Lecture 03

Design of Two-way Slab Systems with Beams

By:

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Lecture Contents

- General
- Analysis of Two-way Slabs
- ACI Code Provisions for Two-way Slabs
- Design Examples
- Homework
- References

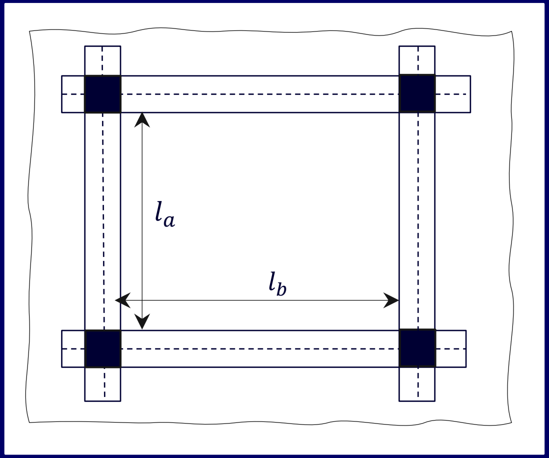
Learning Objectives

- **At the end of this lecture, students will be able to**
  - ***Classify*** one-way and two-way slab systems
  - ***Employ*** ACI coefficient method for two-way slab analyses
  - ***Analyze*** and ***Design*** two-way slabs for flexure
  - ***Compare*** manual and Finite Element Analysis (FEA) results
  - ***Design*** a typical house & regular building for gravity loads

General

❑ Introduction

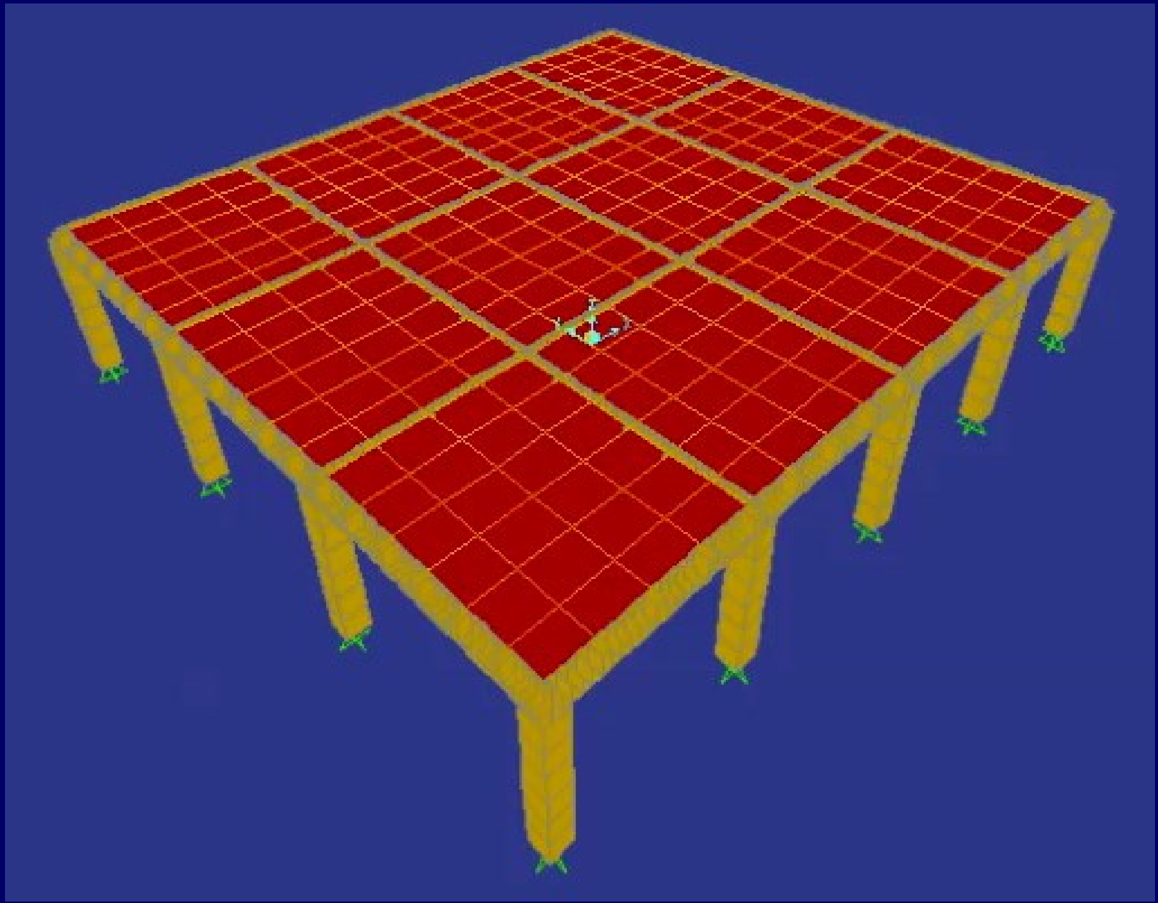
- When the ratio of long to short span in a slab supported on all sides is less than 2, then the bending is in two directions. Such a slab is termed as a two-way slab.
- In two-way slabs, the shorter side receives more demand than the longer side.



