بسم الله الرحمن الرحيم

CE 416
Reinforced Concrete Design – II

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Course Contents

OBE Course Contents Fall 2025

Grading Policy

- Breakdown of Grading Weightage
  - Exam 75%
    - Mid Term 25%
    - Final Term 50%
  - Class Participation 25%
    - Assignments (3) 08%
    - Quizzes (3) 10%
    - CEP (1) 07%

Teaching Plan

Week	Lectures	Assessments
01	**Lecture 1**: Introduction	
02	**Lecture 2 Part_I:** Analysis and Design of One-way Slab System	
03	-Do-	Assignment#1
04	**Lecture 2 Part_II:** Analysis and Design of One-way Slab System	
05	**Lecture 3:** Analysis and Design of Two-way Slab Systems (Two Way Slabs Supported on Stiff Beams Or Walls)	
06	-Do-	Quiz #1
07	**Lecture 4:** Analysis and Design of Two-way Slab System without Beams (Flat Plates and Flat Slabs)	Assignment#2
08	-Do-	
09	**Mid Term Examination**	

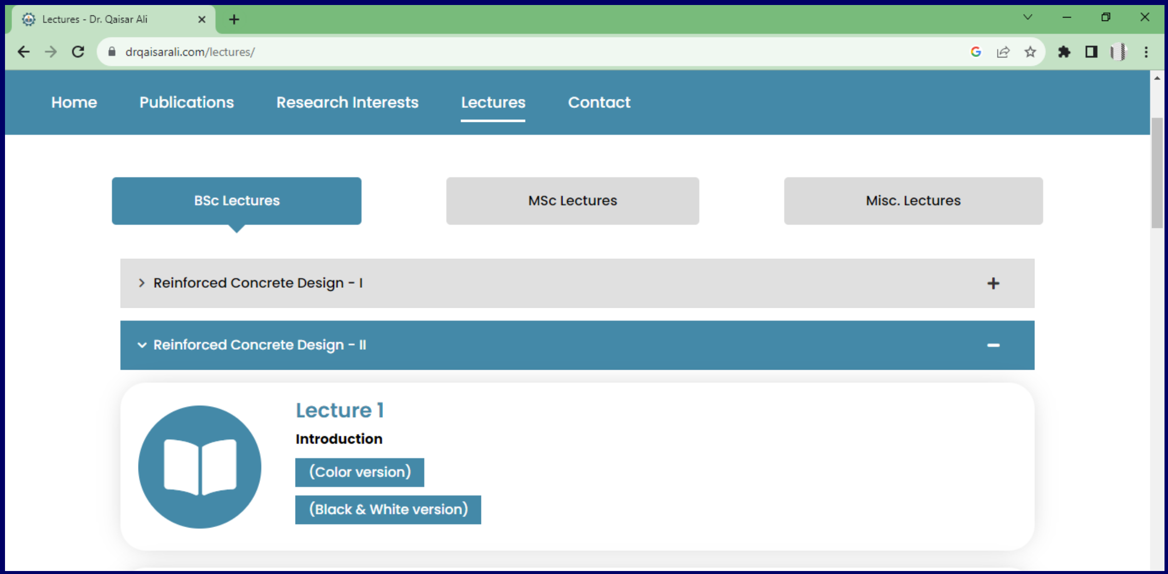
Teaching Plan

Week	Lectures	Assessments
10	**Lecture 5 Part_I:** Introduction to Earthquake Resistant Design of Reinforced Concrete Structures	Assignment#3
11	**Lecture 5 Part_II:** Introduction to Earthquake Resistant Design of Reinforced Concrete Structures	Quiz #2
12	**Lecture 6:** Design of RC Retaining Walls	
13	-Do-	
14	**Lecture 7:** Introduction to Bridge Engineering	
15	**Lecture 8:** Introduction to Prestressed Concrete	Quiz #3
16	**Final Term Examination**	

Lecture Availability

- You can access previous versions of lectures on my website at the following link :

https://drqaisarali.com/lectures/.



- Updated lectures upon completion will be uploaded on website as well as on Google Classroom.

Lecture 01

Introduction

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Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Explain*** Difference between Demand and Capacity
  - ***Compare*** Working stress method with Strength Design method
  - ***Analyze*** and Design Beams for flexure and shear using ACI Recommendations

Lecture Contents

- Concept of Demand and Capacity
- A Glimpse of RCD – I
  - Load Combinations and Strength Reduction Factors
  - ACI Code Provisions related to Flexural Design of beams
  - ACI Code Provisions related to Shear Design of beams
- Flexural and Shear Design of Beam (Example)
- References
- Appendix

Concept of Demand and Capacity

Demand

- Demand on a structure refers to all external actions.
- Gravity, wind, earthquake, snow are external actions.
- These actions when act on the structure will induce internal disturbance(s) in the structure in the form of stresses (such as compression, tension, bending, shear and torsion).
- The internal stresses are also called Load effects.

Concept of Demand and Capacity

❑ Capacity

- Capacity refers to the overall ability of a structure to carry an imposed demand.

Beam resists the applied load up to its capacity.

Beam fails when demand exceeds the capacity.

