Lecture-02

Analysis and Design of One-way Slab System (Part-I)

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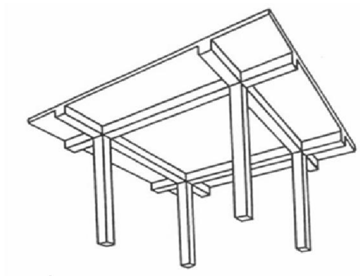
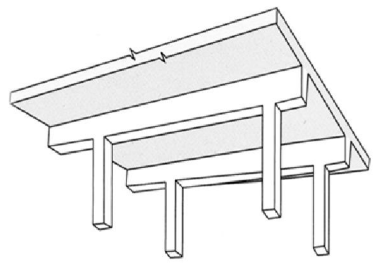
Topics Addressed

- Concrete Floor Systems
- Analysis and Design of Slabs
- Basic Design Steps
- Example: Design of 90′ x 60′ Hall
- References

Concrete Floor Systems

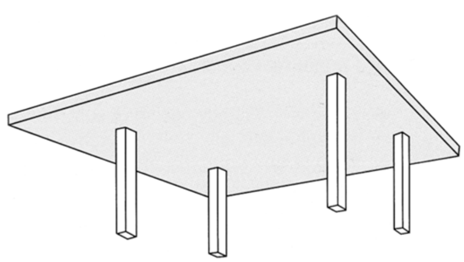
- **Beam Supported Slabs**





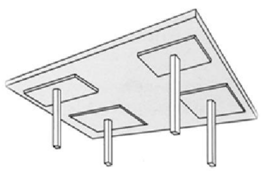
Concrete Floor Systems

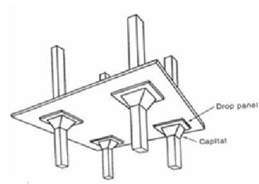
- **Flat Plate**
  - Punching shear is a typical problem in flat plates.



Concrete Floor Systems

- **Flat Slab**
  - **Drop Panel:** Thick part of slab in the vicinity of columns
  - **Column Capital:** Column head of increased size
  - Punching shear can be reduced by introducing drop panel and column capital





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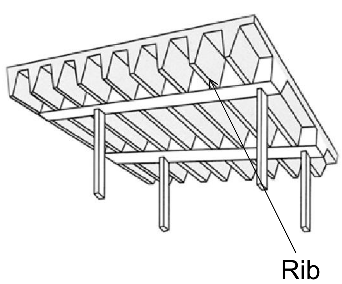
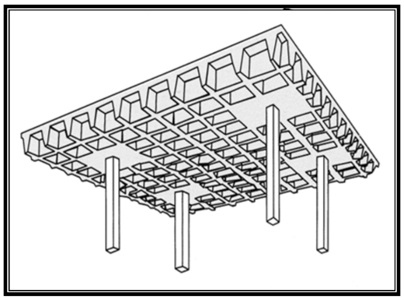
Concrete Floor Systems

- **One-way Joist**
  - Joist construction consists of a monolithic combination of regularly spaced ribs and a top slab arranged to span in one direction or two orthogonal directions.



Concrete Floor Systems

- **Two-way Joist**



Analysis and Design of Slabs

- **Analysis**
  - Unlike beams and columns, slabs are two dimensional members. Therefore their analysis except one-way slab systems is relatively difficult.
- **Design**
  - Once the analysis is done, the design is carried out in the usual manner. So no problem in design, problem is only in analysis of slabs.

Analysis and Design of Slabs

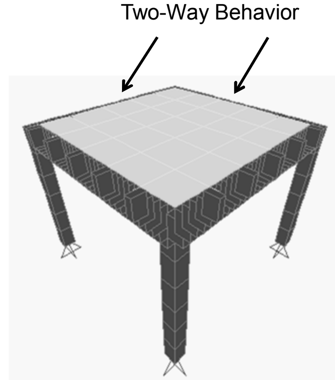
- **Analysis Methods**
  - **Analysis using computer software (FEA)**
    - SAFE, SAP 2000, ETABS etc.
  - **ACI Approximate Method of Analysis**
    - Strip Method for one-way slabs
    - Moment Coefficient Method for two way slabs
    - Direct Design Method for two way slabs

Analysis and Design of Slabs

- **One-Way and Two-Way Behavior**
  - A slab when loaded in flexure may bend in one or both directions

One-Way Behavior

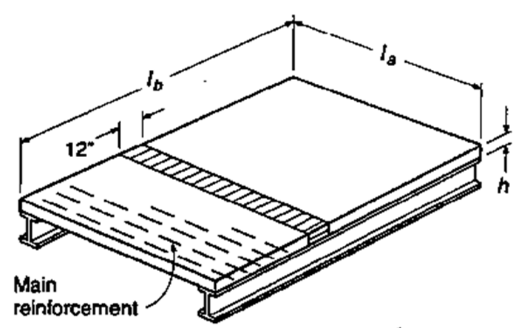
Two-Way Behavior



Analysis and Design of One-Way Slab Systems

Strip Method of Analysis for One-way Slabs

- For purposes of analysis and design, a unit strip of one way slab, cut out at right angles to the supporting beams, may be considered as a rectangular beam of unit width, with a depth h and a span l_a as shown.



Applicability of Strip Method

- The strip method of analysis and design of slabs having bending in one direction is applicable only when:
  - Slab is supported on only two sides on stiff beams or walls,
  - Slab is supported on all sides on stiff beams or walls with ratio of larger to smaller side greater than 2.
  - Note: Not applicable to flat plates etc., even if bending is primarily in one direction.

Basic Design Steps

- **Basic Steps for Structural Design**
  - **Step No. 01: Sizes:**-*Sizes of all structural and non structural elements are decided.*
  - **Step No. 02: Loads:**-*Loads on structure are determined based on occupational characteristics and functionality (refer Appendix C at the end of this lecture)*
  - **Step No. 03: Analysis:**-*Effect of loads are calculated on all structural elements*
  - **Step No. 04: Design:**-*Structural elements are designed for the respective load effects following the code provisions.*

Basic Design Steps

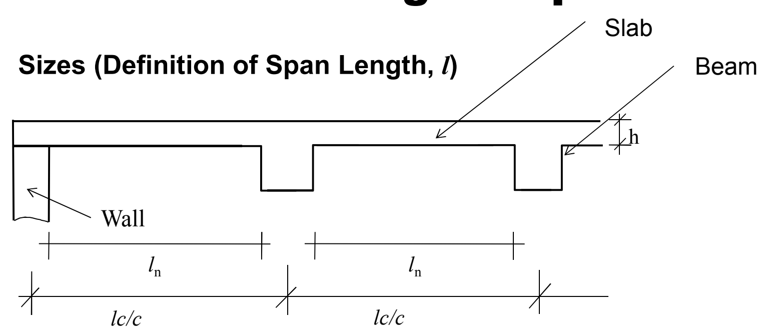
- **Sizes:** ACI table 9.5 (a) gives the minimum one way slab thickness.

Table 9.5(a) – Minimum Thickness of Non-Prestressed Beams or One-Way Slabs Unless Deflections are Computed				
	Minimum thickness, h			
	Simply supported	One end continuous	Both ends continuous	Cantilever
Member	Members not supporting or attached to partitions or other construction likely to be damaged by large deflections			
Solid one-way slabs	$\ell/20$	$\ell/24$	$\ell/28$	$\ell/10$
Beams or ribbed one-way slabs	$\ell/16$	$\ell/18.5$	$\ell/21$	$\ell/8$

l = Span length, defined on the next slide.