Slab supported on all sides, but $\beta = l_b/l_a < 2$

General

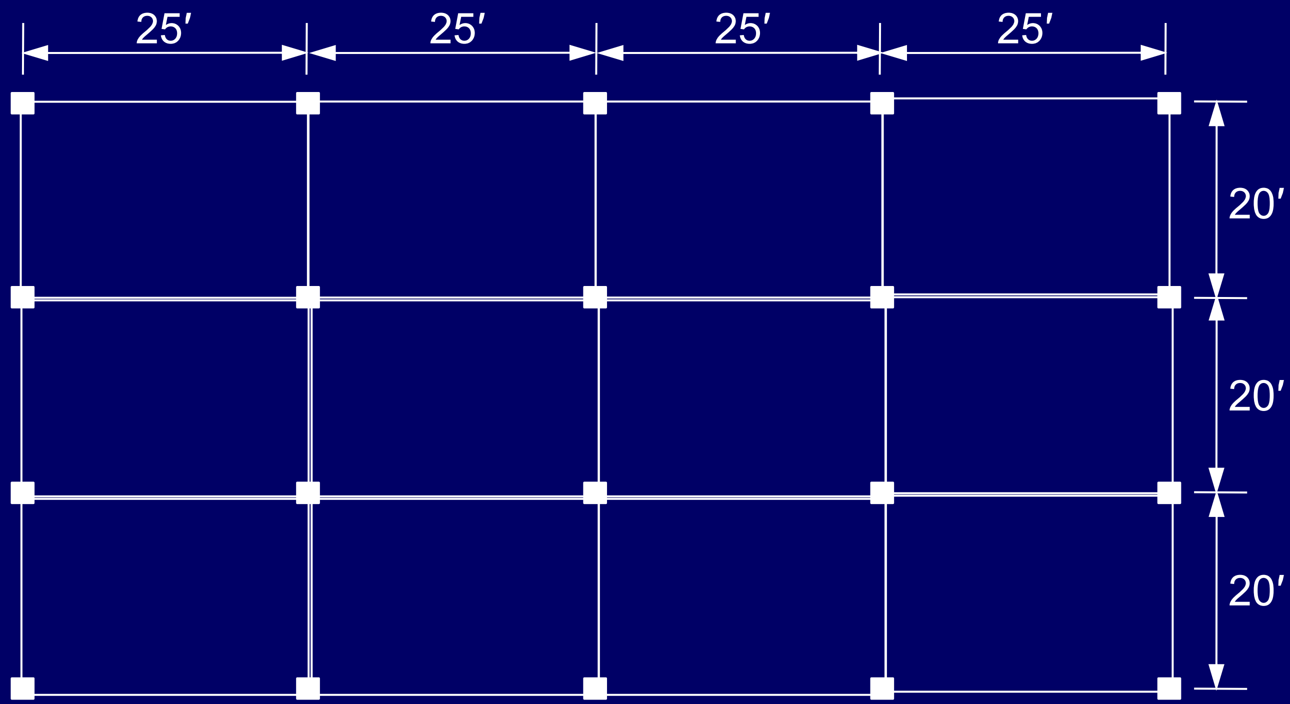
- Bending Behavior of Two-way Slabs



General

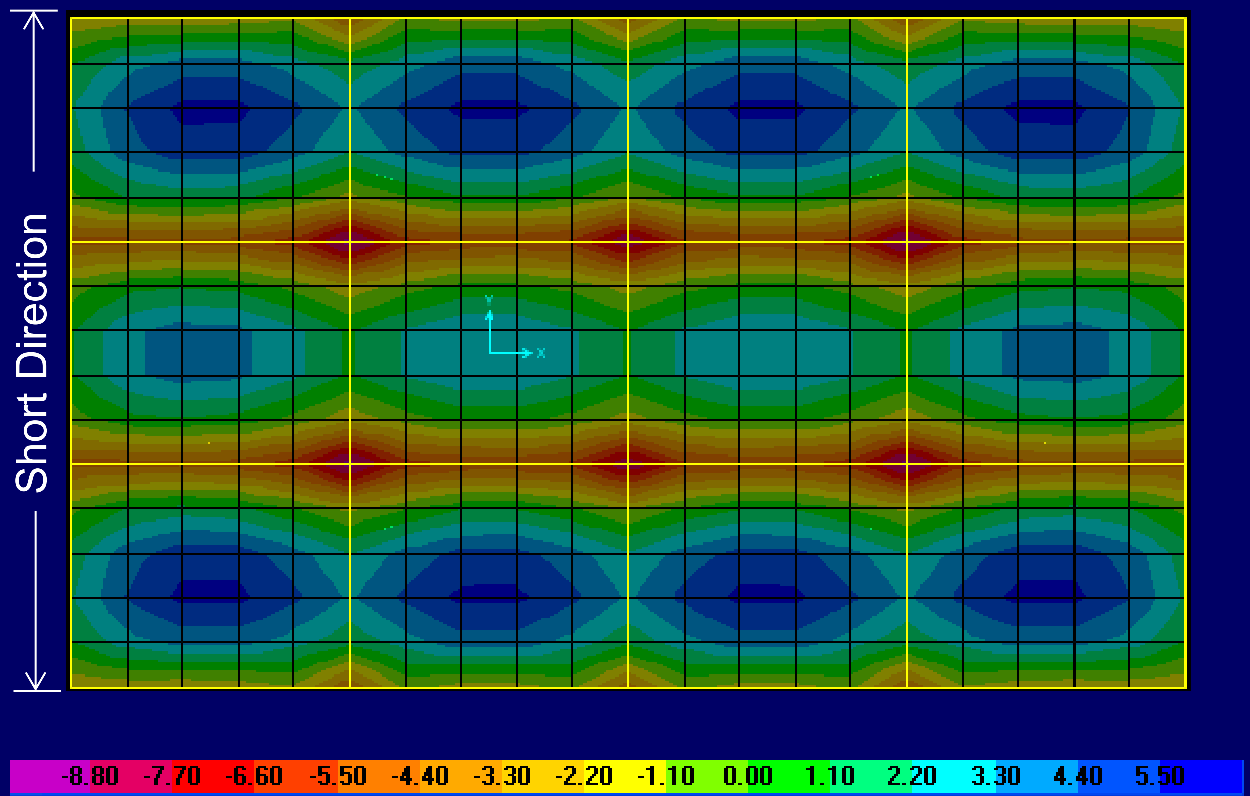
❑ Bending Behavior of Two-way Slabs

- Consider the typical floor plan as shown below



General

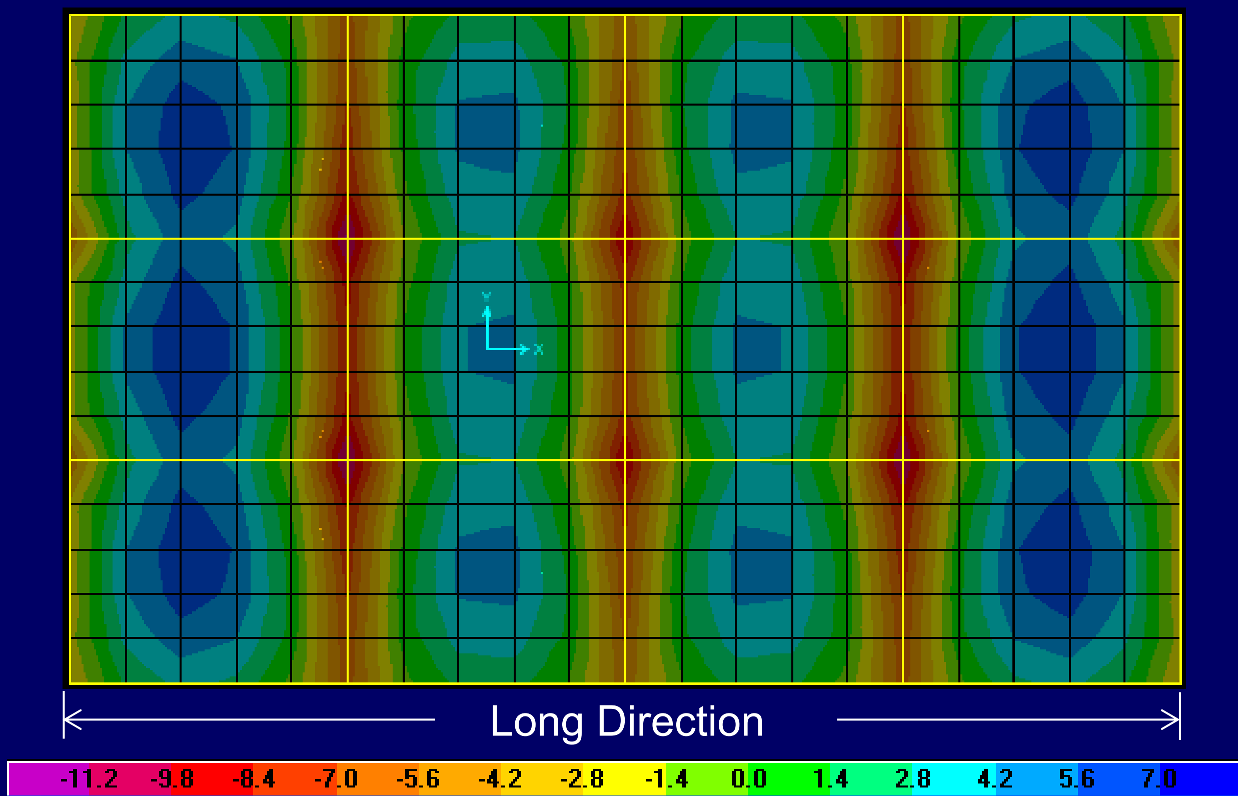
