Accessible Rights-of-Way: A Design Guide. U.S. Architectural and Transportation Barriers Compliance Board. November 1999. **www.access-board.gov/prowac/guide/PROWGuide.htm**

In the Metric Guide for Federal Construction, 1st Ed, published by the National Institute of Building Sciences, there are other guidelines for conversion. No matter which method is used, converting from inch-pounds to SI in a soft conversion should not lead to a false representation of precision.

Measuring instruments and accuracy

There are many instruments that are currently available for measuring distances and angles as well as the surface roughness of accessible elements. 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 instrument but an agreement on which instruments to use and a protocol for using them to check for accessibility compliance.
Generally, a measurement device should read one unit more accurate than the required tolerance reading (one more decimal place or fractional graduation).

Metal measuring tapes are the most commonly used tools for measuring distances. They are inexpensive, easy to use, and are available in English or metric units. Most tapes used in construction are graduated in units of 1/16 inch or millimeters. Accuracy depends on the quality of manufacturing, how they are maintained, and correctness of use.

The National Institute of Standards and Technology publishes tolerances for metal tapes in its Handbook 44, Section 5.52.
Maintenance and Acceptance Tolerances, in Excess and in Deficiency, for Metal Tapes

Nominal interval from zero, ft	Tolerance, in
6 or less	1/32
7 to 30, inclusive	1/16
31 to 55, inclusive	1/8
56 to 80, inclusive	3/16
81 to 100, inclusive	1/4

From NIST Handbook 44, Section 5.52, p. 5-12.
http://ts.nist.gov/WeightsAndMeasures/h44-03.cfm.

The NIST Handbook 44, Section 10.3 gives the following rules for the reading of indications on graduated scales if it is desired to read or record values only to the nearest graduation. If the indicator is between two graduations, but is closer to one graduation than it is 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.
Carpenter's levels are used for setting level and plumb only. To determine 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 (SmartTool®), 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-foot and 4-foot 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 inch in 100 feet (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 can be used to measure slope flatness. Their disadvantages include a high initial cost and training needed for their proper use or the employment of a testing agency. 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 paper. Electronic instruments inclue the F-meter, Dipstick®, and FloorPro®.

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 for accessible design.
Some existing measurement protocols

Currently there are no generally accepted measurement protocols for determining the slope, flatness, or waviness of floor surfaces in terms of accessibility. Some people use spot elevations, some use a 10-foot straightedge, some use a 2-foot digital inclinometer, while others may use special devices that measure slopes in 1-foot increments. ASTM E1155 and ASTM E1486 do prescribe the methods for determining floor flatness and waviness using the F-number system and waviness index, but these standards are not mandated for testing for accessibility, nor are there any standards for accessibility that can be tested other than overall slope of ramps or local slope. There is also no accepted standard method for using a digital inclinometer, lasers, or other surveying equipment to measure ramp slope and cross slope.

Some of the currently available methods of measuring flatness and slope are outlined below. Some of these methods are standardized and others are suggested methods.

10-foot 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 1/4 inch under a 10-foot straightedge." However, there is no standardized protocol to measure deviations in lengths less than ten feet. The same problem exists when measuring slope. There is no way to measure a localized slope that may actually be greater than the overall slope of the straightedge.

The 10-foot straightedge method has been a standard in ACI-117, Standard Tolerances for Concrete Construction, for many years and will be optional as part of the new ACI 117-06. When the 10-foot straightedge method is used for random traffic floors, ACI 117-06 sets the minimum number of samples required at 0.01 times the floor area, measured in square feet. Requirements for compliance are then set based on the floor surface classification and whether 90% or 100% compliance is desired. For ramps ACI 117-06 refers to RMS Levelness tolerance as defined in paragraph 4.11 in ASTM E-1486.

