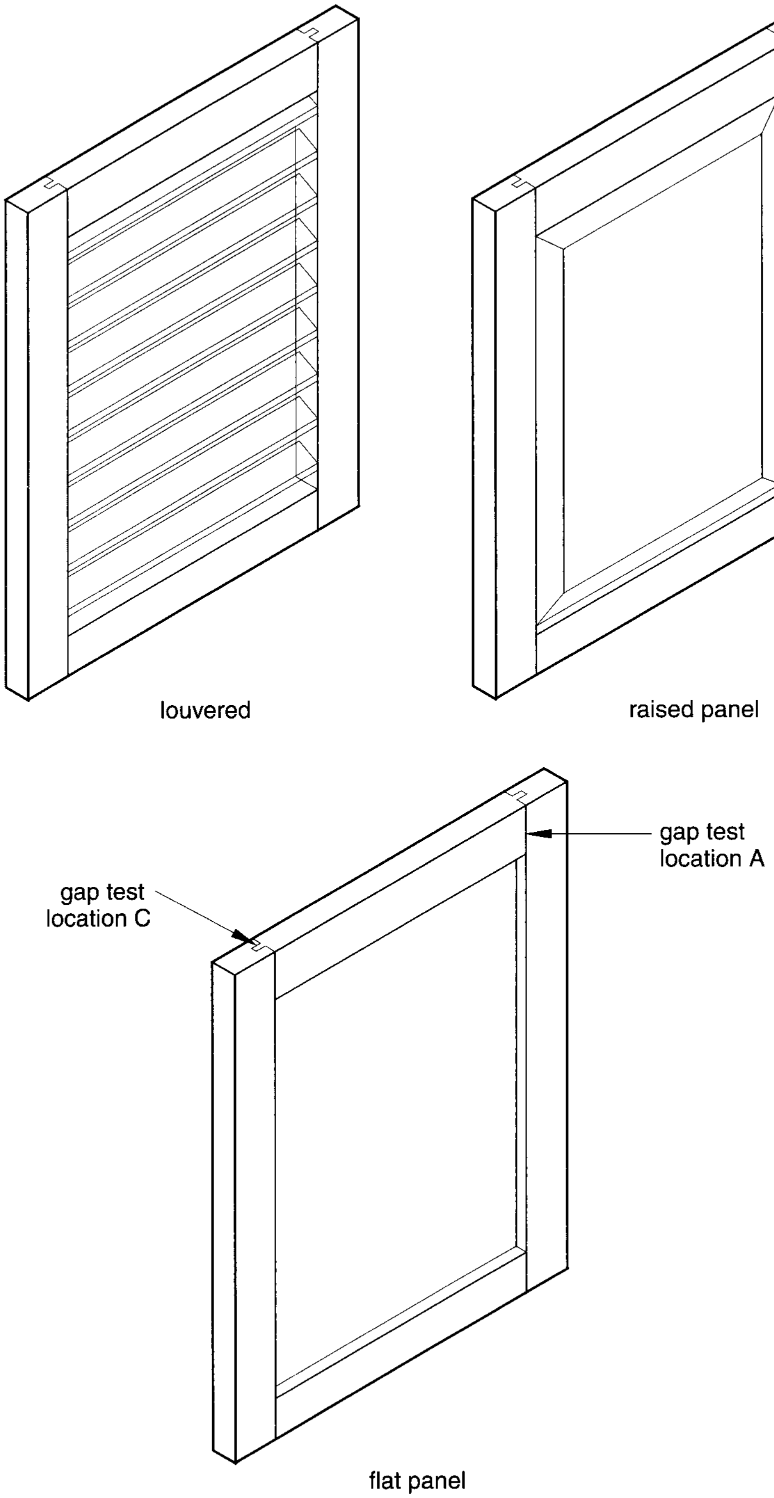
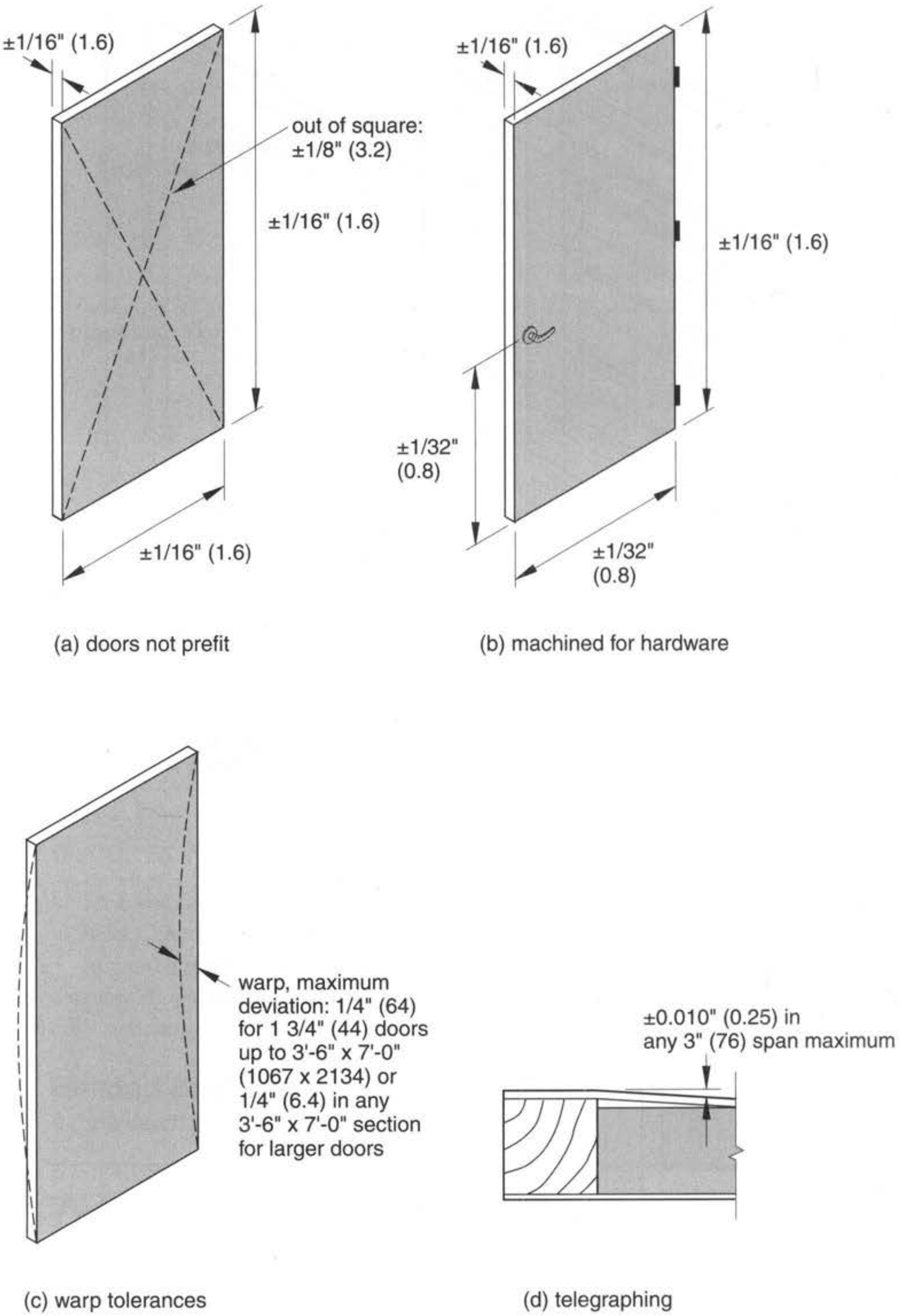


Figure 7–14 Architectural flush doors



Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Figure 7-14 illustrates the tolerances of size, warpage, and show-through or telegraphing. (*Telegraphing* is the distortion of the face veneer of a door caused by variation in thickness between the core material and the vertical or horizontal edge bands.) The tolerances for hardware location for machined doors includes locks, hinges, and other hardware.

Warpage tolerances apply only to the door and not to its position in the frame. The maximum deviation of ¼ in. (6 mm) applies to a maximum door size of 3 ft., 0 in. by 7 ft., 0 in. (900 mm by 2,100 mm) for 1⅜-in.-thick (35-mm-thick) doors and to a maximum door size of 3 ft., 6 in. by 7 ft., 0 in. (1,067 mm by 2,100 mm) for 1¾-in.-thick (44-mm-thick) doors. For larger 1¾-in.-thick doors, the tolerance is measured in any 3-ft., 6-in. by 7-ft., 0-in. section.

Refer to the AWI *Quality Standards* for a complete listing of maximum clearances between doors and frames and maximum extensions of door faces beyond frames.

Related Sections

11–4 Standard Flush Wood Doors
11–7 Installation of Wood Doors

7–15 Stile and Rail Doors—Size and Flatness

Description

This section includes size and flatness tolerances for stile and rail doors manufactured primarily for commercial construction according to AWI standards. Doors conforming to premium, custom, and economy grade are available. Refer to Section 11-5 for tolerances for standard stile and rail doors manufactured according to Window and Door Manufacturers Association standards.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

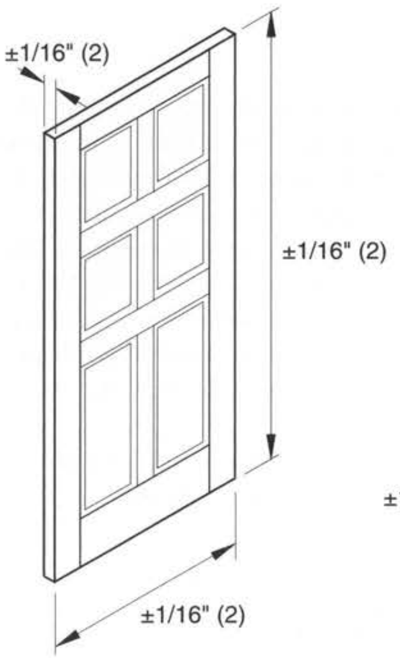
Allowable Tolerances

Figure 7-15 illustrates the tolerances of size, warpage, and show-through or telegraphing. Joint tightness and flushness tolerances are given in Section 7-16. The tolerances for hardware location for machined doors include locks, hinges, and other hardware.

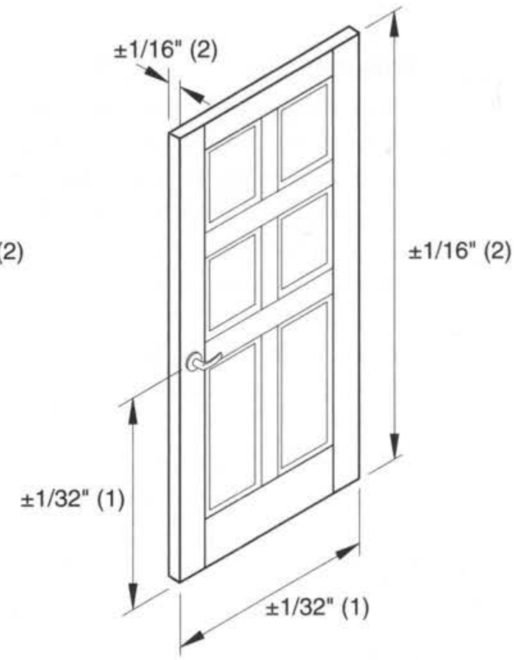
Warpage tolerances apply only to the door and not to its position in the frame. The maximum deviation of ¼ in. (6 mm) applies to a maximum door size of 3 ft., 0 in. by 7 ft., 0 in. (900 mm by 2,100 mm) for 1⅜-in-thick (35-mm-thick) doors and to a maximum door size of 3 ft., 6 in. by 7 ft., 0 in. (1,067 mm by 2,100 mm) for 1¾-in.-thick (44-mm-thick) doors. For larger 1¾-in.-thick doors, the tolerance is measured in any 3-ft., 6-in. by 7-ft., 0-in. section.

Refer to the AWI *Quality Standards* for a complete listing of maximum clearances between doors and frames and maximum extensions of door faces beyond frames.

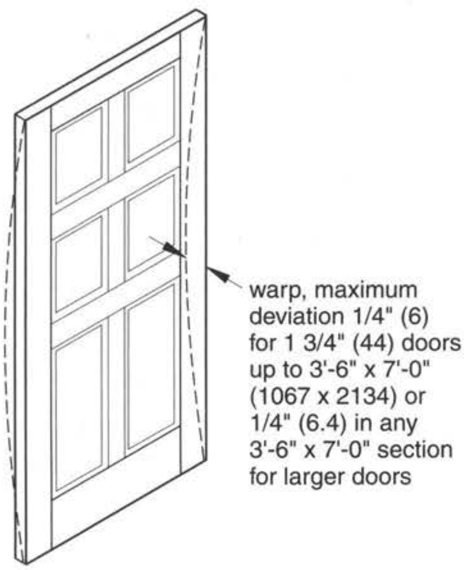
Figure 7–15 Stile and rail doors—size and flatness



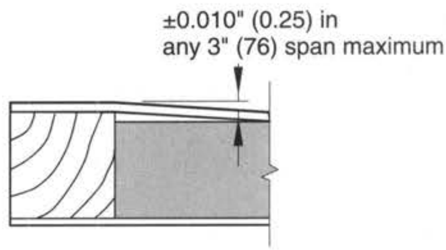
(a) doors not prefit



(b) machined for hardware



(c) warp tolerances



(d) telegraphing

Related sections

7–16 Stile and Rail Doors—Joint Tightness and Flushness
11–5 Standard Stile and Rail Doors
11–7 Installation of Wood Doors

7–16 Stile and Rail Doors—Joint Tightness and Flushness

Description

This section includes joint tightness and flushness tolerances for stile and rail doors manufactured primarily for commercial construction according to AWI standards. Refer to Section 11-5 for tolerances for standard stile and rail doors manufactured according to Window and Door Manufacturers Association standards.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

Joint tightness and flushness for stile and rail intersections are measured at certain standard points on a stile and rail door. These test locations are shown in Figure 7-16, and the maximum deviations permitted are listed in Table 7-12. Flushness tolerances of other joints are listed in Table 7-13.

Table 7–12 Tightness of plant assembled joints

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	**Exterior**	**Interior**	**Exterior**	**Interior**	**Exterior**
Maximum gap: test location A	0.015 (0.4) wide by 20% of joint length	0.025 (0.6) wide by 30% of joint length	0.25 (0.6) wide by 20% of joint length	0.050 (1.3) wide by 30% of joint length	0.050 (1.3) wide by 20% of joint length	0.075 (1.9) wide by 30% of joint length
Maximum gap, test location B	0.015 (0.4) x 3 (76), and no gap may occur within 72 (1829) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 30 (762) of a similar gap	0.025 (0.6) x 6 (152), and no gap may occur within 60 (1524) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 26 (660) of a similar gap	0.050 (1.3) x 8 (203), and no gap may occur within 48 (1219) of a similar gap	0.075 (1.9) x 10 (254), and no gap may occur within 24 (610) of a similar gap
Maximum gap: test location C	0.015 (0.4)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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Figure 7–16 Stile and rail doors—joint tightness and flushness

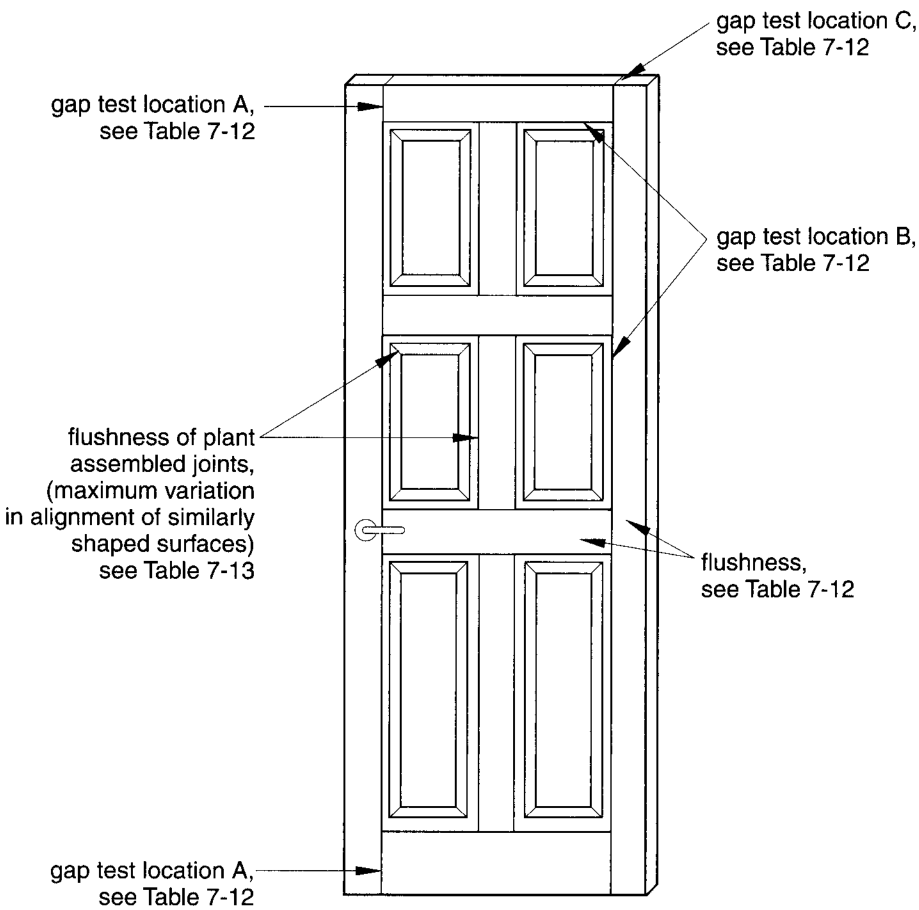


Table 7–13 Flushness of plant assembled joints (Maximum variation in alignment of similarly shaped surfaces)

	AWI grade tolerances, in (mm)					
	Premium		*Custom*		*Economy*	
	Interior	Exterior	Interior	Exterior	Interior	Exterior
Stile and rails	None permitted	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.010 (0.25)	0.050 (1.3)
Moldings, beads, rims, etc.	0.007 (0.2)	0.007 (0.2)	0.015 (0.4)	0.015 (0.4)	0.030 (0.8)	0.030 (0.8)

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

Related Sections

7–15 Stile and Rail Doors—Size and Flatness
11–5 Manufacturing Tolerances for Standard Stile and Rail Doors
11–6 Installation of Wood Doors

7–17 Architectural Woodwork Installation

Description

The *Quality Standards* of the AWI provide general installation standards for various types of woodwork based on one of the three grades. Normally, the same woodworking shop that fabricates the material also installs it. This section includes some of the installation standards that relate to dimensional tolerances.

Industry Standards

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

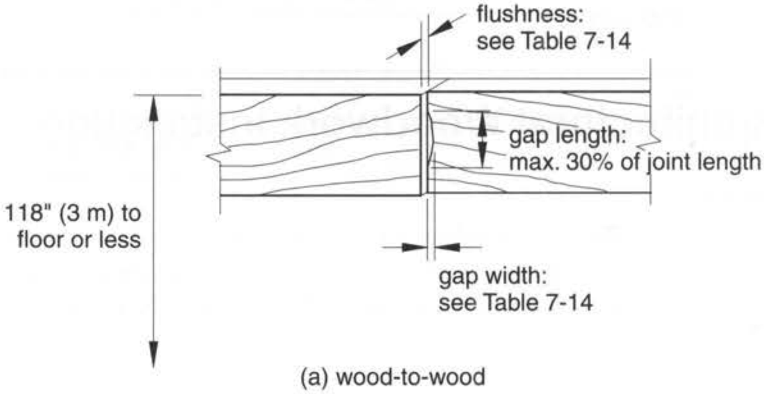
Tolerances for field joints of materials vary depending of whether they are wood-to-wood, wood-to-nonwood, or nonwood-to-nonwood. For example, wood trim may be placed next to a stone panel that is part of the woodworker's responsibility. Tolerances also vary depending on the height of the joint above the floor. Tolerances do not apply for joints not open to building occupants or visible to the general public. These tolerances are shown diagrammatically in Figures 7-17(a), 7-17 (b), and 7-17 (c) and are listed in Tables 7-14 through 7-16. In all cases, the maximum allowable length of the gap is 30 percent of the joint length. An example of these conditions is shown in Figure 7-17.1. The tolerances for field joints above 118 in. (3 m) are a little less restrictive. Refer to AWI standards for a complete listing of installation requirements.

Table 7–14 Wood-to-wood field joints up to 118 inches (3 m) above finished floor

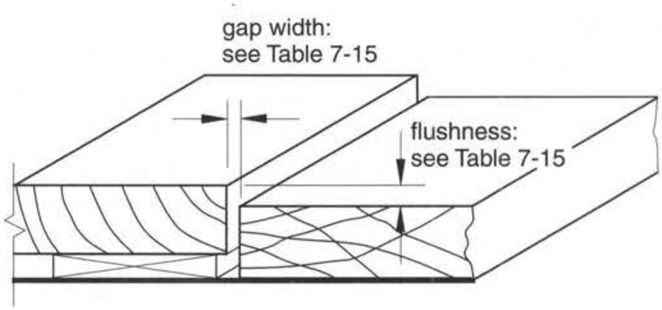
	Maximum tolerance, in (mm)					
	Premium		*Custom*		*Economy*	
	Flat surface	**Shaped surface**	**Flat surface**	**Shaped surface**	**Flat surface**	**Shaped surface**
Gap width	0.012 (0.3)	0.025 (0.65)	0.025 (0.65)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)
Flushness	0.012 (0.3)	0.025 (0.65)	0.025 (0.65)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

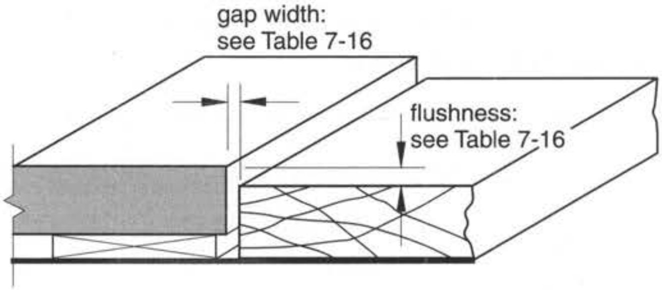
Figure 7–17 Architectural woodwork installation



(a) wood-to-wood



(b) wood-to-nonwood



(c) nonwood-to-nonwood

Table 7–15 Wood-to-non-wood field joints up to 118 inches (3 m) above finished floor

	Maximum tolerance, in (mm)					
	Premium		*Custom*		*Economy*	
	Flat surface	*Shaped surface*	*Flat surface*	*Shaped surface*	*Flat surface*	*Shaped surface*
Gap width	0.025 (0.65)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)	0.075 (1.9)	0.100 (2.5)
Flushness	0.025 (0.65)	0.050 (1.3)	0.050 (1.3)	0.075 (1.9)	0.075 (1.9)	0.100 (2.5)

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

Table 7–16 Non-wood-to-non-wood field joints up to 118 inches (3 m) above finished floor

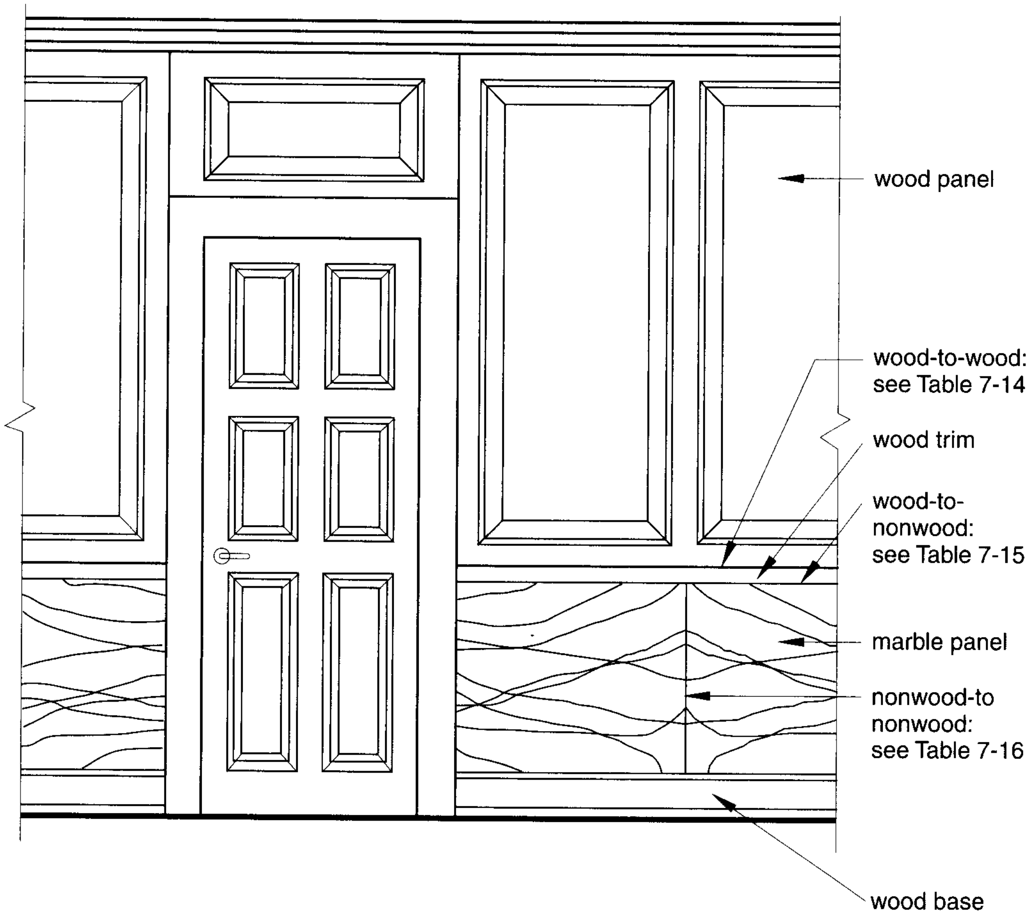
	Maximum tolerance, in (mm)					
	Premium		*Custom*		*Economy*	
	Flat surface	Shaped surface	Flat surface	Shaped surface	Flat surface	Shaped surface
Gap width	0.050 (1.3)	0.075 (1.9)	0.075 (1.9)	0.100 (2.5)	0.100 (2.5)	0.125 (3.2)
Flushness	0.050 (1.3)	0.075 (1.9)	0.075 (1.9)	0.100 (2.5)	0.100 (2.5)	0.125 (3.2)

Compiled from information in Architectural Woodwork Quality Standards, 8th ed., *by the Architectural Woodwork Institute.*

Related Sections

7–2 Site-Built Cabinets and Countertops
7–3 Site-Built Stairs and Trim
7–4 Standing and Running Trim
11–7 Installation of Wood Doors

Figure 7–17.1 Woodwork installation test locations



Chapter 8

Curtain Walls

8–1 Aluminum Curtain Wall Fabrication

Description

Metal curtain wall construction involves several tolerances in addition to fabrication tolerances. There are basic material tolerances, building frame tolerances, and erection tolerances. In addition, there are required clearances between the curtain wall and other building components that must be provided for. Because metal curtain walls are manufactured from fairly precise components (aluminum tubing and other shapes, for example) and factory fabricated under controlled conditions, the tolerances for the finished product as delivered to the job site are small and normally do not affect installation.

Industry Standards

AAMA MCWM-1-89, *Metal Curtain Wall Manual* (Schaumburg, IL: American Architectural Manufacturers Association, 2002).

ANSI H35.2-2003, *Dimensional Tolerances for Aluminum Mill Products* (Arlington, VA: The Aluminum Association, 2003).

GANA *Glazing Manual* (Topeka, KS: Glass Association of North America, 2004).

Allowable Tolerances

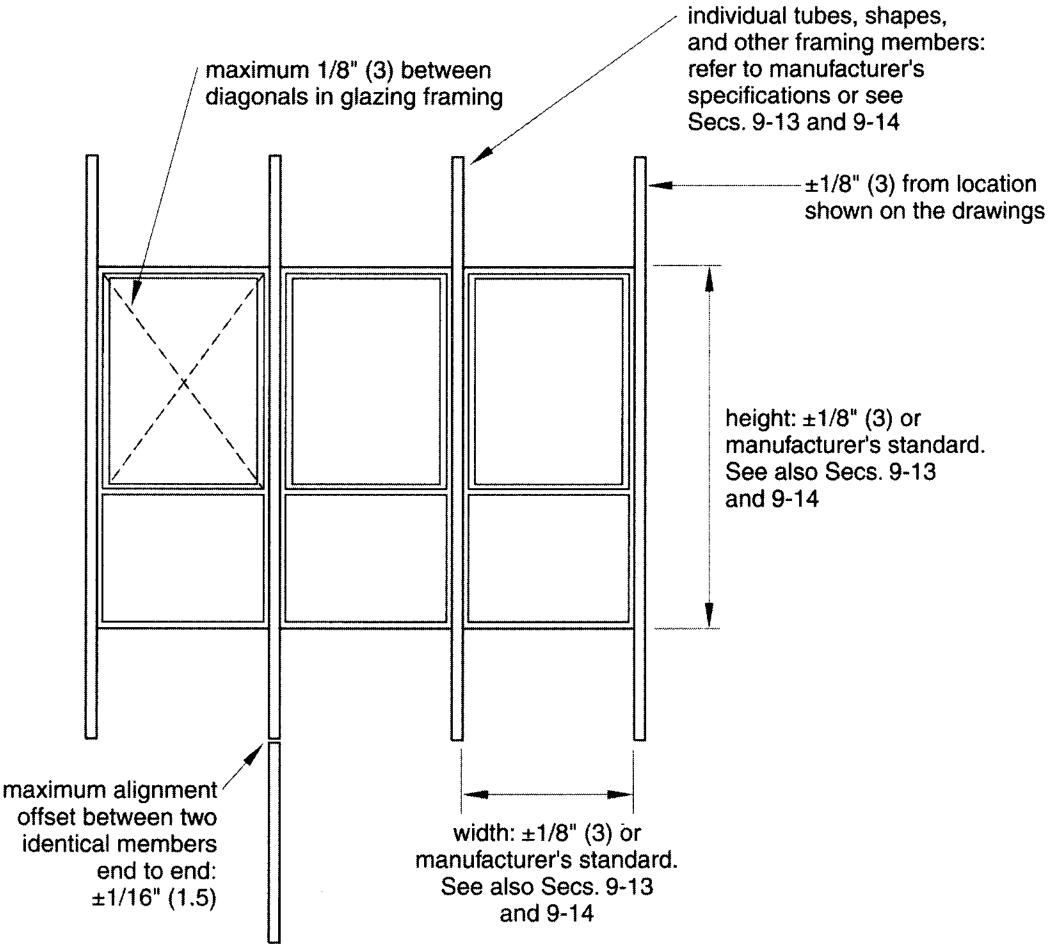
The American Architectural Manufacturers Association (AAMA) does not publish any industry-wide standard tolerances for fabrication. Tolerances for aluminum shapes are given in ANSI H35.2. See Sections 9-13 and 9-14. Commonly used tolerances are shown in Figure 8-1. Exact fabricated tolerances should be verified with the manufacturer, as they will vary with the size, material, and configuration of each curtain wall system. In nearly all cases, minor manufacturing tolerances are easily accommodated during erection and attachment to the building structure.

For erection tolerances, the Glass Association of North America (GANA) *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

Related Sections

8–2 Aluminum Curtain Wall Installation
8–3 Storefront and Entrance Manufacturing
9–13 Extruded Aluminum Tubes
9–14 Aluminum Rods, Bars, and Shapes

Figure 8–1 Aluminum curtain wall fabrication



8–2 Aluminum Curtain Wall Installation

Description

This section includes installation tolerances for aluminum and other metal curtain walls. To meet industry standard tolerances or manufacturers' tolerances, it is imperative that the building frame be constructed within acceptable tolerances and that connection details allow for adjustment during erection.

Industry Standards

AAMA MCWM-1-89, *Metal Curtain Wall Manual.* (Schaumburg, IL: American Architectural Manufacturers Association, 2002).

GANA *Glazing Manual.* (Topeka, KS: Glass Association of North America, 2004).

UFGS Section 08 44 00, *Glazed Curtain Wall*, United Facilities Guide Specifications, December 2005 (Washington, DC: National Institute of Building Sciences, 2005) http://www.wbdg.org/ccb/DOD/UFGS/UFGS%2008%2044%2000.pdf

Allowable Tolerances

Tolerances for aluminum and other metal curtain walls should be stated in the specifications. In many cases, a lesser or greater tolerance than is normally used is required. In addition to erection tolerances, the specifications should clearly state what the tolerances for the building frame will be and that the curtain wall manufacturer must accommodate these framing tolerances. In some cases, the manufacturer will give the required curtain wall fabrication and erections tolerances to the architect prior to issuing construction documents so that the required frame tolerances can be stated for other trades.

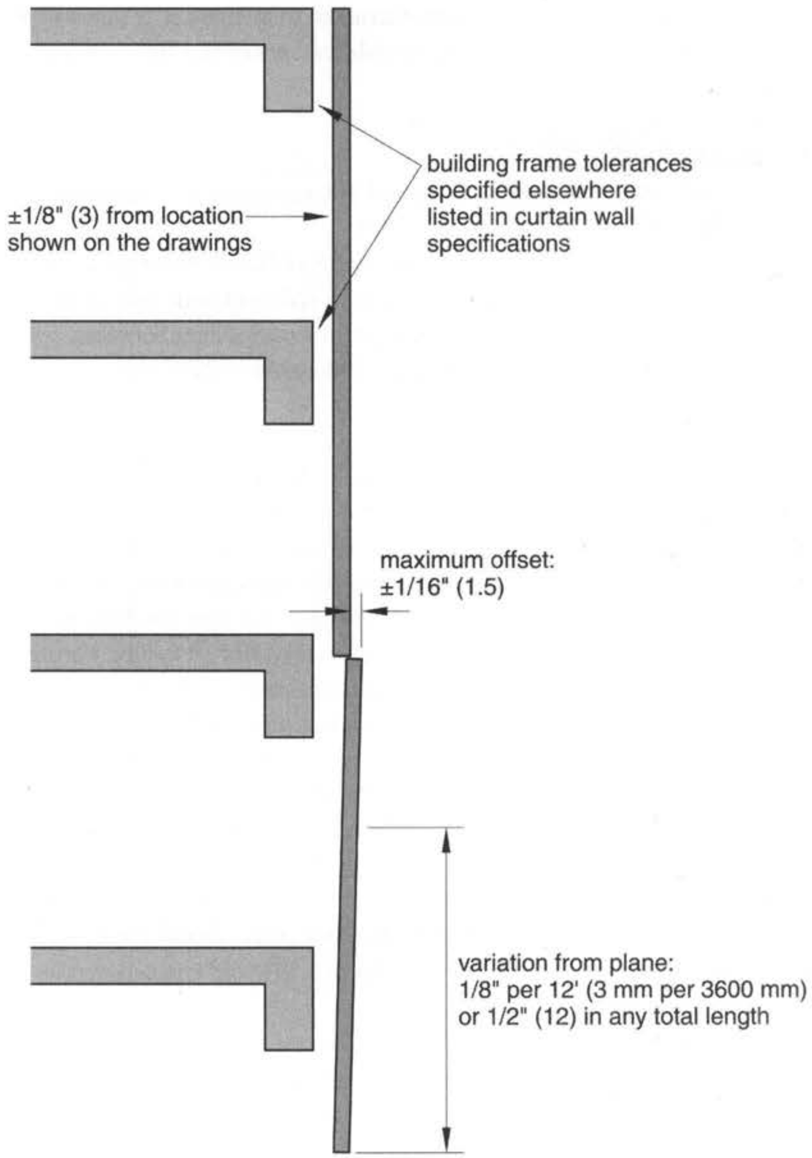
The tolerances recommended by the AAMA for variation from plane and offset of adjacent components are shown in Figure 8-2. For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

The Unified Facilities Guide Specifications (UFGS) master specifications recommend a maximum deviation from plane or location from that on the shop drawings of ⅛ in. per 12 ft. (1 mm per 12 m) up to not more than ½ in. (13 mm) in any total length. The offset from true alignment at the joints between abutting members in line is ±1/16 in. (2 mm).

Related Sections

8–1 Aluminum Curtain Wall Fabrication
8–4 Storefront Installation
12–6 Detailing for Curtain Walls on Concrete Frames
14–7 Detailing for Curtain Walls on Steel Frames

Figure 8–2 Aluminum curtain wall installation



8–3 Storefront and Entrance Manufacturing

Description

Storefront construction involves several tolerances in addition to manufacturing tolerances. There are basic material tolerances, building substrate tolerances, and installation tolerances. Because storefronts, like curtain walls, are manufactured from fairly precise components (aluminum tubing and other shapes, for example) and factory fabricated under controlled conditions, the tolerances for the finished product as delivered to the job site are small and normally do not affect installation.

Industry standards

GANA *Glazing Manual* (Topeka, KS: Glass Association of North America, 2004).
SFM-1-87, *Aluminum Storefront and Entrance Manual* (Schaumburg, IL: American Architectural Manufacturers Association, 2002).

Allowable Tolerances

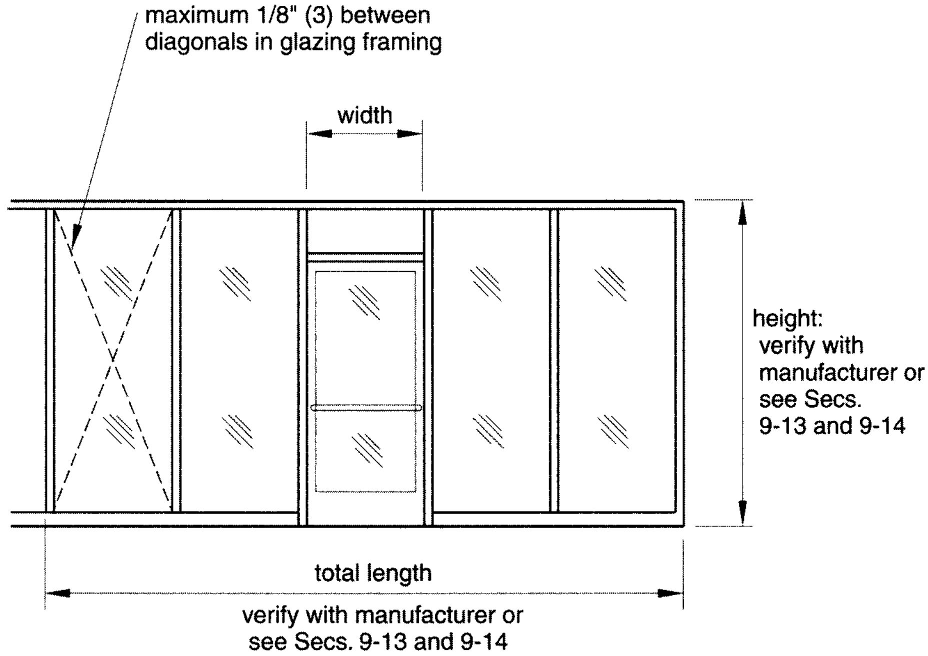
As shown in Figure 8-3, the American Architectural Manufacturers Association does not publish any industry-wide standard tolerances for storefront and entrance. Exact fabricated tolerances should be verified with the manufacturer, as they will vary with the size, material, and configuration of each system. In nearly all cases, minor manufacturing tolerances are easily accommodated during installation if sufficient clearance is provided between the storefront system and the building substrate. A minimum ¼-in. (6-mm) clearance is required, with a ½-in. (13-mm) clearance recommended.

For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

Related Sections

8–1 Aluminum Curtain Wall Fabrication
8–4 Storefront Installation
10–5 All-Glass Entrances

Figure 8–3 Storefront and entrance manufacturing



8–4 Storefront Installation

Description

Because storefront systems are factory manufactured from precise components, installation tolerances can be quite accurate, provided that the substrate tolerances are small enough to allow installation without excessive shimming or calking.

Industry Standards

GANA *Glazing Manual.* Topeka, KS: Glass Association of North America, 2004.

SFM-1-87, *Aluminum Storefront and Entrance Manual.* Schaumburg, IL: American Architectural Manufacturers Association, 2002.

SPECTEXT Section 08410, *Aluminum Entrances and Storefronts* (Bel Air, MD: Construction Sciences Research Foundation, 1989).

Allowable tolerances

Recommended installation tolerances for storefronts are shown in Figure 8-4. In addition, a clearance of ¼ in. minimum to ½ in. (6 mm to 13 mm) is recommended between the storefront system and masonry and other openings. The floor under a swinging door or revolving door should be level to a tolerance of ±1/16 in. (1.5 mm) to prevent the door from binding.

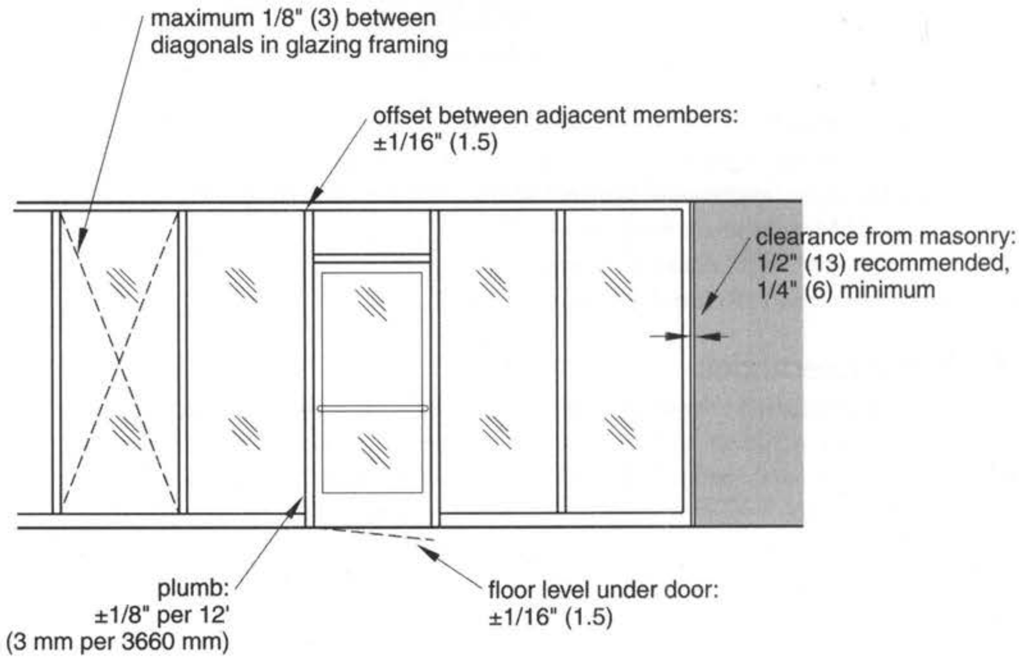
For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

Previous SPECTEXT master specifications recommended a maximum plumb misalignment of 0.06 in. for every 3 ft. (1.5 mm per meter) noncumulative or 1/16 in. per 10 ft. (1.5 mm per 3 meters), whichever is less, with a maximum misalignment of adjacent members of 1/32 in. (0.8 mm).

Related Sections

8–2 Aluminum Curtain Wall Installation
8–3 Storefront and Entrance Manufacturing
10–5 All-Glass Entrances

Figure 8–4 Storefront installation



Chapter 9

Finishes

9–1 Light-Gauge Framing for Gypsum Wallboard

Description

This section includes tolerances for the installation of steel studs for the subsequent application of gypsum wallboard. For gypsum wallboard partitions that are painted or finished with wall covering, the tolerances shown here may not be required. However, if finish materials such as ceramic tile are used or finished clear opening dimensions are required, the smaller tolerances should be specified.

Industry Standards

GA-216, *Application and Finishing of Gypsum Board* (Washington, DC: Gypsum Association, 2004).

"Specification Guide for Cold-Formed Lightweight Steel Framing" in *Lightweight Steel Framing Systems Manual* 3rd ed. (Chicago: Metal Lath/Steel Framing Association, 1987).

ASTM C754, *Standard Specification for Installation of Steel Framing Members to Receive Screw-Attached Gypsum Panel Products* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

ASTM C840, *Standard Specification for Application and Finishing of Gypsum Board* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

ASTM C1007, *Standard Specification for Installation of Load Bearing (Transverse and Axial) Steel Studs and Related Accessories* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

Allowable Tolerances

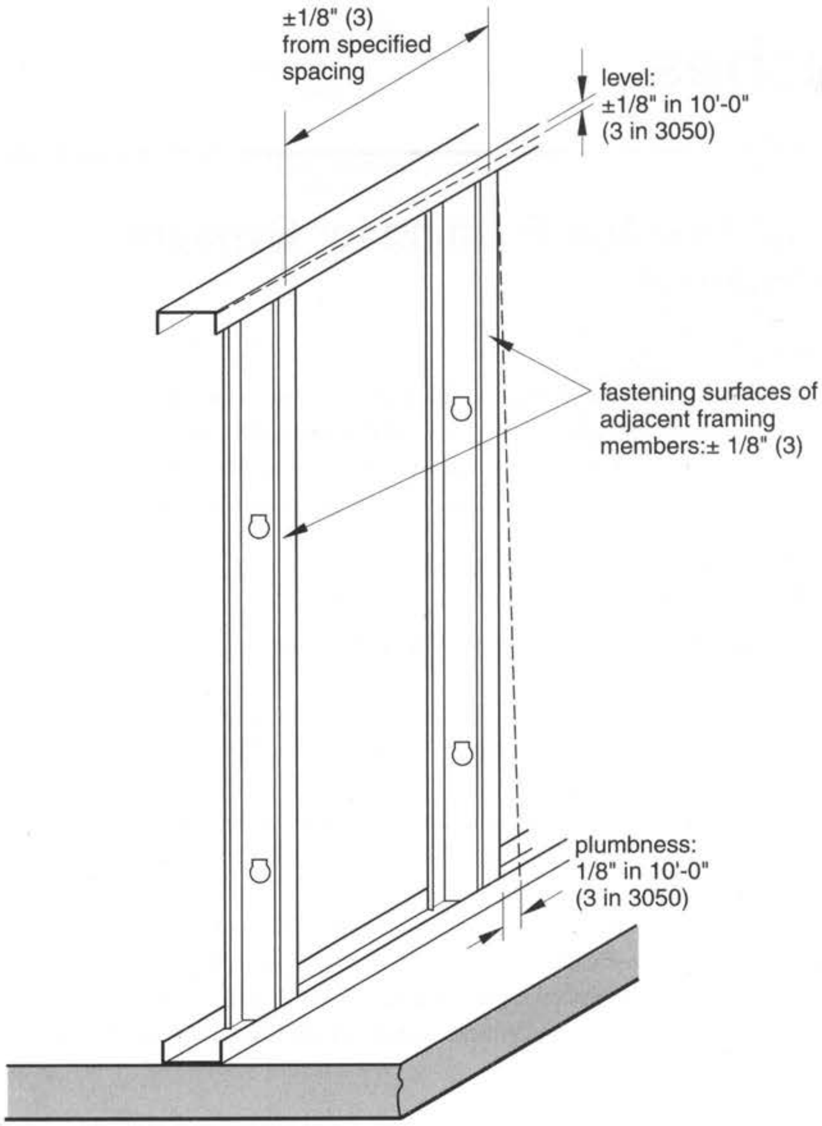
The recommended tolerances from several sources are shown in Figure 9-1. ASTM C1007 recommends that the plumbness and level of studs be within 1/960 of the span, or 1/8 in. in 10 ft. (3 mm in 3,050 mm). ASTM C840 requires that the attachment surface of any framing member shall not vary more than 1/8 in. (3.2 mm) from the plane of the faces of adjacent framing members. The Gypsum Association also states that adjacent fastening surfaces of framing or furring should not vary by more than 1/8 in. (3 mm).

Previous specification guides from the Metal Lath/Steel Framing Association (ML/SFA) also recommended the same tolerances as ASTM C1007. While ASTM C1007 is only for load-bearing studs, the ML/SFA guidelines were for all metal studs.

The 1/8 in.-per-10 ft. tolerance is consistent with the substrate requirements for other finish materials, such as some types of ceramic tile systems.

ASTM C754 requires that the spacing of studs and other framing members not vary by more than 1/8 in. (3 mm) from the required spacing and that the cumulative error does not

Figure 9–1 Light-gauge framing for gypsum wallboard



exceed ⅛ in. (3 mm). This is to ensure that the edge of a piece of gypsum board has sufficient bearing on half of a stud for fastening.

If the tolerances shown here are not required and specified, it is more likely that a ±¼ in. (6 mm) tolerance will be observed in actual construction.

Related Sections

6–6 Rough Lumber Framing
9–2 Wallboard Partitions, Ceilings, and Trim
9–4 Installation of Lath and Plaster
9–5 Floor and Wall Tile

9–2 Wallboard Partitions, Ceilings, and Trim

Description

Although framing tolerances play an important part in the accuracy of gypsum wallboard construction, in most cases the tolerance of the final finished surface is more important than the tolerance of the framing. Several factors can affect the final tolerance. For example, the use of trim pieces, such as corner bead or L-bead, usually extends the edges of finished wallboard out by about ⅛ in. (3 mm) or more because of the small ridge on the trim piece. Shimming the drywall can improve or exaggerate the final surface position. Poor fastening or slightly bent or warped framing can also affect installation.

Industry Standards

ANSI A108.11 *Specification for Interior Installations of Cementitious Backer Units* (Anderson, SC: Tile Council of North American, Inc., 2005).

GA-216 *Application and Finishing of Gypsum Board* (Washington, DC: Gypsum Association, 2004).

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders, 2005).

Allowable Tolerances

For noncritical applications, finished gypsum wallboard tolerances for metal stud framing should be taken at ±¼ in. (6 mm), as shown in Figure 9-2. This includes positioning of partitions based on the dimensions shown on the plans as well as plumbness of walls. This takes into account the tolerances of framing (⅛ in. per 10 feet, or 3 mm in 3,050 mm, at best) and the inaccuracies of fastening and using trim and shim pieces in the application of the wallboard itself. ANSI A108.11 requires framing members of floor joists, wall studs, and ceiling joists for backer board for ceramic tile have a maximum variation from plane of ±⅛ in. in 8 ft. (3 mm in 2,400 mm).

For wood framing, plumbness and positioning tolerances may be slightly greater because of the relatively rough nature of wood studs compared with the accurate manufacture of steel studs. This is reflected in the larger tolerance of ±⅜ in. (9.5 mm) in any 32-in. (813 mm) vertical measurement called for in the *Residential Construction Performance Guidelines*. This translates to a tolerance of ±1⅛ in. (19 mm) in an 8-ft. (29 mm in a 2,440-mm) wall height, although this should be the extreme case.

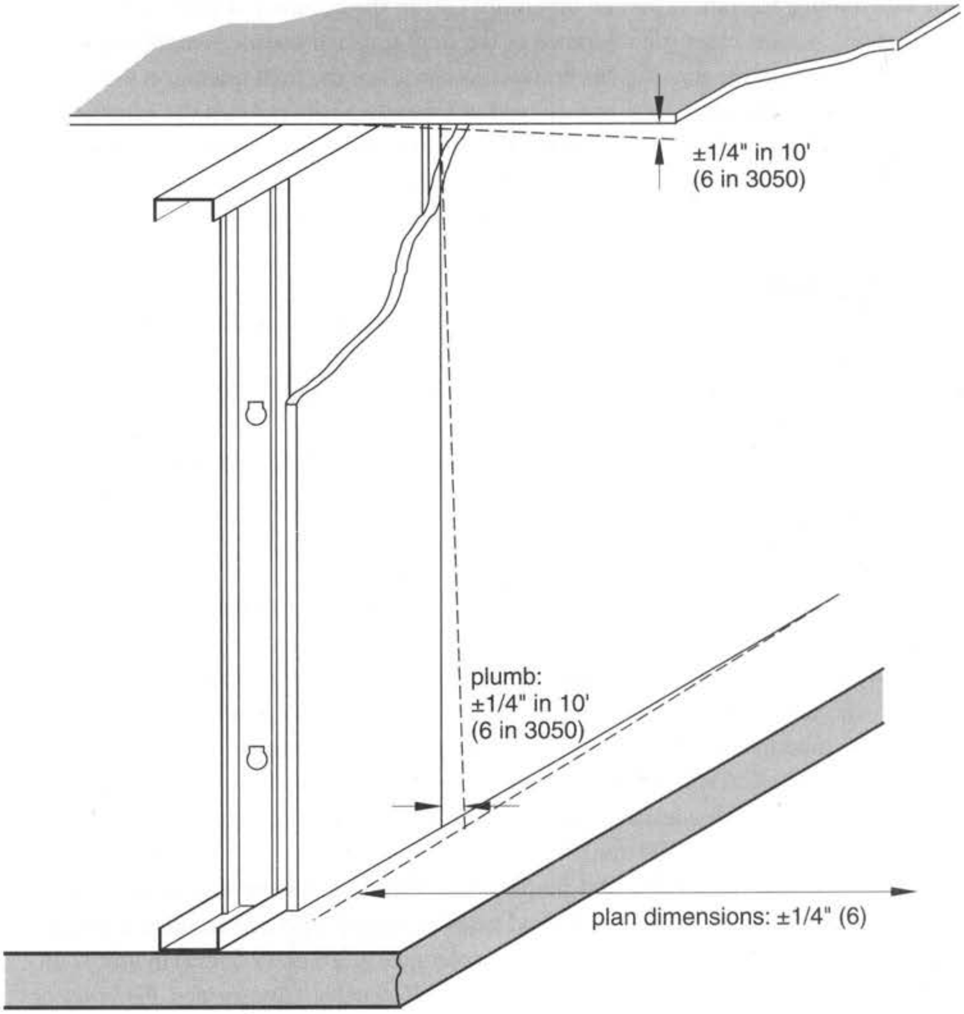
For ceilings, the Gypsum Association requires that deflection not exceed $L/240$ of the span at full design load, where *L* is the length of the span. However, this would result in a ½-in. (13-mm) drop in the middle of a 10-ft. span. In most cases a level tolerance of ¼ in. in 10 ft. (6 mm in 3,050 mm) should be expected for ceilings.

If smaller tolerances are required for additional finish, such as ceramic tile, the required smaller tolerance must be specifically stated in the contract documents.

