Introduction

Section 26.6.1.1 in the ACI 318 Building Code [2014] lists 9 design informational items that must be shown in construction documents, which includes project drawings and project specifications. Five items, 26.6.1.1(b), (d), (e), (f) and (g), are concerned with anchorage and splicing of reinforcement:

(b) Type, size, location requirements, detailing, and embedment of reinforcement;
(d) Location and length of lap splices;
(e) Type and location of mechanical splices;
(f) Type and location of end-bearing splices;
(g) Type and location of welded splices and other required welding of reinforcing bars.

This Technical Note focuses on Items “(b)” and “(d)”, i.e., on determining tension development lengths and tension lap splice lengths of reinforcing bars. A reinforcing bar must be “embedded” or “anchored” a sufficient distance or length in concrete so the bar is capable of developing its design strength. The basic premise is the “anchorage length” or “embedment length” must be equal to or greater than the required tension development length of the bar given by the Code.

Regarding the other items, provisions in other parts of the Code include performance requirements for mechanical and welded splices. Further information on mechanical splices is presented in the CRSI publication, Reinforcing Bars: Anchorages and Splices. Commentary Section R26.6.4 discusses welded splices. The ACI Code cites “Structural Welding Code – Reinforcing Steel (AWS D1.4/D1.4M:2011)” as the standard for welding reinforcing bars.

Development Length. The concept of “development length” of reinforcing bars was introduced in the 318-71 ACI Building Code [1971]. Provisions in the Code attempt to account for the many variables affecting the tension development length, $L_d$, of a straight bar. These variables include:

- Bar size
- Yield strength of the bar
- Compressive strength of the concrete
- Lateral spacing of the bars
- Concrete cover
- Bar position – “other” bar or “top” bar
- Type of concrete – normal weight or lightweight aggregate
- Presence of transverse reinforcement (stirrups or ties)
- Uncoated or epoxy-coated bars

Since the 1971 Code, major changes were made to the provisions for calculating $L_d$ in ACI 318-89 and -95 [1989, 1995]. No major technical revisions were introduced in the 1999 edition through the current 2014 edition, i.e., the provisions for calculating $L_d$ in the 2014 Code are essentially the same as those in the 1995, 1999, 2002, 2005, and 2011 Codes. This Technical Note discusses the provisions in ACI 318-14. Several examples are presented to demonstrate application of the two procedures for calculating $L_d$.

2014 ACI Building Code

Under ACI 318-14, as with the 1995, 1999, 2002, 2005, 2008, and 2011 Codes, the Architect/Engineer has a choice of two procedures for calculating $L_d$, which are presented in Code Sections 25.4.2.2 and 25.4.2.3.

Section 25.4.2.2. This section provides a short-cut approach for calculating $L_d$. The expressions for calculating $L_d$ are reproduced in Table 1, which is based on Table 25.4.2.2 of the Code. Use of Section 25.4.2.2 requires selection of the applicable expression from the four expressions given in Table 1. The applicable expression is based on:

- Bar size; expressions are given for #3 through #6 bars, and for #7 bars and larger.
The Code is clear as to the use or applicability of the $K_{tr}$ term. At the end of Section 25.4.2.3, following the equation for $K_{tr}$, the Code states:

“It shall be permitted to use $K_{tr} = 0$ as a design simplification even if transverse reinforcement is present.”

Thus, for those structural members without transverse reinforcement, or if the stirrups in beams or the ties in columns are ignored, the part of the denominator of Eq. 25.4.2.3a with the $K_{tr}$ term reduces to determining the value of $(c_b/d_b)$ for the particular conditions. The value $c_b$ is the smaller of: (1) one-half of the center-to-center spacing of the bars; and (2) the distance from center of the bar to the nearest concrete surface. The definition of $c_b$ presents new concepts. Center-to-center bar spacing (actually one-half of the center-to-center spacing) is used rather than the clear spacing, which is used in Section 25.4.2.2. Instead of concrete cover to the bar as used in Section 25.4.2.2 and prescribed in Section 20.6, cover as used in Section 25.4.2.2 is the distance from the center of the bar to the nearest concrete surface.

