Lecture 05

Development Length, Splices and Curtailment of Reinforcement

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Lecture Contents

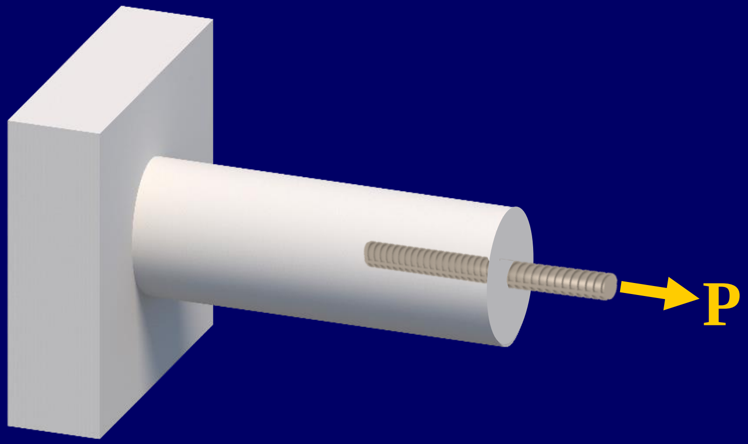
- Development Length
  - Development Length of Compression Reinforcement
  - ACI provisions for Development of Tension Reinforcement
  - ACI provisions for Development of Standard Hook in Tension
- Dimensions & Bends for Standard Hooks
- Splices of Deformed Bars
- Curtailment of reinforcement

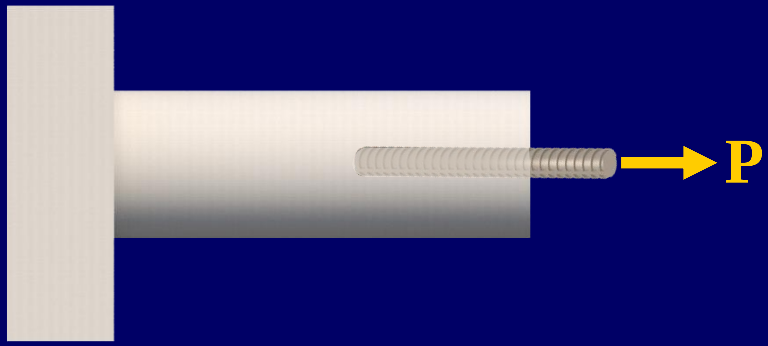
Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Explain*** importance of Development Length in concrete members to avoid bond failure
  - ***Outline*** location of curtailment of reinforcement

Development Length

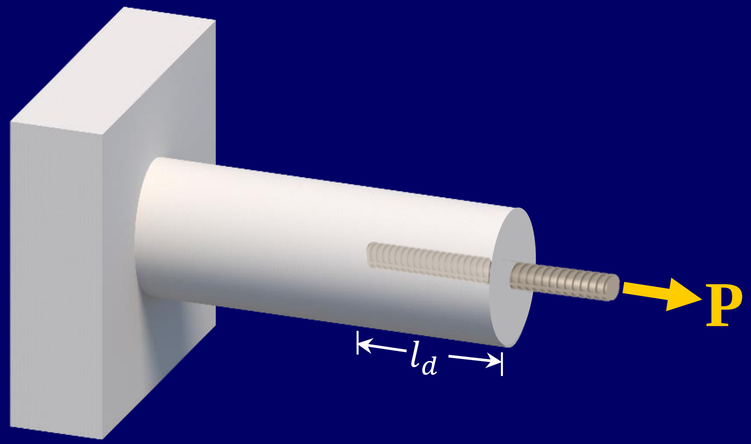
- **Introduction**
  - Consider a steel bar embedded in a concrete block; if force P is gradually increased, depending on the embedment length, either the bar will come out of the concrete block, or the steel will yield.

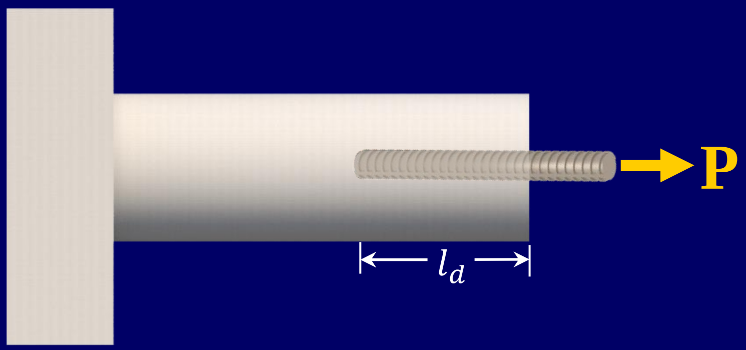




Development Length

- **Introduction**
  - ***Development length*** refers to "the minimum length of the bar that must be embedded in the concrete block so that it yields but does not pull out due to bond failure".
  - Bond failure occurs when the provided embedment length l is less than the development length l_d.