Related Sections

6–6 Rough Lumber Framing
6–7 Wood Floor Framing and Subflooring
9–1 Light-Gauge Framing for Gypsum Wallboard
9–4 Installation of Lath and Plaster
9–5 Floor and Wall Tile

Figure 9–2 Wallboard partitions, ceilings, and trim

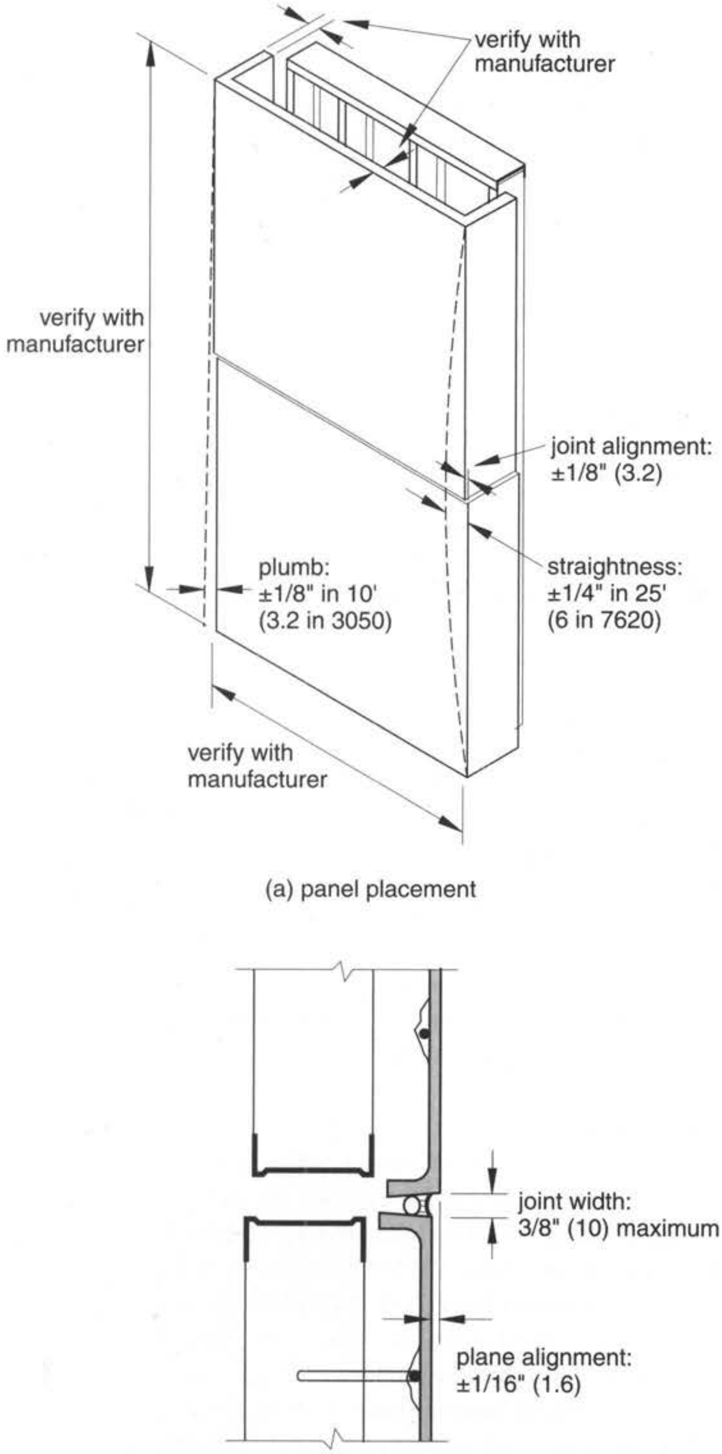


9–3 Glass-Reinforced Gypsum Products

Description

Glass-reinforced gypsum products are factory-fabricated components made by a molding process using high-strength, high-density, gypsum reinforced with continuous filament glass fibers or chopped glass fiber strands. The prefabricated units are attached to steel framing or wood framing, suspended from structure, or otherwise fastened to a suitable substrate.

Figure 9–3 Glass-reinforced gypsum products



(a) panel placement

(b) panel joints

Industry Standards

Glass Reinforced Gypsum: A Guide. (St. Charles, IL: Ceilings and Interior Systems Construction Association, 1990).

Allowable Tolerances

Tolerances for the fabrication of glass-reinforced gypsum products vary with the shape of the component, the final finish, the installed position of the component, and the type of lighting. Tolerances for straightness, length, width, individual dimensions within the overall length, radii, and squareness should be coordinated with the manufacturer and clearly shown on the drawings. All corners should have a radius between 1/16 in. (1.6 mm) and 1/8 in. (3.2 mm) unless otherwise required by the design.

Erection tolerances recommended by the Ceilings and Interior Systems Construction Association are shown in Figure 9-3.

Related Sections

9–1 Light-Gauge Framing for Gypsum Wallboard
9–9 Acoustical Ceiling Installation

9–4 Installation of Lath and Plaster

Description

Lath and plaster includes both veneer plaster installations using gypsum lath and standard, three-coat plaster work. Because plaster work is site applied and subject to the skills of the plasterer, wide variations of tolerances are possible.

Industry Standards

ASTM C843, *Standard Specification for Application of Gypsum Veneer Plaster* (West Conshohocken, PA: American Society for Testing and Materials, 1999).

ASTM C926, *Standard Specification for Application of Interior Portland Cement-based Plaster* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

ASTM C1396/C1396, *Standard Specification for Gypsum Board* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

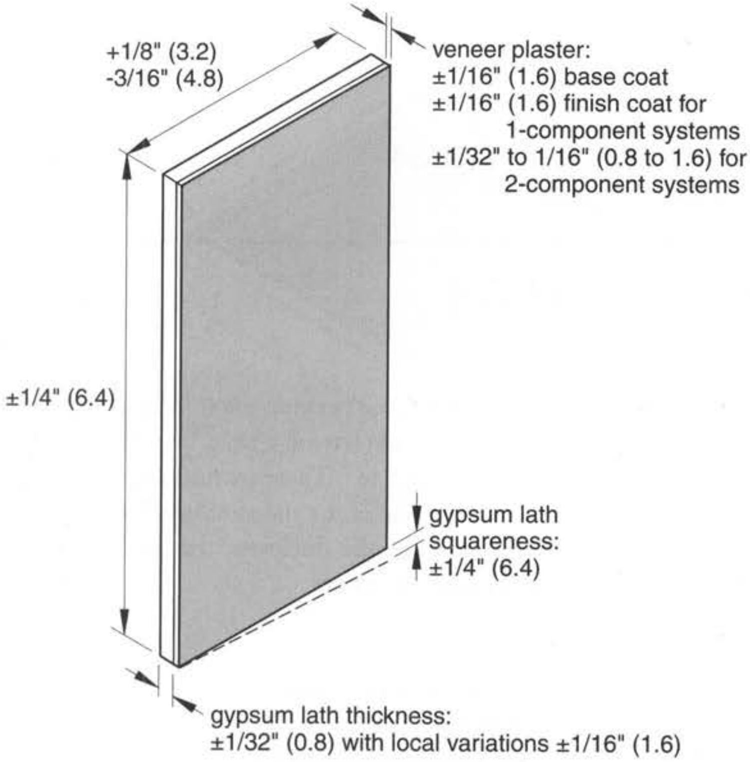
Allowable Tolerances

Published tolerances for lath and plaster are shown in Figure 9-4. Tolerances for gypsum lath are given in ASTM C1396 (shown in Figure 9-4a), but these generally do not affect the finished surface. Although there are no tolerances for the plan dimension position of the finished surface of plaster partitions, ASTM C843 does give tolerances for the thickness for the veneer coats of gypsum plaster. ASTM C843 further requires that all protrusions and ridges greater than 1/8 in. (3.2 mm) be removed and that all depressions greater than 1/4 in. (6.4 mm) be filled level with the surface.

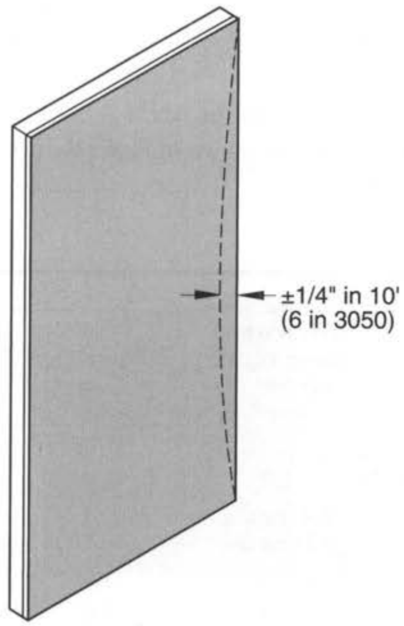
For standard, full-coat, portland cement plaster work, a subsurface plane tolerance of ±1/4 in. in 10 ft. (2.1 mm/m) is standard as given in ASTM C926, although good plasterers can level a surface to a smaller tolerance than this.

In general, because of possible variations with framing installation, the application of lath and trim, and the thickness of plaster, it seems reasonable to expect a tolerance of ±1/4 in. in 10 ft. (6 mm in 3,050 mm) or slightly more for most plaster work.

Figure 9–4 Installation of lath and plaster



(a) gypsum veneer plaster on gypsum lath



(b) Portland cement-based plaster

As with gypsum wallboard, if tighter tolerances are required because of subsequent finish materials, such as ceramic tile, or critical opening dimensions, the tolerances should be clearly stated in the contract documents.

Related Sections

6–6 Rough Lumber Framing
6–7 Wood Floor Framing and Subflooring
9–1 Light-Gauge Framing for Gypsum Wallboard
9–5 Floor and Wall Tile

9–5 Floor and Wall Tile

Description

This section gives tolerances for glazed and unglazed ceramic tile (mosaic and wall tile), quarry tile, and paver tile. *Ceramic mosaic tile* is tile having a facial area less than 6 in.^{2}. *Wall tile* is a glazed interior tile larger in area than 6 in.^{2}. There are tolerances for the manufacture of tile but none for the level of the plane of the tile after installation. This depends on the level of the substrate, the warpage; the thickness, the size, and wedging; tolerances of the tile itself; and the skill of the tile setter.

Industry Standards

ANSI A108/A118/A136, *American National Standard for the Installation of Ceramic Tile* (Anderson, SC: Tile Council of North America, Inc., 1999).

ANSI A137.1, *Specifications for Ceramic Tile* (Anderson, SC: Tile Council of North America, Inc., 1988).

2006 Handbook for Ceramic Tile Installation (Anderson, SC: Tile Council of North America, Inc., 2006).

Allowable Tolerances

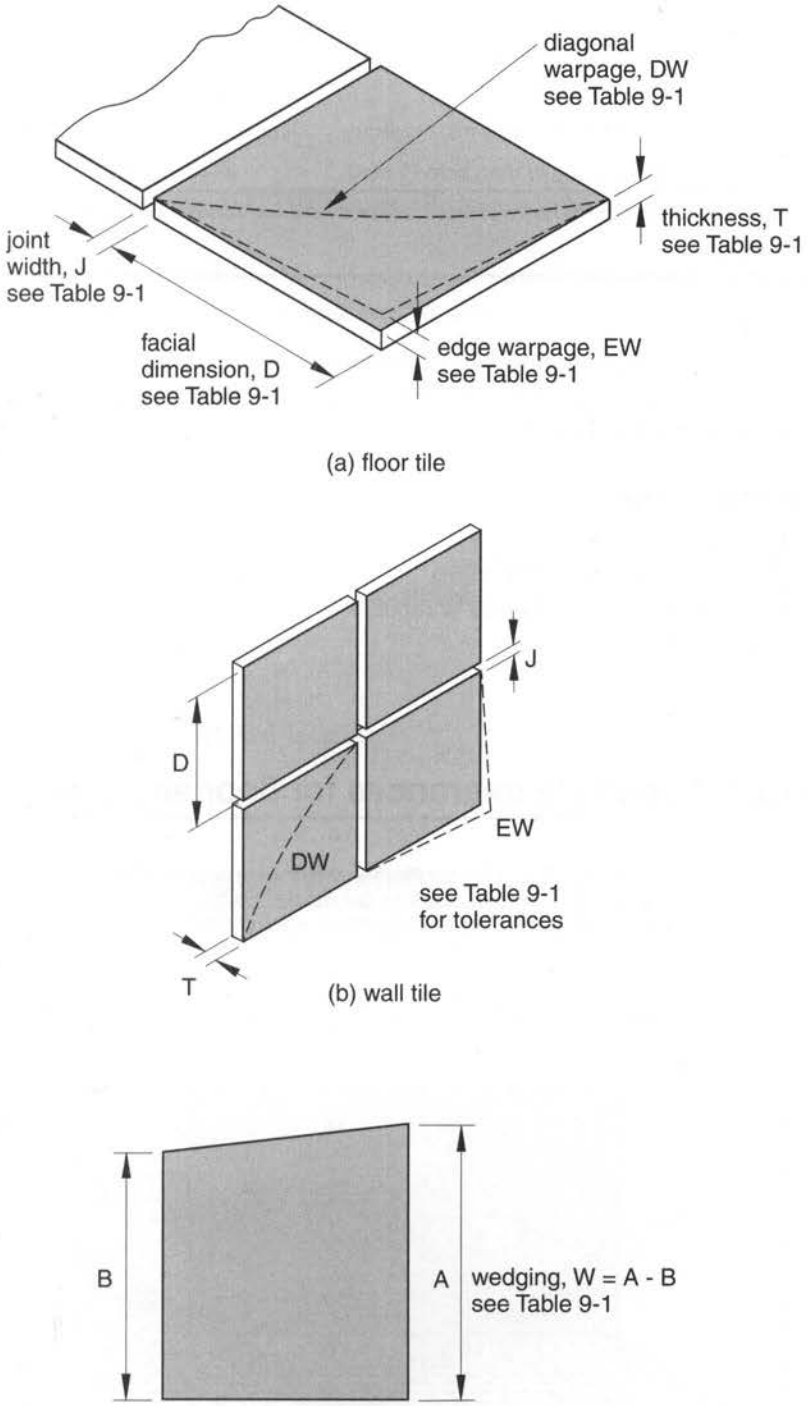
Tolerances for the manufacture of tile are stated in ANSI A137.1 and summarized in Table 9-1. The locations of these tolerances are shown in Figure 9-5(a) and 9-5(b).

Table 9–1 Tile manufacturing tolerances

Tile type	T, thickness, in (mm)	D, facial dimension, percent of length	EW, warpage along edges, percent of length	DW, warpage on diagonal, percent	W, wedging, percent
Unglazed ceramic mosaic	±0.030 (0.76)	±10	1.0	0.75	2.0
Glazed ceramic mosaic	±0.030 (0.76)	±10	1.0	0.75	2.0
Glazed wall tile	±0.031 (0.79)	±4.0	0.4 convex 0.3 concave	0.5	0.6
Unglazed quarry tile	±0.050 (1.3)	±4.0	1.5	1.0	1.0
Glazed quarry tile	±0.050 (1.3)	±4.0	1.5	1.0	1.0
Unglazed paver tile	±0.040 (1.0)	±3.0	1.0	0.75	1.0
Glazed paver tile	±0.040 (1.0)	±3.0	1.0	0.75	1.0

Source: Compiled from information in ANSI A137.1

Figure 9–5 Floor and wall tile



(c) wedging

Table 9–2 Required tolerance for plane of substrate for tile installation

Tile installation	Floor substrate tolerances	Wall substrate tolerances
Portland cement mortar bed	¼ in in 10 ft (6 mm in 3 m)	¼ in in 10 ft (6 mm in 3 m)
Dry-set or latex-Portland cement mortar (thin set)[a]	¼ in in 10 ft (6 mm in 3 m)	¼ in in 10 ft (6 mm in 3 m)
Organic adhesive or epoxy adhesive	1/16 in in 3 ft (2 mm in 1 m); no abrupt irregularities more than 1/32 in (1 mm)	¼ in in 10 ft (6mm in 3 m)

[a] *Also includes chemical resistant water cleanable tile-setting and grouting epoxy, furan, and modified epoxy emulsion mortar installations.*

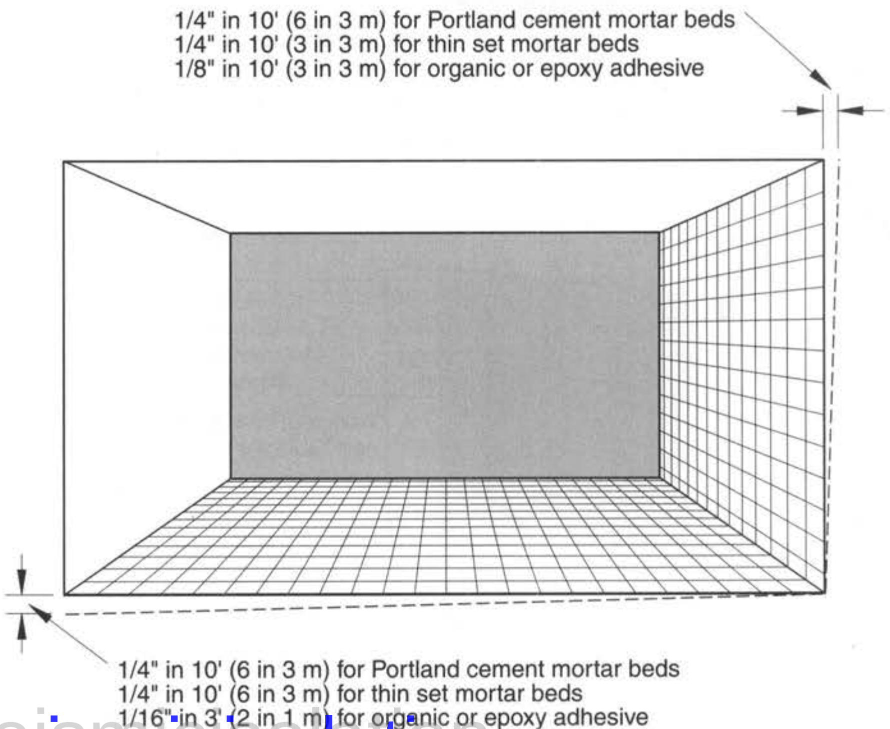
Source: Compiled from information in ANSI A108/A118/A136.

The required tolerances for the plane of the surface over which tile is placed are summarized in Table 9-2 and Figure 9-5.1 and based on ANSI 108.1 and the Tile Council of North America installation handbook.

Related Sections

6–6 Rough Lumber Framing
6–7 Wood Floor Framing and Subflooring
9–1 Light-Gauge Framing for Gypsum Wallboard
9–4 Installation of Lath and Plaster

Figure 9–5.1 Substrate tolerances for floor and wall tile



9–6 Terrazzo Flooring

Description

Terrazzo is a composite material poured in place consisting of stone chips in a matrix that is cementitious, modified cementitious, or resinous. Terrazzo is normally installed over concrete subfloors, but it can be installed over wood floors if deflection is controlled and a sand cushion system is used.

Industry Standards

Specifications (Purcellville, VA: The National Terrazzo and Mosaic Association, Inc., 2005).

Flatness Tolerances (Purcellville, VA: The National Terrazzo and Mosaic Association, Inc., 2005). Available at www.ntma.com/05_flatness_tolerance.php.

Allowable Tolerances

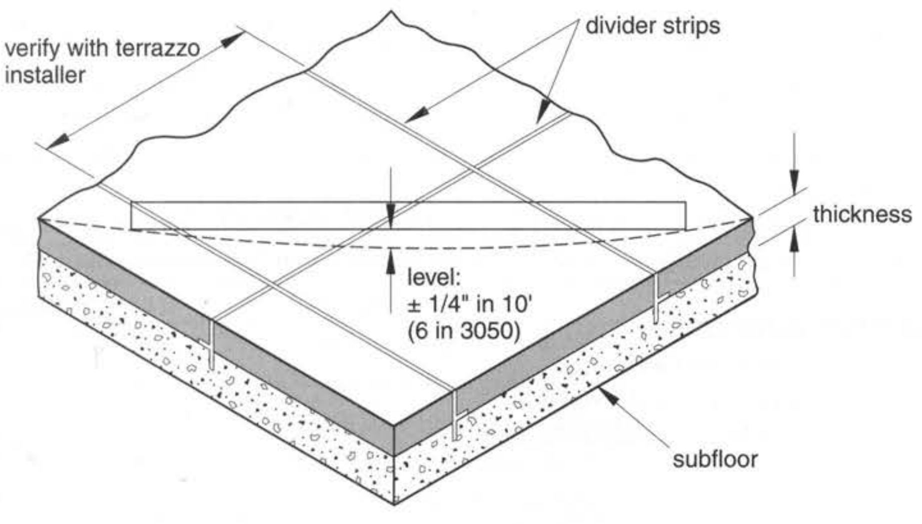
Standard tolerances are shown in Figure 9-6. Because terrazzo is ground smooth after it sets, the level can usually be brought to within ±¼ in. in 10 ft. (6 mm in 3,050 mm). When the pattern and design of the divider strips are critical for appearance, their location tolerance should be verified with the terrazzo contractor.

For terrazzo floors, the subfloor must be within certain tolerances for a satisfactory installation. Concrete subfloors must be level to within ¼ in. in 10 ft. (6 mm in 3,050 mm).

Related Sections

2–4 Concrete Slabs on Grade
2–8 Cast-in-Place Sectional Tolerances

Figure 9–6 Terrazzo Flooring



9–7 Wood Flooring

Description

Wood flooring includes standard strip, parquet, and laminated flooring as well as the various types of cushioned wood flooring systems. Because wood flooring is manufactured to exacting tolerances, a successful installation usually depends more on the level and smoothness of the subfloor than on the tolerances of the wood floor itself.

Industry Standards

ANSI/HPVA EF 2002, *American National Standard for Engineered Wood Flooring* (Reston, VA: Hardwood Plywood and Veneer Association, 2002).

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders, 2005).

SpecGUIDE, 09550, *Wood Flooring*, May 1988 (Alexandria, VA: The Construction Specifications Institute, 1988) Out of print.

UFGS Section 09 64 29, *Wood Strip Flooring*, United Facilities Guide Specifications, July (Washington, DC: National Institute of Building Sciences, 2006) New URL is http://www.wbdg.org/ccb/DOD/UFGS/UFGS%2009%2064%2029.pdf.

Allowable Tolerances

There are no industry standards for manufacturing dimensional tolerances for strip flooring, as shown in Figure 9-7(a). Strip flooring is manufactured to fit a metal size gauge at the time of manufacturing for the moisture content at the time. According to the Forest Products Laboratory, as the environmental moisture content changes, the strip flooring will change size at the rate of about 1/32 in. (0.8 mm) for each 4 percent change in moisture content.

There are few standards for tolerances for the final finish surface of wood floors. The *Residential Construction Performance Guidelines* of the National Association of Home Builders Remodelors™ Council states that a wood floor should not slope more than 1/2 in. in 20 ft. (13 mm in 6,200 mm) for residential work, but this should be the extreme case. A more reasonable tolerance should be the subfloor tolerance as indicated in the following. In any situation, local floor variation may be more important than an overall slope. Tolerances for engineered wood flooring are shown in Figure 9-7(b).

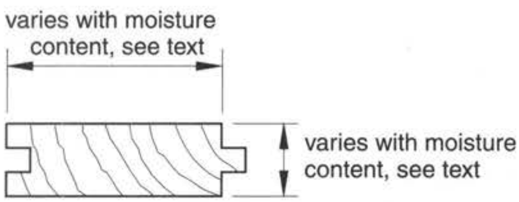
For strip flooring and parquet flooring, the subfloor should be level to within 1/4 in. in 10 ft. (6 mm in 3,050 mm) with no abrupt projections or depressions. The UFGS guide specifications require that concrete slab be level to a tolerance of ±1/8 in. in a 10-ft. radius (±3 mm in a 3-m radius).

The tolerances shown in Table 9-3 for concrete slab substrates for various types of installations were previously recommended by the Construction Specifications Institute.

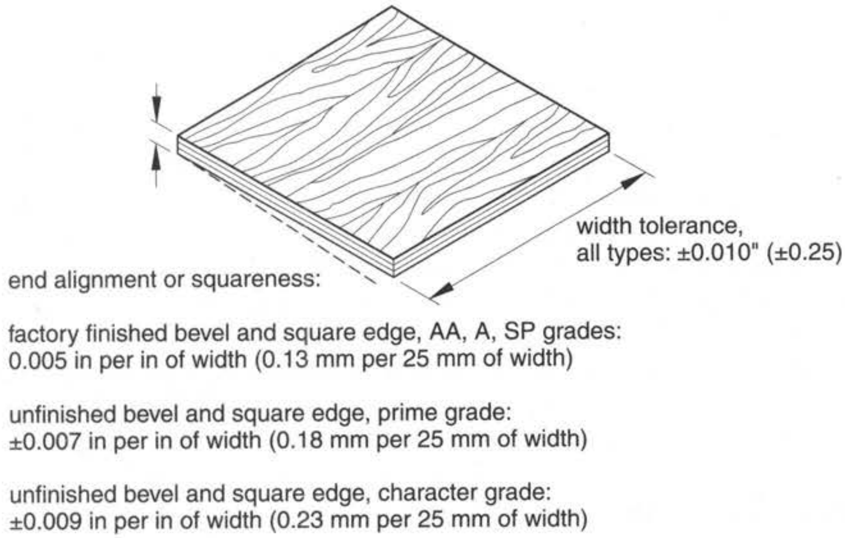
Related Sections

2–4 Concrete Slabs on Grade
2–8 Cast-in-Place Sectional Tolerances
6–7 Wood Floor Framing and Subflooring

Figure 9–7 Wood flooring



(a) strip flooring



(b) plank and block flooring

Table 9–3 Recommended concrete slab tolerances for wood flooring

Installation type	Slab tolerance
Cushioned	3/16-inch in 10-feet (5 mm in 3050)
Laminated	3/16-inch in 10-feet (5 mm in 3050)
Mastic cushioned	1/4-inch in 10 feet (6 mm in 3050 mm)
Rubber cushioned	3/16-inch in 10-feet (5 mm in 3050)
Steel channel	1/8-inch in 10 feet (3 mm in 3050 mm)

Source: Compiled from information in SpecGUIDE, 09550, Wood Flooring, *The Construction Specifications Institute, May, 1988. (out of print)*

9–8 Stone Flooring

Description

Stone flooring includes standard thick-set stone (minimum ¾ in. or 13 mm thick) placed on a thick mortar setting bed and thin stone tiles that are thin-set directly on concrete or wood subfloors.

Industry Standards

Dimension Stone Design Manual VI (Cleveland: Marble Institute of America, Inc., 2003).

Allowable Tolerances

For commercial stone floors using ¾-in- (13-mm-) thick stone on a thick mortar setting bed, the maximum variation of the finished surface is ⅛ in. in 10 ft. (3 mm in 3,050 mm) with no more than 1/32-in. (1-mm) lippage between individual, smooth-faced tiles, as shown in Figure 9-8. *Lippage* is the variation between one edge of a stone tile and the adjacent stone tile edge. It is more pronounced in thin-set stone tile than with thick-set stone floors because there is no thick mortar bed to compensate for minor variations in subfloor level. Natural cleft flooring slate cannot be set to these tolerances because of the natural unevenness of its thickness.

As with ceramic tile and wood flooring, thin stone tile is manufactured to exacting tolerances, and its successful installation depends as much on the level and smoothness of the subfloor as on the skill of the tile setter. The Marble Institute of America recommends that wood subfloors for stone tile have a maximum deflection of no more than 1/720 of the span up to 14 ft. (4,270 mm) and that they be level to within 1/16 in. in 3 ft. (1.6 mm in 900 mm). Maximum allowable deflection is 7/32 in. (5.6 mm). Concrete subfloors for thin-bed mortar tile must be level to within ⅛ in. in 10 ft. (3 mm in 3,050 mm). Maximum allowable deflection is 7/32 in (5.6 mm). When possible, the maximum variation of finished surface for stone tile is the same as for thick-set stone floors.

Related Sections

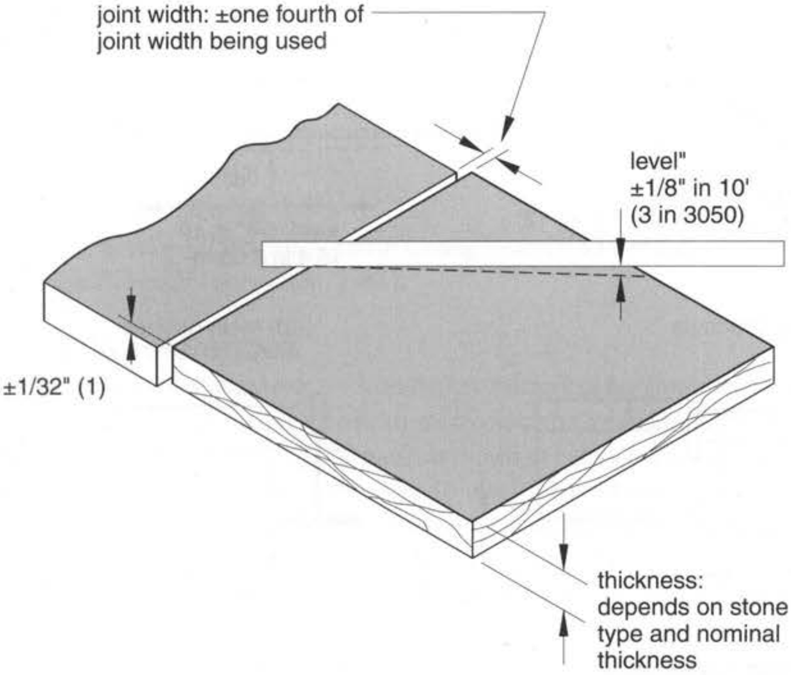
2–4 Concrete Slabs on Grade
2–8 Cast-in-Place Sectional Tolerances
5–1 Granite Fabrication
5–2 Marble Fabrication
5–6 Fabrication and Installation Tolerances for Slate
5–8 Interior Stone Wall Cladding
6–7 Wood Floor Framing and Subflooring

9–9 Acoustical Ceiling Installation

Description

This section includes tolerances for both steel and aluminum ceiling suspension systems installation for exposed and concealed spline acoustical ceiling systems. However, the ASTM standards only give tolerances for steel systems. For aluminum systems, they refer to any tolerances published by the suspension system manufacturer. There are also several manufacturing tolerances for suspension systems given in ASTM C635, but these tolerances are so small that they do not affect the appearance or installation of a ceiling as long as the selected system conforms to the standard.

Figure 9–8 Stone flooring



Industry Standards

ASTM C635, *Standard Specification for the Manufacture, Performance, and Testing of Metal Suspension Systems for Acoustical Tile and Lay-in Panel Ceilings* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

ASTM C636, *Standard Practice for Installation of Metal Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels*. (West Conshohocken, PA: American Society for Testing and Materials, 2004).

SPECTEXT Section 09511, *Suspended Acoustical Ceilings*, April (Baltimore: Construction Sciences Research Foundation,).

Allowable tolerances

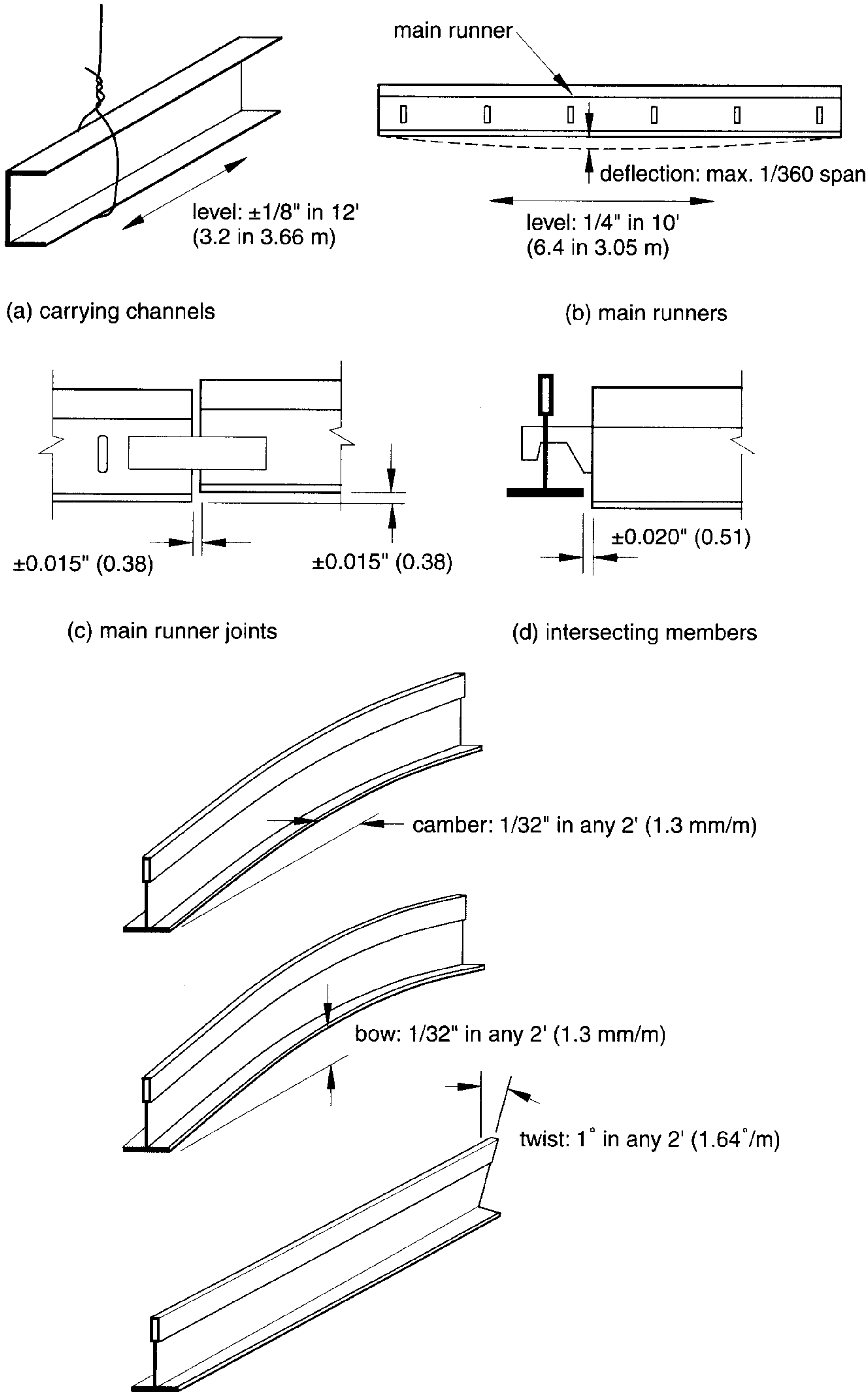
Tolerances for connection and level of the various components of a typical ceiling suspension system are shown in Figures 9-9(a) through 9-9(d). Although ASTM C636 requires a level of ¼ in. per 10 ft. (6.4 mm in 3.05 mm), most ceilings are installed with laser leveling devices and can be leveled to within ⅛ in. in 10 ft. (3.2 mm in 3.05 mm) and often to within ⅛ in. over the entire room area. Master specifications, such as the SPECTEXT, recommend a tolerance of ⅛ in. in 10 ft.

Bow, camber, and twist tolerances are shown in Figure 9-9(e). Unlike normal construction nomenclature, bow refers to deformation in the *vertical* direction, whereas camber refers to deformation in the *horizontal* direction.

Related Sections

9–10 Linear Metal Ceiling Installation

Figure 9–9 Acoustical ceiling installation



(a) carrying channels

(b) main runners

(c) main runner joints

(d) intersecting members

(e) bow, camber, and twist

9–10 Linear Metal Ceiling Installation

Description

Linear metal ceilings are suspended systems using lengths of prefinished aluminum sections that are clipped to carrier sections suspended with wires attached to the structure above. There is usually a gap between each piece to provide for some sound absorption and for return air movement.

Industry Standards

SPECTEXT Section 09546, *Metal Linear Ceiling System*, July (Baltimore: Construction Sciences Research Foundation, 1991).

Allowable Tolerances

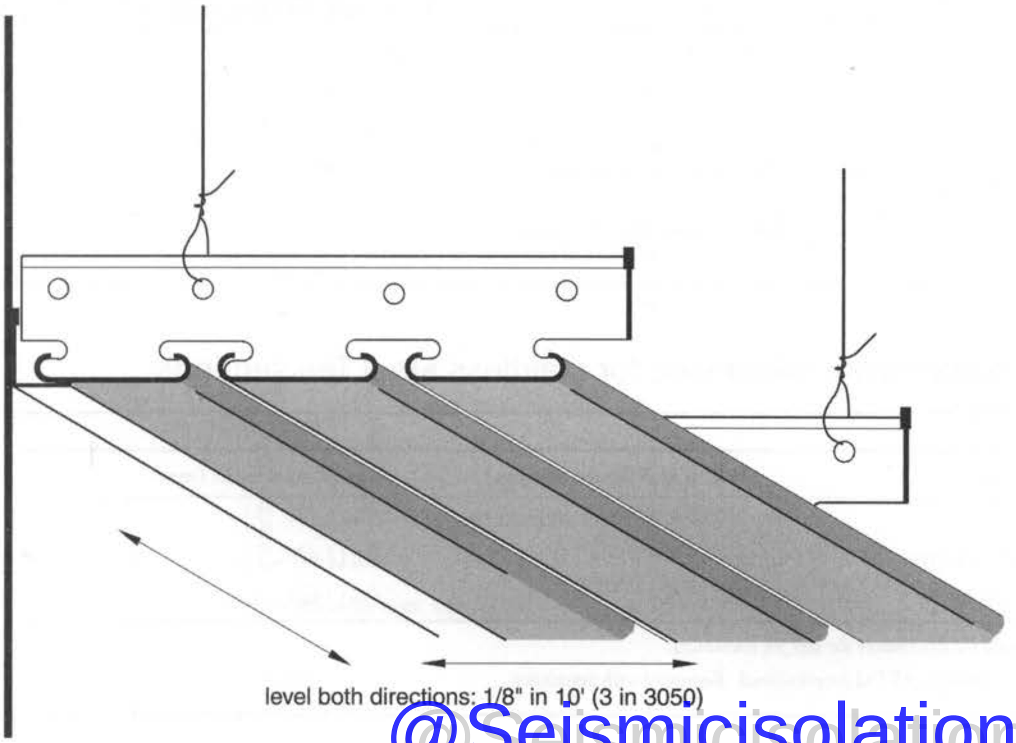
There are no industry standards for installation tolerances for linear metal ceilings, although the SPECTEXT master specifications recommend a maximum variation from flat plane of ⅛ in. in 10 ft. (3 mm in 3,050 mm), as shown in Figure 9-10, and a maximum variation from dimensioned position of ±¼ in. (6 mm). They also recommend a maximum variation from plumb of grid members caused by eccentric loads of 2 degrees. As with acoustical ceilings, the suspension system is installed with laser leveling devices in most cases, so a tolerance of ⅛ in. (3 mm) is a reasonable expectation for the precisely manufactured components of these systems.

Manufacturing tolerances are determined by each manufacturer.

Related Sections

9–9 Acoustical Ceiling Installation

Figure 9–10 Linear metal ceiling installation



9–11 Stainless Steel Ornamental Metal Products

Description

This section includes tolerances for some of the shapes and stainless steel alloys commonly used for ornamental construction purposes. There are many ASTM standards for all the alloys and shapes of stainless steel, and for each product type (bars, sheets, tubes, etc.), there are many individual tolerances such as wall thickness, length, squareness, and so on. However, most of these tolerances are so small as to be insignificant (in the order of thousandths of an inch) for most ornamental design and detailing work.

However, when standard stainless steel sections are used for a custom-designed ornamental fabrication, certain tolerances can be important. These are listed in this section.

Industry Standards

ASTM A484/A484M, *Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

ASTM A554, *Standard Specification for Welded Stainless Steel Mechanical Tubing* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

Tolerances for stainless steel sections that are likely to be important for detailing are shown in Figure 9-11 and given in Tables 9-4 and 9-5.

Table 9–4 Twist tolerances for stainless steel tube sections

Largest size, in (mm)	Twist, max. in/3 feet, (mm/m)
½ to 1½ (12.7 to 38.1), inclusive	±0.075 (2.1)
Over 1½ to 2½ (38.1 to 63.5), inclusive	±0.095 (2.6)
Over 2½ (63.5) to 4 (101.6, inclusive	±0.125 (3.5)
Over 4 to 6 (101.6 to 152.4), inclusive	±0.250 (6.9)
Over 6 (152.4)	±0.375 (10.4)

Source: ASTM A554. Copyright ASTM International. Reprinted with permission.

Table 9–5 Size and squareness tolerances for stainless steel Tee sections

Specified size of Tee, in (mm)[a]	Width and depth, in (mm)	Out-of-square, in (mm)
To 1½ (38.00) inclusive	±5/64 (2.00)	±3/64 (1.20)
Over 1½ to 2 (38.00 to 50.00) inclusive	±3/32 (2.40)	±3/32 (2.40
Over 2 to 3 (50.00 to 75.00) exclusive	±9/64 (3.60)	±9/64 (3.60)

[a] *The longer member of an unequal tee determines the size for tolerances.*

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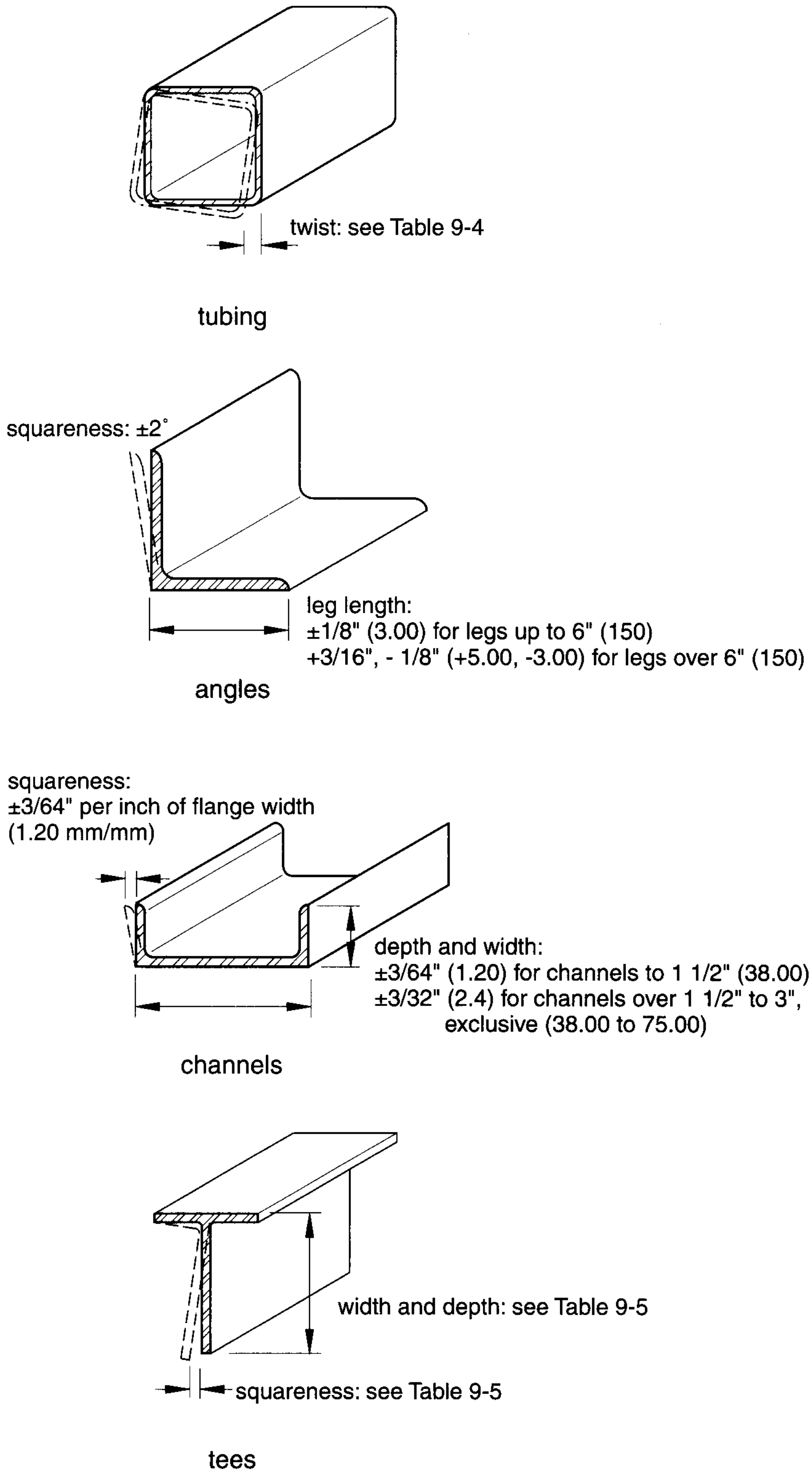
Figure 9–11 Stainless steel ornamental metal products



Related Sections

9–12 Copper Alloy Ornamental Metal Products
9–13 Dimensional Tolerances for Aluminum Mill Products

9–12 Copper Alloy Ornamental Metal Products

Description

This section includes tolerances for some of the shapes and alloys of copper commonly used for ornamental construction purposes. There are many ASTM standards for all the alloys and shapes, and for each product type (bars, sheets, tubes, etc.), there are many individual tolerances such as wall thickness, length, squareness, and so on. However, most of these tolerances are so small as to be insignificant (in the order of thousandths of an inch) for most ornamental design and detailing work.

However, when standard copper alloy sections are used for a custom-designed ornamental fabrication, certain tolerances can be important. These are listed in this section for some of the commonly used architectural alloys.

Industry Standards

ASTM B248 and B248M, *Standard Specification for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar* (West Conshohocken, PA: American Society for Testing and Materials, 2001).

ASTM B249/B249M, *Standard Specification for General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

ASTM B251 and B251M, *Standard Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Tube* (West Conshohocken, PA: American Society for Testing and Materials, 2002).

Allowable Tolerances

Tolerances for copper alloy sections that are likely to be important for detailing are shown in Figure 9-12 and given in Tables 9-6 and 9-7. The tolerances for rectangular and round tubing include the copper alloys C22000 (commercial bronze), C23000 (red brass), C26000 (cartridge brass), and C28000 (Muntz metal). The tolerances shown for drawn rod includes the alloy C65500.

Table 9–6 Straightness tolerances for round tubing[a]

Length of section, ft (mm) b	Maximum curvature, in (mm)
Over 3 to 6, (1000 to 2000), inclusive	±3/16 (5.0)
Over 6 to 8 (2000 to 2500), inclusive	±5/16 (8.0)
Over 8 to 10 (2500 to 3000), inclusive	±1/2 (12)

[a] *Not applicable to pipe, redrawn tube, extruded tube or any annealed tube.*
[b] *For lengths greater than 10 ft. (3000 mm) the maximum curvature shall not exceed 1/2 in. (12 mm) in any 10-ft. (3000 mm) portion of the total length.*
Source: ASTM B251/B251M. Copyright ASTM International. Reprinted with permission.

Figure 9–12 Copper alloy ornamental metal products

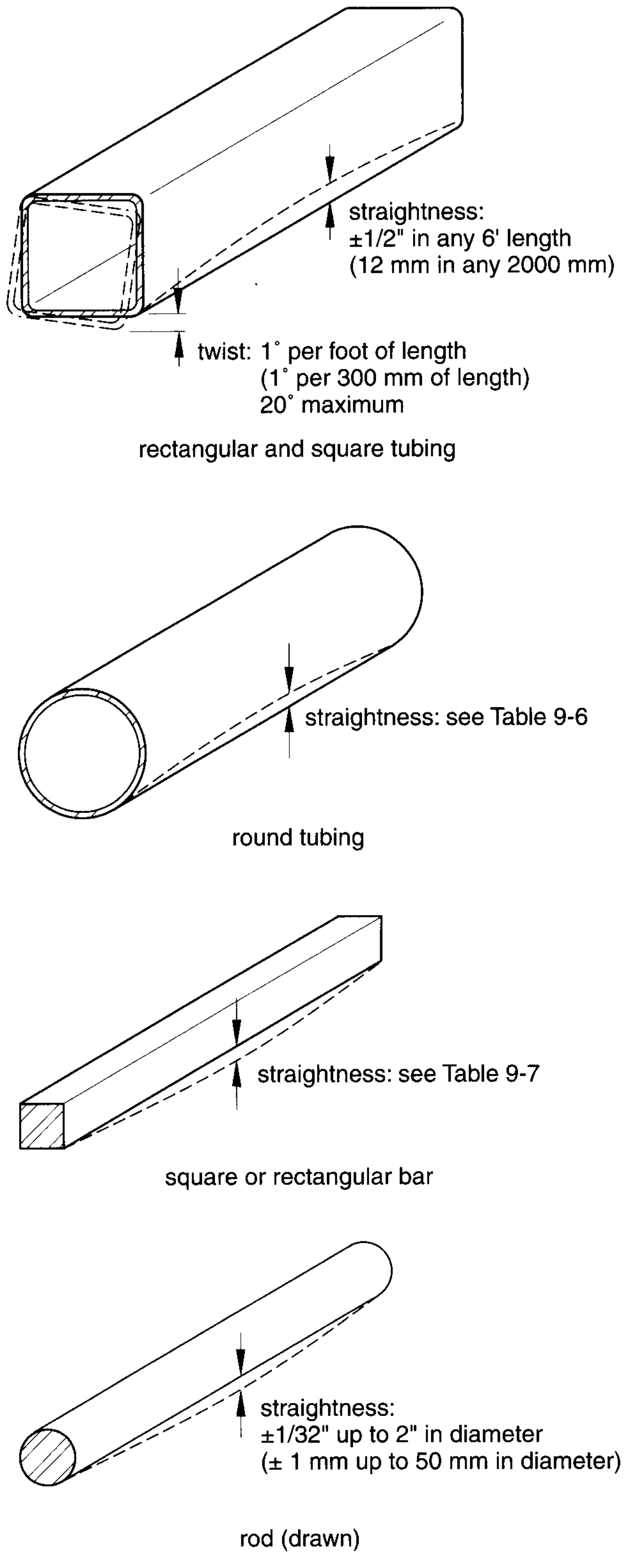


Table 9–7 Straightness tolerances for bars made from square-sheared metal [a]

Thickness, in (mm)	Tolerance for bars up to 10 in (250 mm) wide b	Tolerance for bars over 10 in (250 mm)
1/8 and under (3.2)	±1/16 (1.6)	1/32 (0.79
Over 1/8 to 3/16 (3.2 to 5.0), inclusive	±1/8 (3.2)	3/64 (1.2
Over 3/16 (5.0)	±1/8 (3.2)	1/16 (1.6)

[a] *Includes alloys C22000 (commercial bronze), C23000 (red brass), and C26000. (cartridge brass).*
[b] *Maximum edgewise curvature (depth of arc) in any 72-inch (1800 mm) portion of the total length.*
Source: ASTM B248/B248M. Copyright ASTM International. Reprinted with permission.

Related Sections

9–11 Stainless Steel Ornamental Metal Products
9–13 Dimensional Tolerances for Aluminum Mill Products

9–13 Extruded Aluminum Tubes

Description

This section includes the aluminum products and tolerances that are most likely to be of concern to a designer detailing a custom-fabricated component using aluminum tubing. Many of the other tolerances for aluminum tubing are not included.

Industry Standards

ANSI-H35.2, *Dimensional Tolerances for Aluminum Mill Products* (Arlington, VA: The Aluminum Association, Inc., 2003).

Allowable Tolerances

ANSI-H35.2 contains many tolerances for individual elements of aluminum tubing. However, most of these tolerances are so small as to be insignificant (in the order of thousandths of an inch) for most ornamental design and detailing work. Mill tolerances for construction usually affect only the fabrication of components made from aluminum, such as curtain walls and windows. When standard aluminum tubing sections are used for a custom-designed ornamental fabrication, certain tolerances can be important, such as width, straightness, and twist. These are listed in Table 9-8 and shown in Figure 9-13.

Related Sections

8–1 Aluminum Curtain Wall Fabrication
8–4 Storefront and Entrance Manufacturing
11–9 Aluminum Window Manufacturing

Figure 9–13 Extruded aluminum tubes

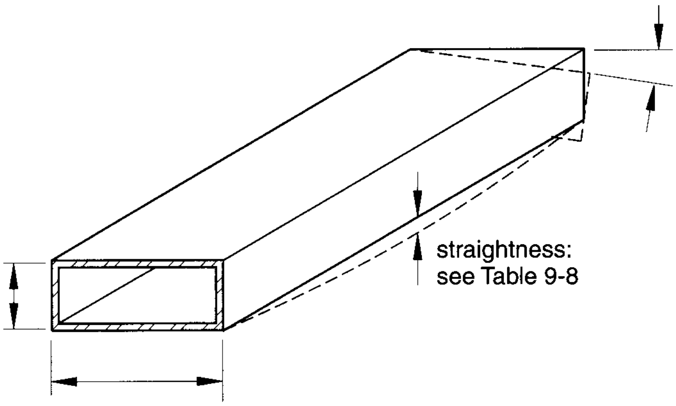


Table 9–8 Selected tolerances for extruded aluminum tube sections[a]

	Inches		mm	
Type of tolerance	Specified width	Deviation, in. or degrees[b]	Specified width	Deviation, mm or degrees[b]
Width and depth	0.500-0.749	±0.012	12.50-20.00	±0.030
	0.750-0.999	±0.014	20.00-25.00	±0.36
	1.000-1.999	±0.018	25.00-50.00	±0.46
	2.000-3.999	±0.025	50.00-100.00	±0.64
	4.000-4.999	±0.035	100.00-130.00	±0.88
	5.000-5.999	±0.045	130.00-150.00	±1.15
	6.000-6.999	±0.055	150.00-180.00	±1.40
	7.000-7.999	±0.065	180.00-200.00	±1.65
	8.000-8.999	±0.075	200.00-230.00	±1.90
Straightness	0.500-5.999	0.010 x measured length, ft.[c]	12.5-150.00	1 mm/m[d]
	6.000 and over	0.020 x measured length, ft.	150.00 and over	2 mm/m
Twist	0.500-1.499	1° x measured length, ft; max. of 7°	12.50-40.00	3°/m but not greater than 7°
	1.500-2.999	0.5° x measured length, ft, max. of 5°	40.00-80.00	1.5°/m but not greater than 5°
	3.000 and over	0.25° x measured length, ft, max. of 3°	80.00 and over	1°/m but not greater than 3°

[a] *This table includes tolerances for alloys and sizes normally used in construction. See ANSI H35.2 for a complete listing of all alloys, sizes, and tolerances.*
[b] *Deviation at corners of section. See ANSI H35.2 for allowable deviation in width between corners.*
[c] *Deviation from straight in total length or in any segment of one foot or more of total length.*
[d] *Deviation from straight in total length or in any 300 mm or longer chord segment of total length.*
Source: Based on information from ANSI H35.2-2003.

9–14 Aluminum Rods, Bars, and Shapes

Description

This section includes the aluminum products and tolerances that are most likely to be of concern to a designer detailing a custom-fabricated component using rods, bars, and various aluminum extruded shapes.

Industry Standards

ANSI-H35.2, *Dimensional Tolerances for Aluminum Mill Products* (Arlington, VA: The Aluminum Association, Inc., 2003).

Allowable Tolerances

ANSI-H35.2 contains many tolerances for individual elements of aluminum rods, bars, and shapes. However, most of these tolerances are so small as to be insignificant (in the order of thousandths of an in) for most ornamental design and detailing work. Mill tolerances for construction usually only affect the fabrication of components made from aluminum, such as curtain walls, windows, and railings.