### Table 1 – Tension Development Length – Section 25.4.2.2 in ACI 318-14*

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Bar Sizes #3 to #6</th>
<th>Bar Sizes #7 to #18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear spacing of bars or wires being developed or lap spliced not less than $d_b$, clear cover not less than $d_b$, and stirrups or ties throughout $\ell_d$ not less than the Code minimum; or Clear spacing of bars or wires being developed or lap spliced not less than $2d_b$ and concrete cover not less than $d_b$</td>
<td>$f_y \psi \psi \psi \frac{2}{\lambda \sqrt{f_c^*}} d_b$ (a)</td>
<td>$f_y \psi \psi \psi \frac{2}{20 \lambda \sqrt{f_c^*}} d_b$ (b)</td>
</tr>
<tr>
<td>Other cases</td>
<td>$\frac{3f_y \psi \psi \psi}{50 \lambda \sqrt{f_c^*}} d_b$ (c)</td>
<td>$\frac{3f_y \psi \psi \psi}{40 \lambda \sqrt{f_c^*}} d_b$ (d)</td>
</tr>
</tbody>
</table>

* The notation is defined in the discussion of Code Section 25.4.2.2.

**Section 25.5.1.** This section presents the Code requirements for tension lap splices, \( \ell_{st} \). Table 2, which is based on Table 25.5.2.1 in the Code, defines the conditions under which lap Class A or B can be used, where Class A is defined as 1.00 \( \ell_d \), and Class B is defined as 1.3 \( \ell_d \).

Note that the 12 in. minimum is not imposed on \( \ell_d \) if it is used to determine lap lengths, so the Code imposes this limit after lap length has been calculated. For example, if \( \ell_d \) without the 12 in. minimum is determined to be 10 in., a Class A \( \ell_{st} \) would be 1.0 \times 10 = 10 in., increased to 12 in. and Class B \( \ell_{st} \) would be 1.3 \times 10 = 13 in. Other key points for lap splices:

- Tension lap splices are not permitted for #14 or #18 bars.
- Lap spliced reinforcing bars are permitted not to be in contact, but the maximum center-to-center spacing of lap splices bars cannot be the lesser of one-fifth the required lap splice length and 6 in.
- When calculated for lap splice lengths, \( \ell_d \) cannot be reduced by ratio of \( A_{s,provided}/A_{s,required} \).

### Examples

The provisions in Section 25.4.2.3 can be used advantageously for certain structural members and conditions—those applications that may be ignored if \( K_{tr} \) is regarded as being relevant only to structural members with transverse reinforcement. Generally, slabs, footings and walls, in which the reinforcing bars have relatively large concrete cover and spacing, will be the candidates where the use of Eq. 25.4.2.3a and taking \( K_{tr} = 0 \) will often result in significantly shorter values of \( \ell_d \).

**Example No. 1**

**Given:** An 8-in. thick slab is reinforced with #6 Grade 60 uncoated bars with a center-to-center spacing of 10 in. Concrete cover is 2 in.; normal-weight concrete with \( f_y = 4,000 \) psi.

**Find:** \( \ell_d \) and \( \ell_{st} \) for the #6 bars using Code Sections 25.4.2.2 and 25.4.2.3:

**Solution:**

(A) \( \ell_d \) by Section 25.4.2.2

Clear spacing of the bars = \( 10.0 - 0.75 = 9.25 \) in. or \( 12.3d_b \)

Concrete cover = 2.0 in. or \( 2.7d_b \).