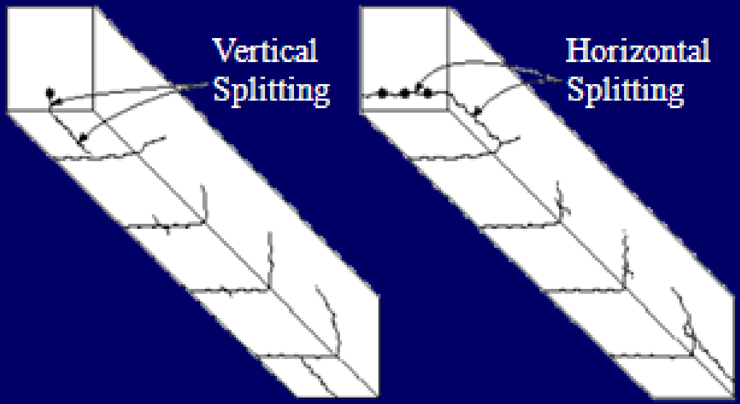
Development Length

- **Introduction**
  - Rebar Pullout Test

Development Length

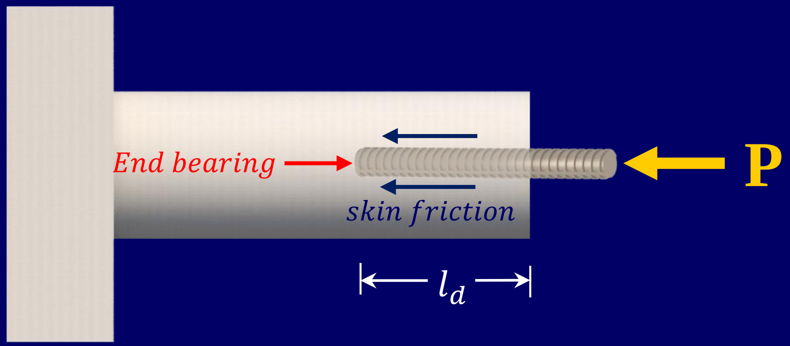
- **Bond Failure**
  - There are two types of bond failure

1. **Direct pullout of reinforcement:** Direct pullout of reinforcement occurs in members subjected to direct tension.
2. **Splitting of concrete:** In members subjected to tensile flexural stresses, the reinforcement causes splitting of concrete as shown.



Development Length

- **Development Length of Compression Members**
  - In the case of bars in compression, a part of the total force is transferred by bond along the embedded length, and a part is transferred by end bearing of the bars on the concrete.
  - As the surrounding concrete is relatively free of fractures and because of the beneficial effect of end bearing, compression bars can have shorter basic development lengths than tension bars.



Development Length

- **Development Length of Compression Members**
  - The development length of tension reinforcement will be discussed in the next section of the lecture only, because it is the governing criteria in most reinforced concrete structures.
  - For more details refer to section 5.8 of Design of Concrete Structures 14th Ed. by Nilson, Darwin and Dolan.

Development Length

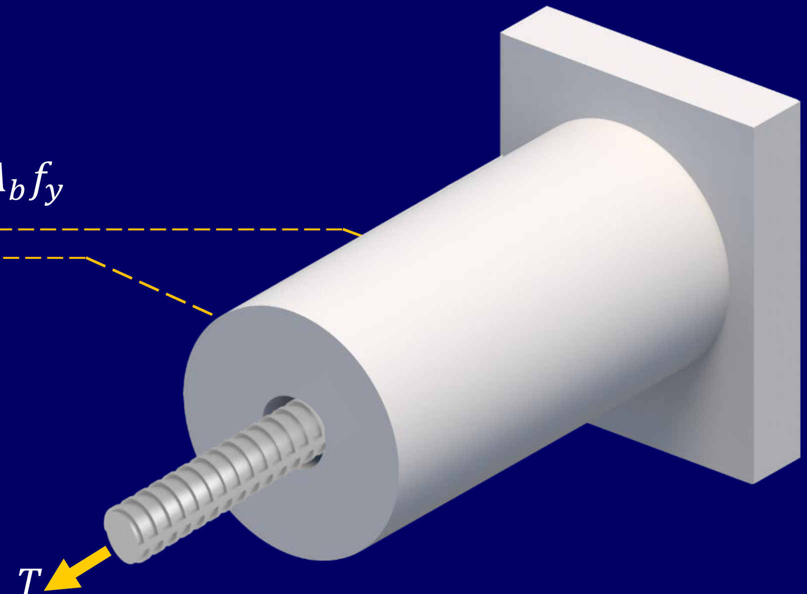
- **Development Length of Tension Reinforcement**
  - Tensile force T, acting on bar A_b having yield strength f_y , tends to pullout bar embedded in concrete member with bond strength f_b
  - Resistance R against the force T, offered by skin friction around bar is given as;

