Development and Splicing of Flexural Reinforcement Based on ACI 318-08

By Jerry M. Spiker, P.E., AIA, LEED AP
Development and Splicing of Flexural Reinforcement Based on ACI 318-08

By Jerry M. Spiker, P.E., AIA, LEED AP

Reinforcement is used in concrete flexural members to resist flexural tension or to increase the flexural compression capacity of the member. The American Concrete Institute’s Building Code Requirements for Structural Concrete (ACI 318-08) requires the calculated tension or compression in reinforcement at each section to be developed on either side of that section. The reinforcement may be developed by embedment length, hooks, mechanical anchorage devices, headed deformed reinforcement, or a combination of these methods.

This article discusses development and splicing of reinforcement steel in flexural members. It does not include reinforcement for columns, compression reinforcement in flexural members, or deep beams. It also does not address development or splicing of wire, welded wire fabric, or post-tensioning cables.

Tension development length

The basic parameter for development and splicing of reinforcement steel in flexural members is the tension development length, \( \ell_d \). According to ACI 318-08, the tension development length is a function of the diameter of the reinforcement bar (\( d_b \)), the yield strength of the reinforcement (\( f_y \)), and the specified concrete compressive strength (\( f_{ct} \)).

Five other factors affect the tension development length:

• Reinforcement location (\( \psi_t \)): For bars that are placed so that there is more than 12 inches of fresh concrete cast below the development length or splice (top bars), \( \psi_t = 1 \). For all other bars, \( \psi_t = 1.0 \).
• Epoxy-coated reinforcement (\( \psi_e \)): For epoxy-coated bars that are closely spaced or have limited concrete cover, \( \psi_e = 1.5 \). For other epoxy coated bars, \( \psi_e = 1.2 \). For uncoated bars or galvanized bars, \( \psi_e = 1.0 \).
• Smaller bar sizes (\( \psi_s \)): For bars that are No. 6 or smaller, \( \psi_s = 0.8 \). For bars that are No. 7 or larger, \( \psi_s = 1.0 \).
• Lightweight concrete: For lightweight concrete, \( \lambda \) cannot exceed 0.75. For normal weight concrete, \( \lambda = 1.0 \). If the average splitting tensile strength, \( f_{ct} \), of the concrete is specified, \( \lambda \) can be determined from the specified \( \ell_f \). The value of \( \lambda \) is applied in the denominator of the tension development length equation.
• Confinement: The confinement term, \( (c_b + K_{tr})/d_b \), accounts for close bar spacing or limited concrete cover on the reinforcement, and the lack of confining reinforcement, such as stirrups or ties. In many current practical construction cases, the confinement term is at least 1.5. The confinement term is also applied in the denominator of the tension development length equation.

The equation for tension development length in ACI 318-08 is as follows:

\[
\ell_d = \frac{0.85 f_{ct}}{f_y} \left( \frac{d_b}{\psi_t} \right) \left( \frac{1}{\psi_e} \right) \left( \frac{1}{\psi_s} \right) \left( \frac{1}{\lambda} \right) \left( \frac{1}{K_{tr}/c_b} \right)
\]
Development and Splicing of Flexural Reinforcement

\[
\ell_d = \left(\frac{3}{40} \frac{f_y}{\lambda \sqrt{f_c}} \psi_e \psi_t \psi_s \left(\frac{c_b + K_{tr}}{d_b}\right)\right) d_b \quad \text{(Equation 1)}
\]

Although Equation 1 appears intimidating, the calculation of development length can be greatly simplified for specific conditions. For Grade 60 reinforcement, assuming normal weight concrete \((\lambda = 1.0)\) and uncoated \((\psi_e = 1.0)\) bottom bars \((\psi_t = 1.0)\), values of \(\ell_d\) as a function of \(d_b\) can be determined from Table 1 for various concrete compressive strengths.

When reinforcement in a flexural member exceeds the reinforcement required by analysis, the tension development length can be reduced by the ratio \([\left(A_i \text{ required}\right)/\left(A_i \text{ provided}\right)]\), where \(A_i\) is the area of tension reinforcement.

The minimum tension development length, including the various modification factors, is 12 inches.