Concept of Demand and Capacity

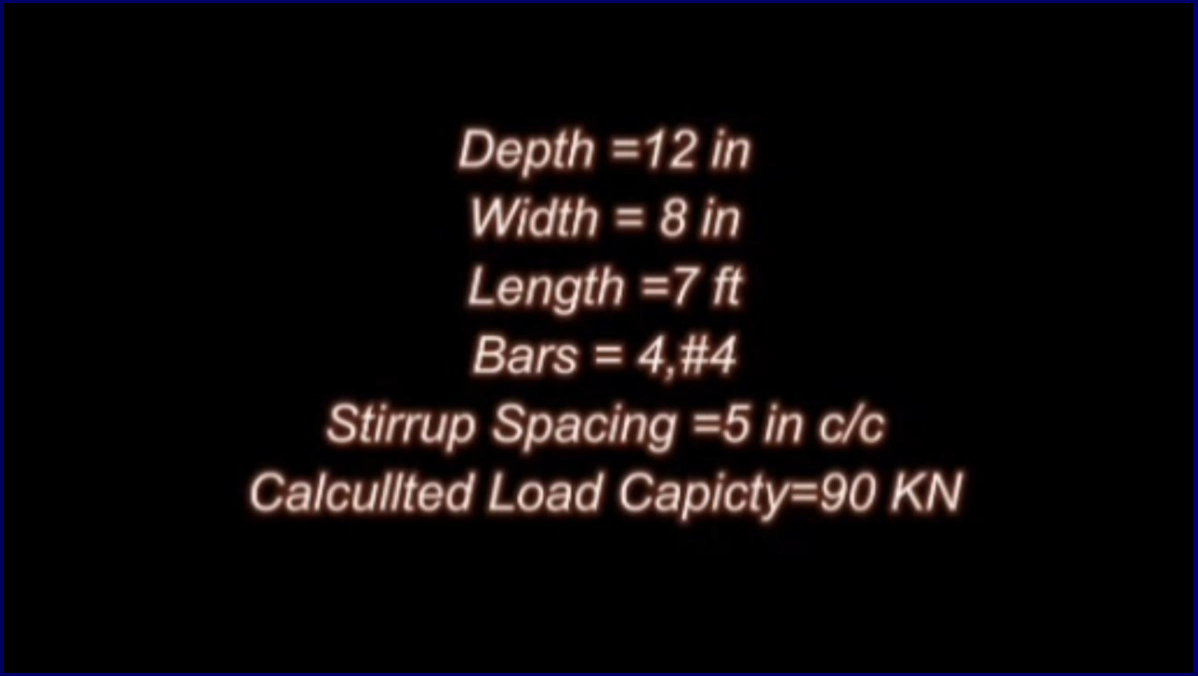
❑ Failure

- Failure occurs when Capacity is less than Demand.
- To avoid failure, capacity to demand ratio should be kept greater than one, or at least equal to one.
- It is, however, intuitive to have some margin of safety i.e., to have capacity to demand ratio more than one. How much?

Concept of Demand and Capacity

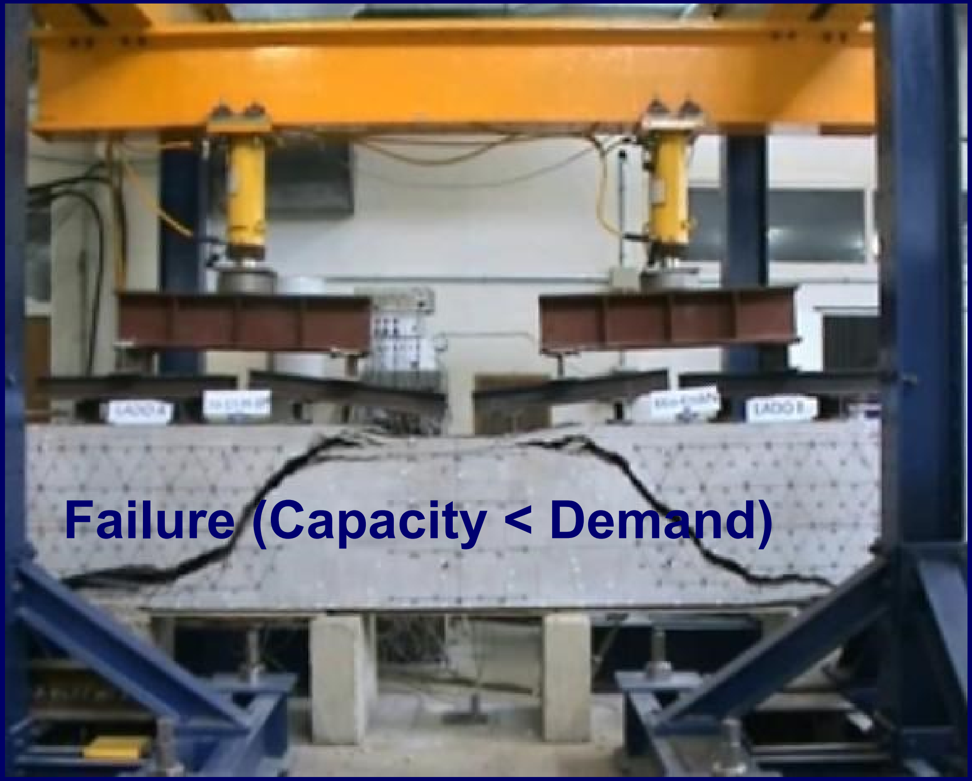
❑ Failure

- An Experimental Test on Beam’s Capacity under Point load



Concept of Demand and Capacity

- Failure



Concept of Demand and Capacity

About Ton

- **Ton** is the name which basically describes the unit of weight. Different types of Ton are tabulated below.

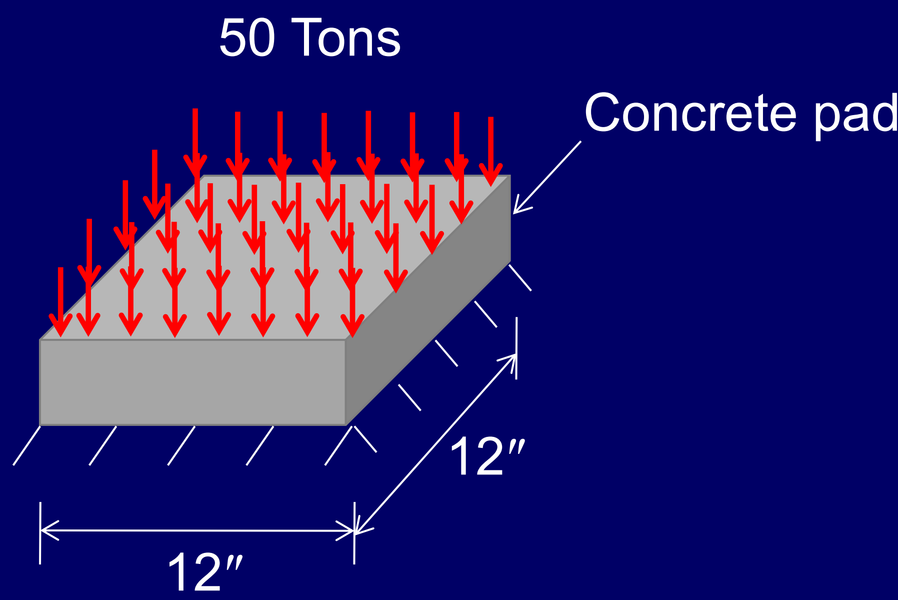
S. No.	Name	Quantity
1	**Long Ton (US)**	2240 pounds
2	**Short Ton (US)**	2000 pounds
3	**Tonne** or **Metric Ton**	2204.6226 pounds Or 1000kg

- In Pakistan, the use of metric ton is very common; therefore; we will refer to Metric Ton in our discussion.

Concept of Demand and Capacity

❑ Example 1.1

- Calculate demand in the form of stresses or load effects on the given concrete pad of size 12″ × 12″.



Concept of Demand and Capacity

Solution

- **Given Data**
  - Load, P = 50 Tones = 50 X 2204 = 110200 lb.
  - Area of concrete Pad, A = 12 X 12 = 144 in^2
- **Required Data**
  - Calculate the capacity of concrete pad for the given demand

Concept of Demand and Capacity

❑ Solution

- Based on convenience either the loads or the load effects as demand are compared to the load carrying capacity of the structure in the relevant units.

As we know that

$$Capacity = Strength \times Area \Rightarrow C = \sigma_{max} \times A$$

For concrete pad; $\sigma_{max} = f_s$

$$C = f_s \times 144$$

Concept of Demand and Capacity

❑ Solution

- For safety, Capacity should be equal to or greater than demand.

For $Capacity = Demand$;

$$f_s \times 144 = 110200$$

$$f_s = \frac{110200}{144} = 765.28psi$$

- This means Capacity of the pad in the form of resistance should be able to carry a stress of 765.28 psi.
- In other words, the compressive strength of concrete pad (capacity) should be more than 765.28 psi (demand).