From Table 1, under the heading “Conditions” with clear spacing > \( 2d_b \), concrete cover > \( d_b \), and bar size #6, the applicable expression is:

\[
\ell_d = \frac{f_y \psi \psi' \psi''}{25 \lambda \sqrt{\psi'}} d_b
\]

For this example, the factors \( \psi' = 1.0 \) and \( \psi'' = 1.0 \). Thus,

\[
\ell_d = \frac{(60,000)(1.0)(1.0)(0.75)}{25 (1.0)/\sqrt{4,000}} = 28.5 \text{ or } 29 \text{ in.}
\]

If the bars are epoxy-coated, the coating factor, \( \psi_e \), has to be determined. Because the concrete cover value of \( 2.7d_b \) is less than \( 3d_b \), the coating factor \( \psi_e = 1.5 \). Thus, for the #6 epoxy-coated bars:

\[
\ell_d = 1.5(28.5) = 42.7 \text{ or } 43 \text{ in.}
\]

(B) \( \ell_d \) by Section 25.4.2.3

Determine the value of \( c_b \) which is the smaller of:

\[
2.0 + 0.75 / 2 = 2.4 \text{ in.} \vee 10 / 2 = 5.0 \text{ in.}
\]

Determine the value of \( (c_b + K_{tr})/d_b \) where \( K_{tr} = 0 \):

\[
(c_b + K_{tr})/d_b = (2.4 + 0)/0.75 = 3.2 > 2.5, \text{ use } 2.5.
\]

Calculate \( \ell_d \) using Code Eq. 25.4.2.3a:

\[
\ell_d = \frac{3}{40} \frac{f_y \psi \psi' \psi'' \psi_e}{\lambda} \left( \frac{c_b + K_{tr}}{d_b} \right) d_b
\]

For this solution, the factor \( \psi_e = 0.8 \) for the #6 bars, and the factors \( \psi', \psi'' \), and \( \lambda \) are equal to 1.0.

\[
\ell_d = \frac{3}{40} \frac{60,000 (1.0)(1.0)(0.8)}{2.5} \approx 17.1 \text{ or } 17 \text{ in.}
\]

If the #6 bars are epoxy-coated, the coating factor \( \psi_e = 1.5 \) as determined in the preceding section:

\[
\ell_d = 1.5(17.1) = 25.6 \text{ or } 26 \text{ in.}
\]

*It is CRSI practice in technical publications to round the development and lap splice lengths up to the next whole number if the decimal is 0.2 or higher.
(C) $\ell_d$ by Section 25.4.2.2

For uncoated bars, $\ell_d = 28.5$ in.
- Class A $\ell_d = 1.0 \times 28.5 = 28.5 = 29$ in.
- Class B $\ell_d = 1.3 \times 28.5 = 37.1 = 37$ in.

For epoxy-coated bars, $\ell_d = 42.7$ in.
- Class A $\ell_d = 1.0 \times 42.7 = 42.7 = 43$ in.
- Class B $\ell_d = 1.3 \times 42.7 = 55.5 = 56$ in.

(D) $\ell_d$ by Section 25.4.2.3

For uncoated bars, $\ell_d = 17.1$ in.
- Class A $\ell_d = 1.0 \times 17.1 = 17.1 = 17$ in.
- Class B $\ell_d = 1.3 \times 17.1 = 22.2 = 23$ in.

For epoxy-coated bars, $\ell_d = 25.6$ in.
- Class A $\ell_d = 1.0 \times 25.6 = 25.6 = 26$ in.
- Class B $\ell_d = 1.3 \times 25.6 = 33.3 = 34$ in.

Comments: The results are summarized in Table 3. Note that $\ell_d$ for the uncoated #6 bars under Section 25.4.2.2 is 71% longer than the $\ell_d$ required by Section 25.4.2.3. For epoxy-coated #6 bars, Section 25.4.2.2 requires an $\ell_d$ which is 65% longer than the $\ell_d$ required by Section 25.4.2.3. Similar results were observed for Class A and Class B $\ell_d$.