Table 9–9 Selected tolerances for aluminum rods, bars, and shapes[a]

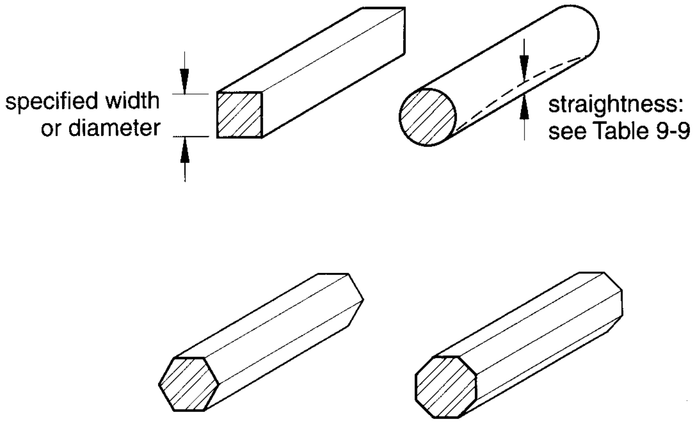
	Inches		mm	
Product type	***Specified width or diameter (and thickness)***[b]	***Deviation, in. or degrees, times the measured length in feet***	***Specified width or diameter (and thickness)***[b]	***Deviation, mm or degrees***
		Straightness		
Shapes	Width up through 1.4999 with thickness up through 0.094	0.050	Width up through 40.00 with thickness up through 2.50	4 mm/m
	Width up through 1.4999 with thickness 0.095 and over	0.0125	Width up through 40.00 with thickness over 2.50	1 mm/m
	Width 1.500 and over of all thicknesses	0.0125	Width over 40.00 of all thicknesses	1 mm/m
Rectangular bar	Width up through 1.499 and thickness up through 0.094	0.050	Width up through 40.00 and thickness up through 2.50	4 mm/m
	Width up through 1.499 with thickness 0.095 and over	0.0125	Width up through 40.00 and thickness 2.50 and over	1 mm/m
Rod, square, hexagonal, octagonal bar	All	0.0125	All	1 mm/m
		Twist		
Shapes/bars	Width up through 1.499	1° with max. of 7°	Width through 40.00	3°/m; max. of 7°
	1.500-2.999	0.5° with max. of 5°	40.00-80.00	1.5°/m; max. of 5°
	3.000 and over	0.25° with max. of 3°	80.00 and over	1°/m; max. of 3°

a This table includes tolerances for alloys and sizes normally used in construction. See ANSI H35.2 for a complete listing of all alloys, sizes, and tolerances.

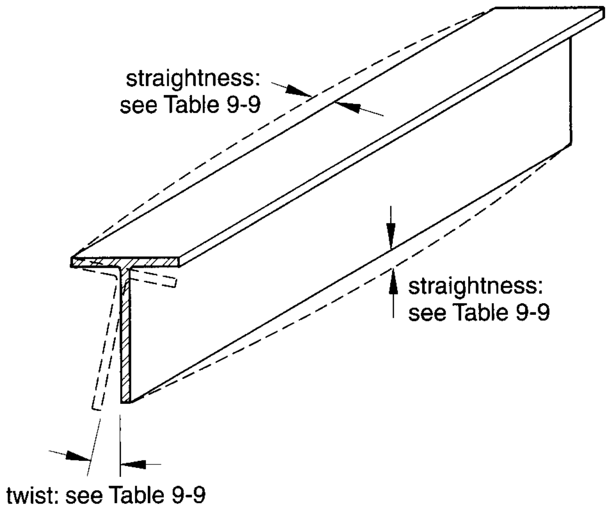
b Diameter includes circumscribing circle around shapes like hexagonal bars.

Source: Based on information from ANSI H35.2-2003.

Figure 9–14 Aluminum rods, bars, and shapes



(a) rods and bars



(b) shapes

When standard aluminum shapes are used for a custom-designed ornamental fabrication, certain tolerances can be important, such as straightness and twist. These are listed in Table 9-9 and shown in Figure 9-14.

Related Sections

8–1 Aluminum Curtain Wall Fabrication

9–13 Extruded Aluminum Tubes

Figure 10–1 Manufacturing tolerances for flat glass

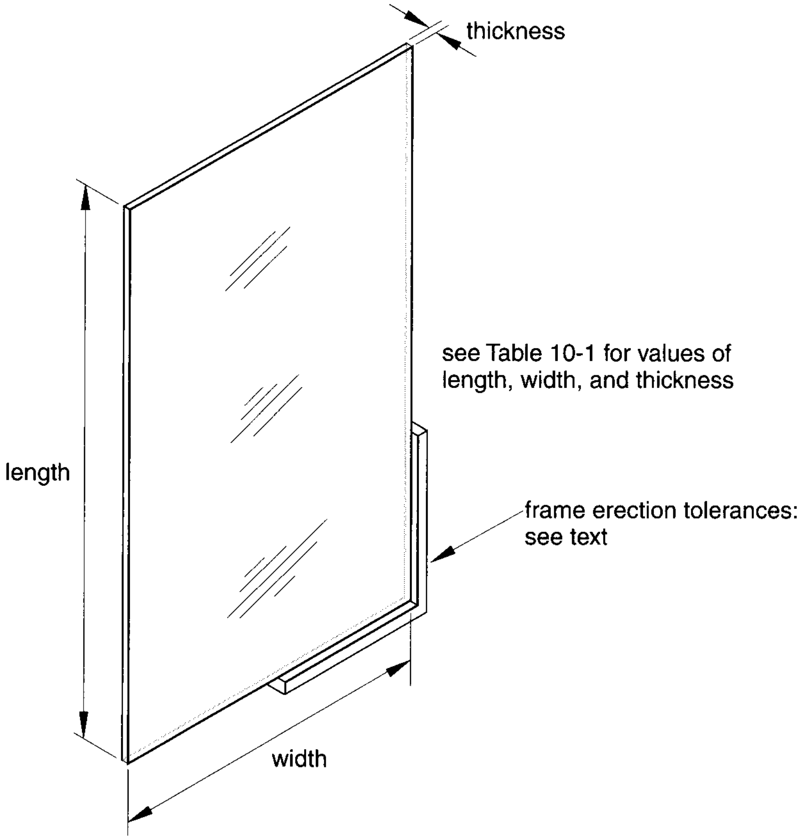


Table 10–1 Allowable tolerances for clear, flat glass

Ordering thicknesses		*Thickness range*				
Traditional designation, in	Designation, mm	in Min.	in Max.	mm Min.	mm Max.	Cut size, length and width, in (mm)
Single	2.5	0.085	0.101	2.16	2.57	±1/16 (1.6)
Double, 1/8"	3.0	0.115	0.134	2.92	3.40	±1/16 (1.6)
5/32	4.0	0.149	0.165	3.78	4.19	±1/16 (1.6)
3/16	5.0	0.180	0.199	4.57	5.05	±1/16 (1.6)
1/4	6.0	0.219	0.244	5.56	6.20	±1/16 (1.6)
5/16	8.0	0.292	0.332	7.42	8.43	±5/64 (2.0)
3/8	10.0	0.355	0.406	9.02	10.31	±3/32 (2.4)
1/2	12.0	0.469	0.531	11.91	13.49	±1/8 (3.2)
5/8	16.0	0.595	0.656	15.09	16.66	±5/32 (4.0)
3/4	19.0	0.719	0.781	18.26	19.84	±3/16 (4.8)
7/8	22.0	0.844	0.906	21.44	23.01	±7/32 (5.6)
1	25.0	0.969	1.031	24.61	26.19	±1/4 (6.4)

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Chapter 10

Glazing

10–1 Manufacturing Tolerances for Flat Glass

Description

This section includes tolerances for the manufacture of flat glass. It does not include glass as part of a window assembly. Refer to Chapter 11 for window assembly tolerances.

Industry Standards

GANA *Glazing Manual* (Topeka, KS: Glass Association of North America, 2004).

ASTM C1036, *Standard Specification for Flat Glass* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Allowable Tolerances

Tolerances for the most common thicknesses of flat glass are shown diagrammatically in Figure 10-1 and given in Table 10-1. For a complete listing, refer to ASTM C1036.

For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of ¹⁄₃₂ in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

Related Sections

10–2 Manufacturing Tolerances for Patterned And Wired Glass
10–3 Tempered, Heat-Strengthened, and Spandrel Glass
10–4 Sealed Insulated Glass Units
11–13 Lockstrip Gasket Glazing

10–2 Manufacturing Tolerances for Patterned and Wired Glass

Description

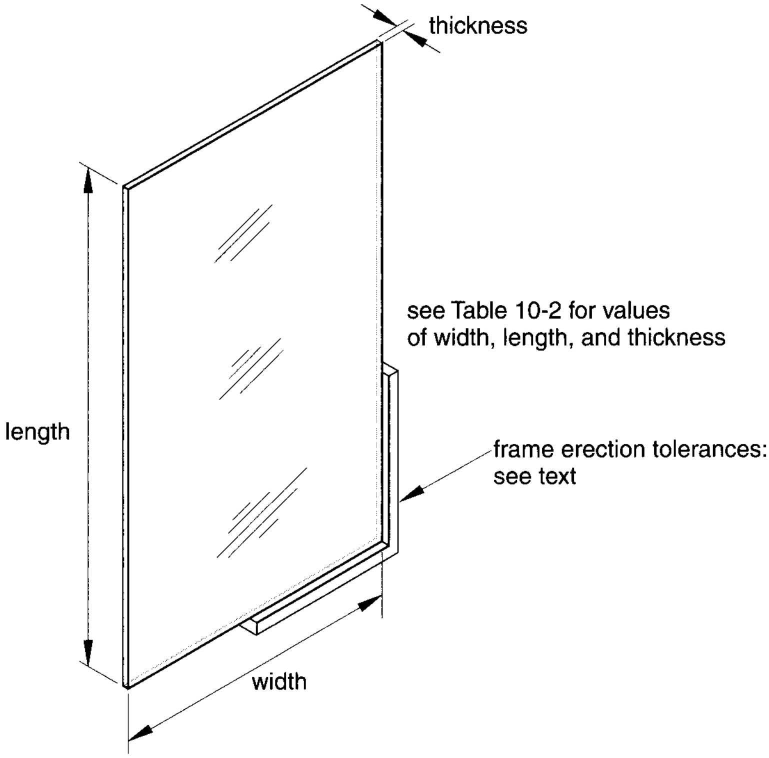
This section includes tolerances for the manufacture of patterned and wired glass. It does not include glass as part of a window assembly. Refer to Chapter 11 for window tolerances.

Industry Standards

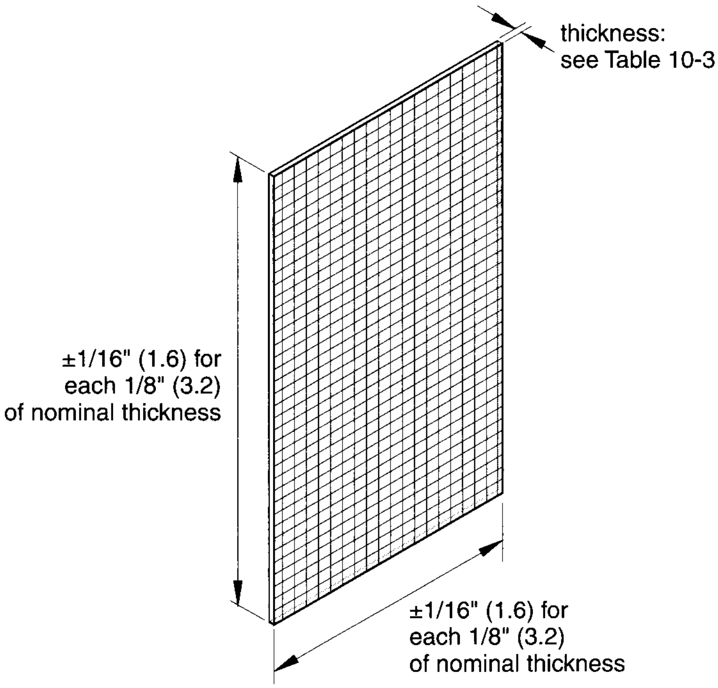
GANA *Glazing Manual* (Topeka, KS: Glass Association of North America, 2004).

ASTM C1036, *Standard Specification for Flat Glass* (West Conshohocken, PA: American Society for Testing and Materials, 2005).

Figure 10–2 Manufacturing tolerances for patterned and wired glass



(a) patterned glass



(b) wired glass

Allowable Tolerances

Tolerances are shown in Figure 10-2 and listed in Tables 10-2 and 10-3. Note that Underwriters Laboratories has never approved 7/32-in. wired glass for fire resistance.

For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a 1/8-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±1/8 in. (3 mm) in 12 ft. (3,660 mm) or ±1/4 in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

Table 10–2 Tolerances for patterned glass

Thickness designation, (mm) in	*Thickness tolerances, (mm) in* minimum, (mm) in	maximum, (mm) in	Length and width, (mm) in
(2.5) SS	(2.15) 0.085	(2.9) 0.114	±(1.6) 1/16
(3.0) DS	(3.0) 0.118	(3.61) 0.142	±(1.6) 1/16
(4.0) 5/32	(3.62) 0.143	(4.37) 0.172	±(1.6) 1/16
(5.0) 3/16	(4.39) 0.173	(5.42) 0.213	±(1.6) 1/16
(5.5) 7/32	(5.43) 0.214	(5.90) 0.232	±(2.4) 3/32
(6.0) 1/4	(5.91) 0.233	(7.60) 0.299	±(3.2) 1/8
(8.0) 5/16	(7.61) 0.300	(9.10) 0.358	±(4.0) 5/32

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Table 10–3 Tolerances for wired glass

Thickness designation, (mm) in	*Thickness tolerances, (mm) in* Min.	Max.
(6.0) 1/4	(6.40) 0.252	(7.60) 0.299
(10.0) 3/8	(8.76) 0.303	(10.0) 0.390

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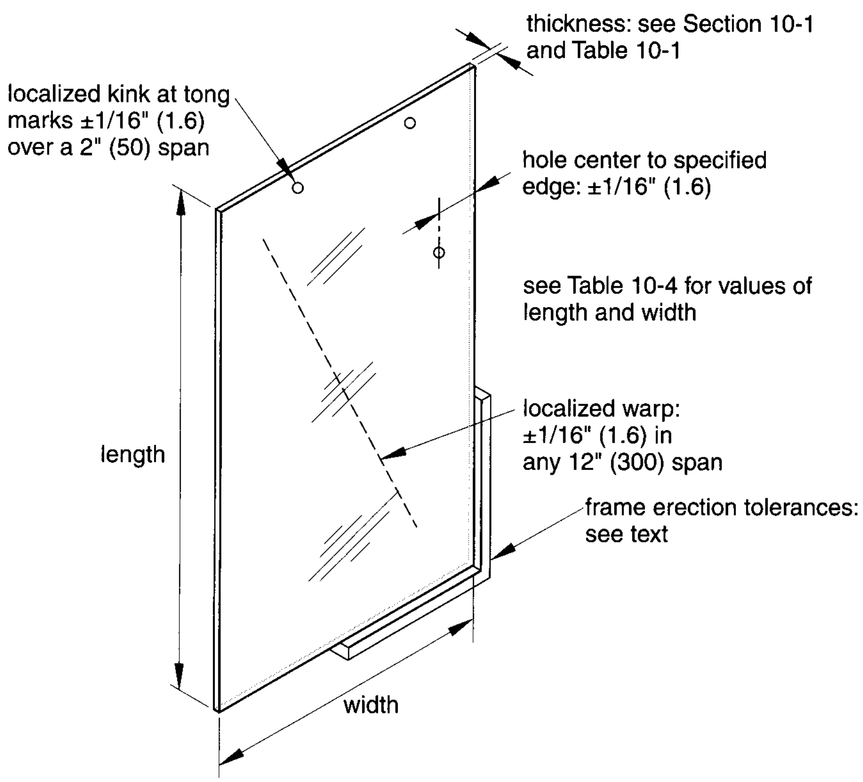
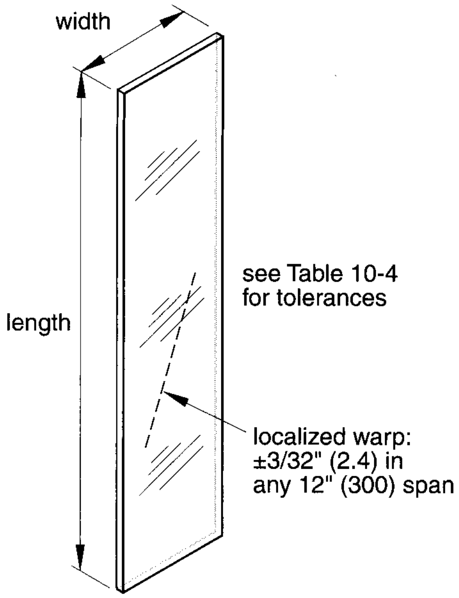
Related Sections

10–1 Manufacturing Tolerances for Flat Glass
10–3 Tempered, Heat-Strengthened, and Spandrel Glass
10–4 Sealed Insulated Glass Units
11–13 Lockstrip Gasket Glazing

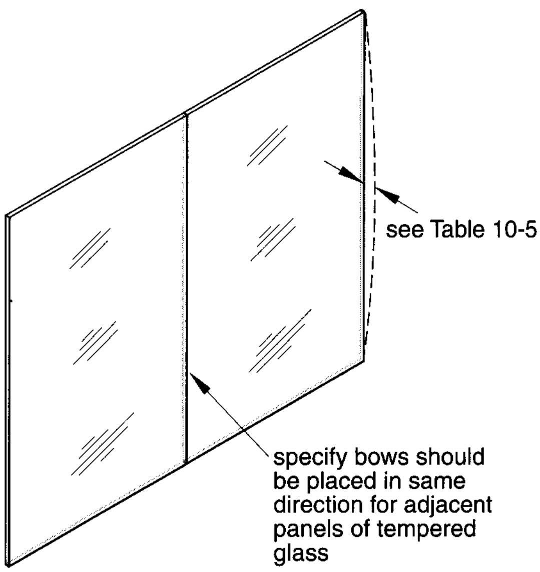
Figure 10–3 Tempered, heat-strengthened, and spandrel glass



(a) dimensional and flatness tolerances



(b) strips



(c) bow tolerances

10–3 Tempered, Heat-Strengthened, and Spandrel Glass

Description

This section includes tolerances for the manufacture of the various types of heat-treated flat glass.

Industry Standards

ASTM C1048, *Standard Specification for Heat-Treated Flat Glass–Kind HS, Kind FT Coated and Uncoated Glass* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

GANA *Glazing Manual* (Topeka, KS: Glass Association of North America, 2004).

Specification No. 64-3-16a Rev. 5, *Specification or Fully Tempered Safety Glass for General Construction Usage, CPSC 16 CFR 1201* (Topeka,.KS: Glass Association of North America, 2001).

Specification No. 66-9-20 Rev. 6, *Specification for Heat-strengthened for Fully-Tempered Ceramic Enameled Spandrel Glass for use in Building Window/Curtain Walls and Other Architectural Applications* (Topeka, KS: Glass Association of North America, 2001).

Allowable Tolerances

Tolerances are shown in Figure 10-3 and listed in Tables 10-4 and 10-5. *Strips* are defined when one of the following three conditions are met: (1) for glass up to 72 in. (1,830 mm) long when the width is equal to or less than the length divided by 8, (2) for glass over 72 to 96 in. (1,830 to 2,440 mm) when the width is equal to or less than the length divided by 7, or (3) for glass over 96 to 132 in. (2,440 to 3,350 mm) when the width is equal to or less than the length divided by 5. The ratios of length to width can be increased by substituting thicknesses greater than 6 mm (¼ in.). Glass for all types of heat treatment must conform to ASTM C1036 for flat glass.

Table 10–4 Dimensional tolerances for tempered, heat-strengthened, and spandrel glass

Glass thickness, mm (in)	Finished size tolerance, plus or minus, mm (in)
3.0 (⅛)	1.6 (1/16)
4.0 (5/32)	1.6 (1/16)
5.0 (3/16)	1.6 (1/16)
6.0 (¼)	1.6 (1/16)
8.0 (5/16)	2.0 (5/64)
10.0 (⅜)	2.4 (3/32)
12.0 (½)	3.2 (⅛)
16.0 (⅝)	4.0 (5/32)
19.0 (¾)	4.8 (3/16)

Source: Based on information from ASTM C1048. Copyright ASTM International. Reprinted with permission.

Table 10–5 Bow and warp tolerances for tempered, heat-strengthened, and spandrel glass

	Maximum bow and warp, in (mm)				
	Glass thickness, in (mm)				
Edge dimension, in (mm)	⅛, 5/32, 3/16 (3, 4, 5)	¼ (6)	5/16 (8)	⅜ (10)	½–⅞ (12–22)
0–20 (0–500)	0.12 (3.0)	0.08 (2.0)	0.08 (2.0)	0.08 (2.0)	0.04 (1.0)
>20–35 (>500–900)	0.16 (4.0)	0.12 (3.0)	0.08 (2.0)	0.08 (2.0)	0.08 (2.0)
>35–47 (>900–1200)	0.20 (5.0)	0.16 (4.0)	0.12 (3.0)	0.08 (2.0)	0.08 (2.0)
>47–59 (>1200–1500)	0.28 (7.0)	0.20 (5.0)	0.16 (4.0)	0.16 (4.0)	0.08 (2.0)
>59–71 (>1500–1800)	0.35 (9.0)	0.28 (7.0)	0.20 (5.0)	0.20 (5.0)	0.16 (4.0)
>71–83 (>1800–2100)	0.47 (12.0)	0.35 (9.0)	0.24 (6.0)	0.24 (6.0)	0.20 (5.0)
>83–94 (>2100–2400)	0.55 (14.0)	0.47 (12.0)	0.31 (8.0)	0.28 (7.0)	0.20 (5.0)
>94–106 (>2400–2700)	0.67 (17.0)	0.55 (14.0)	0.39 (10.0)	0.35 (9.0)	0.28 (7.0)
>106–118 (>2700–3000)	0.75 (19.0)	0.67 (17.0)	0.51 (13.0)	0.47 (12.0)	0.39 (10.0)
>118–130 (>3000–3300)	–	0.75 (19.0)	0.59 (15.0)	0.55 (14.0)	0.47 (12.0)
>130–146 (>3300–3700)	–	0.83 (21.0)	0.71 (18.0)	0.67 (17.0)	0.55 (14.0)
>146–158 (>3700–4000)	–	0.94 (24.0)	0.79 (20.0)	0.75 (19.0)	0.67 (17.0)

Source: Compiled from ASTM C 1048. Copyright ASTM International. Reprinted with permission.

For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in. (3-mm) difference in the length of the diagonals. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

Related Sections

10–1 Manufacturing Tolerances for Flat Glass

10–4 Sealed Insulated Glass Units

Description

Insulated glass units consist of two panes of glass that enclose a hermetically sealed air space. The panes are held apart by a spacer around the perimeter.

Industry Standards

AAMA MCWM 1-89, *Metal Curtain Wall Manual* (Schaumburg, IL: American Architectural Manufacturers Association, 1989).

GANA *Glazing Manual* (Topeka, KS: Glass Association of North America, 2004).

TR-1200-83 SIGMA *Voluntary Guidelines for Commercial Insulating Glass—Dimensional Tolerances*. (Ottawa, ON: Insulating Glass Manufacturers Alliance, 1983).

Figure 10–4 Sealed insulated glass units

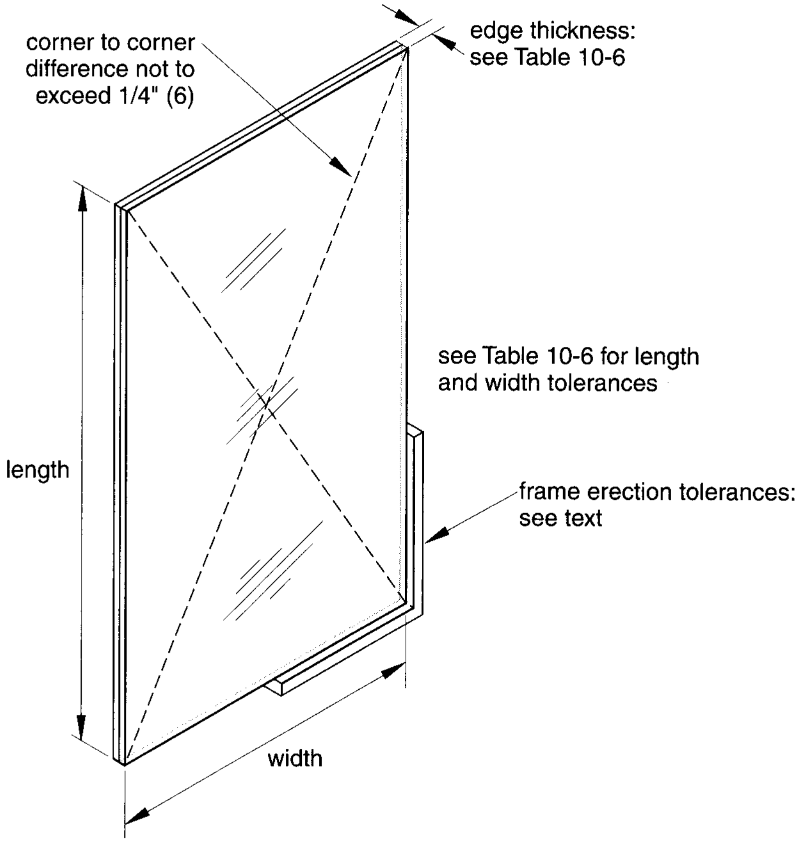


Table 10–6 Dimensional tolerances for insulating glass units

Width or length, in (mm)	Plus, in (mm)	Minus, in (mm)
Up to 30 (760)	⅛ (3.2)	1/16 (1.6)
Over 30 to 60 (760 to 1525)	5/32 (4.0)	1/16 (1.6)
Over 60 to 84 (1525 to 2134)	3/16 (4.8)	1/16 (1.6)
Over 84 (2134)	Consult manufacturer	
Edge thickness, in (mm)	**Thickness, range, in**	**Thickness, range (mm)**
½ (13)	0.475 to 0.550	12.1 to 14.0
9/16 (14)	0.535 to 0.625	13.6 to 15.9
⅝ (16)	0.600 to 0.700	15.2 to 17.8
¾ (19)	0.700 to 0.810	17.8 to 20.6
1 (25)	0.938 to 1.062	23.8 to 27.0

Source: Compiled from TR-1200-83, Insulating Glass Manufacturers Alliance

Allowable Tolerances

Recommended tolerances are shown in Figure 10-4 and listed in Table 10-6. For insulating units fabricated from flat glass, these tolerances can usually be maintained. When tempered glass is used, the bow tolerance is often the controlling factor. In many cases the tempered glass manufacturer must reduce the range of bow tolerances to allow the insulating unit to be fabricated to within or close to the tolerances recommended by the Insulating Glass Manufacturers Alliance.

For erection tolerances, the *Glazing Manual* recommends that within any rectangular framing opening there should be not more than a ⅛-in (3-mm) difference in the length of the diagonals. Note that this is less than the SIGMA Guidelines shown in Figure 10-4. Further, the maximum variation of mullions from plumb or horizontals from level should not exceed ±⅛ in. (3 mm) in 12 ft. (3,660 mm) or ±¼ in. (6 mm) in any single run. Framing systems that are designed to have the horizontal and vertical glazing legs in the same plane should have a maximum out-of-plane offset of 1/32 in. (0.8 mm) at the frame corners to avoid unequal stresses on the glass.

The AAMA guidelines set dimensional tolerances on insulating glass units as +3/16 in. and –1/16 in. (+5.0 mm and –1.5 mm).

Related Sections

10–1 Manufacturing Tolerances for Flat Glass
10–3 Tempered, Heat-Strengthened, and Spandrel Glass

10–5 All-Glass Entrances

Description

All-glass entrances consist of a glazing system using a minimum of visible framing members relying instead on silicon sealant, suspended glazing, glass mullions, clamps, and other special fittings to support fixed glass and glass doors.

Industry Standards

ASTM C1048, *Standard Specification Heat-Treated Flat Glass: Kind HS, Kind FT Coated and Uncoated Glass*. (West Conshohocken, PA: American Society for Testing and Materials, 2004).

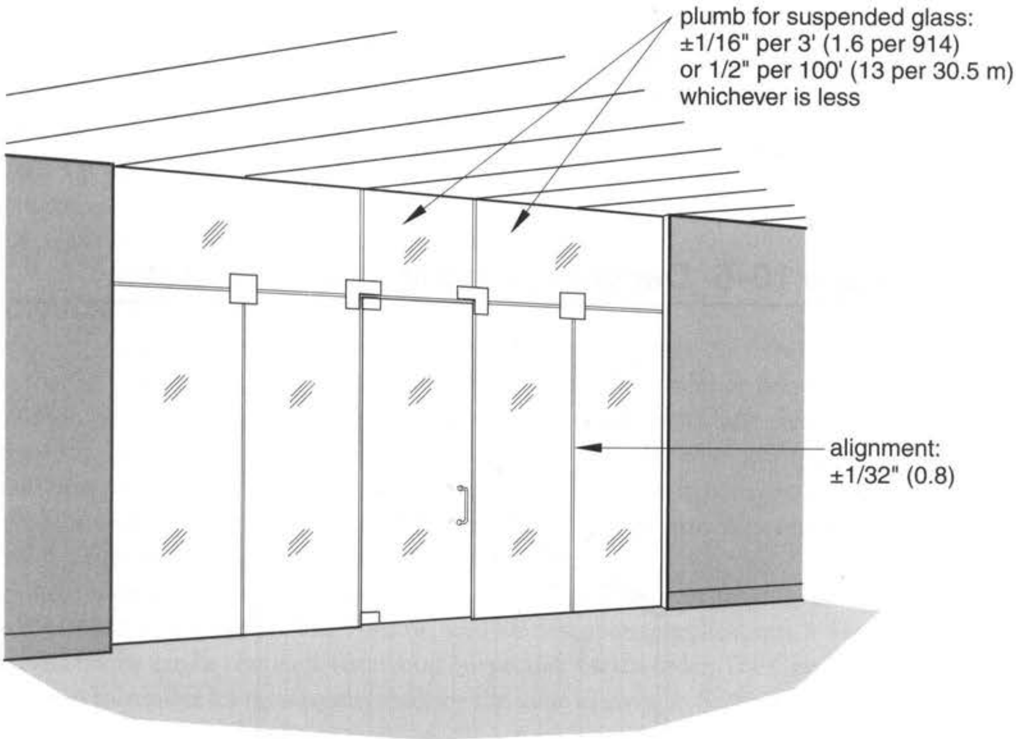
SPECTEXT Section 08971, *Suspended Glass*, July (Bel Air, MD: Construction Sciences Research Foundation, 1988).

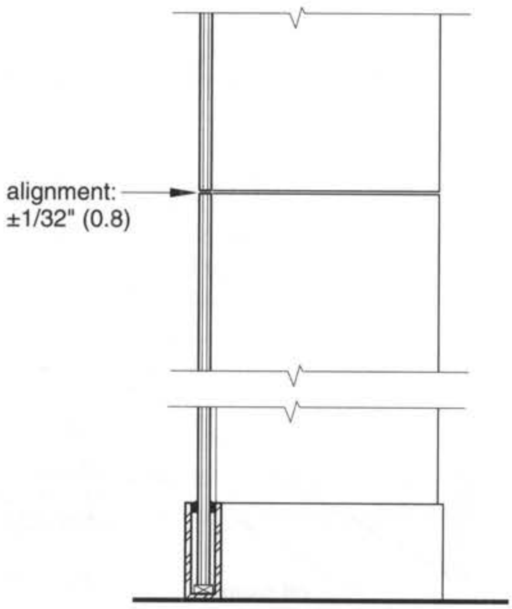
Allowable Tolerances

Because all-glass systems do not rely on rigid framing members of aluminum, steel, wood, or other materials, the accuracy of the installation depends primarily on the tolerances of the glass. Most all-glass entrances are in hazardous locations, so tempered or laminated glass is used. For tempered glass installations, the bow tolerances listed in Table 10-5 often govern. These affect both the plumbness of the glass and the relative alignment of two butt-jointed pieces. To minimize misalignment, adjacent tempered-glass units should be installed with the bow in the same direction. When tempered glass is installed in concealed framing at the floor and ceiling, the dimensional tolerances listed in Table 10-4 must also be accommodated.

For suspended glazing, previous SPECTEXT master specifications recommended a noncumulative plumb tolerance of 1/16 in. (1.6 mm) per 3 ft. (900 mm) or ½ in. (13 mm)

Figure 10–5 All-glass entrances



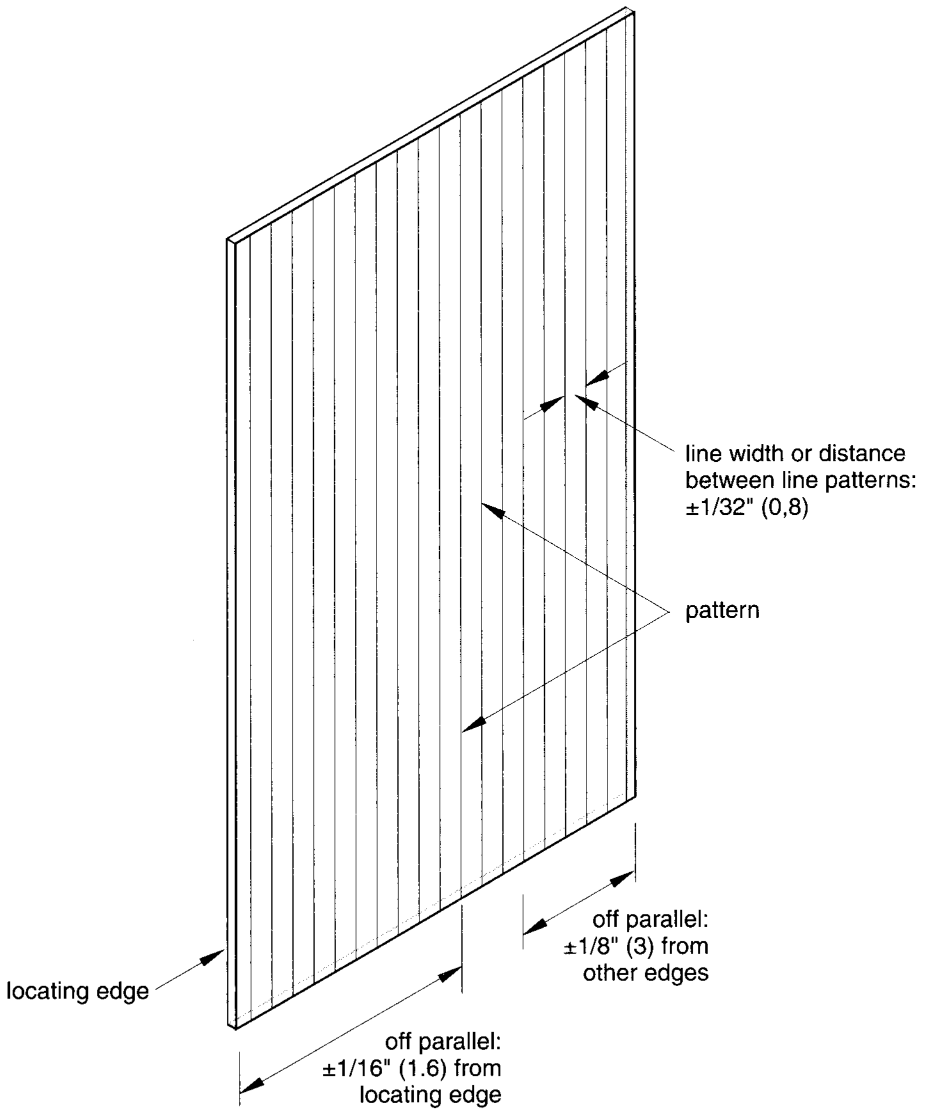


section through sill and horizontal joint per 100 ft. (30.5 m), whichever is less. See Figure 10-5. SPECTEXT also recommended a maximum misalignment of adjoining glass units of 1⁄32 in. (0.8 mm).

Related Sections

10–1 Manufacturing Tolerances for Flat Glass
10–3 Tempered, Heat-Strengthened, and Spandrel Glass
10–4 Sealed Insulated Glass Units

Figure 10–6 Decorative architectural flat glass



10–6 Decorative Architectural Flat Glass

Description

Decorative architectural flat glass consists of laminated glass products manufactured by using a screen printing process with fired-on ceramic enamel, typically between the two sheets of glass. This type of glazing is often used to reduce light glare, to print images, or for purely decorative purposes The product may be used in exterior or interior applications.

Industry Standards

Specification No. 95-1-31, *Specification for Decorative Architectural Flat Glass* (Topeka, KS: Glass Association of North America, 2001).

Allowable Tolerances

This type of glazing product may be produced in a variety of patterns. As shown in Figure 10-6, there is a "locating glass edge" that should be identified on the shop drawings. This is the edge from which critical pattern measurements are made. In a single piece of glass, patterns may be located off parallel up to $\pm\frac{1}{16}$ in. (3 mm) from this edge and up to $\pm\frac{1}{8}$ in. (3 mm) from other edges. For line patterns, the maximum variation in both line width and distance between lines may be $\pm\frac{1}{32}$ in. (0.8 mm). Matching patterns between adjacent pieces of glass is dependent on the skills of the installer.

Unless otherwise specified, the pattern may cover the entire glass panel up to a clear edge border of $\frac{3}{8}$ in. (10 mm) or less. For structural silicone glazing applications, a $\frac{1}{8}$-in. (3-mm) clear border can be obtained, but it must be specified on the order. The *Glazing Manual* erection tolerances for framing members are the same as given in Section 10-1.

Related Sections

10–3 Tempered, Heat-Strengthened, Spandrel Glass, and Bent Glass

10–7 Laminated Architectural Flat Glass

Description

Laminated architectural flat glass consists of two or more lites of glass or polycarbonate with one or more interlayers between the glazing lites permanently bonded under heat and pressure. The glass may be annealed, heat-treated, tempered, chemically strengthened, wired, tinted, patterned, or coated. Various types of interlayers are used to impart desired qualities to the assembly, with polyvinyl butyral (PVB) being one of the most common. Laminated glass is used in exterior and interior applications.

Industry Standards

ASTM C1172:,*Standard Specification for Laminated Architectural Flat Glass*. (West Conshohocken, PA: American Society for Testing and Materials, 2003).

Allowable Tolerances

Tolerances for laminated glass units are shown in Figure 10-7 and listed in Tables 10-7 and 10-8. For special laminations, such as those that use polycarbonate, tempered glass, and complex combinations of lites and interlayers, verify tolerances with the manufacturer. The *Glazing Manual* erection tolerances for framing members are the same as given in Section 10-1.

Figure 10–7 Laminated architectural flat glass

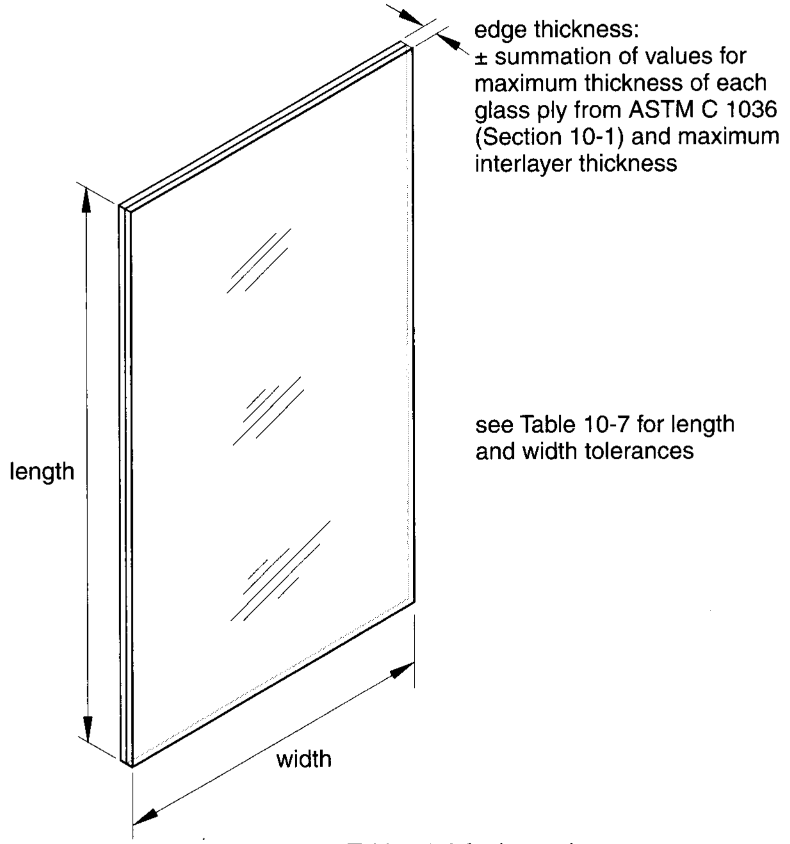


Table 10–7 Length and width tolerances for symmetrically laminated architectural glass

Laminate thickness, t, in (mm)	Transparent glass	Patterned and wired glass	Heat strengthened and tempered glass
$t \leq 1/4$ ($t \leq 6.4$)	+5/32, −1/16 (+4, −1.6)	+5/16, −1/8 (+7.9, −3.2)	+7/32, −3/32 (+5.6, −2.4)
$1/4 < t \leq 1/2$ ($6.4 < t \leq 12.7$)	+1/4, −1/16 (+6.4, −1.6)	+5/16, −1/8 (+7.9, −3.2)	+1/4, −1/8 (+6.4, −3.2)
$1/2 < t \leq 1$ ($12.7 < t \leq 25.4$)	+1/4, −1/8 (+6.4, −3.2)	+5/16, −1/8 (+7.9, −3.2)	+5/16, −1/8 (+7.9, −3.2)

Source: Compiled from TR-1200-83, Insulating Glass Manufacturers Alliance

Table 10–8 Bow tolerances for laminated glass

Edge length, in (mm)	*Nominal glass thickness, in (mm)* 1/8, 5/32, 3/16 (3.0, 4.0, 5.0)	1/4 (6.0)	5/16 (8.0)	3/8 (10.0)	1/2–7/8 (12.0–22.0)
0–18 (0–460)	1/8 (3.2)	1/16 (1.6)	1/16 (1.6)	1/16 (1.6)	1/16 (1.6)
18–36 (460–910)	3/16 (4.8	1/8 (3.2)	3/32 (2.4)	3/32 (2.4)	1/16 (1.6)
36–48 (910–1220)	9/32 (7.1)	3/16 (4.8)	5/32 (4.0)	1/8 (3.2)	3/32 (2.4)
48–60 (1220–1520)	3/8 (9.5)	9/32 (7.1)	7/32 (5.6)	3/16 (4.8)	1/8 (3.2)
60–72 (1520–1830)	1/2 (12.7)	3/8 (9.5)	9/32 (7.1)	1/4 (6.4)	3/16 (4.8)
72–84 (1830–2130)	5/8 (15.9)	1/2 (12.7)	11/32 (8.7)	5/16 (7.9)	1/4 (6.4)
84–96 (2130–2440)	3/4 (19.0)	5/8 (15.9)	7/16 (11.1)	3/8 (9.5)	9/32 (7.1)
96–108 (2440–2740)	7/8 (22.2)	3/4 (19.0)	9/16 (14.3)	1/2 (12.7)	3/8 (9.5)
108–120 (2740–3050)	1 (25.4)	7/8 (22.2)	11/16 (17.5)	5/8 (15.9)	1/2 (12.7)
120–132 (3050–3350)	—	1 (25.4)	13/16 (20.6)	3/4 (19.0)	5/8 (15.9)
132–144 (3350–3660)	—	1 1/8 (28.6)	15/16 (23.8)	7/8 (22.2)	3/4 (19.0)
144–156 (3660–3960)	—	1 1/4 (31.8)	1 1/16 (27.0)	1 (25.4)	7/8 (22.2)

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Related Sections

10–1 Manufacturing Tolerances for Flat Glass
10–3 Tempered, Heat-Strengthened, Spandrel Glass, and Bent Glass
10–4 Sealed Insulated Glass Units

10–8 Bent Glass

Description

Bent glass is flat glass that has been shaped while hot into a body having curved surfaces. Bent glass can be shaped into a single bend or a compound bend, which is composed of curvature of one or more radii, curved on two or more axes. A single bend normally consists of one or two flat areas tangent to the curvature.

Industry Standards

ASTM C1464, *Standard Specification for Bent Glass* (West Conshohocken, PA: American Society for Testing and Materials, 2000).

Allowable Tolerances

Tolerances for bent glass units are shown in Figure 10-8 and listed in Tables 10-9 through 10-11. As shown in Figure 10-8, the crossbend is the deviation from a straightedge along a line perpendicular to the curvature measured on the concave side.

For special laminations, such as those that use polycarbonate, tempered glass, and complex combinations of lites and interlayers, verify tolerances with the manufacturer. The *Glazing Manual* erection tolerances for framing members are the same as given in Section 10-1.

Table 10–9 Height and girth tolerances for bent glass

Height, in (mm)	Height tolerances, in (mm)		Girth Tolerances, in (mm)	
	Nominal glass thickness		*Nominal glass thickness*	
	Up to ½ in (12 mm)	Over ½ in (>12 mm)	Up to ½ in (12 mm)	Over ½ in (>12 mm)
0–60 (0–1520)	±1/8 (3.2)	±3/16 (4.8)	±1/8 (3.2)	±3/16 (4.8)
>60 to 78 (>1520 to 2000)	±1/8 (3.2)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)
>78 (>2000)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)

Source: ASTM C 1464. Copyright ASTM International. Reprinted with permission.

Table 10–10 Shape accuracy and crossbend tolerances for bent glass

	Nominal glass thickness, in (mm)			
	1/8–3/16 (3–5)	1/4–5/16 (6–8)	3/8–1/2 (10–12)	>1/2 (>12)
Shape accuracy Girth, in (mm)				
0–48 (0–1220)	±1/8 (3.2)	±1/8 (3.2)	±1/8 (3.2)	±3/16 (4.8)
>48–96 (>1220–2440)	±1/8 (3.2)	±1/8 (3.2)	±1/8 (3.2)	±3/16 (4.8)
>96–132 (>2440–3350)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)
>132 (>3350)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)
Maximum crossbend deviation, in (mm)				
0–48 (0–1220)	±3/32 (2.4)	±1/8 (3.2)	±1/8 (3.2)	±1/8 (3.2)
>48–96 (>1220–2440)	±1/8 (3.2)	±1/8 (3.2)	±3/16 (4.8)	±3/16 (4.8)
>96–132 (>2440–3350)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)
>132 (>3350)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)

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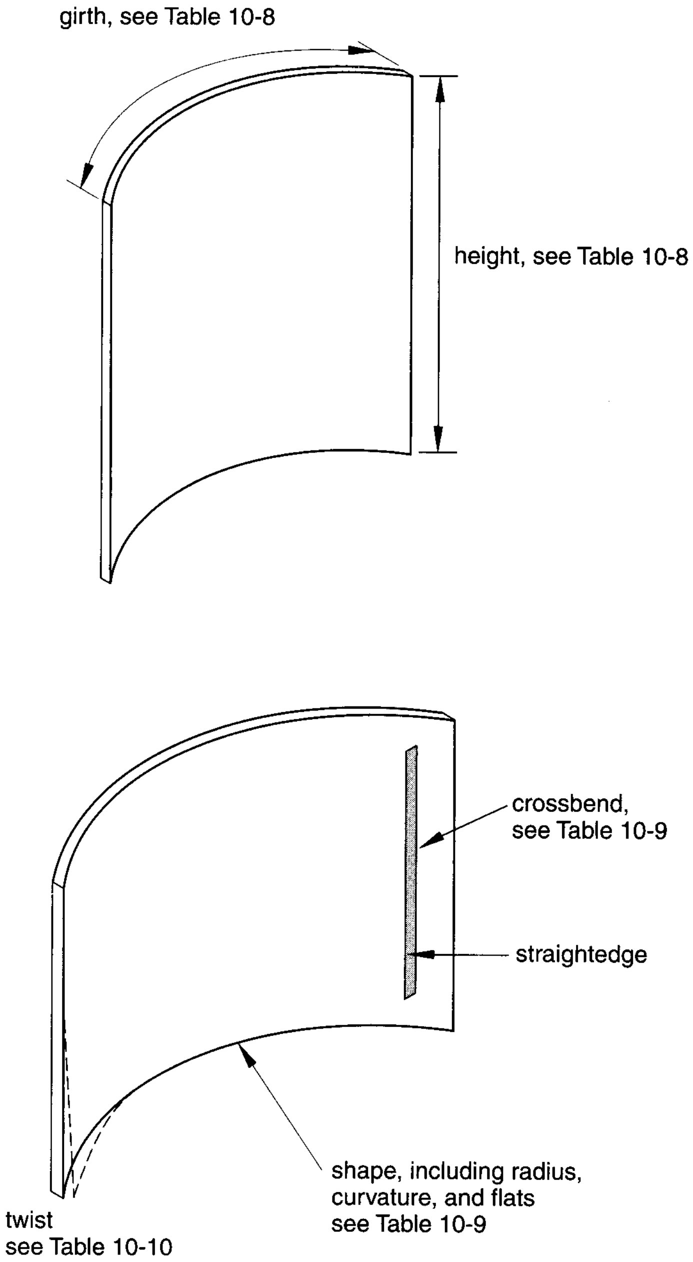
Table 10–11 Maximum twist deviation for bent glass

Height, in (mm)	*Girth, in (mm)* 0-72 (0-1830)	>72-96 (>1830-2440)	>96-120 (>2440-3050)	>120-144 (>3050-3660)	>144 (>3660)
0-72 (0-1830)	±1/8 (3.2)	±1/8 (3.2)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)
>72-96 (>1830-2440)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±5/16 (7.9)
>96-120 (>2440-3050)	±3/16 (4.8)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)	±5/16 (7.9)
>120 (>3050)	±3/16 (4.8)	±3/16 (4.8)	±1/4 (6.4)	±1/4 (6.4)	±3/8 (9.5)

Note: Table applies to 1/8 in to 1/2 in (3 mm to 12 mm) glass with a radius greater than 18 in (460 mm). For twist tolerances on other thicknesses or radiuses, contact the supplier.

Source: ASTM C 1464. Copyright ASTM International. Reprinted with permission.

Figure 10–8 Bent glass

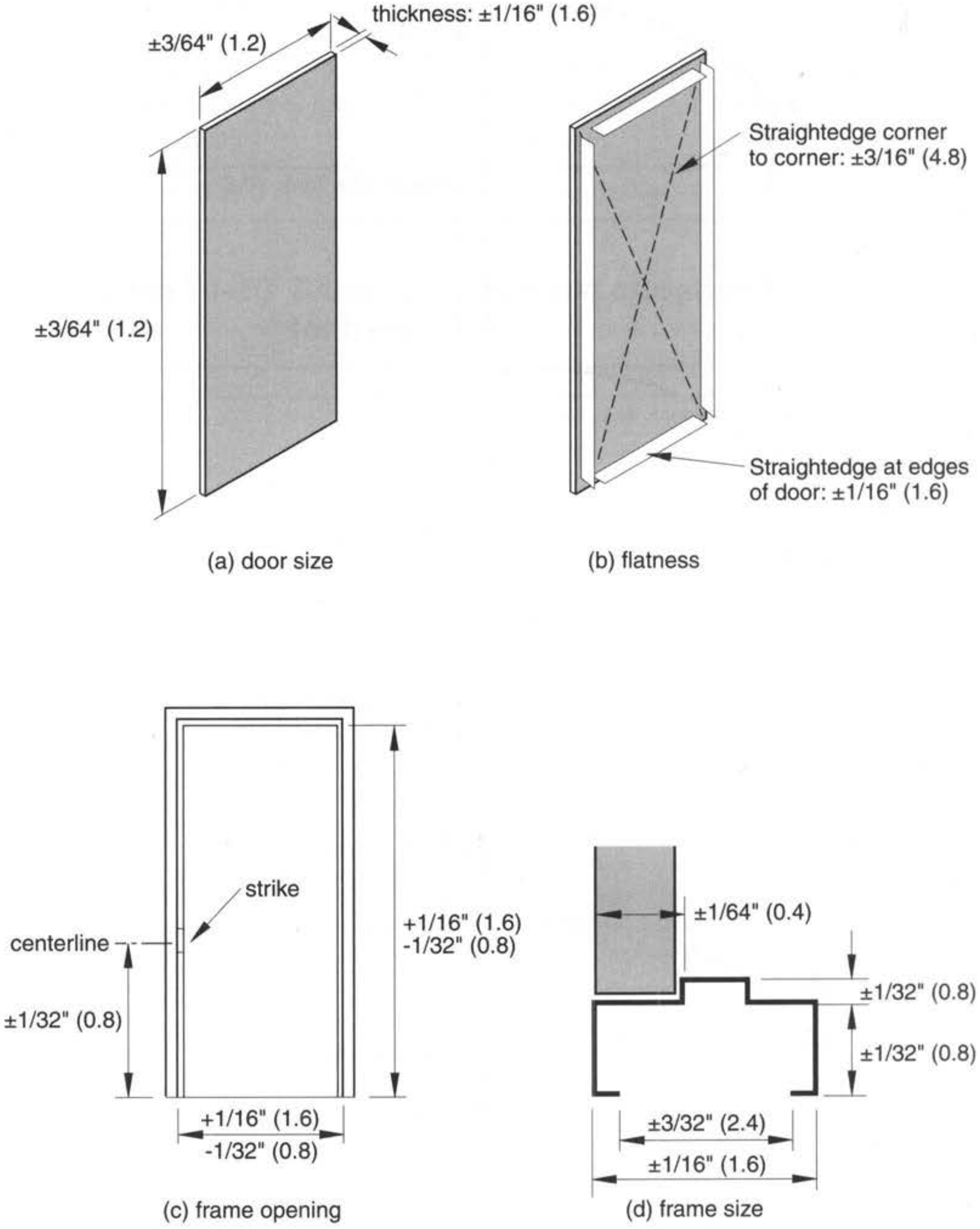


Related Sections

10–1 Manufacturing Tolerances for Flat Glass

10–3 Tempered, Heat-Strengthened, and Spandrel Glass

Figure 11–1 Standard steel doors and frames



Chapter 11

Doors and Windows

11–1 Standard Steel Doors and Frames

Description

Standard steel doors and frames include products manufactured according to ANSI A250.8 (previously SDI 100), *Recommended Specifications for Standard Steel Doors and Frames*, and include both single- and double-rabbeted frames. This section does not include special or unusual doors or frame conditions.

Industry Standards

SDI 117, *Manufacturing Tolerances, Standard Steel Doors and Frames.* (Cleveland: Steel Door Institute, 2000).

Allowable Tolerances

Tolerances for door and frame size, flatness, and frame preparation are shown in Figure 11-1. In addition to the door size tolerances shown, the squareness of a door is determined by measuring the diagonals. The two diagonals should not vary by more than $\frac{1}{16}$ in. (1.6 mm). To determine flatness, three measurement positions are used. The door is checked with a straightedge at the top and bottom of the door on both faces and along both hinge and lock edges on both faces. The out-of-straightness measurement cannot exceed $\frac{1}{16}$ in. (1.6 mm). The door is also checked with a straightedge from corner to corner on both sides of the door. The out-of-straightness measurement on the diagonal cannot exceed $\frac{3}{16}$ in. (4.8 mm).

For additional tolerances on frame thickness and hinge cutout and placement, refer to SDI 117.