Concept of Demand and Capacity

❑ Example 1.2

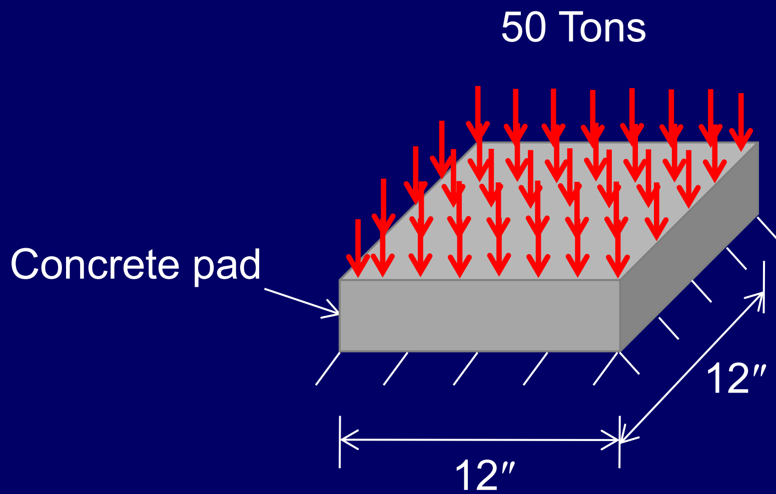
- Determine capacity to demand ratio for the pad of example 1.1 for the following capacities given in the form of compressive strength of concrete. Comment on the results

  i. 500 psi

  ii. 765.28 psi

  iii. 1000 psi

  iv. 2000 psi.



Concept of Demand and Capacity

❑ Solution

Part	Capacity/Demand	Remarks
i	500/765.28 $= 0.7$	Capacity is less than Demand
ii	765.28/765.28 $= 1.0$	Capacity is just equal to Demand
iii	1000/765.28 $= 1.3$	Capacity is 1.3 times greater than Demand
iv	1200/765.28 $= 1.6$	Capacity is 1.6 times greater than Demand

- In (iii) and (iv), there is some margin of safety normally called as factor of safety.

Concept of Demand and Capacity

❑ Factor of Safety

- The factor by which the capacity exceeds the demand is known as Factor of Safety.
- It is always better to have a factor of safety in our designs.
- It can be achieved easily if we fix the ratio of capacity to demand greater than 1.0, say 1.5, 2.0 or so, as shown in example 1.2.

Concept of Demand and Capacity

❑ Factor of Safety

- For certain reasons, however, let say we insist on a factor of safety such that capacity to demand ratio remains 1.0. Then there are three ways of doing this:

  1. Take an increased demand instead of actual demand (load), e.g., 70 ton instead of 50 ton in the previous example,
  2. Take a reduced capacity instead of actual capacity such as 1500 psi for concrete whose actual strength is 3000 psi
  3. Doing both.

- How are these three situations achieved?

Concept of Demand and Capacity

Factor of Safety

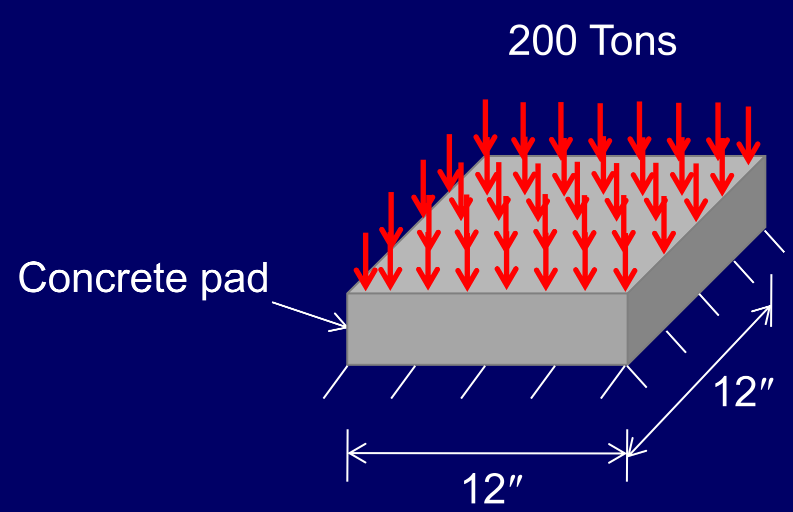
- Following are the two methods of achieving appropriates factor of safety in Design.

1. **Working Stress Method**
   - In the Working Stress or Allowable Stress Design method, the material strength is knowingly taken less than the actual one.
2. **Strength Design Method**
   - In the Strength Design method, the increased loads and the reduced strength of the material are considered, but both based on scientific rationale.

Concept of Demand and Capacity

❑ Example 1.3

- Design the 12″ × 12″ pad to carry a load of 200 tons. The area of the pad cannot be increased for some reasons. Take Concrete compressive strength, fc′ = 3 ksi.



Concept of Demand and Capacity

❑ Solution

- **Given Data**
  - Load, P = 200 Tones
  - Area of concrete Pad, A = 12 X 12 = 144 in^2
  - Concrete Strength, $f_c' = 3000psi$
- **Required Data**
  - Design Concrete Pad for the given demand

Concept of Demand and Capacity

Solution

- First calculate Demand in the form of load effect

$$\sigma = \frac{P}{A} = \frac{200 \times 2204}{144} = 3061.11 psi$$

- Now, determine Factor of Safety

$$FOS = \frac{C}{D} = \frac{3000}{3061.11} = 0.98 < 1$$

Food for Thought

What are some possible solutions to this problem?

Concept of Demand and Capacity

❑ Solution

- There are three possible options to resolve this problem:

  1. Increase area of the pad (geometry)
  2. Increase the strength (by using high strength concrete, steel or other material
  3. Using combination of steel with concrete.

- The first option is not possible as the size of pad is restricted in the given example.

- Now Let us assume that we want to use steel bar reinforcement of yield strength f_y = 40 ksi. Now again calculate the capacity using Working Stress Method.