- **Bending Behavior of Two-way Slabs**
  - **Short Direction Moments**



General

❑ Bending Behavior of Two-way Slabs

❖ Long Direction Moments



Analysis of two-way Slabs

❑ Moment Coefficient Method

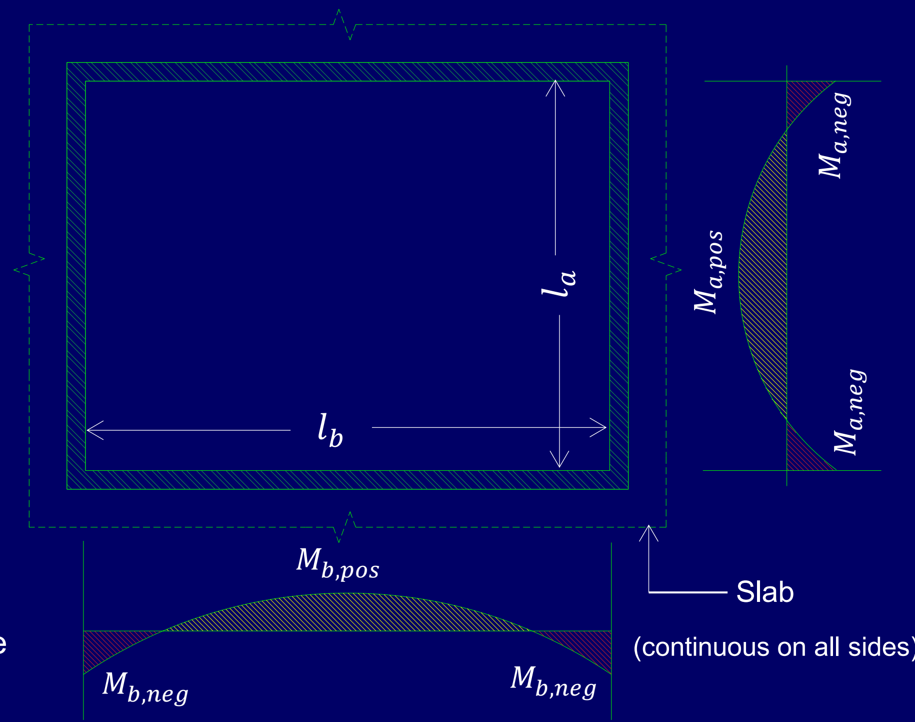
- The Moment Coefficient Method, first introduced in the ACI Code in 1963, is applicable to two-way slabs with walls, steel beams, and relatively deep, stiff edge beams supporting each slab panel on its four sides ($h = 3h_f$).
- Although, not included in 1977 and later versions of ACI code, its continued use is permissible under Section 8.2.1. ACI 318-19 Code.
- The procedure for using this method is explained in the following slides.