Development of standard hooks in tension

Standard hooks (with either a 90° or 180° hook) are used where there is not sufficient room to develop a bar by development lengths, such as at the end of a beam framing into another beam or a column. Like tension development length, the development length for hooked bars is a function of the diameter of the reinforcement bar \((d_b)\), the yield strength of the reinforcement \((f_y)\), and the specified concrete compressive strength \((f_c')\), with factors for epoxy-coated reinforcement and lightweight concrete. The development length is measured from the critical section to the outside end or edge of the hook. The equation for development length of standard hooks in tension is as follows:

\[
\ell_{dh} = \left(\frac{0.02 \psi_e f_y}{\lambda \sqrt{f_c'}}\right) d_b \quad \text{(Equation 2)}
\]

For Grade 60 reinforcement, assuming normal weight concrete \((\lambda = 1.0)\) and uncoated \((\psi_e = 1.0)\) bars, the development length of hooked bars as a function of \(d_b\) can be determined from Table 2 (page PDH4) for various concrete compressive strengths.

The primary cause of failure of hooked bars is splitting of the concrete in the plane of the hook, so the Code permits shorter development lengths where the hook is confined by additional concrete cover or closely spaced ties or stirrups. As for tension development length, the development length for standard hooks may be reduced by the ratio \([\left(A_i \text{ required}\right)/\left(A_i \text{ provided}\right)]\) when reinforcement in a flexural member exceeds the reinforcement required by analysis. The minimum development length for hooks, including the various modification factors, is 6 inches or \(8d_b\).

Development of headed and mechanically anchored deformed bars in tension

Where a beam frames into an exterior column, the vertical column reinforcement and the hooked beam reinforcement can become very congested. Mechanical anchors or headed deformed bars can be used instead of hooks to reduce congestion. Mechanical anchors must be proven by test to show they can adequately anchor the reinforcement. Use of heads to develop deformed bars in tension shall be limited to the following conditions:

- \(f_y \leq 60,000\) pounds per square inch (psi);
- bar size must be less than No. 11;
- concrete must be normal weight;
- net bearing area of the head, \(A_{bgr}\), must not be less than four times the bar area \(A_b\);
- clear cover for bar shall not be less than \(2d_b\);
- clear spacing between bars shall not be less than \(4d_b\); and
- value of \(f_c'\) used to calculate \(\ell_{dt}\) shall not exceed 6,000 psi.

<table>
<thead>
<tr>
<th>Table 1: Development length (\ell_d) for Grade 60, uncoated, bottom reinforcement in normalweight concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_c') psi</td>
</tr>
<tr>
<td>Clear spacing of bars being developed or spliced not less than (d_b), clear cover not less than (d_b), and beam stirrups or column ties throughout (\ell_d) not less than the code minimum</td>
</tr>
<tr>
<td>or</td>
</tr>
<tr>
<td>Clear spacing of bars being developed or spliced not less than (2d_b) and clear cover not less than (d_b)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Clear spacing of bars being developed or spliced not less than (d_b), clear cover not less than (d_b), and beam stirrups or column ties throughout (\ell_d) not less than the code minimum</td>
</tr>
<tr>
<td>or</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Other cases
The equation for the development length of headed deformed bars in tension is given as follows:

\[ \ell_{dt} = \left( \frac{0.016 \psi \sqrt{f_y}}{f_c} \right) d_b \]  
(Equation 3)

Except where the development of \( f_y \) is specifically required, the development length for headed deformed bars may be reduced by the ratio \([ (A_s \text{ required})/(A_s \text{ provided})] \) when reinforcement in a flexural member exceeds the reinforcement required by analysis. Also as for hooks, the minimum development length, including the various modification factors, is 6 inches or 8\( d_b \). For Grade 60 reinforcement, assuming normal weight concrete (\( \lambda = 1.0 \)) and uncoated (\( \psi_e = 1.0 \)) bars, the development length \( \ell_{dt} \) of headed deformed bars as a function of \( d_b \) can be determined from Table 3 for various concrete compressive strengths, provided the net bearing area of the head is not less than four times the area of the bar, and the clear cover and spacing requirements are met.

When beam reinforcement with headed bars terminates at a column, the reinforcement should extend through the column to the far face of the confined core (while still maintaining the required cover and avoiding interference with the vertical column reinforcement), even though the anchorage length exceeds \( \ell_{dt} \), to anchor compressive forces that may develop and to improve the performance of the joint.