Department of Justice method
In the tips and techniques section of "Survey Tools and Techniques," (www.usdoj.gov/crt/ada/ckstools.htm) the checklist states that slopes can be measured in three ways: with a land survey to shoot grades, using a digital level, or using a 24-inch long builders level and tape measure.
The directions for using a level are as follows. "Using a builders 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 1/2 inch; for a 1:20 slope it is approximately 1-1/4 inch and for a 1:12 slope it is 2 inches."

F-number system
The F-number system, ASTM E 1155, Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers, was developed primarily to aid in the construction of superflat 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 FF and the FL. The FF defines the maximum floor curvature allowed over a 24-inch (600 mm) length computed on the basis of successive 12-inch (300 mm) elevation differentials. The FL defines the relative conformity of the floor surface to a horizontal plane as measured over a 10-foot (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 FF30/FL24. 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 or a testing agency can be employed.

Although direct equivalents are not appropriate, approximate correlations are shown in the following table.

F-number	Gap under an unleveled 10-ft straightedge, in (mm)
FF 12	1/2 in (13)
FF 20	5/16 in (8)
FF 25	1/4 in (6)
FF 32	3/16 in (4.8)
FF 50	1/8 in (3)

For vibration and rollability, the F-number system is probably a better measure than the straightedge because it takes into account local variations of flatness. Although it was developed to measure level floors, it can be used measure sloped floors.

For slabs-on-grade the F-numbering system works well. However, to determine the F-number for levelness of suspended slabs, 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 when the floor deflects when the shoring is removed and loads 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 two feet from penetrations. Construction joints as well as other types of joints can affect vibration and rollability. The F-number system is optional as part of ACI 117-06.

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 feet. FF detects floor quality for wavelengths of 1.5 to 4 feet. FL detects variations when wavelengths are from 15 feet to 80 feet. The Waviness Index provides information about flatness in the wavelength range between 1.5 feet and 20 feet, 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 mid-points of 2-, 4-, 6-, 8-, and 10-foot chords. In addition to providing a single Waviness Index number, the measurement method can also provide a computer-simulated deviation from a 10-foot 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 is also optional as part of ACI 117-06.
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.

Unified Facilities Guide Specifications
In Section 02752, Portland Cement Concrete Pavement for Roads and Site Facilities, published by the National Institute of Building Sciences, it is stated that surfaces should be tested with a 4-meter (12 ft) straightedge in both a longitudinal and transverse direction on parallel lines approximately 4.5 meters (15 ft) apart. The straightedge is to be held in contact with the surface and moved ahead one-half of the length of the straightedge for each successive measurement. The amount of surface irregularity is to be determined by placing the straightedge on the pavement surface and allowing it to rest on the two highest spots covered by its length and measuring the maximum gap between the straightedge and the pavement, in the area between the two high points.

Suggestion by Eldon Tipping
As published in Concrete Construction magazine, September 1998, 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.

Mr. Tipping 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-foot overlapping intervals along each sample measurement line. His suggestions for tolerances are given later in this paper.

Suggestions by Jean Tessmer

As published in Concrete Technology Today, April 2001, Jean Tessmer, accessibility consultant for Space Options, suggested that ramp slopes be measured with a digital inclinometer mounted to measure 1-foot increments. The line of measurement should be parallel to the long edge of the ramp. Longitudinal measurement lines should be spaced 3 feet apart, but in no case should fewer than two lines be used. For cross slopes, measurements should be taken every 6 feet. Her suggestions for tolerances are given later in this paper.

Construction Specification Institute

While developing suggested tolerances for surface materials, the Construction Specifications Institute developed a suggested method for measuring ramp slopes. These have neither been adopted nor are they published.

CSI suggested taking measurements using a digital inclinometer with an accuracy of ±0.1 degree mounted on an aluminum beam with rotating ball joint on metal pads at 12 inches on center. For longitudinal lines, measurements were to be taken in minimum 5-foot lengths running parallel to the long dimension, with one measurement line per 3 feet of width and within 2 feet 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-foot lengths along a line running parallel to the long dimension, with one measurement line per 6 feet of length and within 2 feet of ends, spaced equidistant apart, with not less than two lines evaluated for each ramp.