Analysis of two-way Slabs

❑ Moment Coefficient Method

- The figure below shows the four critical locations where bending moments for a two-way slab panel are calculated.

1) $M_{a,neg}$
2) $M_{b,neg}$
3) $M_{a,pos}$
4) $M_{b,pos}$



Note:

l_a and l_b are the clear lengths of the short and long sides, respectively.

Analysis of two-way Slabs

❑ Moment Coefficient Method

- These four bending moments are calculated in the following manner.

1) $M_{a,neg} = C_a w_u l_a^{\,2}$
2) $M_{b,neg} = C_b w_u l_b^{\,2}$
3) $M_{a,pos} = C_{a,dl}\, w_{u,dl}\, l_a^{\,2} + C_{a,ll}\, w_{u,ll}\, l_a^{\,2}$
4) $M_{b,pos} = C_{b,dl}\, w_{u,dl}\, l_b^{\,2} + C_{b,ll}\, w_{u,ll}\, l_b^{\,2}$

where;

w_u = total factored load

$w_{u,dl}$ = total factored dead load

$w_{u,ll}$ = total factored live load

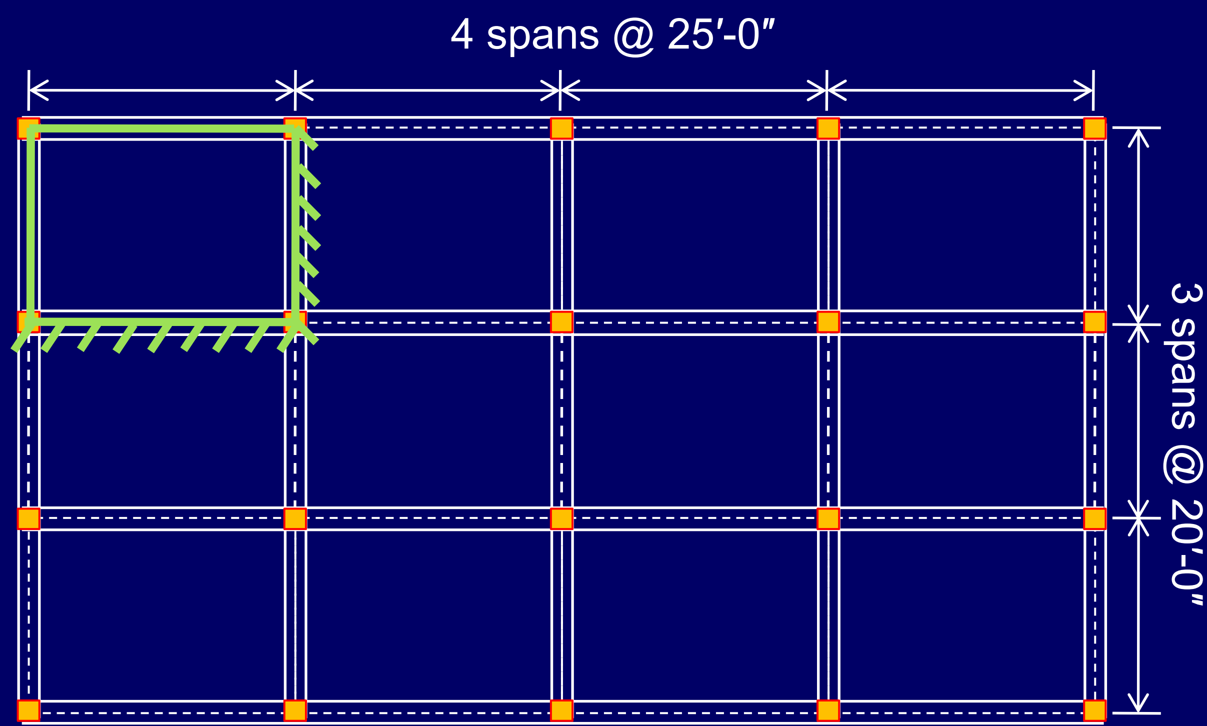
$C_a, C_b, C_{a,dl}, C_{a,ll}, C_{b,dl}, C_{b,ll}$ = coefficients obtained from ACI Tables.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ Various Cases of Slab Panel