<table>
<thead>
<tr>
<th>2014 Code Section</th>
<th>Tension Development Length, $\ell_d$ and Class A $\ell_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4.2.2</td>
<td>29 in.</td>
</tr>
<tr>
<td>25.4.2.3</td>
<td>17 in.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2014 Code Section</th>
<th>Class B $\ell_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4.2.2</td>
<td>37 in.</td>
</tr>
<tr>
<td>25.4.2.3</td>
<td>23 in.</td>
</tr>
</tbody>
</table>

A substantial reduction in reinforcement could be realized by using Section 25.4.2.3 if the 8-in. thick slab had large plan dimensions and the #6 bars at 10 in. were typical reinforcement. Savings in reinforcement would result from shorter lap splice lengths, because tension lap lengths are multiples of tension development length: Class A = 1.0 $\ell_d$ and Class B = 1.3 $\ell_d$.

The preceding calculated values of $\ell_d$, using Sections 25.4.2.2 and 25.4.2.3, would not be affected if the bars are lap spliced. Lap splicing would reduce the clear spacing by one bar diameter, i.e., the clear spacing = $10 – 0.75 = 8.5$ in. or 11.3 $d_p$, which is still greater than the clear spacing criterion of 2$d_p$ in Table 1 (Section 25.4.2.2). And with regard to Section 25.4.2.3, one-half of the c.–c. spacing of the bars = $(8.5 + 0.75) / 2 = 9.25 / 2 = 4.6$ in., which is still greater than the governing value of $c_b = 2.4$ in.

If the concrete cover to the #6 bars was 3/4 in. rather than 2 in., i.e., cast-in-place concrete not exposed to weather or earth (Code Section 20.6.1.3.1), the calculated $\ell_d$ by Section 25.4.2.2 or Section 25.4.2.3 would be the same. Confirming this:

Using Section 25.4.2.2, the applicable expression for $\ell_d$ from Table 1 is:

$$\ell_d = \frac{f_y}{25} \frac{d_p}{\sqrt{f_{c'}^e}}$$

As in the previous Section 25.4.2.2 solution, the factors $\psi_{f_y}$, $\psi_{d_p}$ and $\lambda$ are equal to 1.0. Thus,

$$\ell_d = \frac{60,000(1.0)(1.0)(0.75)}{25 (1.0) \sqrt{4000}} = 28.5 \text{ or } 29 \text{ in.}$$

Using Section 25.4.2.3 and Code Eq. 25.4.2.3a:

$c_b$ is smaller of $(0.75 + 0.75/2) = 1.1$ in. $\checkmark$ governs or 10/2 = 5 in.

c_b = 1.1 in.

$(c_b + K_{tr})/d_p = (1.1 + 0)/0.75 = 1.5 < 2.5$, use 1.5

$$\ell_d = \frac{3}{40} \frac{60,000 (1.0)(1.0)(0.8)}{\sqrt{4000} 1.5} = 28.5 \text{ or } 29 \text{ in.}$$

For 3/4 in. concrete cover, $\ell_d = 29$ in. using Section 25.4.2.2 or Section 25.4.2.3.

The rationale for $\ell_d$, being the same value, based on Section 25.4.2.2 or 25.4.2.3, is: the value of $(c_b + K_{tr})/d_p$ in Eq. 25.4.2.3a is equal to 1.5; then dividing the 3/40 in Eq. 25.4.2.3a by $(c_b + K_{tr})/d_p$ and multiplying by $\psi_s$ results in $((3/40)/1.5):0.8=0.04=1/25$, which is the constant in the expression from Table 1.

Example No. 2

Given: A spread footing has plan dimensions of 13'-6" x 13'-6" and an overall depth of 56 in. The footing is reinforced with 117 – #10 Grade 60 uncoated bars each way; normal-weight concrete with $f_{c'} = 3,000$ psi; the column dimension is 2'-6" square.
**Find:** Check the required tension development length of the #10 bars versus the available embedment.