$$R \geq T \qquad \Rightarrow A_{sk} f_b \geq A_b f_y$$

$$Length \times circumference \times f_b \geq A_b f_y$$

$$l_d \times \pi d_b \times \alpha\sqrt{f_c'} \geq \frac{\pi (d_b)^2}{4} f_y$$

$$l_d = \left(\frac{f_y}{4\alpha\sqrt{f_c'}}\right) d_b$$



Development Length

- **ACI 318 Code Provisions for Development of Tension Reinforcement**
  - As per ACI 318, section 25.4.2.4, for deformed bars or deformed wires, l_d shall be calculated by:

$$l_d = \left[\frac{3}{40}\frac{f_y}{\lambda\sqrt{f_c'}}\frac{\Psi_t\Psi_e\Psi_s\Psi_g}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right] d_b$$

Where;

- λ, Ψ_t, Ψ_e, Ψ_s, Ψ_g are called modification factors
- C_b is a factor that represents the least of the side cover, the concrete cover to the bar.
- K_{tr} is a factor that represents the contribution of confinement reinforcement across potential splitting planes. It shall be permitted to take $K_{tr} = 0$ for design simplification.
- The term $\left(\frac{c_b+K_{tr}}{d_b}\right)$ shall not exceed 2.5. For practical cases, it is taken as 1.5.

Development Length

- **ACI 318 Code Provisions for Development of Tension Reinforcement**

Table 25.4.2.5 —Modification factors for development of deformed bars in tension		
Modification factor	**Condition**	**Value of factor**
Lightweight λ	Lightweight concrete	0.75
	Normal weight concrete	1
Reinforcement grade Ψ_g	Grade 40 or Grade 60	1
	Grade 80	1.15
	Grade 100	1.3
Epoxy Ψ_e	Epoxy-coated or zinc and epoxy dual-coated reinforcement with clear cover less than 3db or clear spacing less than 6db	1.5
	Epoxy-coated or zinc and epoxy dual-coated reinforcement for all other conditions	1.2
	Uncoated or zinc-coated (galvanized) reinforcement	1
Size Ψ_s	No. 7 and larger bars	1
	No. 6 and smaller bars and deformed wires	0.8
Casting position Ψ_t	More than 12 in. of fresh concrete placed below horizontal reinforcement	1.3
	Other	1

Development Length

- **ACI 318 Code Provisions for Development of Tension Reinforcement**

  - If the values of λ ,Ψ_t ,Ψ_e ,Ψ_g are taken equal to 1, and $\left(\frac{c_b+K_{tr}}{d_b}\right) = 1.5$ then the previous equation reduces to;

$$l_d\,(in.) = \left(\frac{f_y}{20\sqrt{f_c{}'}}\right) d_b$$

(For No. 7 and larger bars, Ψ_s = 1)

and

$$l_d\,(in.) = \left(\frac{f_y}{25\sqrt{f_c{}'}}\right) d_b$$

(For No.6 and smaller bars, Ψ_s = 0.8)

Development Length

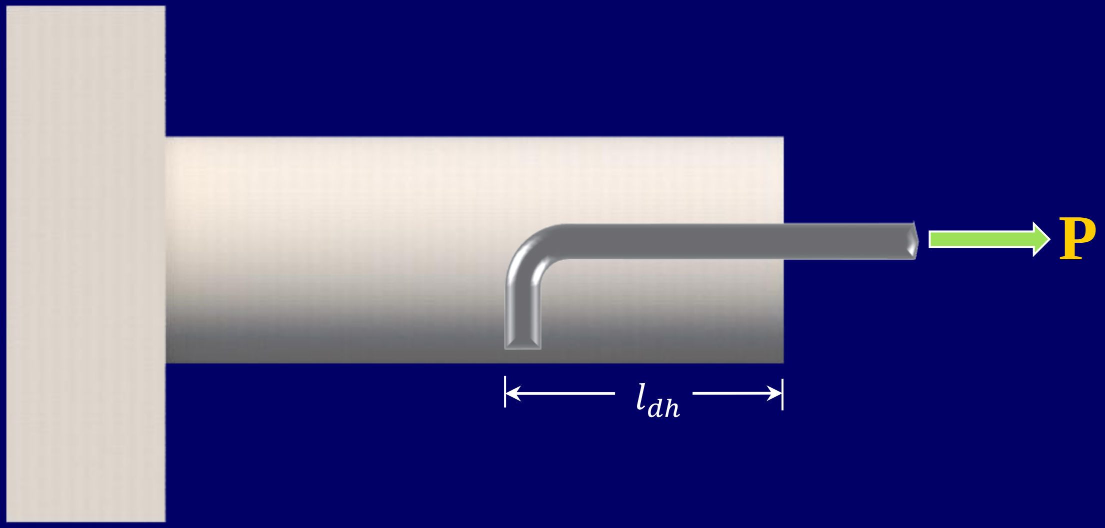
- **ACI 318 Code Provisions for Development of Tension Reinforcement**