- Depending on the support conditions, several cases are possible

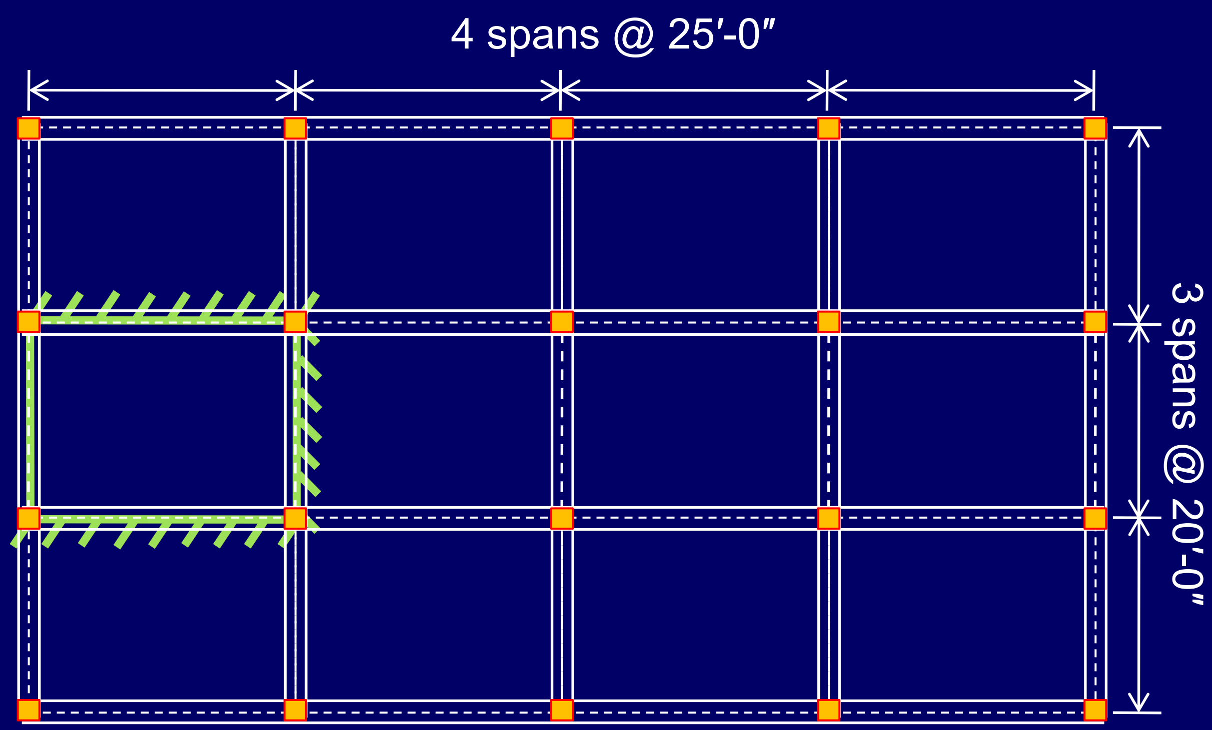


Analysis of two-way Slabs

Moment Coefficient Method

Various Cases of Slab Panel

- Depending on the support conditions, several cases are possible

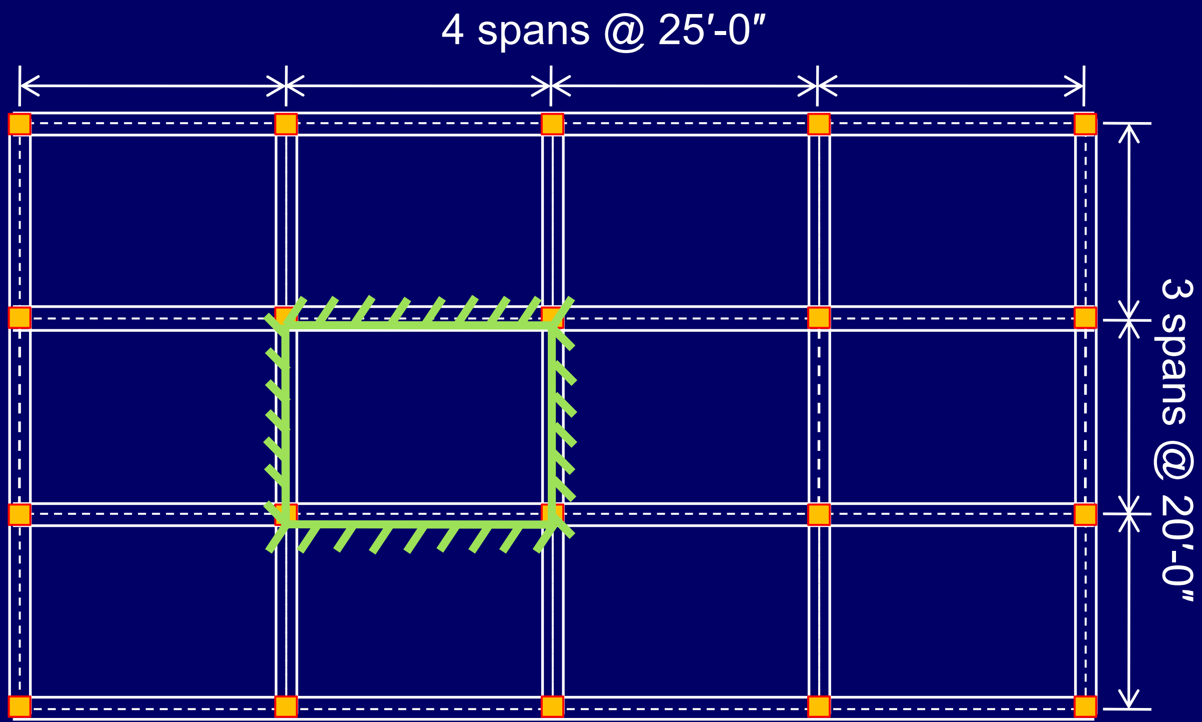


Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ Various Cases of Slab Panel

- Depending on the support conditions, several cases are possible

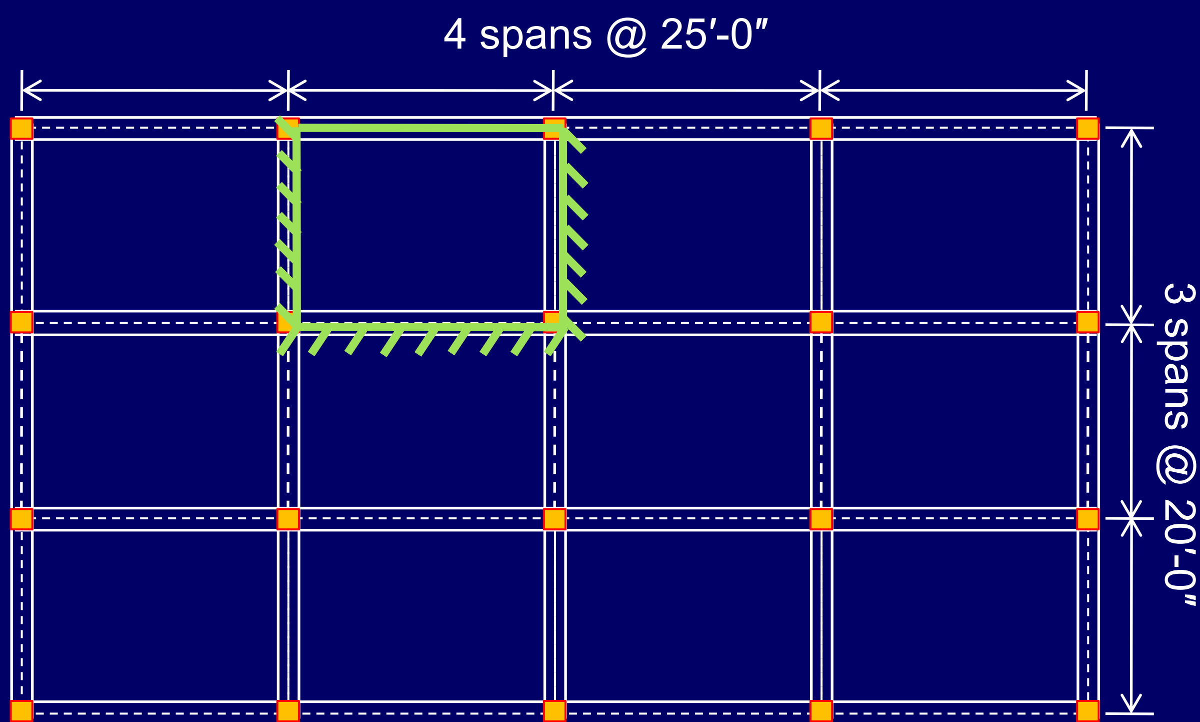


Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ Various Cases of Slab Panel