Concept of Demand and Capacity

❑ Solution

- For Demand = Capacity; and using Working Stress Method

$$P = R_c + R_s$$

$$P = \left(\frac{f_c'}{2}\right)(A_g - A_s) + \left(\frac{f_y}{2}\right)A_s$$

By Substituting the relevant values, we get

$$200 \times 2.204 = \left(\frac{3}{2}\right) \times (144 - A_s) + \left(\frac{40}{2}\right)A_s$$

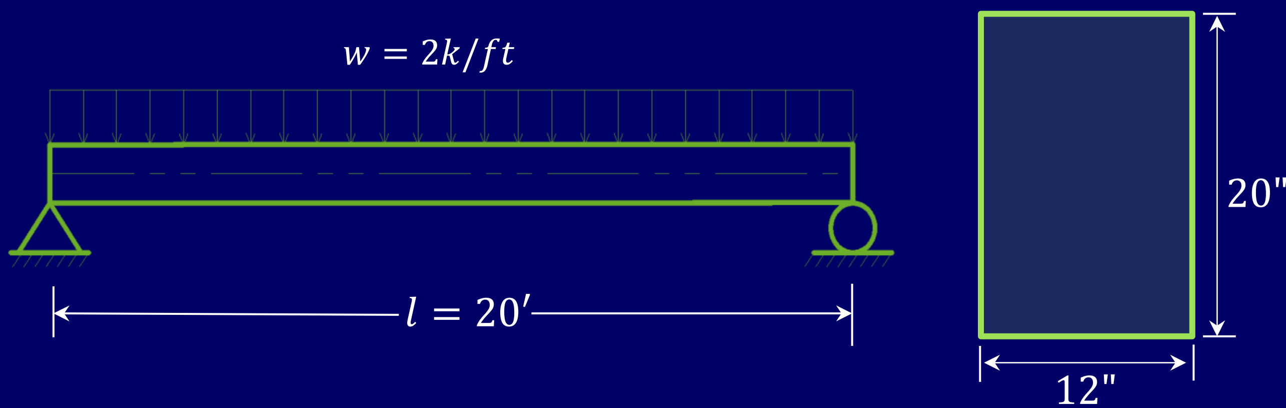
Which on solving for A_s gives

$$A_s = 12.15in^2$$

Concept of Demand and Capacity

❑ Example 1.4

- Check the capacity of the plain concrete beam given in figure below against flexural stresses within the linear elastic range. Concrete compressive strength (fc′) = 3 ksi. Consider Self weight of the beam.



Concept of Demand and Capacity

❑ Solution

- **Given Data**
  - Load on beam (excluding self weight) , W = 2 kip/ft
  - Width, b = 12″
  - Depth, h = 20″
  - Concrete Strength, $f_c' = 3000psi$
- **Required Data**
  - Calculate the Capacity of the beam

Concept of Demand and Capacity

Solution

Step 1: Calculate Demand Moment on Beam

Self weight of beam, SW = $\dfrac{12 \times 20}{144} \times 0.145 = 0.242 \text{kip/ft}$

Maximum Bending Moment at the midspan of the beam is given by;

$$M_u = \frac{W_u l^2}{8}$$

$$M_u = \frac{(2 + 0.242)20^2}{8} \times 12$$

$$M_u = 1345.2 \text{ in. kip}$$

Concept of Demand and Capacity

Solution

Step 2: Calculate Flexural Capacity of beam

In the linear elastic range, flexural stress in concrete beam can be calculated as:

$$f = \frac{Mc}{I}$$

Where;

$$I = \frac{bh^3}{12} = \frac{12 \times 20^3}{12} = 8000 \text{ in}^4$$

and

$$c = \frac{h}{2} = \frac{20}{2} = 10 \text{ in}$$

Concept of Demand and Capacity

❑ Solution

➢ Step 2: Calculate Flexural Capacity of beam

As we know that for a plain concrete beam Flexural strength is equal to modulus of rupture which is given by;

$$f = f_r = 7.5\sqrt{f_c'} = 7.5\sqrt{3000} = 410.79 \text{ psi}$$

Now,

$$M = \frac{fI}{c} = \frac{410.79 \times 8000}{10} = 328632 \text{ lb.in } \ or\ 328.63 \text{ in.kip}$$

Hence, Demand = 1345.2 in-kips and Capacity = 328.63 in-kips

A Glimpse of RCD – I

- In RCD – I, you have already studied the detailed procedure of designing Beams, Slabs, Columns and Footings.
- However, for the sake of revision, we will briefly go over some of those concepts here.

A Glimpse of RCD – I

❑ Load Combinations

Table 5.3.1 - Load combinations

Load combination	Notations
U = 1.4D	D = Dead Load L = Live Load L_r = Roof Live Load R = Rain Load S = Snow Load W = Wind Load E = Earthquake Load
U = 1.2D + 1.6L + 0.5 (L_r or S or R)	
U = 1.2D + 1.6(L_r or S or R) + (1.0L or 0.5W)	
U = 1.2D + 1.0W + 1.0L + 0.5(L_r or S or R)	
U = 1.2D + 1.0E + 1.0L + 0.2S	
U = 0.9D + 1.0W	
U = 0.9D + 1.0E	

A Glimpse of RCD – I

❑ Strength Reduction Factors

Table 21.2.1—Strength reduction factors		
S. No.	**Action or structural element**	ϕ
1	Tension controlled regions (Moment)	0.90
2	Compression controlled regions (Axial force)	0.65
3	Shear	0.75
4	Torsion	0.75

A Glimpse of RCD – I

Flexural Design of Beam

- The Design Flexural Capacity of an RC beam is given by

$$\emptyset M_n = \emptyset A_s f_y \left(d - \frac{a}{2}\right)$$

$$a = \frac{A_s f_y}{0.85 f_c{}' b}$$

Where A_s which is tensile reinforcement, is subjected to the following restrictions.

$$A_{s,min} < A_s < A_{s,max}$$

A Glimpse of RCD – I

Flexural Design of Beam

- **Minimum Reinforcement Limit**

$$A_{s,min} = \frac{3\sqrt{f_c'}}{f_y}bd \quad or \quad \frac{200}{f_y}bd \quad which\ ever\ is\ greater$$

- **Maximum Reinforcement Limit**

$$A_{s,max,40} = \frac{f_c{}'}{136}bd$$

$$A_{s,max,60} = \frac{f_c{}'}{223}bd$$

Food for Thought

Why have these restrictions been imposed on the steel area ?

A Glimpse of RCD – I

Shear Design of Beam

Design Shear Capacity of beam is given by

$$\emptyset V_n = \emptyset V_c + \emptyset V_s$$

Where;

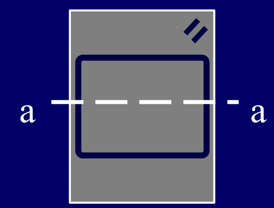
$$\emptyset V_c = 2\emptyset\sqrt{f_c{}'}bd$$

and

$$\emptyset V_s = \frac{\emptyset A_v f_y d}{s_d}$$

A_v is the cross-sectional area of web reinforcement within a distance "s", for single loop stirrups (2 legged), $A_v = 2A_s$

A_s = cross sectional area of the stirrup bar



At section a-a, if #3 bar is used A_s = 0.11 in^2,

A_v = 2 x 0.11= 0.22 in^2

A Glimpse of RCD – I

Shear Design of Beam

- The beam is designed for the ultimate shear force V_u at critical location (which in most cases is at a distance "d" from the face of support.)

