Introduction

Section 1.2.1 in the 2002 ACI Building Code lists 13 items that must be shown on design drawings or in project specifications. Two items, 1.2.1(h) and 1.2.1(i), are concerned with anchorage and splicing of reinforcement:

(h) Anchorage length of reinforcement and location and length of lap splices

(i) Type and location of mechanical and welded splices of reinforcement

This report focuses on Item “(h)”, i.e., on determining tension development lengths and tension lap splice lengths of reinforcing bars. “Anchorage length” can also be called “embedment length”. A reinforcing bar must be “embedded” or “anchored” a sufficient distance or length in concrete so the bar will be 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.


Development Length. The concept of “development length” of reinforcing bars was introduced in the 1971 ACI Building Code. Provisions in Chapter 12 of 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
- Uncoated or epoxy-coated bars

Since the 1971 Code, major changes were made to the provisions for calculating $L_d$ in the 1989 and 1995 editions. No technical revisions were introduced in the 1999 edition or in the current 2002 edition, i.e., the provisions for calculating $L_d$ in the 2002 Code are the same as those in the 1995 and 1999 Codes. This report discusses the provisions in ACI 318-02. Several examples are presented to demonstrate application of the two procedures for calculating $L_d$.

2002 ACI Building Code

Under ACI 318-02, as with the 1995 and 1999 Codes, the Architect/Engineer has a choice of two procedures for calculating $L_d$, which are presented in Code Sections 12.2.2 and 12.2.3. There were actually three acceptable procedures in the 1995 and 1999 Codes, because Commentary Section R12.2 in those Code editions sanctioned the use of the provisions in the 1989 Code. This reference to the 1989 Code was removed in Commentary Section R12.2 of the 2002 Code. Therefore, discussion of Sections 12.2.2 and 12.2.3 in ACI 318-02 is the thrust of this report.

Section 12.2.2. This section provides a short-cut approach for calculating $L_d$. The expressions for calculating $L_d$ are reproduced in Table 1. Use of Section 12.2.2 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 #10 through #19 bars, and for #22 bars and larger.
- Concrete cover and clear spacing of the bars are compared with the limiting values under the “Conditions” heading of Table 1.
- If the structural member is a beam or a column, another consideration is the amount of stirrups or ties being provided throughout the distance $L_d$.

Section 12.2.3. This section presents a general approach in which particular values of concrete cover and bar spacing as well as the amount of transverse reinforcement is taken into account. Code Eq. 12-1 in Section 12.2.3 includes the effects of several of the major variables:

* Due to equipment limitations, the notation, $L_d$, is used throughout this report for the tension development length of a straight bar rather than ACI 318’s script ell.

† See “Notes on Soft Metric Reinforcing Bars” on Page 8 of this report.
Atr = 1.5 for epoxy-coated bars with concrete

\( \beta = 1.0 \) for uncoated bars

\( \alpha = 1.0 \) for concrete cover not less than \( 2d_b \) and concrete cover not less than \( d_b \)

Clear spacing of bars being developed or lap spliced not less than \( 2d_b \) and concrete cover not less than \( d_b \)

Other cases

\( L_d = 0.04 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} \)

\( L_d = 0.05 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} \)

\( L_d = 0.06 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} \)

\( L_d = 0.075 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} \)

* The notation is defined in the discussion of Code Section 12.2.3 and Eq. 12-1.

The quantity \( (c + K_{tr}) / d_b \) is limited to a maximum value of 2.5.

Where:

\( f_y \) = specified yield strength of reinforcing bars, psi

\( \alpha = 1.3 \) for “top” bars

\( \alpha = 1.0 \) for “other” bars

\( \beta = 1.0 \) for uncoated bars

\( \beta = 1.5 \) for epoxy-coated bars with concrete cover < 3 \( d_b \), or clear spacing < \( 6d_b \)

\( \beta = 1.2 \) for epoxy-coated bars with concrete cover \( \geq 3d_b \), and clear spacing \( \geq 6d_b \)

The product of \( \alpha \beta \) need not be taken greater than 1.7.