**Development of flexural reinforcement**

ACI 318-08 requires flexural reinforcement steel to be developed at critical sections, which are defined as points of maximum stress, and at points within the span where adjacent bars are terminated. It is usually not economical to provide the same amount of reinforcement that is required at the point of maximum stress for the entire length of a flexural member. ACI 318-08 permits reinforcement to be omitted beyond the point where calculation indicates that reinforcement is not required, provided that the continuing reinforcement bars have adequate anchorage, \( \ell_{d} \), beyond the theoretical cut-off point of the terminated bars.

Moment diagrams used to determine the points of maximum positive or negative moment are typically approximate; the point of maximum moment may shift approximately a distance \( d \) due to changes in loading, settlement of supports, lateral loads, or other causes. To provide for these shifts, ACI 318-08 requires flexural reinforcement to extend a distance of \( d \) or 12\( d_b \), whichever is greater, beyond the point where the reinforcement is theoretically no longer required.

When flexural reinforcement is terminated in a tension zone, additional conditions must be satisfied to prevent diagonal tension cracks from opening early (see ACI 318-08 section 12.10.5).

**Development of positive moment reinforcement**

For simple span members, at least one-third the positive moment reinforcement

![Table 2: Development length \( \ell_{dh} \) (inches) of standard hooks for uncoated Grade 60 bars*](Image)

<table>
<thead>
<tr>
<th>Bar Size No.</th>
<th>( f'_c ) (Normalweight Concrete), psi</th>
<th>3,000</th>
<th>4,000</th>
<th>5,000</th>
<th>6,000</th>
<th>8,000</th>
<th>10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>8.2</td>
<td>7.1</td>
<td>6.4</td>
<td>5.8</td>
<td>5.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11.0</td>
<td>9.5</td>
<td>8.5</td>
<td>7.7</td>
<td>6.7</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>13.7</td>
<td>11.9</td>
<td>10.6</td>
<td>9.7</td>
<td>8.4</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>16.4</td>
<td>14.2</td>
<td>12.7</td>
<td>11.6</td>
<td>10.1</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>19.2</td>
<td>16.6</td>
<td>14.8</td>
<td>13.6</td>
<td>11.7</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>21.9</td>
<td>19.0</td>
<td>17.0</td>
<td>15.5</td>
<td>13.4</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>24.7</td>
<td>21.4</td>
<td>19.1</td>
<td>17.5</td>
<td>15.1</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>27.8</td>
<td>24.1</td>
<td>21.6</td>
<td>19.7</td>
<td>17.0</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>30.9</td>
<td>26.8</td>
<td>23.9</td>
<td>21.8</td>
<td>18.9</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>37.1</td>
<td>32.1</td>
<td>28.7</td>
<td>26.2</td>
<td>22.7</td>
<td>20.3</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>49.5</td>
<td>42.8</td>
<td>38.3</td>
<td>35.0</td>
<td>30.3</td>
<td>27.1</td>
<td></td>
</tr>
</tbody>
</table>

* Development length \( \ell_{dh} \) (including modification factors) must not be less than the larger of 8\( d_b \) or 6 inches.
must extend into the support at least 6 inches. For continuous members, one-fourth of the positive reinforcement must extend into the support. If the beam is part of a primary seismic load-resisting system, this reinforcement must be anchored to develop $f_y$ in tension at the face of support to ensure ductility in the event of a serious overstress. It is not acceptable to use more reinforcement at lower stresses.

At locations with small moment but a large shear, such as at simple supports or at points of inflection, the development length, $l_d$, computed for $f_y$ must not exceed the value $M_n/V_u + l_a$, where $M_n$ is the nominal strength of the beam without the $\theta$-factor. At a simple support, $l_a$ is the embedment length beyond the center of support. At an inflection point, $l_a$ is limited to $d$ or $12d_p$, whichever is greater. The value of $M_n/V_u$ can be increased by 30 percent if the end of the reinforcement is confined by a compressive reaction, such as provided by a column below the beam, but not when a beam frames into a girder. If the computed $l_a$ exceeds the given value, smaller bars must be used to decrease the computed $l_d$, or at a simple support, the reinforcement must terminate beyond the centerline of the support with a standard hook or a mechanical anchor equivalent to a standard hook.