Basic Design Steps

- **Sizes (Definition of Span Length, *l*)**



1) $l = l_n$; for integral supports such as beams and columns with $l_n \le 10'$
2) l = Minimum of [(l_n +h) or c/c distance] ; for non-integral supports such as walls with any distance & for integral supports (beams and columns) with $l_n > 10'$

- ***l*** (span length) is used in calculating depth of members.
- l_n (clear span) is used for determining moments using ACI coefficients.
- $l_{c/c}$ is (center to center distance) is used for analysis of simply supported beam.

Basic Design Steps

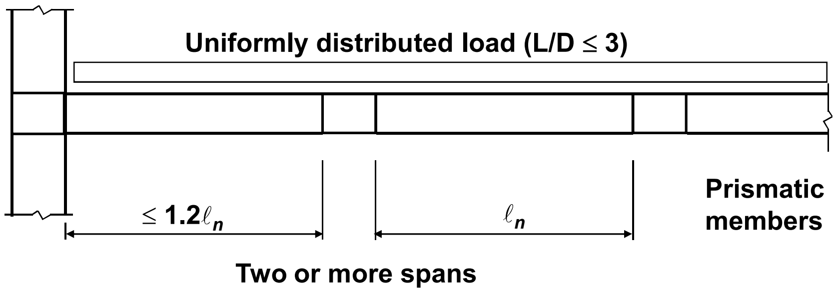
- **Loads:**
  - According to ACI 8.2.2 — Service loads shall be in accordance with the general building code of which this code forms a part, with such live load reductions as are permitted in the general building code.
    - BCP SP-2007 is General Building Code of Pakistan and it refers to ASCE 7-10 for minimum design loads for buildings and other structures.
  - One way slabs are usually designed for gravity loading (U = 1.2D + 1.6L).

Basic Design Steps

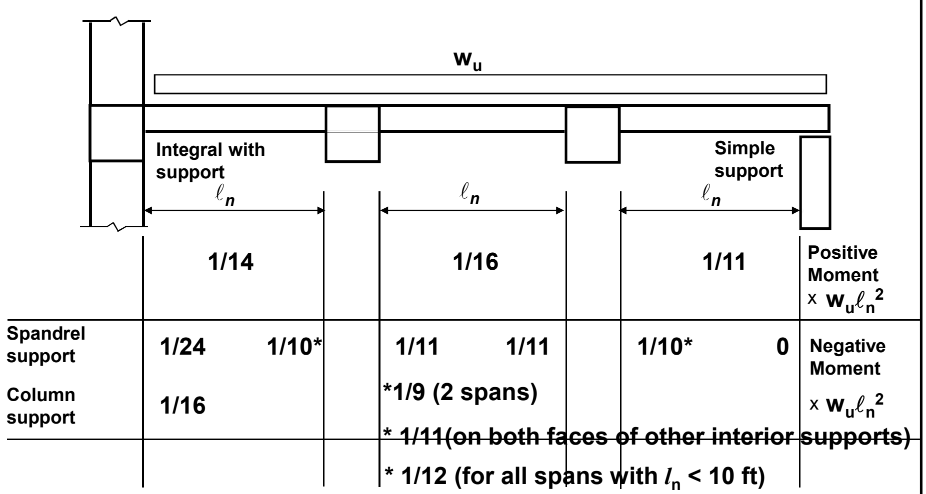
- **Analysis:**
  - Chapter 8 of the ACI addresses provisions for the analysis and design of concrete members.
  - According to ACI 8.3.3, as an alternate to frame analysis, ACI approximate moments shall be permitted for design of one-way slabs with certain restrictions, which are as follows:

Basic Design Steps

- **Analysis:** ACI 8.3.3



Basic Design Steps



Note: For simply supported slab, $M = w_u l^2/8$, where l = span length (ACI 8.9).

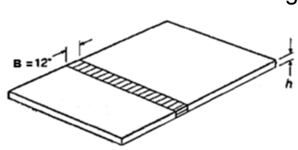
Basic Design Steps

- **Design:**
  - Capacity ≥ Demand
  - Capacity or Design Strength = Strength Reduction Factor (ϕ) × Nominal Strength
  - Demand = Load Factor × Service Load Effects
  - Bar spacing (in inches) = $A_b/A_s \times 12$

    (A_b = area of bar in in^2, A_s = Design steel in in^2/ft)

Basic Design Steps

- **Design:**
  - Shrinkage and Temperature Reinforcement (ACI 7.12):
    - Reinforcement is placed perpendicular to main steel to control shrinkage and temperature cracking.



Gross Area of slab = bh

b = 12''

h = thickness of slab

7.12.2.1 — Area of shrinkage and temperature reinforcement shall provide at least the following ratios of reinforcement area to gross concrete area, but not less than 0.0014:

(a) Slabs where Grade 40 or 50 deformed bars are used 0.0020

(b) Slabs where Grade 60 deformed bars or welded wire fabric (plain or deformed) are used................ 0.0018

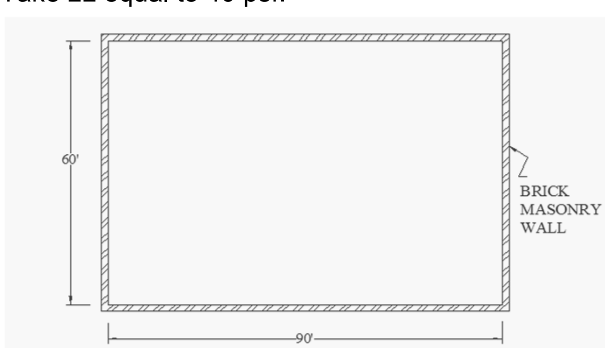
(c) Slabs where reinforcement with yield stress exceeding 60,000 psi measured at a yield strain of 0.35 percent is used ....$\frac{0.0018 \times 60{,}000}{f_y}$

Basic Design Steps

- **Design:**
  - Maximum Spacing Requirement:
    - Main Reinforcement
      - Least of 3h or 18" (ACI 7.6.5)
    - Shrinkage Reinforcement
      - Least of 5h or 18" (ACI 7.12.2.2)
  - Minimum reinforcement Requirement for main reinforcement
    - Same as shrinkage reinforcement requirement (ACI 7.12.2.1)

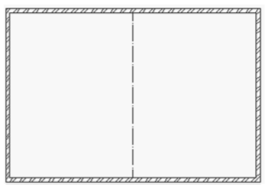
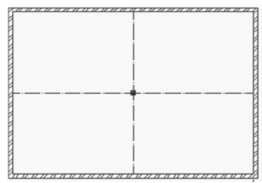
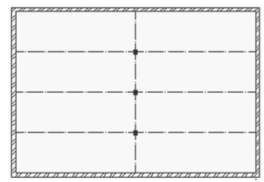
Example: Design of 90′ x 60′ Hall

- Design slab and beams of a 90′ × 60′ Hall. The height of Hall is 20′. Concrete compressive strength (f_c') = 3 ksi and steel yield strength (f_y) = 40 ksi. Take 3″ mud layer and 2″ tile layer above slab. Take LL equal to 40 psf.



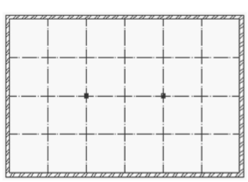
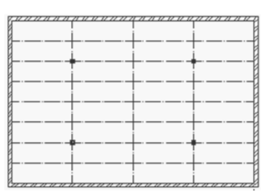
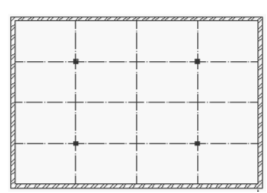
Example: Design of 90′ x 60′ Hall

- **Structural Configurations**
  - Assume structural configuration. Take time to reach to a reasonable arrangement of beams, girders and columns. It depends on experience. Several alternatives are possible.