Development Lengths for Normal weight Concrete of 3000psi

Bar No.	Equation	Development length l_d	
		Grade 40	Grade 60
#3	$l_d(in) = \left(\frac{f_y}{25\sqrt{f_c{}'}}\right) d_b$	11″	17″
#4		15″	22″
#5		19″	28″
#6		22″	33″
#7	$l_d(in) = \left(\frac{f_y}{20\sqrt{f_c{}'}}\right) d_b$	32″	48″
#8		37″	55″
#9		41″	62″

Development Length

- **ACI 318 Code Provisions for Development of Standard hook in Tension**
  - If a hook is provided at the end of the embedded bar, the requirement on the straight length portion of embedded bar is reduced.



Development Length

- **ACI 318 Code Provisions for Development of Standard hook in Tension**
  - As per ACI 318 -19, section 18.8.5.1, for bar sizes No. 3 through No. 11 terminating in a standard hook, l_{dh} shall be calculated as follows;

Concrete type	Standard hook length l_{dh} (in)
Normalweight concrete	$Larger\ of\ \left(\frac{f_y}{65\sqrt{f_c{}'}}\right)d_b, 8d_b, 6"$
Lightweight concrete	$Larger\ of\ \left(\frac{f_y}{48.75\sqrt{f_c{}'}}\right)d_b, 10d_b, 7.5"$

Development Length

- **ACI 318 Code Provisions for Development of Standard hook in Tension**

Standard hook in Tension for Normal-weight concrete of 3000psi		
Bar No.	Development length l_d	
	Grade 40	Grade 60
#3	5″	7″
#4	6″	9″
#5	7″	11″
#6	9″	13″
#7	10″	15″
#8	12″	17″
#9	13″	19″

Development Length

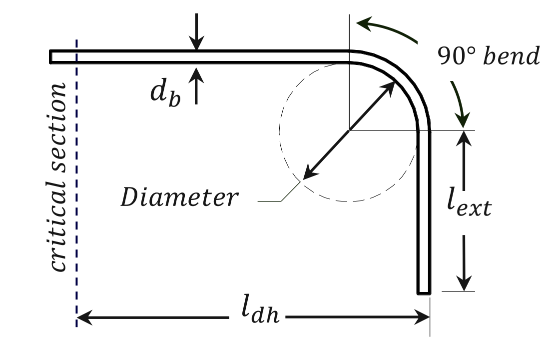
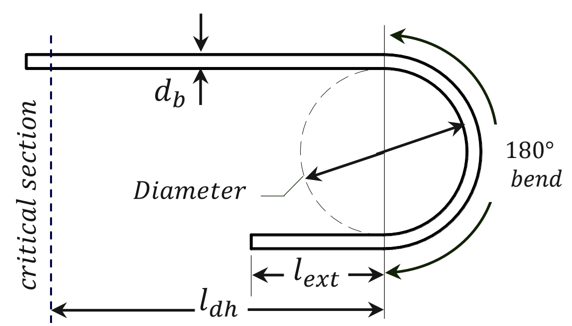
- **ACI 318 Code Provisions for Development of Standard hook in Tension**

Comparison between l_d and l_{dh} for normalweight concrete of 3000psi

Bar No.	Grade 40		Grade 60	
	l_d	l_{dh}	l_d	l_{dh}
#3	11″	5″	17″	7″
#4	15″	6″	22″	9″
#5	19″	7″	28″	11″
#6	22″	9″	33″	13″
#7	32″	10″	48″	15″
#8	37″	12″	55″	17″
#9	41″	13″	62″	19″

Development Length

- **Dimensions and bends for standard hooks (Table 25.3.1)**

Type of standard hook	Bar size	Min. inside bend diameter (in.)	Straight extension[1] l_{ext}, in.	Type of standard hook
90 – degree hook	#3 through #8	$6d_b$	$10d_b$	
180 – degree hook	#3 through #8	$6d_b$	Greater of $4d_b$ and 2.5″	

[1]A standard hook for deformed bars in tension includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