\( \gamma = 0.8 \) for bar sizes \#10 - \#19

\( \gamma = 1.0 \) for bar sizes \#22 - \#57

\( \lambda = 1.0 \) for normal-weight concrete

\( d_b \) = nominal diameter of the bar, in.

\( f_c'' \) = specified compressive strength of concrete, psi

\( c \) = see discussion in text, in.

\( K_{tr} = A_{tr} f_{yt} / 1500 \text{ sn, in.} \)

\( A_{tr} = \text{total area of all transverse reinforcement within the spacing } s \), which crosses the potential plane of splitting through the bars being developed, in.

\( f_{yt} = \text{specified yield strength of transverse reinforcement, psi} \)

\( s = \text{maximum center-to-center spacing of transverse reinforcement within } L_d \), in.

\( n = \text{number of bars being developed along the plane of splitting} \)

Table 1 Tension Development Length – Section 12.2.2 in ACI 318-02 *

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Bar Sizes #10 – #19</th>
<th>Bar Sizes #22 – #57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear spacing of bars being developed or lap spliced not less than ( d_b ), concrete cover not less than ( d_b ), and stirrups or ties throughout. ( L_d ) not less than the code minimum.</td>
<td>( L_d = 0.04 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} )</td>
<td>( L_d = 0.05 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} )</td>
</tr>
<tr>
<td>Clear spacing of bars being developed or lap spliced not less than ( 2d_b ) and concrete cover not less than ( d_b )</td>
<td>( L_d = 0.06 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} )</td>
<td>( L_d = 0.075 f_y \alpha \beta \lambda (d_b) / \sqrt{f_c''} )</td>
</tr>
<tr>
<td>Other cases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Presumably, the presence of the \( K_{tr} \) term in the denominator of Eq. 12-1 has an influence for such treatment.

The Code is clear as to the use or applicability of the \( K_{tr} \) term. At the end of Section 12.2.4, following the equation for \( K_{tr} \), and the definitions of the terms making up the equation for \( K_{tr} \), the Code states:

“\( K_{tr} = 0 \) 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. 12-1 with the \( K_{tr} \) term reduces to determining the value of \( (c / d_b) \) for the particular conditions. The value \( c \) is the smaller of: (1) one-half of the center-to-center spacing of the bars; or (2) the concrete cover to the bar plus \( d_b / 2 \). The definition of \( c \) poses new wrinkles. Center-to-center bar spacing (actually one-half of the c.-c. spacing) is used rather than the clear spacing which is used in Section 12.2.2. Instead of concrete cover to the bar as used in Section 12.2.2 and prescribed in Section 7.6, cover as used in Section 12.2.4 is the distance from the center of the bar to the nearest concrete surface.

Examples

The provisions in Section 12.2.3 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. 12-1 and taking \( K_{tr} = 0 \) will often result in significantly shorter values of \( L_d \).

Example No. 1. An 8-in. thick slab is reinforced with \#19 Grade 60 uncoated bars with a center-to-center spacing of 10 in. Concrete cover is 2 in.; normal-weight concrete with \( f_c'' = 4,000 \text{ psi} \).

Compute \( L_d \) for the \#19 bars using Code Sections 12.2.2 and 12.2.3:
**L_d by Section 12.2.2**

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

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

From Table 1; under heading “Conditions” with clear spacing > 2.0 \(d_b\), concrete cover > \(d_b\), and bar size #19, the applicable expression is:

\[
L_d = 0.04 f_y \frac{\alpha \beta \gamma \lambda}{\sqrt{f'_c}}
\]

For this example, the factors \(\alpha, \beta, \gamma\) and \(\lambda\) are equal to 1.0. Thus,

\[
L_d = 0.04 (60,000)(1.0)(1.0)(0.75)/\sqrt{4000} = 28.5 \text{ or 29 in.}^*
\]

If the bars are epoxy-coated, the coating factor, \(\beta\), has to be determined from Section 12.2.4. Since the concrete cover value of 2.7 \(d_b\) is less than the governing value of \(c\) = 2.4 in.