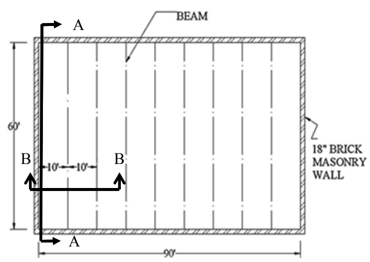
Example: Design of 90′ x 60′ Hall

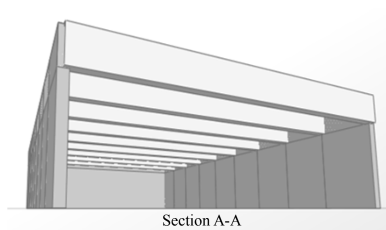
- **Structural Configurations**

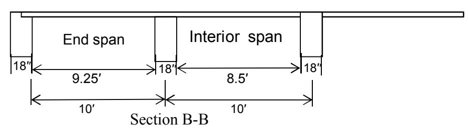




Example: Design of 90′ x 60′ Hall

- **Structural configuration selected for this problem**
  - (Note that this is not the only option or the best option. Just selected to make a one-way slab design case)







Wall width = 18 in, given
Assume beam width = 18 in

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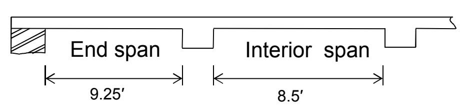
Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Step No 01: Sizes



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- $h = l/24 \times (0.4+f_y/100000) = 3.7''$ (Minimum by ACI for end span) $[l = l_n = 9.25']$
- $h = l/28 \times (0.4+f_y/100000) = 2.9''$ (Minimum by ACI for interior span) $[l = l_n = 8.5']$
- Take $h = 6''$

($l = l_n$; for integral supports such as beams and columns with $l_n \leq 10'$ (slide 16))

Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Step No 02: Loads

Table: Dead Loads			
Material	**Thickness (in)**	**γ (kcf)**	**Load = thickness × γ (ksf)**
Slab	6	0.15	(6/12) × 0.15 = 0.075
Mud	3	0.12	(3/12) × 0.12 = 0.03
Tile	2	0.12	(2/12) × 0.12= 0.02
		Total	0.125 ksf

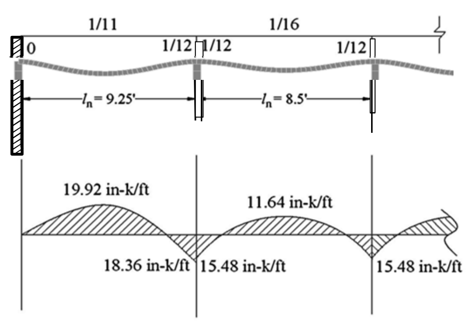
- Factored Load (w_u) = 1.2D.L + 1.6L.L

  = 1.2 × 0.125 + 1.6 × 0.04 = 0.214 ksf

Example: Design of 90′ x 60′ Hall

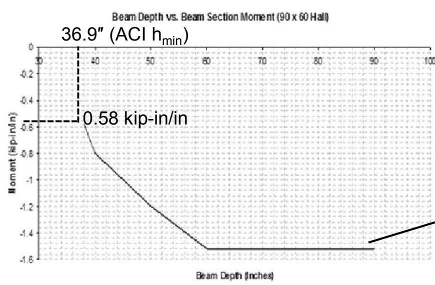
- **Slab Design**
  - Step No 03: Analysis
    - Bending moment diagram for slab
  - Assume beam width = 18″, clear lengths area shown in the figure:

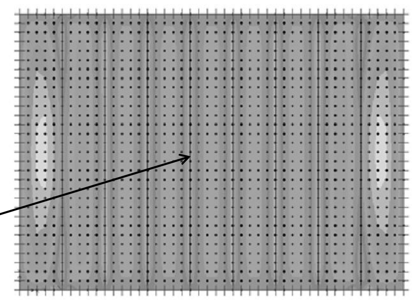
M = coefficient × w_u × l_n^2



Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - **Beam Depth vs. Slab Deflection:**
    - Slab moment variation with change in beam depth

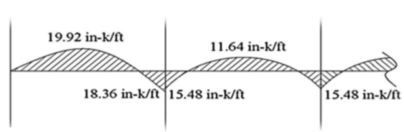




ACI Coefficient	Moment (kip-in/in)
- (1/12)	-1.29

Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Step No 04: Design
    - Calculate moment capacity provided by minimum reinforcement in slab:
      - $A_{smin} = 0.002bh_f = 0.002 \times 12 \times 6 = 0.144$ in^2/ft
      - $\Phi M_n = \Phi A_{smin} f_y (d-a/2) = 0.9 \times 0.144 \times 40 \times (5-0.188/2) = 25.4$ in-k/ft
      - ΦM_n calculated from A_{smin} is > all moments calculated in Step No 3.
      - Therefore $A_s = A_{smin} = 0.144$ in^2/ft (#3 @ 9.166″ c/c)
      - This will work for both positive and negative steel as A_{smin} governs.



Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Step No 04: Design
    - Main Reinforcement:
      - Maximum spacing for main steel reinforcement in one way slab according to ACI 7.6.5 is minimum of:
        - $3h_f = 3 \times 6 = 18''$
        - 18″
      - Finally use, #3 @ 9″ c/c.

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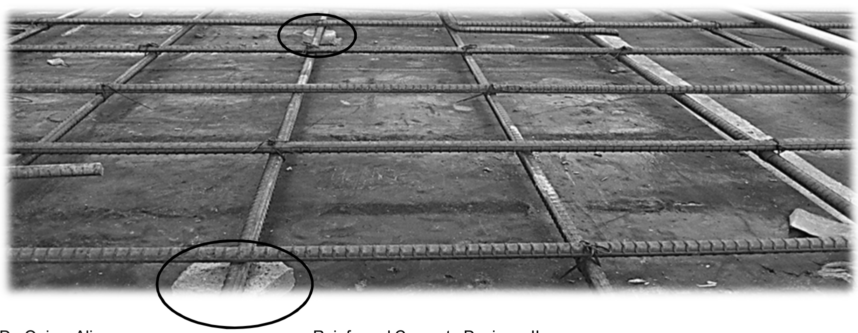
Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Step No 04: Design
    - Shrinkage steel or temperature steel (A_{st}):
      - $A_{st} = 0.002bh_f$ $A_{st} = 0.002 \times 12 \times 6 = 0.144$ in^2/ft
      - Shrinkage reinforcement is same as main reinforcement, because:
      - $A_{st} = A_{smin} = 0.144$ in^2
    - Maximum spacing for temperature steel reinforcement in one way slab according to ACI 7.12.2.2 is minimum of:
      - $5h_f = 5 \times 6 = 30''$ OR 18″
    - Therefore 9″ spacing is O.K.