1. When $\emptyset V_c/2 > V_u$, no web reinforcement is required.
2. When $\emptyset V_c \geq V_u$ but $\emptyset V_c/2 < V_u$, theoretically no web reinforcement is required. However, minimum web reinforcement in the form of maximum spacing S_{max} shall be provided:

$$s_{max} = \text{minimum of} \left\{ \frac{A_v f_y}{50 b_w}, \frac{A_v f_y}{0.75\sqrt{f_c{}'} b_w}, \frac{d}{2}, 24" \right\}$$

A Glimpse of RCD – I

❑ Shear Design of Beam

3. When $\emptyset V_c < V_u$, web reinforcement is required.

- In this case, the required spacing s_d can be calculated using

$$s_d = \frac{\emptyset A_v f_y d}{V_u - \emptyset V_c}$$

- If s_d is greater than s_{max}, use s_{max}

A Glimpse of RCD – I

Shear Design of Beam

- **Necessary Checks**

1. **Check for Depth of Beam**

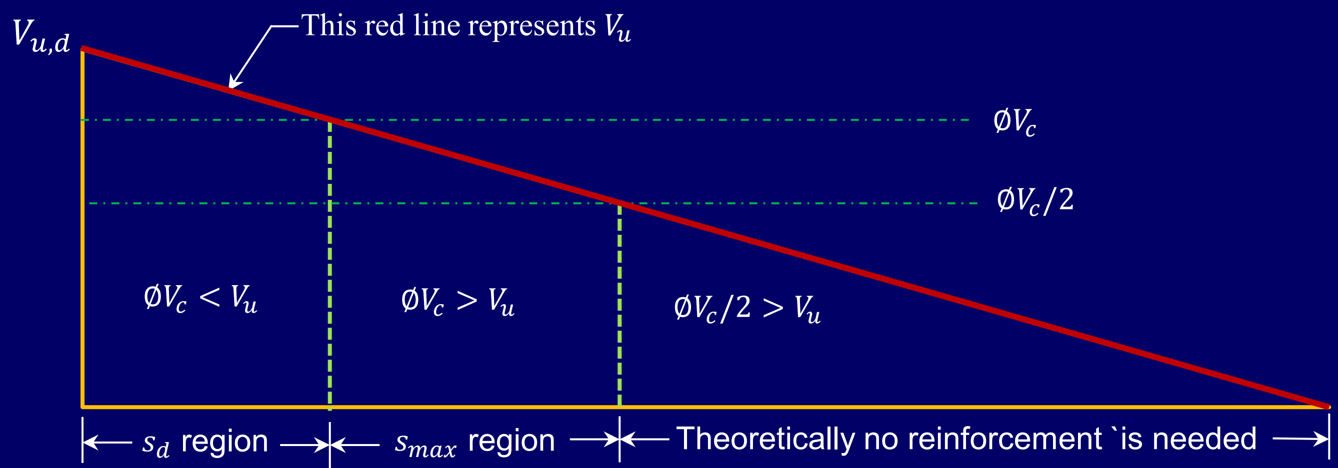
$\emptyset V_s \leq \emptyset 8\sqrt{f_c{}'}b_w d$ → Depth of beam is OK!, otherwise increase depth

2. **Check for maximum Spacing of stirrups**

$\emptyset V_s \leq \emptyset 4\sqrt{f_c{}'}b_w d$ → S_{max} is OK!, otherwise divide S_{max} by 2

A Glimpse of RCD – I

Shear Design of Beam



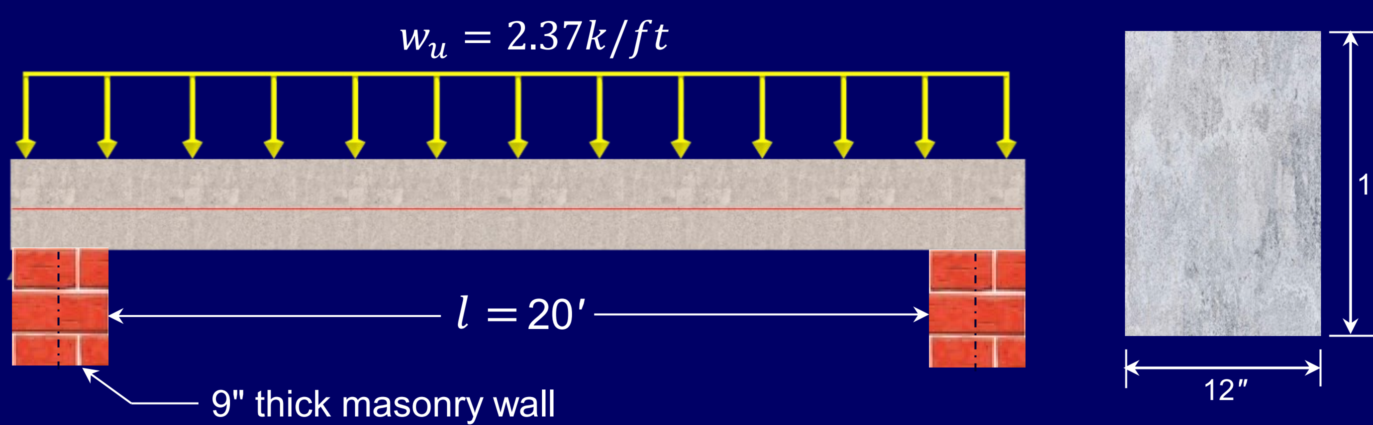
- For $\emptyset V_c < V_u \rightarrow$ use s_d
- For $\emptyset V_c > V_{u,}$ use s_{max}
- For $\emptyset V_c/2 > V_{u,}$ no reinforcement is required

Flexural and Shear Design of RC Beam

❑ Example 1.5

- A simply supported beam with given cross sectional dimensions is subjected to a uniformly distributed factored load of 2.37 kip/ft as shown in the figure below.

Analyze and ***Design*** the beam for flexure and shear in accordance with ACI 318-19. Take $f_c{}' = 3ksi$ and $f_y = 40ksi$



Flexural and Shear Design of RC Beam

Solution

Step 1: Selection of sizes

Cross sectional dimensions are already given

$b_w = 12"$

$h = 18"$

Assuming $\bar{y} = 2.5"$

$d = 18 - 2.5 = 15.5"$

Step 2: Calculation of loads

$w_u = 2.37k/ft$

Flexural and Shear Design of RC Beam

❑ Solution

➢ Step 3: Analysis

1. **Analysis for Flexure**

$$M_u = \frac{w_u l^2}{8} = \frac{2.37(20.75)^2}{8} \times 12 = 1530.65\ in.kip$$

1. **Analysis for Shear**

From eq.(6.5), we have

$$V_u = w_u(\ l_n/2 - d)$$

$$V_u = 2.37(20/2 - 15.5/12)$$

$$V_u = 20.64\ \text{kips}$$

Flexural and Shear Design of RC Beam

❑ Solution

➢ Step 4: Determination of flexural steel area

Using direct method, we have

$$a = 15.5 - \sqrt{15.5^2 - \frac{2.614 \times 1530.65}{3 \times 12}} = 4.1''$$

Putting $a = 4.14$" and $\emptyset = 0.90$, we get

$$A_s = \frac{M_u}{\emptyset f_y(d - \frac{a}{2})} = \frac{1530.65}{0.9 \times 40\left(15.5 - \frac{4.14}{2}\right)}$$

$$A_s = 3.17\ in^2$$

Flexural and Shear Design of RC Beam

Solution

Step 5: Check for flexural steel area

- Minimum reinforcement limit

$$A_{s,min} = \frac{200}{f_y} b_w d = \frac{200}{40000} \times 12 \times 15.5 = 0.93\ in^2$$