Thus, the #19 epoxy-coated bars:

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

**L_d by Section 12.2.3**

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

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

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

\[
(c + K_{tr}) / d_b = (2.37 + 0) / 0.75 = 3.2 > 2.5, \text{ use 2.5}
\]

Calculate \(L_d\) using Code Eq. 12-1:

\[
L_d = 0.075 f_y \frac{\alpha \beta \gamma \lambda (d_b)}{\sqrt{f'_c}} \left[ (c + K_{tr})/d_b \right]
\]

For this solution, the factor \(\gamma = 0.8\) for the #19 bars, and the factors \(\alpha, \beta, \lambda\) are equal to 1.0. Thus,

\[
L_d = 0.075 (60,000)(1.0)(1.0)(0.8)(1.0)(0.75)/\sqrt{4000} (2.5)
\]

= 17.1 or 17 in.

If the #19 bars are epoxy-coated, the coating factor \(\beta\) is 1.5 as determined in the preceding solution:

\[
L_d = 1.5 (17.1) = 25.7 \text{ or 26 in.}
\]

The results are summarized in Table 2. Note that \(L_d\) for the uncoated #19 bars under Section 12.2.2 is 71% longer than the length required by Section 12.2.3. For epoxy-coated #19 bars, Section 12.2.2 requires a \(L_d\) which is 65% longer than the length required by Section 12.2.3.

**Table 2 Results of Example No. 1**

<table>
<thead>
<tr>
<th>2002 Code Section</th>
<th>Tension Development Length, (L_d), for #19 Bars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uncoated</td>
</tr>
<tr>
<td>12.2.2</td>
<td>29 in.</td>
</tr>
<tr>
<td>12.2.3</td>
<td>17 in.</td>
</tr>
</tbody>
</table>

A substantial reduction in reinforcement could be realized by using Section 12.2.3 if the 8-in. thick slab had large plan dimensions and the #19 bars at 10 in. were typical reinforcement. Savings in reinforcement would result from shorter lap splice lengths since tension lap lengths are multiples of tension development length: Class A = 1.0 \(L_d\) and Class B = 1.3 \(L_d\).

The preceding calculated values of \(L_d\), using Sections 12.2.2 and 12.2.3, 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 – 0.75 = 8.5 in. or 11.3 \(d_b\), which is still greater than the clear spacing criterion of 2 \(d_b\) in Table 1 (Section 12.2.2). And with regard to Section 12.2.3, 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 \(c\) = 2.4 in.

If the concrete cover to the #19 bars was 3/4 in. rather than 2 in., i.e., cast-in-place concrete not exposed to weather or earth (Code Section 7.7.1-c), the calculated \(L_d\) by Section 12.2.2 or Section 12.2.3 would be the same. Confirming the proposition:

Using Section 12.2.2, the applicable expression for \(L_d\) from Table 1 is:

\[
L_d = 0.04 f_y \frac{\alpha \beta \gamma \lambda (d_b)}{\sqrt{f'_c}}
\]

As in the previous Section 12.2.2 solution, the factors \(\alpha, \beta, \gamma\) and \(\lambda\) are equal to 1.0. Thus,

\[
L_d = 0.04 (60,000)(1.0)(1.0)(0.75)/\sqrt{4000} = 28.5 \text{ or 29 in.}
\]

Using Section 12.2.3 and Code Eq. 12-1:

\[
(c + K_{tr}) / d_b = (1.1 + 0) / 0.75 = 1.5 < 2.5, \text{ use 1.5}
\]

\[
L_d = 0.075 f_y \frac{\alpha \beta \gamma \lambda (d_b)}{\sqrt{f'_c}} \left[ (c + K_{tr})/d_b \right]
\]

Here again, as in the previous Section 12.2.3 solution, the factor \(\gamma = 0.8\) for the #19 bars, and the factors \(\alpha, \beta, \lambda\) are equal to 1.0. Thus,

\[
L_d = 0.075 (60,000)(1.0)(1.0)(0.8)(1.0)(0.75)/\sqrt{4000} (1.5)
\]

= 28.5 or 29 in.

