

CHAPTER

Prentice Hall Reinforced Concrete Design Fifth Edition

UNIVERSITY OF MARYLAND COLLEGE PARK

DEVELOPMENT, SPLICES, AND SIMPLE SPAN BAR CUTOFFS

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Part I – Concrete Design and Analysis

FALL 2002



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ENCE 355 - Introduction to Structural Design
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5b

Prentice Hall

CHAPTER 5b. DEVELOPMENT, SPLICES, AND SIMPLE SPAN BAR CUTOFFS Slide No. 1

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Development Length: Compression Bars

- Deformed Bars in Compression
 - The method for determining the development length in compression l_d involves finding the the basic development length l_{db} and multiplying it by applicable modification factors.
 - The modification factors reflect special conditions.
 - Note: l_d shall not be less than 8 in.



Development Length: Compression Bars

■ Basic Development Length (compression)

The basic development length in compression is given by

$$l_{db} = 0.02d_b \frac{f_y}{\sqrt{f'_c}} \quad (1)$$

But it shouldn't be less than $0.0003f_y d_b$ according to the ACI Code, Section 12.3.



Development Length: Compression Bars

■ Modification Factors (Compression)

- The following modification factors may be applied to the basic development length for compression bars:

1. Reinforcement in excess of that required:

$$\frac{A_s \text{ required}}{A_s \text{ provided}}$$

2. Bars enclosed within a spiral that is not less than $\frac{1}{4}$ in. in diameter and not more than 4 in. in pitch or within No. 4 ties and spaced at not more than 4 in. on center: USE 0.75



Development Length: Compression Bars

- Tables 1a through 1c gives values of the basic development length l_{db} for compression bars in inches for the following combinations of f'_c and f_y :

f'_c : 3000, 4000, 5000, and 6000 psi

f_y : 40,000, 50,000, and 60,000 psi



Development Length: Compression Bars

Table 1a. Basic Development Length l_{db} for Compression Bars (in.) for $f_y = 40,000$ psi

Bar Size	f'_c (normal-weight concrete), psi			
	3000	4000	5000	6000
3	5.5	4.7	4.5	4.5
4	7.3	6.3	6.0	6.0
5	9.1	7.9	7.5	7.5
6	11.0	9.5	9.0	9.0
7	12.8	11.1	10.5	10.5
8	14.6	12.6	12.0	12.0
9	16.5	14.3	13.5	13.5
10	18.5	16.1	15.2	15.2
11	20.6	17.8	16.9	16.9
14	24.7	21.4	20.3	20.3
18	33.0	28.5	27.1	27.1



Development Length: Compression Bars

Table 1b. Basic Development Length l_{db} for
Compression Bars (in.) for $f_y = 50,000$ psi

Bar Size	f'_c (normal-weight concrete), psi			
	3000	4000	5000	6000
3	6.8	5.9	5.6	5.6
4	9.1	7.9	7.5	7.5
5	11.4	9.9	9.4	9.4
6	13.7	11.9	11.3	11.3
7	16.0	13.8	13.1	13.1
8	18.3	15.8	15.0	15.0
9	20.6	17.8	16.9	16.9
10	23.2	20.1	19.1	19.1
11	25.7	22.3	21.2	21.2
14	30.9	26.8	25.4	25.4
18	41.2	35.7	33.9	33.9



Development Length: Compression Bars

Table 1c. Basic Development Length l_{db} for
Compression Bars (in.) for $f_y = 60,000$ psi

Bar Size	f'_c (normal-weight concrete), psi			
	3000	4000	5000	6000
3	8.2	7.1	6.8	6.8
4	11.0	9.5	9.0	9.0
5	13.7	11.9	11.3	11.3
6	16.4	14.2	13.5	13.5
7	19.2	16.6	15.8	15.8
8	21.9	19.0	18.0	18.0
9	24.7	21.4	20.3	20.3
10	27.8	24.1	22.9	22.9
11	30.9	26.8	25.4	25.4
14	37.1	32.1	30.5	30.5
18	49.4	42.8	40.6	40.6



Development Length: Standard Hooks in Tension

- Need for Hooks
 - In the event that the desired development length in tension cannot be furnished, it will be necessary to provide mechanical anchorage at the end of the bars



