Anchor Bolt Specification Conflicts

Resolving differences between ACI and AISC tolerances

BY BRUCE A. SUPRENANT

Using the Construction Specifications Institute Master-Format™ notation, project manuals are structured so that Division 3 governs concrete construction and Division 5 governs steel construction. Within these divisions, tolerances are normally defined by reference to industry standards such as ACI 117-90 or the recently published ACI 117-06 for Division 3 and the American Institute of Steel Construction (AISC) 303-05 for Division 5. Typically, this structure clearly defines the requirements that each trade is expected to meet. Conflicts can arise, however, where construction by the two trades intersect.

The tolerances for the placement of anchor bolts or rods (the term used by AISC) are a good example of one of these conflicts. Because the tolerances for anchor bolt locations in ACI and AISC documents aren’t currently compatible (refer to sidebar), it’s not surprising that conflicts can occur when a steel structure is to be constructed on a concrete substructure. Clearly, to provide the best product for building owners, the construction industry must eliminate tolerance incompatibilities.

Some recommendations for resolving the conflicts in the specification of tolerances for the placement of anchor bolts are provided in this article.

MEASURING ACCURACY

To determine if tolerances can be reasonably attained, we first need to discuss the measuring accuracy of the methods used at the site to locate anchor bolts. The location of an anchor bolt is typically established using a steel tape measure to determine its distance from two reference lines. The accuracy of the layout depends not only on the accuracy of this final measurement, but also on the accuracy of the working lines themselves. The accuracy of the final layout therefore depends on the accuracy of the following items:

- Primary control lines;
- Secondary control lines;
- Working lines; and
- Distances from working lines to the bolt location.

A primary control line is a permanent baseline that exists throughout the life of the project. It’s typically set at the edge of the site or possibly even off the site. Although it’s obviously very important that this line be located accurately, its accuracy usually doesn’t affect tolerance conflicts because all building trades should use the primary control line as their starting point for setting secondary control lines.

A secondary control line is a semi-permanent control line that’s established within a tape measure’s length (typically no more than 25 ft [8 m]) of the work to be executed. There are typically multiple secondary control lines for a building, and they’re used for weeks, months, or even for the entire project. The construction manager (CM) or general contractor (GC) often establishes the secondary control lines for the project and requires all trades to work off the same lines. This helps minimize disputes...
regarding measurement accuracy. The secondary control line is typically laid out with an accuracy of 0.01 ft or 1/8 in. (3 mm).

A working line is temporary and is often removed the instant a worker marks a location or is later covered up by ongoing work. The recommended accuracy of the working control line is 1/2 that of the work it is locating. For instance, the working control line (tape measure distance) should be located to within ±1/32 in. (±0.8 mm) for setting anchor bolts to the nearest ±1/16 in. (±1.6 mm).

**Where to measure**

Whether the anchor bolt location is controlled at the top of concrete, top of bolt, top of base plate, or some other point is a critical choice. Field engineers often lay out anchor bolt locations along the top of the concrete. When they check installed anchor bolts, however, they often measure to the top of the anchor bolt.

If the anchor bolt isn’t perfectly plumb, the position or location of the anchor bolt varies depending on which point is measured. If the anchor bolt tilts at only a 5 degree
angle and projects 6 in. (150 mm) above the concrete, the
difference in measuring location (top of bolt or top of
concrete) can result in a location difference of as much
as 1/2 in. (13 mm).

Another measurement difficulty is that anchor bolts
are often measured to the centerline of the bolt. This
requires either marking the centerline on the bolt—which
is rarely done—or, more often, holding the tape measure
at the estimated centerline. Because typical anchor bolt
diameters range from about 1 to 3 in. (25 to 75 mm), it’s
reasonable to assume that the centerline can’t be estimated
with an accuracy any better than ±1/32 in. (±0.8 mm).

Measurement tolerance
The standard deviation of the final anchor bolt location \( T \)
can be estimated by the square root of the sum of the
squares (SRSS) of the standard deviations of the individual
measurements for the secondary control line \( SCL \), the
working line \( WCL \), and the estimated bolt centerline \( ECL \)
using the following equation

\[
T = \sqrt{SCL^2 + WCL^2 + ECL^2} \tag{1}
\]

Because all trades work from the primary control line,
we don’t need to consider its accuracy in this equation.
If we assume that the secondary control and working
lines can be located within ±1/8 in. (±3 mm)\(^7\) of the
time, then we can estimate the standard deviations of
these measurements (\( SCL \) and \( WCL \)) at 1/24 in. (1 mm).
Similarly, if we assume an accuracy for estimating the
centerline of the bolt of ±1/32 in. (±0.8 mm), then the
standard deviation can be estimated at 1/96 in. (0.26 mm).
Using these estimates in Eq. (1) results in a total standard
deviation of 0.06 in. (1.5 mm).