In addition to the requirements for development of the reinforcement, the code requires reinforcement to be detailed to improve the integrity of the overall structure. At beams along the perimeter of the building, at least one-fourth of the positive moment reinforcement must be continuous over the length of the span and pass through the vertical column reinforcement. At noncontinuous supports, the reinforcement must be developed using development length, a standard hook, or a headed deformed bar. As with bars that are extended into the support to provide ductility for seismic members, the reinforcement must develop the full $f_y$ in tension. It is not acceptable to use more reinforcement at lower stresses. In addition, the continuous positive reinforcement must be enclosed by transverse reinforcement (closed stirrups), except the transverse reinforcement does not need to extend through the column. In non-perimeter beams, either the transverse reinforcement or the continuous positive moment reinforcement described above must be provided.

---

**Table 3: Development length $l_d$ (inches) of headed deformed bars for uncoated Grade 60 bars**

<table>
<thead>
<tr>
<th>Bar Size No.</th>
<th>3,000</th>
<th>4,000</th>
<th>5,000</th>
<th>6,000 or larger</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6.6</td>
<td>5.7</td>
<td>5.1</td>
<td>4.6</td>
</tr>
<tr>
<td>4</td>
<td>8.8</td>
<td>7.6</td>
<td>6.8</td>
<td>6.2</td>
</tr>
<tr>
<td>5</td>
<td>11.0</td>
<td>9.5</td>
<td>8.5</td>
<td>7.7</td>
</tr>
<tr>
<td>6</td>
<td>13.1</td>
<td>11.4</td>
<td>10.2</td>
<td>9.3</td>
</tr>
<tr>
<td>7</td>
<td>15.3</td>
<td>13.3</td>
<td>11.9</td>
<td>10.8</td>
</tr>
<tr>
<td>8</td>
<td>17.5</td>
<td>15.2</td>
<td>13.6</td>
<td>12.4</td>
</tr>
<tr>
<td>9</td>
<td>19.8</td>
<td>17.1</td>
<td>15.3</td>
<td>14.0</td>
</tr>
<tr>
<td>10</td>
<td>22.3</td>
<td>19.3</td>
<td>17.2</td>
<td>15.7</td>
</tr>
<tr>
<td>11</td>
<td>24.7</td>
<td>21.4</td>
<td>19.1</td>
<td>17.5</td>
</tr>
</tbody>
</table>

* Development length $l_d$ (including modification factors) must not be less than the larger of $8d_p$ or 6 inches.

---

**Figure 1: Positive moment reinforcement** — Note: a portion of total positive reinforcement ($A_{s+}$) must be continuous (or spliced with a Class B splice or a mechanical or welded splice satisfying 12.14.3) along the full length of perimeter beams and of beams without closed stirrups (7.13.2.2).
In joist construction, at least one bottom bar must be continuous, and anchored to develop $f_y$ at noncontinuous supports.

Development of negative moment reinforcement

Because the maximum negative moment usually occurs at the support, the negative moment reinforcement in a continuous, restrained, or cantilevered member, or a member in a rigid frame, must be developed at the supporting member by embedment length, hooks, or mechanical anchorage. To provide for any shifts in the moment diagram at the inflection point, at least one-third of the negative reinforcement must have an embedment length beyond the point of inflection of at least $d$, $12 \, d_b$, or $l_d/16$.

For structural integrity, at least one-sixth of the negative reinforcement, but not less than two bars, must be continuous over the span length at perimeter beams, and must be enclosed by transverse reinforcement (closed stirrups).

Splices of reinforcement in tension

If the length of reinforcement bars is greater than what can be fabricated, transported, or installed economically, it may be necessary to splice reinforcement bars. ACI 318-08 permits three types of splices — lap splices, mechanical splices, and welded splices. Tension lap splices of bars larger than No. 11 are not permitted. Lap splices are also not permitted in tension tie members.

There are two classes of tension lap splices — Class A and Class B. The length of the tension lap is a function of the tension development length, $l_d$, as follows:

- Class A splice – $1.0 \, l_d$
- Class B splice – $1.3 \, l_d$

All tension lap splices must be Class B splices unless the area of steel provided is at least twice the area of steel determined by analysis over the entire length of the lap splice, and only one-half of the total reinforcement is spliced within the lap length. Class B lap splices must be provided for structural integrity reinforcement.