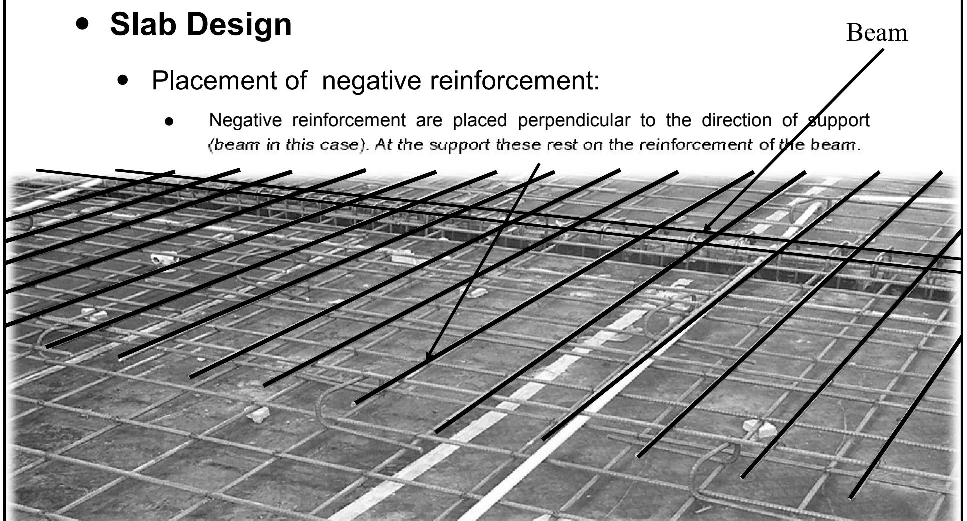
Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Placement of positive reinforcement:
    - Positive reinforcing bars are placed in the direction of flexure stresses and placed at the bottom(at the required clear cover) to maximize the "d", effective depth.



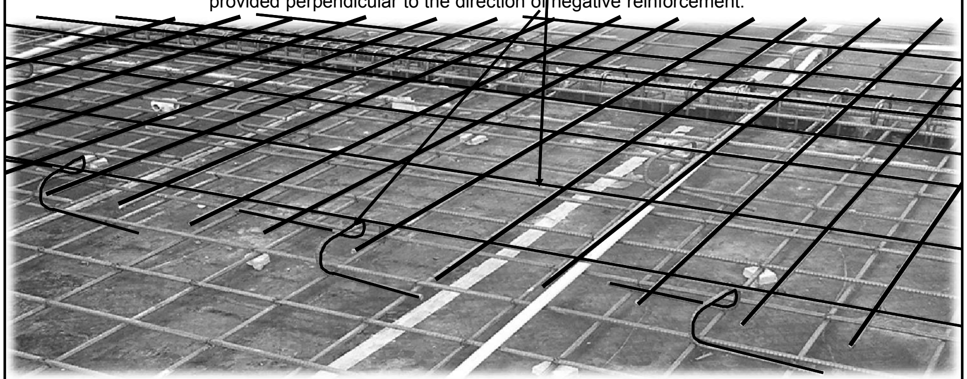
Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Placement of negative reinforcement:
    - Negative reinforcement are placed perpendicular to the direction of support (beam in this case). At the support these rest on the reinforcement of the beam.



Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Placement of negative reinforcement:
    - At the far end the chairs are provided to support the negative reinforcement. As each bar will need a separate chair therefore to reduce the number of chairs supporting bars are provided perpendicular to the direction of negative reinforcement.

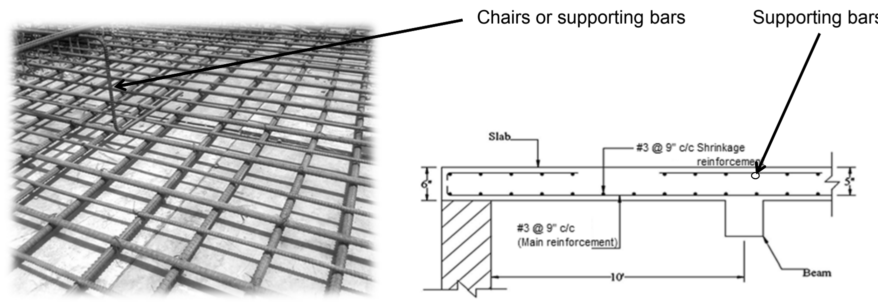


Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Reinforcement at discontinuous support:
    - At the discontinuous end, the ACI code recommends to provide reinforcement equal to 1/3 times the positive reinforcement provided at the mid span. As this reinforcement generally yields large spacing, it is a common field practice to provide #3 at 18” c/c.

Example: Design of 90′ x 60′ Hall

- **Slab Design**
  - Step No 05: Drafting
    - Main reinforcement = #3 @ 9″ c/c (positive & negative)
    - Shrinkage reinforcement = #3 @ 9″ c/c
    - Supporting bars = #3 @ 18″ c/c



Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 01: Sizes
    - Minimum thickness of beam (simply supported) = h_{min} = $l/16$

      l = clear span (l_n) + depth of member (beam) ≤ c/c distance between supports
    - Let depth of beam = 5′

      l_n + depth of beam = 60′ + 5′ = 65′

      c/c distance between beam supports = 60 + 2 × (9/12) = 61.5′
    - Therefore l = 61.5′

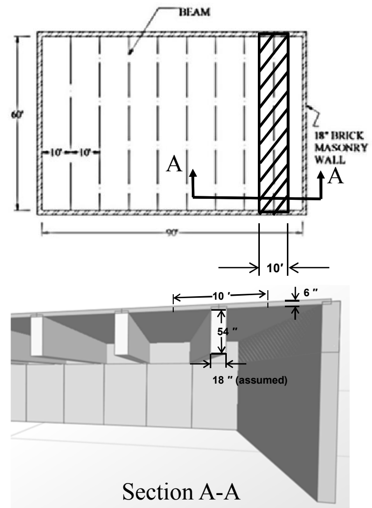
      Depth (**h**) = (61.5/16)×(0.4+f_y/100000)×12= **36.9″** (Minimum by ACI 9.5.2.2).
    - Take h = 5′ = 60″

      d = h – 3 = 57″

      b_w = 18″ (assumed)

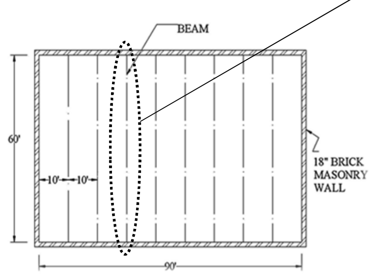
Example: Design of 90′ x 60′ Hall

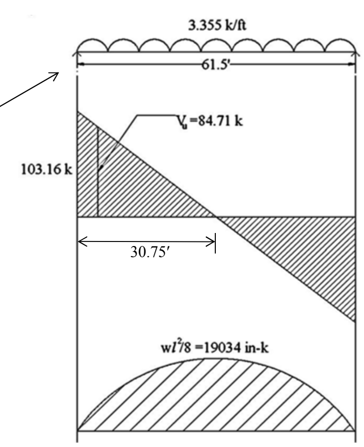
- **Beam Design**
  - Step No 02: Loads
    - Load on beam will be equal to
    - Factored load on beam from slab + factored self weight of beam web
    - Factored load on slab = 0. 214 ksf
    - Load on beam from slab = 0. 214 ksf x 10 = 2.14 k/ft
    - Factored Self load of beam web =
    - = 1.2 x (54 × 18/144) × 0.15 =1.215 k/ft
    - Total load on beam = 2.14 + 1.215 = 3.355 k/ft



Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 03: Analysis
    - V_u = 84.71 kip
    - M_u = 19034 in-kip





Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for flexure
      - Step (a): According to ACI 8.12, b_{eff} for T-beam is minimum of:
        - $16h_f + b_w$ = 16 × 6 + 18 =114″
        - (c/c span of beam)/4 =(61.5′/4) × 12 =184.5″
        - c/c spacing between beams =10′ × 12 =120″
      - So b_{eff} = 114″

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Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for flexure
      - Step (b): Check if beam is to be designed as rectangular beam or T-beam.
      - Assume a = h_f = 6″ and calculate A_s:

        $A_s = M_u / \{\Phi f_y (d–a/2)\}$ =19034/ {0.9 × 40 × (57–6/2)} = 9.79 in^2
      - Re-calculate “a”:

        $a = A_s f_y / (0.85 f_c' b_{eff})$ =9.79 × 40/ (0.85 × 3 × 114) = 1.34″ < h_f

        Therefore design beam as rectangular beam.
      - After trials A_s = 9.38 in^2 {A_{smax} = 20.83 in^2 ;A_{smin} = 5.13 in^2}
      - Therefore A_s = 9.38 in^2 {12 #8 bars}

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Skin Reinforcement : ACI 10.6.7
      - As the effective depth ***d*** of a beam is greater than 36 inches, longitudinal skin reinforcement is required as per ACI 10.6.7.
      - $A_{skin,}$ = Main flexural reinforcement/2 = 9.60/2 = 4.8 in^2
      - Range up to which skin reinforcement is provided:

        d/2 = 56.625/2 = 28.3125″

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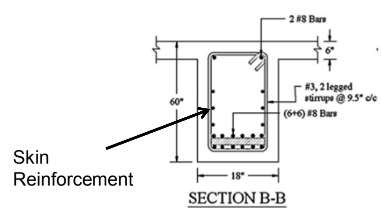
Example: Design of 90′ x 60′ Hall



- **Beam Design**
  - Step No 04: Design
    - Skin Reinforcement
      - For #8 bar used in skin reinforcement, s_{sk} (skin reinforcement spacing) is least of:
        - d/6 = 56.625/6 = 9.44″, 12″, or
        - $1000A_b/(d – 30)$ = 1000×0.79/(56.625 – 30) = 29.67″
      - Therefore s_{sk} = 9.44″ ≈ 9″
      - With this spacing, 3 bars on each face are required. And for # 8 bar, the total area of skin reinforcement is:

        A_{skin} = 6 × 0.79 = 4.8 in^2

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for Shear

      V_u = 84.71 kip

      $\Phi V_c = \Phi 2\sqrt{f'_c} b_w d$ = (0.75 × 2 × $\sqrt{3000}$ × 18 × 57)/1000 = 84.29 kip

      - $\Phi V_c < V_u$ {Shear reinforcement is required}

      $s_d = \Phi A_v f_y d/(V_u - \Phi V_c)$

      - Using #3, 2 legged stirrups with A_v = 0.11 × 2 =0.22 in^2}

      s_d = 0.75 × 0.22 × 40 × 57/(84.71 – 84.29) = 895″

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for Shear
      - Maximum spacing and minimum reinforcement requirement as permitted by ACI 11.4.5 and 11.4.6 shall be minimum of:
        - $A_v f_y/(50 b_w)$ =0.22 × 40000/(50 × 18) ≈ 9.5″
        - d/2 =57/2 =28.5″
        - 24″
        - $A_v f_y/ 0.75 \sqrt{f'_c}\, b_w$ = 0.22 × 40000/ {(0.75 × $\sqrt{3000}$ × 18} = 11.90″
      - Therefore, s_{max} = 9.5″

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for Shear
      - ΦV_c /2 = 84.29/2 = 42.15 kips at a distance of 17.5 ft from face of the support. Therefore no reinforcemnt is required in this zone, however, we will provide #3, 2-legged vertical stirrups at 12 in. c/c

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for Shear
      - Other checks:
        - Check for depth of beam:
          - $\mathbf{\Phi V_s \leq \Phi 8 \sqrt{f'_c}\, b_w d}$ (ACI 11.4.7.9)
          - $\Phi 8 \sqrt{f'_c}\, b_w d$ = 0.75 × 8 × $\sqrt{3000}$ × 18 × 57/1000 = 337.18 k
          - $\Phi V_s = (\Phi A_v f_y d)/s_d$
            = (0.75 × 0.22 × 40 × 57)/9.5 = 39.6 k < 337.18 k, O.K.
          - So depth is O.K. If not, increase depth of beam.

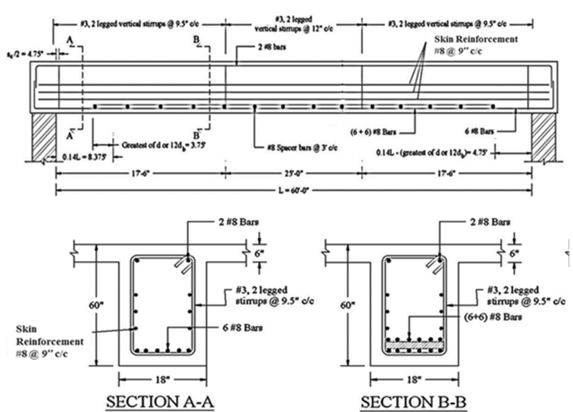
Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 04: Design
    - Design for Shear
      - Other checks:
        - Check if "$\Phi V_s \le \Phi 4 \sqrt{f'_c}\, b_w d$" {ACI 11.4.5.3}:
          - If "$\Phi V_s \le \Phi 4 \sqrt{f'_c}\, b_w d$", the maximum spacing ($s_{max}$) is O.K. Otherwise reduce spacing by one half.
          - $\Phi 4 \sqrt{f'_c}\, b_w d = 0.75 \times 4 \times \sqrt{3000} \times 18 \times 57/1000 = 168.58$ k
          - $\Phi V_s = (\Phi A_v f_y d)/s_d$

            $= (0.75 \times 0.22 \times 40 \times 57)/9.5 = 39.6 \text{ k} < 168.58 \text{ k}$, O.K.

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Step No 05: Detailing

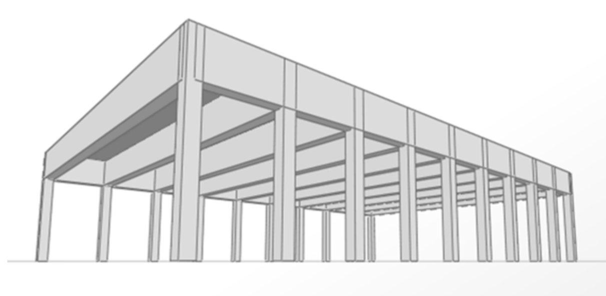


Example: Design of 90′ x 60′ Hall

- In this design example, the beams were supported on walls. This was done to simplify analysis.
- For practical reasons, however, the beams must be supported on columns and hence the structural analysis will be that of a frame rather than simply supported beam.
- In the subsequent slides, the analysis and design results for beams supported on columns have been provided.

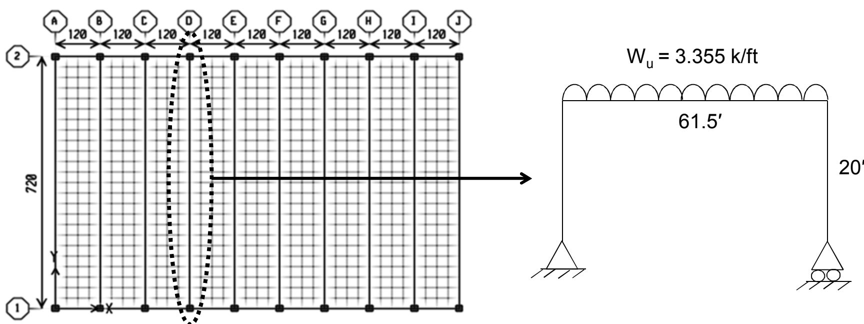
Example: Design of 90′ x 60′ Hall

- Frame Analysis
  - 3D model of the hall showing beams supported on columns.