For 3/4 in. concrete cover, \(L_d = 29\) in. using Section 12.2.2 or Section 12.2.3.

The rationale for \(L_d\) being the same value, based on Section 12.2.2 or 12.2.3, is: the value of \((c + K_{tr}) / d_b\) in Eq. 12-1 is equal to 1.5; then dividing the constant 0.075 in Eq. 12-1 by \((c + K_{tr}) / d_b\) and multiplying by \(\gamma\) results in \((0.075 / 1.5)(0.8) = 0.04\), which is the constant in the expression from Table 1.

**Example No. 2.** A spread footing has plan dimensions of 13’-6” x 13’-6” and an overall depth of 56 in. The footing is reinforced with 17 – #32 Grade 60 uncoated bars each way; normal-weight concrete with \(f'_c = 3,000\) psi; the column dimensions are 30 in. x 30 in.

Check the required tension development length of the #32 bars versus the available embedment.

* It is CRSI practice in technical publications to round the values of \(L_d\) up to the next whole number if the decimal is 0.2 or higher.
Bar spacing and concrete cover:

c−c. spacing #32 bars: 
\[ \frac{(13.5)(12) - (2)(3) - 1.27}{16} = 9.7 \text{ in.} \]
Clear spacing: 
\[ 9.7 - 1.27 = 8.4 \text{ in. or } 6.6 \, d_b \]
Concrete cover: 
\[ 3.0 / 1.27 = 2.4 \, d_b \]

**L_d by Section 12.2.2**

The applicable expression from Table 1 is:

\[ L_d = 0.05 \, f_y \, \alpha \beta \lambda (d_b) / \sqrt{f'_c} \]

For this example, the factors \( \alpha, \beta, \gamma \) and \( \lambda \) are equal to 1.0. Thus,

\[ L_d = 0.05 (60,000)(1.0)(1.0)(1.0)(1.27) / \sqrt{3000} \]
\[ = 69.6 \text{ or } 70 \text{ in.} \]

Maximum factored moment occurs at the face(s) of the column. Thus, the available embedment length for the #32 bars is 63 in. Since the available embedment length of 63 in. is less than the calculated \( L_d \) of 70 in., the #32 straight bars are unacceptable according to Code Section 12.2.2. (If the reinforcement were changed to 22−#29 bars, \( L_d \) according to the Table 1 expression would be 62 in. Since \( L_d \) of 62 in. is less than the available embedment, the #29 bars would be acceptable.)

**L_d by Section 12.2.3**

\( c \) is smaller of (3.0 + 1.27)/2 = 3.6 in. \( \checkmark \) governs

\( (c + K_{tr}) / d_b = (3.6 + 0)/1.27 = 2.8 > 2.5 \), use 2.5

Calculate \( L_d \) using Code Eq. 12-1:

\[ L_d = 0.075 \, f_y \, \alpha \beta \gamma \lambda (d_b) / \sqrt{f'_c} \left[ (c + K_{tr}) / d_b \right] \]

For this example, the factors \( \alpha, \beta, \gamma, \) and \( \lambda \) are equal to 1.0. Thus,

\[ L_d = 0.075 (60,000)(1.0)(1.0)(1.0)(1.0)(1.27) / \sqrt{3000} (2.5) \]
\[ = 41.7 \text{ or } 42 \text{ in.} \]

Since the \( L_d \) of 42 in. is less than the available embedment length of 63 in., the #32 bars are satisfactory according to Section 12.2.3. The results are summarized in Table 3.
**L_d by Section 12.2.2**

The applicable expression from Table 1 is:

\[ L_d = 0.05 \frac{f_y \alpha \beta \lambda (d_b)}{\sqrt{f'_c}} \]

For this example, the factors \( \alpha, \beta, \) and \( \lambda \) are equal to 1.0. Thus,

\[ L_d = 0.05(60,000)(1.0)(1.0)(1.27) / \sqrt{4000} = 60.2 \text{ or } 61 \text{ in.} \]

**L_d by Section 12.2.3**

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

\[ K_{tr} = A_{tr} f_y / (1500 \text{ sn}) \]

\[ = 2 (0.20) (60,000) / [1500 (13) (5)] = 0.25 \text{ in.} \]