- Maximum reinforcement limit

$$A_{s,max} = \frac{f_c' b_w d}{136} = \frac{3 \times 12 \times 15.5}{136} = 4.1\ in^2$$

$$A_{s,min} < A_s < A_{s,max} \Rightarrow OK!$$

Flexural and Shear Design of RC Beam

❑ Solution

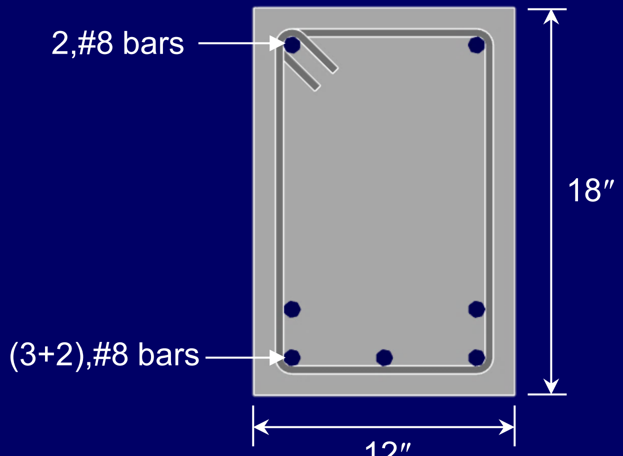
➢ Step 6: Detailing of flexural reinforcement

Using #8 bar with $A_b = 0.79 in^2$

$$No. of\ bars = \frac{A_s}{A_b} = \frac{3.17}{0.79} = 4.01 \approx 5$$

Provide 5,#8 bars in two layers

- 3 in first layer and
- 2 in second layer



Flexural and Shear Design of RC Beam

❑ Solution

➢ Step 7: Check for requirement of Shear reinforcement

From eq.(6.2), Design shear capacity of concrete can be calculated as;

$$\emptyset V_c = 2\emptyset\sqrt{f_c'}b_w d = 2 \times 0.75\sqrt{3000}\,12 \times 15 = 15281.5\ lb$$

$$\emptyset V_c = 15.28k$$

$\emptyset V_c < V_u = 20.64\ k \rightarrow$ Shear reinforcement is required.

Flexural and Shear Design of RC Beam

❑ Solution

➢ Step 8: Determination of stirrup spacing

Calculate design spacing s_d using eq. (6.4)

$$s_d = \frac{\emptyset A_v f_y d}{V_u - \emptyset V_c}$$

Using 2 legged #3 stirrups, $A_v = 2A_b = 2(0.11) = 0.22in^2$

$$s_d = \frac{0.75 \times 0.22 \times 40 \times 15.5}{20.64 - 15.28}$$

$$s_d = 19.1"$$

Flexural and Shear Design of RC Beam

Solution

Step 8: Determination of stirrup spacing

Calculate maximum spacing s_{max} using eq. (6.6)

$$s_{max} = Least\ of \left\{ \begin{array}{l} \dfrac{A_v f_y}{50 b_w} = \dfrac{0.22 \times 40{,}000}{50 \times 12} = 14.67" \\[2ex] \dfrac{A_v f_y}{0.75\sqrt{f_c{}'} b_w} = \dfrac{0.22 \times 40{,}000}{0.75\sqrt{3000} \times 12} = 17.85" \\[2ex] \dfrac{d}{2} = \dfrac{15.5}{2} = 7.75" \\[2ex] 24" \end{array} \right.$$

$$s_{max} = 7.75" < s_d$$

Flexural and Shear Design of RC Beam

❑ Solution

➢ Step 9: Apply necessary checks

1. **Check for Depth of Beam**

$$\emptyset V_s \leq \emptyset 8\sqrt{f_c{}'}b_w d$$

$$\emptyset V_s = \frac{\emptyset A_v f_y d}{s} = \frac{0.75 \times 0.22 \times 40 \times 15.5}{7.5} = 13.64 \text{ kip}$$

$$\emptyset 8\sqrt{f_c{}'}b_w d = 4\emptyset V_c = 4 \times 15.28 = 61.12kip > \emptyset V_s \rightarrow OK!$$

2. **Check for Maximum spacing of stirrups**

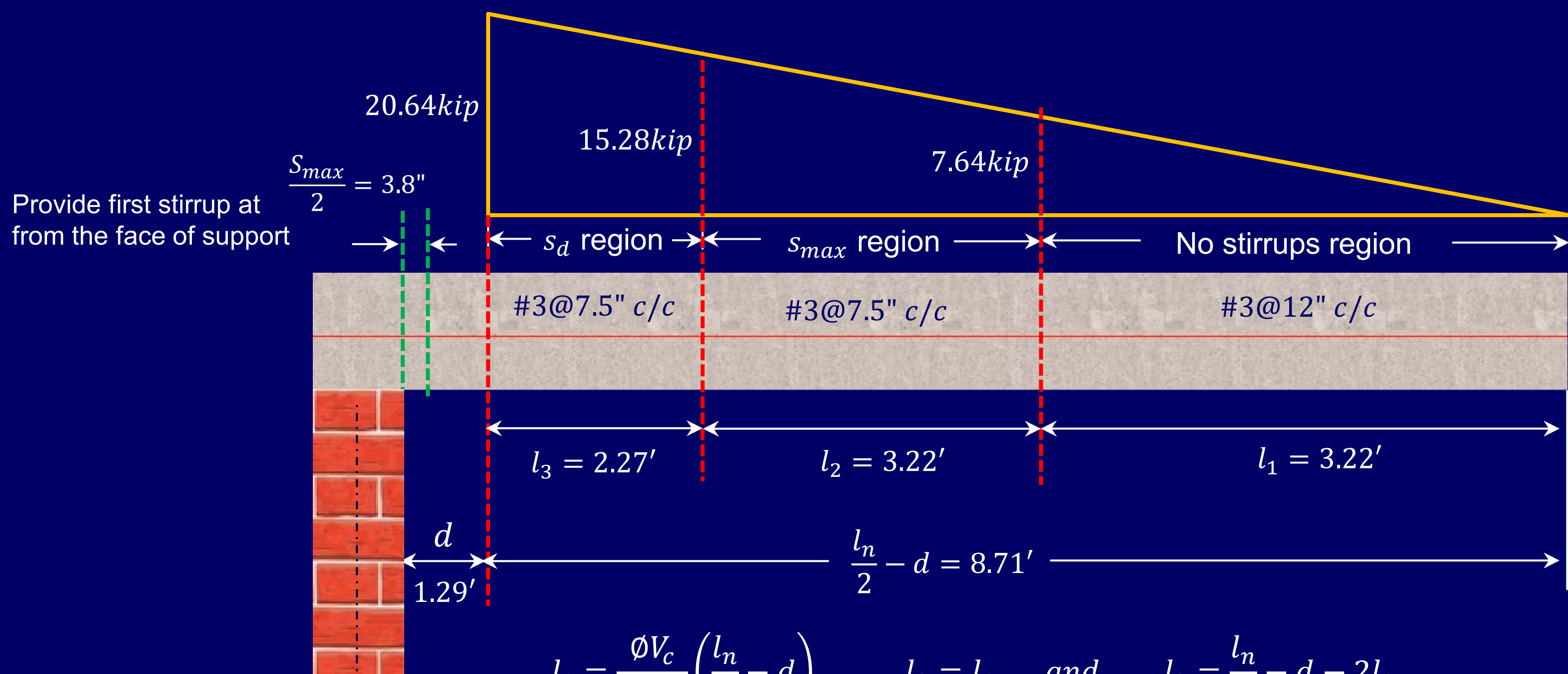
$$\emptyset V_s \leq \emptyset 4\sqrt{f_c{}'}b_w d \quad , \quad \emptyset V_s = 13.64kip$$