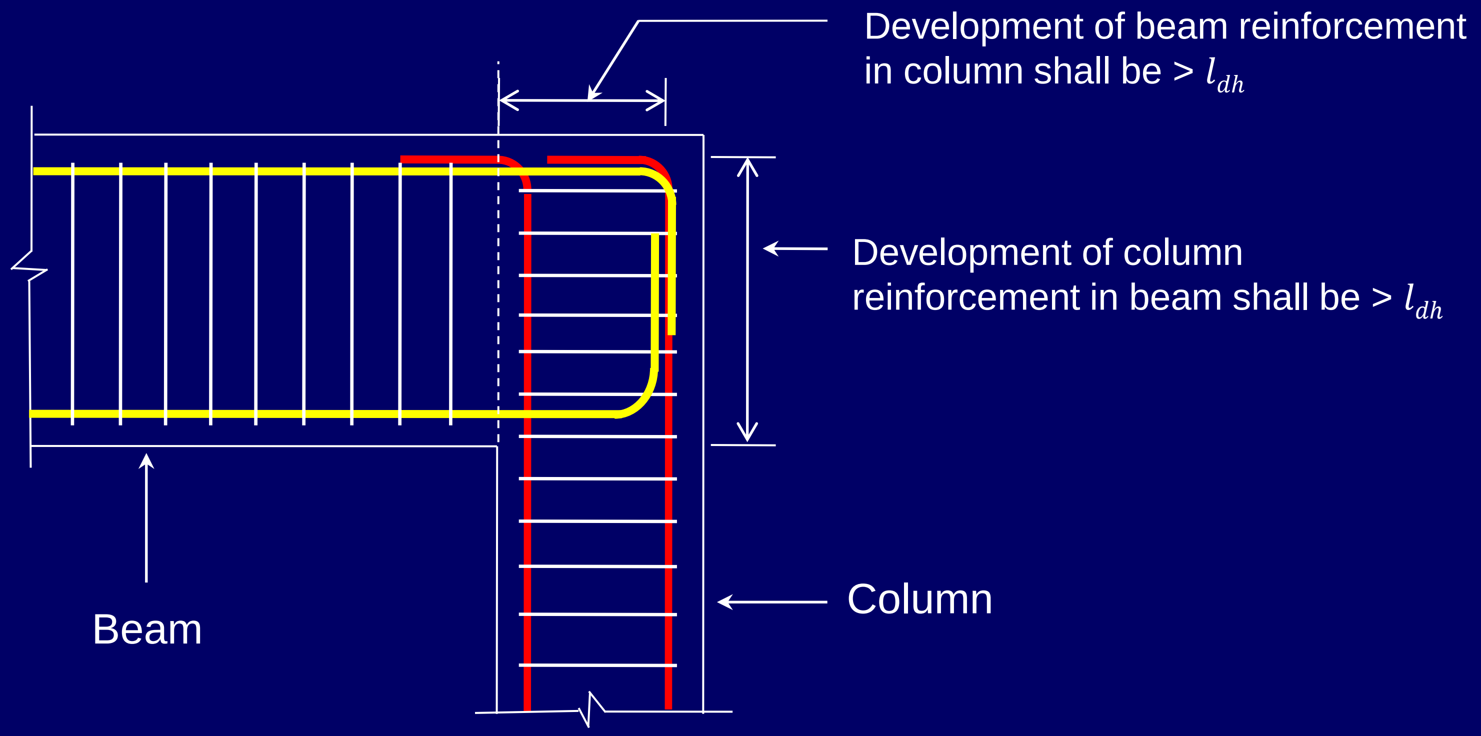
Development Length

- **Critical sections for measuring development length**
  - Development length of a rebar is measured from critical section.
  - A critical section is the location where Load effects such as Bending moment, Shear or Torsion are maximum.
  - Critical sections for various cases are shown below.