This value tells us that even if the anchor bolt is
placed perfectly, the tolerance would have to be ±2\( T \) or
about ±1/8 in. (±3 mm)\(^7\) to have about a 95% probability
that its location would fall within the tolerance, and we
still haven’t even considered the accuracy with which we
can place the anchor bolt relative to its intended position
and keep it there while the concrete is being placed. Even
using a total station, current technology limits measuring
accuracy to about ±1/8 in. (±3 mm).

Construction tolerances are typically set to include a
measurement tolerance. The PCI Tolerance Manual, for
example, states that “the precision of the measuring
technique used to verify a dimension, either pre- or post-
casting, should be capable of reliably measuring to a
precision of one-third the magnitude of the specified
tolerance.” Typically, the total tolerance is 3 to 4 times
the measuring accuracy. Based on the previous estimates
of anchor bolt measurement accuracy, 3 to 4 times the
±1/8 in. (±3 mm) measuring accuracy would provide an
anchor bolt tolerance of about 3/8 to 1/2 in. (9 to 12 mm).

\*

Fig. 1: The only way to ensure that anchor bolt locations meet
both ACI and AISC tolerances is to locate them within ±1/16 in. (±1.6 mm) of their intended location. These scaled drawings
showing the anchor bolt diameter (green), placing tolerance
(yellow), and the remaining hole size (red) illustrate that this
would result in an inordinate amount of the available adjustment
being allocated to the steel erector (1 in. = 25.4 mm)

**WHAT TO MEASURE**

Comparing the ACI and AISC tolerances shown in the
sidebar on anchor bolt tolerances reveals a conflict in the
manner in which the two organizations specify anchor
bolt tolerances. While ACI places limits on the deviation
of an individual bolt from its intended position, the
majority of the AISC tolerances place limits on the deviation
between bolts in a group (such as all the bolts for a single
column base plate) and the deviation between centerlines
of bolt groups. Obviously, AISC’s tolerances are intended
to ensure that the steel structure can be erected without
having to modify the structure or deviate from the
tolerances for the steel structure. Because the tolerances
can’t be directly compared, however, it isn’t possible to
determine whether an anchor bolt meeting one organization’s
tolerances will meet the other organization’s tolerances.

As a simple example, consider an anchor bolt for a
column base plate that is out of position by 1/4 in. (6 mm),
which would meet ACI’s tolerances. This anchor bolt
would also meet AISC’s tolerances if all of the other
anchor bolts for the base plate were out of position by
1/4 in. (6 mm) in the same direction and the bolts for the
adjacent columns were at their intended positions. If all
of the other anchor bolts for the base plate are at their
intended position, however, the anchor bolt would not
meet AISC’s tolerances because the distance between
anchor bolts in a group would deviate from the intended
dimension by more than 1/8 in. (3 mm).

With the current tolerances specified by ACI and AISC,
the only way to ensure that anchor bolt locations will
meet both sets of tolerances is to locate the anchor bolts
within ±1/16 in. (±1.6 mm) of their intended location. As
shown previously, it’s highly unlikely that the locations
can even be determined with this degree of accuracy.
Also, as shown in Fig. 1, requiring the concrete contractor
to locate anchor bolts within ±1/16 in. (±1.6 mm) would
result in an inordinate amount of available adjustment being allocated to the steel erector.

Even using steel templates to attempt to meet the 1/8 in. tolerance on the dimension between anchor bolts in a group is no guarantee that the AISC tolerance will be met. The dimensions of the template and the hole locations will likely have accuracies no better than 1/16 in. (1.6 mm), and each hole will have to be oversized by at least 1/16 in. (1.6 mm) to accommodate the bolt. As a result, an individual anchor bolt could be mislocated by as much as 1/8 in. (3 mm) and the distance between two anchors could deviate from the intended distance by as much as 1/4 in. (6 mm).