Related Sections

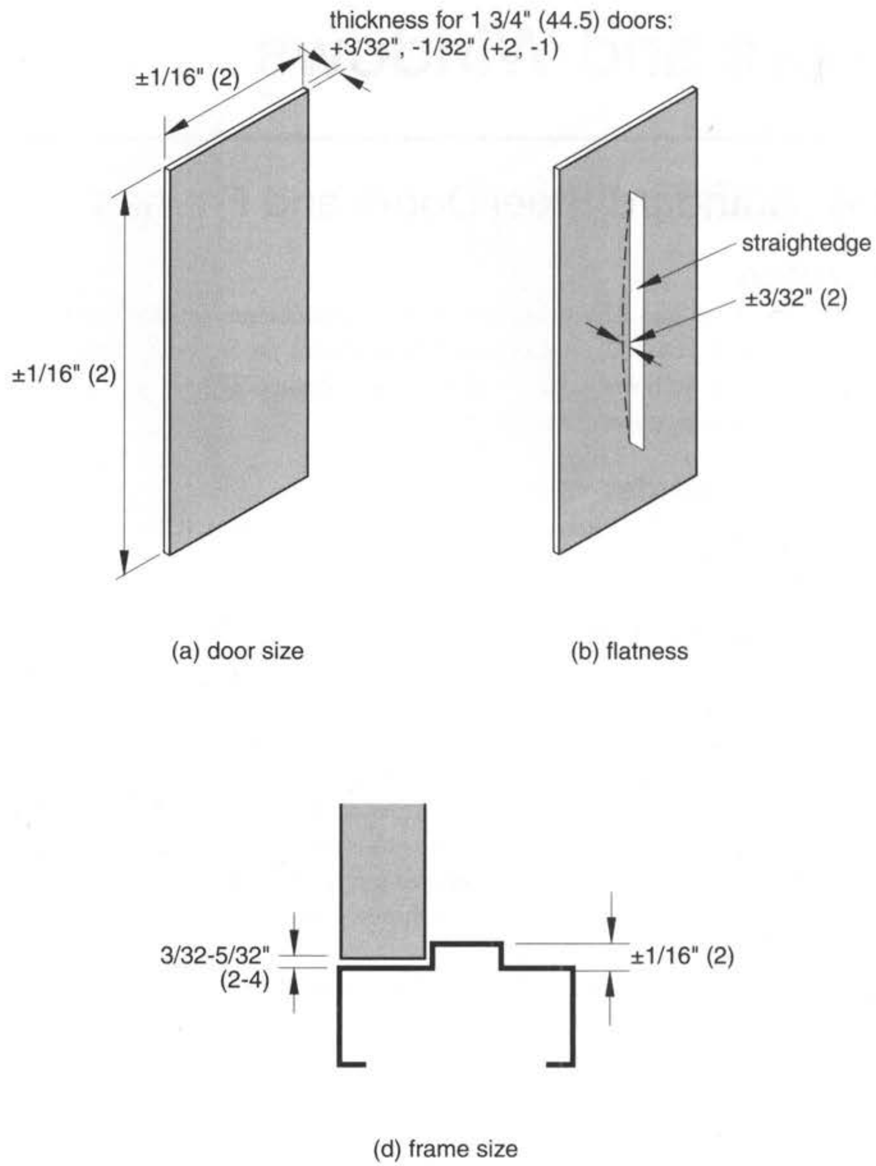
11–2 Insulated Steel Door Systems
11–3 Detention Security Hollow Metal Doors and Frames

11–2 Insulated Steel Door Systems

Description

The tolerances in this section cover doors and frames. Doors are manufactured to fit the standard frame opening sizes, with a $\frac{3}{32}$-in. to $\frac{5}{32}$-in. (2-mm to 4-mm) clearance between the door and the frame. The width is measured from inside of jamb to inside of jamb, and the height is measured from the top of the threshold to the inside of the header rabbet.

Figure 11–2 Insulated steel door systems



Industry Standards

ISDI 100, *Door Size Dimensional Standard and Assembly Tolerances for Insulated Steel Door Systems* (Cleveland, OH: Insulated Steel Door Institute, 1990) Out of print.

Allowable Tolerances

Tolerances for door and frame size and flatness previously established are shown in Figure 11-2. These were developed by the Insulated Steel Door Institute, which is no longer in existence. The flatness tolerances shown apply to warpage of the door as well as other surface irregularities.

Related Sections

11–1 Standard Steel Doors and Frames
11–3 Detention Security Hollow Metal Doors and Frames

11–3 Detention Security Hollow Metal Doors and Frames

Description

This section includes tolerances for heavy-duty doors and frames used for detention facilities. Standard steel doors and frames include products manufactured according to ANSI A250.8 (previously SDI 100), *Recommended Specifications for Standard Steel Doors and Frames* and include both single- and double-rabbeted frames.

Industry Standards

ANSI/NAAMM HMMA 863, *Guide Specifications for Detention Security Hollow Metal Doors and Frames* (Chicago: Hollow Metal Manufacturers Association, Division of National Association of Architectural Metal Manufacturers, 2004).

Allowable Tolerances

Tolerances for door and frame size and flatness are shown in Figure 11-3. The flatness tolerances shown apply to warpage and bow of the door. Installation tolerances cannot exceed $\frac{1}{16}$ in. (1.5 mm), and plumbness and out-of-square tolerances for installed frames is $\pm\frac{1}{16}$ in. ($\pm$1.5 mm). Plumbness is measured on a perpendicular line from the head to the floor, and squareness is measured on a line from a jamb perpendicular to the jamb at the head.

Refer to ANSI/NAAMM/HMMA 863 for standardized hardware locations and standard clearances.

Related Sections

11–1 Standard Steel Doors and Frames
11–2 Insulated Steel Door Systems

11–4 Standard Flush Wood Doors

Description

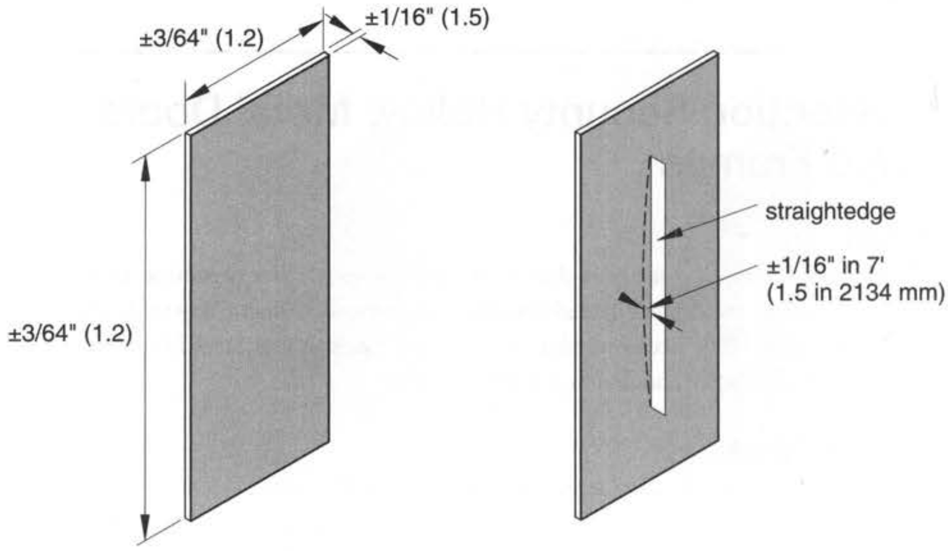
This section includes flush wood doors manufactured according to the Window and Door Manufacturers Association (WDMA) standards. Refer to Section 7-14 for tolerances for standard flush wood doors manufactured according to Architectural Woodwork Institute's standards. However, the tolerances are very similar for both standards.

Industry Standards

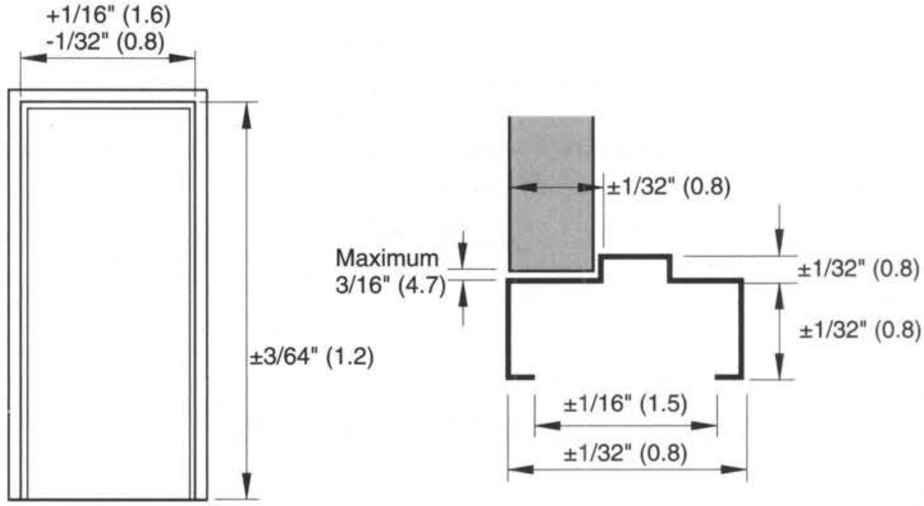
WDMA I.S. 1A, *Industry Specification for Architectural Wood Flush Doors* (Des Plaines, IL: Window and Door Manufacturers Association, 1997).

Residential Construction Performance Guidelines, 3rd ed. (Washington, DC: National Association of Home Builders Remodelors™ Council, 2005).

Figure 11–3 Detention security hollow metal doors and frames



(a) door size (b) flatness

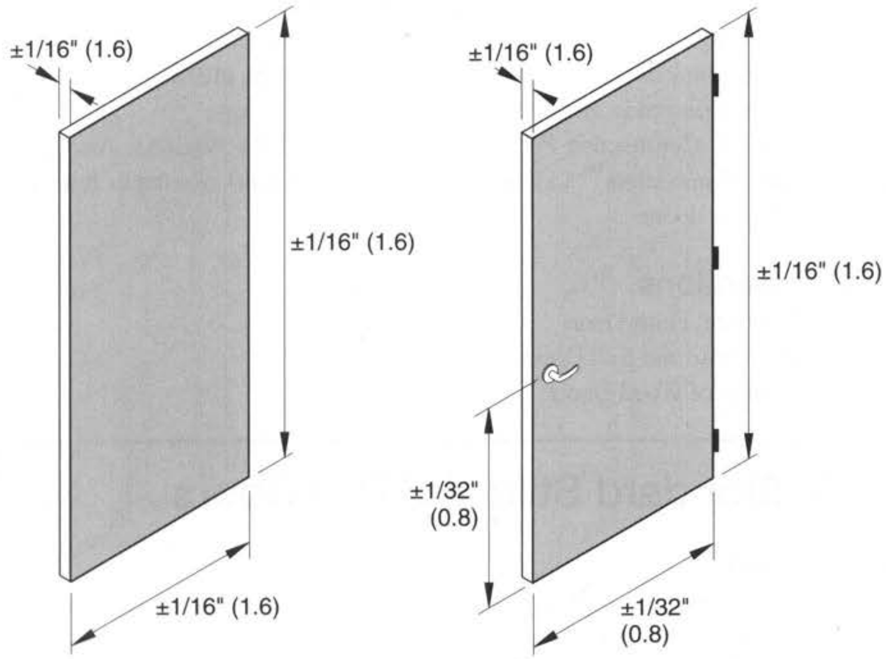


(c) frame opening (d) frame size

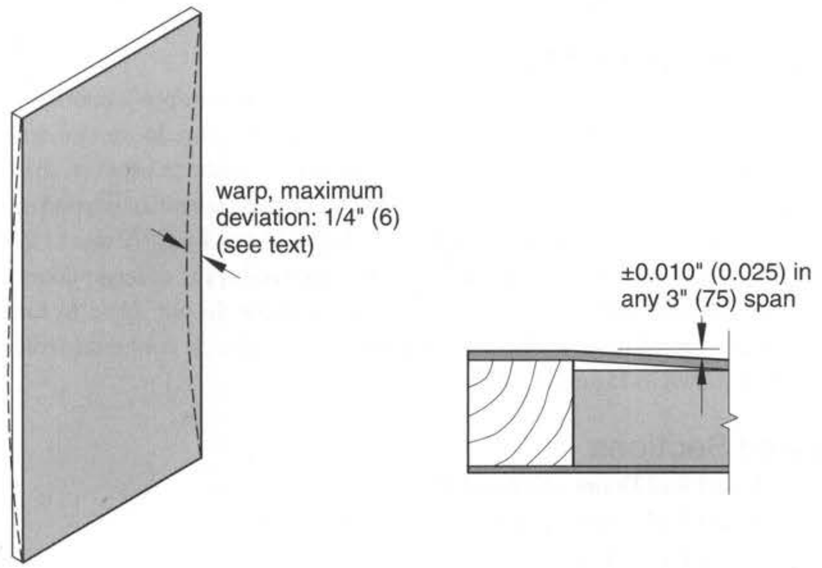
Allowable Tolerances

Figure 11-4 illustrates the tolerances of size, warpage, and show-through or telegraphing. (Telegraphing is the distortion of the face veneer of a door caused by variation in thickness between the core material and the vertical or horizontal edge bands.) The tolerances for hardware location for machined doors includes locks, hinges, and other hardware.

Figure 11–4 Standard flush wood doors



(a) doors not prefit (b) machined for hardware



(c) warp tolerances (d) telegraphing

Warpage tolerances apply only to the door and not to its relation to the frame. The maximum deviation of ¼ in. (6 mm) applies to a maximum door size of 3 ft., 0 in. by 7 ft., 0 in. (900 mm by 2100 mm) for 1⅜-in.-thick (35-mm-thick) doors and to a maximum door size of 3 ft., 6 in. by 7 ft., 0 in. (1,050 mm by 2,100 mm) for 1¾-in.-thick (44-mm-thick) doors. For 1¾-in.-thick doors larger than 3 ft., 6 in. by 7 ft., 0 in. (1,050 mm by 2,100 mm), the tolerance is measured in any 3-ft., 6-in. by 7-ft., 0-in. section.

The *Residential Construction Performance Guidelines* of the National Association of Home Builders Remodelors™ Council uses the ¼-in. (6-mm) maximum tolerance for warping of interior doors.

Related Sections

7–14 Architectural Flush Doors
11–5 Standard Stile and Rail Doors
11–7 Installation of Wood Doors

11–5 Standard Stile and Rail Doors

Description

This section includes size and flatness tolerances for stile and rail doors manufactured according to WDMA standards. Refer to Section 7-15 for tolerances for standard stile and rail doors manufactured according to Architectural Woodwork Institute's standards.

Industry Standards

WDMA I.S. 6, *Industry Standard for Architectural Wood Stile and Rail Doors* (Des Plaines, IL: Window and Door Manufacturers Association, 1997).

Allowable Tolerances

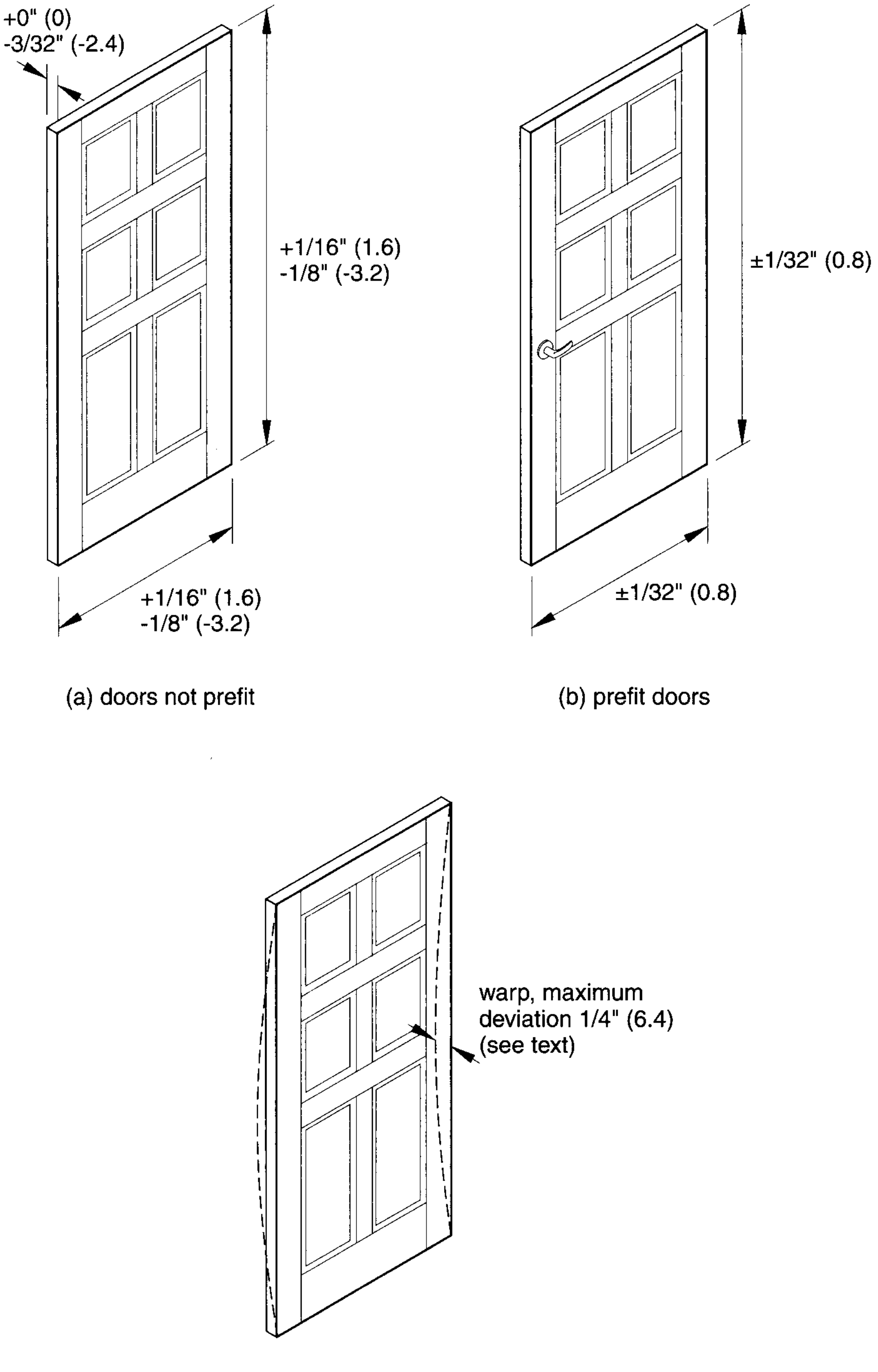
Figure 11-5 illustrates the size tolerances for both prefit and non-prefit doors as well as tolerances for warpage. Warpage is measured by placing a straightedge or taut string on the concave face of the door at any angle and measuring the distance between the bottom of the straightedge or string and the face of the door. Warpage tolerance is based on a 1¾-in.-thick door that is 3 ft., 6 in. wide and 7 ft., 0 in. high (44 mm by 1,070 mm by 2,130 mm). The ¼-in. (6-mm) maximum warpage dimension does not apply to larger doors.

The height and width tolerances for doors not prefit do not apply to bifold doors. These are considered prefit at the time of manufacture and must conform to tolerances for prefit doors shown in Figure 11-5(b).

Related Sections

7–15 Stile and Rail Doors—Size and Flatness
7–16 Stile and Rail Doors—Joint Tightness and Flushness
11–4 Standard Flush Wood Doors
11–7 Installation of Wood Doors

Figure 11–5 Standard stile and rail doors



(a) doors not prefit

(b) prefit doors

(c) warp tolerances

11–6 Wood Swinging Patio Doors

Description

This section includes size and flatness tolerances for wood patio doors manufactured according to the National Wood Window and Door Association's standards. The tolerances apply to the overall dimensions of all doors if more than one door leaf is used.

Industry Standards

AAMA/WDMA/CSA 101/I.S. 2/A440, *Standard/Specification for Windows, Doors, and Unit Skylights* (Schaumburg, IL: American Architectural Manufacturers Association, Wood and Door Manufacturers Association, and Canadian Standards Association, 2005).

WDMA I.S. 6, *Industry Standard for Architectural Wood Stile and Rail Doors* (Des Plaines, IL: Window and Door Manufacturers Association, 1997).

Allowable Tolerances

Figure 11-6 illustrates the size and warpage tolerances for patio doors. Warpage is measured by placing a straightedge or taut string on the concave face of the door at any angle and measuring the distance between the bottom of the straightedge or string and the face of the door after accounting for glazing recess.

Related Sections

11–4 Standard Flush Wood Doors
11–7 Installation of Wood Doors

11–7 Installation of Wood Doors

Description

Installation of wood doors includes the manufacture and installation of the frame pieces as well as the hanging of the door. The Wood Moulding and Millwork Producers Association (WMMPA) publishes quality standards for the fabrication of one-piece and two-piece interior wood jambs and for exterior wood frames. However, they do not state any tolerances for hanging doors within the frames. Prefit clearances of ⅛ in. (3 mm) between the door and the frame are given in *Architectural Wood Flush Doors* (WDMA I.S. 1A) published by the Wood and Door Manufacturers Association.

The Architectural Woodwork Institute (AWI) lists tolerances for frames fabricated according to one of their grades (see Section 7-11) and also publishes installation standards, which are summarized in this section. For AWI installation standards to apply, they must be specifically called out in the specifications and the doors manufactured according to AWI standards.

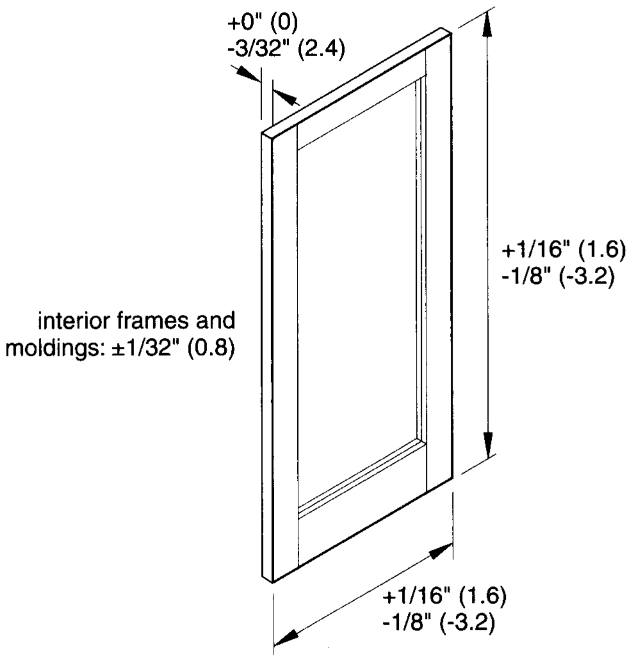
Industry Standards

WM 1-99, *Quality Standards, Hinged Interior Wood Door Jambs* (Woodland, CA: Wood Moulding and Millwork Producers Association, 1999).

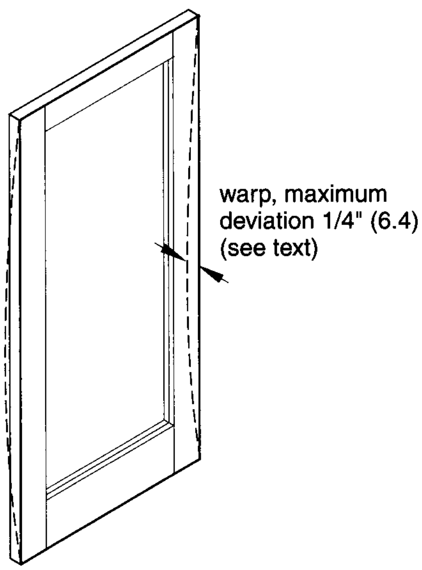
WM 3-99, *Quality Standards, Exterior Wood Door Frames* (Woodland, CA: Wood Moulding and Millwork Producers Association, 1999).

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Figure 11–6 Wood swinging patio doors

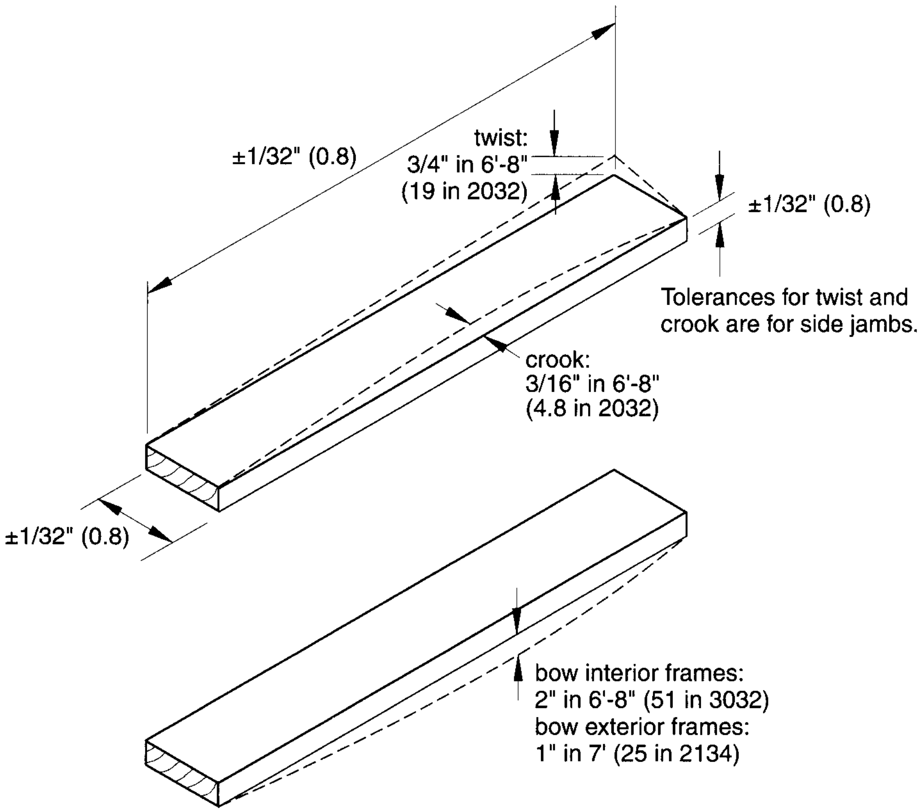


(a) size tolerances

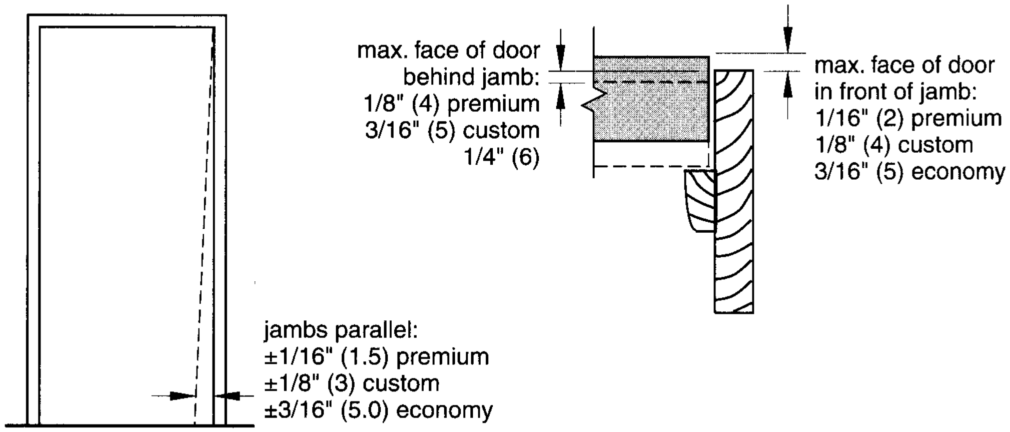


(b) warp tolerances

Figure 11-7 Installation of wood doors



(a) WMMPA frame tolerances



(b) AWI installation tolerances

Allowable Tolerances

WMMP standards for jamb fabrication are summarized in Figure 11-7(a). The tolerance for *cupping*, which is a deviation in the face of a piece from a straight line drawn from edge to edge, is limited to 1/32 in. (0.8 mm) in widths less than 4 in. (100 mm) and to 1/16 in. (1.6 mm) in widths 4 in. and over.

AWI tolerances for installation are shown in Figure 11-7(b).

Related Sections

7–11 Frames, Jambs, and Windows
11–4 Standard Flush Wood Doors
11–5 Standard Stile and Rail Doors
11–6 Wood Swinging Patio Doors

11–8 Wood Windows

Description

This section includes windows manufactured according to NWWDA standards or custom-build windows made according to AWI standards. Most wood windows for residential or commercial construction are factory-built units fabricated to very close tolerances. Therefore, in most cases, the tolerances shown in Figure 11-8(a) apply.

Industry Standards

AAMA/WDMA/CSA 101/I.S. 2/A440, *Standard/Specification for Windows, Doors, and Unit Skylights* (Schaumburg, IL: American Architectural Manufacturers Association, Wood and Door Manufacturers Association, and Canadian Standards Association, 2005).

Architectural Woodwork Quality Standards, 8th ed. (Potomac Falls, VA: Architectural Woodwork Institute, 2003).

Allowable Tolerances

NWWDA tolerances are shown in Figure 11-8(a), and AWI tolerances are indicated in 11-8(b). Specific tolerances are listed in Table 11-1.

Table 11–1 AWI joint tolerances for factory assembled windows

	AWI grade tolerances, in, (mm)					
	Premium		*Custom*		*Economy*	
	Interior	Exterior	Interior	Exterior	Interior	Exterior
Maximum gap at test location	0.015 (0.4) by 20% of joint length	0.025 (0.6) by 30% of joint length	0.025 (0.6) by 20% of joint length	0.050 (1.3) by 30% of joint length	0.050 (1.3) by 20% of joint length	0.075 (1.9) by 30% of joint length
Flushness	0.001 (0.03)	0.015 (0.4)	0.005 (0.1)	0.025 (0.6)	0.025 (0.6)	0.050 (1.3)

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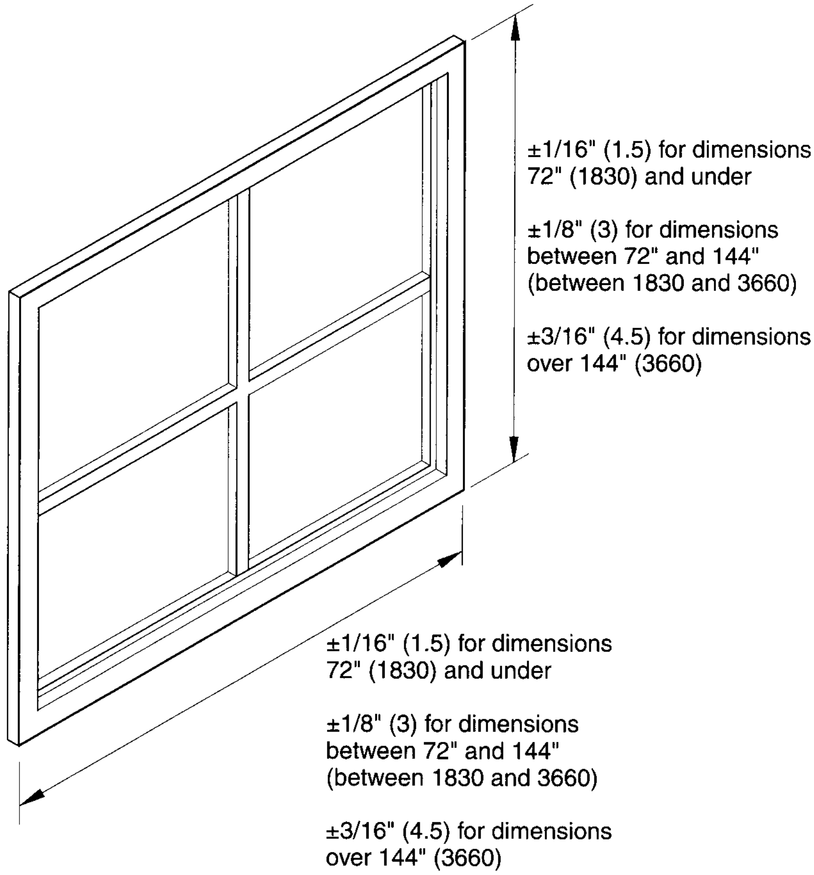
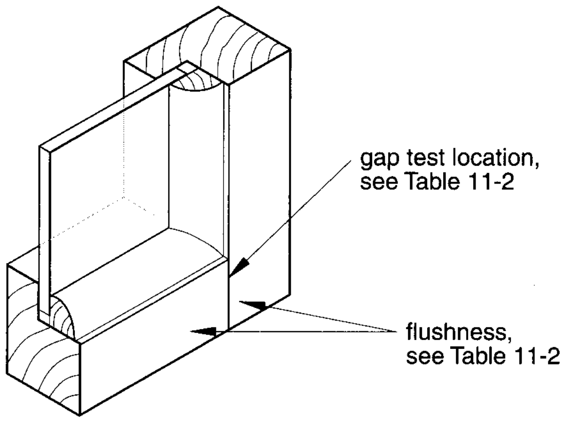
Figure 11–8 Wood windows



(a) NWWDA tolerances



(b) AWI tolerances

Related Sections

7–11 Frames, Jambs, and Windows

11–9 Aluminum Windows and Sliding Doors

Description

This section includes aluminum prime windows and sliding glass doors that are manufactured according to AAMA/WDMA/CSA 101/I.S. 2/A440. As with other premanufactured window and door units, aluminum windows and doors seldom present problems with installation or operation as a result of dimensional tolerance problems.

Industry Standards

AAMA/WDMA/CSA 101/I.S. 2/A440, *Standard/Specification for Windows, Doors, and Unit Skylights* (Schaumburg, IL: American Architectural Manufacturers Association, Wood and Door Manufacturers Association, and Canadian Standards Association, 2005).

Allowable Tolerances

Tolerances are shown in Figure 11-9. In addition to these size tolerances, the tolerances of wall thicknesses and other cross-sectional dimensions of aluminum extrusions given in ANSI H35.2 apply. Refer to Section 9-14. Note that the tolerances shown in Figure 11-9 do not apply to diagonal measurements.

Related Sections

9–14 Aluminum Rods, Bars, and Shapes

11–10 Steel Windows

Description

This section includes standard and detention steel window units that are manufactured according to the Steel Window Institute's (SWI) *Specifications*. As with other premanufactured windows, steel windows seldom present problems with installation or operation as a result of tolerance problems.

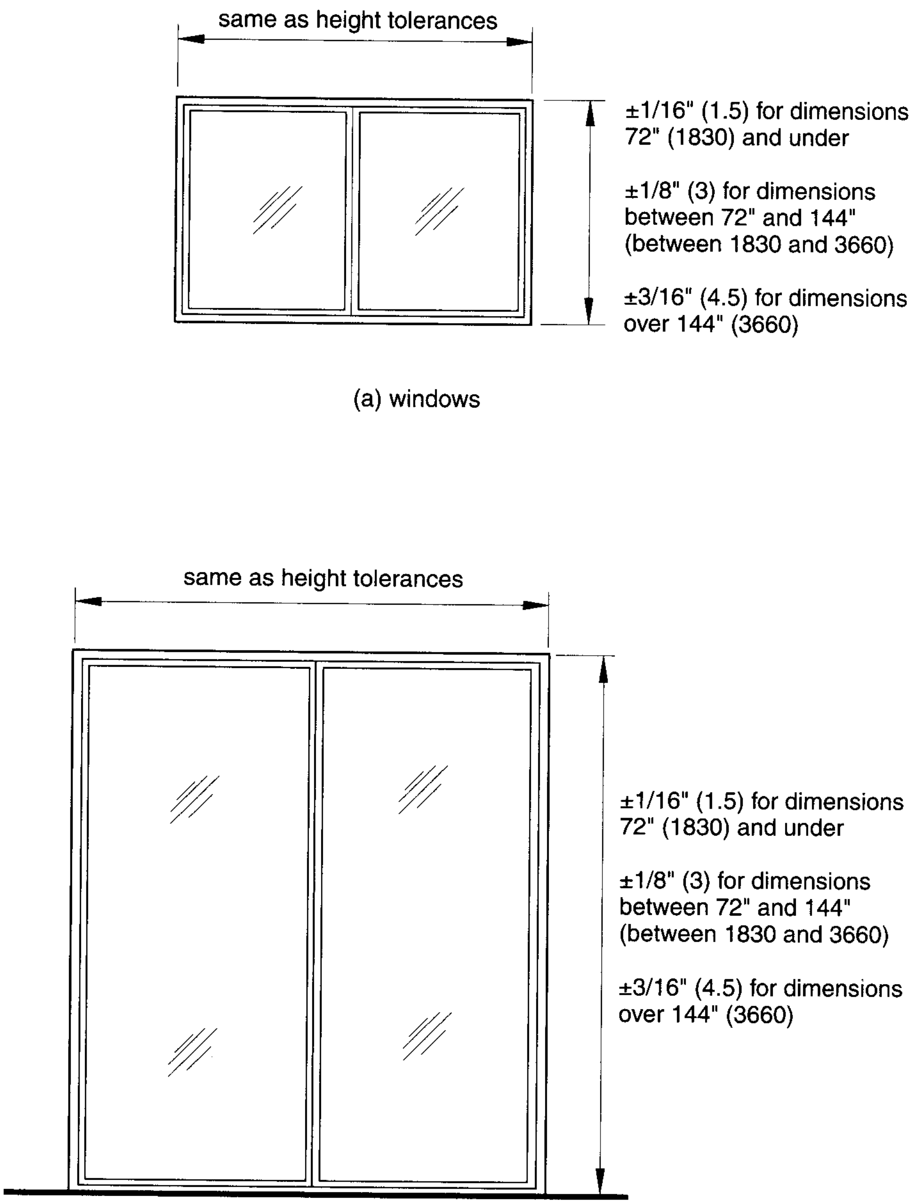
Industry Standards

Steel Windows, Specifications (Cleveland: Steel Window Institute, 2006).

Allowable Tolerances

Typical dimension tolerances from a number of manufacturers are shown in Figure 11-10. In addition, SWI specifications require limits on gaps between metal when ventilator units are locked and tested before leaving the factory. For commercial side-hung ventilators, it should not be possible to freely insert, without forcing, a steel feeler gauge 2 in. (50 mm) wide by 0.020 in. (0.51 mm) thick between the inside contacts of more than 40 percent of the contacts. For projected ventilators, it should not be possible to insert a feeler gauge 0.031 in. (0.79 mm) thick between the inside contacts or to freely insert a 0.020-in. (0.51-mm) feeler gauge between more than 40 percent of the contacts.

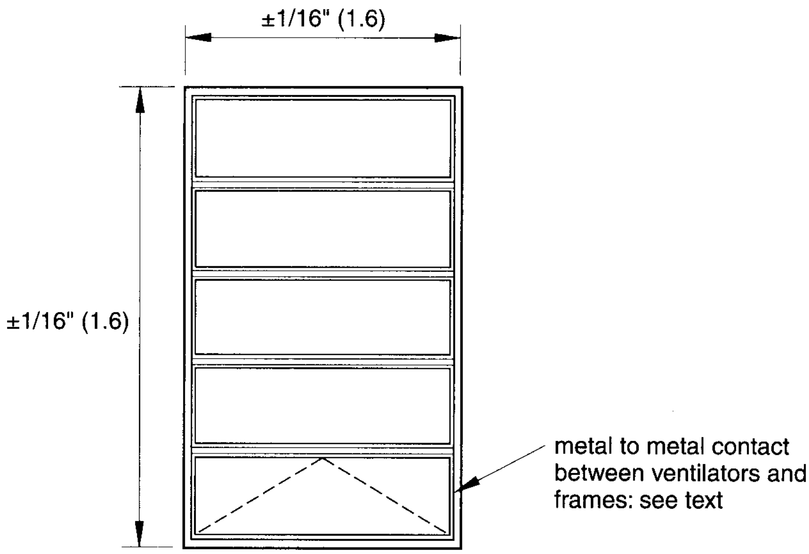
Figure 11–9 Aluminum windows and sliding doors



(a) windows

(b) sliding glass doors

Figure 11–10 Steel Windows



For residential window units, it should not be possible to insert a feeler gauge 0.031 in. (0.79 mm) thick between the inside contacts or to freely insert a 0.020-in. (0.51 mm) feeler gauge between more than 40 percent of the contacts.

Framing sections made from cold-rolled steel must be constructed so that the glass in each window will line in the same plane within a tolerance of ±¼ in. (±6 mm). Framing members must be designed so that the deflection at the required wind load will not exceed $\frac{1}{175}$ of the span of the member. A 3 percent mill tolerance in the minimum weights of sections is allowed. Outside frame members must be designed to lap masonry by at least ½ in. (13 mm).

Part 2

Accommodating Construction Tolerances

Guidelines for Accommodating Construction Tolerances

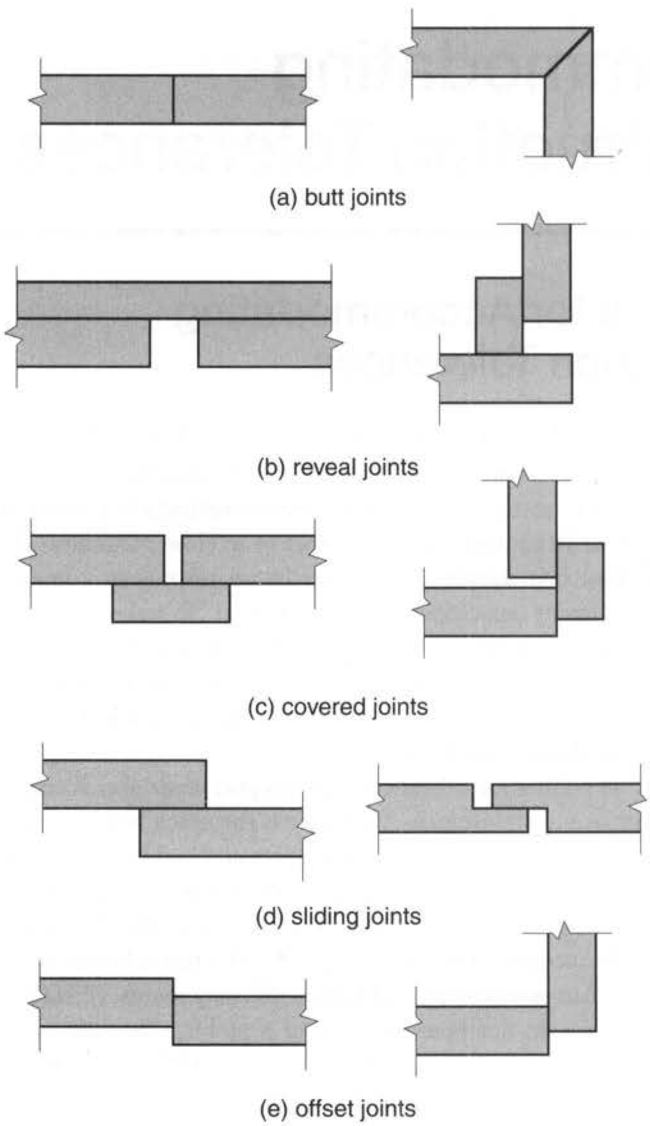
The tolerances shown in Part 1 describe generally accepted industry standard variations in the manufacture, fabrication, and installation of individual materials and construction components. However, nearly all finished building construction is composed of two or more materials, either in contact with each other or in close proximity. These materials usually have different manufacturing and installation tolerances, come from different sources, and have different capacities to be field-adjusted. To make matters more difficult, some materials are field-fabricated, which can create problems by requiring relatively large tolerances or can alleviate problems because they allow custom fitting. Therefore, it is critical for the designer to consider the cumulative effect of different material and erection tolerances when developing details.

In addition to providing for tolerances, the designer must also account for building movement and for required clearances. *Clearance* is the space between two components and is normally provided to accommodate tolerances and building movement, but clearance can also be required for attached materials, such as fireproofing on steel, or for working space as the building is constructed, such as space for a worker to tighten a bolt.

Tolerances can be accommodated in several ways. The first is by specifying and enforcing tolerances as small as practical for field-fabricated components. (Prefabricated component tolerances usually do not pose as much of a problem because industry-standard tolerances are smaller and can be controlled in the shop.) While this method can minimize assembly problems and improve the appearance of visible portions of the building, tight tolerances generally increase construction costs and place an additional burden on the architect or construction supervisor to make sure that all tolerances are being met. Even strict supervision is not always practical. For example, under a strict interpretation of the specifications, a contractor could be required to demolish an entire section of concrete construction because it exceeded the specified tolerances by ¼ in., but this could seriously delay construction, lead to litigation, make for an adversarial work environment for the remainder of the project, and increase cost unnecessarily.

The more practical method is to understand the reality of construction methods and plan for them in the design and detailing of the building. This usually involves designing joints and connections with sufficient clearance and adjustability to accommodate the majority of expected problems, including the fact that many times actual erection tolerances exceed recommended industry-standard tolerances. If visual appearance is critical, the joint or connection also can be designed to make irregularities less noticeable. For example, a wide reveal between two surfaces can conceal a slight misalignment of surfaces, or an overlapping joint easily hides variations in material length and installation tolerance.

Figure P2–1 Types of Joints

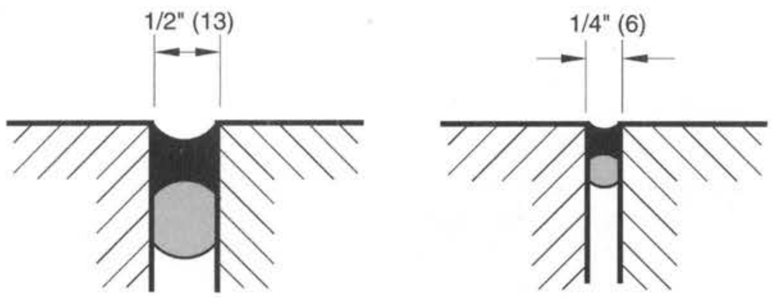


Joint Design

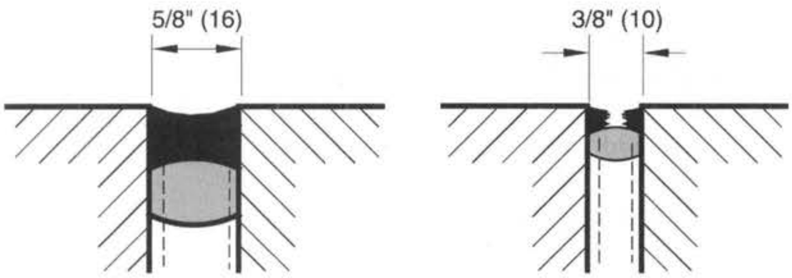
A *joint* is a place where two or more materials come together, either rigidly fastened or with provision for movement. There are several basic methods of creating a joint; some are better than others for accommodating construction tolerances and building movement. These are shown in Figure P2-1.

A butt joint, Figure P2-1(a), is normally used where two identical materials meet and no movement is expected. However, even two normally rigid pieces of material, such as interior wood trim, can shrink or move just enough to be noticeable. When movement is expected and tolerances must be allowed, the two materials may be separated slightly and the joint filled with sealant. When sealant is not required, a reveal joint, shown in Figure P2-1(b), can be used, the reveal concealing both minor misalignments of the material faces as well as allowing for some sideways movement.

Figure P2–2 Sealant Joints



(a) sealant as installed



joint expands 1/8" (3); 25% expandability of sealant allows for ±1/8" movement

joint expands 1/8" (3) 25% expandability of sealant allows for only ±1/16" movement

(b) sealant when expanded

Covered joints, Figure P2-1(c), can accommodate either small or large clearances and movement, but they impose a particular appearance to the joint. Sliding joints, Figure P2-1(d), also allow for a wide range of clearance and movement without requiring a third piece of material. Offset joints, shown in Figure P-1(e), also articulate a joint and conceal minor movement. However, if size or installation tolerances must be accommodated, a reveal or space is required when the two materials are in the same plane or when sealant is required.

For nearly all exterior materials and many interior materials, a joint must be filled with sealant. The size of the joint is critical for proper performance. For example, if a joint that is too narrow expands beyond the capability of the sealant, the sealant will fail. This is shown in Figure P2-2.

The size of a joint depends on the movement expected, construction tolerances, and the movement capability of the sealant. Joint movement may be caused by factors such as thermal expansion and contraction, moisture absorption, and the various forms of structural movement. Construction tolerances include both manufacturing and erection tolerances. The movement capability of the sealant is measured in the percentage from original size the sealant can expand or contract without failing. Common sealant performances are 7½, 10, 12, and 25 percent. Some high-performance sealants are capable of 50 percent movement.

Joint width can be calculated using the following formula:

$$J = \frac{100(e\Delta tL + S)}{M} + T$$

where:

J = Joint width, in. (mm)
e = Coefficient of thermal expansion, in./in./°F (mm/mm/°C)
Δt = Expected temperature change, °F (°C)
L = Length of the material being joined, in. (mm)
M = Movement capability of sealant, in percent expressed as whole numbers
T = Construction tolerance of the material, in. (mm)
S = Other expected movement caused by seismic forces or other nonthermal causes

For example, what would be the minimum joint width between two granite panels, each 5 ft. wide and exposed to a temperature change of 120 °F, if a 25 percent performance sealant was used? Assume that the coefficient of thermal expansion for granite is 4.7×10^{-6} and that no other movement is expected. From Sections 5-1 and 5-4, the dimensional tolerance for granite is ±¼ in. (6 mm) and the relative alignment tolerance is ±⅛ in. (3 mm). Joint width would be calculated as follows:

$$J = \frac{100[(4.7 \times 10^{-6})120(60)]}{25} + 0.25 + 0.125$$

$$J = 0.1354 + 0.25 + 0.125$$
$$J = 0.5104 \text{ or about } ½ \text{ in.}$$

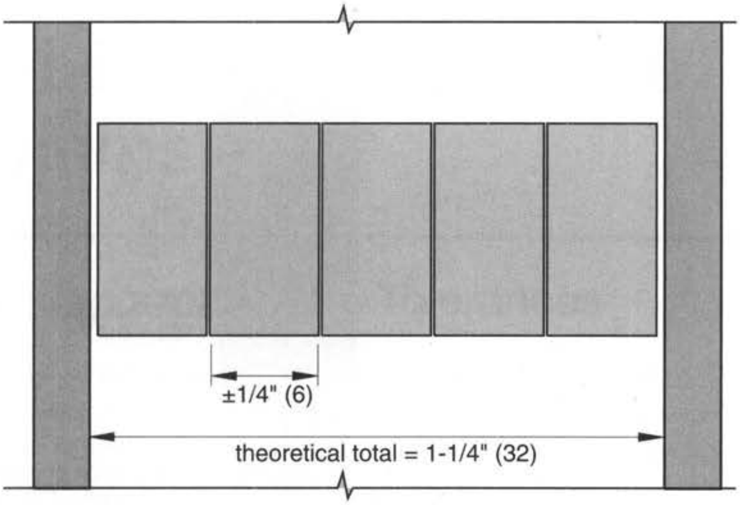
Using the tolerance figures of ¼ in. (6 mm) and ⅛ in. (3 mm) and adding them gives the worst case. This assumes that two adjacent panels will be oversized by the full ¼-in. (6-mm) dimension tolerance and one of the panels will be misaligned by ⅛ in. (3 mm). However, if this occurred, there would only be about a ⅛-in. (3-mm) joint at the time of construction. Besides being less than the recommended minimum joint of ¼ in. (6 mm) any bead of sealant would be crushed when the panels expanded the remaining ⅛ in. (3 mm), or the joint would break if the panels contracted and stressed the sealant beyond its 25 percent capability. In the case of only two panels, the joint size might have to be enlarged to accommodate this worst case. However, as discussed in the next section, it is statistically improbable that all three conditions would occur simultaneously or that there would only be one joint. Chances are greater that several panels would be in line and create a number of joints, each of which could accommodate a portion of the total required tolerance clearance.

Accumulated Tolerances

When several construction components are combined, it is entirely possible that the tolerance for each component will vary to the allowable maximum in the same direction. For instance, if the allowable tolerance on a stone panel is ±¼ in. (6 mm) and five of them are installed in a row, the total length could be as much as 1¼ in. (32 mm) shorter or longer than designed (not accounting for joints). See Figure P2-3.

However, statistically it is unlikely that this would occur; some panels will be a little longer, some a little shorter than the specified size. This statistically probable total tolerance resulting from several combined tolerances can be calculated according to the following formula:

Figure P2–3 Accumulated tolerances



$$T = \sqrt{t_1{}^2 + t_2{}^2 = t_3{}^2 = t_n{}^2}$$

where T is the total tolerance and $t_1{}^2$, $t_2{}^2$, to $t_n{}^2$ are the tolerances of the number, n, of the individual components. When the tolerances of the individual components are different in the plus-and-minus direction, two calculations are required to determine the probable plus and minus tolerances. This formula is applicable where all components have the same individual tolerances or where various materials and components are combined.

With this formula and the preceding example of five stone panels, the total tolerance would be as follows:

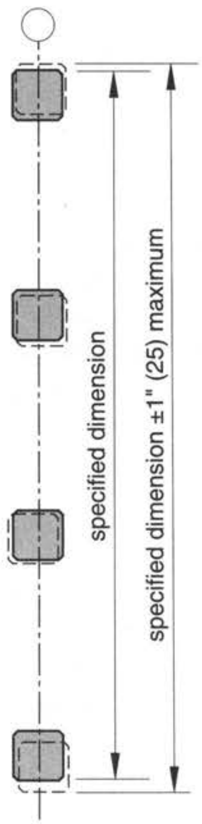
$$T = \sqrt{0.25^2 + 0.25^2 + 0.25^2 + 0.25^2 + 0.25^2}$$

$$= \sqrt{0.313}$$

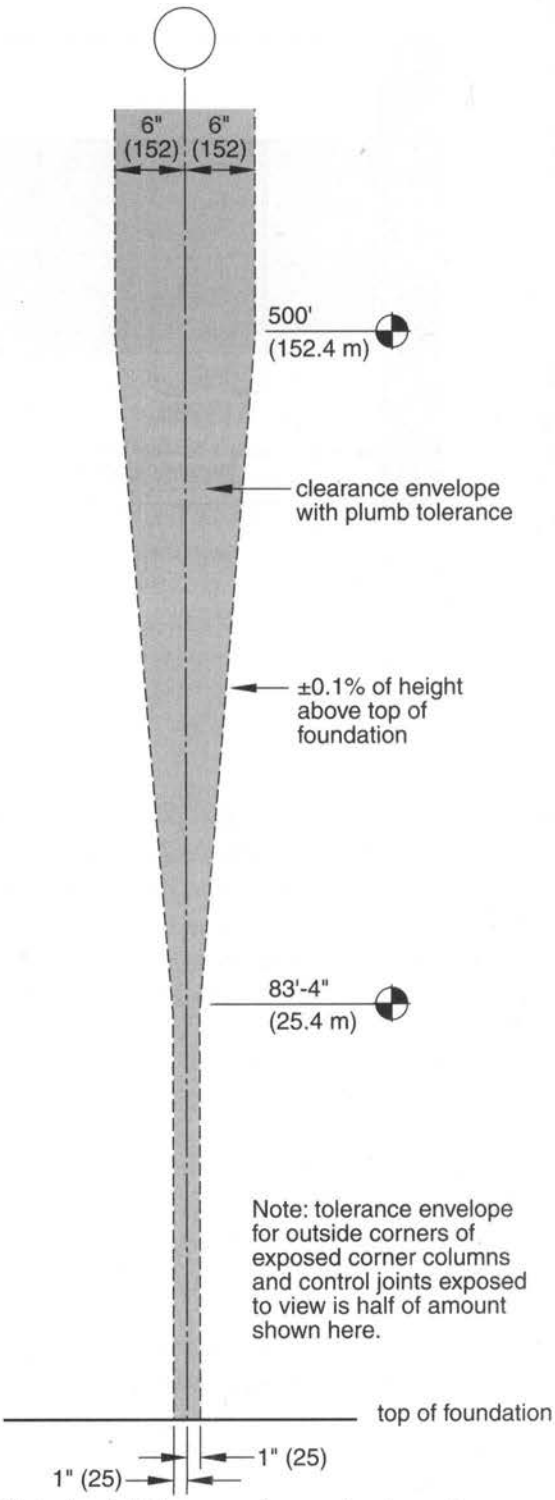
= 0.559" (about $\frac{9}{16}$ in.), in this case, slightly less than one-half of the tolerance based on simple addition.