Development Length: Standard Hooks in Tension

- Need for Hooks

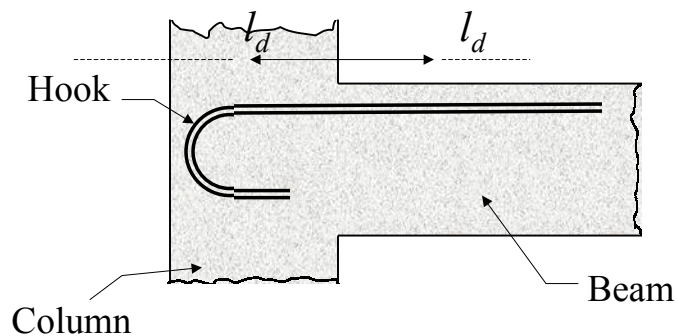


Figure 1. 180°-Hook



Development Length: Standard Hooks in Tension

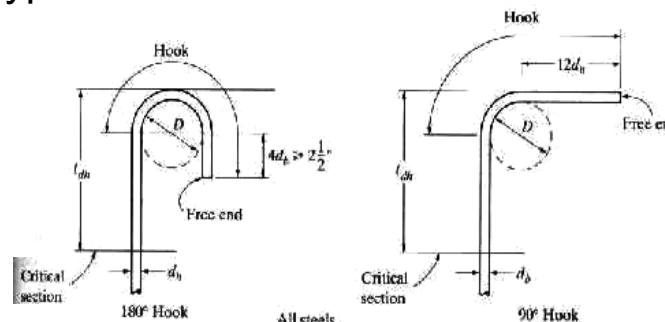
■ Types of Hooks

- Anchorage for main or primary reinforcement is usually accomplished by means of 90° or 180° hook.
- The dimensions and bend radii for these hooks have been standardized by the ACI Code.
- Standard reinforcement hooks are shown in Fig. 2.



Development Length: Standard Hooks in Tension

■ Types of Hooks



All steels
 $D = 6d_b$ for #3 to #8
 $D = 8d_b$ for #9 to #11
 $D = 10d_b$ for #14 and #18
Primary Reinforcement

Figure 2a. Standard Hooks



Development Length: Standard Hooks in Tension

■ Types of Hooks

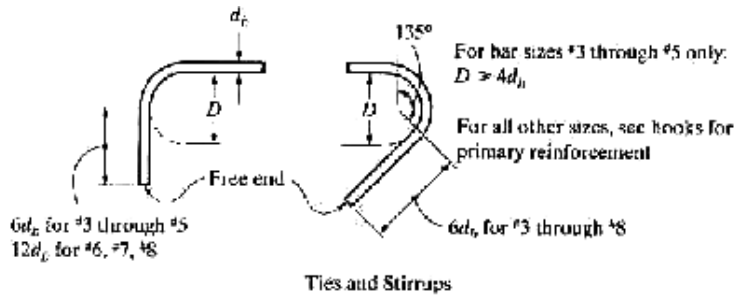


Figure 2b. Standard Hooks



Development Length: Standard Hooks in Tension

■ Types of Hooks

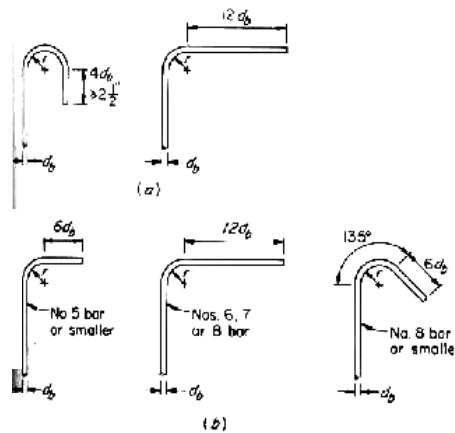


Figure 3. Standard Hooks



Development Length: Standard Hooks in Tension

■ ACI Code Specifications

- The ACI Code specifies that the development length l_{dh} (see Fig. 2) for deformed bars in tension, which terminate in a standard hook, be computed as the product of a basic development length l_{hb} and any applicable modification factors.
- Mathematically, this may expressed as

$$l_{dh} = l_{hb} \times \text{MF} \quad (2)$$



Development Length: Standard Hooks in Tension

■ ACI Basic Development Length, l_{hb}

- For a hooked bar with $f_y = 60,000$ psi,

$$l_{hb} = \frac{1200d_b}{\sqrt{f'_c}} \quad (3)$$

- Table 1 (Table A-13, Textbook) provides values for l_{hb} .



Development Length: Standard Hooks in Tension

- ACI Modification Factors (MF)
 - Modification factors are to be used if applicable:
 1. Bars with f_y other than 60,000 psi, USE

$$MF = \frac{f_y}{60,000} \quad (4)$$

2. Concrete cover for No. 3 through No. 11: Side cover (normal to the plane of the hook) $\geq 2 \frac{1}{2}$ in. and, for 90° hooks, cover on bar extension beyond the bend ≥ 2 in.: USE 0.7 for MF