Development Length

- **Critical sections for measuring development length**

1. Beam Column Joint

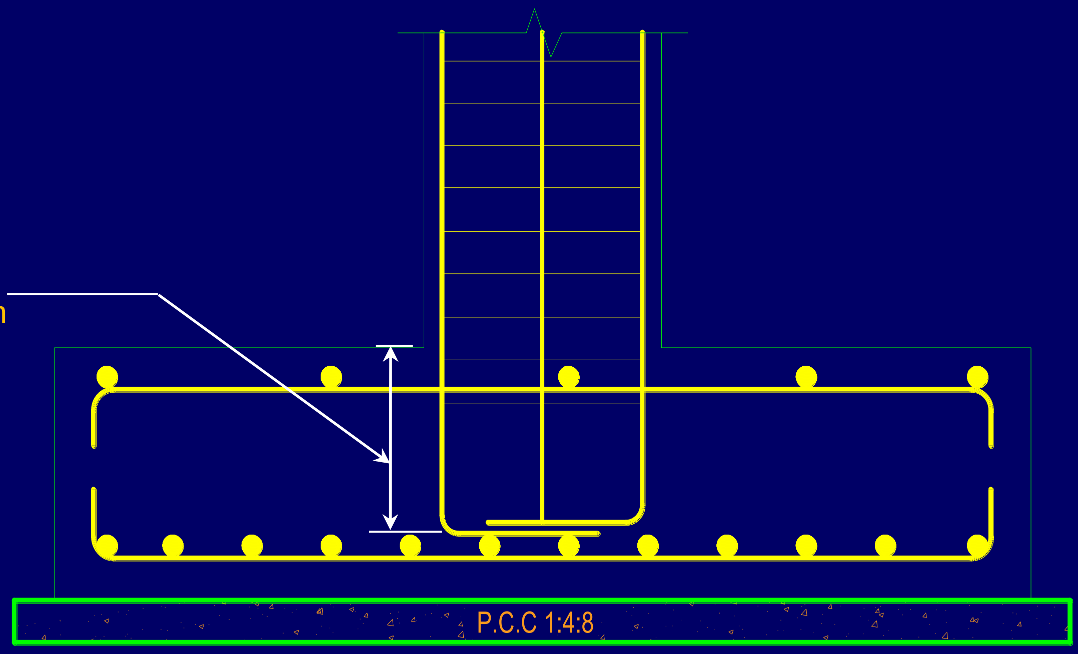


Development Length

- **Critical sections for measuring development length**

  2. Development of column reinforcement in foundation

Development of column reinforcement in foundation

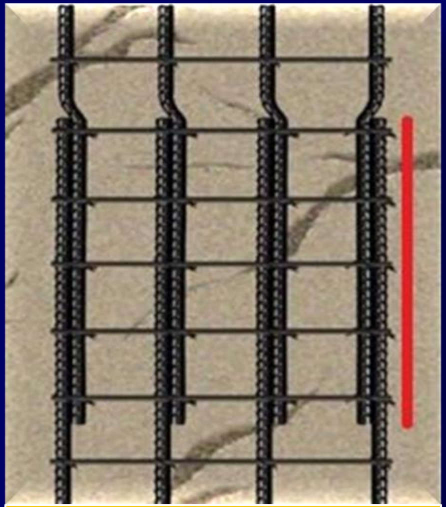


Splices of Deformed bars

- **Introduction**
  - Splice means "to join".
  - In general, reinforcing bars are stocked by supplier in lengths up to 60ft.
  - For this reason, and because it is often more convenient to work with shorter bar lengths, it is frequently necessary to splice bars.
  - Splices in the reinforcement at points of maximum stress should be avoided.
  - Splices should be staggered.

Splices of Deformed bars

- **Various Types of Splices**
  - Bar splicing can be done in three ways:



1. Lap Splice

2. Mechanical Splice

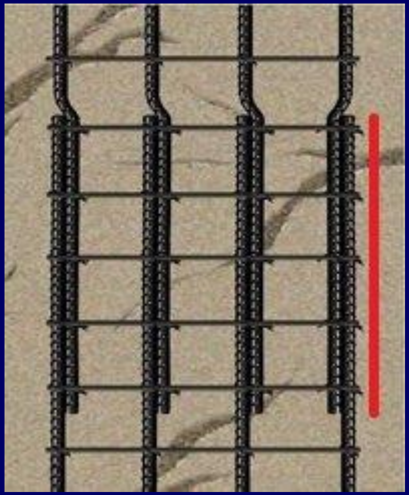
3. Weld Splice

Splices of Deformed bars

- **Various Types of Splices**

  1. **Lap Splice**

     - Splices for #11 bars and smaller are usually made simply lapping the bars by a sufficient distance to transfer stress by bond from one bar to the other.



Splices of Deformed bars

- **Various Types of Splices**

  1. **Lap Splice**

     - The lapped bars are usually placed in contact and lightly wired so that they stay in position as the concrete is placed.

     - According to ACI 318-19, Section 25.5.1.3, bars spliced by noncontact lap splices in flexural members shall not be spaced transversely farther apart than one-fifth the required lap splice length, nor 6 inches.

Splices of Deformed bars

- **Various Types of Splices**

  1. **Lap Splice**

     - According to ACI 318-19, Section 25.5.2.1, minimum length of lap for tension lap splices shall be as required for Class A or B splice, but not less than 12 inches, where:
       - Class A splice .... 1.0 l_d
       - Class B splice ....1.3 l_d

       Where l_d as per ACI 25.4 (discussed earlier).
     - As per ACI Code, Lap splices in general must be class B splices.

Splices of Deformed bars

- **Various Types of Splices**

  2. **Mechanical Splice**

     - In this method of splicing, the bars in direct contact are mechanically connected through couplers.