**Solution:**

![Figure 1 – Spread Footing—Side Elevation](image)

**Figure 1 – Spread Footing—Side Elevation**

(A) $\ell_d$ by Section 25.4.2.2

Bar spacing and concrete cover:

\[
\text{c.–c. spacing #10 bars} = \frac{[(13.5)(12) - (2)(3) - 1.27]}{16} = 9.7 \text{ in.}
\]

Clear spacing = 9.7 – 1.27 = 8.4 in. or 6.6 $d_b$

Concrete cover = 3.0 / 1.27 = 2.4 $d_b$

The applicable expression from Table 1 is:

\[
\ell_d = \frac{f_y}{20 \lambda \sqrt{f'_c}} \frac{\psi_t \psi_e \psi_s}{d_b}
\]

For this example, the factors $\psi_t, \psi_e, \psi_s$ and $\lambda$ are equal to 1.0. Thus,

\[
\ell_d = \frac{60,000(1.0)(1.0)(0.75)}{20 (1.0) \sqrt{3,000}} = 69.6 \text{ or 70 in.}
\]

Maximum factored moment occurs at the face(s) of the column. Thus, the available embedment length for the #10 bars = (13.5)(12)/2 – (15 + 3) = 63 in. Because the available embedment length of 63 in. is less than the calculated $\ell_d$ of 70 in., the #10 straight bars are unacceptable according to Code Section 25.4.2.2. (If the reinforcement were changed to 22 – #9 bars, $\ell_d$, according to the Table 1 expression would be 62 in. Because $\ell_d$ of 62 in. is less than the available embedment, the #9 bars would be acceptable.)

(B) $\ell_d$ by Section 25.4.2.3

$c_b$ is smaller of (3.0 + 1.27/2) = 3.6 in. $\sqrt{\text{governs}}$

or 9.7/2 = 4.9 in.

\[(c_b + K_b)/d_b = (3.6 + 0)/1.27 = 2.8 > 2.5, \text{ use } 2.5\]

Calculate $\ell_d$ using Code Eq. 25.4.2.3a:

\[
\ell_d = \frac{3}{40 \lambda \sqrt{f'_c}} \frac{f_y}{c_b + K_b} d_b
\]

For this example, the factors $\psi_t, \psi_e, \psi_s$ and $\lambda$ are equal to 1.0. Thus,

\[
\ell_d = \frac{3}{40 (1.0) \sqrt{3,000}} \frac{60,000 (1.0)(1.0)(1.0)}{2.5} = 41.7 \text{ or 42 in.}
\]

Because the $\ell_d$ of 42 in. is less than the available embedment length of 63 in., the #10 bars are satisfactory according to Section 25.4.2.3. The results are summarized in Table 4.

**Table 4 – Results of Example No. 2**

<table>
<thead>
<tr>
<th>2014 Code Section</th>
<th>$\ell_d$</th>
<th>Available Embedment</th>
<th>Properly Anchored?</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4.2.2</td>
<td>70 in.</td>
<td>63 in.</td>
<td>No</td>
</tr>
<tr>
<td>25.4.2.3</td>
<td>42 in.</td>
<td>63 in.</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Example No. 3**

**Given:** This example demonstrates the use of Sections 25.4.2.2 and 25.4.2.3 for calculating $\ell_d$ for beam bars with stirrups. Grade 60, uncoated bottom bars in the interior span of a continuous beam. Other data are: $b_w = 24$ in.; $h = 30$ in.; concrete cover to the stirrups is 1.5 in.; normal-weight concrete with $f'_c = 4,000$ psi; #4 U-stirrups are spaced at 13 in. on center and provided throughout $\ell_d$.