$$\emptyset 4\sqrt{f_c{}'}b_w d = 2\emptyset V_c = 2 \times 15.28 = 30.56kip > \emptyset V_s \rightarrow OK!$$

Flexural and Shear Design of RC Beam

❑ Solution

➢ Step 10: Detailing of shear reinforcement

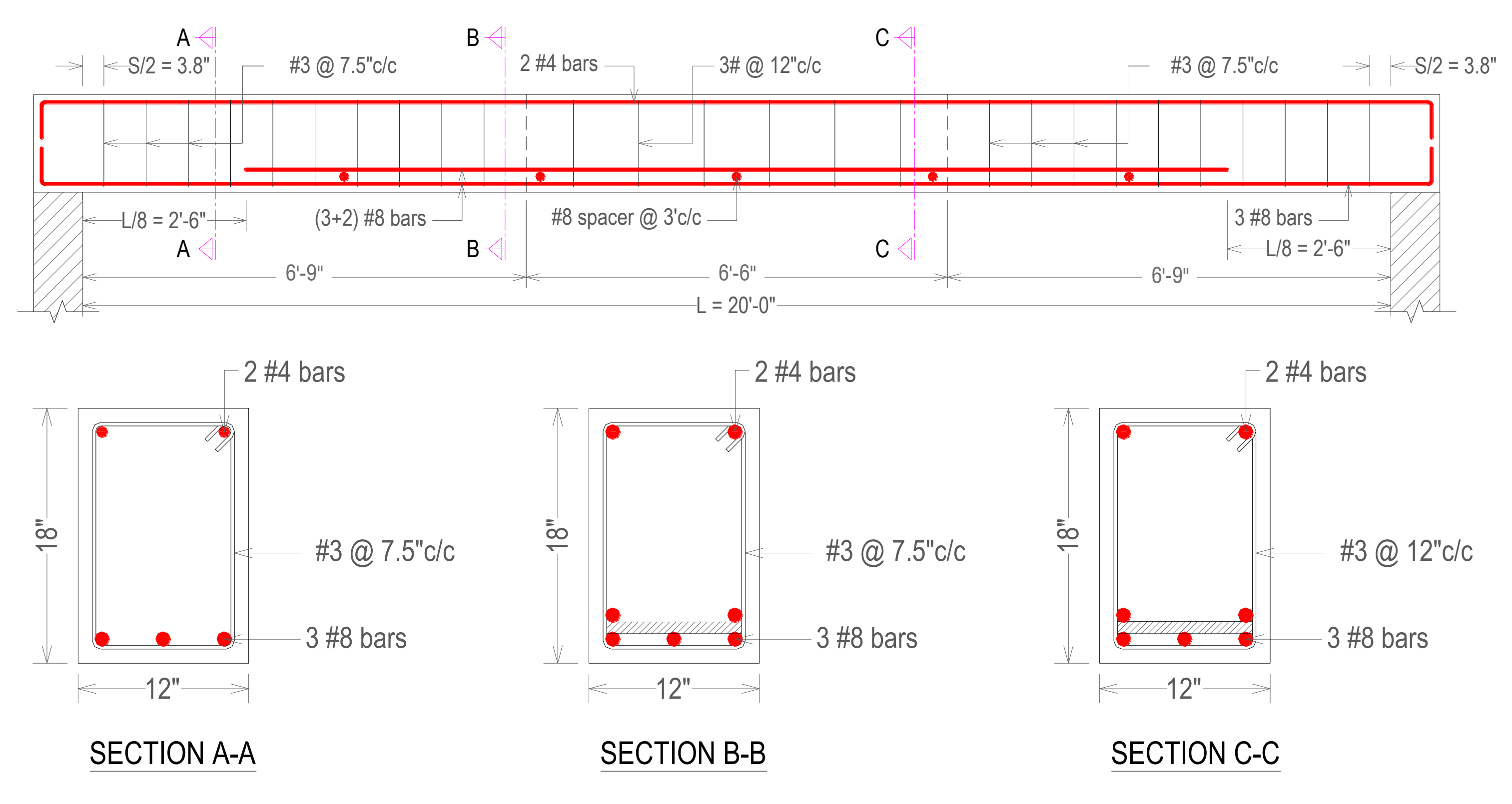


$$l_1 = \frac{\emptyset V_c}{2V_{u,d}}\left(\frac{l_n}{2} - d\right), \quad l_2 = l_1 \quad and \quad l_3 = \frac{l_n}{2} - d - 2l_1$$