Splices of Deformed bars

- Various Types of Splices

2. Mechanical Splice

   - According to ACI 318-19, Section 25.5.7.1, a full mechanical splice shall develop in tension or compression, as required, at least 125 percent of specified yield strength f_y of the bar.
   - This ensures that the overloaded spliced bar would fail by ductile yielding in the region away from the splice, rather than at the splice where brittle failure is likely.

Splices of Deformed bars

- **Various Types of splices**

  3. **Welded splice**

     - Splicing may be accomplished by welding in which bars in direct contact are welded so that the stresses are transferred by weld rather than bond.
     - According to ACI 25.5.7.1, a full welded splice shall develop at least 125% of the specified yield strength f_y of the bar.

Splices of Deformed bars

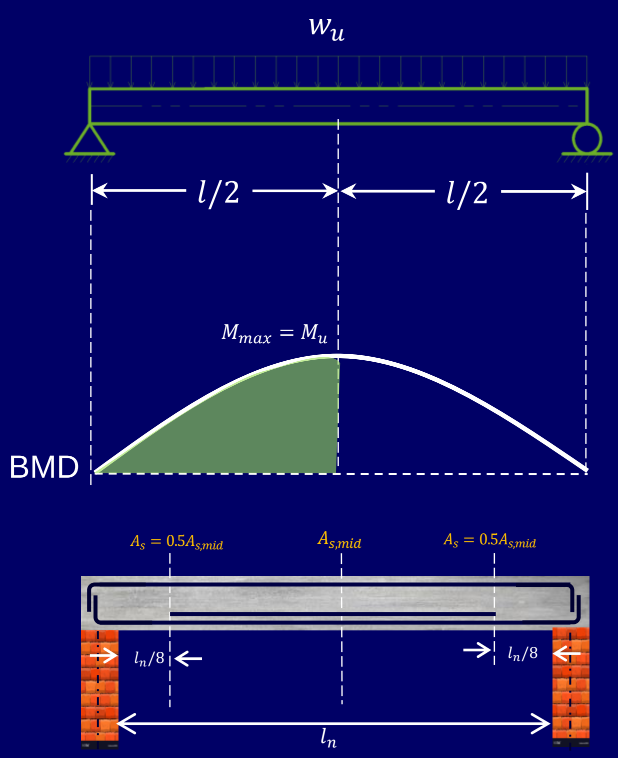
- **Splice Location**
  - The splicing should be avoided in the critical locations, such as at the maximum bending moment locations and at the shear critical locations.