![Figure 2 – Beam Cross-Section](image)

**Figure 2 – Beam Cross-Section**

**Find:** Compute the tension development length for the 5 – #10

**Solution:** From Figure 3, dimension X is the larger of:

\[2d_b = 2(0.5) = 1.0 \text{ in. } \sqrt{\text{governs}}\]

\[d_b/2 = 1.27/2 = 0.64 \text{ in.}\]
Bar spacing and concrete cover:
From side face of beam to center of outermost #10 bar, the distance is: 1.5 (cover) + 0.5 (stirrup diameter) + 1.0 (X) = 3.0 in.

c.–c. spacing of the 5 – #10 bars = (24 – (2)(3))/4 = 4.5 in.
Clear spacing = 4.5 – 1.27 = 3.2 in. or 2.5 in.
Concrete cover = 1.5 + 0.5 = 2.0 in. or 1.6 in.

(A) \( \ell_d \) by Section 25.4.2.2

The applicable expression from Table 1 is:
\[
\ell_d = \left( \frac{f_y \psi_t \psi_e \psi_s}{20 \lambda \sqrt{f_c'}} \right) d_b
\]

For this example, the factors \( \psi_t, \psi_e, \text{and } \lambda \) are equal to 1.0. Thus,
\[
\ell_d = \left( \frac{60,000(1.0)(1.0)(1.27)}{20(1.0)\sqrt{4,000}} \right) d_b
\]
\[
= 60.2 \text{ in.}
\]

(B) \( \ell_d \) by Section 25.4.2.3

\( c_b \) is smaller of 4.5/2 = 2.25 in. \( \checkmark \) governs or (1.5 + 0.5 + 1.27/2) = 2.6 in.

\( c_b = 2.25 \text{ in.} \)

\( K_{tr} = 40 A_t/sn = 40(2)(0.20)/13(5) = 0.25 \text{ in.} \)

\( (c_b + K_{tr})/d_b = (2.25 + 0.25)/1.27 = 2.0 \leq 2.5, \text{ use } 2.0 \)

Calculate \( \ell_d \) using Code Eq. 25.4.2.3a:
\[
\ell_d = \left( \frac{3 f_y \psi_t \psi_e \psi_s}{40 \lambda \sqrt{f_c'}} \right) \frac{c_b + K_{tr}}{d_b} d_b
\]

For this example, the factors \( \psi_t, \psi_e, \psi_s \) and \( \lambda \) are equal to 1.0. Thus,
\[
\ell_d = \left( \frac{3 f_y \psi_t \psi_e \psi_s}{40 \lambda \sqrt{f_c'}} \right) \frac{2.25 + 0.25}{2.0} 1.27 d_b
\]
\[
= 45.2 \text{ or } 46 \text{ in.}
\]

If \( K_{tr} \) is taken as zero:
\[
(c_b + K_{tr})/d_b = (2.25 + 0)/1.27 = 1.8 < 2.5, \text{ use } 1.8
\]

Then \( \ell_d = (45.2)(2.0)/1.8 = 50.2 \text{ or } 51 \text{ in.} \)

This example shows a reduction in \( \ell_d \) using Section 25.4.2.3 instead of Section 25.4.2.2 of 25% when taking the #4 stirrups into account, and 16% when the stirrups are neglected. The results are summarized in Table 5.

<table>
<thead>
<tr>
<th>2014 Code Section</th>
<th>( \ell_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.2.2</td>
<td>61 in.</td>
</tr>
<tr>
<td>25.4.2.3 (with ( K_{tr} = 0.25 ))</td>
<td>46 in.</td>
</tr>
<tr>
<td>25.4.2.3 (with ( K_{tr} = 0 ))</td>
<td>51 in.</td>
</tr>
</tbody>
</table>

Example No. 4

Given: Consider the base slab of a cantilever retaining wall. The concrete is normal weight with \( f_c' = 3,000 \text{ psi.} \)
Assume that the #11 bars, spaced at 8 in. c. to c., are required to resist the factored moment at Point A, i.e., the tension \( \ell_d \) cannot be reduced by the ratio of \( A_{t,s} \text{ (required)} / A_{t,s} \text{ (provided)} \).

