6.11.5 Welded, Mechanical, and Butt Splices:

In addition to lap splices, bars stressed in tension or compression may be spliced by welding, or by various mechanical devices, such as threaded sleeves. The use of such splices is governed by ACI Code 12.14.3 and ACI Code 12.16.3.

6.12 Bar Cutoffs And Development Of Flexural Reinforcement

Some of the flexural reinforcement bars can be cutoff where they are no longer needed to resist tensile forces or where the remaining bars are adequate to do so. In a continuous beam of constant cross section, if the areas of steel required at the sections of maximum moment are made continuous throughout each region of positive or negative moment, the beam will be over-designed at most sections. It is often desirable to terminate a portion of the steel when the moment decreases significantly. Reducing the area of reinforcement in regions of low bending moment in a concrete element lowers the cost of the element. Furthermore, for heavily reinforced elements, the reduction in a number of reinforcement bars improves concrete casting and compaction operations.

There must be sufficient extension of each bar, on each side of every critical moment section to develop the force in that bar at that section.

Tension bars, cutoff in a region of moderate shear force, cause a major stress concentration which can lead to major inclined cracks at the bar cutoff. Thus, bar cutoffs should be kept to a minimum, particularly, in zones of tension for ease of design and fabrication.
6.12.1 Development of Flexural Reinforcement - General

According to ACI Code 12.10.2, critical sections for development of reinforcement in flexural members are at points of maximum stress and at points within the span where adjacent reinforcement terminates, or is bent.

To account for the possibility of higher than anticipated moment at cutoff point due to possible variations in the position of live load, settlements of support, lateral loads, or other causes, ACI Code 12.10.3 requires the reinforcement to be extended beyond the point at which it is no longer required to resist flexure for a distance equal to the effective depth of the member $d$ or $12d_b$, whichever is greater, except at supports of simple spans and at free ends of cantilevers. When bars of different sizes are used, the extension should be in accordance with the diameter of bar being terminated. See Figure 6.14 for reinforcement layout of a simply supported beam.
Based on ACI Code 12.10.4, continuing reinforcement is to have an anchorage length not less than the development length $l_d$ beyond the point where bent or cutoff reinforcement is no longer required to resist flexure.

6.12.1.1 Development of Positive Moment Reinforcement

Failure of a beam will occur suddenly if the ends of the positive steel extending into a point of inflection are not properly anchored and slip out. Although the moment is zero at these points and the stress in the steel is low, the bond stresses are related to the shear which is maximum at a simple support and often high at a point of inflection.

As specified by ACI Code 12.11.1, at least one-third of the positive moment reinforcement in simply supported elements and one-fourth of the positive moment reinforcement in continuously supported elements shall be extended along the same face of member into the support. In beams such reinforcement is extended into the support at least 15 cm. Positive moment reinforcement is carried out into the support to provide for some shifting of the moments due to changes in loading, settlement of supports, and lateral loads.

6.12.1.2 Development Of Negative Moment Reinforcement

According to ACI Code 12.12.1, negative moment reinforcement in a continuous, restrained cantilever member, or in any member of rigid frame, is to be anchored in or through the supporting member by development length, hooks, or mechanical anchorage, as shown in Figure 6.15.

![Figure 6.15: Anchorage into exterior column](image)

Based on ACI Code 12.12.3, at least one-third of the total tension reinforcement provided for negative moment at a support shall have a development length beyond the point of...
inflection not less than the effective depth of member $d$, $12d_b$, or one-sixteenth the clear span, whichever is greatest to provide for possible shifting of the moment diagram at a point of inflection. Inflection point locations for a continuous beam are shown in Figure 6.16.

![Figure 6.16: (a) Beam and loads; (b) Inflection points](image)

**Example (6.7):**
In the simply supported beam subjected to factored loads shown in Figure 6.17, 4 $\Phi$ 22 $mm$ bars are to be cutoff between the supports. Determine bar cutoff location and development requirements of the rest of the reinforcement bars, according to *ACI Code* provisions.

Use $f'_c = 250 \, kg/cm^2$ normal weight concrete, and $f_y = 4200 \, kg/cm^2$ and width of support is equal to 0.3 $m$.