The following sections in Part 2 illustrate some common construction and detailing situations and show how accumulated and multiple tolerances can be accommodated.

Figure 12–1 Concrete frame tolerances



(a) tolerances of multiple columns



(b) horizontal tolerance of concrete elements

Chapter 12

Cast-in-Place Concrete Systems

12–1 Concrete Frame Tolerances

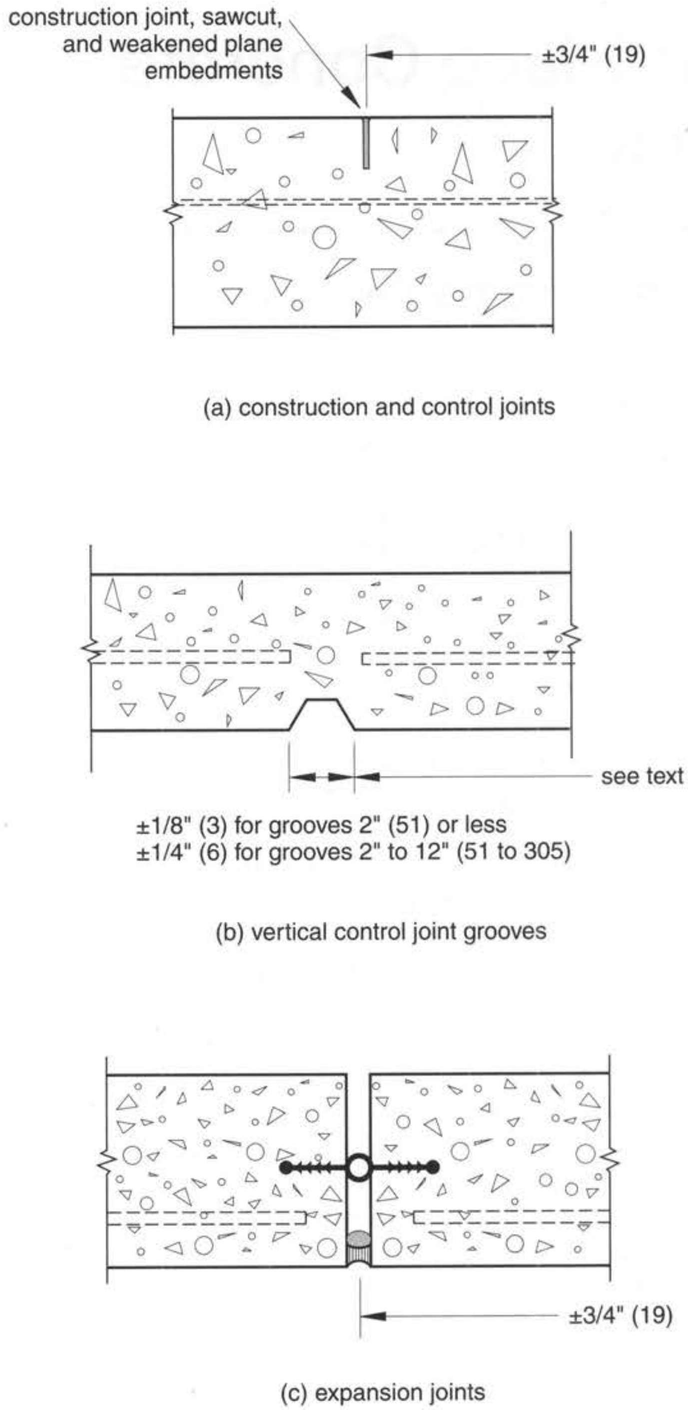
There are several tolerances for the lateral alignment of the structural frame of a cast-in-place building as stated in ACI 117, *Specifications for Tolerances for Concrete Construction and Materials*. In general, columns, walls, and edges of slabs can vary as much as 1 in. (25 mm), and the edges of horizontal openings can vary as much as ½ in. (13 mm). Any material adjacent or connected to a concrete frame must take these tolerances into account. ACI 117 specifically states that tolerances are not cumulative and that the most restrictive tolerance controls. The application of a location tolerance, as discussed in Section 2-9, cannot be used to increase the plumb tolerance, discussed in Section 2-7, nor can a member thickness tolerance increase other tolerances. For example, the lateral position tolerance is not cumulative along several columns or walls. As shown in Figure 12-1(a), the total length of a frame should vary no more than 1 in. (25 mm) one way or the other.

A common problem in attaching a facing material, such as brick veneer or curtain wall, to a concrete frame is the misalignment of the faces of the concrete. As shown in Figure 12-1(b) and described in Section 2-7, the faces of the concrete, columns, or walls can vary from plumb no more than the lesser of 0.3 percent of the height from the top of the foundation or up to 1 in. (25 mm) maximum on either side of the theoretical line for heights under 83 ft., 4 in. (25.4 m). For heights over this, the deviation can be no more than 0.1 percent (1/1,000) times the height (up to a maximum of 6 in. or 152 mm). This creates a total required clearance envelope of 2 in. (51 mm) for buildings under 83 ft., 4 in. (25.4 m) and much more for higher buildings, as shown in Figure 12-1(b). However, between any two adjacent floors, the misalignment cannot exceed ±0.3 percent over a distance of 10 ft. (3 m) or ±0.2 percent for the outside corner of an exposed corner column or in a contraction joint groove in concrete exposed to view. A percentage of 0.3 is about ⅜ in. in 10 ft. (10 mm in 3 m). Refer to the following sections in this chapter for common methods of accommodating concrete frame misalignments.

When exposed, the outside corners of exterior columns and control joint grooves in concrete have a tighter tolerance. They can vary from plumb no more than the lesser of 0.2 percent or ±½ in. (13 mm) for building heights 83 ft., 4 in. (25.4 m) or less and no more than the lesser of 0.05 percent (½,000) of the height, or a maximum of 3 in. (76 mm), for buildings over 83 ft., 4 in. (25.4 m). (See Section 2-7.)

For level alignment, or the position of the tops and bottoms of slabs and beams, the tolerance is ±¾ in. (19 mm) from the specified elevation before the removal of supporting shores. Even though the thickness of slabs or the depth of beams can vary (see Section 2-

Figure 12–2 Joint tolerances



8), the final position of the member must fall within this ¾-in. (19-mm) tolerance. The tolerance is not cumulative from floor to floor. When concrete slabs are poured on structural steel or precast concrete, the final tolerance is determined by the tolerance of the supporting steel or precast concrete in addition to the variation in slab thickness, as discussed in Section 2-8.

Although concrete tolerances have been set by the American Concrete Institute, experience has shown that many times actual construction exceeds recommended tolerances, even when specifically written into the specifications. When conditions warrant, tighter tolerances may need to be specified and carefully controlled as construction progresses, even though this may increase costs beyond what normal tolerances would.

Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan

12–2 Joint Tolerances

Cast-in-place concrete joints include construction, control, isolation, expansion, and building joints. The location tolerance of these joints, either in the horizontal or vertical plane, varies depending on the type of joint and whether or not it is exposed to view.

As shown in Figure 12-2(a), construction joints, saw cuts, control joints, and weakened plane embedments can vary ¾ in. (19 mm) from their location on the plans. The deviation from plumb for control joint grooves exposed to view cannot exceed the lesser of 0.2 percent of the height from the top of the foundation or up to ½ in. (13 mm) maximum for heights under 83 ft., 4 in. (25.4 m). For heights over this, the deviation can be no more than 0.05 percent (1/2,000) times the height (up to a maximum of 3 in. or 76 mm).

The width of grooves must be within ⅛ in. (3 mm) for grooves 2 in. (51 mm) or less in width and within ¼ in. (6 mm) for grooves from 2 to 12 in. wide (51 mm to 305 mm).

The relative alignment of the faces of the two separate sections of concrete can vary depending on which class of surface is specified. These are summarized in Table 12.1. Class A surfaces are those prominently exposed to public view where appearance is of special importance. Class B surfaces are for coarse-textured concrete intended for plaster, stucco, or similar coverings. Class C is the general standard for exposed surfaces where other finishes are not specified. Class D surfaces are for concealed concrete elements where roughness is not objectionable. For walls poured in two separate operations, such as the expansion joint shown in Figure 12-2(c), alignment is usually not a problem because the cured portion of the wall is used to align the formwork for the second pour.

Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–9 Cast-in-Place Concrete Elements in Plan

Table 12–1 Offset between adjacent pieces of formwork facing

Class of surface	Offset tolerance, in (mm)
Class A	±⅛ (3)
Class B	±¼ (6)
Class C	±½ (13)
Class D	±1 (25)

Source: Compiled from ACI 117

12–3 Detailing for Cast-in-Place and Precast Systems

Cast-in-place and precast concrete are normally used together when precast architectural panels are supported with a cast-in-place structural frame or when columns are supported by cast-in-place foundations. Because both systems have relatively large tolerances, connection detailing must accommodate the worst expected combination of tolerances while still providing for erection clearances and minimizing erection time.

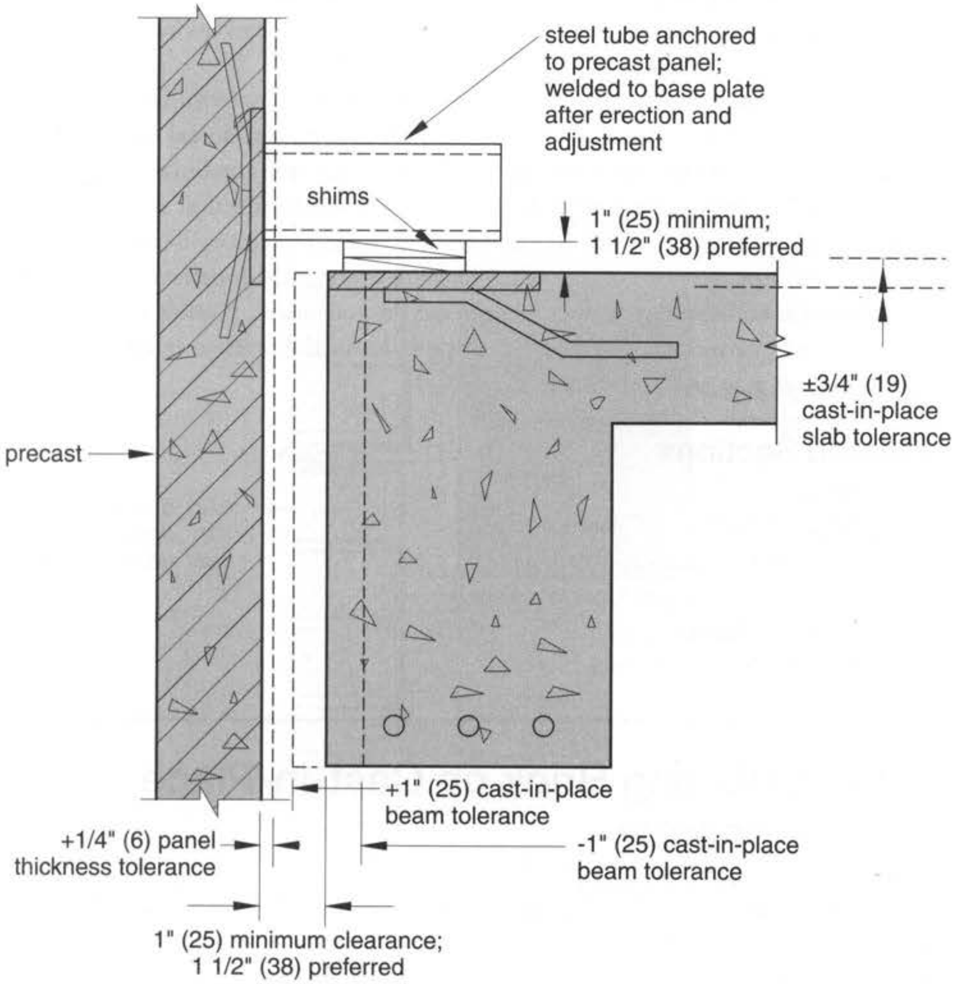
A common condition is shown in Figure 12-3(a), where a precast cladding panel is attached to a cast-in-place beam. This detail shows only one of many possible ways to accommodate tolerances. In addition to clip angles anchored to the precast panel and set on shims, angles, channels, and other support members can be cast into the cladding panel. Vertical adjustment can also be accomplished with leveling bolts instead of shims. The recommended design clearance is 1½ in. (38 mm). This allows for the beam to be out by the maximum of 1 in. (25 mm) and for the panel thickness to be over by the allowable ¼ in. (6 mm). (See Section 2-12.)

To minimize cost, the connections should be designed to minimize the time the panel must be held in place with a crane while adjustments and fastening are made. Connections should also be designed to be made on the top of the concrete frame so access is not required between the back of the panel and the face of the beam.

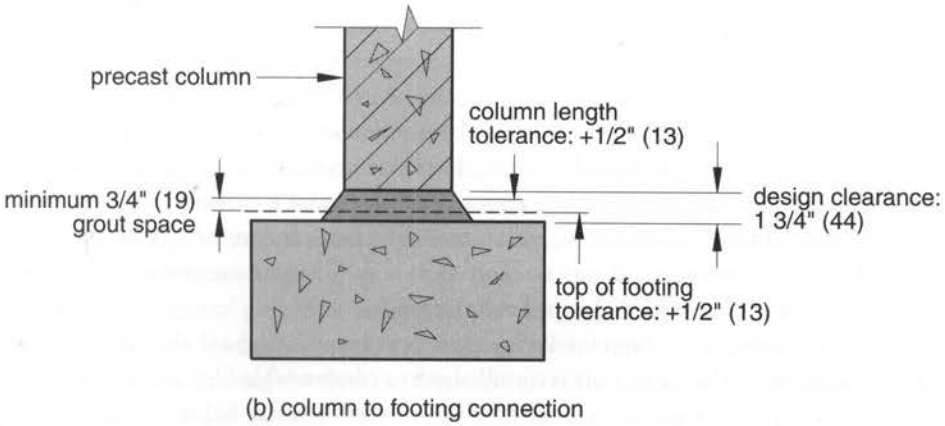
For horizontal alignment of several panels within a cast-in-place structural bay, the vertical joints are typically used to accommodate tolerance problems, with each joint accommodating a portion of the total expected tolerance. Because it is highly unlikely that all panels will be either oversized or undersized by the maximum allowable tolerance, the formula described in the introduction to Part 2 can be used to estimate the total tolerance likely from several individual panels. Procedures for determining joint width are also given in the introduction to Part 2.

Another condition is shown in Figure 12-3(b), where a precast column is supported on a cast-in-place footing. The footing length must be designed to accommodate possible variations in length of the column and placement tolerances of the footing while providing for sufficient clearance for grouting under the base plate cast onto the bottom of the column. The column length may vary by ½ in. (13 mm), and the top of the footing may vary ½ in. (13 mm) higher than specified or as much as 2 in. (51 mm) lower. Assuming the haunch is set at its intended elevation, the worst case when allowing for grouting would be when the column is ½ in. too long and the footing is ½ in. too high. If a ¼-in.

Figure 12–3 Detailing for cast-in-place and precast systems



(a) panel to beam connection



(b) column to footing connection

(19-mm) grout space is required, the total required clearance should be 1¾ in. (44 mm). In case the column is ½ in. short and the footing is 2 in. below the specified elevation, there will be a potential grout space of 3¼ in. (83 mm). If this is too much, it could be decreased by setting the haunch at an acceptable ½ in. (13 mm) below its intended elevation (see Section 2-23) and shimming at the haunch.

In both of these examples, the relevant tolerances for each system must be determined along with any required clearances for erection, insulation, mechanical and electrical interface, or other construction components. Then the extreme conditions must be determined based on the worst-case tolerances. Finally, the connection or joint must be designed to accommodate all the required tolerances and clearances. If the worst-cast situation results in a connection that is too large for economical construction, a judgment must be made concerning whether to decrease the tolerances, possibly increasing construction costs, or recognize that some compromises in the position, plumb, or level of some elements may need to be made.

Related Sections

2–5 Footings
2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–12 Architectural Precast Concrete Panels
2–21 Precast Columns
2–23 Precast Column Erection

12–4 Detailing Brick on Cast-in-Place Concrete

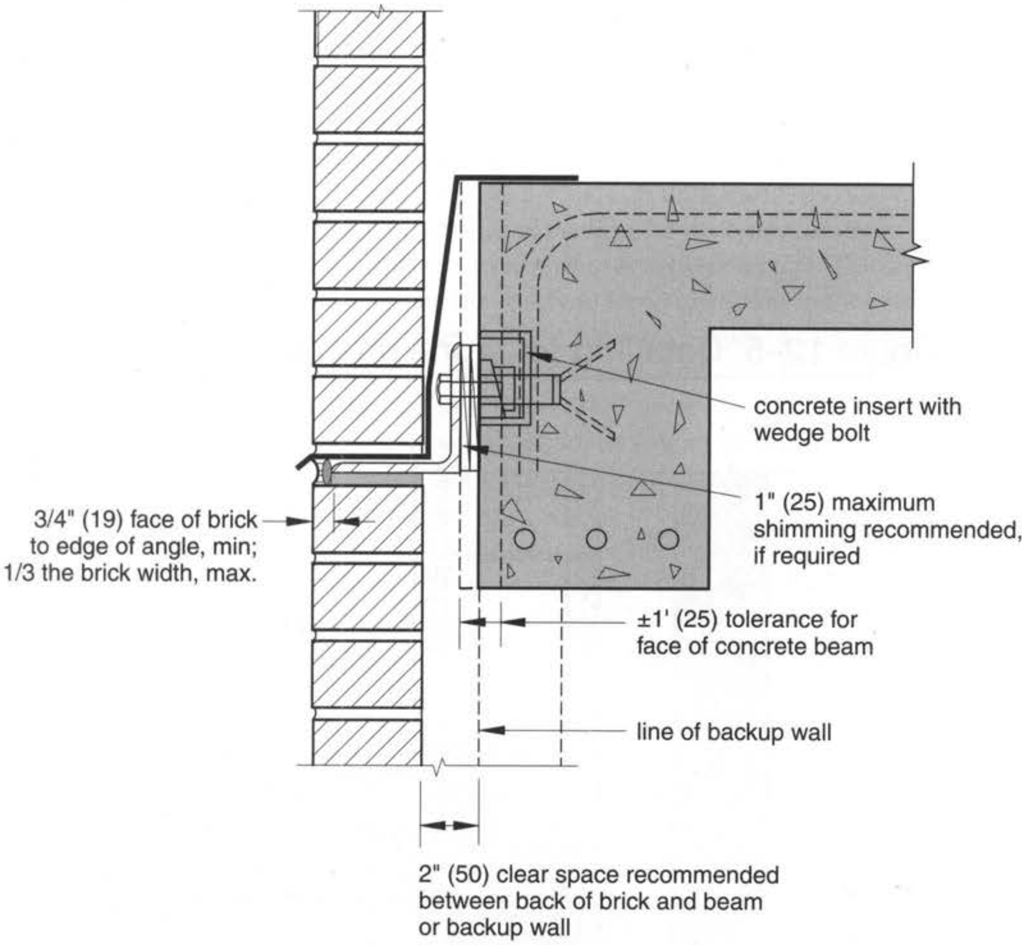
When brick and cast-in-place concrete are used together, the construction tolerance of the concrete frame usually dictates the method of detailing. Dimensional and distortion tolerances of brick are relatively minor, as described in Section 4-5. At most, a surface of an individual, standard-size brick may be out of specified plane by about ⁵⁄₃₂ in. (4 mm) as a result of a worst-case combination of size and warp tolerance.

When brick is laid as an exterior veneer to a backup wall of other masonry or metal studs in a one-story building, the recommended 2-in. (50-mm) cavity between the walls is adequate to accommodate any minor tolerance of brick manufacturing or construction. When brick is used with multistory cast-in-place concrete buildings, the exterior faces of the columns, beams, and slabs may vary as much as 1 in. (25 mm) in either direction.

Because brick is normally supported at each floor line in multistory buildings, the connection and support systems must be designed to accommodate the concrete frame tolerance as well as provide the required clearance between the back of the brick wall and the structural frame and whatever backup wall is used. The Brick Industry Association recommends that brick veneer should vary no more than ½ in. (13 mm) out of plumb, and most masons lay up walls to an even closer plumb tolerance.

Figure 12-4 shows a common brick veneer support system using a shelf angle bolted to the concrete frame. The shelf angle is installed over a compressible filler so that minor deflection of the wall above can occur without bearing on the brick below and cracking or collapsing it. Because the actual elevation of the top of the last brick below the shelf angle may vary slightly, the shelf angle must be adjustable in the vertical direction. This is usu-

Figure 12–4 Detailing brick on cast-in-place concrete



ally accomplished with a concrete insert with a wedge bolt or with slotted holes in the vertical leg of the angle.

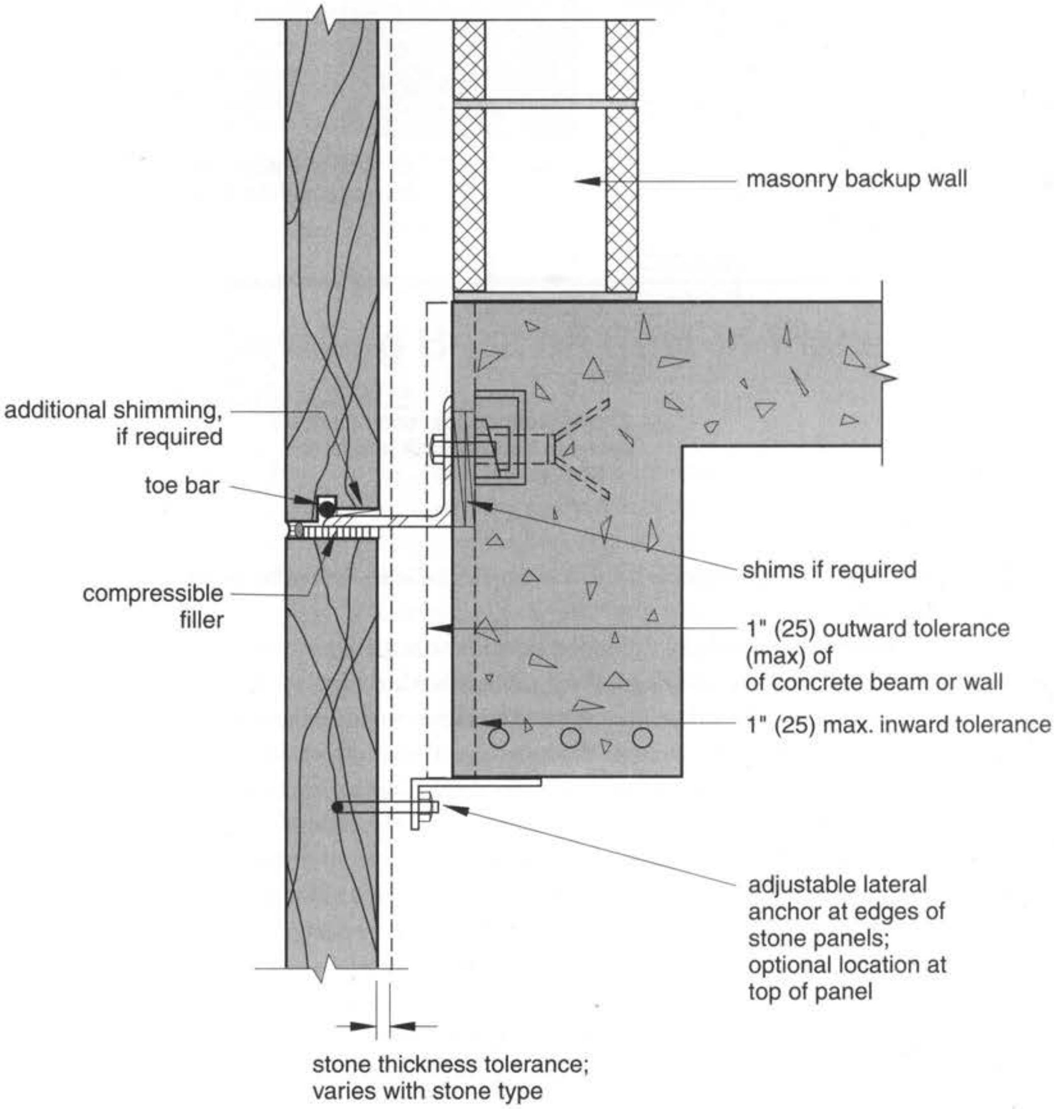
Horizontal adjustment is made by shimming behind the angle if necessary. The maximum recommended shimming distance is 1 in. (25 mm), which can accommodate the maximum concrete frame tolerance toward the inside. However, horseshoe-shaped shims (not washers) should be used with a length about equal to the length of the vertical leg of the angle so there is full bearing against the concrete. If the concrete frame is constructed at the theoretical location, no shimming will be necessary. If the concrete beam extends too far outward, some of the horizontal leg of the angle can be slid farther outward, but the minimum ¾-in. (19-mm) recess should not be decreased so there is adequate room for applying the sealant. In extreme cases, an angle with a shorter horizontal leg may be used, subject to engineering review.

Note that potential problems can arise if the clearance becomes so small that there is not adequate space for the bolt head, flashing, and any material that is used to prevent the bolt head from puncturing the flashing. Depending on the thickness of the angle, the size of the fastener, and the method of flashing, the 2-in. clearance may need to be increased, especially in tall buildings. This also provides extra space to allow for oversize manufacturing tolerances of the brick.

Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan
4–5 Brick Manufacturing
4–6 Brick Wall Construction
15–2 Detailing Brick and Concrete Masonry Systems

Figure 12–5 Detailing for stone on concrete systems



12–5 Detailing for Stone on Concrete Systems

To maintain the installation tolerances for granite, marble, and limestone shown in Sections 5-4 and 5-5, adequate clearances and adjustable connections must be detailed when stone is attached to concrete. Detailing for stone is similar to brick, but there are some important differences. Among them are the wider variety of anchoring systems available, larger thickness tolerances, and the ability for stone panels to be installed slightly out of plumb (within the standards described in Sections 5-4 and 5-5) along the height of a building to partially accommodate minor irregularities of the frame, if absolutely necessary.

Figure 12-5 shows a typical gravity support and anchor at a spandrel beam. This is the most critical connection to accommodate the structural frame tolerances and the stone tolerances. A variety of lateral anchors are available for various types of backup walls, which provide for sufficient adjustment to maintain the erection tolerances shown in Sections 5-4 and 5-5. As with brick, vertical deviations of the concrete frame are accommodated with adjustable concrete inserts or slotted angles. Deviations perpendicular to the building face are taken up by shimming the support angles. Additional vertical adjustment can be made by shimming between the angle and the bottom edge of the stone.

When determining the minimum design clearance, the following tolerances and construction elements must be combined: the ±1-in. (25-mm) tolerance of the face of the concrete beam or wall; the thickness of the stone, which will vary depending on the type of stone and thickness (see Sections 5-1, 5-2, and 5-3); the thickness of the angle; the size of the bolt head; working space required for erection and fastening; and any flashing, weep tubes, or other accessories behind the stone.

As with precast panels, horizontal joints and stone movement are normally accommodated by designing the vertical joints between stone sections large enough to absorb both movement and dimensional tolerances of the stone and concrete frame. Refer to the introduction to Part 2 for procedures for estimating total expected tolerance of several panels and the method for calculating joint width.

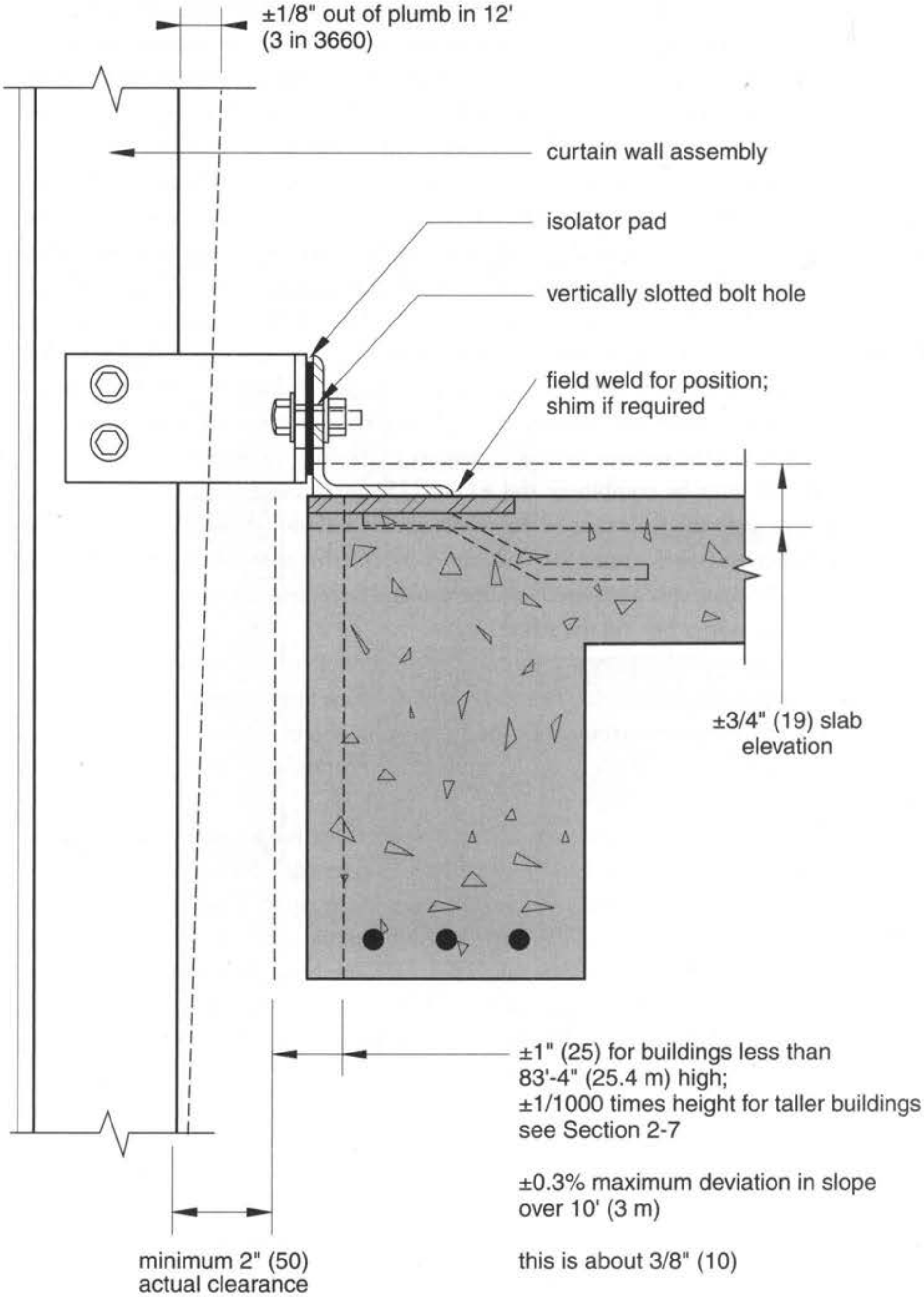
Because Figure 12-5 shows a pressure-relieving joint, there is a separate lateral anchor for the bottom panel. If the joint does not have to accommodate deflection of the panel above or building movement, both gravity anchorage of the upper panel and lateral anchorage of the lower panel can be made with the same connection.

Because the exact method of anchorage varies with the type of structural frame, the type of stone, loading, and other factors, along with the preferences of individual fabricators and installers, final details should be verified with the stone fabricator and contractor.

Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan
5–1 Granite Fabrication
5–2 Marble Fabrication
5–3 Limestone Fabrication
5–4 Granite and Marble Installation
5–5 Limestone Installation

Figure 12–6 Detailing for curtain walls on concrete frames



no scale

12–6 Detailing for Curtain Walls on Concrete Frames

If adequate allowance is made for concrete frame tolerances and these tolerances are controlled during construction, most curtain walls can be installed to the tolerances indicated in Section 8-2. There must be provisions for adjustment in three directions: vertical, horizontal, and lateral. In addition, a minimum clearance of 2 in. (50 mm) between the curtain wall and the frame is recommended for curtain wall construction. If adjustment and clearances are provided, then the minor manufacturing and fabrication tolerances of the curtain wall can be accommodated, as well as any movement of the building frame and expansion and contraction of the curtain wall. In extreme cases, where the frame exceeds tolerances, the curtain wall can be installed slightly out of plumb, following the line of the frame along the height of the building.

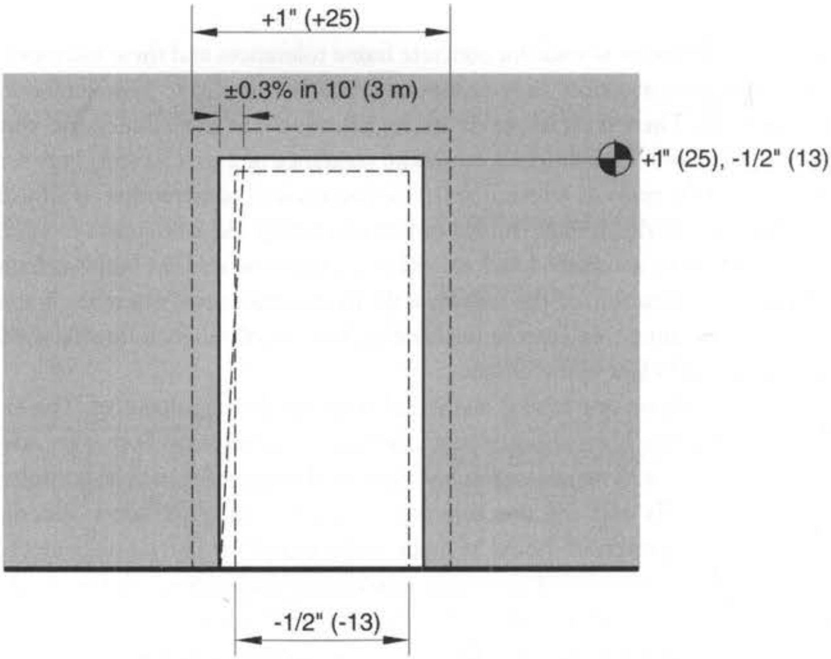
Figure 12-6 shows one typical method of accommodating tolerances. The exact detail varies with the type of curtain wall used, the interior finishes, and other construction details. The curtain wall manufacturer and structural engineer should be consulted for recommended details and for the tolerances that the manufacturer's system requires. Generally, the connection should be made at the top of the slab to make erection easier. Serrated angles and bolts, T-shaped clips, slotted holes, embedded anchors, and shims can all be used to provide the necessary adjustments. When shims are used, the height of the shim stack should not exceed the diameter of the fastener securing the anchor. If the anchor must be higher, special shims and connection details may be required.

Lateral tolerances of the frame can be accommodated by proper design of the vertical joints of the curtain wall. The lateral frame tolerance can be up to 1 in. (25 mm) between columns or in the total length of the building. At individual connectors, lateral alignment can be made by field welding clip angles, with slotted bolt holes or other means. Refer to the introduction to Part 2 for joint design procedures.

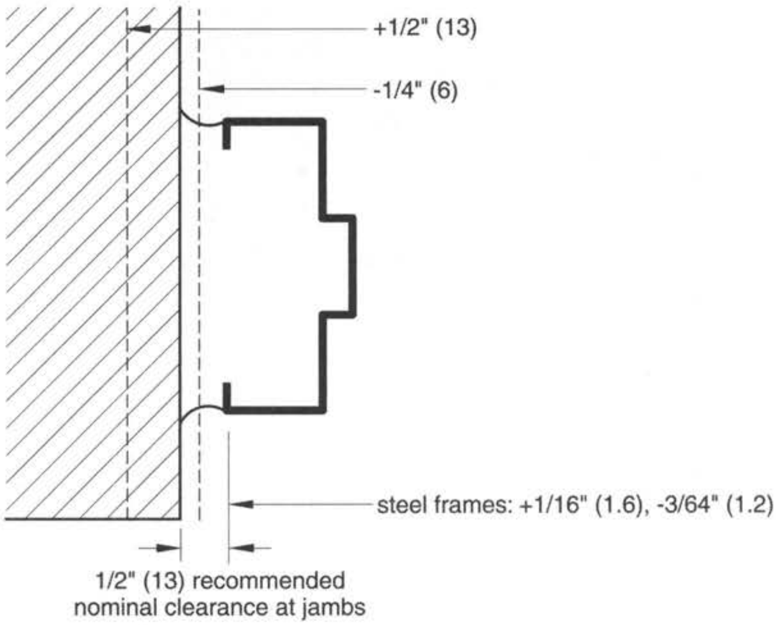
Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan
8–1 Aluminum Curtain Wall Fabrication
8–2 Aluminum Curtain Wall Installation
9–13 Extruded Aluminum Tubes

Figure 12–7 Detailing doors in cast-in-place concrete



(a) opening tolerances



(b) jamb detail

12–7 Detailing Doors in Cast-in-Place Concrete

In most construction, only steel or aluminum door frames are used with cast-in-place concrete. If wood frames are used, there is usually a rough wood buck placed between the two materials, which can be trimmed or shimmed to accommodate the concrete tolerances. Steel frames are fixed in size, so the frame detail and clearance are critical to sizing the opening to allow for tolerances and to provide space for a good sealant joint.

Figure 12-7 shows the possible tolerances of both the concrete opening and a steel frame. The width of the concrete opening may deviate up to ½ in. (6 mm) inward or ¼ in. (6 mm) on each side. The opening width may also deviation up to 1 in. (25 mm) outward or ½ in. (13 mm) on each side. The steel frame may deviate up to 1/16 in. (1.6 mm) outward and 3/64 in. (1.2 mm) inward. This is a combination of frame and steel frame opening tolerances as outlined in Section 11-1. The worst case would be when the frame is larger and the concrete opening is smaller. These combined tolerances are 5/16 in. (8 mm). If a nominal ½-in. (13-mm) clearance were detailed, there would be 3/16-in. (5 mm) gap for applying sealant.

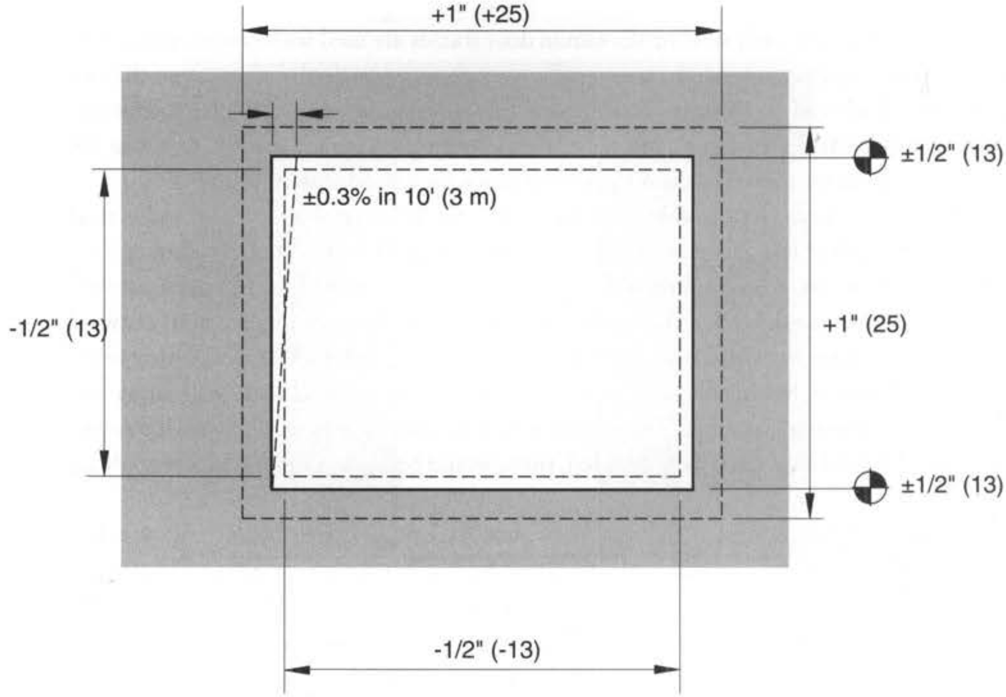
The sides of the opening could also slope, but ACI requirements do not allow tolerances to be cumulative. The allowable deviation from plane for an opening is 0.3 percent of the height. This translates to about ¼ in. (6 mm) in a 7-ft. (2,134-mm) door opening height, which is within the allowable ACI opening size tolerances.

The vertical portion of the opening can vary as much as 1 in. (25 mm) oversize and ½ in. (13 mm) undersize. Because the worst-case combined tolerances of the concrete and the door frame need to be accommodated in the head detail only, the clearance of the head joint needs to be increased by an additional ⅜ in. (10 mm) over the ½ in. (13 mm) design clearance in the jamb details in order to allow for a 5/16-in. (8-mm) gap for sealant. Therefore, a minimum ⅞-in. (22-mm) design dimension is required between the top of the frame and the concrete opening. Detailing a full 1-in. (25-mm) gap between the frame and the concrete would allow for a 7/16-in. (11-mm) gap for sealant if the worst combined tolerances existed. The extra tolerance requirement of ⅜ in. (10 mm) for opening height could also be accommodated in the sill detail.

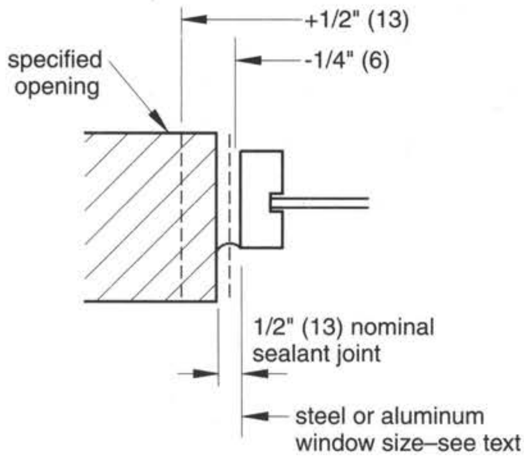
Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan
11–1 Standard Steel Doors and Frames

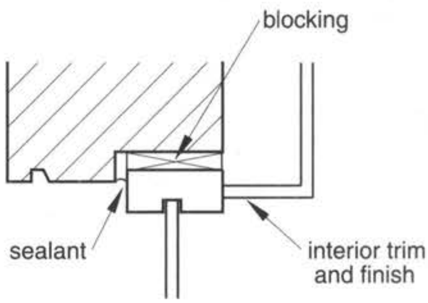
12–8 Detailing windows in cast-in-place concrete



(a) opening tolerances



(b) fitting frames in openings



(c) accommodating fixed window sizes

12–8 Detailing Windows in Cast-in-Place Concrete

Several types of windows can be used in cast-in-place concrete. These include steel, aluminum, and wood. Standard details for steel and aluminum windows are usually the most sensitive to construction tolerances because these window types are commonly placed directly in the opening. When wood windows are used, they are usually framed into a rough wood buck and the exterior and interior joints are covered with some type of trim, which conceals any accommodation for construction tolerances. Only steel and aluminum windows are considered here.

For a window opening, the finished size can be as much as ½ in. (13 mm) too small or 1 in. (25 mm) too large. This means a possible variation of ¼ in. (6 mm) inward and ½ in. (13 mm) outward for any jamb, head, or sill section. See Figure 12-8(a). This does not include any variation in plumb or level for any of the four sides. Although ACI requirements state that tolerances are not cumulative, some additional variation is possible.

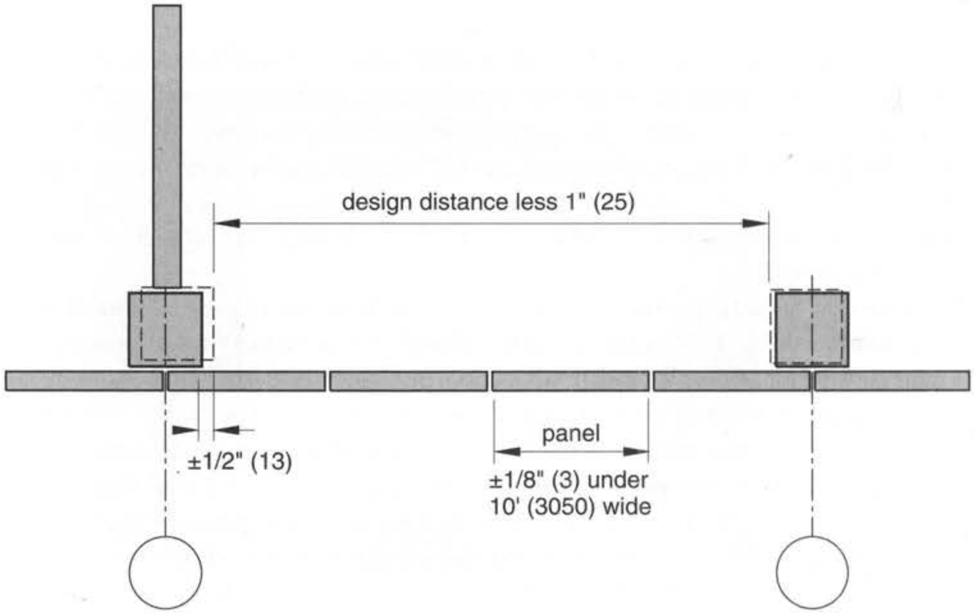
If an aluminum window is used, one jamb may be as much as 1/16 in. (1.6 mm) large (see Section 11-9) and the concrete opening may be as much as ¼ in. (6 mm) too small. If a nominal ¼-in. (6-mm) clearance were provided, this would not provide sufficient space for sealant. As with doors, a minimum ½-in. (30-mm) nominal clearance is a better choice. This means that the entire opening should be dimensioned 1 in. (25 mm) larger than the specified width of the frame. See Figure 12-8(b). For storefronts, a ½-in. (13-mm) clearance between framing and the concrete on each jamb is recommended, or a total opening width 1 in. (25 mm) larger than the storefront framing.

Although misformed openings are not a problem if each is field-measured for a custom window, this is generally not the case. One method of accommodating fixed window sizes is shown in Figure 12-8(c). If a notch is cast in the concrete opening, both in or out tolerances can be concealed and the joint can be properly sealed without oversizing the sealant joint. Although this increases formwork costs slightly, in some cases it is a preferable option.

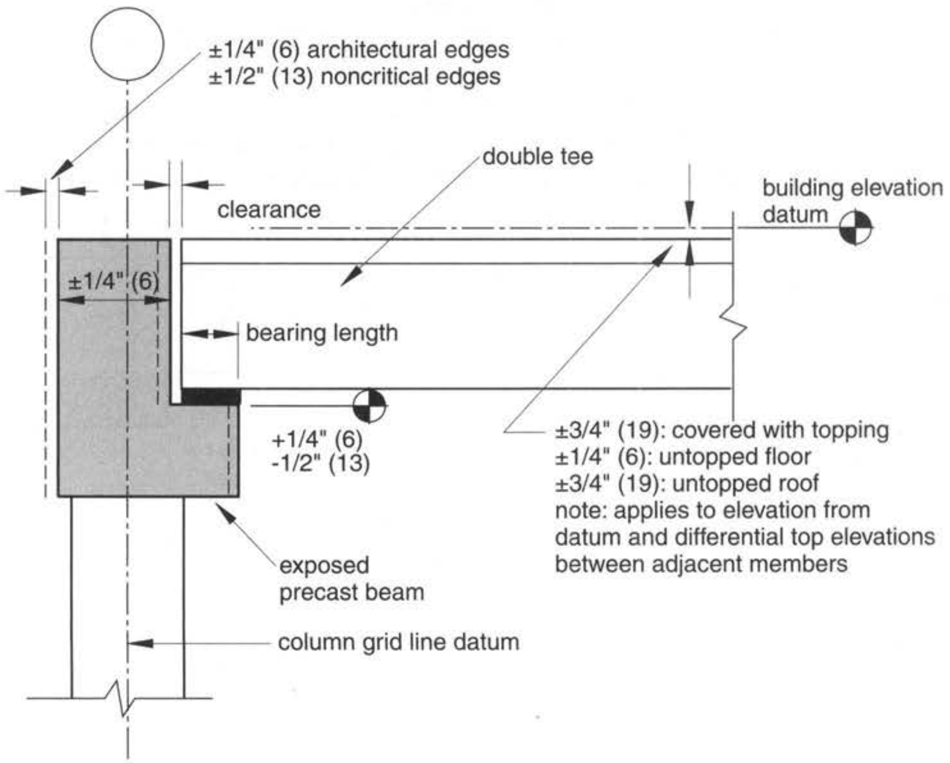
Related Sections

2–7 Cast-in-Place Plumb Tolerances
2–8 Cast-in-Place Sectional Tolerances
2–9 Cast-in-Place Concrete Elements in Plan
11–9 Aluminum Windows and Sliding Doors
11–10 Steel Windows

Figure 13–1 Combined precast concrete frame tolerances



(a) combined frame tolerances



(b) beam/double tee connection

Chapter 13

Precast Concrete Systems

13–1 Combined Precast Concrete Frame Tolerances

There are three types of tolerances in precast work that, when combined, can affect the performance and appearance of a structure: product tolerances, erections tolerances, and interfacing tolerances. Product and erection tolerances are given in Chapter 2. *Interfacing tolerances* are the clearances required for joining different materials in contact with or in close proximity to the precast work. Interface tolerances also allow for building movement. Because precast work has larger tolerances than many other materials connected to it, such as masonry, doors, and windows, designing connections, joints, and details is critical to a successful project. This chapter describes some of the more common types of interfaces.

When precast is joined to other precast work, the product tolerances may or may not be additive to the erection tolerances depending on what part of the precast governs erection. When erection tolerances govern the setting of a primary control surface of a member, that erection tolerance is *not* additive to the product tolerances. A *primary control surface* is a surface on a precast element that is dimensionally set and controlled during the erection process. Two examples are the exposed face of an architectural panel and the elevation of a bearing haunch on a column.

However, erection tolerances of secondary control surfaces and product tolerances *are* additive. A *secondary control surface* is one that is dependent on the location tolerance of the primary control surface. For example, if the top of an exposed L-shaped beam is designated as the primary control surface for purposes of appearance, the tolerance for the secondary control surface of the bearing ledge is added to the dimensional tolerance from the top of the beam to the bearing ledge.

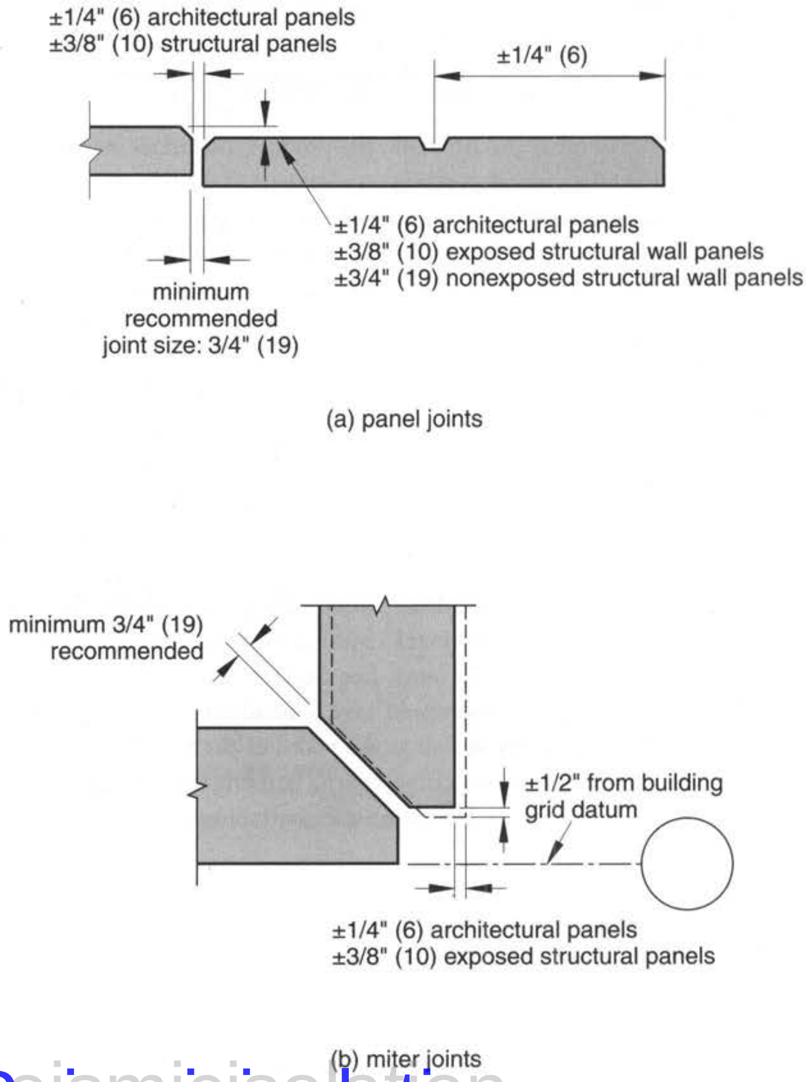
Figure 13-1(a) shows one typical example of combined frame tolerances. Two nonexposed columns may be erected to within ½ in. (13 mm) of their designed locations, creating a possible total variance of 1 in. (25 mm). See Section 2-23 for column erection tolerances. The panels enclosing the frame would have to be adjusted at the joints in order to accommodate the frame tolerances as well as the width of the panels. In an extreme case the panels could be shifted toward the corners of the building to accommodate a large difference. Refer to the introduction to Part 2 for information on calculating combined tolerances.

Figure 13-1(b) illustrates a case where the primary control surface would have to be designated. In this case the floor elevation might be the controlling factor for the erection of the double tee, while the primary control surface for the exposed beam might be the bottom of the beam so it aligns with adjacent construction. Sufficient clearance for the bearing pad would then have to be determined to accommodate both of these tolerances: the product size tolerance of both beam and double tee as well as the combined erection tolerances of the bottom of the double tee and the bearing elevation of the beam. The clearance between the inside of the beam and the end of the double tee also depends on erection tolerances and the product tolerances of both beam and double tee.

13–2 Joint Tolerances

Joints are sized to allow for building movement as well as to accommodate product and erection tolerances. In addition, joints between precast elements have their own tolerance. These apply primarily to exposed wall panels. The tolerances of a joint depend on whether it is part of an architectural panel, an exposed structural wall panel, or a nonexposed structural panel.

Figure 13–2 Joint tolerances



As shown in Figure 13-2(a), joints between panels can vary between ±¼ in. (6 mm) for architectural panels to ±⅜ in (9.5 mm) for structural panels. False joints may be expected to fall within ±¼ in. (6 mm) from the designated location as measured from the edge of a panel.

The alignment between two panels varies from ±¼ in. (6 mm) for architectural panels to a maximum of ±¾ in. (19 mm) for nonexposed structural wall panels. If the outside surface is designated as a primary control surface, this possible lateral variation must be taken into account when the clearance is calculated between the back of the panel and the structural frame, but it would not be additive to the product thickness tolerance. Chamfered or reveal joints should be used to conceal misalignment.

Usually, joints are sized so that product and erection tolerances can be apportioned among the joints. Refer to the introduction to Part 2 for the method of doing this. Generally, a ¾-in. (19-mm) joint between panels is considered as a minimum to account for tolerances and building movement while still providing a large enough joint for sealant.

Figure 13-2(b) illustrates the possible tolerances in a miter joint. Some accumulated panel tolerances can be accommodated with a miter joint, but if large deviations along a series of panel are expected and if the variation is designed to be taken up at the corners of the building, a quirk miter should not be used. Some type of an overlapping joint is a better alternative. See Section 13-3.