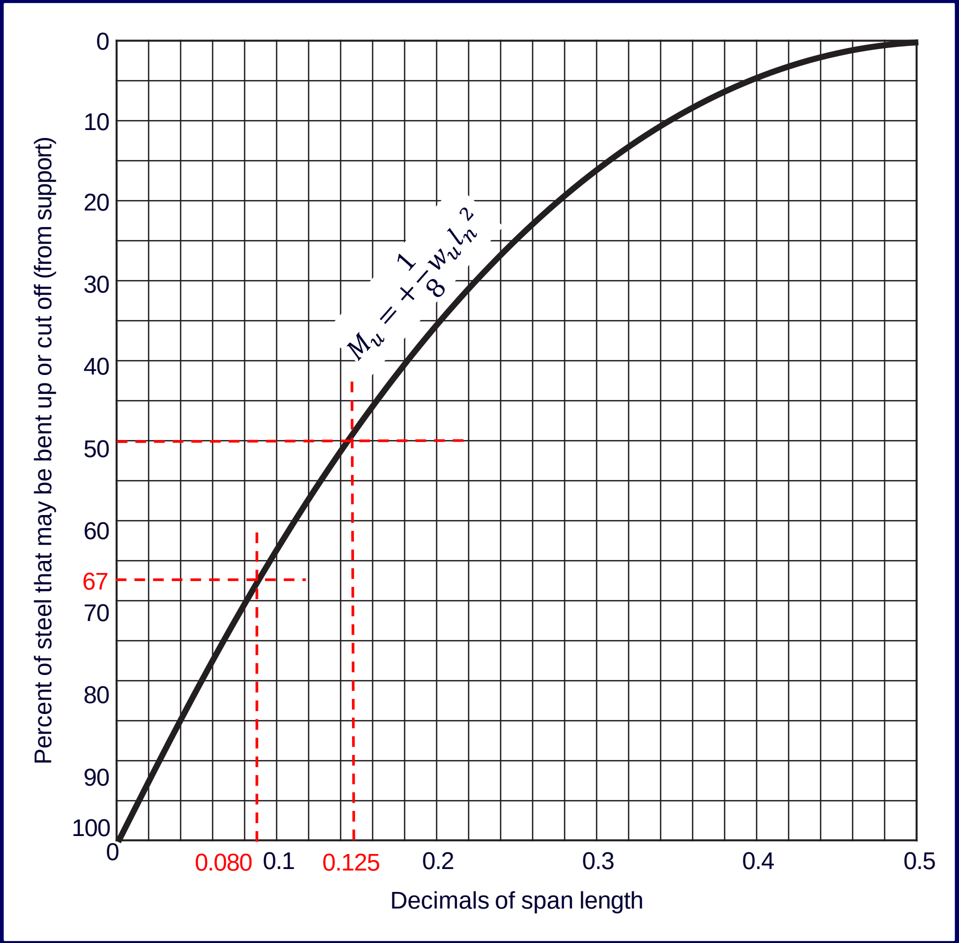
Curtailment of reinforcement

- **Introduction**
  - It is common practice to cut off bars where they are no longer needed to resist stress.
  - In the case of simply supported beams, the figure on the next slide shows cut off locations for various percentages of reinforcement curtailment.

Curtailment of reinforcement

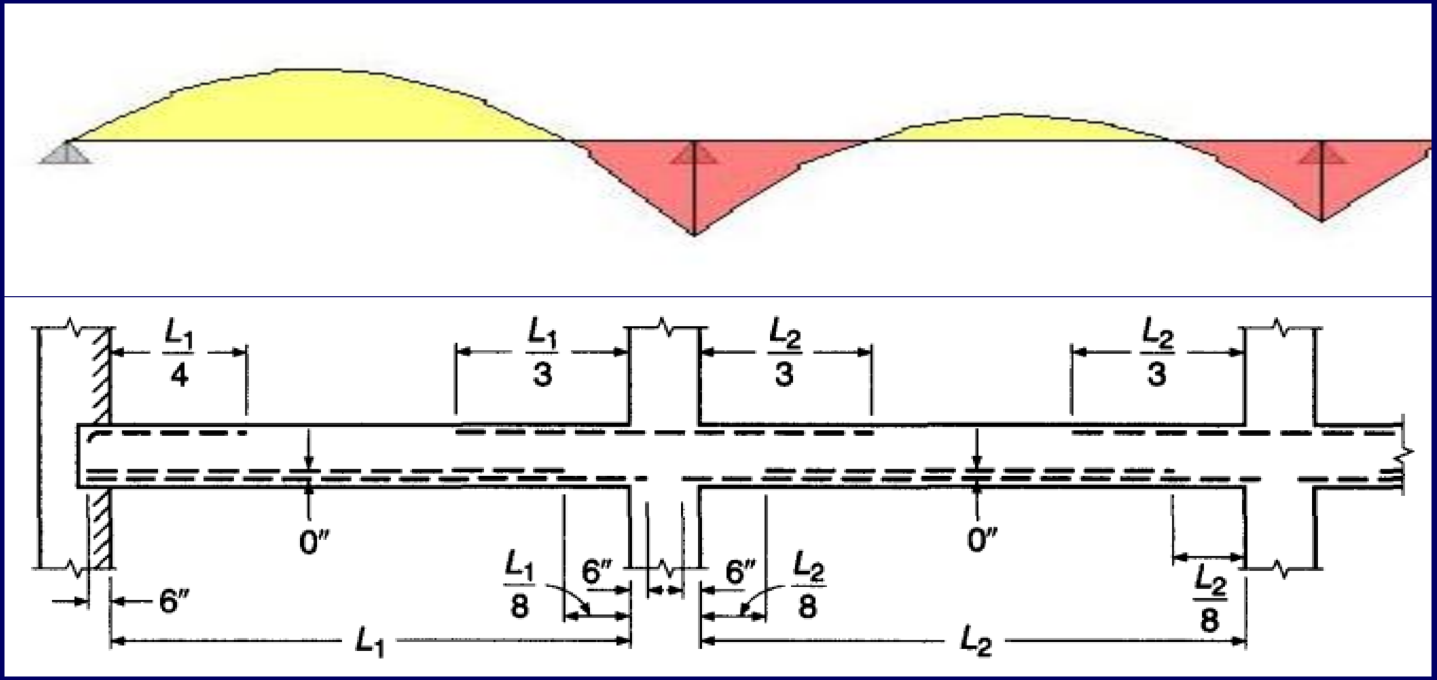
- **Cut off locations for various percentages of reinforcement curtailment.**





Curtailment of reinforcement

- **Cut off locations for various a typical continuous beam**
  - For nearly equal spans, uniformly loaded, in which not more than about one-half the tensile steel is to be cut off, the locations shown in figure are satisfactory.



References

- Design of Concrete Structures 14th / 15th edition by Nilson, Darwin and Dolan.
- Building Code Requirements for Structural Concrete (ACI 318-19)