Example: Design of 90′ x 60′ Hall

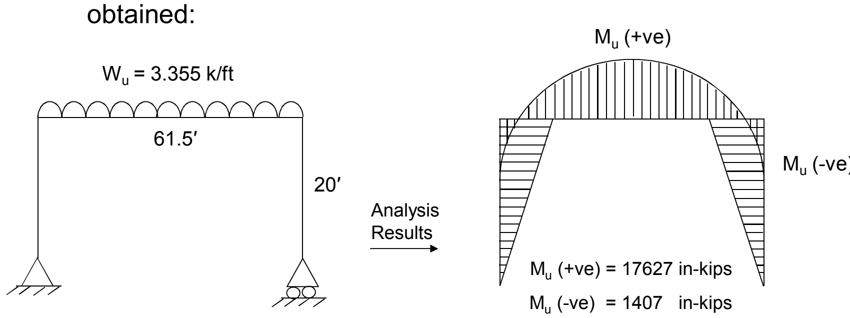
- **Frame Analysis**
  - A 2D fame can be detached from a 3D system in the following manner:



Column size = 18″ × 18″

Example: Design of 90′ x 60′ Hall

- **Frame Analysis**
  - Various methods can be used for frame analysis. Using moment distribution method the following results can be obtained:



Column size = 18″ × 18″

Example: Design of 90′ x 60′ Hall

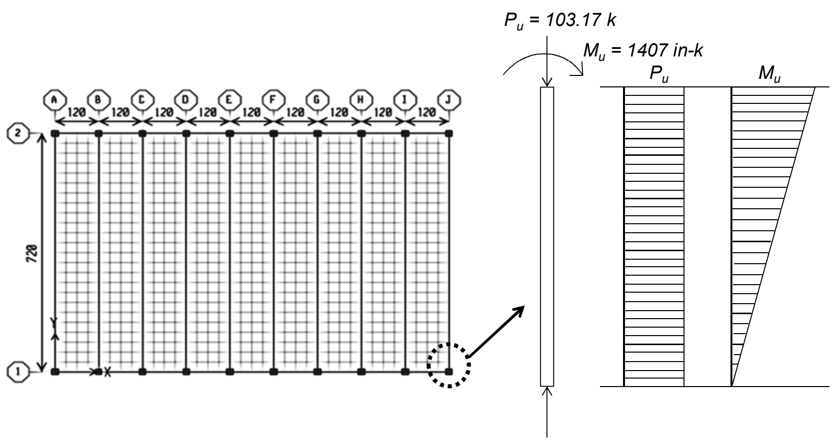
- **Slab Design**
  - Slab design will be remain the same as in case of beams supported on walls.
    - Main reinforcement = #3 @ 9″ c/c (positive & negative)
    - Shrinkage reinforcement = #3 @ 9″ c/c
    - Supporting bars = #3 @ 18″ c/c

Example: Design of 90′ x 60′ Hall

- **Beam Design**
  - Beam design will be as follows:
    - M_u (+ve) = 17627 in-kips
    - M_u (-ve) = 1407 in-kips
    - A_s (+ve) = 8.68 in^2
      - Use 6 #8 in 1st layer & 2 #8 + 4 #7 bars in 2nd layer)
      - A_s = (8)(0.79) + (4)(0.60) = 8.72 in^2 ($A_{s,max}$ = 0.0203bd = 20.83 in^2 OK)
    - A_s (-ve) = 0.69 in^2 ($A_{s,min}$ = 0.005bd = 5.13 in^2, so $A_{s,min}$ governs)
      - Use 7 #8 bars (5 bars in 1st layer and 2 bars in 2nd layer
      - A_s = (7)(0.79) = 5.53 in^2

Example: Design of 90′ x 60′ Hall

- **Column Design**



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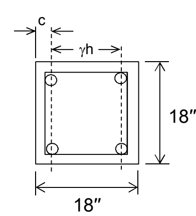
Example: Design of 90′ x 60′ Hall

- **Column Design: Using ACI Design Aids**
  - **Main Reinforcement Design**
    - Size:
      - 18 in. × 18 in.
    - Loads:
      - P_u = 103.17 kips
      - M_u = 1407 in-kips



f'_c = 3 ksi, f_y = 60 ksi

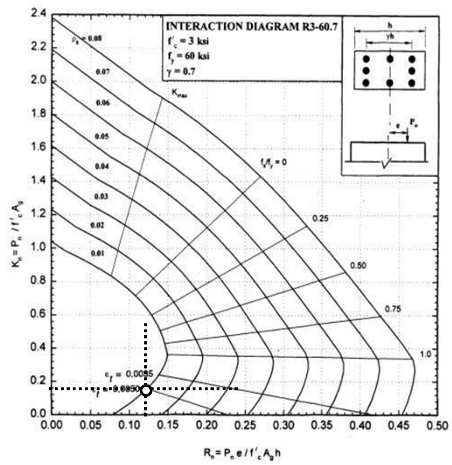
- Calculate the ratio γ , for 2.5 in. cover (c): $\gamma = (h - 2c) / h$

  $= (18 - 5)/18 = 0.72$

- Calculate K_n, $K_n = P_u/(\text{Ø}f'_cA_g) = 103.17/(0.65 \times 3 \times 324) = 0.16$
- Calculate R_n, $R_n = M_u/(\text{Ø}f'_cA_gh) = 1407/(0.65 \times 3 \times 324 \times 18) = 0.12$

Example: Design of 90′ x 60′ Hall

- **Column Design**
  - **Main Reinforcement Design**
    - For given material strength, the column strength interaction diagram gives the following reinforcement ratio:
      - ρ = 0.01
    - A_{st} = 0.01 × 324 = 3.24 in.^{2}
      - Using 8 #6 bars



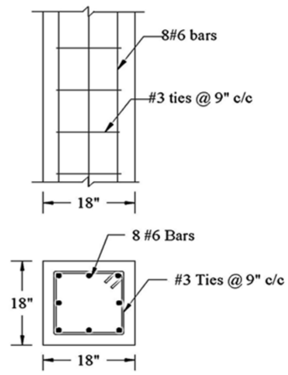
Strength Interaction Diagram (ACI Design Handbook)

Example: Design of 90′ x 60′ Hall

- **Column Design**
  - **Tie Bars:**
    - Using 3/8″ Φ (#3) tie bars for 3/4″ Φ (#6) main bars (ACI 7.10.5),
    - Spacing for Tie bars according to ACI 7.10.5.1 is minimum of:
    - 16 × dia of main bar =16 × 3/4 =12″ c/c
    - 48 × dia of tie bar = 48 × (3/8) =18″ c/c
    - Least column dimension =18″ c/c
    - Finally use #3, tie bars @ 9″ c/c

Example: Design of 90′ x 60′ Hall

- **Column Design**
  - Drafting



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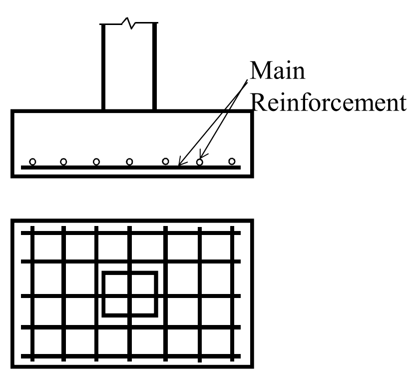
Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Isolated column footing; square or rectangular



Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Data Given:
    - Column size = 18″ × 18″
    - f_c' =3 ksi
    - f_y = 40 ksi
    - q_a = 2.204 k/ft^2
    - Factored load on column = 103.17 kips (Reaction at the support)
    - Service load on column = 81.87 kips (Reaction at the support due to service load)

Example: Design of 90′ x 60′ Hall

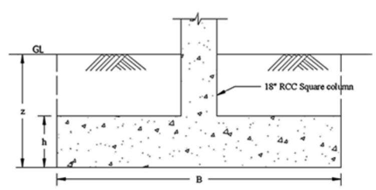


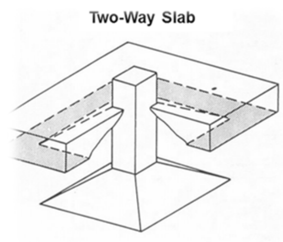
Figure 19: Footing sizes.