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

Calculate \( L_d \) using Code Eq. 12-1:

\[ L_d = 0.075 \frac{f_y \alpha \beta \gamma \lambda (d_b)}{\sqrt{f'_c} \left[ \frac{(c + K_{tr})}{d_b} \right]} \]

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

\[ L_d = 0.075(60,000)(1.0)(1.0)(1.0)(1.0)(1.27)/\sqrt{3000}(2.0) = 45.2 \text{ or } 46 \text{ in.} \]

If \( K_{tr} \) is taken as zero:

\[ (c + K_{tr})/d_b = (2.25 + 0)/1.27 = 1.8 < 2.5, \text{ use } 1.8 \]

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

This example shows a reduction in \( L_d \) using Section 12.2.3 instead of Section 12.2.2 — of 25% when taking the #13 stirrups into account, and 16% when the stirrups are neglected. The results are summarized in Table 4.

**Table 4  Results of Example No. 3**

<table>
<thead>
<tr>
<th>2002 Code Section</th>
<th>( L_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.2.2</td>
<td>61 in.</td>
</tr>
<tr>
<td>12.2.3 (with ( K_{tr} = 0.25 ))</td>
<td>46 in.</td>
</tr>
<tr>
<td>12.2.3 (with ( K_{tr} = 0 ))</td>
<td>51 in.</td>
</tr>
</tbody>
</table>

**Example No. 4.** Consider the base slab of a cantilever retaining wall. Using Code Sections 12.2.2 and 12.2.3, calculate the tension \( L_d \) for the #36 Grade 60 uncoated bars in the top of the slab. And determine whether the bars can be anchored in the available embedment length. The concrete is normal-weight with \( f'_c = 3,000 \text{ psi.} \) Assume that the #36 bars, spaced at 8 in. c. to c., are required to resist the factored moment at Point A, i.e., the tension \( L_d \) cannot be reduced by the ratio of \( A_s \) (required) to \( A_s \) (provided).

**L_d by Section 12.2.2**

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:

\[ L_d = 0.075 \frac{f_y \alpha \beta \gamma \lambda (d_b)}{\sqrt{f'_c}} \]

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

\[ L_d = 0.075(60,000)(1.3)(1.0)(1.0)(1.41)/\sqrt{3000}(2.0) = 150.6 \text{ or } 151 \text{ in.} \]

The available embedment length to the left of Point A is 81 in. Since the required \( L_d = 151 \text{ in.} \) is greater than the available embedment length, the #36 bars cannot be anchored as straight bars according to Section 12.2.2.

**L_d by Section 12.2.3**

\( c \) is smaller of \( (2.0 + 1.41/2) = 2.7 \text{ in.} \). \( \checkmark \) governs

\[ (c + K_{tr})/d_b = (2.7 + 0)/1.41 = 1.92 < 2.5, \text{ use } 1.92 \]

Calculate \( L_d \) using Code Eq. 12-1:

\[ L_d = 0.075 \frac{f_y \alpha \beta \gamma \lambda (d_b)}{\sqrt{f'_c} \left[ \frac{(c + K_{tr})}{d_b} \right]} \]

For this example, the bar location factor \( \alpha = 1.3 \), and the factors \( \beta, \gamma \) and \( \lambda \) are equal to 1.0. Thus,

\[ L_d = 0.075(60,000)(1.3)(1.0)(1.0)(1.0)(1.0)/\sqrt{3000}(1.92) = 78.4 \text{ or } 79 \text{ in.} \]

Since \( L_d = 79 \text{ in.} \) does not exceed the available embedment length of 81 in., the #36 bars can be anchored as straight bars. This example clearly demonstrates the significant reduction in \( L_d \) that is possible, under certain conditions, by using Section 12.2.3 instead of Section 12.2.2. The computed \( L_d \) of 79 in. by Section 12.2.3 is 48% shorter than the 151 in. computed by Section 12.2.2. The results are summarized in Table 5.