**Solution:**
For section A-A:

\[
d = 70 - 4 - 0.8 - 2.2 - 2.5/2 = 61.75 \, cm
\]

For section B-B:
\[ d = 70 - 4 - 0.8 - 2.2/2 = 64.10 \text{ cm} \]

Moment capacity of section B-B, reinforced with 4 \( \Phi \) 22 mm

\[
M_u = \frac{0.9 \times (15.2) \times (4200)}{10^5} \left[ 64.1 - \frac{15.2 \times (4200)}{1.7 \times (250) \times (30)} \right] = 33.95 \text{ t.m}
\]
CHAPTER SIX ANCHORAGE AND DEVELOPMENT OF REINFORCEMENT

Theoretical cutoff points of 4ϕ 22 mm are located at distance \( x \) from the centerline of the left support, evaluated by equating the bending moment at distance \( x \) to the moment capacity of the section, or

\[
33.95 = 29 \ x - 1.5 \ x^2
\]

or,

\[
1.5 \ x^2 - 29 \ x + 33.95 = 0
\]

Solving this quadratic equation in terms of \( x \) gives

\[
x = \frac{29 \pm \sqrt{(29)^2 - 4 \cdot (1.5) \cdot (33.95)}}{2 \cdot (1.5)}
\]

\[
x = \frac{29 \pm 25.24}{2 \cdot (1.5)} \text{ and } x = 1.25 \ m, \text{ or } x = 18.08 \ m \text{ (rejected)}
\]

**ACI Code Requirements:**

1. Bars must be extended at least a distance equal to the larger of the effective depth \( d = 61.75 \ cm \) and \( 12 \ d_b = 12 \cdot (2.2) = 26.4 \ cm \), thus extension on both sides of the centerline of the beam is taken as 62 cm.

Length of cutoff bars = 2 \((175 + 62) = 474 \ cm\)

2. Distance from point of maximum stress to end of cutoff bars on each side should be equal or larger than the development length of the bars in tension, \( l_d \)

For bars in tension

\[
\psi_t = 1, \ \psi_e = 1, \ \psi_s = 1, \text{ and } \lambda = 1
\]

\[
c_b = 4.0 + 0.8 + 1.1 = 5.9 \ cm
\]

or

\[
c_b = [30 - 2(4) - 2(0.8) - 2.2]/6 = 3.03 \ cm
\]

i.e., \( c_b \) is taken as the smaller of the two values, is equal to 3.03 cm.

\[
K_{tr} = \frac{40 \ A_{tr}}{s \ n} = \frac{40 \cdot (2) \cdot (0.5)}{(20) \cdot (4)} = 0.5 \ cm
\]

\[
\frac{c_b + K_{tr}}{d_b} = \frac{3.03 + 0.5}{2.2} = 1.6 < 2.5 \ \text{O.K}
\]
\[ l_d = \left( \frac{f_y \psi_t \psi_e \psi_s}{3.5 \lambda \left( \frac{c_b + K_{tr}}{d_b} \right) \sqrt{f'_c}} \right) \]

\[ d_b = \left( \frac{4200 (1.0)}{3.5 (1.6) \sqrt{250}} \right) (2.2) = 104.36 \text{ cm} \]

Available development length = \( \frac{474}{2} = 237 \text{ cm} > 104.36 \text{ cm} \).

3. At least one-third of the positive moment reinforcement is extended 15 cm into the supports:

One-half of the total positive moment reinforcement is to be extended 15 cm into the supports. Thus, minimum length of these bars = 600 – 30 + 15 + 15 = 600 cm.

### 6.13 Standard Bend and Cutoff Points

Approximate bend and cutoff points can be used in continuous beams or one-way slabs where the following conditions are satisfied:

- Not more than half the reinforcement is bent or cutoff.
- Two or more spans.
- Spans are approximately equal with the larger of two adjacent spans not greater than the shorter by more than 20%.
- Loads are uniformly distributed.
- Unit live load does not exceed 3 times unit dead load.

The ACI Detailing Manual shows the following bend and cutoff points for continuous beams and one-way slabs reproduced in Figure 6.18.
Figure 6.18: (a) Beam (cut-off bars); (b) beam (bent-up bars); (c) one way slab (cut-off bars); (d) one way slab (bent-up bars)