Related Sections

2–25 Precast Floor and Roof Member Erection
2–26 Precast Structural Wall Panel Erection
2–27 Precast Architectural Wall Panel Erection

13–3 Detailing for Precast Systems

Most precast-to-precast tolerances can be easily accommodated by using some basic design concepts, as shown in Figure 13-3. Either reveal joints or chamfered joints should be used and butt joints avoided. These minimize any minor misalignments by creating a strong shadow line at each joint. See Figure 13-3(a).

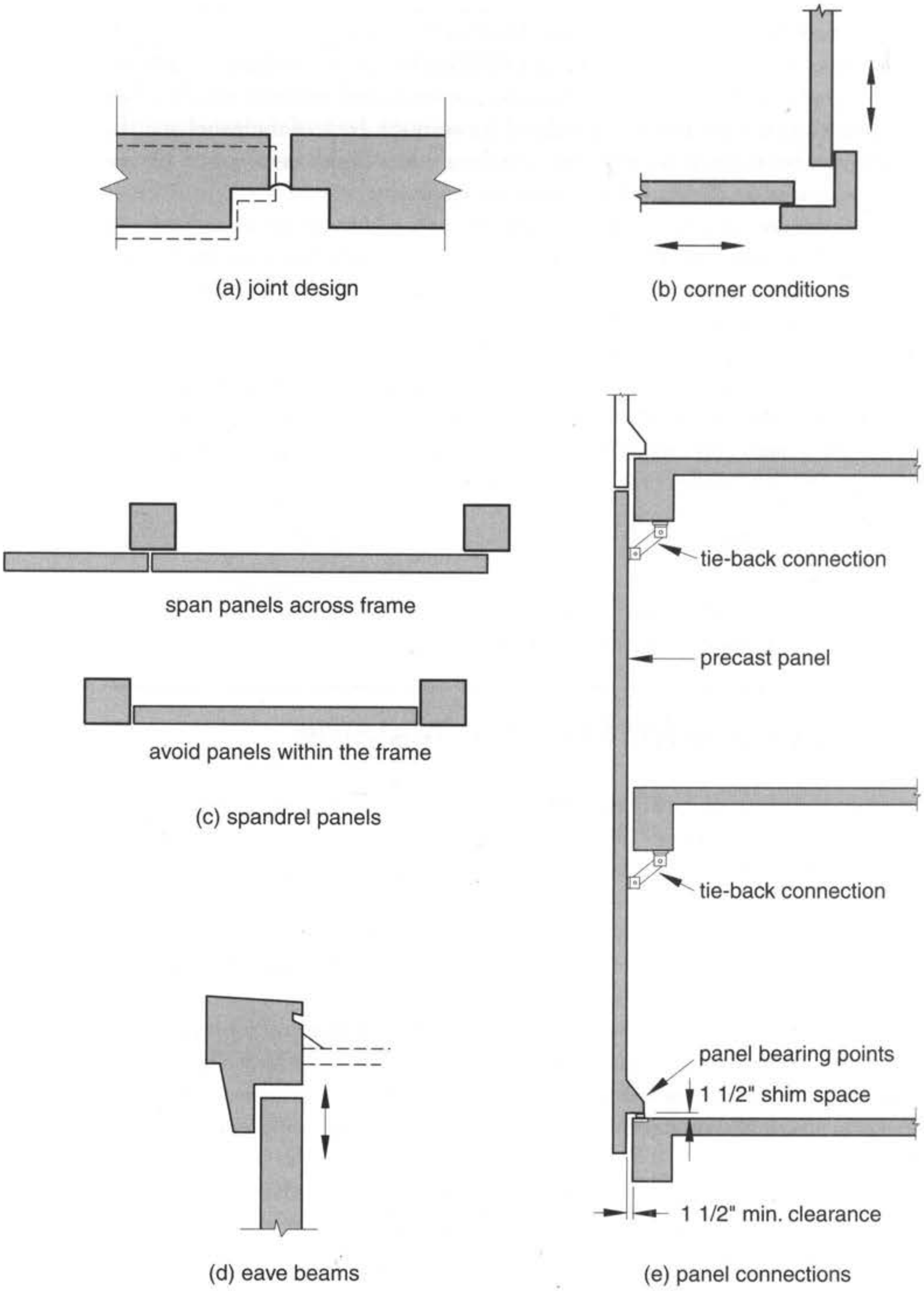
If possible, create overlapping joints at the corners to accommodate accumulated panel tolerances along the length of the building as illustrated in Figure 13-3(b). Avoid miter joints, because these have very little room for adjustment.

Spanning across beams and exposed structural columns with spandrel panels and infill panels is preferable to placing panels within the frame. See Figure 13-3(c). The accumulated tolerances of the columns and panels may result in uneven or oversized joints. If articulated columns or beams lines are desired, they can be covered with separate precast architectural panels.

As shown in Figure 13-3(d), eave beams can be used to accommodate inaccuracies in panel length and erection tolerances at the roof line in much the same way as corner panels are used. Because eave beams span across several panels, they can also accommodate reglets for flashing more accurately than trying to align reglets at each panel joint.

When non-load-bearing panels are attached to a structural frame, only two points of bearing should be designed into the panel support system, as illustrated in Figure 13-3(e). These are the points where erection tolerances are accommodated, usually with shims or leveling bolts. Various types of tieback connections are used at other points to provide lateral support while accommodating product and erection tolerances and allowing for panel movement.

Figure 13–3 Detailing for Precast Systems



Related Sections

Section 2–16 Stairs
Section 2–27 Precast Pilings
13–1 Combined Precast Concrete Frame Tolerances
13–2 Joint Tolerances

13–4 Detailing for Precast and Steel Systems

Detailing combined precast and steel systems can be difficult because the accumulated tolerances can be substantial and tolerances for both systems vary depending on the size and type of member. For example, wide-flange tolerances vary with length and size of flange, and vertical alignment of the frame varies with building height. Each detail has to be evaluated individually based on product tolerances, erection tolerances, anticipated building movement, clearance for fireproofing, structural adequacy, and cost.

Figure 13-4 illustrates a common condition where an architectural precast panel is attached to a steel frame in a perfectly plumb condition for the entire height of the building. To determine the horizontal design clearance required between the back of the precast panel and the outside edge of the beam and also the possible minimum and maximum variation in the bearing length of the precast anchor, several tolerances must be accommodated.

First, erection tolerances of the steel are the most critical. In a building up to 20 stories high, the steel may vary as much as 1 in. (25 mm) out (toward the building line) and 2 in. (50 mm) in (away from the building line). See Section 3-6 for exact values. Beam size tolerances and beam sweep could add to these distances, but current AISC codes (AISC 303) state that the accumulation of mill and fabrication tolerances shall not cause the erection tolerances to be exceeded. Second, the precast thickness can vary by ¼ in. (6 mm), and precast bowing could add about ⅛ in. (3 mm) for a 5-ft. (1525-mm) panel. If the outside face was the primary control surface, this additional ⅜ in. (10 mm) would need to be accommodated in the clearance space. These tolerances add up to a total *minimum* clearance of 1⅜ in. (435mm), not accounting for fireproofing and building movement and assuming the edge of the columns did not extend beyond the edge of the beam flange.

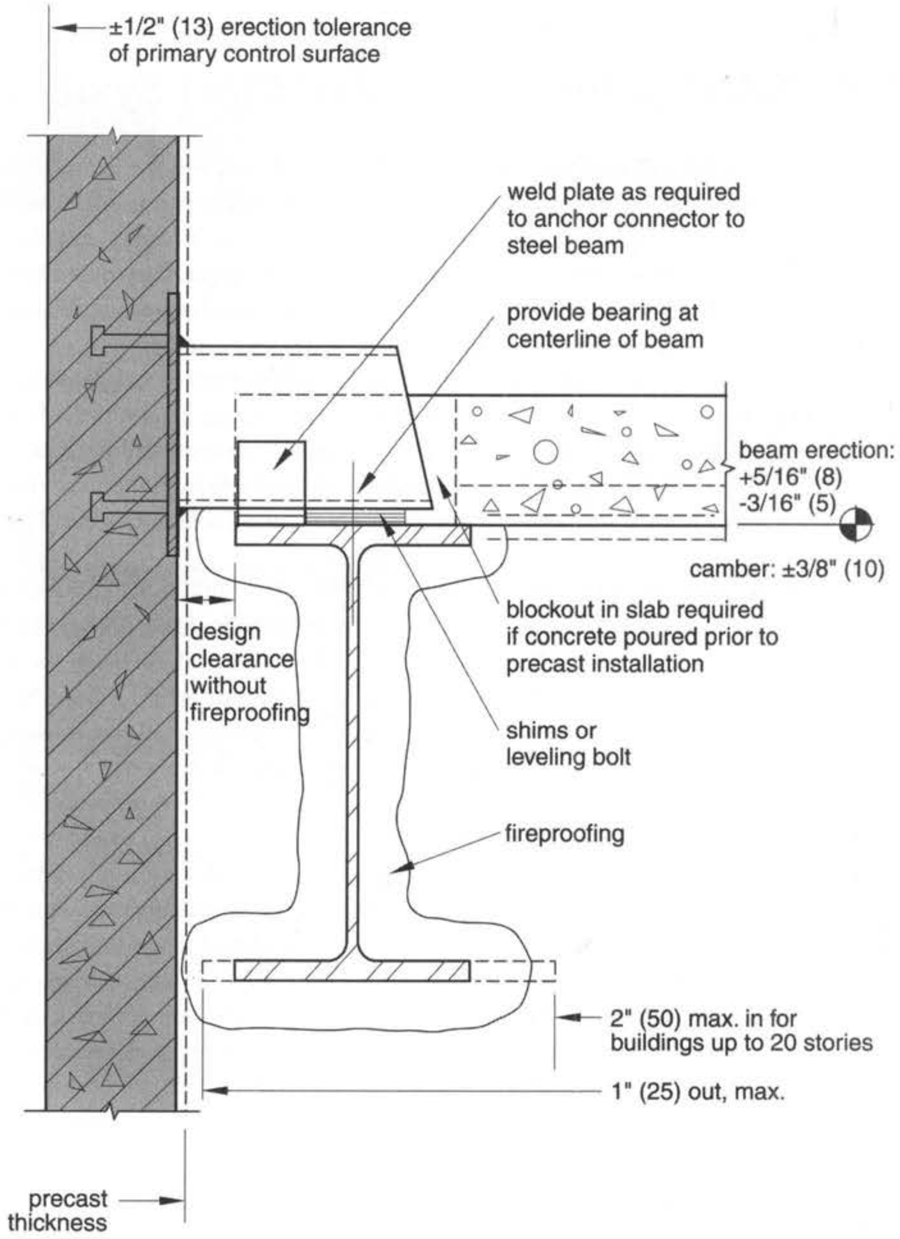
If the *maximum* possible clearance is calculated using this 1⅜-in. (35-mm) design clearance, in the worst case, the edge of the steel will be 3¾ in. (95 mm) from the back of the precast panel if the steel deviates away from the building line and the panel deviates outward. Using these maximum inward and outward deviations, panel anchors would have to accommodate a 3⅝-in. (92-mm) adjustment. Additional clearance for fireproofing would add to this.

For buildings over 20 stories high, the design clearance and subsequent anchor adjustments would need to be increased by an additional 2 in. (51 mm) if the face of the panel was to remain plumb. Because of the large amount adjustment required, structural considerations, and cost, it is generally impractical in tall buildings to maintain perfectly plumb precast panels. In these cases the precast concrete panels usually follow the steel frame.

The design clearance between the floor slab and the precast anchor can be estimated in a similar way. For example, the top of the beam can be set 5/16 in. (8 mm) high and camber can add another ⅜ in. (10 mm).

In all cases, the architect, engineer, and precast supplier and erector should review tolerance and clearance requirements before fabrication begins. The Precast/Prestressed

Figure 13–4 Detailing for precast and steel systems



Concrete Institute recommends a minimum clearance of 1½ in. (38 mm) between the back of the precast panel and the surface of the fireproofing. Refer to MNL 135-00 *Tolerance Manual for Precast and Prestressed Concrete Construction* for more information on interfacing tolerances.

Related Sections

2–12 Architectural Precast Concrete Panels
2–27 Precast Architectural Wall Panel Erection
3–1 Mill Tolerances for W and HP Shapes
3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
14–4 Detailing for Precast on Steel

13–5 Detailing Masonry and Precast Systems

When masonry and precast concrete are used together, the construction tolerance of the precast frame usually dictates the method of detailing. Dimensional and distortion tolerances of concrete block and brick are relatively minor, as described in Sections 4-1 and 4-5. At most, an individual concrete block may be ⅛ in. (3 mm) larger or smaller than specified. Tolerance standards of the American Concrete Institute, American Society of Civil Engineers, and The Masonry Society (ACI 530.1/ASCE 6/TMS 602) require masonry walls to be laid up to within a ±½-in. (13-mm) vertical alignment along the total height of the wall, with a maximum vertical misalignment of ¼ in. in any 10-ft. section (6.4 mm in 3.05 m). The top of bearing walls must be within ½ in. (13 mm) of the specified elevation.

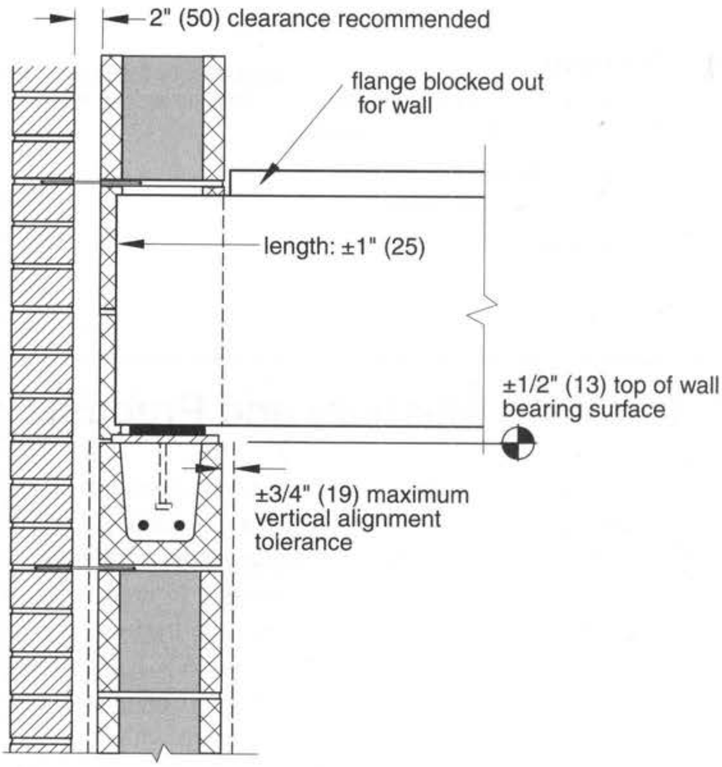
Figure 13-5 shows one of many possible combinations of masonry and precast: a double tee supported by a reinforced concrete block wall with a self-supporting brick veneer. The end of the double tee (or any other floor or roof member used) should not extend into the recommended 2-in. (50-mm) cavity, so the minimum clearance between the end of the tee and the outside face of the block wall should be determined.

In the worst case, the block wall could slope inward up to ½ in. (13 mm) and the tee could be 1 in. (25 mm) too long, so a total clearance of 1½ in. (38 mm) could be specified. (Other types of members, such as hollow-core slabs, have other length tolerances.) The wall and tee might also vary in opposite directions at some point along the wall, so the 1 ½-in. design clearance added to a ¾-in. outward slope of wall and a tee that is 1 in. short could result in as much as a 3¼-in. (83-mm) clearance, leaving only a 4⅜-in. (111-mm) bearing surface on a standard 8-in. block. This is too small and results in eccentric bearing on the wall, creating structural problems or requiring an expensive connection and additional wall reinforcing. To alleviate this problem, the minimum design clearance could be reduced to 1 in. and the recommended 2-in. cavity increased slightly to account for any tees that might extend slightly into the cavity. Required clearances for other types of masonry/precast details can be estimated in a similar manner.

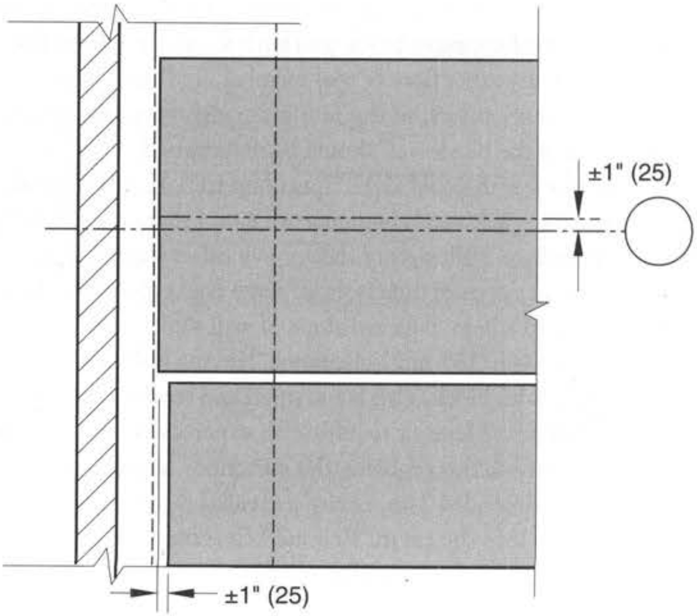
Related Sections

2–20 Prestressed Double Tees
2–25 Precast Floor and Roof Member Erection
4–3 Masonry Construction Tolerances

Figure 13–5 Detailing masonry and precast systems

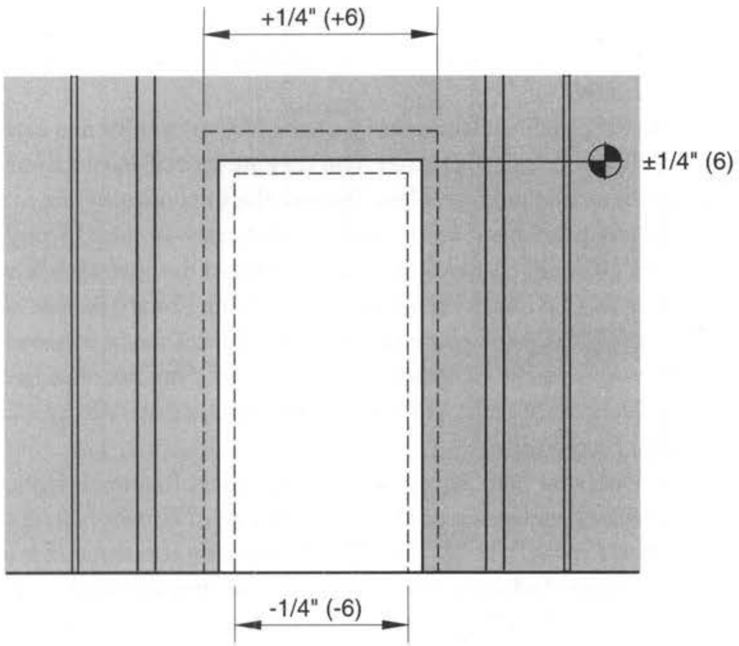


(a) section view

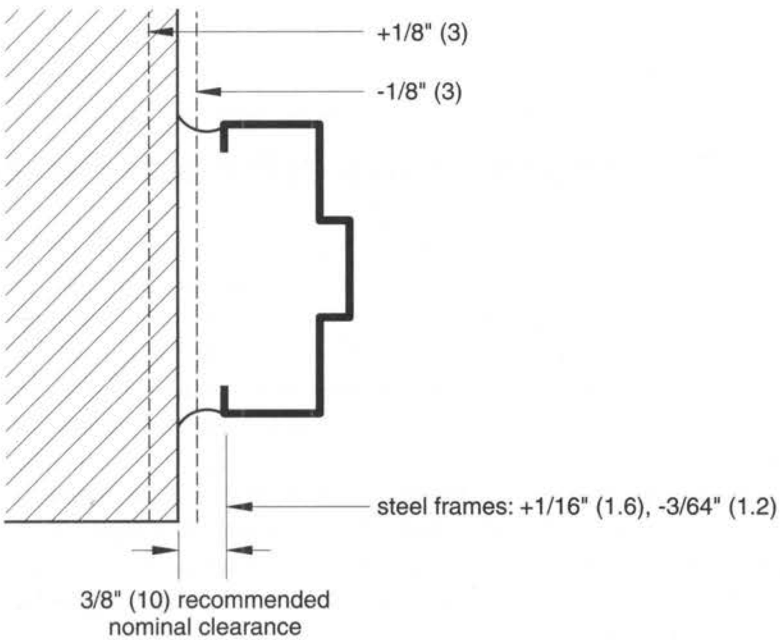


(b) plan view

Figure 13–6 Detailing doors in precast concrete



(a) opening tolerances



(b) jamb detail

13–6 Detailing Doors in Precast Concrete

As with cast-in-place concrete, doors in precast concrete are typically framed with steel and, in some cases, aluminum. If wood frames are used, there is usually a rough wood buck placed between the two materials, which can be trimmed or shimmed to accommodate tolerances of the concrete.

Figure 13-6 shows the possible tolerances of both the precast opening and a steel frame. Tolerances for the precast opening are tighter than they are for cast-in-place frame, so accommodating a door is usually not a problem. Because the total opening size of an architectural precast concrete panel has a ±¼-in. (6-mm) tolerance—or ⅛ in. (3 mm) on each side—a nominal ⅜-in. (10-mm) clearance is sufficient. Even if the opening is ⅛ in. smaller and the steel door is 1/16 in. (1.6 mm) larger, there is still a 3/16-in. (5-mm) sealant joint. Aluminum frames have about the same tolerance. Height tolerances can be adjusted either at the door head or by modifying the clearance at the floor line. If precast ribbed wall panels are used, opening tolerances are ±½ in. (13 mm), so the clearance needs to be increased to at least ½ in. (13 mm) on each side.

For large garage doors that span across two or more panels, framing is more difficult. The edges of each precast panel at the head of the opening can be over ½ in. (13 mm) off (depending on the type of panel), unless the top of the opening is designated as a primary control surface. If the edges of adjacent panels are offset, the irregular head section can be framed with steel angles or channels to provide a straight, true rough opening.

Related Sections

2–12 Architectural Precast Concrete Panels
2–13 Precast Ribbed Wall Panels
2–14 Precast Insulated Wall Panels
8–4 Storefront Installation
11–1 Standard Steel Doors and Frames

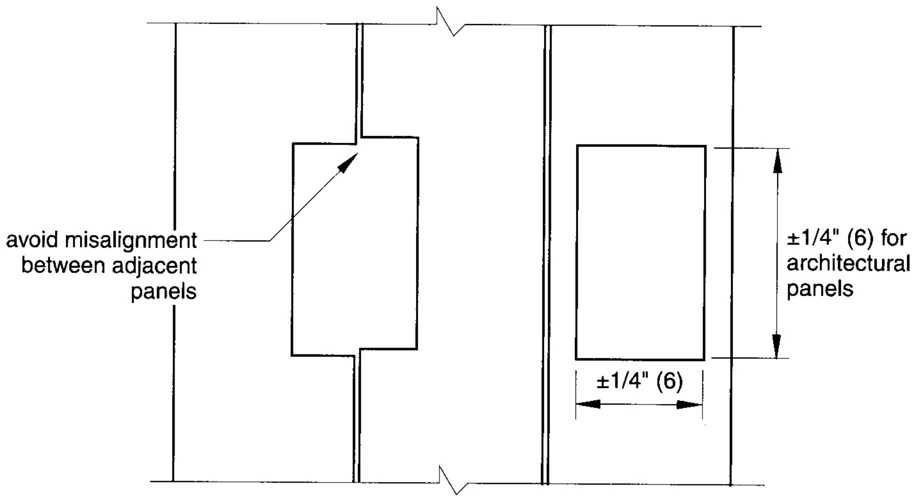
13–7 Detailing Windows in Precast Concrete

Several types of windows can be used in precast concrete. These include steel, aluminum, and wood. Standard details for steel and aluminum windows are usually the most sensitive to construction tolerances because these window types are commonly placed directly in the opening. When wood windows are used, they are usually framed into a rough wood buck and the exterior and interior joints are covered with trim, which conceals any accommodation for construction tolerances. Only steel and aluminum windows are considered here.

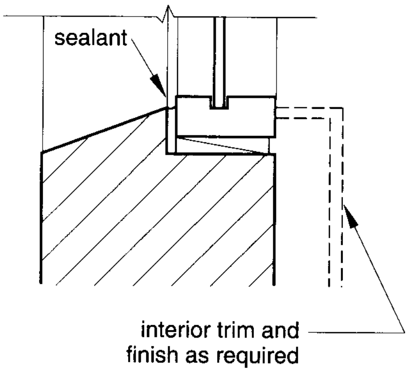
For a window opening, the finished size can be as much as ¼ in. (6 mm) too small or too large in architectural panels and ±½ in. (13 mm) in ribbed and insulated wall panels. This means a possible variation of ⅛ in. or ¼ in. (3 mm or 6 mm) in and out for any jamb, head, or sill section. See Figure 13-7(a). This does not include any variation in plumb or level for any of the four sides.

If an aluminum window is used, one jamb may be as much as 1/16 in. (1.6 mm) too large (see Section 11-9) and the concrete opening may be as much as ⅛ in. (3 mm) too small. If a nominal ¼-in. (6-mm) clearance is provided, this provides only a 1/16-in. (1.6-mm) space for sealant. A minimum ⅜-in. nominal clearance is a better choice. For storefronts, a ½-in. (13-mm) clearance between framing and the concrete is recommended.

13–7 Detailing windows in precast concrete



(a) window locations



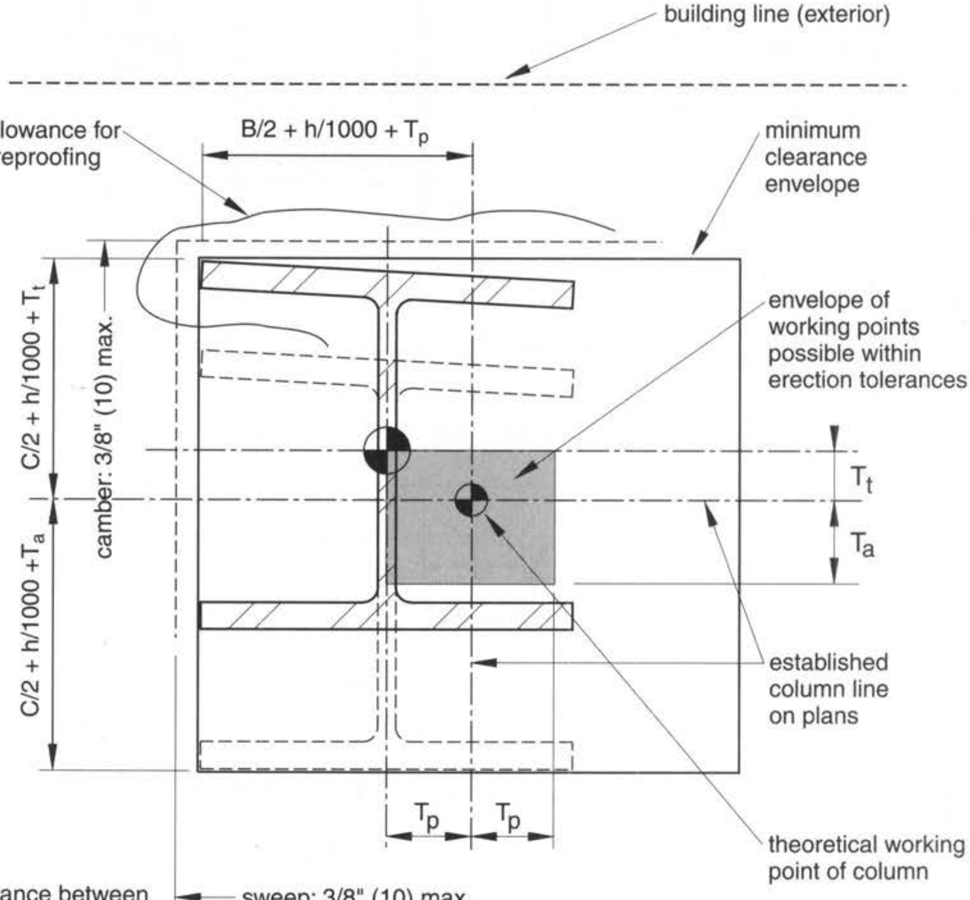
(b) accommodating fixed window sizes

One method of accommodating fixed window sizes is shown in Figure 13-7(b). By casting a notch in the concrete opening, both in and out tolerances can be concealed and the joint can be properly sealed without oversizing the sealant joint. Although this increases formwork costs slightly, in some cases it is a preferable option. With steel windows part of the steel sash can be cast directly into the concrete.

Related Sections

2–12 Architectural Precast Concrete Panels
2–13 Precast Ribbed Wall Panels
2–14 Precast Insulated Wall Panels
8–4 Storefront Installation
11–9 Aluminum Windows and Sliding Doors
11–10 Steel Windows

Figure 14–1 Accumulated column tolerances



h = distance between braced points

B = flange width, max.

C = column depth, max.

T_p = 2" (50) maximum in first 20 stories 1/16" (1.6) for each additional story up to a maximum of 3" (76)

Note: for enclosures or cladding that may follow column alighnment the size of the minimum clearance envelope may be decreased by the values of T_t, T_a, and T_p.

Chapter 14

Steel Frame Systems

14–1 Accumulated Column Tolerances

Figure 14-1 shows the minimum clearance envelope based on steel erection tolerances used with enclosures or attachments that must be held to a precise plan location. This clearance envelope includes the variations in maximum beam depth and width, C and B; the maximum variation in slope between braced points, *h*; and the allowable erection tolerances toward, away from, and parallel to the building line, T_t, T_a, and T_p (see Section 3-6). The clearance envelope is measured from the theoretical working point of the column, which is the actual center of the steel column at the end of the shipping piece. Current American Institute of Steel Construction (AISC) standards state that the accumulation of mill tolerances and fabrication tolerances shall not cause the erection tolerances to be exceeded.

However, when the alignment of lintels, spandrels, wall supports, and similar members are used to connect other building construction elements to the structural steel frame, there should be sufficient provisions for adjustment to allow for the accumulation of mill and fabrication tolerances as well as erection tolerances. Figure 14-1 also shows the additional tolerances for camber and sweep of the steel framing. Tolerances for adjustable items are shown in Section 14-3.

Because the various tolerances vary with beam size and height of the building, a tolerance envelope can be calculated for each story, but in most cases the worst condition is determined for detailing purposes. For example, in a 20-story building the column can vary up to 1 in. (25 mm) toward the building line or 2 in. (50 mm) away from the building line because of erection tolerances. If the column straightness varies by $h/1{,}000$, the envelope could be as much as 1⅛ in. (29 mm) outward or as much as 2⅛ in. (54 mm) inward (assuming a 12-ft. or 3,660-mm distance between braced points). At the midpoint of the column between splice points, camber or sweep could add as much as ⅜ in. (10 mm) to the basic erection tolerance envelope. See Figure 3-1 and Table 3-1 for sweep and camber tolerances.

Even though the envelope of working point tolerance for an individual column can be up to 3 in. (76 mm) for a 20-story building, AISC standards require that all exterior columns along one side of a building at each splice line be limited to a 1½.-in- (38-mm-) wide band, as shown in Section 3-7. The adjacent envelope above or below each band must be within the 1:500 slope restriction illustrated in Section 3-6.

In general, if connections between the steel frame and exterior cladding provide for a total adjustment of 3 in. (76 mm) in a 20-story building, the exterior building line can be maintained in a true vertical plane. Above this, the facade can be erected to within 1/16 in. (1.6 mm) of plumb per story, with a maximum total deviation of 1 in. (25 mm) from a true vertical plane. If dimensional or erection tolerances of the cladding material are substantial, these should be added to the steel tolerances as illustrated in sections of this chapter that follow.

Related Sections

3–1 Mill Tolerances for W and HP Shapes
3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections

14–2 Accumulated Steel Frame Tolerances

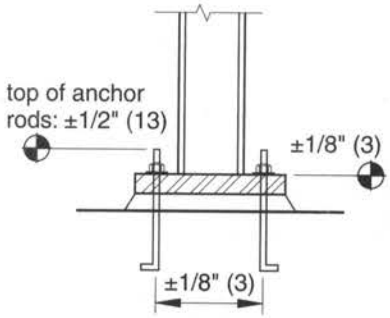
Accumulated tolerances of an entire building frame and the members used to connect other building elements to the frame can be a combination of mill, fabrication, and erection tolerances. AISC standards state that the accumulation of mill tolerances and fabrication tolerances shall not cause the erection tolerances to be exceeded. Therefore, the expected deviation of a steel structural frame can be calculated using the erection tolerances given in Sections 3-6, 3-7, 3-8, 3-9, and 14-1. When other members attached to the frame are considered, mill and fabrication tolerances may need to be taken into account. Some of the common conditions are illustrated in this section.

Steel framing begins with the connection of the frame to the foundation with anchor rods, foundation bolts, and other embedded items. Figure 14-2(a) shows acceptable tolerances of bearing devices and anchor rod groups. Although these are normally set by a contractor other than the steel erector, individual rods within a group must be set within ⅛ in. (3 mm) of each other and the group must be set to within ¼ in. (6 mm) of the established column line through that group. There cannot be more than a ¼ in. (6 mm) variation between adjacent anchor rod groups. As shown in Figure 14-2(b), the accumulated variance per 100 ft. is also limited to ¼ in. (2 mm per 10,000 mm), with a maximum overall variance of 1 in. (25 mm) along the entire length of the building.

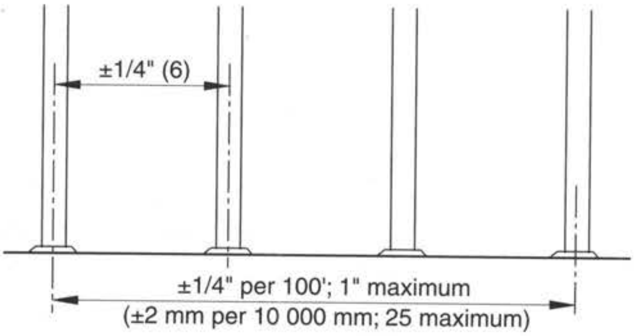
The location of beam edges relative to other parts of the building can vary as a result of a combination of tolerances on base plate location, column erection, column out-of-straightness, member size, and beam sweep. Although current AISC standard practices do not allow mill and fabrication tolerances to cause the erection tolerances to be exceeded, when the attachment of exterior cladding is considered, all tolerances would have to be taken into account in order to design the necessary adjustment for the cladding. Figure 14-2(c) shows an example of a possible condition at the twentieth floor of a building with 30-ft. (9,140 mm) spacing between columns. In the worst case, the base plate could be out by ¼ in. (6 mm) and the column out by the maximum of 1 in. (25 mm) toward the building line. AISC standards state that the alignment of an individual, straight member, such as a beam, is acceptable if the columns to which it is attached are within permissible variations for fabrication and erection. The beam connecting two columns could be oversized by ⅛ in. (¼ in. total but only half of this on one side) and have a sweep up to ⅜ in. (10 mm). Direct addition of all these tolerances gives a maximum possible outside variance at the midpoint of the beam of 1¾ in. (44 mm). It is unlikely that all of these would occur simultaneously, so the total probable tolerance can be calculated by taking the square root of the sum of the squares of the individual tolerances according to the method described in the introduction to Part 2. With this calculation, the total deviation in this example would be about 1⅛ in. (29 mm).

Steel frame tolerances also vary in the vertical direction as diagrammed in Figure 14-2(d). The elevation of any beam as measured from the splice point can vary by +5⁄16 in. (7.9 mm) toward the splice point or –3⁄16 in. (4.8 mm), as shown in Figure 3-8. In addition, allowable variations in length of columns can accumulate in a tall building. As the

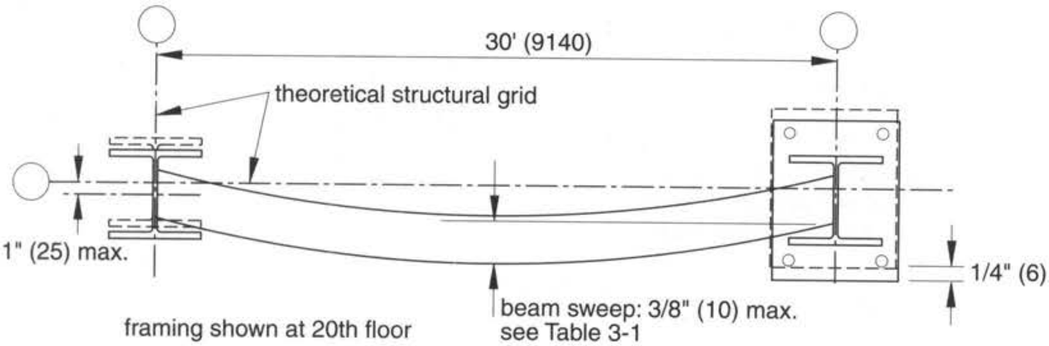
Figure 14–2 Accumulated steel frame tolerances



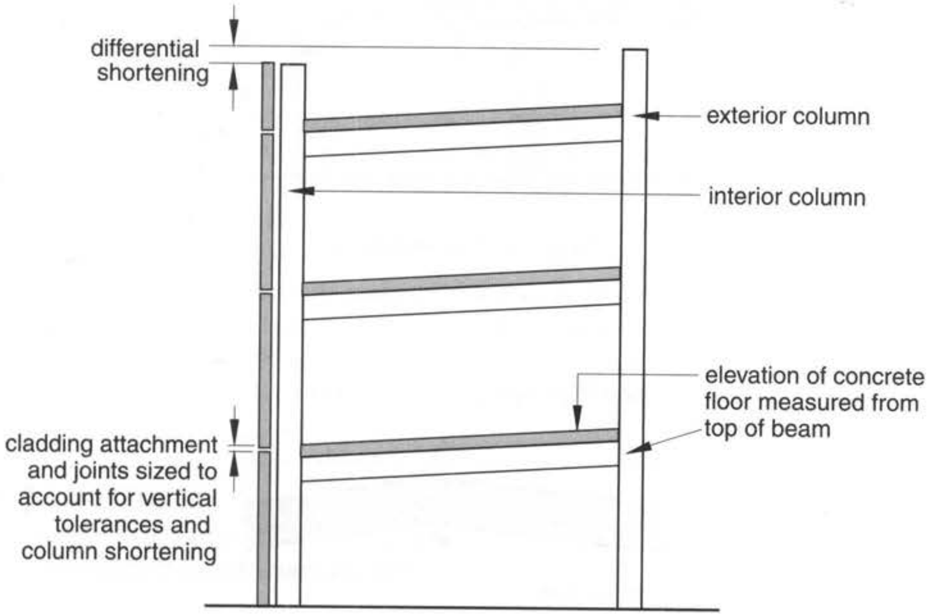
(a) bearing devices and anchor rods



(b) accumulated anchor rod groups

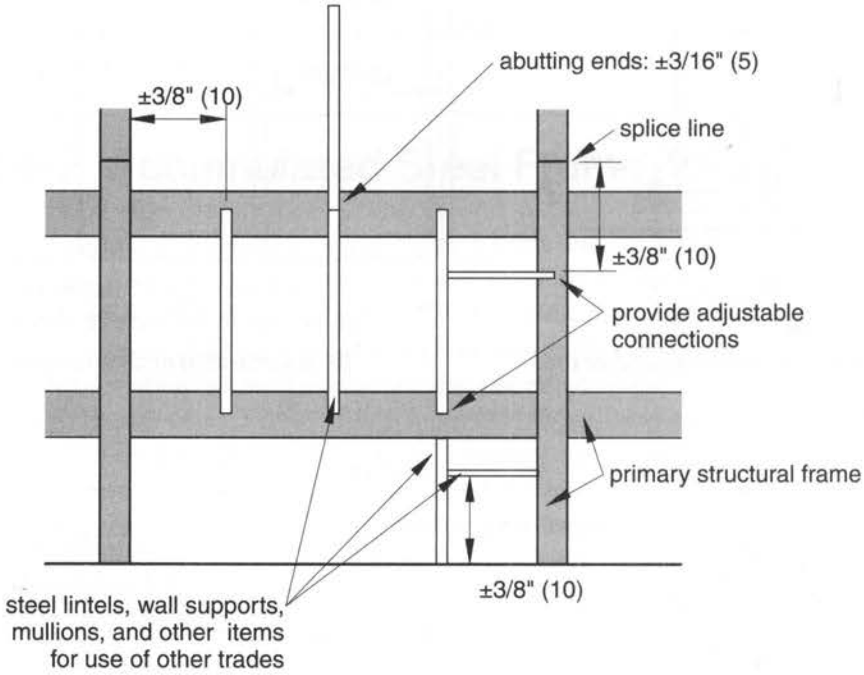


(c) accumulated frame tolerance example

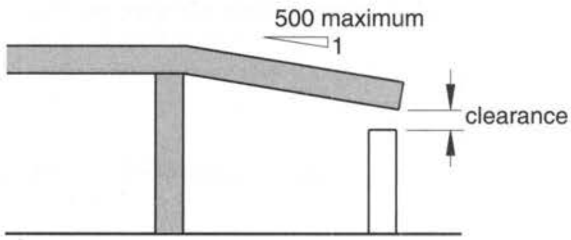


(d) differential column shortening

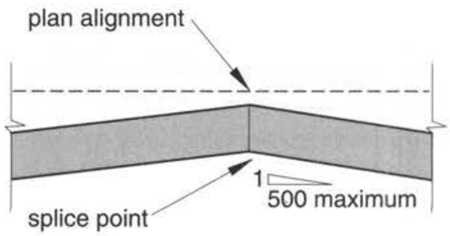
Figure 14–3 Detailing for steel structural system tolerances



(a) adjustable items



(b) cantilevered members



(c) field-assembled members

building is constructed, depending on the sequence of construction, the interior columns may carry a greater percentage of load, resulting in a differential shortening between interior and exterior columns. Because of this, construction elements on each floor should be installed based on the elevation of the beams or splice points rather than on a fixed benchmark on the ground. There should be enough vertical adjustment in the connections between the steel frame and the exterior cladding to account for these accumulated tolerances and shortening of the building frame. Joints should allow for a ±⅝-in. (16-mm) vertical adjustment.

Related Sections

2–5 Footings and Anchor Bolts
3–8 Beam/Column Connections
Introduction to Part 2

14–3 Detailing for Steel Structural System Tolerances

In addition to the mill, fabrication, and erection tolerances described in the preceding sections and in Chapter 3, some additional tolerances must be considered in some circumstances. Secondary steel members attached to the primary structural frame for the purpose of supporting work of other trades have their own tolerances. These members are known as "adjustable items" and are shown diagrammatically in Figure 14-3(a). The tolerance for both horizontal and vertical positioning is ±⅜ in. (10 mm). This tolerance is valid only if sufficient clearance and adjustment are shown on the drawings so the steel erector can meet the tolerances. Vertical position is measured to the upper milled splice line of the nearest column, and horizontal position is measured relative to the established finish line at any floor. Architectural exposed structural steel must meet tolerances that are one-half those for structural steel.

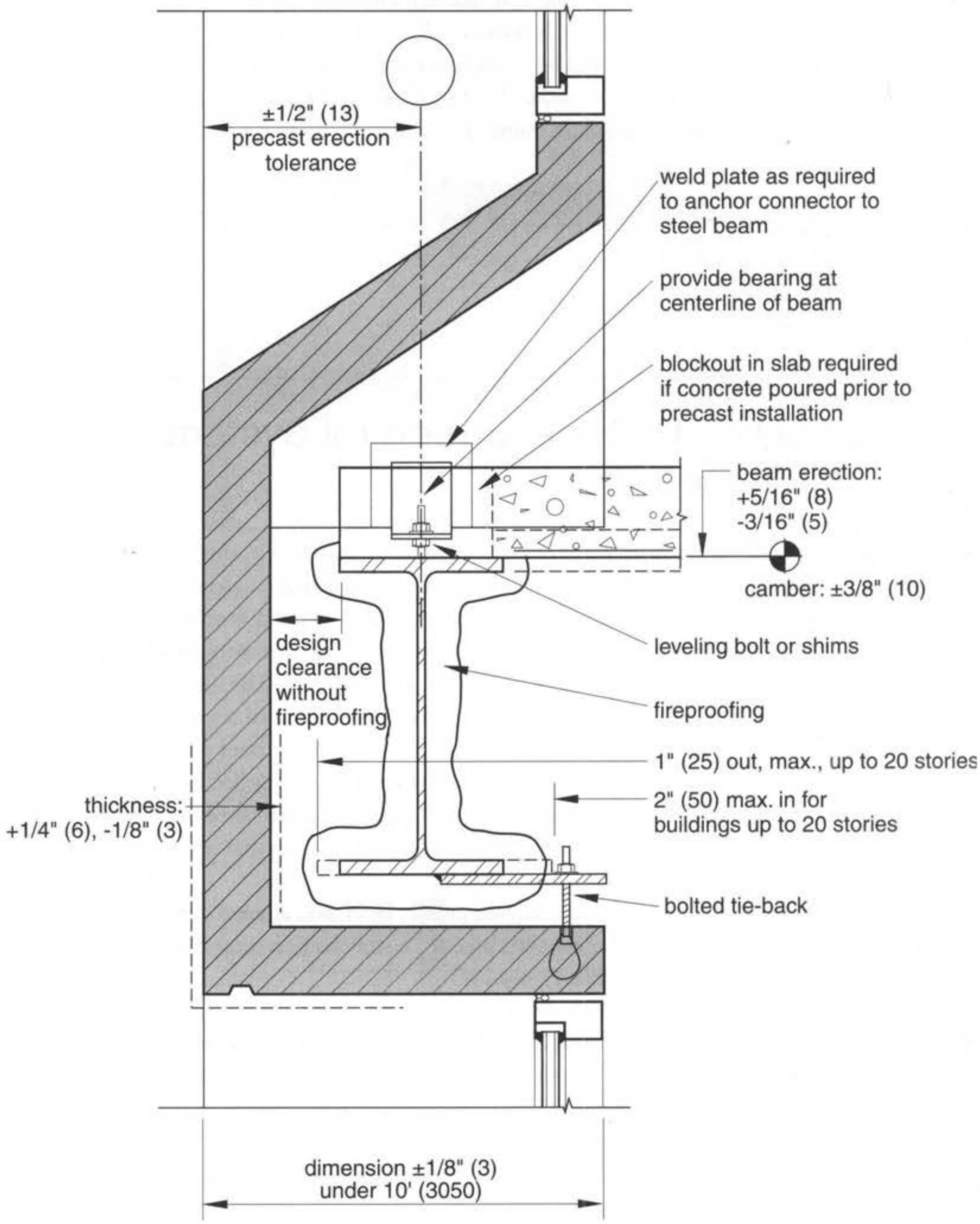
For cantilevered steel, the member is considered plumb, level, and aligned if the angular variation from a working line of the installed piece to a straight line extending in the plan direction does not exceed 1:500. See Figure 14-3(b).

When steel members are field-assembled, the same angular variation applies. The field member is considered plumb, level, or aligned if the actual installed alignment does not vary from the planned alignment by more than this amount. For example, in a 10-ft. length (3,050 mm) this means that the member could be as much as ¼ in. (6 mm) off. See Figure 14-3(c). For irregular shapes, if the fabricated member is within tolerance and the supporting members are erected with standard tolerances, the irregular shape is considered to be within acceptable tolerance.

Related Sections

3–7 Location of Exterior Steel Columns in Plan
3–9 Architecturally Exposed Structural Steel

Figure 14–4 Detailing for precast on steel



14–4 Detailing for Precast on Steel

Detailing for precast concrete on steel framing requires that the mill, fabrication, and erection tolerances for the steel be calculated and added to the possible fabrication and erection tolerances of the precast. Because tolerances for both materials vary depending on the type and size of member as well and the height of the building separate calculations need to be made for various conditions and locations in the building.

Figure 14-4 shows an example of a precast/steel detail. The location of the steel beam can vary as much as 1 in (25 mm) toward the building line and 2 in (50 mm) away from the building line on a building up to 20 stories. For shorter structures the rate of slope from plumb is 1:500 as described in Section 3-6. In addition, the width of the flange can vary ±¼ in. (6 mm) or ⅛ in. (3 mm on one side). Beam sweep varies with the length of the beam but can account for another ⅜ in (10 mm) for a 30-ft. (9,140-mm) length. In the worst case, these might place the outside edge of the beam 1½ in. (38 mm) toward the precast. Using the root sum-of-the-squares method for determining accumulated tolerances described in the introduction to Part 2, the more likely deviation would be about 1⅛ in. (29 mm). Normally, mill and fabrication tolerances cannot cause the erection tolerances to be exceeded; however, for cladding elements, such as that shown in Figure 14-4, the designer may want to provide sufficient clearance and adjustment for the accumulation of mill, fabrication, and erection tolerances.

The precast thickness can vary up to ¼ in. (6 mm) oversize, but the precast erector is allowed to have the primary control surface within ½ in. (13 mm) from the centerline of the structural grid. If fireproofing is required around the steel, this must also be added to the tolerances to determine the total design clearance between the back of the precast and the edge of the beam or face of fireproofing.

Related Sections

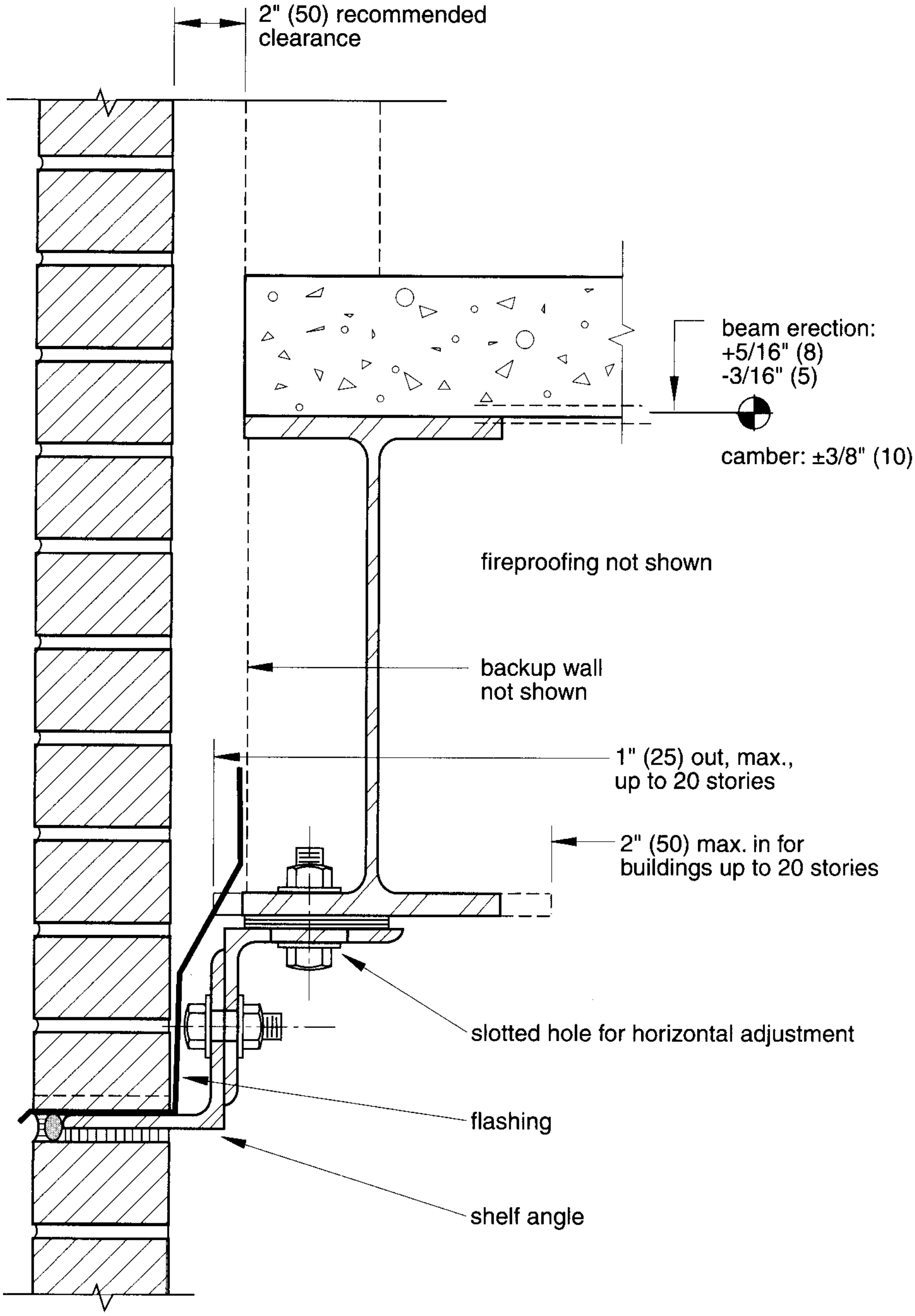
2–12 Architectural Precast Concrete Panels
2–15 Hollow-Core Slabs
2–27 Precast Architectural Wall Panel Erection
3–6 Steel Column Erection Tolerances
3–8 Beam/Column Connections
13–4 Detailing for Precast and Steel Systems

14–5 Detailing for Brick on Steel

When brick and steel framing are used together, the construction tolerance of the steel frame usually dictates the method of detailing. Dimensional and distortion tolerances of brick are relatively minor, as described in Section 4-5. At most, a surface of an individual, standard-size brick may be out of specified plane by about 5/32 in. (4 mm) because of a worst-case combination of size and warp tolerance.

In other than one- or two-story buildings, the brick is usually supported on shelf angles at every story. A compressible filler below the angle allows for deflection of the angle as well as building movement and expansion of the brick panel below. The connection and support systems must be designed to accommodate the steel frame tolerance as well as to provide the recommended 2-in. (50-mm) clearance between the back of the brick wall and the structural frame and whatever backup wall is used. Vertical adjustment must also

Figure 14–5 Detailing for brick on steel



be provided so the shelf angle can match the joint location as the brick is laid. In designing the adjustable connection, both the erection and fabrication tolerances of the steel beam should be considered.

Figure 14-5 shows only one possible way of attaching the shelf angle to the beam. With this detail. vertical adjustment can be provided by shimming or with vertically slotted holes. Horizontal adjustment can be provided with slotted holes. Generally, shimming should not exceed 1 in. (25 mm) and should be done with horseshoe-shaped shims with a length equal to the length of the angle. Where the steel frame varies at its maximum, the size of the shelf angle can be decreased or increased subject to engineering review.

Note that potential problems can arise if the clearance becomes so small that there is not adequate space for the bolt head, flashing, and any material that is used to prevent the bolt head from puncturing the flashing. Depending on the thickness of the angle, the size of the fastener and the method of flashing, the 2-in. (50-mm) clearance may need to be increased, especially in tall buildings.