Flexural and Shear Design of RC Beam

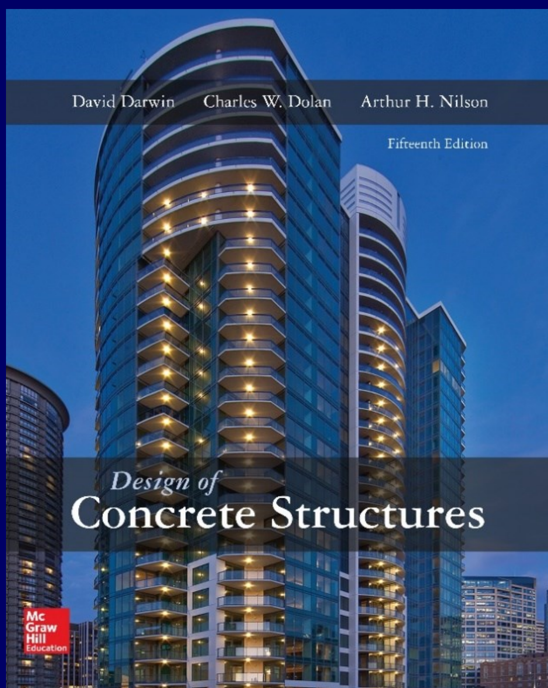
❑ Solution

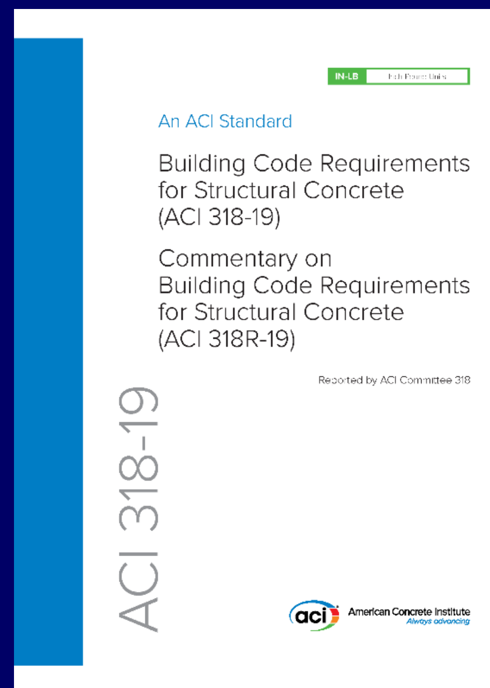
- **Step 11: Drafting**



References

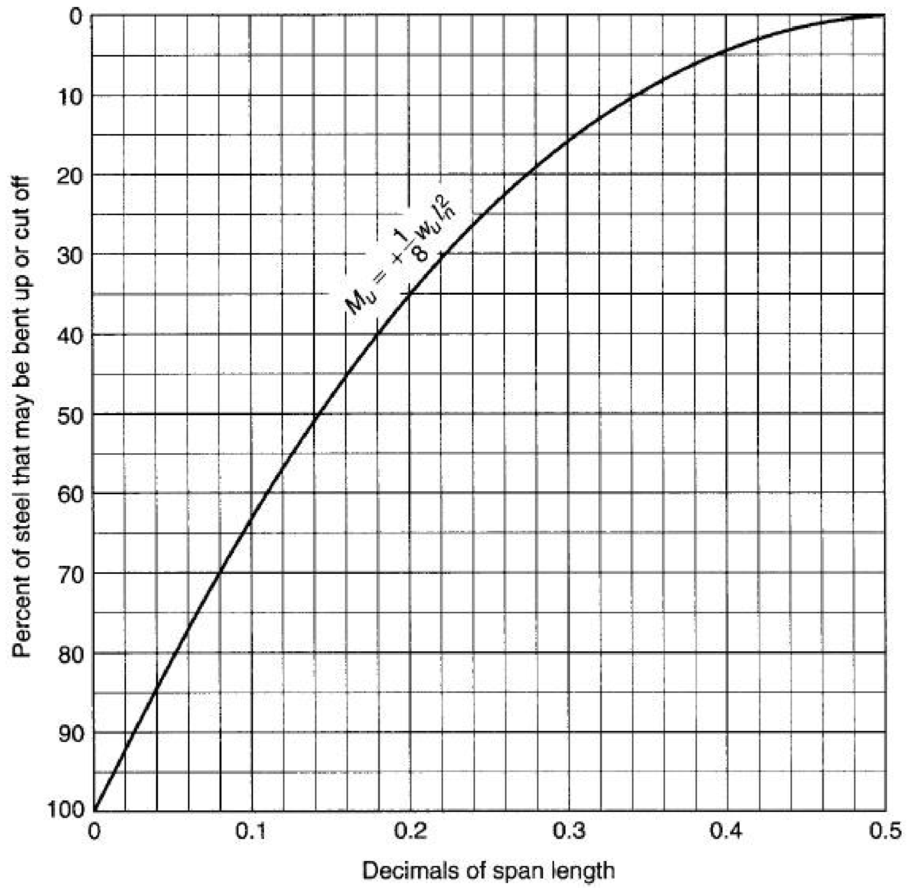
- Design of Concrete Structures 14th / 15th edition by Nilson, Darwin and Dolan.
- Building Code Requirements for Structural Concrete (ACI 318-19)





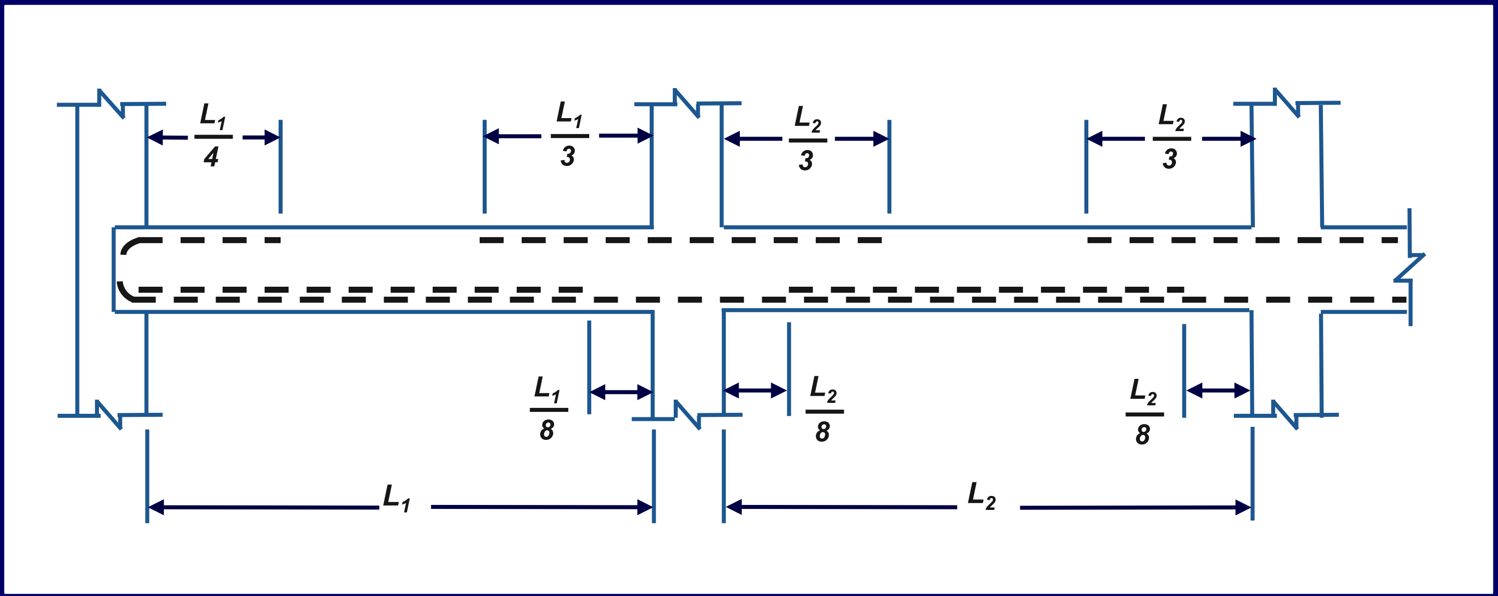
Appendix

GRAPH A.2
Location of points where bars can be bent up or cut off for simply supported beams uniformly loaded.



Exact curtailments lengths for simply supported positive moments (to be measured from face of the support)

Appendix



Cutoff for bars in approximately equal spans with uniformly distributed loads for 50% curtailment