If the bars to be spliced have different sizes, the required lap splice length is the tension lap splice length of the smaller bar or the development length, $l_d$, of the larger bar, whichever is greater.

If welded or mechanical splices are used, they must develop 125 percent of the tension yield strength, $f_y$, except that splices with lesser strength are permitted for No. 5 or smaller bars if the additional requirements listed in paragraph 12.15.5 of ACI 318-08 are met.

Reference

ACI Committee 318, Building Code Requirements for Structural concrete (ACI 318-08) And Commentary (ACI 318R-08), American Concrete Institute, Farmington Hills, Mich., 2008.

Jerry M. Spiker, P.E., AIA, LEED AP, is the regional engineering manager — Eastern U.S. at the Portland Cement Association. He is a member of ACI Committee 408—Development and Splicing of Deformed Bars. He can be reached at structures@cement.org.
Quiz Instructions
On the Professional Development Series Reporting Form below, circle the correct answer for each of the following questions.

1. Which of the following is not included in the calculation for determining tension development length?
   a) Specified compressive strength of concrete, \( f'_c \)
   b) Strength reduction factor, \( \phi \)
   c) Specified yield strength of reinforcement, \( f_y \)
   d) Reinforcement location factor, \( \psi_t \)

2. What value for the lightweight concrete factor \( \lambda \) is to be used in determining the tension development length when lightweight concrete is used?
   a) \( \lambda = 1.0 \)
   b) \( \lambda = 0.85 \) for sand-lightweight concrete or \( \lambda = 0.75 \) for all-lightweight concrete
   c) \( \lambda \) shall not exceed 0.75 unless \( f_y \) is specified
   d) \( \lambda = 1.3 \)

3. What is the minimum size of the head required to anchor a headed deformed bar?
   a) A diameter of 2 inches
   b) Twice the diameter of the reinforcement bar
   c) The net bearing area of the head must be at least four times the area of the bar.
   d) No more than one-half the clear spacing between the headed bars

4. Which of the following is not included in the calculation for determining the development length of standard hooks in tension?
   a) Specified compressive strength of concrete, \( f'_c \)
   b) Reinforcement location factor, \( \psi_t \)
   c) Lightweight concrete factor, \( \lambda \)
   d) Specified yield strength of reinforcement, \( f_y \)

5. Which of the following is a critical section for development of reinforcement in a flexural member?
   a) At the maximum positive moment near midspan
   b) At the maximum negative moment at the face of the support
   c) At points within the span where adjacent reinforcement bars are terminated
   d) All of the above

6. In perimeter beams, how much of the positive moment reinforcement is required to extend into the supporting column to provide for structural integrity?
   a) All of the positive moment reinforcement bars
   b) At least one-fourth of the positive moment reinforcement, but not less than two bars
   c) Positive moment reinforcement need not extend beyond the point where it is no longer theoretically required.
   d) Two bars if \( b \leq 24 \) inches, 4 bars if \( b > 24 \) inches

7. The largest bar that may use a tension lap splice is:
   a) #18 bar
   b) #14 bar
   c) #11 bar
   d) #10 bar

8. Class B lap splices are required where:
   a) The area of reinforcement steel at a lap splice is less than twice the areas of steel determined by analysis
   b) More than one-half of the total reinforcement is to be lap spliced within the lap length
   c) Structural integrity reinforcement is to be lap spliced
   d) All of the above

9. Mechanical or welded splices for a #8 bar must develop:
   a) 125 percent of the tension yield strength, \( f_y \)
   b) 48 kips in tension
   c) The actual tensile strength of the reinforcement
   d) The stress in the reinforcement determined by analysis

10. The minimum development length for hooks and for headed deformed bars is:
    a) 12 inches
    b) 6 inches or \( 8d_b \), whichever is greater
    c) 4\( d_b \)
    d) No minimum required
The cement industry is committed to making a high-quality product safely and efficiently. That commitment includes sustainable manufacturing practices that minimize emissions, waste, energy consumption, and use of virgin raw materials.

Portland Cement Association members—cement companies in the U.S. and Canada—have adopted voluntary reduction targets for key environmental performance measures, including carbon dioxide emissions and energy use.

Find out more at www.cement.org/sustainable.

PCA also developed www.concretethinker.org, a Web site devoted to how concrete can be used to achieve sustainable solutions for infrastructure, housing, buildings, and more.