Related Sections

3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
4–5 Brick Manufacturing
4–6 Brick Wall Construction
12–4 Detailing Brick on Cast-in-Place Concrete
15–2 Detailing Brick and Concrete Masonry Systems

14–6 Detailing for Stone on Steel Systems

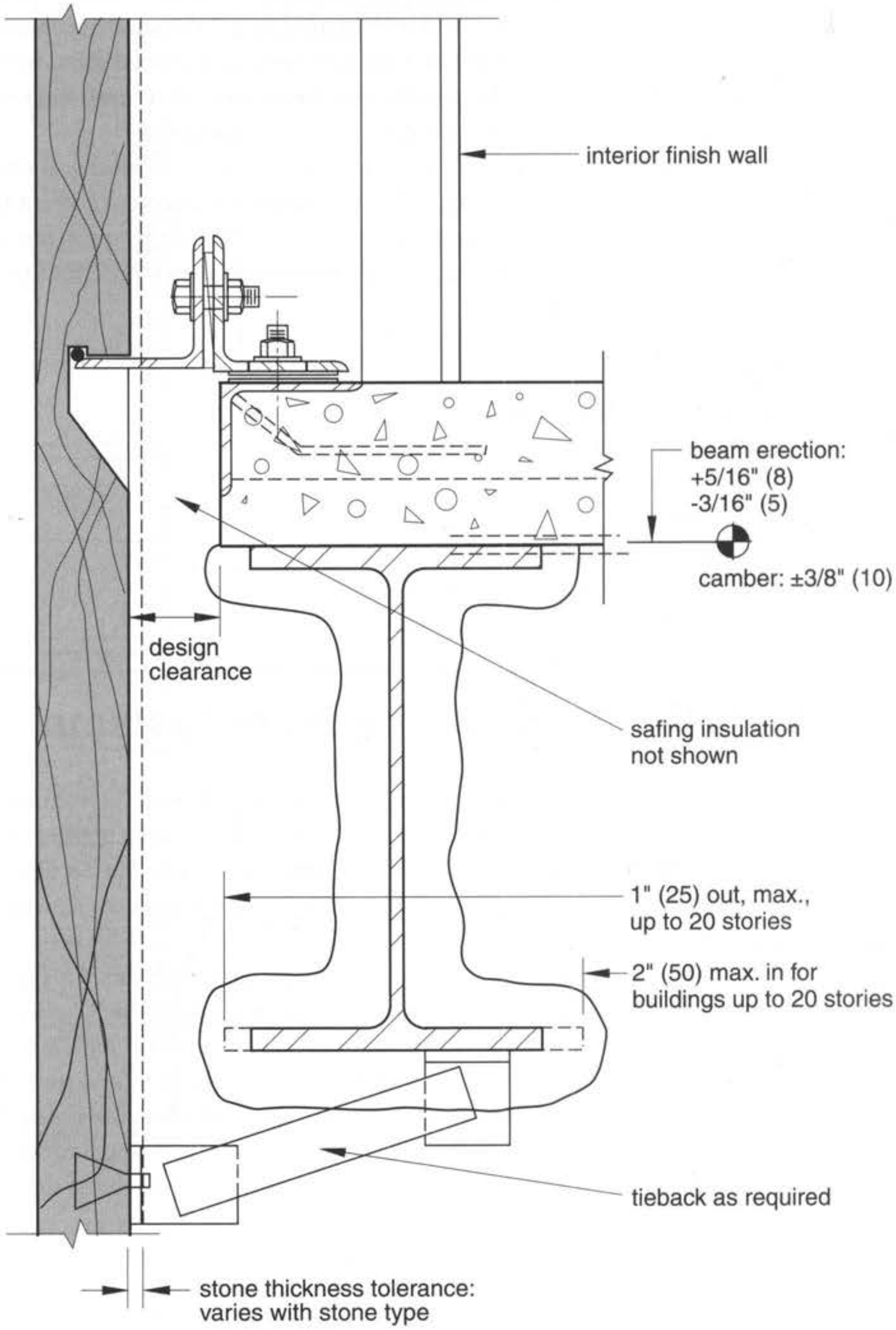
Detailing for stone facades attached to steel framing is similar to stone on concrete except that the tolerances for steel framing can be larger for tall buildings. However, in most cases stone can be installed slightly out of plumb (within the standards described in Sections 5-4 and 5-5) along the height of a building to partially accommodate minor irregularities of the frame, if necessary.

Figure 14-6 shows a typical gravity support and anchor at a spandrel beam. This is the most critical connection to accommodate both the steel and stone tolerances. A variety of lateral anchors is available for various types of backup walls that provide for sufficient adjustment to maintain the erection tolerances shown in Sections 5-4 and 5-5. Vertical deviations of the steel frame are accommodated with shims or vertically slotted holes in the angles. Deviations perpendicular to the building face are taken up by shimming the support angles or with slotted holes where the angle is attached to the anchor plate in the slab.

In determining the minimum design clearance, the following tolerances and construction elements must be combined: the erection tolerance of the steel beam, which varies with height (see Section 3-6); the thickness of the stone, which will vary depending on the type of stone and thickness (see Sections 5-1, 5-2, and 5-3); working space required for erection and fastening; and allowance for fireproofing of the steel, if required.

As with precast panels, horizontal joints and stone movement are normally accommodated by designing the vertical joints between stone sections large enough to absorb both movement and dimensional tolerances of the stone and steel frame. Refer to the introduction to Part 2 for estimating total expected tolerance of several panels and for calculating joint width.

Figure 14–6 Detailing for stone on steel systems



Because the exact method of anchorage varies with the type of structural frame, the type of stone, loading, and other factors, along with the preferences of individual fabricators and installers, final details should be verified with the stone fabricator and contractor.

Related Sections

3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
5–1 Granite Fabrication
5–2 Marble Fabrication
5–3 Limestone Fabrication
5–4 Granite and Marble Installation
5–5 Limestone Installation
14–1 Accumulated Column Tolerances
14–3 Detailing for Steel Structural System Tolerances

14–7 Detailing for Curtain Walls on Steel Frames

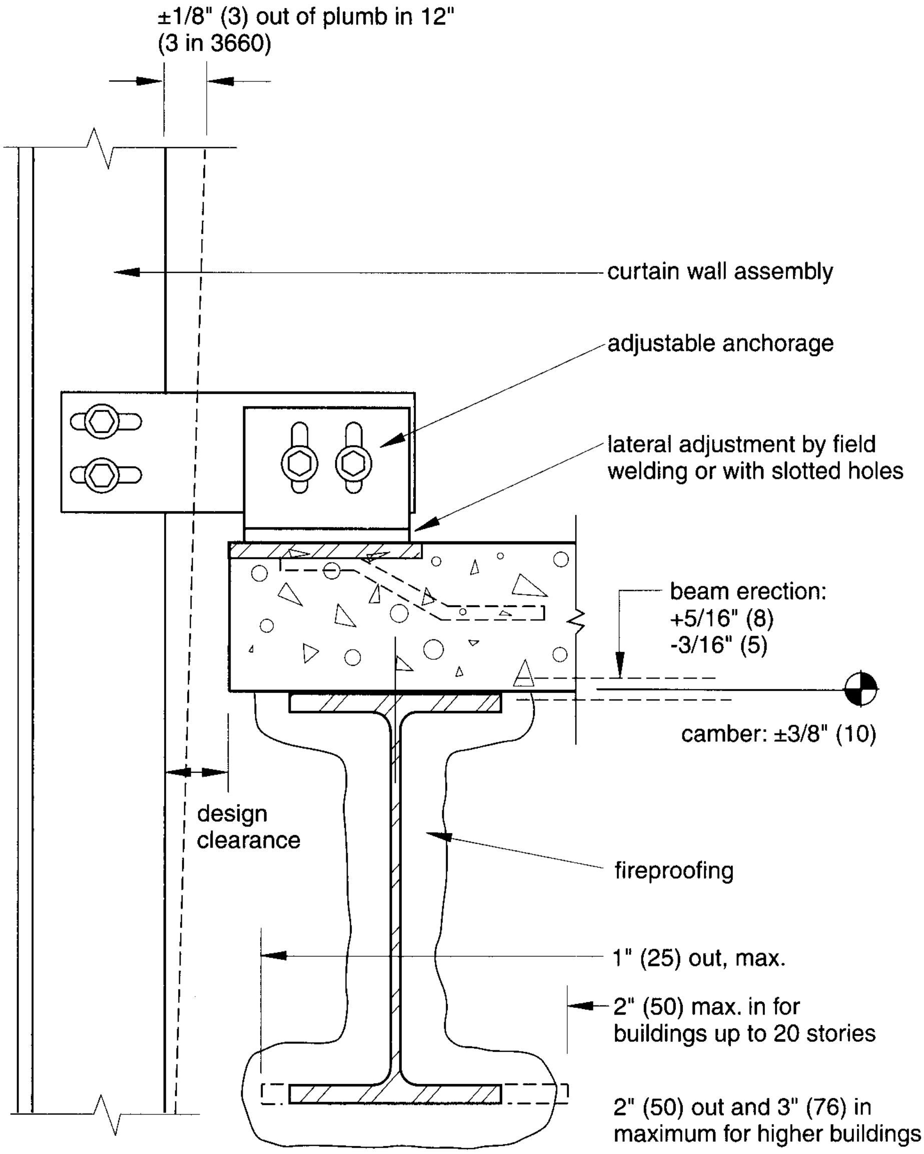
Steel framing is one of the most common structural systems used to support curtain walls. Even though steel frames have large tolerances, especially for high-rise buildings, the curtain wall can be installed to the tolerances indicated in Section 8-2 if adequate adjustable connections are detailed and sufficient design clearance is provided. Figure 14-7 shows some of the tolerance requirements for a typical curtain wall/spandrel beam connection. Because individual conditions will vary, exact details should be verified with the curtain wall fabricator and the structural engineer.

Adjustment needs to be provided in three directions: vertical, horizontal, and lateral. In addition, a minimum clearance of 2 in. (50 mm) between the curtain wall and the frame is recommended. If adjustment and clearances are provided, the minor manufacturing and fabrication tolerances of the curtain wall can be accommodated, as well as any movement of the building frame and expansion and contraction of the curtain wall. In extreme cases, where the frame exceeds tolerances, the curtain wall can be installed slightly out of plumb, following the line of the frame along the height of the building.

Generally, the connection should be made at the top of the slab to make erection easier. Serrated angles and bolts, T-shaped clips, slotted holes, embedded anchors, and shims can all be used to provided the necessary adjustments. When shims are used, the height of the shim stack should not exceed the diameter of the fastener securing the anchor. If the anchor must be higher, special shims and connection details may be required.

Lateral tolerances of the frame can be accommodated by proper design of the vertical joints of the curtain wall or, in extreme cases, at the building corners. The lateral deviation from plumb of exterior column as indicated in Section 3-6 can vary at a slope of 1:500 up to a maximum of 1 in. (20 mm) to the twentieth story and up to 2 in. (50 mm) beyond that. At individual connectors, lateral alignment can be made by field welding clip angles, with slotted bolt holes, or other means. Refer to the introduction to Part 2 for joint design procedures.

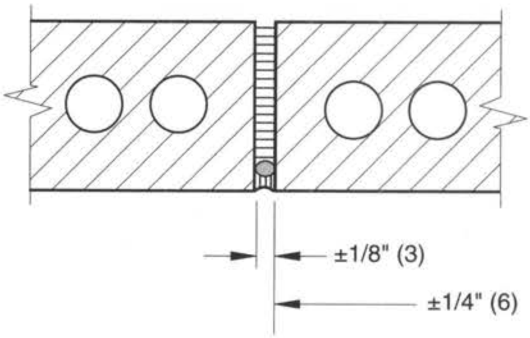
Figure 14–7 Detailing for curtain walls on steel frames



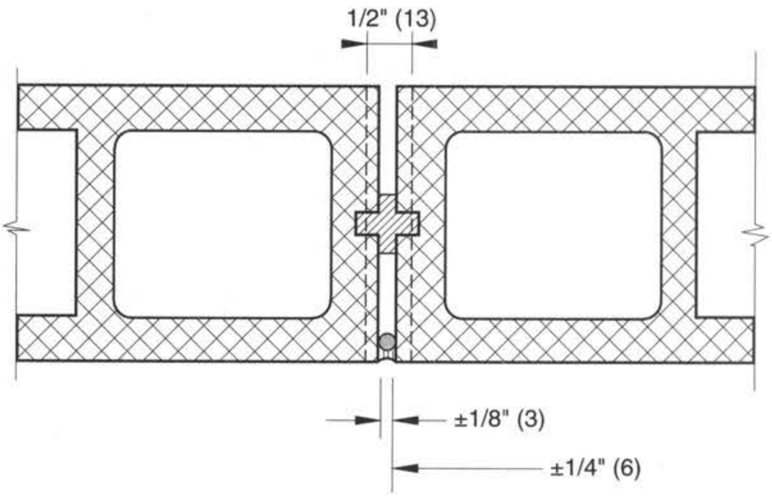
Related Sections

3–6 Steel Column Erection Tolerances
3–7 Location of Exterior Steel Columns in Plan
3–8 Beam/Column Connections
8–1 Aluminum Curtain Wall Fabrication
8–2 Aluminum Curtain Wall Installation
9–13 Extruded Aluminum Tubes
14–1 Accumulated Column Tolerances
14–3 Detailing for Steel Structural System Tolerances

Figure 15–1 Masonry joint tolerances



(a) brick joints



(b) concrete masonry joints

Chapter 15

Masonry Systems

15–1 Masonry Joint Tolerances

The thickness of masonry joints can usually be held to a ±⅛-in. (3-mm) tolerance, with the edges of all vertically aligned joints within a ½-in. (13-mm) envelope. See Figure 15-1. These tolerances allow for both minor size variations of the masonry and inaccuracies in laying up the wall. The end of a wall can usually be held to within ¼ in. (6 mm) of the location shown on the plans.

When expansion joints are required, they should be sized to account for both expansion and contraction caused by temperature changes and for expansion caused by moisture absorption, as well as for size and construction tolerances. The expansion joint size for a brick wall depends on the distance between the expansion joints as well as the maximum expected temperature differential. In most cases, a ½-in. (13-mm) expansion joint will accommodate joint spacing of 20 ft. (6,100 mm) and a 140°F (60°C) temperature differential. A ⅝-in. (16-mm) joint will allow expansion joints spaced 25 ft. (7,620 mm) apart at the same temperature differential. If allowances for size tolerances are added and a sealant with a 25 percent movement capacity is used, most masonry expansion joints will be in the range of ¾ in. to 1 in. (38 mm to 50 mm).

Related Sections

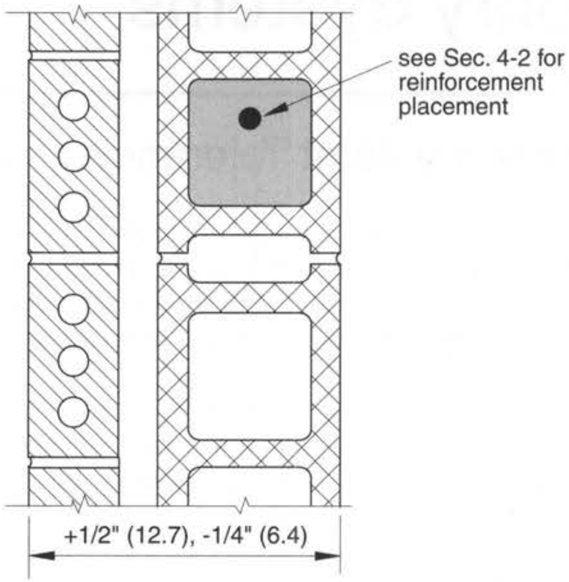
4–1 Concrete Unit Masonry Manufacturing
4–3 Concrete Unit Masonry Construction
4–5 Brick Manufacturing
4–6 Brick Wall Construction

15–2 Detailing Brick and Masonry Systems

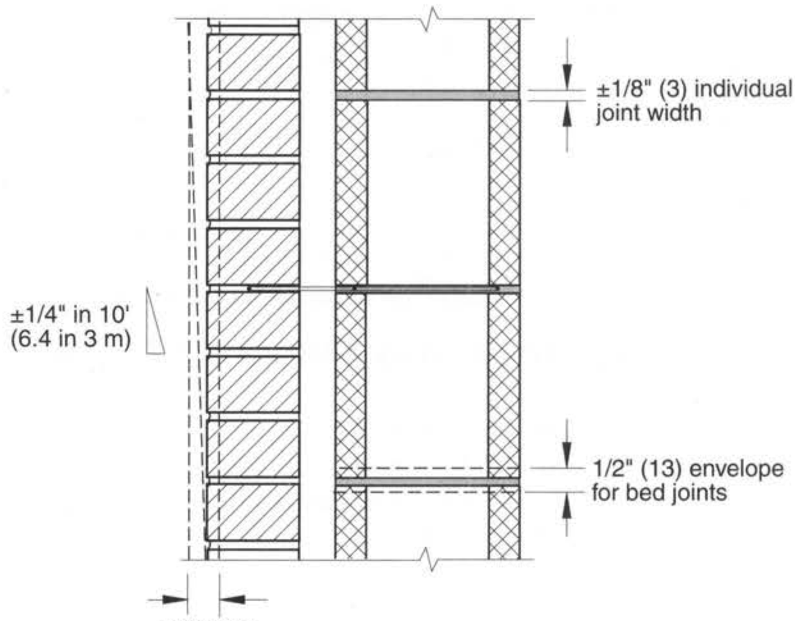
Brick and masonry systems usually consist of a backup wall of concrete unit masonry with a brick facing, as shown in Figure 15-2. If the multi-wythe construction is a bearing wall, the concrete block is reinforced and grouted. As shown in 15-2(a), the tolerances for the total width of multi-wythe construction are +½ in. (13 mm) and –¼ in. (6 mm). This is based on American Concrete Institute standards. Any furring or interior dimensions that are critical should take this into account. The face of both wythes must fall within a ½-in. (13-mm) envelope along the total height of the wall, with no more than a ¼ in. per 10 ft. (6.4 mm per 3 m) variation in vertical slope. See Figure 15-2(b).

Because the cavity between the brick and concrete block is so large (recommended width is 2 in. or 50 mm), any variation in the size of either masonry unit is easily accommodated in the cavity.

Figure 15–2 Detailing brick and masonry systems



(a) plan view



(b) vertical section

Related Sections

4–2 Concrete Unit Masonry Reinforcement Placement
4–3 Concrete Unit Masonry Construction
4–6 Brick Wall Construction

15–3 Detailing for Stone on Masonry Backup

To maintain the installation tolerances for granite, marble, and limestone given in Sections 5-4 and 5-5, adequate clearances and adjustable connections must be detailed when stone is attached to masonry. Detailing for stone on masonry is similar to stone on concrete, but there are some differences. Among them is the need for the stone gravity anchor locations to be coordinated with the coursing of the masonry. Generally, these anchors must be made in bond beams as shown in Figure 15-3. As with concrete backup, the stone panels can be installed slightly out of plumb (within the standards described in Sections 5-4 and 5-5) along the height of a building to partially accommodate minor irregularities of the frame if absolutely necessary. However, if sufficient clearance and adjustable anchors are provided, this is usually not necessary.

Figure 15-3 shows a typical gravity support and anchor at a bond beam. This is the most critical connection to accommodate the tolerances of the masonry and the stone. A variety of lateral anchors are available that provide for sufficient adjustment to maintain the erection tolerances given in Sections 5-4 and 5-5. Vertical deviations of the masonry are accommodated with adjustable anchors or slotted angles. Additional vertical adjustment can be made by shimming between the angle and the bottom edge of the stone. In some cases, a separate steel grid system is attached to the masonry wall and the stone is adjusted as it is anchored to the grid. Deviations perpendicular to the building face are taken up by shimming the support angles.

To determine the minimum design clearance, the following tolerances and construction elements must be combined: the ½-in. (13-mm) tolerance envelope of the face of the wall; the thickness of the stone, which will vary depending on the type of stone and thickness (see Sections 5-1, 5-2, and 5-3); the thickness of the angle; the size of the bolt head; the working space required for erection and fastening; and any flashing, weep tubes, or other accessories behind the stone. Generally, a 2-in. (50-mm) clearance is considered minimum. For adhered veneer, the mortar between the masonry and stone should be between ½ and 1¼ in. (13 to 32 mm) thick.

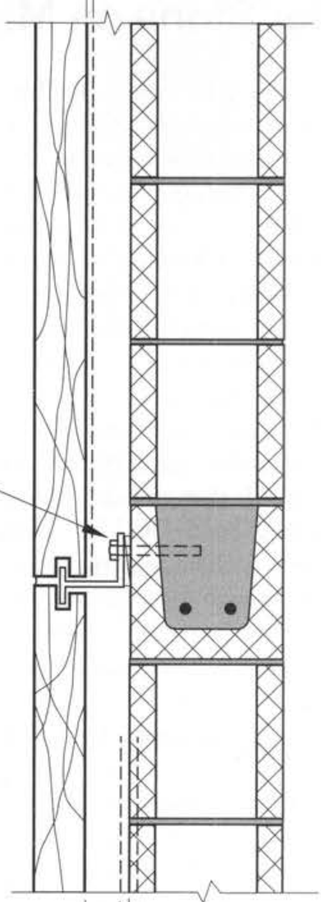
Horizontal size tolerances and stone movement are normally accommodated by designing the vertical joints between stone sections large enough to absorb both movement and dimensional tolerances of the stone. Refer to the introduction to Part 2 for procedures for estimating total expected tolerance of several panels and the method for calculating joint width.

Because the exact method of anchorage varies with the type of masonry structure, the type of stone, loading, and other factors, along with the preferences of individual fabricators and installers, final details should be verified with the stone fabricator and contractor.

Related Sections

4–3 Concrete Unit Masonry Construction
5–1 Granite Fabrication
5–2 Marble Fabrication
5–3 Limestone Fabrication
5–4 Granite and Marble Installation
5–5 Limestone Installation

Figure 15–3 Detailing for stone on masonry backup

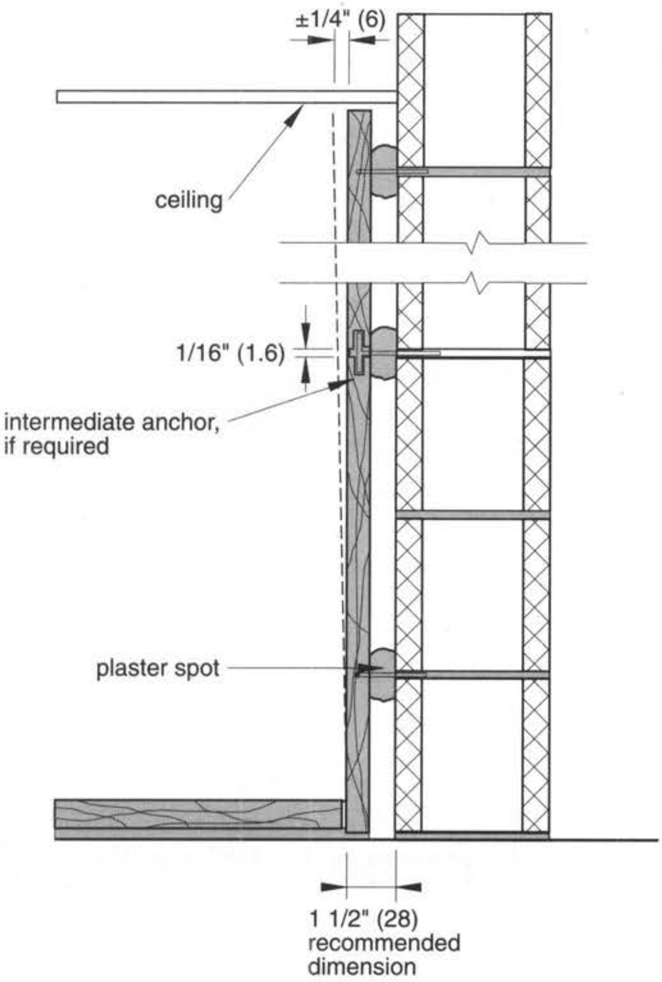


15–4 Detailing Interior Stone on Masonry

Stone can be applied to interior walls by directly applying the stone to the masonry with mortar or by using the standard-set method as shown in Figure 15-4. Direct application is normally only used with thin stone tiles placed in a mortar setting bed, so any variation in the masonry must be concealed within the thickness of the mortar or the stone must follow the irregularities of the masonry.

The standard-set method uses anchors set into the masonry coursing and plaster spots at each anchor to hold the assembly tightly together. Because of the gap between the

Figure 15–4 Detailing interior stone on masonry



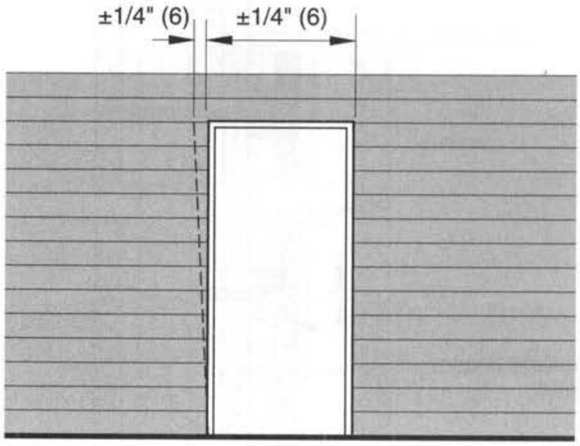
stone and the masonry and the adjustability of the anchors and plaster spots, the finished surface of the stone can be installed almost perfectly plumb in installations with standard ceiling heights.

For high spaces where several stone panels are used vertically, intermediate gravity supports may be required. This can be accomplished by using a steel angle anchored to the backup wall similar to the detail shown in Figure 15-3. Adjustable anchors can be used in much the same way they are in exterior applications so that the final wall finish is within ¼ in. (6 mm) of plumb or closer.

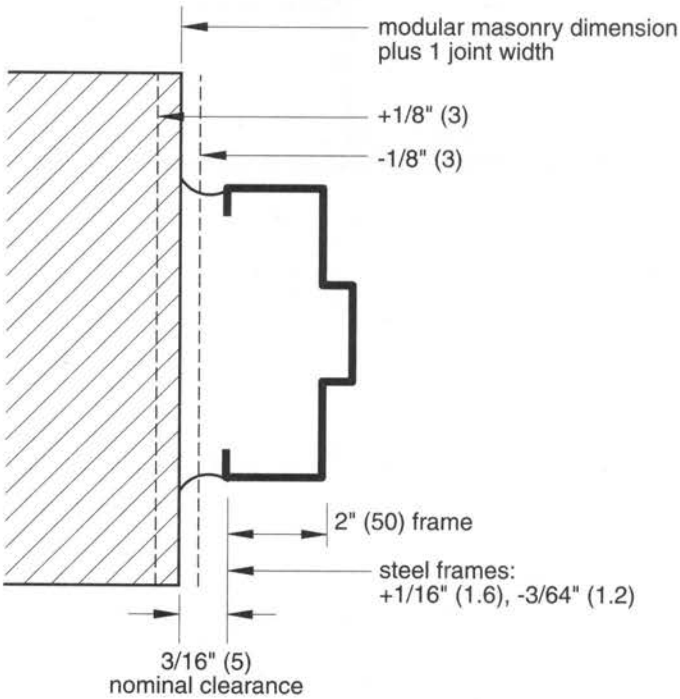
Related Sections

4–3 Concrete Unit Masonry Construction
5–1 Granite Fabrication
5–2 Marble Fabrication
9–8 Stone Flooring

15–5 Detailing doors in masonry



(a) opening tolerances



(b) fitting frames in openings

15–5 Detailing Doors in Masonry

In most masonry construction, only steel door frames are used. If wood frames are used, a rough wood buck is usually placed between the two materials, which can be trimmed or shimmed to accommodate the masonry tolerances. Steel frames are fixed in size, so the frame detail and clearance are critical to sizing the opening to allow for tolerances and a good sealant joint. When possible, the masonry opening size should conform to standard modular masonry sizes (8 in. or 200 mm) to avoid the expense of cutting the masonry. This way either full or half-size blocks can be used.

Figure 15-5 shows the possible tolerances of both the masonry opening and a steel frame. For example, using a 36-in. (914-mm) door with 2-in. (51-mm) frames gives a total frame width of 40 in. (1,016 mm). The total width of the masonry opening is 40 in. plus the width of one joint (about ⅜ in. [10 mm]). This leaves just 3⁄16 in. (5 mm) on each side to accommodate the door and any tolerances that may exist. If the steel frame is oversized by its tolerance of 1⁄16 in. (1.6 mm) and the masonry is inward by ⅛ in. (3 mm) and slightly out of plumb, there may be inadequate space for the frame. Normally, this problem is prevented by placing the frames in position and building the wall around them. If this is not possible, it is better to use 1½-in. (38-mm) frames to provide more clearance. Other door sizes may require cutting the blocks.

Related Sections

4–3 Concrete Unit Masonry Construction
4–6 Brick Wall Construction
11–1 Standard Steel Doors and Frames
11–3 Detention Security Hollow Metal Doors and Frames

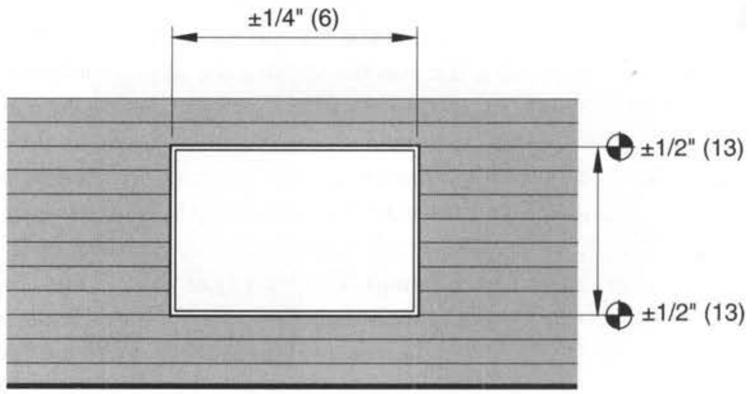
15–6 Detailing Windows in Masonry

Several types of windows can be used in masonry openings. These include steel, aluminum, and wood. Standard details for steel and aluminum windows are usually the most sensitive to construction tolerances because these window types are commonly placed directly in the opening. When wood windows are used, they are usually framed into a rough wood buck and the exterior and interior joints are covered with some type of trim, which conceals any accommodation for construction tolerances. Only steel and aluminum windows are considered here.

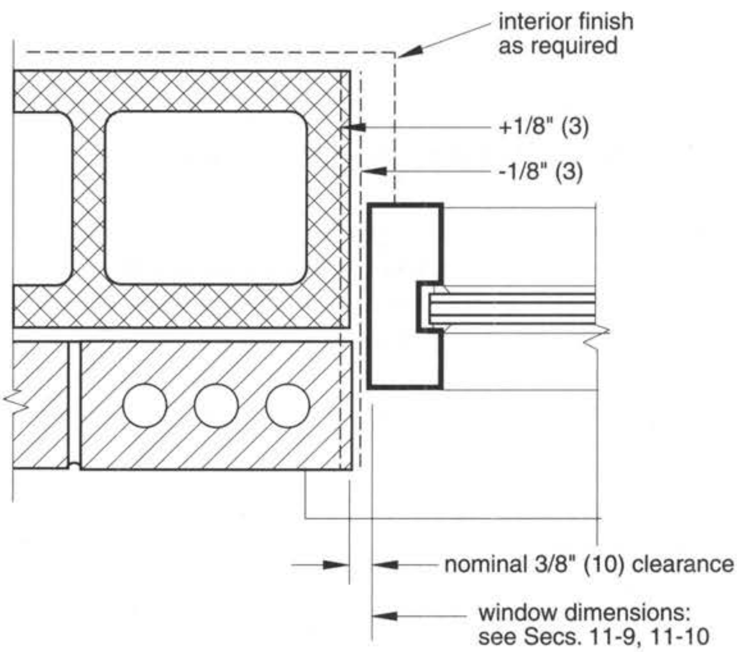
As with doors, the masonry opening size should conform to standard modular masonry sizes to avoid cutting the masonry. For a window opening, the finished size can be as much as ¼ in. (6 mm) too small or too large or a possible variation of ⅛ in. at each jamb. See Figure 15-6(a). Although ACI standards allow bed joints to fall within a ½-in. (13-mm) tolerance envelope, the vertical dimension of a masonry opening usually varies no more than ¼ in. in 10 ft. (6 mm in 3,050 mm).

The flange of steel windows is usually placed between the wythes of masonry, so tolerances are easily accommodated. If aluminum windows are used, one jamb may be as much as 1⁄16 in. (1.6 mm) too large (see Section 11-9) and the masonry opening may be as much as ⅛ in. (3 mm) too small. If a nominal ¼-in. (6-mm) clearance is provided, this would provide only a 1⁄16-in. (1.6-mm) space for sealant and for expansion of the window and ma-

15–6 Detailing windows in masonry



(a) opening tolerances



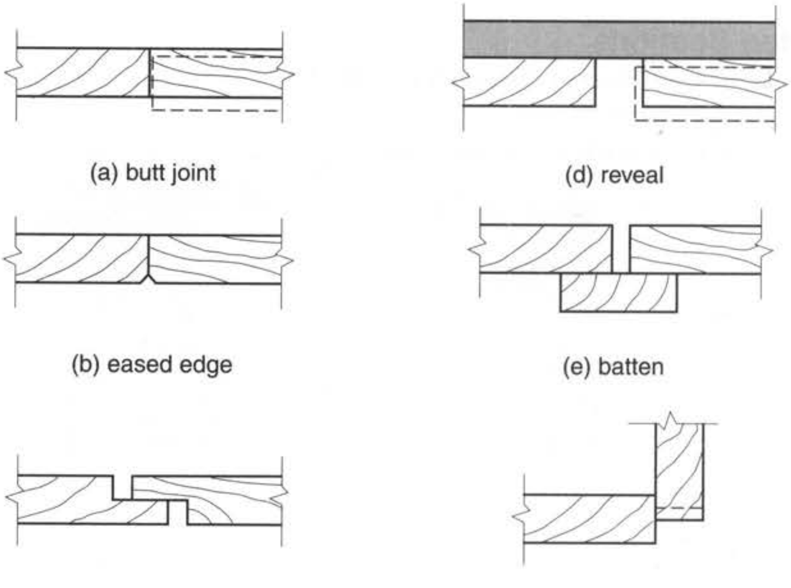
(b) fitting frames in openings

sonry and any movement that may occur. A minimum ⅜-in. (10-mm) nominal clearance is a better choice. For storefronts, a ½-in. (13-mm) clearance between framing and the masonry is recommended.

Related Sections

4–3 Concrete Unit Masonry Construction
4–6 Brick Wall Construction
11–9 Aluminum Windows and Sliding Doors
11–10 Steel Windows

Figure 16–1 Detailing wood joints



(a) butt joint

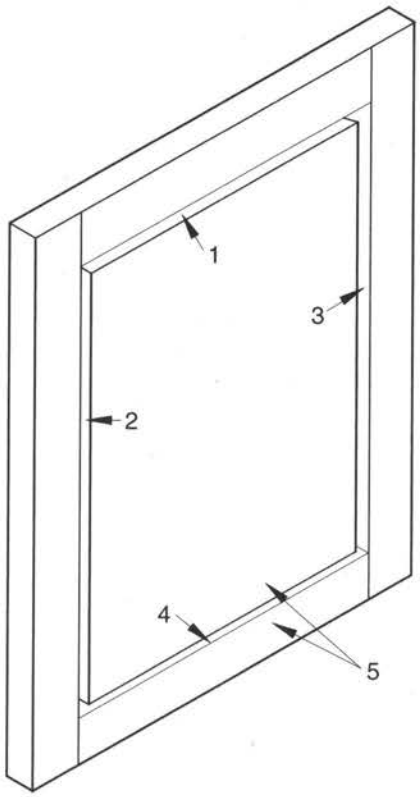
(b) eased edge

(c) overlapping joint

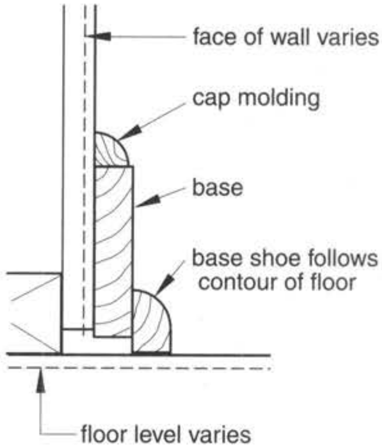
(d) reveal

(e) batten

(f) corner reveal



(g) alignment in five planes



(h) base detail

Chapter 16

Timber and Carpentry Construction

16–1 Detailing Wood Joints

Tolerances of rough carpentry, finish carpentry, and architectural woodwork are normally accommodated by designing joints that conceal or allow for size and movement deviations. Even when wood is precisely cut to fit a particular construction detail, either on the job site or in the mill shop, the tendency for wood to shrink and expand with changes in moisture content requires joints that conceal movement.

A typical butt joint, as shown in Figure 16-1(a), may be perfectly fit in the shop, but any slight movement or change in moisture will cause it to open. Using an eased edge as shown in Figure 16-1(b) conceals any slight movement or cracking at the joint line. However, even this type of joint cannot accommodate larger movement or size tolerances of the wood or the substrate to which it is applied. An overlapping joint with a reveal can easily accommodate fabrication and installation tolerances and any movement that may occur. One type of overlapping joint is shown in Figure 16-1(c).

Other types of joints that accommodate tolerances and movement by emphasizing the joint are shown in Figures 16-1(d), 16-1(e), and 16-1(f). These concepts work with finish carpentry as well as architectural woodwork. For example, any misalignment of the two planes of wood shown in 16-1(d) is not noticeable because of the space separating them. In addition, if one piece is undersize or oversize, the reveal space can take up the extra dimension.

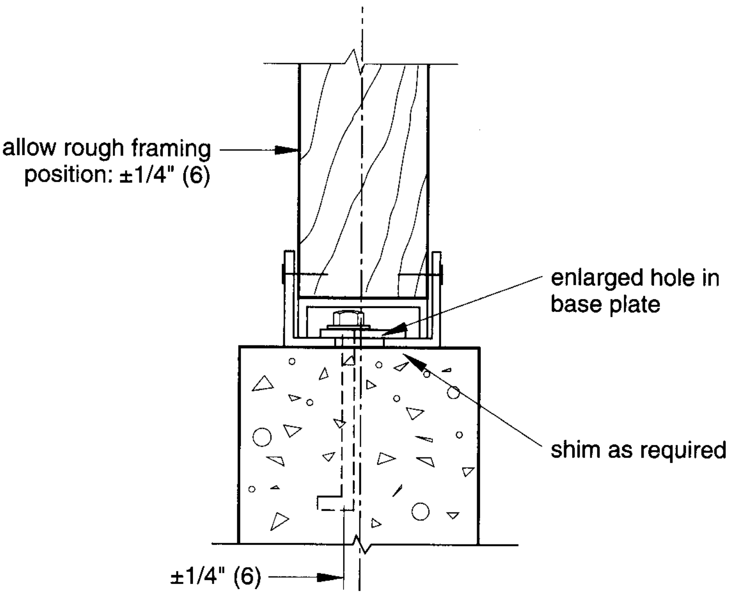
Whenever possible, joints or details that requirement alignment in three, four, or five planes should be avoided because it is very difficult to get everything aligned and all joints equal. Figure 16-1(g) shows one example: a cabinet door for which maintaining alignment and allowance for tolerances throughout the life of the cabinet is nearly impossible.

Figure 16-1(h) shows one common example of how wood trim is used to accommodate and conceal tolerances of adjacent construction. The wood base covers most of the gap between the wall and floor, while the relatively flexible base shoe follows any contour variations of an uneven floor. The cap molding is flexible enough to follow any contour variations of the wall.

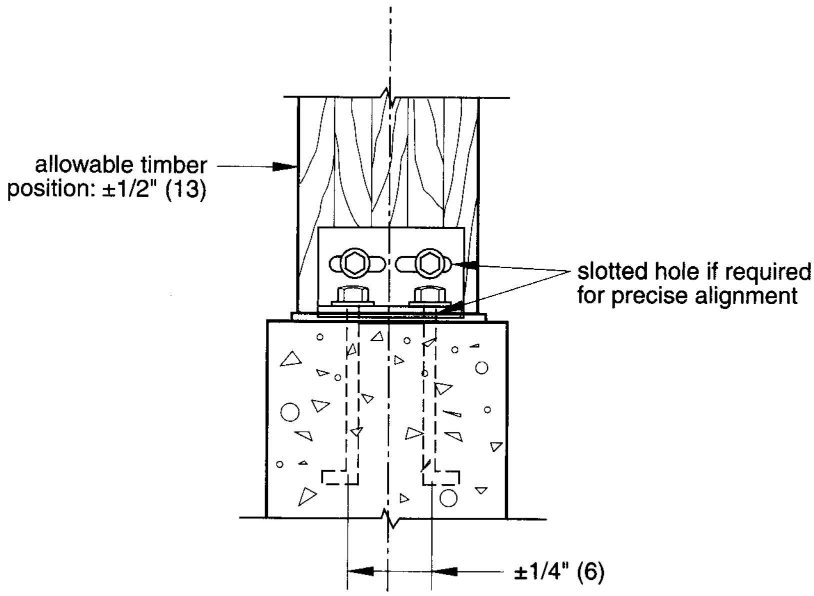
Related Sections

7–1 Manufacturing Tolerances for Board Lumber
7–2 Site-Built Cabinets and Countertops
7–3 Site-Built Stairs and Trim
7–4 Standing and Running Trim
7–17 Architectural Woodwork Installation

Figure 16–2 Detailing for timber columns



(a) small columns



(b) heavy timber columns

16–2 Detailing for Timber Columns

Timber columns can be either dimension lumber (up to 4½ in. [114 mm] in thickness), heavy timber (5 in. [127 mm] or over), or glued laminated timber. In each case, the construction tolerances involved include the size and installation tolerances of the timber, as well as the tolerances of any attached construction such as concrete foundations and anchoring devices.

Figure 16-2 illustrates how timber columns can be positioned accurately when attached with anchor bolts to foundations. As shown in 16-2(a), column base plates are available with enlarged holes, allowing the plate to be positioned even when the anchor bolt is out of location by ¼ in. (6 mm) or more. See Section 2-5. If such an adjustable anchor is *not* used, the position of the column should still be within its allowable ¼-in. (6-mm) position tolerance, as described in Section 6-6.

For heavy-timber and laminated columns, anchors with slotted holes can be used if precise alignment is required and the columns are predrilled. However, in most cases, the position of the timber is not critical and can be off by the allowable ¼ in. (6 mm) of the anchor bolts and still be within allowable tolerances for heavy-timber position. To accommodate size and squareness tolerances and expansion, there should be a ⅛-in. (3-mm) clearance between the timber and any steel anchorage device.

Related Sections

6–1 Glued Laminated Timber Fabrication
6–2 Manufacturing Tolerances for Structural Lumber
6–6 Rough Lumber Framing
16–3 Detailing for Timber Beams

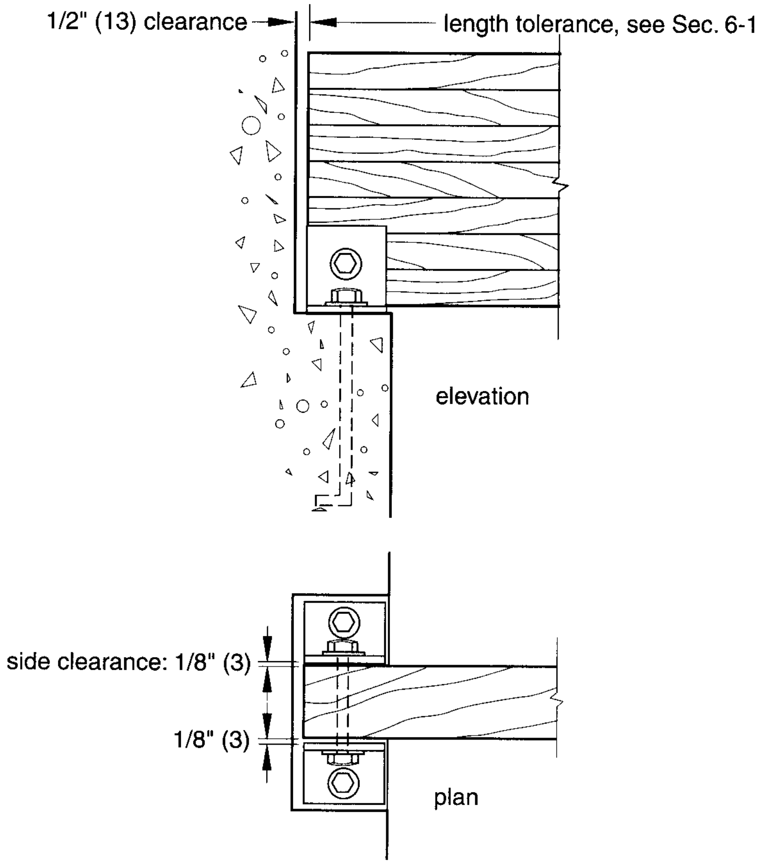
16–3 Detailing for Timber Beams

As with columns, timber beam can either be dimension lumber (thicknesses up to 4½ in. [114 mm]), heavy timber (5 in. [127 mm] or over), or glued laminated timber. There are generally few problems with dimension lumber because it can be cut, trimmed, and shimmed on the job site to meet positioning tolerances of ±¼ in. (6 mm), as detailed in Section 6-6. Any misalignments are normally concealed with finish materials.

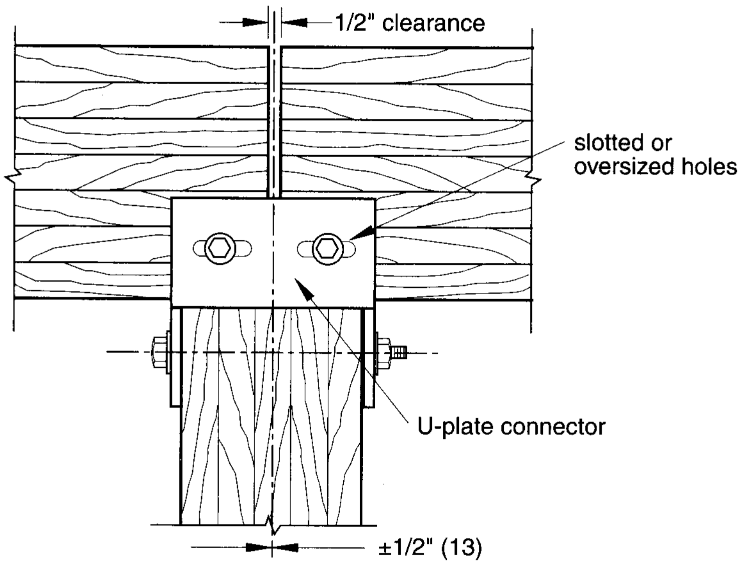
Heavy-timber and glued laminated timber construction requires more thought in detailing because these are often exposed and are part of the design aesthetic of the building. Figure 16-3 shows two common framing situations where clearances for construction tolerances are critical. At least a ½-in. (13-mm) clearance should be detailed between the end of a beam and any other structure, such as a concrete beam pocket. See Figure 16-3(a). The clearance allows for any length tolerance of the beam and minor misalignments of the anchor device and bolt hole position. As with any heavy-timber framing, there should be a ⅛-in. (3-mm) clearance between the timber and any steel anchorage device.

As shown in Figure 16-3(b), oversized or slotted holes can be used in steel connectors to accommodate size and position tolerances if positioning is critical and if allowed by the structural requirements of the bolted connection. If steel columns are used, their erection tolerance must also be considered

Figure 16–3 Detailing for timber beams



(a) beam at foundation wall



(b) beam at column

Related Sections

6–1 Glued Laminated Timber Fabrication
6–2 Manufacturing Tolerances for Structural Lumber
6–6 Rough Lumber Framing
16–2 Detailing for Timber Columns

16–4 Detailing for Prefabricated Structural Wood

Prefabricated structural wood members—such as trusses, I-joists, and thin, glued laminated framing—are made to exacting standards, and their manufacturing tolerances are clearly defined. However, when these materials are used with other structural components such as dimension lumber, masonry, and steel, the combined effects of all tolerances must be considered to prevent misfits during erection, field cutting or trimming, or tights that do not allow for wood expansion or building movement.

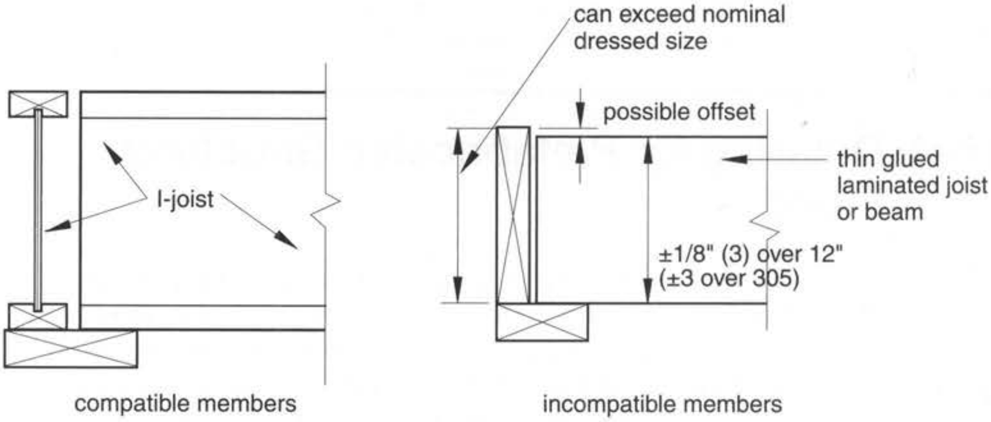
Whenever possible, prefabricated structural wood should be used with compatible framing. Even using prefabricated structural wood members with standard dimension lumber can result in undesirable offsets because the manufacturing tolerances of both materials are different. For example, as shown in Figure 16-4(a), a thin, glued laminated joist over 12 in. (305 mm) deep could be ⅛ in. (3 mm) smaller than its nominal depth dimension. An adjacent piece of dimension lumber could be oversized by the same amount, resulting in a misalignment of ¼ in. (6 mm) or more.

Supporting framework for either pitched or parallel chord trusses should be dimensioned to accommodate the length tolerances of the trusses as well as possible out-of-alignment plan tolerances of the supporting members. This is especially critical where sheathing or other exterior finish materials must be applied over both construction assemblies. See Figures 16-4 (b) and (c). In most cases, elevation tolerances for trusses are not critical.

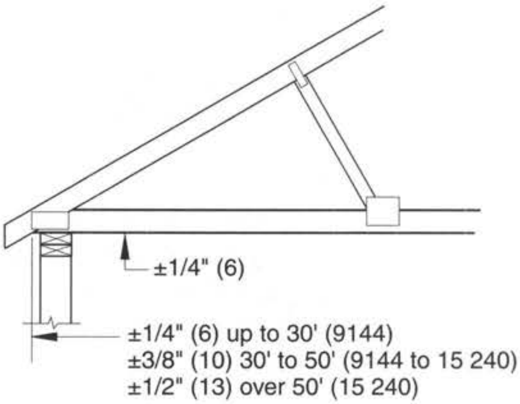
Related Sections

6–8 Metal-Plate-Connected Wood Truss Fabrication
6–9 Metal-Plate-Connected Wood Truss Erection
6–10 Prefabricated Structural Wood

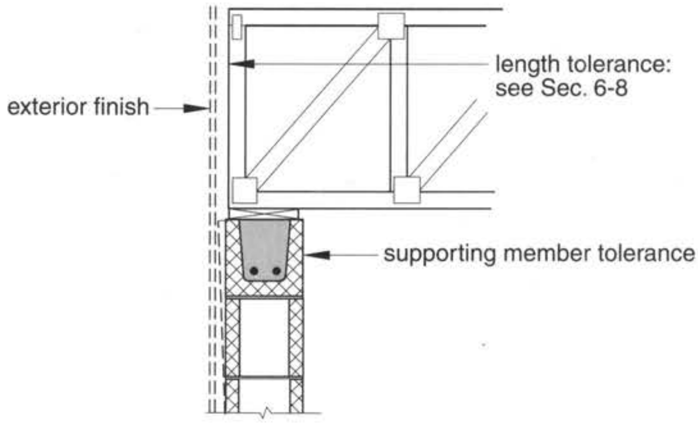
Figure 16–4 Detailing for prefabricated structural wood



(a) prefabricated structural wood

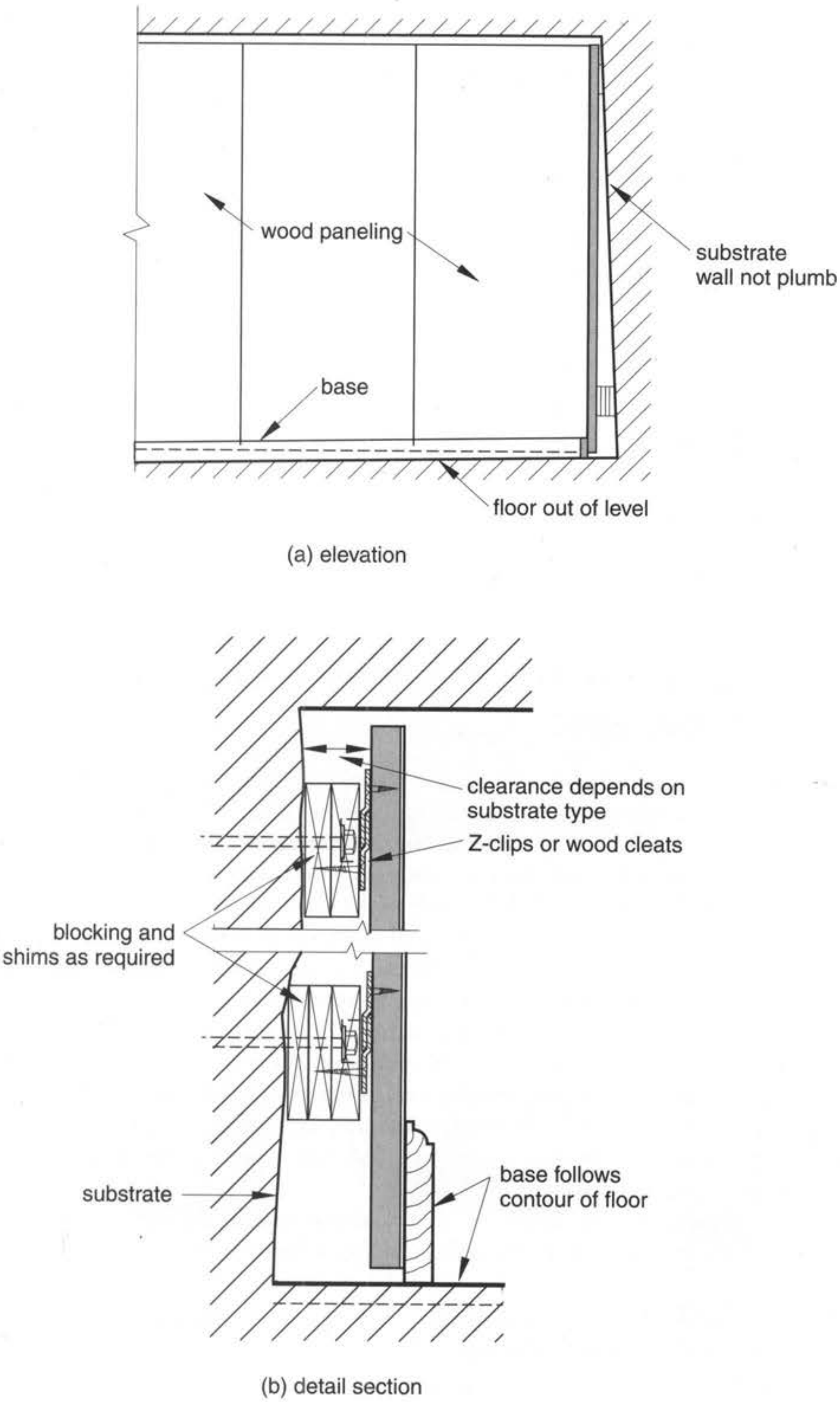


(b) pitched wood truss



(c) parallel chord truss

Figure 16–5 Detailing for paneling on site-built substrates



16–5 Detailing for Paneling on Site-Built Substrates

Wood paneling is fabricated in the mill shop to exact sizes and squareness but must be installed on substrates that are usually not level, plumb, or square. See Figure 16-5(a). If sufficient clearance is provided, blocking can be installed against the wall substrate so a line connecting the faces of the blocking is plumb. When the paneling is suspended or fastened on the blocking, it will also be plumb. In some cases, such as with accurately constructed gypsum wallboard partitions, only minor shimming of the Z-clips or wood cleats used to suspend the paneling is required. In other situations, such as on rough concrete walls or in older buildings, extensive blocking and shimming may be required to build out to a plumb and level plane. See Figure 16-5(b).