The uncertainty of measurement

No measurement is exact. There are always uncertainties about the accuracy of the measurement; that is, how close is the measurement to what is theoretically exact. Measurement imperfections have many causes. These can include variables of the measuring instrument, the skill and care of the person taking the measurement, the measurement process, and environmental factors, as well as others.

Technically defined, the uncertainty of measurement is a parameter associated with a measurement that defines the range of the values that can reasonably be attributed to the measured quantity. It is an expression of the doubt that exists about a measurement expressed as a high and low value from the measurement.

There are methods and procedures to calculate, define, and express uncertainty, which are used in physics, precise manufacturing, the automotive business, and other industries. The methods are well defined and include sophisticated statistical analysis and mathematical calculations. These methods could be used in the construction industry, but it is

questionable whether the additional time and effort would achieve any greater accessibility compliance than with simpler methods.
When uncertainty is included in a reported measurement there are three parts to the measurement: the value of the measurement, the expected tolerance, and an expression of the level of confidence that the measurement will fall within the upper and lower bounds of the tolerance. For example, one can stay that a measurement is 53 inches, ±1/8 inch, with a 68 percent confidence level. This means that if the same measurement was taken 100 times, in 68 measurements the value would probably fall between 52.875 inches and 53.125 inches. The confidence levels relate to the standard deviation of a series of measurements of the same item. One standard deviation gives approximately 68 percent confidence, two times the standard deviation gives approximately a 95 percent confidence level.

In the case of surface measurement of slope or planarity, there will always be some doubt as to whether a ramp is with required bounds. However, if there is a tolerance limit and the uncertainty of a measurement can be calculated then one can calculate the probability that the measurement or building element is within the tolerance.

Construction tolerances
A construction tolerance is the allowable deviation from a given dimension, location, line, grade, or other value given in the contract documents. Tolerances are necessary in construction because no manufacturing, fabrication, or construction process is perfect. There are only degrees of accuracy. For example, woodwork fabricated in a millshop with precise equipment can be closer to perfection than a concrete ramp poured in poor weather against wood forms.

Many building product manufacturers and trades have established tolerances that are published and generally accepted in the construction industry. These are based on past experience, professional judgment, and realistic expectations of the materials and construction processes involved. For example, the American Concrete Institute publishes ACI 117, which lists many acceptable tolerances for a wide range of concrete construction applications.

Unfortunately, most of the existing construction tolerances were not developed for constructing or evaluating accessible elements. This is especially true for exterior ramps and other surfaces. In addition to the issue of compliance for newly constructed elements, there is also the question of how well an exterior material can maintain tolerances over time.
Selection of materials

Some materials may be more suitable than others for accessible surfaces. With some materials it is easier to form smooth, planar surfaces at a given slope. Some exterior materials are also more likely to retain their qualities over time. Certain materials are inherently more problematic for smoothness than others although research has shown that segmental pavers may be acceptable if the roughness is within certain limits.

The design and selection question is whether all surfaces should have the same slope and smoothness requirements with the same tolerances and measurement protocols or whether different tolerances and measurement protocols should be developed. In addition, some materials may produce undesirable vibrations for people using wheelchairs and excessive roughness for people using walking aids.

The implication is that potentially more troublesome materials might be specified more often if material-appropriate requirements and measurement protocols were developed. Otherwise, the material most easily formed to the requirements would be the default material-namely, concrete.

Existing industry tolerances

American Concrete Institute
The American Concrete Institute (ACI) has developed an extensive collection of industry tolerances. Although most of the tolerances are for building construction three are specifically set for exterior construction. The current tolerance standards are published in ACI 117-06.
The three tolerances in ACI 117-90 of interest include the following for vertical deviation of surface:

"Mainline pavements in longitudinal direction, the gap below a 10 ft (3 m) unleveled straightedge resting on high spots shall not exceed 1/8 in. (3 mm)."