TABLE 1: PREVIOUS AND CURRENT HOLE SIZES FOR ANCHOR BOLTS RECOMMENDED BY AISC

<table>
<thead>
<tr>
<th>Bolt size, in.</th>
<th>Previous hole size, in.</th>
<th>Current hole size, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>1-1/16</td>
<td>1-5/16</td>
</tr>
<tr>
<td>7/8</td>
<td>1-3/16</td>
<td>1-9/16</td>
</tr>
<tr>
<td>1</td>
<td>1-1/2</td>
<td>1-13/16</td>
</tr>
<tr>
<td>1-1/4</td>
<td>1-3/4</td>
<td>2-1/6</td>
</tr>
<tr>
<td>1-1/2</td>
<td>2</td>
<td>2-5/16</td>
</tr>
<tr>
<td>1-3/4</td>
<td>2-1/4</td>
<td>2-3/4</td>
</tr>
<tr>
<td>2</td>
<td>2-1/2</td>
<td>3-1/4</td>
</tr>
<tr>
<td>2-1/2</td>
<td>3-1/2</td>
<td>3-3/4</td>
</tr>
</tbody>
</table>

Note: 1 in. = 25.4 mm

AISC HOLE SIZE VERSUS ANCHOR BOLT CONSTRUCTION TOLERANCE

As shown in Table 1, the hole sizes for anchor bolts recommended by AISC prior to the publication of the 1994 Load and Resistance Factor Design (LRFD) Manual of Steel Construction were 5/16 to 1 in. (8 to 25 mm) larger than the anchor bolt diameter. Also shown in Table 1, AISC currently recommends hole sizes that are 9/16 to 1-1/4 in. (14 to 32 mm) larger than the anchor bolt. While the hole sizes have increased, the AISC anchor bolt location tolerances for the concrete contractor have remained the same.

AISC 303-05 indicates that few fabricators or erectors have the capability to provide the survey for as-built locations of anchor rods and delegates responsibility for an anchor bolt survey to others, presumably the GC or CM. The measuring system, accuracy, and elevation at which the anchor bolt locations are measured
are all undefined, adding another problem to the coordination of ACI anchor bolt tolerances with AISC tolerances.

Also, the new second edition of AISC Design Guide 1, “Base Plate and Anchor Rod Design,” recommends that Division 3 specifications refer to the AISC tolerance requirements for anchor bolts instead of the ACI tolerances. This presents a major problem for concrete contractors, who can be back-charged by the GC or CM when either prepares as-builts showing that the anchor bolt tolerances are not met. This can be an opportunity for the GC or CM to keep retainage even though the bolts can be used for steel erection without any corrective work.

Finally, the Structural Steel Educational Council cites the following example: “If bolts are misplaced up to 1/2 in., the oversized base plate holes normally allow the base plate and column to be placed near or on the column line. If the bolts are misplaced by more than 1/2 in., then corrective work is required.” While this document suggests that the erector can cope with a 1/2 in. (13 mm) tolerance on anchor bolt placement, the AISC Code of Standard Practice maintains that the contractor must place anchor bolts to a much tighter tolerance. The concrete contractor is being held to a much tighter standard than the steel erector.

**ADDING STEEL AND CONCRETE TOGETHER—PROPOSED NEW HOLE SIZES**

Representatives of ACI, ASCC, and AISC recently met in St. Louis, MO. Steel erectors present at the meeting indicated that they needed the tolerances shown in Fig. 2 for steel fabrication and erection. The SRSS of the three tolerances needed by the steel erectors gives a combined tolerance required for steel erection of about 1/8 in. (3 mm). Based on previous ASCC work, the concrete construction representatives indicated...
that 3/8 in. (9.5 mm) was a reasonable tolerance for anchor bolt placement.

The SRSS of the 1/8 in. (3 mm) steel and the 3/8 in. (9.5 mm) concrete tolerances produces a combined tolerance requirement of 7/16 in. (11 mm). For each anchor bolt diameter and hole size, Table 2 shows the hole sizes required to provide the 7/16 in. (11 mm) combined tolerance. The hole sizes currently recommended by AISC for 1-3/4 in. (45 mm) and larger bolts are sufficient for the proposed tolerances. The hole sizes currently recommended by AISC for the 1 to 1-1/2 in. (25 to 38 mm) bolts are only 1/16 in. (1.6 mm) smaller than required to accommodate the proposed tolerances and can be left at their current recommended size. Only the hole sizes required for 3/4 and 7/8 in. (19 and 22 mm) bolts need to increase to accommodate the proposed tolerances. A change in AISC hole sizes for two bolt diameters and a change in the anchor bolt tolerance requirements would seem to be a reasonable compromise for both the steel and concrete industries.