**Table 5  Results of Example No. 4**

<table>
<thead>
<tr>
<th>2002 Code Section</th>
<th>( L_d )</th>
<th>Available Embedment</th>
<th>Properly Anchored?</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.2.2</td>
<td>151 in.</td>
<td>81 in.</td>
<td>No</td>
</tr>
<tr>
<td>12.2.3</td>
<td>79 in.</td>
<td>81 in.</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Tabular Values Based on Section 12.2.3

Tables 6 and 7 give values of \( L_d \), based on Code Section 12.2.3 and Eq. 12-1, for walls and slabs. The values for “Lap Class A” are also the values of \( L_d \), because the required lap length for a Class A tension lap splice is 1.0 \( L_d \).

An important restriction on the use of the Tables 6 and 7 is described in Note 4 under each table, i.e., it is assumed that the value “c” in the quantity, \( (c + K_{tr}) / d_b \), in Code Eq. 12-1 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 6 and 7.

Example 1. For the slab with \#19 bars spaced at 10 in. c.–c., concrete cover of 2 in., normal-weight concrete with \( f'_c = 4,000 \) psi...

Enter Table 7; for Lap Class A and “other” bars:

\[
L_d = 17 \text{ in. for uncoated bars} \\
L_d = 26 \text{ in. for epoxy-coated bars}
\]

By inspection, the tabulated values are valid for this example because one-half of the c.–c. bar spacing = 5 in., which is much greater than the concrete cover plus one-half of a bar diameter, i.e., 2.4 in.

For the second part of Example 1, the concrete cover is only 0.75 in. From Table 7 for Lap Class A and “other” bars:

\[
L_d = 29 \text{ in. for uncoated bars}
\]

### Table 6  Tension Development and Lap Splice Lengths for Bars in Walls and Slabs

<table>
<thead>
<tr>
<th>( f'_c = 3000 \text{ psi} )</th>
<th>Concrete Cover = 0.75 in.</th>
<th>Concrete Cover = 1.00 in.</th>
<th>Concrete Cover = 1.50 in.</th>
<th>Concrete Cover = 2.00 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>| Top</td>
<td>Other</td>
<td>Top</td>
<td>Other</td>
<td>Top</td>
</tr>
<tr>
<td>#10 A</td>
<td>13</td>
<td>12</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>17</td>
<td>16</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>#13 A</td>
<td>22</td>
<td>17</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>28</td>
<td>22</td>
<td>37</td>
<td>32</td>
</tr>
<tr>
<td>#16 A</td>
<td>32</td>
<td>24</td>
<td>41</td>
<td>37</td>
</tr>
<tr>
<td>B</td>
<td>41</td>
<td>32</td>
<td>54</td>
<td>47</td>
</tr>
<tr>
<td>#19 A</td>
<td>43</td>
<td>33</td>
<td>56</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>56</td>
<td>43</td>
<td>73</td>
<td>64</td>
</tr>
<tr>
<td>#22 A</td>
<td>69</td>
<td>53</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>B</td>
<td>90</td>
<td>69</td>
<td>117</td>
<td>104</td>
</tr>
<tr>
<td>#25 A</td>
<td>86</td>
<td>66</td>
<td>112</td>
<td>99</td>
</tr>
<tr>
<td>B</td>
<td>111</td>
<td>86</td>
<td>146</td>
<td>128</td>
</tr>
<tr>
<td>#29 A</td>
<td>104</td>
<td>80</td>
<td>136</td>
<td>120</td>
</tr>
<tr>
<td>B</td>
<td>135</td>
<td>104</td>
<td>176</td>
<td>155</td>
</tr>
<tr>
<td>#32 A</td>
<td>125</td>
<td>96</td>
<td>163</td>
<td>144</td>
</tr>
<tr>
<td>B</td>
<td>162</td>
<td>125</td>
<td>212</td>
<td>187</td>
</tr>
<tr>
<td>#36 A</td>
<td>146</td>
<td>113</td>
<td>191</td>
<td>169</td>
</tr>
<tr>
<td>B</td>
<td>190</td>
<td>146</td>
<td>248</td>
<td>219</td>
</tr>
</tbody>
</table>