Find:
Using Code Sections 25.4.2.2 and 25.4.2.3, calculate the tension \( \ell_d \) for the #11 Grade 60 uncoated bars in the top of the slab. And determine whether the bars can be anchored in the available embedment length.

Solution:
(A) \( \ell_d \) by Section 25.4.2.2

Clear spacing of the bars = 8.0 – 1.41 = 6.59 in. or 4.7 \( d_b \)

Concrete cover = 2 in. or 1.4 \( d_b \)

The applicable expression from Table 1 is:
\[
\ell_d = \left( \frac{3 f_y \psi_t \psi_e \psi_s}{20 \lambda \sqrt{f_c'}} \right) d_b
\]

For this example, the factors \( \psi_t, \psi_e, \psi_s \) and \( \lambda \) are equal to 1.0. Thus,
\[
\ell_d = \left( \frac{3 \times 60,000(1.0)(1.0)(1.0)}{40 \times 4,000(2.0)} \right) 1.27 d_b
\]
\[
= 45.2 \text{ or } 46 \text{ in.}
\]
Table 7 – Tension Development and Lap Splice Lengths for Bars in Walls, Slabs and Footings (ACI 25.4.2.3)

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Lap Class</th>
<th>Concrete Cover = 0.75 in.</th>
<th>Concrete Cover = 1.50 in.</th>
<th>Concrete Cover = 2.00 in.</th>
<th>Concrete Cover = 3.00 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Uncoted</td>
<td>Epoxy-Coated</td>
<td>Uncoted</td>
<td>Epoxy-Coated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Top</td>
<td>Other</td>
<td>Top</td>
<td>Other</td>
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<tr>
<td>B</td>
<td>#3</td>
<td>13</td>
<td>12</td>
<td>17</td>
<td>15</td>
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<td>A</td>
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<td>128</td>
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Notes:
1. Tabulated values are based on a minimum yield strength of 60,000 psi and normal-weight concrete. Lengths are in inches.
2. Tension development lengths and tension lap splice lengths are calculated per ACI 318-14, Sections 25.4.2.3 and 25.5.1, respectively, with bar sizes limited to #3 through #11.
3. When the variable \( \psi_s \) from ACI 25.4.2.3 was calculated, it was assumed that concrete cover controlled. That is, c-c. spacing was assumed to be greater than \( 1.0 \, \psi_s \) plus twice the concrete cover.
4. Lap splice lengths (minimum of 12 inches) are multiples of tension development lengths; Class A = 1.0 \( \ell_d \) and Class B = 1.3 \( \ell_d \) (ACI 318 25.5.1). When determining the lap splice length, \( \ell_d \) is calculated without the 12-inch minimum of ACI 25.4.2.1.
5. Top bars are horizontal bars with more than 12 inches of concrete cast below the bars.
6. For epoxy-coated bars, if the c-c. spacing is at least \( 7.0 \, \psi_s \) and the concrete cover is at least \( 3.0 \, \psi_s \), then lengths may be multiplied by 0.918 (for top bars) or 0.8 (for other bars).
7. For Grade 75 reinforcing bars, multiply the tabulated values by 1.25. For Grade 80 reinforcing bars, multiply the tabulated values by 1.33.
8. For lightweight concrete, divide the tabulated values by 0.75.

For this example, the bar location factor \( \psi_s = 1.3 \) for top bars, and the factors \( \psi_s \) and \( \lambda \) are equal to 1.0. Thus

\[
\ell_d = \frac{60,000(1.3)(1.0)(1.41)}{20 (1.0) \sqrt[3]{3,000}} = 100.4 \text{ or } 101 \text{ in.}
\]

The available embedment length to the left of Point A is 6 ft.-9 in. or 81 in. Because the required \( \ell_d = 101 \text{ in.} \) is greater than the available embedment length, the #11 bars cannot be anchored as straight bars according to Section 12.2.2.
(B) $\ell_d$ by Section 25.4.2.3

$c_b$ is smaller of $(2.0 + 1.41/2) = 2.7$ in. $\sqrt{g}$ governs or $8/2 = 4.0$ in.