"Mainline pavements in transverse direction, the gap below a 10 ft (3 m) unleveled straightedge resting on high spots shall not exceed ¼ in. (6 mm)."
"Ramps, sidewalks, and intersections, in any direction, the gap below a 10 ft (3 m) unleveled straightedge resting on high spots shall not exceed ¼ in. (6 mm)."

However, the new standards state that random traffic floor surface finish tolerances can now meet one of three standards: ASTM E 1155 (F-number system), the 10-foot straightedge method, or ASTM E 1486 (Waviness index). With the waviness index method, one provision allows its use for floors purposely pitched in one direction (ramps) if the requirements of paragraph 4.11 of ASTM E 1486 are followed. In each of the three allowed methods, detailed requirements are given on how samples are to be taken.
American Association of State Highway and Transportation Officials
The AASHTO Standard Specifications and Supplements contain little information regarding tolerances for pedestrian facilities in right-of-ways. There are tolerances for alignment for concrete barriers and portland cement concrete pavement. Pavement forms must have a maximum top of form variance of 3 mm in 3 m (about 1/8 inch per 10 feet) with maximum face variance of 5 mm in 3 m. Surface tolerances are limited to 5 mm as measured under a 3-m straightedge positioned at random locations (This is about 1/4 inch in 10 feet). Other tolerances relate to roadway paving.

Asphalt Institute
The Asphalt Institute previously included tolerances in their publication, Model Construction Specifications for Asphalt Concrete and Other Plant-Mix Types, Specification Series No. 1, SS-1. This publication is out of print and the Asphalt Institute no longer has guidelines or specifications for construction limits. However, the previous publication did include the following tolerances:

"The surface of the completed pavement will be checked longitudinally and transversely for smoothness with a 3-m (10-ft.) straightedge. The surface shall not vary more than 3 mm (1/8 in.) in 3 m (10 ft.) parallel to the centerline and not more than 6 mm (1/4 in.) at right angles to the centerline." The term centerline refers to the centerline of the compaction roller. These translate approximately to a 1 percent slope tolerance for the cross slope at a pedestrian intersection crossing and roughly 2 percent running grade (parallel to the direction of travel) for a pedestrian intersection crossing.

Australian standards
Australian standards recommend a surface level tolerance for external pavements of ±10 mm (±3/8 inch) for both graded and non-graded pavements and for control points at the top and bottom of graded pavements. Flatness

deviations are suggested as a maximum of 12 mm along a 3 m straightedge (±1/2 inch in 10 feet). (AS 3600, Concrete Structures, Standards Australia, 2001 and Concrete Finishes Section, NATSPEC Reference Volume 1: Building Works, 2003)

Wood floor framing and subflooring
There is no single accepted tolerance for flatness of wood subfloors and none for framing of exterior wood ramps. The Residential Construction Performance Guidelines, 3rd ed. by the National Association of Home Builders Remodelors Council state a maximum out-of-level tolerance of ¼ inch in 32 inches (6 mm in 813 mm) for floor framing measured parallel to joists.

Floors with ceramic tile
There are no standard tolerances for the finished surface flatness of ceramic tile. The only requirements are for the substrates for the installation of tile as given in ANSI 108.1 and Handbook for Ceramic Tile Installation by the Tile Council of North America, Inc. These include ±1/4 inch in 10 feet (6 mm in 3000 mm) for nearly all tile installations.

Terrazzo
Terrazzo can be ground smooth to within ±1/4 inch in 10 feet (6 mm in 3 m). The National Terrazzo and Mosaic Association requires concrete subfloors for monolithic and thin-set terrazzo systems to be level to within ¼ inch in 10 feet. (6 mm in 3 m). For specialty terrazzo flooring, such as polyacrylate-modified terrazzo, epoxy and epoxy-modified terrazzo, subfloors must be level to within ±1/8 inch in 10 feet (3 mm in 3 m).