If floors or ceilings are extremely out of level, base trim or cornice molding can be used to conceal the variation in gap size between the bottom or top edge of the paneling and the ceiling or floor, respectively. Corner details must also be developed that allow the paneling to be installed in rooms that are out of square.

Related Sections

7–4 Standing and Running Trim
7–8 Flush Paneling
7–9 Stile and Rail Paneling
7–17 Architectural Woodwork Installation

16–6 Detailing for Cabinetry and Site-Built Substrates

Most cabinets are manufactured in a shop or factory to exact sizes and squareness and must be fit into less exacting construction where walls are not plumb, floors level, or corners square. Even site-built cabinets must be fit into less-than-perfect existing construction. Cabinet detailing should provide ways to tightly mate the cabinets to adjacent construction while maintaining the overall design style of the installation.

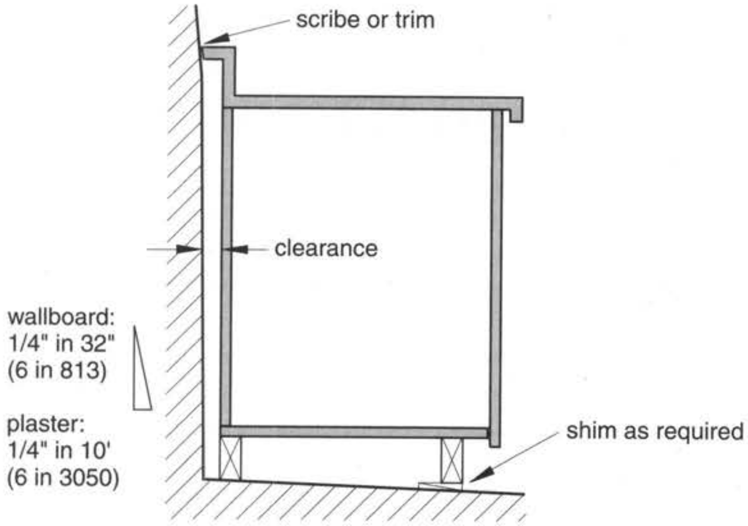
Figures 16-6(a) and 16-6(b) schematically illustrate the places where typical cabinets must be matched to the surrounding construction. For upper cabinets and shelving, similar fits must also be made at the ceiling. Because most partitions are not exactly plumb or perfectly smooth, there should be a clearance behind the cabinet back so the cabinet only touches the partition at the countertop. The dimension of the clearance depends on the condition of the partition, but it is normally ¼ in. to ½ in. (6 mm to 13 mm). In most cases, the top of the backsplash is built wider than necessary so it can be scribed to fit the outline of the partition when the countertop is installed. Any shimming required to level the cabinet must be concealed with a finish base.

Where a vertical edge of a cabinet or other woodwork touches the partition, the joint can be finished with one of the methods diagrammed in Figure 16-6(c).

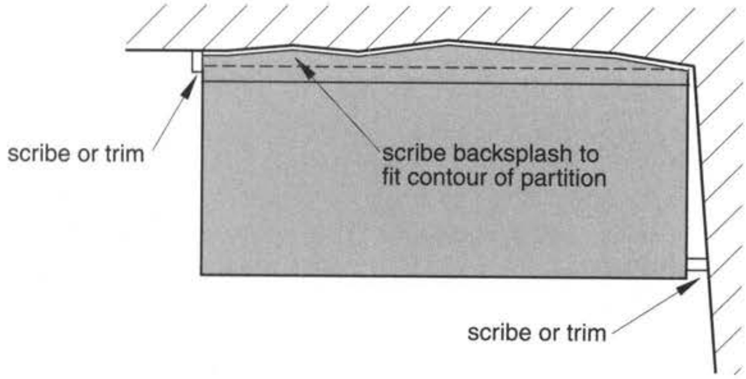
Related Sections

7–2 Site-Built Cabinets and Countertops
7–5 Architectural Cabinets
7–6 Modular Cabinets
7–7 Countertops
7–17 Architectural Woodwork Installation

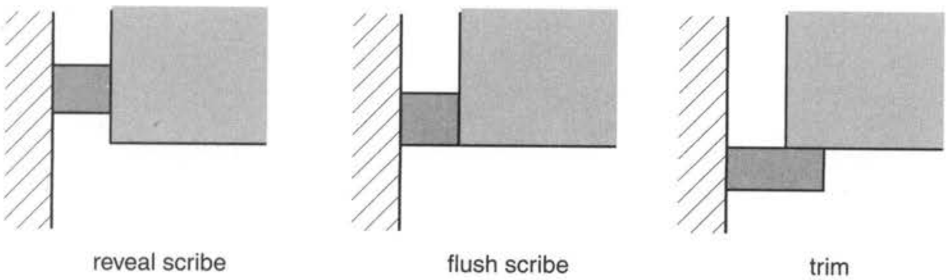
Figure 16–6 Detailing for cabinetry and site-built substrates



(a) schematic cabinet section



(b) plan view



(c) types of scribes and trim

Part 3

Measuring Compliance and Documenting Construction Tolerances

The individual and combined tolerances and methods of detailing shown in Parts 1 and 2 give the design professional guidance in how to accommodate inaccuracies in construction. However, construction must be measured to verify that tolerances are within the required standards or that they exceed standards and justify remedial work.

Like construction, measurement itself is not completely accurate and introduces some uncertainty into the process of verifying compliance. This part describes the instruments commonly used in construction measurement, measurement protocols, how measurement is expressed, and the uncertainty of measurement and offers some suggestions for documenting design requirements for tolerances in order to minimize problems on the job site.

Chapter 17

Methods of Measurement

17–1 Measuring Devices

Many instruments are currently available for measuring distances, angles, and slopes, as well as the roughness of surfaces. These range from inexpensive, moderately accurate measuring tapes and carpenter's levels to extremely accurate, automated electronic devices costing tens of thousands of dollars. The problem is not a need for a good measuring instruments but an agreement on which instruments to use and a protocol for using them to check for tolerance compliance.

Metal measuring tapes are the most commonly used tools for measuring distances. They are inexpensive, easy to use, and available in English or metric units. Most tapes used in construction are graduated in units of 1/16 in. or in millimeters. Accuracy depends on the quality of manufacturing, how they are maintained, and correctness of use.

The dimensional accuracy for a 100-ft. (30.5-m) steel tape depends on the amount of sag, temperature, tension, and angle of use. The National Institute of Standards and Technology (NIST) sets tolerances for metal tapes as previously shown in Table 1-1. However, for typical situations and when sag is minimized, the tolerances shown in Figure 1-1 can be expected. If higher accuracy is required, a laser should be used or steel tapes with correction factors included for temperature and other variables.

Sonic measuring devices send out an inaudible noise and measure the time it takes to receive the echo. They are inexpensive and easy to use, but their range is limited; they can only measure a hard, reflective surface perpendicular to the sending unit; and they are not very accurate. Accuracy depends on the manufacturer, but it is approximately ±3 in. (76 mm) over a distance of 50 ft. (15 m).

Laser rangefinders, also called electronic distance meters (EDM), are small, handheld devices that measure the time it takes for light to travel from the instrument to the measured surface and back. The accuracy varies with the individual manufacturer's device and whether it is used with or without a reflector, but for a reflector unit, ranges are from ±1/16 in. at 650 ft. (±1.5 mm at 200 m) to ±1/8 in. at 330 ft. (±3 mm at 100 m). Accuracy decreases over longer distances. They are moderately expensive but much less costly than construction lasers.

Carpenter's levels are used for setting level and plumb only. For determining angles, the level must be used with a measuring tape to determine slope. This introduces several sources of possible errors but uses inexpensive and readily available tools.

Digital inclinometers, while slightly more expensive than standard levels, are easy to calibrate and use and can measure slopes in degrees, percent, and fractions per foot. They have an accuracy of 0.1 degree and come in 2-ft. and 4-ft. lengths. The individual electronic module can also be mounted on other devices to create customized measuring instruments.

Transits and *construction lasers* are useful for setting or measuring overall elevation points to determine a total slope. Most construction lasers have an accuracy of ±1/16 in. in 100 ft. (1.6 mm in 30.5 m) and even greater accuracies in shorter distances. While these instruments have the necessary accuracy to determine distances and elevation points, they are not as well suited for measuring local variations of slope over small distances.

Electronic instruments have been developed to measure floor flatness. Originally created to measure the flatness of concrete floors in critical applications such as narrow-aisle warehouses, these devices might also be adapted for use in measuring slope flatness. Their disadvantages include a high initial cost and training needed for their proper use. Some of these devices were developed to more accurately and easily measure floors according to the F-number system and the waviness index, which are described later in this chapter. Electronic instruments include the F-meter, Dipstick®, and FloorPro®. Other devices are listed in the References section at the end of this chapter.

Laser scanners use laser beams to automatically develop a three-dimensional image of a space. These types of instruments could be used to measure floor flatness and level, but they are very expensive, require training, and give accuracies in excess of what is needed to verify compliance with most construction tolerances. For example, one manufacturer's laser instrument can measure to within 0.001 in. (0.025 mm).

17–2 Measuring Length

The method of measuring length depends on the type of tool being used, the distance being measured, and the degree of accuracy required. For example, using a standard metal tape measure with a hooked end requires different techniques than using a laser range finder.

When a metal tape is used, at least two measurements should be taken, preferably in opposite directions. Three measurements are even better so the third can confirm which of the first two is more accurate.

ISO Standard 4463-1 states that when one is measuring distances with a tape, the measured distance should not be greater than twice the length of the tape. When accuracy is critical, the measured values should be corrected for temperature, sag, slope, and tension. A tension device should also be used with the tape. However, for most construction measurement and verification of tolerances, these additional steps may not be required.

The *NIST Handbook* 44, Section 10.3 gives the following rules for the reading of indications on graduated scales if one desires to read or record values only to the nearest graduation. If the indicator is between two graduations but is closer to one graduation than to the other, the value of the closer graduation is the one to be read or recorded. In the case where, as nearly as can be determined, the indicator is midway between two graduations, the odd-and-even rule is invoked and the value to be read or recorded is that of the graduation whose value is even. In most cases, readings can be no more accurate than the smallest graduation. Generally, a measurement device should read one unit more accurate than the required tolerance reading (one more decimal place or fractional graduation).

For measurements using an EDM between primary points and secondary points and between secondary points, ISO Standard 4463-1 recommends that the distance should be greater than 30 m (100 ft.) and should be measured from each end. If it can be demonstrated that a particular instrument has a greater accuracy at shorter distances, lengths less than 30 m are acceptable. For all electronic instruments, the manufacturer's recommendations should be followed.

17–3 Measuring Angles

For verifying compliance with most tolerance requirements, the measurement of angles is generally not as important as measuring length or slope. ISO Standard 4463-1 states that angles should be established with a theodolite reading directly to one minute of angle or better. Angle measurements should be made in at least one set, and the set defined by two observations, one on each face of the instrument. An accuracy of greater than 1 minute of angle is readily possible with construction lasers. Some instruments can measure to within 1 second of angle (0.00278 degrees) and most to within 5 seconds of angle (0.01389 degrees).

17–4 Measuring Slopes

Measurement of surface slopes for conformance to tolerance requirements is usually required for accessible ramps and other surfaces and for drainage. Requirements for accessible ramps generally give a maximum allowable slope and requirements for drainage typically call for a minimum slope.

Although many proposals have been made, there are no standard protocols for measuring the slope or cross-slope of a surface, especially one that is designed as part of an accessible route. The *slope* of walking surface is the angle from level in the direction of travel. The *cross-slope* is the angle from level perpendicular to the direction of travel.

Some of the currently available methods of measuring slope are outlined in the following. Some methods are standardized and others are merely suggested. At this writing, there are no industry standards for measuring slopes, although a project by the U.S. Access Board is attempting to encourage the development by industry trade groups of standard ways of measurement for various materials.

Spot Elevations and Calculation Method

This is one of the standard methods of determining slope. With a transit or theodolite, spot elevations are taken at the top and bottom of a ramp or other slope. Then the distance between the elevations is used to calculate the overall slope, either in percent or inches per foot (millimeters per meter). Although this method is easy, it is not good for determining local variations, which can be important for drainage or accessibility.

Department of Justice Method

In the tips and techniques section of *Survey Tools and Techniques*, the checklist states that slopes can be measured in three ways: with a land survey to shoot grades, with a digital level, or with a 24-inch-long builder's level and tape measure. The directions for using a builder's level are as follows: "Using a builder's level, place the level on the pavement at the steepest point parallel to the direction of the slope. While holding the uphill end of the level on the pavement, place a pencil under the other end and roll it toward the uphill end of the level until the horizontal air bubble shows level. Use the tape measure and measure the open gap at the downhill end of the level to establish the critical dimension. For a 1:50 slope this is ½ inch; for a 1:20 slope it is approximately 1¼ inch and for a 1:12 slope it is 2 inches."

Digital Inclinometer Method

Digital inclinometers provide a fairly convenient way to measure slope. After a simple calibration process, the inclinometer is placed on the surface and the reading is taken off the device, either in percent, angle, or feet per inch. Inclinometers are available in 2-ft. and 4-ft. lengths, so local variations can be checked against requirements. The individual electronic unit can also be mounted on a shorter beam, usually 1-ft. (305-mm) in length, to measure even smaller local variations. However, there are no standards specifying how many individual measurements should be taken or where they should be taken.

Original Research for ANSI A117.1 (1957–1961)

In the original research for ANSI A117.1-1961, *American National Standard Specifications for Making Buildings and Facilities Accessible to, and Usable by, the Physically Handicapped*, ramps were assessed for flatness based on measuring 18-inch increments on both edges of the ramped surface. Both slope and cross-slope were measured. These guidelines for measurement were deleted from later versions of the standard.

Grid Method

In a draft document for accessibility design guidelines, one U.S. city suggested that slope and cross-slope of exterior ramps and landings should be measured with a 2-ft. (600-mm) digital level, every 24 in. (600 mm) in both directions, providing a 24-in. (600-mm) grid. If obvious troughs or ridges were visible, the level was to be placed so that it read the steepest slopes on the surface. The slope tolerance was to be based on the surface slope requirements. For measuring surface plane, the guidelines suggested that the level be placed so that its center was over a trough or on the high point of a ridge with an equal gap at both ends of the level. The gaps were then to be measured with the measurement falling within certain tolerances. For slopes less than 5 percent, the tolerance was +0.9 percent maximum, with an allowable ¼-in. (6-mm) gap under the straightedge. For slopes from 5 percent to 8.3 percent (1:12), the tolerance was +1.2 percent maximum, with an allowable ⅜-in. (10-mm) gap.

5-Ft. Overlapping Intervals

As published in *Concrete Construction* magazine, September 1998, author Eldon Tipping made suggestions for a specification for sloped random-traffic floors such as parking decks, ramps, and other sloped surfaces, but not necessarily for accessible ramps. The author suggested that each ramp should be evaluated independently as a Random-Traffic Test Surface. Slopes were to be measured with a Dipstick Floor Profiler (Face Construction Technologies) within 16 hours after completion of final finishing and, where applicable, before removal of any supporting shores. Sample measurement lines were to be parallel or perpendicular to slopes shown on the drawings. Measurement lines that were parallel to slopes were to connect elevation control points. At least two sample measurement lines were to be taken per bay and in perpendicular directions where slopes permitted. The minimum length of measurement lines perpendicular to the slope were to be one column bay. In the testing report, slope departures were to be calculated at 5-ft. overlapping intervals along each sample measurement line.

The author suggested a maximum departure from specified slope of concrete of ±⅜ in. over a distance of 10 ft., ±½ in. over a distance of 20 ft., and ±¾ in. between control points.

1-Ft. Incremental Methods

As published in *Concrete Technology Today*, April 2001, author Jean Tessmer, accessibility consultant for Space Options, suggested that ramp slopes be measured with a digital inclinometer mounted to measure 1-ft. increments. The line of measurement should be parallel to the long edge of the ramp. Longitudinal measurement lines should be spaced 3 ft. apart, but in no case should fewer than two lines be used. For cross-slopes, measurements should be taken every 6 ft.

Similar to this method was one developed by a professional trade association committee to measure ramp slopes. The committee suggested taking measurements using a digital inclinometer with an accuracy of ±0.1 percent mounted on an aluminum beam with rotating ball joint on metal pads at 12 in. on center. For longitudinal lines, measurements were to be taken in minimum 5-ft. lengths running parallel to the long dimension, with one measurement line per 3 ft. of width and within 2 ft. of edges, spaced equidistant apart, with not less than two lines evaluated for each ramp.

For transverse lines, measurements were to be taken in minimum 2-ft. lengths along a line running parallel to the long dimension, with one measurement line per 6 ft. of length and within 2 ft. of ends, spaced equidistant apart, with not less than two lines evaluated for each ramp.

17–5 Measuring Flatness, Level, and Smoothness

Measurement of floor surface flatness, level, and smoothness for conformance to tolerance requirements is usually required for super-flat floors, for the application of finish flooring materials, and for accessible surfaces. *Flatness* is the degree to which the surface approximates a plane. *Levelness* is the degree to which the surface parallels horizontal. *Smoothness* is the degree to which the surface is free from roughness.

There are no standards for how smoothness of surfaces is defined for accessibility or how a surface can be measured directly. However, ISO 2631-1, *Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements*, does describe methods of measuring whole-body vibration as a result of surface finish.

There are three standard methods for measuring surface flatness of smooth, concrete floors: the 10-ft. straightedge method, ASTM E 1155, and ASTM E 1486. However, there are currently no generally accepted measurement protocols for determining the flatness, waviness, or smoothness of floor surfaces for accessibility.

10-Ft. Straightedge Method

This is the classic method for determining the flatness of concrete and other types of finished floors. When used as a specification or requirement, a maximum deviation in length under the straightedge is given, such as "no point shall exceed ¼ in. under a 10-ft. straightedge." However, there is no standardized protocol to measure deviations in lengths less than 10 feet unless a specification states a maximum gap under a shorter straightedge.

The 10-ft. straightedge method has been a standard in ACI 117, *Specifications for Tolerances for Concrete Construction and Materials*, for many years and will be optional as part of the new ACI 117-06. For ramps, ACI 117-06 will refer to RMS levelness tolerance as defined in paragraph 4.11 in ASTM E 1486.

F-Number System

The F-number system, ASTM E 1155, *Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers*, was developed primarily to aid in the construction of super-flat industrial floors. When tolerances are specified using the F-number system, both the overall levelness and the flatness can be defined. The flatness number also gives an indication of the "bumpiness" of the surface.

The F-number system develops two number ratings, the F_F and the F_L. The F_F defines the maximum floor curvature allowed over a 24-in. (600-mm) length computed on the basis of successive 12-in. (300-mm) elevation differentials. The F_L defines the relative conformity of the floor surface to a horizontal plane as measured over a 10-ft. (3.05-m) distance. Statistical sampling procedures are used to determine a floor's F-numbers. F-numbers are reported as two numbers such as F_F30/F_L24. The higher the number, the flatter and more level the floor.

There are several methods given in ASTM E 1155 that can be used to measure a floor and develop the F-numbers. However, in practical terms, sophisticated electronic measuring devices developed specifically for this purpose are used. They are expensive and require some amount of training.

Although direct equivalents are not appropriate, an F_F of 25 approximately correlates to a ¼-in. variation under an unleveled 10-ft. straightedge. An F_F of 50 approximately correlates to a ⅛-in. variation under a 10-ft. straightedge. Other approximate correlations are shown in Table 17-1.

Concerning issues of vibration and rollability, the F-number system is probably a better measure than the straightedge because it takes into account local variations of flatness. However, it was not developed to measure slope.

For slabs-on-grade the F-numbering system works well. However, to determine the F-number for levelness of suspended slabs, ASTM E 1155 requires that measurements must be taken within 72 hours of floor installation and before shoring and forms are removed. For elevated slabs under current standards, the specified levelness and flatness of a floor may be compromised as the floor deflects when the shoring is removed and loads are applied. However, local variations that could affect vibration and rollability would probably not be affected to any significant degree by slab deflection.

Additional limitations with the F-number system are that the measurements do not cross construction joints and only come within 2 ft. of penetrations. Construction joints as well as other types of joints can affect vibration and rollability. The F-number system will be optional as part of ACI 117-06.

Table 17–1 Approximate correlations between F-numbers and straightedge gaps

F-number	Gap under an unleveled 10-ft (3.05 m) straightedge, in (mm)
F_F 12	½ in (13)
F_F 20	5⁄16 in (8)
F_F 25	¼ in (6)
F_F 32	3⁄16 in (4.8)
F_F 50	⅛ in (3)

Source: ACI 117

Waviness Index

The Waviness Index, ASTM E 1486, *Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path and Levelness Criteria,* was developed in response to the discovery that the F-number system was not particularly responsive to floor deviation wavelengths between 4 and 15 ft. F_F detects floor quality for wavelengths of 1.5 to 4 ft. F_L detects variations when wavelengths are from 15 ft. to 80 ft. The Waviness Index provides information about flatness in the wavelength range between 1.5 ft. and 20 ft., which was deemed important to measure floor flatness as required by forklift trucks.

The Waviness Index measures the bumps and dips in a floor surface as the average of deviations up or down from the midpoints of 2-, 4-, 6-, 8-, and 10-ft. chords. In addition to providing a single Waviness Index number, the measurement method can also provide a computer-simulated deviation from a 10-ft. straightedge. This gives similar values as using a straightedge manually, but with the advantages of following a defined profile line according to the procedures in ASTM E 1486 and using an instrument that more accurately measures deviations.

As with the F-number system, determining the Waviness Index can be performed in a variety of ways, but practically, a sophisticated instrument must be used, along with computer software that performs the calculations and reporting. The test method does *not* apply to clay or concrete unit pavers. The Waviness Index method will be an alternate method of determining flatness as part of ACI 117-06.

Industry Standards

ASTM E 1486, *Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path and Levelness Criteria* (West Conshohocken, PA: American Society for Testing and Materials, 2004).

ASTM E 1155, *Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers* (West Conshohocken, PA: American Society for Testing and Materials, 2001).

ISO 2631-1, *Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-body Vibration—Part 1: General Requirements* (Geneva, Switzerland: International Organization for Standardization, 1997).

ISO 4463-1, *Measurement Methods for Buildings—Setting Out and Measurement—Part 1: Planning and Organization, Measuring Procedures, Acceptance Criteria*, November 1 (Geneva, Switzerland: International Organization for Standardization, 1989).

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Related Sections

1–1 Horizontal Building Layout
1–2 Vertical Building Layout
1–7 Right-of-Way Construction

Chapter 18

The Uncertainty of Measurement in Construction

In construction, as in any other discipline, no measurement is exact. There are always uncertainties about any measurement, and these uncertainties need to be taken into account when verifying compliance with an allowable tolerance. There are several interrelated aspects to measurement uncertainty, which are described in this chapter.

18–1 The Expression of Measurement

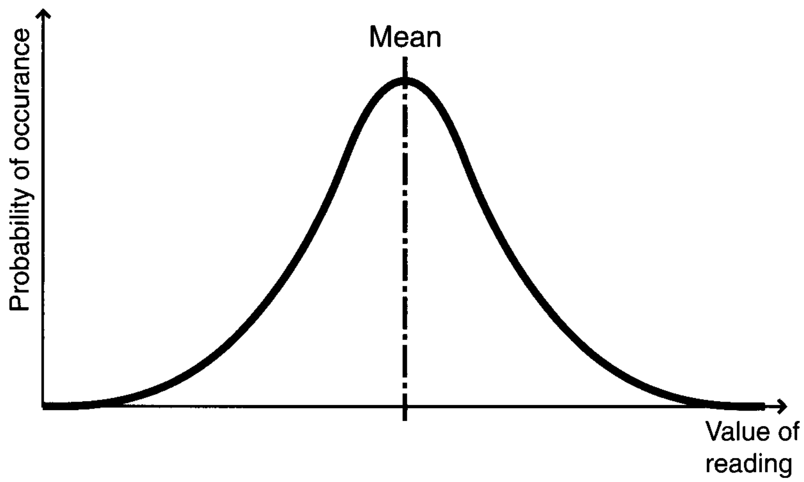
Expression is how a measurement is stated, whether it is a design requirement on drawings or a measurement of an existing physical element. How a value is stated may imply, but doesn't always, a certain amount of accuracy. For example, saying something is 2.5568 feet long implies an accurate measurement. Saying the same thing is "two and one-half feet long" implies the measurement is approximate.

In the way most construction measurements are expressed, the number may or may not indicate the accuracy of the measurement. For example, in construction, writing or saying an item is 6 ft., 4 in. long could mean it is very close to that length—say, within 1/16 in., or that the measurement has been rounded off to the nearest inch and the measurement is only within about one-half inch of the stated value. In architecture and construction, there is no standard way, typically, to designate the precision of a measurement when the feet and inch system is used.

With SI units the situation is less ambiguous. Because it is standard practice in the construction industry when using SI to use either millimeters or meters for design dimensions and most tape measures and other instruments are graduated in millimeters, a design requirement or measurement in millimeters, especially if it ends in a nonzero number, implies an accuracy of ±0.5 mm. If meters are being used, the position of the decimal point (if any) indicates (or should indicate) the precision based on significant figures as discussed later in this chapter.

One of the problems with using fractional units in construction is that fractions are expressed to the nearest "reduction" even though the design requirement or measurement might have been established to a greater degree of accuracy. For example, a measurement expressed as 4¾ in. could mean the item was measured as 4 12/16 in. with the fraction reduced or that it was measured to the nearest quarter of an inch so the accuracy is ±1/8 in. rather than ±1/32 in.

18–1 Normal distribution



18–2 Expressing Uncertainty

Measurement uncertainty is a factor that is widely used in many other fields, such as surveying, automotive manufacturing, machining, and physics. To date, it has not been used in the construction industry to any appreciable extent. A measurement uncertainty is simply a quantified doubt about the result of a measurement. An error is the difference between a measured value and the theoretical true value. Any error whose value is unknown is a source of uncertainty. The measurement uncertainty must be known to determine if compliance with a tolerance has been achieved.

Uncertainties and errors in measurement can come from many sources, such as the measuring instrument, the item being measured, the skill of the person measuring, the measurement process, and the environment. For example, in measuring the distance between two stud walls with a metal tape measure, uncertainties and errors could come from one or more of the following conditions:

- The tape measure could be slightly mismarked or the end hook could be out of position.
- The tape might sag or be bowed during the measurement.
- The tape may not be placed perpendicular to the studs, resulting in a slightly diagonal measurement.
- The studs could be out of plumb, making a measurement taken at the floor level different than one taken 5 ft. above the floor.
- The person measuring could bend the end of the tape on one of the studs to get an inside measurement instead of overlapping the tape on the face of the stud, resulting in a less accurate reading.
- The person measuring might have poor eyesight or the measurement could be taken in dim lighting conditions, resulting in a reading error.
- The person measuring could round off from the smallest tape graduations to a larger fraction, thinking that it was "close enough."

In addition, errors and uncertainties may accumulate. In the preceding example, the desired measurement may have been made to mark a chalk line on the floor for stud layout. The initial measurement may be slightly off, the position of the stud runner may not have been placed exactly on the chalk line, the studs may be out of plumb or twisted, and the wallboard might bow slightly or otherwise not be installed tightly on the stud. Any one of these errors and uncertainties may in itself be insignificant, but added together, they may create a problem. However, as described in the following, the combination of two or more uncertainties is not a direct addition, but a statistical calculation.

In the preceding example, the accuracy of the measurement may or may not be important. If the two walls were for an office, the measurement and any fractional errors would probably not be important. If the measurement was part of the construction process to build a required exit or an accessible corridor, or a space for a piece of built-in equipment, the final distance between finished walls would be important.

In some cases the source of the error, such as a temperature differential affecting a metal tape measure, may be so small as to be insignificant. In other cases, such as tape sag or out-of-plumb or out-of-square construction, the uncertainty can be important.

Calculating Uncertainty

The calculation of measurement uncertainty is based on theories and methods of statistics and involves some complex mathematics. There is a standard method for calculating and expressing measurement uncertainty. The method is described in the *Guide to the Expression of Uncertainty in Measurement* (often called GUM). This guide is the result of an international effort to standardize the expression of the uncertainty of measurement. For the United States, minor editorial changes were made and the guide is published as the *U.S. Guide to the Expression of Uncertainty in Measurement*, ANSI/NCSL Z540.2. Although it is beyond the scope of this book to describe the method of calculating uncertainty in detail, the following process outlines the basis of the procedure. The reader is directed to the references at the end of this chapter for a more complete description.

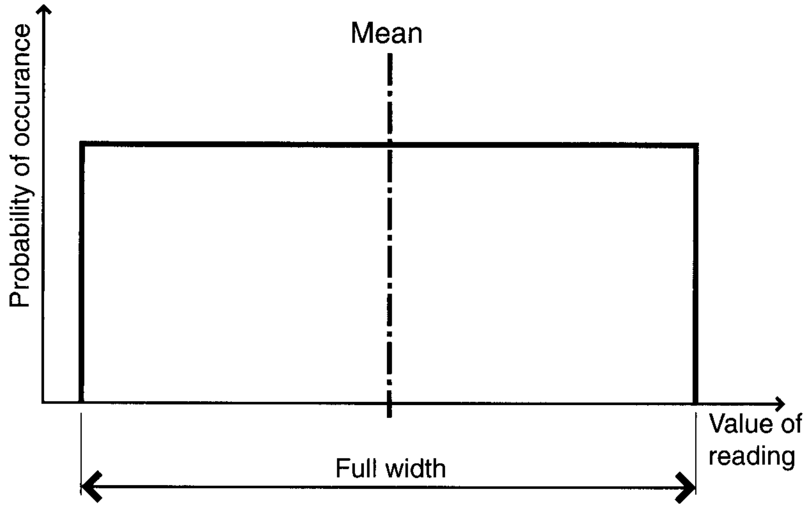
Before uncertainties can be calculated, it is important to understand that anytime more than one measurement is taken of the same distance, there will be slightly different readings. The differences may be the result of several factors, some of which were given previously in the example of measuring between two stud walls. The values of many measurements may be spread out or distributed in several different ways, but two are most common. These are also called *probability distributions*.

The first type of distribution is called *normal*. When many measurements are taken of the same distance, their values may randomly fall anywhere, but most values will likely fall near the mean (or average) than farther away from the mean. That is, the probability of any measurement falling near the mean is higher when it is near the mean than when it differs widely from the mean. When graphed, the results form the classic bell-shaped curve shown in Figure 18-1. To determine how far values vary from the mean, the standard deviation is used. The *standard deviation* is a statistical calculation and is a measure of how far all the individual values in a set of numbers differ from the mean of the set.

The second type of distribution is called *rectangular*, or uniform. In this case, values are likely to be spread evenly above and below the average (mean). As the name implies, when graphed, the distribution is in the shape of a rectangle, as shown in Figure 18-2.

The first step in calculating uncertainty is to recognize the various contributing factors and determine which way to evaluate them. There are two ways to evaluate uncertainty: Type A and Type B evaluations. Type A evaluations are based on statistical methods and are generally based on many readings of the same measurement. Type B evaluations are

18–2 Rectangular distribution



based on anything other than statistical estimates and may include factors such as past experience with similar measurements, manufacturers' specifications of a measuring instrument, or simply professional judgment. For example, a Type A evaluation could be several measurements taken with the same tape measure of the same distance. This would be evaluated statistically and would result in a normal distribution, as shown in Figure 18-1.

Reading a tape measure is an example of a Type B evaluation. If the tape is graduated in eighths of an inch, then any reading would give an error of ±1⁄16 in., for a total interval of 1⁄8 in. It is equally likely that any reading would be evenly distributed within this interval. This would result in a rectangular distribution, as shown in Figure 18-2.

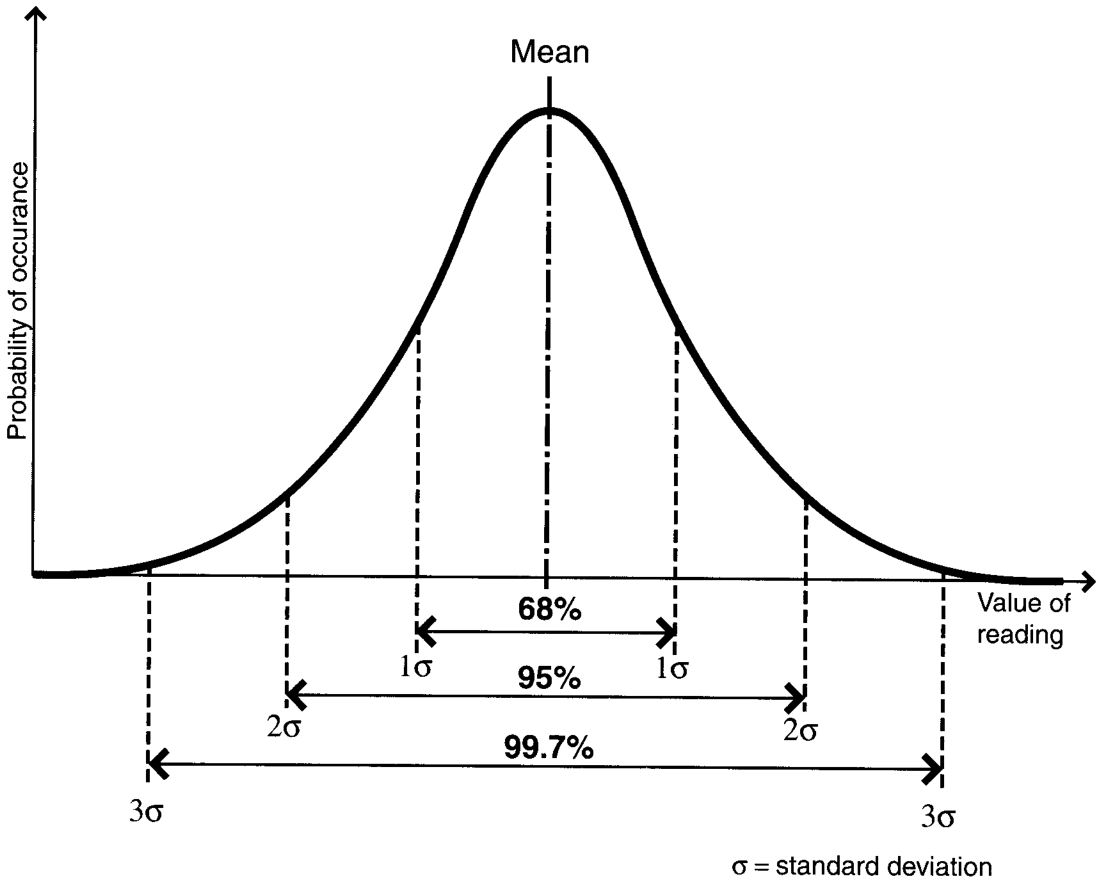
The second step in the process is to calculate the uncertainty of each contributing factor in a measurement and express each as a standard uncertainty. The *standard uncertainty* represents the uncertainty of a measurement expressed as a margin equal to plus-or-minus one standard deviation. Each contributing factor must be reduced to a standard uncertainty so they can be combined in the next step.

The third step is to calculate the combined uncertainty using the root sum-of-the-squares method. This is the same formula described in the introduction to Part 2. Each uncertainty is squared, then all are added together, and then the square root of the total is taken.

The resulting combined uncertainty represents a confidence level of approximately 68 percent, or one standard deviation, σ. This can be represented on a bell-shaped graph similar to that shown in Figure 18-1. Figure 18-3 shows the same graph with standard deviations applied. Within one standard deviation from the mean, statistical analysis states that approximately 68 percent of all points will fall within this area.

In most cases a higher level of confidence is wanted, so the combined standard uncertainty is multiplied by a coverage factor. A coverage factor of 2 gives a confidence level of approximately 95 percent, which is two standard deviations, as illustrated in Figure 18-3. A coverage factor of 3 gives a confidence level of over 99 percent. Generally, a coverage factor of 2 is used.

18–3 Measurement of confidence level

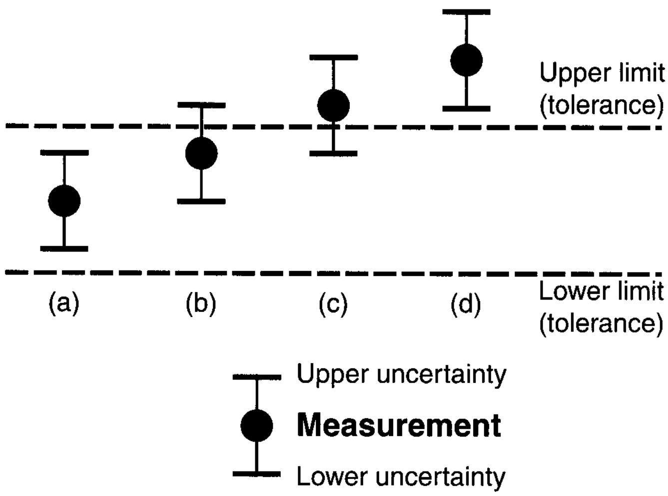


After the calculations are made, the measurement can be stated so the information can be used. When measurements are expressed to include uncertainty, three things must be included: the value of the measurement, the calculation of the uncertainty, and the level of confidence. For example, "The distance is 48½ in. ±3⁄16 in. with a 95 percent confidence level." This means that there is a 95 percent probability that the distance and any measurement taken will be within 3⁄16 in. of 48½ in.

When verifying that a construction element or measurement is within tolerance limits, one must know the value of the measurement as well as its uncertainty. There are four possibilities, as shown in Figure 18-4.

Figure 18-4(a) shows that a measurement and its uncertainty range may be totally with tolerances limits, in which case it can be confidently stated that the item complies with tolerances. A measurement and its uncertainty range may be totally outside of tolerance limits, as shown in Figure 18-4(d). In this case, the item clearly does not comply. In some cases the measurement may be within tolerance limits and a portion of the uncertainty range may be within tolerance limits, but some of the limit may lie outside of the tolerance range. See Figure 18-4(b). In this case it is likely that the measurement complies with tolerance limits, but there is some doubt. Figure 18-4(c) shows an instance where there is even more doubt about compliance. A measurement and most of the uncertainty range lies outside the tolerance limits, but a portion lies within the limits. In this case the measure probably does not comply, but it is possible that it does meet the requirements.

18–4 Four conditions or tolerance compliance



18–3 Units of Measure

Even though the United States has officially adopted the SI system, the customary U.S. (inch–pound) system is still the predominant method used for construction measurement. The SI system is used for federal construction, for military work, and for work done outside of the United States. Some trade associations and publications (such as the American Society of Heating, Refrigerating, and Air Conditioning Engineers, or ASHRAE) have adopted the SI system as their primary method, with customary U.S. units being secondary. Some publications, such as the *ADA Accessibility Guidelines*, give requirements in both units so no conversion is necessary.

Units of length are generally in feet, inches, and fractions of an inch for most architectural and interior design work and in feet and decimals of a foot for civil engineering work. Millimeters and meters are used when the SI system is employed.

Angles and slope are expressed in many different ways in architectural and landscape design. For slopes and angles, in the customary U.S. system, designers use percent (feet per 100 feet), ratio (e.g., 1:12), inches per foot, degrees, and inches per 12 inches (for roof slope). These different methods can cause confusion and errors and can create inaccuracies and some difficulty in converting one unit to another.

Although the official unit of two-dimensional angles in the SI system is the radian, the *Metric Guide for Federal Construction* recognizes that degrees are used worldwide and the modern metric system allows their use with SI when the radian is impractical. The preferred method for expressing surface slope in SI units is millimeter/meter for drainage slope. The *Metric Guide for Federal Construction* recognizes the use of nonmetric degrees/minutes/seconds for representing plane angles in surveying.

For surface smoothness and planarity, the traditional system has been to describe the amount of variation from a true plane within a certain distance, such as ¼ in. under a 10-

ft. straightedge. Newer electronic devices make it possible to express and measure planarity more precisely, such as with the F-number system, as described in Section 17-5.

As described in Section 18-1, the expression of measurement can communicate the level of accuracy required in a design dimension or in a measurement result. The SI system is better suited to expressing accuracy because significant figures imply a level of accuracy that fractions of an inch do not as they are currently used in construction industry.

18–4 Significant Figures and Rounding

Significant figures in a number are all the nonzero digits and any zeros between them and any trailing zeros to the right of the decimal place. For example, the number 20.030 has five significant figures, while 0.0034 has only two. A number such as 300 has only one significant figure. If it is written as 300., with the decimal point included, it has three significant figures. However, there are differences in usage, with trailing zeros in numbers greater than 1 and various methods for expressing them.

Significant figures can be used to express a desired degree of accuracy or an uncertainty in measurement. For example, if an item is described as being measured 3.05 m long, it could mean that the item was between 3.045 m and 3.055 m, or a range of 0.010 m or 10 mm (not using the rounding-to-even method). If the same item was described as being measured 3050. mm long (with the decimal), it could mean that the item was between 3049.5 to 3050.5 mm, or a range of only 1.0 mm.

However, significant figures can only be used with decimal numbers. They cannot be extended to fractional measurements like ¼ in., based on current practice, which is to reduce fractions. The measurement ¼ in. *could* be expressed as 4/16 in. to indicate that the nearest sixteenth of an inch was the accuracy, but this would take a change in industry standard practice. Another way to do the same thing is to specifically indicate the tolerance required by using a plus-or-minus dimension. For example, 6'4" (±⅛"). Converting a fraction to a decimal can be problematic because as the fraction gets smaller, the number of significant figures in the conversion increases and the converted decimal number may suggest a higher degree of accuracy than the corresponding fraction would. For example, ½ is clearly 0.5, but 1/16 is 0.0625. To compare both equally, the 0.5 would have to be expressed as 0.5000.

For slopes, the use of percent or angles as units allows decimals to indicate accuracy or uncertainty, but "fractions of an inch per foot" does not.

Rounding is reducing the significant digits in a number while trying to keep its value similar. Rounding can be used to reduce decimal numbers when they are generated by soft conversion from inch-pound units or fractions. Rounding can also be used to change one number into a less-accurate number when a larger tolerance is acceptable. For example, if a tolerance is ±0.5 in., then a measurement of 12.4 in. could be rounded to 12 in.

Generally, rounding is performed one of two ways. (1) If the last digit is between 1 and 4, the next-to-last digit remains as is. If the last digit is between 5 and 9, the next-to-last digit is increased by 1. (2) The second method is similar, except that when the last digit is 5, the next-to-last digit is increased by 1 if it is an odd number; otherwise, the next-to-last digit is left even. This is sometimes known as the "round-to-even" method and attempts to eliminate bias that results when 5 is always rounded up.

The National Institute of Standards and Technology, in its Handbook 44, Section 10.2, gives general rules for rounding-to-even as described in the preceding paragraph. The NIST guidelines further state that when the figure to be rounded off is 5 followed by any figures other than zero(s), the figure in the last place to be retained should be increased by 1. When there are two or more figures to the right of the place where the last significant figure is to be, the entire series of figures must be rounded off in one step and not in two or more successive rounding steps.

The *NIST Handbook* 44, Section 10.4 also gives rules for rounding common fractions. The rules are applied to the numerators of the fractions that have, if necessary, been reduced to a common denominator. If the numerator is less than one-half, then drop; if more than one-half, then add. If the numerator is exactly one-half, then round to the nearest even numerator in the round-off fraction. For example, rounding off a $\frac{3}{8}$-in. measurement to the nearest quarter inch would be $\frac{1}{2}$ in. because it is between $\frac{1}{4}$ in. and $\frac{2}{4}$ in. and the numerator in the $\frac{2}{4}$ is even. However, $\frac{5}{8}$ in. would be rounded down to $\frac{1}{2}$ in. because the numerator in $\frac{2}{4}$ is even, rather than the odd numerator in $\frac{3}{4}$ in.

18–5 Metric Conversion

Converting dimensions from one system of measurement to another can create problems when trying to establish tolerances or verify compliance with tolerance limits. If not done thoughtfully, conversion can lead to an increase or decrease in implied accuracy, losing the intent of the original value.

Using conversion factors to change inch-pound units to SI units (soft conversion) can lead to a misleading level of accuracy. For example, $8\frac{3}{8}$ in. converted to SI using the conversion factor of "25.4 mm = 1 in." yields 212.725 mm. The $\frac{3}{8}$ dimension suggests an accuracy of $\pm\frac{1}{16}$ in., which is 1.5875 mm. The 0.725 part of the converted dimension suggests an accuracy of ±0.0005 mm, which is 3,175 times smaller! Clearly, reasonable judgment must be used when making soft conversions.

In the *Metric Guide for Federal Construction*, 1st edition, published by the National Institute of Building Sciences, the following conversion method is suggested. To convert inch-pound measurements to metric, convert the mixed inch-pound units (feet and inches) to the smaller unit (inches) before converting to metric and rounding. Then,

Table 18–1 Suggested inch-pound measurements to SI units

English (inch/feet)	Metric Rounding Tolerance (inches x 25.4, rounded to mm/m)
< $\frac{1}{2}$ inch	nearest tenth of a millimeter
$\frac{1}{2}$ inch to < 3 inches	nearest millimeter
3 inches to < 10 feet	nearest 5 millimeters
10 feet to ~ 33 feet	nearest 10 millimeters (where conversion is less than 10 000 mm)
~ 33 feet and greater	nearest meter (where conversion equals or exceeds 10 000 mm)

Source: Accessible Rights-of-Way: A Design Guide. U.S. Architectural and Transportation Barriers Compliance Board. November 1999.

www.access-board.gov/publications/PROW%20Guide/PROWGuide.htm round the metric value to the same number of significant digits as there were in the inch-pound number. For example, using this system, 6 ft, 10 in. becomes 82 in.; 82 in. × 25.4 mm/in. = 2,082.8 mm; round to 2,100 mm. No matter which method is used, converting from customary U.S. units to SI in a soft conversion should not lead to a false representation of precision.

Another method of converting from inch-pound units to the SI equivalent is to base the rounding in SI on the size of the inch-pound unit. The U.S. Access Board has proposed a conversion table for converting from English units to the SI equivalent that includes rounding of the metric equivalent. This method is shown in Table 18-1.

Several methods can be used to convert SI units to inch-pound units. A conversion calculator can be used that will generally give, depending on the calculator, an equivalent in feet, inches, and fractions down to 1/64 in. If this level of corresponding accuracy is not required, the user must decide what other smallest fractional unit will be used; for example, 1/8 in., 1/16 in., or 1/32 in.

In some cases, conversion is not necessary because the agency or publication being used has developed requirements in both measurement systems or is explicit in how any conversion is to be made. For example, the *ADA Accessibility Guidelines* gives requirements in both units. The *ASHRAE Handbook* is published in two versions, one with SI and one with inch-pound units. The *International Building Code* gives the exact conversion factors that should be used when switching from inch-pound units to SI units.

Generally, when measuring for compliance with tolerances, the same unit of measurement should be used for checking as was used to state the requirement in the first place. When decimal numbers are used, the number of significant figures stated in the requirement should be used to determine the suggested tolerance, if none is otherwise stated. For example, if a ramp slope is required to be 4 percent, any slope from 3.5 percent to 4.5 percent should be acceptable (a ±0.5 percent tolerance).

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Related Sections

Part 2 Accumulated Tolerances

Chapter 19

Documenting and Enforcing Tolerances

For any construction project, the architect and engineer should clearly state in the construction documents what tolerances will apply and how those tolerances will be enforced. Lacking clear definition of tolerances in the construction documents, industry standard tolerances as described in this book generally apply. When there are no industry standard tolerances and none have been defined in the documents, resolution of problems related to tolerances must be accomplished by general agreement, arbitration, mediation, or litigation.

Regardless of what tolerances or measurement protocols may or may not exist, architects, engineers, and other designers have the tools with existing construction practices to achieve compliance with tolerances. It is simply a matter of clearly communicating four things: (1) the tolerance allowed, (2) the standards used, (3) how compliance will be verified, and (4) what the result of noncompliance will be. Of course, if industry standards do not exist, the architect or designer must create their own for each project. The existing tools for communicating and enforcing tolerance limits include drawings, specifications, preconstruction meetings, and construction observation. In some cases, designers can use these tools as they exist. In other cases, only slight changes are required to adapt them to communicate tolerance requirements.

In addition to documenting tolerances, other traditional techniques can also be used, as they always have been, to accommodate the inaccuracies of construction. These techniques include providing proper clearances in details, building in adjustability, designing proper joint widths, using overlaps, and employing similar construction methods.

19–1 Documenting Tolerances on Drawings

Existing Practice

Current practice for architectural and construction engineering drawings establish ambiguity and the potential for accumulated measurement error. For example, architects typically use chain dimensioning. If the contractor follows the chain in layout, slight errors can accumulate to the final dimension. It is also *not* standard practice to assume that a fractional measurement indicates a significant figure or the implied accuracy required. An architect may dimension something as 14'-6" and want that to be built within a ¼-in tolerance, not a ½-in tolerance, as the number 6 might indicate.

It is also typical practice for architects to use the values published in guidelines and standards and repeat the value on the drawings. If the value is a minimum or maximum or a range, this fact may not be communicated to the contractor, who may think that there is a tolerance allowed.

When a dimension is especially important, drafters may use the word "HOLD" or a similar word to indicate that a dimension is important. Less important dimensions may have a plus-or-minus sign (±) as a prefix or suffix to indicate that this dimension may vary slightly. However, in both cases the amount of the allowable variation is not clear.

Although significant figures could be used as a way to state expected accuracy or certainty in a measurement, the practice of using feet, inches, and fractions of an inch do not allow this as the method is currently used.

Possible Changes

There are several modifications to drawing practices that could be made to improve communication of important values. These include the following:

- When a dimension range is the regulatory requirement, use the midpoint of the range as the drawing dimension.
- When a maximum or minimum dimension is a regulatory requirement, use a drawing dimension that is less or more than the limit. The amount should be determined by the expected tolerance of the construction element.
- Use the plus-or-minus symbol (±) after a dimension when it must be made clear what the expected tolerance is. Also include a general note stating that no additional allowances either plus or minus will be allowed. For example, 6'-4" (±⅛").
- When using feet and inches to dimension drawings, use the denominator of fractions to indicate the "significant figure." Alternately, use the reduced fraction with the significant figure fraction in parentheses. For example, in communicating that the tolerance is ±1/16 in., write 6'-4 8/16" or 6'-4½" (8/16").
- Use datum dimensioning when the position of one item is particularly important. Do not dimension it based on one or more dimensions in a string.
- For ramps, dimension both overall length and elevation to indicate a slope less than the maximum allowable. If necessary, include requirements for smoothness and the method of taking measurements to verify compliance.

19–2 Documenting Tolerances in Specifications

Specifications provide an ideal place to solve many of the problems with communication. Specifications allow the requirements to be stated as succinctly or as elaborately as required. Further, courts place great importance on specifications when disputes arise.

Current practice using the Construction Specification Institute's standard three-part format for writing specifications has places to include all requirements related to tolerances and measurement protocols. One or more of them can be used as needed to describe the requirements of a project. These include the following:

- References to industry standards: Part 1, "References"
- Required test reports and similar documents: Part 1, "Submittals"
- Mockup requirements: Part 1, "Quality Assurance"
- Regulatory requirements, mock-ups, and preinstallation meetings: Part 1, "Quality Assurance"
- Shop fabrication of elements: Part 2, "Fabrication Tolerances"

- Special techniques and interface with other work: Part 3, "Construction Requirements"
- Final, installed tolerances: Part 3, "Site Tolerances"

Many manufacturers and trade groups have guide specifications that include their product's tolerances. In addition, master specifications, such as SPECTEXT and Masterspec® include tolerances in many of their sections.

If specific tolerances or requirements are not stated in the specifications (or drawings), it is generally held that industry standards apply. However, many industries do not have tolerance standards, or the problematic element may be part of a larger assembly for which there are no standard tolerances; the placement of a toilet, for example. When tolerances do not exist and there are no clear standards, disputes arise and the courts may decide the issue.

In cases where the measuring devices and/or measuring techniques used will affect the accuracy of the construction, the expected tolerances must be clearly stated. For example, it may be considered industry standard to lay out a house or small commercial building using a transit and measuring tape. If no other guidance or accuracy requirements are specified, the contractor may be considered within industry standards when the resulting building is constructed with these tools and techniques. Unless specific tolerances are called out, expectations of higher accuracy resulting from using laser-based instruments in this case cannot be expected.

19–3 Contract Administration

Contract administration provides two points during which tolerance issues can be addressed: preconstruction meetings and construction observation. Preconstruction meetings provide a commonly used technique to communicate the required needs of the project. All interested parties are together (or on a conference call or teleconference). The designer may ask if everyone has read the specification requirements and interpreted the drawings correctly. Everyone may discuss unusual or particularly tight tolerances, ask questions, suggest construction techniques, review measurement protocols, and verify how compliance will be checked. As with all meetings, written notes should be distributed to all parties.

Construction observation is the stage at which tolerances are enforced. Even though the final responsibility rests with the contractor, the architect, engineer, or other design professional should be observing construction and requiring the contractor to use the measurement protocols outlined in the specifications. For large projects, checking for compliance with tolerances may be done early in a construction process to suggest needed adjustments to techniques for subsequent construction. For many tolerances, the final check is by the regulatory agencies.

19–4 Tolerances and Accessibility

Compliance with tolerances for accessible construction is especially problematic for two reasons. First, although the *Americans with Disabilities Act Accessibility Guidelines* (ADAAG) states that all dimensions are subject to conventional building industry tolerances for field conditions, there are no industry standard tolerances for many accessible elements. Second, accessible design may be required by both a local building code as well as by ADAAG or the newer *Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines* (ADA/ABA AG), which, at this writing, has not yet been adopted by the U.S. Department of Justice. While the local authority having jurisdiction will check compliance with any requirements in the local code being used, other ADA compliance problems may not be discovered until a complaint is made to and investigated by the U.S. Department of Justice. Accessible elements that may seem in compliance immediately after construction may later be deemed to be unacceptable. For these reasons, it is especially important for the architect, engineer, or designer to provide for tolerances and construction inaccuracies in the design and documentation of a project.

The ADA/ABA AG attempts to address the first problem by stating that all dimensions are subject to conventional industry tolerances *except where the requirement is stated as a range with specific minimum and maximum endpoints*. In the advisory to the section on construction and manufacturing tolerances (Advisory 104.1.1), it is suggested that when a range of dimensions is stated, the designer should indicate on the drawings a dimension somewhere within the range to allow for less than exact field construction. No tolerance outside of the range at either endpoint is permitted. Likewise, when a maximum or minimum dimension is stated, good practice is to indicate a dimension less than the required maximum or more than the required minimum by the amount of the expected field or manufacturing tolerance. However, when a requirement is a minimum or a maximum dimension that does not have two specific endpoints, tolerances may apply.

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