Development Length: Standard Hooks in Tension

- ACI Modification Factors, MF (cont'd)
 3. Ties or stirrups: For No. 3 through No. 11 with hook enclosed vertically or horizontally within ties or stirrup ties spaced along the full development length l_{dh} not greater than $3d_b$: USE MF = 0.8.
 4. Reinforcement in excess of that required, where anchorage or development for f_y is not specifically required:

$$MF = \frac{A_s \text{ required}}{A_s \text{ provided}} \quad (5)$$



Development Length: Standard Hooks in Tension

- ACI Modification Factors, MF (cont'd)
 - 5. Lightweight aggregate concrete: USE

$$MF = 1.3 \quad (6)$$

- 6. Epoxy-coated reinforcement: USE

$$MF = 1.2 \quad (7)$$



Development Length: Standard Hooks in Tension

- ACI Modification Factors, MF (cont'd)
 - The basic development length l_{hb} must be multiplied by the application factors outlined in the previous viewgraphs.
 - In no case may l_{db} be less than $8d_b$ or 6 in., whichever is greater.



Development Length: Standard Hooks in Tension

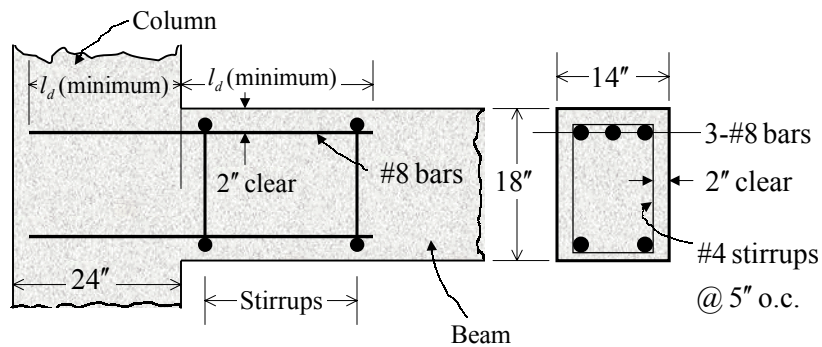
■ Example 1

Determine the anchorage or development length required for the conditions shown in the figure. Use $f'_c = 3,000$ psi (normal-weight concrete) and $f_y = 60,000$ psi. The No. 8 bars may be categorized as top bars. Assume a side cover on the main bars of $2\frac{1}{2}$ in. minimum. Bars are uncoated.



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)





Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

Anchorage into the exterior column:

1. Establish values for the multiplying factors α , β , γ , and λ :
 - a. $\alpha = 1.3$ (the bars are top bars).
 - b. $\beta = 1.0$ (the bars are uncoated).
 - c. $\gamma = 1.0$ (the bars are No. 8)
 - d. $\lambda = 1.0$ (normal-weight concrete used)
2. The product $\alpha \times \beta = 1.3 < 1.7$ (OK)



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

3. Determine c . Based on cover (center of bar to nearest concrete surface), consider the clear cover, the No. 4 stirrups diameter, and one-half the diameter of the No. 8 bar:

$$c = 2.0 + 0.5 + \frac{1.0}{2} = 3.0 \text{ in.}$$

Based on bar spacing:

$$c = \frac{14 - 2(2.0) - 2(0.5) - 2(0.5)}{2(2)} = 2.0 \text{ in.} \quad \leftarrow \text{Controls}$$

Therefore, use $c = 2.0 \text{ in}$ (smallest)



Development Length: Standard Hooks in Tension

Table 2. ASTM Standard - English Reinforcing Bars

Bar Designation	Diameter in	Area in ²	Weight lb/ft
#3 [#10]	0.375	0.11	0.376
#4 [#13]	0.500	0.20	0.668
#5 [#16]	0.625	0.31	1.043
#6 [#19]	0.750	0.44	1.502
#7 [#22]	0.875	0.60	2.044
#8 [#25]	1.000	0.79	2.670
#9 [#29]	1.128	1.00	3.400
#10 [#32]	1.270	1.27	4.303
#11 [#36]	1.410	1.56	5.313
#14 [#43]	1.693	2.25	7.650
#18 [#57]	2.257	4.00	13.60

Note: Metric designations are in brackets



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

4. The figure shows stirrups in the beam. However, there are no stirrups in the column, and K_{tr} can be taken as zero for the column anchorage.

5. Check $(c + K_{tr})/d_b \leq 2.5$:

$$\frac{c + K_{tr}}{d_b} = \frac{2.0 + 0}{1.0} = 2.0 < 2.5 \Rightarrow \text{USE 2.0}$$

6. The access reinforcement can be ignored and the factor applied can be omitted.



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

7. Calculate l_d :

$$l_d = \frac{3}{40} \left(\frac{f_y}{\sqrt{f'_c}} \right) \left[\frac{\alpha\beta\gamma\lambda}{\left(\frac{c+k_{tr}}{d_b} \right)} \right] d_b$$

$$l_d = \frac{3}{40} \left(\frac{60,000}{\sqrt{3,000}} \right) \left[\frac{1.3(1)(1)(1)}{2.0} \right] (1.0) = 53.4 \text{ in.} > 12 \text{ in. OK}$$

Since 53.4 in > 24 in. (column width), use a standard hook, either a 90° hook or a 180° hook.