Notes:

1. Tabulated values are based on Grade 60 reinforcing bars and normal-weight concrete. Lengths are in inches.
2. Tension development lengths and tension lap splice lengths are calculated per ACI 318-02, Sections 12.2.3 and 12.15, respectively.
3. Lap splice lengths are multiples of tension development lengths; Class A = 1.0 \( L_d \) and Class B = 1.3 \( L_d \) (ACI 318-02, Section 12.15.1).
4. Center-to-center spacing of bars is assumed to be greater than twice the concrete cover plus one bar diameter, so that the value of “c” is governed by concrete cover rather than by bar spacing.
5. Bar sizes #43 and #57 were intentionally omitted from this table.
6. Top bars are horizontal bars with more than 12 in. of concrete cast below the bars.
7. For epoxy-coated “top” bars, where applicable, a value of 1.7 is used for the product \( \alpha \beta \) in Eq. 12-1 (ACI 318-02, Section 12.2.4).
8. For lightweight aggregate concrete, multiply the tabulated values by 1.3.
Example 2. For the spread footing with uncoated #32 bars and concrete cover of 3 in. to the layer of bars nearest the bottom, normal-weight concrete with $f'_c = 3,000$ psi...

Table 6 is not applicable. Values of $L_d$ have not been tabulated for 3 in. of concrete cover to avoid mis-use.

Example 3. Tables 6 and 7 are not intended for and consequently are not applicable for closely-spaced bars in beams. For the beam in Example 3, the value of $c$ 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.

Table 7  Tension Development and Lap Splice Lengths for Bars in Walls and Slabs

$\ f'_c = 4000 \ \text{psi}$

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Lap Class</th>
<th>Concrete Cover = 0.75 in.</th>
<th>Concrete Cover = 1.00 in.</th>
<th>Concrete Cover = 1.50 in.</th>
<th>Concrete Cover = 2.00 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Uncoated</td>
<td>Epoxy-Coated</td>
<td>Uncoated</td>
<td>Epoxy-Coated</td>
</tr>
<tr>
<td>#10</td>
<td>A</td>
<td>12</td>
<td>12</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>16</td>
<td>16</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>#13</td>
<td>A</td>
<td>19</td>
<td>15</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>24</td>
<td>19</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>#16</td>
<td>A</td>
<td>28</td>
<td>21</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>36</td>
<td>28</td>
<td>47</td>
<td>41</td>
</tr>
<tr>
<td>#19</td>
<td>A</td>
<td>37</td>
<td>29</td>
<td>49</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>48</td>
<td>37</td>
<td>63</td>
<td>56</td>
</tr>
<tr>
<td>#22</td>
<td>A</td>
<td>60</td>
<td>46</td>
<td>78</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>78</td>
<td>60</td>
<td>102</td>
<td>90</td>
</tr>
<tr>
<td>#25</td>
<td>A</td>
<td>74</td>
<td>57</td>
<td>97</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>96</td>
<td>74</td>
<td>126</td>
<td>111</td>
</tr>
<tr>
<td>#29</td>
<td>A</td>
<td>90</td>
<td>69</td>
<td>117</td>
<td>104</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>117</td>
<td>90</td>
<td>153</td>
<td>135</td>
</tr>
<tr>
<td>#32</td>
<td>A</td>
<td>108</td>
<td>83</td>
<td>141</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>140</td>
<td>108</td>
<td>183</td>
<td>162</td>
</tr>
<tr>
<td>#36</td>
<td>A</td>
<td>127</td>
<td>98</td>
<td>166</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>165</td>
<td>127</td>
<td>215</td>
<td>190</td>
</tr>
</tbody>
</table>

Notes:
1. Tabulated values are based on Grade 60 reinforcing bars and normal-weight concrete. Lengths are in inches.
2. Tension development lengths and tension lap splice lengths are calculated per ACI 318-02, Sections 12.2.3 and 12.15, respectively.
3. Lap splice lengths are multiples of tension development lengths; Class A = 1.0 $L_d$ and Class B = 1.3 $L_d$ (ACI 318-02, Section 12.15.1).
4. Center-to-center spacing of bars is assumed to be greater than twice the concrete cover plus one bar diameter, so that the value of "c" is governed by concrete cover rather than by bar spacing.
5. Bar sizes #43 and #57 were intentionally omitted from this table.
6. Top bars are horizontal bars with more than 12 in. of concrete cast below the bars.
7. For epoxy-coated "top" bars, where applicable, a value of 1.7 is used for the product $\alpha \beta$ in Eq. 12-1 (ACI 318-02, Section 12.2.4).
8. For lightweight aggregate concrete, multiply the tabulated values by 1.3.