- **Footing Design**
  - Sizes:
    - Assume h = 15 in.
    - d_{avg} = h – clear cover – one bar dia

      = 15 – 3 – 1(for #8 bar) = 11 in.
    - Assume depth of the base of footing from ground level (z) = 5′
    - Weight of fill and concrete footing, W= $\gamma_{fill}(z - h) + \gamma_c h$

      =100 × (5 – 1.25) +150 × (1.25) = 5625 psf = 0.5625 ksf

Example: Design of 90′ x 60′ Hall



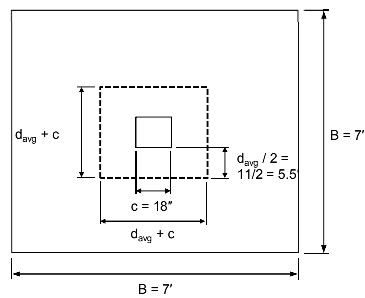
- **Footing Design**
  - Sizes:
    - Effective bearing capacity, $q_e = q_a - W$

      $= 2.204 - 0.5625 = 1.642$ ksf
    - Bearing area, A_{req} = Service Load/ q_e

      $= 81.87/1.642 = 49.86$ ft^2

      $A_{req} = B \times B = 49.86$ ft^2 => $B = 7$ ft.
    - Critical Perimeter, $b_o = 4 \times (c + d_{avg})$

      $= 4 \times (18 + 11) = 116$ in

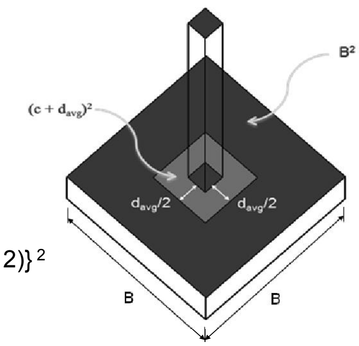


Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Loads:
    - q_u (bearing pressure for strength design of footing):
      - q_u = factored load on column / A_{req} = 103.17 / (7 × 7) = 2.105 ksf

Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Analysis:
    - Punching shear:
    - $V_{up} = q_u B^2 - q_u(c + d_{avg})^2$
    - $V_{up} = 2.105 \times 7^2 - 2.105 \times \{(18+11)/12)\}^2$
      $= 90.85$ kip



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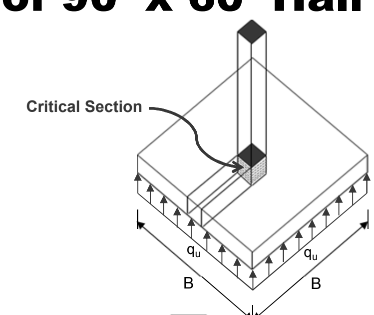
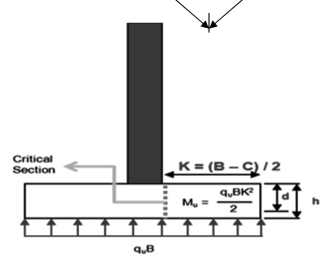
Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Analysis:
    - Flexural Analysis:
    - $M_u = q_u B k^2/2$
    - $k = (B - c)/2 = (7 \times 12 - 18)/2$
      $= 33$ in $= 2.75′$
    - $M_u = 2.105 \times 7 \times 2.75 \times 2.75/2$
      $= 55.72$ ft-k
      $= 668.60$ in-kip





Critical Section for Flexure

Example: Design of 90′ x 60′ Hall

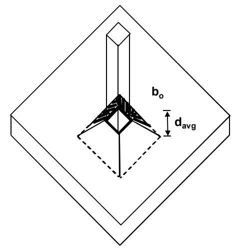
- **Footing Design**
  - Design:
    - Design for Punching Shear:
      - V_{up} = 90.85 kip

        Punching shear capacity (ΦV_{cp})

        $= \Phi 4 \sqrt{f'_c}\, b_o d_{avg}$

        $= 0.75 \times 4 \times \sqrt{3000} \times 116 \times 11/1000$

        = 209.66 k >V_{up}, O.K



Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Design:
    - Design for Flexure:
      - M_u = 668.60 kip-in

        $a = 0.2d_{avg} = 0.2 \times 11 = 2.2''$

        $A_s = M_u / \{\Phi f_y(d_{avg} - a/2)\} = 668.60/ \{0.9 \times 40 \times (11 - 2.2/2)\} = 1.87$ in^2

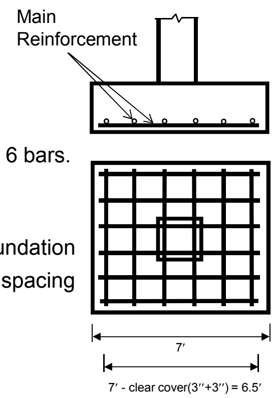
        $a = A_s f_y / (0.85 f_c' B) = 1.83 \times 40/ (0.85 \times 3 \times 7 \times 12) = 0.35''$

        After trials, A_s = 1.71 in^2 ($A_{smin} = 0.005Bd_{avg}$ = 4.62 in^2 so A_{smin} governs)
      - Now, the spacing can be calculated as follows:

        Next Slide

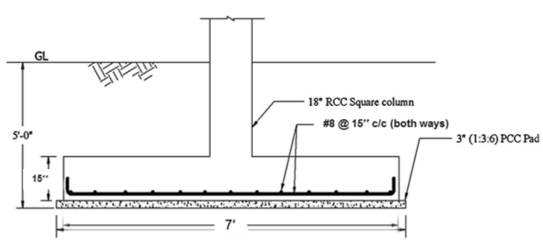
Example: Design of 90′ x 60′ Hall

- **Footing Design**
  - Design:
    - Design for Flexure:
      - Using #8 bars: No. of bars = 4.62/0.79 ≈ 6 bars.
      - Spacing = 6.5 × 12 / 5 = 15 in. c/c
      - Hence 6 bars can be provided in the foundation if they are placed 15 in. c/c (Max. spacing should not exceed 3h or 18 in.)



Example: Design of 90′ x 60′ Hall

- **Drafting**



FOOTING DETAIL

Example: Design of 90′ x 60′ Hall

- Actual pictures of a hall of almost the same size in Peshawar University:

Slab Reinforcement

Beam Reinforcement

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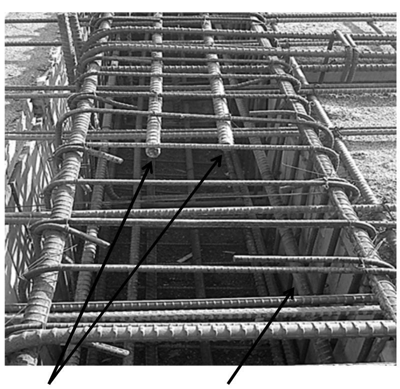
Example: Design of 90′ x 60′ Hall

- Actual pictures of a hall of almost the same size in Peshawar University:



Curtailed Bars Skin Reinforcement

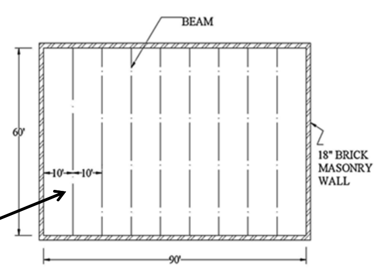
Hall After Completion

Example: Design of 90′ x 60′ Hall

- Pictures of Column

Example: Design of 90′ x 60′ Hall

- **Case Studies**
  - In the subsequent slides two case studies are carried out to investigate the variation of moments in beams, moments and slab thickness due to change in spacing between the beams.