Wood flooring
There are no standards for the flatness of finished wood flooring at the time of installation. Wood flooring flatness will reflect the flatness of the substrate and any change in thickness due to variation in moisture content. Generally, for wood strip flooring and parquet flooring the subfloor should be level to within ¼ inch in 10 feet (6 mm in 3 m).

Stone flooring
The Dimension Stone Design Manual of the Marble Institute of America sets the maximum variation of the finished surface of commercial stone floors set on a thick mortar setting bed at ±1/8 inch in 10 feet (3 mm in 3 m) with no more than a 1/32 inch (1 mm) lippage. For thin stone tile laid with the thin-set method the flatness of the finished surface depends primarily on the flatness of the substrate. The Marble Institute of American recommends that concrete subfloors be flat to within 1/8 inch in 10 feet of the required plane. For wood floors, the MIA recommends a flatness of 1/16 inch in 3 feet (1.6 mm in 900 mm).

Recent work on tolerances for exterior surfaces
In the last ten years there have been suggestions by industry experts and research projects that have attempted to establish some consensus in tolerances for exterior surfaces. These are summarized below.
Orange Empire Chapter of ICBO

The Orange Empire Chapter of the International Council of Building Officials compiled a document in 2000 titled Reasonable Construction Tolerances for Disabled Access Construction (Orange Empire Chapter of ICBO, June 15, 2000, no longer available to the general public). It was compiled by regulatory officials in the local chapter of ICBO and purported to represent over twenty years of experienced gained by the members of the committee when enforcing accessibility regulations. It was partially a response to the fact that three access codes used in California (Title 24 CCR; Health & Safety Code; and ADAAG, Section 3.2) all allow tolerances to be applied to accessibility construction, but do not specify what the acceptable tolerances are if none exist in the industry.

Among recommendations, they suggested the following tolerances for horizontal surfaces:

Sidewalks: +1% slope tolerance or a 4% maximum cross slope for up to 30 feet.

Curb cuts: 8.4% maximum average slope checked at quarter points with 9.5% maximum slope at only one point.

Curb cut bottom landing: 6% maximum slope instead of 5%.

Pedestrian ramps: a +1.17% tolerance at any one point when the ramp is checked at quarter points. 8.33% maximum average slope when checked at quarter points.

Survey by the Construction Specifications Institute
In 2000, the Construction Specifications Institute (CSI) began the development of a document on tolerances for exterior ramp and walking surfaces as previously described.

CSI documented construction tolerances for materials commonly used as walk and ramp surfaces, including concrete, asphalt, brick pavers, cast-in-place concrete, ceramic tile, concrete pavers, stone pavers and wood. Issues of flatness, roughness, and methods of measurement were also discussed. CSI did not address tolerance issues of other right-of-way construction such as handrails, controls, bus stops, and the like.

In the final CSI draft, which was not published, the authors stated that an FF of 35 for ramps (about 3/16 inch under a 10-foot straightedge) and of 25 for walking surfaces have been proposed as giving reasonable results and being readily achievable. The final draft also listed suggested tolerances for the various materials based on the opinions and experience of many people in the construction industry.

Recommendations by industry experts:
Eldon Tipping, President of Structural Services, Inc., suggested a maximum departure from specified slope of concrete of ±3/8 inch over a distance of 10 feet, ±1/2 inch over a distance of 20 feet, and ±3/4 inch between control points. (Proposed Tolerances for Sloped Surfaces, Concrete Construction, September 1998, pp. 769-770)

Bruce Suprenant, President of Concrete Engineering Specialists, suggested that for large sloped areas an FF of 35 and an FL of 20 ±3 should be used with the number of measurements to be taken as something that would need to be worked out. For small, sloped areas, he suggested that measuring the gap under a straightedge would have to suffice. For hand-worked slopes, he suggested an allowable gap between 5/16 inch and 3/8 inch. For slopes worked with a straightedge, the allowable gap would probably be less than ¼ inch. (Birdbaths: Expectations vs. Reality. Concrete International, February 2002, pp. 67-69)