Example 4. For the base slab of the cantilever retaining wall with uncoated #36 bars spaced at 8 in. c-c., concrete cover of 2 in., normal-weight concrete with $f'_c = 3,000$ psi...

Enter Table 6; for Lap Class A and “top” bars:

$L_d = 79$ in. for uncoated bars (same as the calculated value noted in Table 5)
Closing Comments

This report discusses the provisions in Sections 12.2.2 and 12.2.3 of the 2002 ACI Building Code for determining tension development lengths, \( L_d \), of reinforcing bars. Several examples are presented to complement the discussion. The examples serve to identify some of the conditions and structural members for which the more rigorous provisions in Section 12.2.3 can be used advantageously.

CRSI Computer Software

CRSI's computer program DEVLAP 3.0 calculates development and lap splice lengths for reinforcing bars. The program generates tables or specific cases can be considered. DEVLAP 3.0 has the capability of determining tension development lengths in accordance with the requirements of Sections 12.2.2 and 12.2.3 in the ACI 318 Building Code. The program is based on the 1995 Code. However, the program is applicable under the current 2002 edition of the Code because, as cited in the Introduction of this report, no technical revisions were made to Sections 12.2.2 and 12.2.3 in the 2002 Code. The DEVLAP 3.0 program is available from the CRSI Publications Center.

Notes on Soft Metric Reinforcing Bars

Soft metric designations for the sizes of reinforcing bars are used throughout this report. This approach follows current industry practice. In 1997, producers of reinforcing bars (the steel mills) began to phase in the production of soft metric bars. The shift to exclusive production of soft metric bars has been essentially achieved. Virtually all reinforcing bars currently produced in the USA are soft metric. The steel mills’ initiative of soft metric conversion enables the industry to furnish the same reinforcing bars to inch-pound construction projects as well as to metric construction projects, and eliminates the need for the steel mills and fabricators to maintain a dual inventory.

The sizes of soft metric reinforcing bars are physically the same as the corresponding sizes of inch-pound bars. Soft metric bar sizes, which are designated #10, #13, #16, and so on, correspond to inch-pound bar sizes #3, #4, #5, and so on. Table 8 shows the one-to-one correspondence of the soft metric bar sizes to the inch-pound bar sizes. More information about soft metric reinforcing bars is given in Engineering Data Report No. 42, “Using Soft Metric Reinforcing Bars in Non-Metric Construction Projects”. EDR No. 42 can be found on CRSI’s Website at www.crsi.org.

<table>
<thead>
<tr>
<th>Soft Metric Bar Size Designation</th>
<th>Inch-Pound Bar Size Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>#10</td>
<td>#3</td>
</tr>
<tr>
<td>#13</td>
<td>#4</td>
</tr>
<tr>
<td>#16</td>
<td>#5</td>
</tr>
<tr>
<td>#19</td>
<td>#6</td>
</tr>
<tr>
<td>#22</td>
<td>#7</td>
</tr>
<tr>
<td>#25</td>
<td>#8</td>
</tr>
<tr>
<td>#29</td>
<td>#9</td>
</tr>
<tr>
<td>#32</td>
<td>#10</td>
</tr>
<tr>
<td>#36</td>
<td>#11</td>
</tr>
<tr>
<td>#43</td>
<td>#14</td>
</tr>
<tr>
<td>#57</td>
<td>#18</td>
</tr>
</tbody>
</table>

Table 8: Soft Metric Bar Sizes vs. Inch-Pound Bar Sizes