Spacing Between Beams

Example: Design of 90′ x 60′ Hall

- **Case Study 01: Variation of Slab Thickness and Moments Vs Spacing Between the Beams**

Variation of Slab thickness and Moments Vs Spacing Between Beams						
	Spacing Between the Beams (ft)					
	10	12	14	16	18	20
Slab Thickness (in.)	4.0 (Using 6)	4.8 (Using 6)	5.6 (Using 6)	6.4 (Using 7)	7.2 (Using 8)	8.0 (Using 8)
Max Moment in Slab (in-kip) (1/11 coefficient)	19.97	29.55	40.99	58.10	79.21	98.64
Area of steel (in.^{2}) (for Grade 40 Steel)	0.144	0.17	0.24	0.28	0.32	0.41
c/c spacing of #3 main bars (in)	9	7	5	4	4	3

- Note: clear length (l_n) have been used in determining moments.

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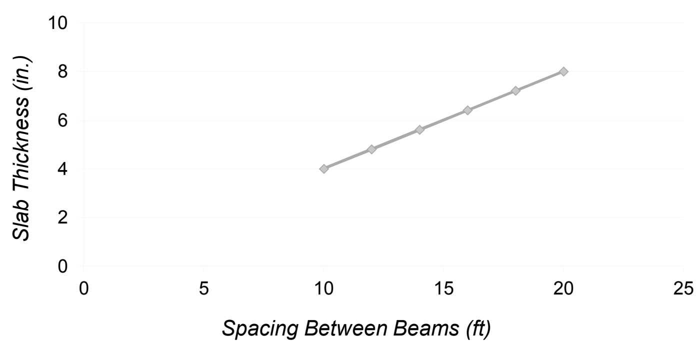
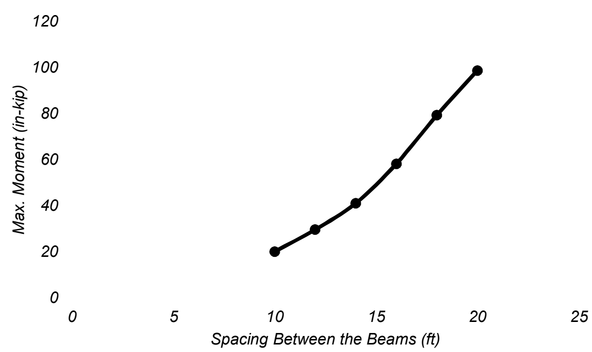
Example: Design of 90′ x 60′ Hall

- **Case Study 01: Variation of Slab Thickness and Moments Vs Spacing Between the Beams**



Example: Design of 90′ x 60′ Hall

- **Case Study 01: Variation of Slab Thickness and Moments Vs Spacing Between the Beams**



Example: Design of 90′ x 60′ Hall

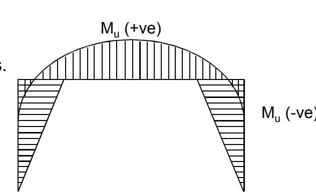
- **Case Study 02: Variation of Moments in Beam Vs Spacing Between Beams**

Variation of Moments Vs Spacing Between Beams					
	Spacing Between the Beams (ft)				
	5	8	10	12	14
M_u (+ve)(in-kip)	12007	15380	17627	19877	22126
M_u (-ve) (in-kip)	957	1226	1407	1585	1764
A_s (+ve) (in^2)	5.90	7.56	8.68	9.80	10.93

- Note:

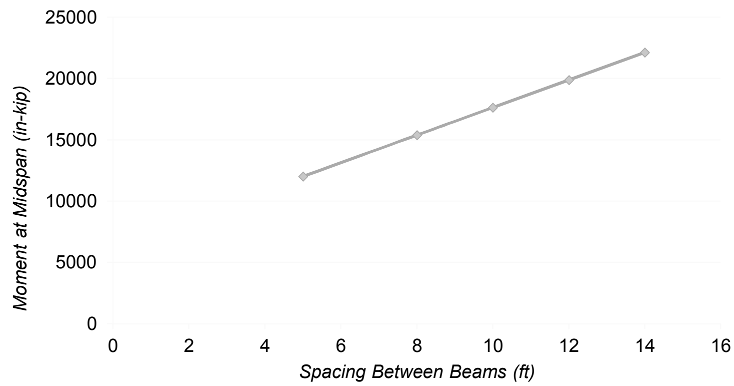
  c/c length ($l_{c/c}$ = *61.5′*) has been used in determining moments.

  Analysis done using moment distribution method.



Example: Design of 90′ x 60′ Hall

- **Case Study 02: Variation of Moments in Beam Vs Spacing Between Beams**



Example: Design of 90′ x 60′ Hall

- Conclusions
  1. Slab thickness increases by increasing the spacing between the beams.
  2. Moments in slab increases by increasing the spacing between the beams.
  3. Moments in beams increases by increasing spacing between the beams.

Appendix C

- MINIMUM DESIGN LOADS

MINIMUM DESIGN LOADS

Table 4-1 Minimum Uniformly Distributed Live Loads, L_o, and Minimum Concentrated Live Loads

Occupancy or Use	Uniform psf (kN/m^2)	Conc. lb (kN)
Apartments (see Residential)		
Access floor systems		
Office use	50 (2.4)	2,000 (8.9)
Computer use	100 (4.79)	2,000 (8.9)
Armories and drill rooms	150 (7.18)[a]	
Assembly areas and theaters		
Fixed seats (fastened to floor)	60 (2.87)[a]	
Lobbies	100 (4.79)[a]	
Movable seats	100 (4.79)[a]	
Platforms (assembly)	100 (4.79)[a]	
Stage floors	150 (7.18)[a]	
Balconies and decks	1.5 times the live load for the occupancy served. Not required to exceed 100 psf (4.79 kN/m^2)	
Catwalks for maintenance access	40 (1.92)	300 (1.33)
Corridors		
First floor	100 (4.79)	
Other floors, same as occupancy served except as indicated		
Dining rooms and restaurants	100 (4.79)[a]	
Dwellings (see Residential)		

Appendix C

- MINIMUM DESIGN LOADS

Elevator machine room grating (on area of 2 in. by 2 in. (50 mm by 50 mm))		300 (1.33)
Finish light floor plate construction (on area of 1 in. by 1 in. (25 mm by 25 mm))		200 (0.89)
Fire escapes	100 (4.79)	
On single-family dwellings only	40 (1.92)	
Fixed ladders	See Section 4.5	
Garages		
Passenger vehicles only	40 (1.92)[a,b,c]	
Trucks and buses	[c]	
Handrails, guardrails, and grab bars	See Section 4.5	
Helipads	60 (2.87)[d,e] Nonreducible	[e,f,g]
Hospitals		
Operating rooms, laboratories	60 (2.87)	1,000 (4.45)
Patient rooms	40 (1.92)	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
Hotels (see Residential)		
Libraries		
Reading rooms	60 (2.87)	1,000 (4.45)
Stack rooms	150 (7.18)[a,h]	1,000 (4.45)
Corridors above first floor	80 (3.83)	1,000 (4.45)
Manufacturing		
Light	125 (6.00)[a]	2,000 (8.90)
Heavy	250 (11.97)[a]	3,000 (13.40)

References

- ACI 318
- Design of Concrete Structures by Nilson, Darwin and Dolan
- ACI Design Handbook

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The End