$c_b = 2.7$ in.

$(c_b + K_{tr})/d_b = (2.7 + 0)/1.41 = 1.9 < 2.5$, use 1.9

Calculate $\ell_d$ using Code Eq. 25.4.2.3a:

$$\ell_d = \frac{3 \sqrt{f_{c'}}}{40 \lambda \sqrt{f_{c'}}} \cdot \frac{\psi_t \psi_e \psi_s}{d_b} \cdot \left( \frac{c_b + K_{tr}}{d_b} \right)$$

For this example, the bar location factor $\psi_t = 1.3$, and the factors $\psi_e$, $\psi_s$ and $\lambda$ are equal to 1.0. Thus,

$$\ell_d = \frac{3 \cdot 60,000 \cdot (1.3)1.0(1.0)}{40 (1.0)} \cdot \frac{1.9}{3,000} \cdot 1.41 = 79.3 \text{ or } 80 \text{ in.}$$

Because $\ell_d = 80 \text{ in.}$ does not exceed the available embedment length of 81 in., the #11 bars can be anchored as straight bars. This example clearly demonstrates the significant reduction in $\ell_d$ that is possible, under certain conditions, by using Section 25.4.2.3 instead of Section 25.4.2.2. The computed $\ell_d$ of 80 in. by Section 25.4.2.3 is 21% shorter than the 101 in. computed by Section 25.4.2.2. The results are summarized in Table 6.

<table>
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<tr>
<th>2014 Code Section</th>
<th>$\ell_d$</th>
<th>Available Embedment</th>
<th>Properly Anchored?</th>
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</thead>
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<tr>
<td>25.4.2.2</td>
<td>101 in.</td>
<td>81 in.</td>
<td>No</td>
</tr>
<tr>
<td>25.4.2.3</td>
<td>80 in.</td>
<td>81 in.</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Tabular Values Based on Section 25.4.2.3**

Tables 7 and 8 give values of $\ell_d$, based on Code Section 25.4.2.3 and Eq. 25.4.2.3a, for walls, slabs and footings. The values for "Lap Class A" are also the values of $\ell_d$, because the required lap length for a Class A tension lap splice is $1.0 \ell_d$.

An important restriction on the use of Tables 7 and 8 is described in Note 3, i.e., it is assumed that the value "$c_b$" in the quantity, $(c_b + K_{tr})/d_b$, in Code Eq. 25.4.2.3a is governed by concrete cover rather than by one-half the center-to-center spacing of the bars.

The preceding examples are re-considered using Tables 7 and 8, and identified with a "T".

**Example No. 1T** For the slab with #6 bars spaced at 10 in. c.–c., concrete cover of 2 in., normal weight concrete with $f_{c'} = 4,000$ psi...

**Example No. 2T** For the spread footing with uncoated #10 bars and concrete cover of 3 in. to the layer of bars nearest the bottom, normal-weight concrete with $f_{c'} = 3,000$ psi...

**Example No. 3T** Tables 7 and 8 are not intended for and consequently are not applicable for closely-spaced bars in beams. For the beam in Example 3, the value of $c_b$ would be governed by one-half of the c.–c. spacing of the bars, i.e., 2.25 in., rather than by the concrete cover plus one-half of a bar diameter, i.e., 2.6 in.

**Example No. 4T** For the base slab of the cantilever retaining wall with uncoated #11 bars spaced at 8 in. c.–c., concrete cover of 2 in., normal-weight concrete with $f_{c'} = 3,000$ psi...

**Summary**

This Technical Note discusses the provisions in Sections 25.4.2.2 and 25.4.2.3 of the 2014 ACI Building Code for determining the tension development lengths, $\ell_d$, of reinforcing bars. Several examples are presented to complement the discussion. The examples serve to identify some of the conditions and the structural members for which the more rigorous provisions in Section 25.4.2.3 can be used advantageously.
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