**PLUMB TOLERANCE**

The proposed tolerances are based on a two-tiered tolerance concept: 1) control of the envelope; and 2) control of the rate of change within the envelope. Regardless of where the field engineer measures the anchor bolt (top, bottom, or middle), the distance from the anchor bolt to the reference line can’t be more than 3/8 in. (9.5 mm) if it is to allow the tolerances the steel erector needs.

If we just limit the bolt location, however, then theoretically the bolt could be out of plumb by as much as 3/4 in. (19 mm) from top of bolt to top of concrete (Fig. 3). Although these calculations indicate the location could vary that much and still fit, this would make it difficult to properly tighten and seat the nuts on the anchor bolts. To provide some margin for error, however, and to provide concrete contractors some plumb tolerance, it’s recommended that the plumb tolerance be set at 1/2 the maximum envelope tolerance or 3/16 in. (5 mm).

Two measurements at specific locations are needed to determine if the plumb tolerance is satisfied. Both of these measurements could also be used to verify that the location tolerance has been met.

**SPECIFICATION REQUIREMENTS FOR SETTING ANCHOR BOLTS**

Section 2.3.1 of ACI 301-05, “Specifications for Structural Concrete,”12 contains the following provisions related to embedded items:

2.3.1.10 Place sleeves, inserts, anchors, and embedded items required for adjoining work or for support of adjoining work before concrete placement.

2.3.1.11 Position and support expansion joint materials, waterstops, and other embedded items to prevent displacement. Fill voids in sleeves, inserts, and anchor slots temporarily with readily removable material to prevent entry of concrete into voids.

To help ensure that anchor bolts are set within the specified tolerances proposed in this article, the following additions are proposed for ACI 301:

2.3.1.10.1 Anchor bolts within a group shall be positioned using a template. Contractor shall construct the necessary templates from rigid materials or use templates provided by the erector of the adjoining work. Groups of anchor bolts that project more than 24 in. above the concrete surface shall be positioned with two templates. One template shall be located within 3 in. of the concrete surface, and the other template shall be located within 3 in. of the top surface of the anchor bolts. Contractor may develop an alternate plan for positioning groups of

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**TABLE 2: \_**

**ANCHOR BOLT HOLE SIZES REQUIRED TO ACCOMMODATE SUGGESTED TOLERANCES**

<table>
<thead>
<tr>
<th>Anchor bolt diameter, in.</th>
<th>3/4</th>
<th>7/8</th>
<th>1</th>
<th>1-1/4</th>
<th>1-1/2</th>
<th>1-3/4</th>
<th>2</th>
<th>2-1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current hole size, in.</td>
<td>1-5/16</td>
<td>1-9/16</td>
<td>1-13/16</td>
<td>2-1/16</td>
<td>2-5/16</td>
<td>2-3/4</td>
<td>3-1/4</td>
<td>3-3/4</td>
</tr>
<tr>
<td>Current hole clearance, in.</td>
<td>9/32</td>
<td>11/32</td>
<td>13/32</td>
<td>13/32</td>
<td>13/32</td>
<td>1/2</td>
<td>5/8</td>
<td>5/8</td>
</tr>
<tr>
<td>Steel tolerance, in.</td>
<td>±1/8</td>
<td>±1/8</td>
<td>±1/8</td>
<td>±1/8</td>
<td>±1/8</td>
<td>±1/8</td>
<td>±1/8</td>
<td>±1/8</td>
</tr>
<tr>
<td>Combined tolerance, in.</td>
<td>±7/16</td>
<td>±7/16</td>
<td>±7/16</td>
<td>±7/16</td>
<td>±7/16</td>
<td>±7/16</td>
<td>±7/16</td>
<td>±7/16</td>
</tr>
<tr>
<td>Suggestion</td>
<td>enlarge</td>
<td>enlarge</td>
<td>say ok</td>
<td>say ok</td>
<td>say ok</td>
<td>ok</td>
<td>ok</td>
<td>ok</td>
</tr>
</tbody>
</table>

Note: 1 in. = 25.4 mm
anchor bolts and submit it for approval by the Architect/Engineer.

2.3.1.10.2 Individual anchor bolts shall be installed in sleeves that permit adjustment of the anchor bolt position after the concrete has hardened. Contractor shall ensure that the sleeve is not filled during the concrete operation and that it is filled with grout after final positioning of the bolt. Contractor shall submit sleeve material for approval. Contractor may develop an alternate plan for positioning individual anchor bolts and submit it for approval by the Architect/Engineer.

References

12. ACI Committee 301, “Specifications for Structural Concrete (ACI 301-05),” American Concrete Institute, Farmington Hills, MI, 2005, 49 pp.

Selected for reader interest by the editors.

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