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

Anchorage using a standard 180° hook:

1. The basic development length l_{hb} for the standard hook shown in the figure can be computed from

$$l_{hb} = \frac{1200d_b}{\sqrt{f'_c}} = \frac{1200(1)}{\sqrt{3000}} = 21.9 \text{ in. (also check Table 1c)}$$

2. The only applicable MF is based on side cover of 2 ½ in.

Therefore, **USE MF = 0.7**



Development Length: Standard Hooks in Tension

Table 1c. Basic Development Length l_{db} for Compression Bars (in.) for $f_y = 60,000$ psi

Bar Size	f'_c (normal-weight concrete), psi			
	3000	4000	5000	6000
3	8.2	7.1	6.8	6.8
4	11.0	9.5	9.0	9.0
5	13.7	11.9	11.3	11.3
6	16.4	14.2	13.5	13.5
7	19.2	16.6	15.8	15.8
8	21.9	19.0	18.0	18.0
9	24.7	21.4	20.3	20.3
10	27.8	24.1	22.9	22.9
11	30.9	26.8	25.4	25.4
14	37.1	32.1	30.5	30.5
18	49.4	42.8	40.6	40.6



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

- The required development length is then calculated from

$$l_{dh} = l_{hb} \times MF = 21.9(0.7) = 15.3 \text{ in.}$$

Check minimum :

$$\text{minimum } l_{dh} = 8d_b \geq 6 \text{ in.}$$

$$8d_b = 8 \text{ in.} < 15.3 \text{ in.}$$

OK

The minimum width of column required is

$$15.3 + 2.5 = 17.8 \text{ in.} < 24 \text{ in. (column width)}$$

OK

Therefore, the hook will fit into the column.



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

Anchorage into beam:

The development length required if bars are straight can be taken as 53.4 in. as determined previously. However, this number is conservative ($K_{tr} = 0$).

To determine a more accurate value, we have to take into consideration the transverse reinforcement index K_{tr} because there are stirrups in the beam.



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd) Area of 2 #4 stirrups

$$K_{tr} = \frac{A_{tr} f_{yt}}{1500 s n} = \frac{0.4(60,000)}{1500(5)(3)} = 1.067$$

$$\frac{c + K_{tr}}{d_b} = \frac{2.0 + 1.067}{1.0} = 3.07 < 2.5 \Rightarrow \text{USE } 2.5$$

$$l_d = \frac{3}{40} \left(\frac{f_y}{\sqrt{f'_c}} \right) \left[\frac{\alpha \beta \gamma \lambda}{\left(\frac{c + k_{tr}}{d_b} \right)} \right] d_b$$

$$l_d = \frac{3}{40} \left(\frac{60,000}{\sqrt{3,000}} \right) \left[\frac{1.3(1)(1)(1)}{2.5} \right] (1.0) = 42.7 \text{ in.} > 12 \text{ in. OK}$$



Development Length: Standard Hooks in Tension

Table 2. ASTM Standard - English Reinforcing Bars

Bar Designation	Diameter in	Area in ²	Weight lb/ft
#3 [#10]	0.375	0.11	0.376
#4 [#13]	0.500	0.20	0.668
#5 [#16]	0.625	0.31	1.043
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#18 [#57]	2.257	4.00	13.60

Note: Metric designations are in brackets



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

Anchorage into beam (cont'd):

- The development length required if bars are straight is **42.7 in.**
- Therefore, the bars must extend at least this distance into the span.
- Figure 4 shows the detailed sketch for the development length.



Development Length: Standard Hooks in Tension

■ Example 1 (cont'd)

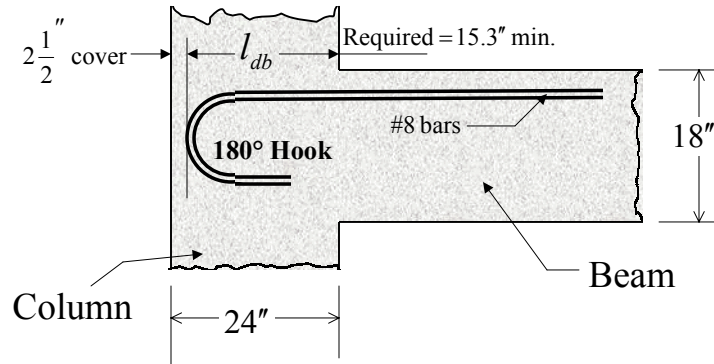


Figure 4. Detailed Sketch for Example 1