Jean Tessmer, accessibility consultant for Space Options, suggested that designers should design ramps with slopes of 7.5% to 7.8% to allow a reasonable slope tolerance of 0.5% to 0.8%, which contractors are capable of meeting. She suggested the cross slope should be designed to 1.5% to allow for the same 0.5% construction tolerance. She also suggested a method of measuring ramps for compliance described previously in the section under Some Existing Measurement Protocols. (Building Flatness into Walkways and Ramps. Portland Cement Association, Concrete Technology Today, Vol. 22, No.

1, April 2001, pp. 1-3.)

David Ballast, Architectural Research Consulting, recommended, among others, the following tolerances for exterior right-of-way construction based on a survey of state and local departments of transportation. These were average values that departments of transportation felt they could reasonable achieve based on current construction methods.

Running grade of sidewalks and pedestrian overpasses/underpasses: +1%. Running slopes and cross slopes of curb ramps, counter slopes in gutters and similar areas: +0.5% for maximum slopes, where designated and -0.5% for minimum slopes.

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

Accumulated tolerances

When two or more construction components are used together, the individual tolerances may accumulate to create a larger deviation than the individual tolerances alone. This may occur with multiple uses of the same construction component (such as four precast concrete panels placed side by side) or when one component is placed on another (such as a cabinet with its own fabrication and installation tolerances placed on an out-of-level floor with its own tolerance). In some cases, standard industry tolerances specifically state that tolerances are not cumulative.

Theoretically, it may be possible that several tolerances would act together in the same direction, each at its extreme value to create a maximum possible tolerance. For example, if four precast concrete panels each had a maximum oversize manufacturing tolerance of +1/8 inch the total theoretical oversize tolerance could be ½ inch. However, statistically this is unlikely to happen; some undersize panels would balance some oversize panels. To account for this statistical probability, the sum of the squares method is used to estimate total accumulated tolerance. In this formula, the individual tolerances are squared and added together. Then, the square root of this summation is taken to give the most probable total tolerance. Accumulated tolerances are not as much an issue for exterior surfaces as they are for other architectural elements. For accessibility, the question is whether accumulated tolerances should be considered or whether the final finished surface is the only consideration.

Communicating needs

Regardless of what tolerances or measurement protocols currently exist or don't exist, architects, engineers, and other designers have the tools with existing construction practices to achieve accessibility. It is simply a matter of clearly communicating four things: (1) what is wanted, (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 include drawings, specifications, pre-construction meetings, and construction observation. In some cases, designers can use these tools as they exist. In other cases only slight changes may be required to adapt them to communicate accessibility requirements.

Other traditional procedures can be used to accommodate the inaccuracies and tolerances of construction. These include providing clearances, adjustability, joint design, overlaps, and other techniques.

Drawings

Current 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 1/4-inch tolerance, not a 1/2-inch 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 some similar word to indicate that a dimension is important. Less important dimensions may have a ± as a 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 are things that trade and professional groups such as the AIA and CSI, should undertake as part of their "best" practices.

Some suggestions:
* 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" (±1/8").
* 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 tolerances is ±1/16 inch use 6'-4 8/16" or 6'-4 1/2" (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.

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, specifications are generally given a great deal of importance by courts when legal disputes arise.

Current practice using the CSI standard 3-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 pre-installation 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.

Pre-construction meetings

Pre-construction meetings provide another 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 can ask if everyone has read the specification requirements and interpreted the drawings correctly. Unusual or particularly tight tolerances can be discussed, questions asked, construction techniques suggested, measurement methods outlined, and how compliance will be checked can all be brought into the open.

Construction observation

Construction observation is the final step in building an accessible element to meet the design and regulatory requirements. 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 for where extensive accessible surfaces are required, early checking should be done to suggest needed adjustments to construction techniques. The final check, of course, is with the regulatory agencies.