- Depending on the support conditions, several cases are possible

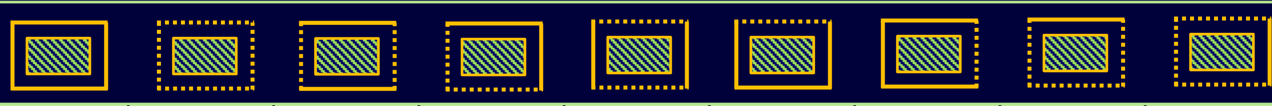


Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A1: Coefficients ($C_{a,\ Negative}$) For Negative Moment in Slab along Short Direction



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.000	0.086	0.000	0.094	0.090	0.097	0.000	0.089	0.088
0.55	0.000	0.084	0.000	0.092	0.089	0.096	0.000	0.085	0.086
0.60	0.000	0.081	0.000	0.089	0.088	0.095	0.000	0.080	0.085
0.65	0.000	0.077	0.000	0.085	0.087	0.093	0.000	0.074	0.083
0.70	0.000	0.074	0.000	0.081	0.086	0.091	0.000	0.068	0.081
0.75	0.000	0.069	0.000	0.076	0.085	0.088	0.000	0.061	0.078
0.80	0.000	0.065	0.000	0.071	0.083	0.086	0.000	0.055	0.075
0.85	0.000	0.060	0.000	0.066	0.082	0.083	0.000	0.049	0.072
0.90	0.000	0.055	0.000	0.060	0.080	0.079	0.000	0.043	0.068
0.95	0.000	0.050	0.000	0.055	0.079	0.075	0.000	0.038	0.065
1.00	0.000	0.045	0.000	0.050	0.075	0.071	0.000	0.033	0.061

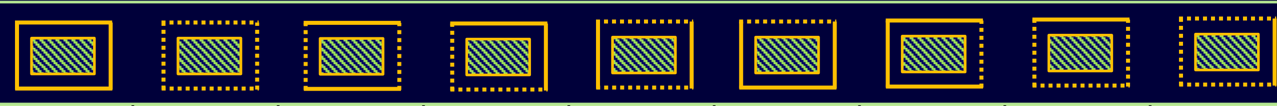
Note: Horizontal sides of the figure represents long side while vertical side represents short side.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A2: Coefficients ($C_{b,\ Negative}$) For Negative Moment in Slab along Long Direction



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.000	0.006	0.022	0.006	0.000	0.000	0.014	0.010	0.003
0.55	0.000	0.007	0.028	0.008	0.000	0.000	0.019	0.014	0.005
0.60	0.000	0.010	0.035	0.011	0.000	0.000	0.024	0.018	0.006
0.65	0.000	0.014	0.043	0.015	0.000	0.000	0.031	0.024	0.008
0.70	0.000	0.017	0.050	0.019	0.000	0.000	0.038	0.029	0.011
0.75	0.000	0.022	0.056	0.024	0.000	0.000	0.044	0.036	0.014
0.80	0.000	0.027	0.061	0.029	0.000	0.000	0.051	0.041	0.017
0.85	0.000	0.031	0.065	0.034	0.000	0.000	0.057	0.046	0.021
0.90	0.000	0.037	0.070	0.040	0.000	0.000	0.062	0.052	0.025
0.95	0.000	0.041	0.072	0.045	0.000	0.000	0.067	0.056	0.029
1.00	0.000	0.045	0.076	0.050	0.000	0.000	0.071	0.061	0.033

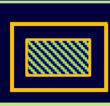
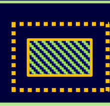
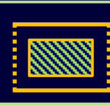
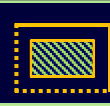
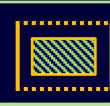
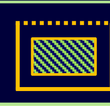
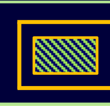
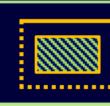
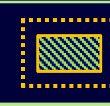
Note: Horizontal sides of the figure represents long side while vertical side represents short side.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A3: Coefficients ($C_{a,\,dl}$) For Dead Load Positive Moment in Slab along Short Direction

									
m	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**
0.50	0.095	0.037	0.080	0.059	0.039	0.061	0.089	0.056	0.023
0.55	0.088	0.035	0.071	0.056	0.038	0.058	0.081	0.052	0.024
0.60	0.081	0.034	0.062	0.053	0.037	0.056	0.073	0.048	0.026
0.65	0.074	0.032	0.054	0.050	0.036	0.054	0.065	0.044	0.028
0.70	0.068	0.030	0.046	0.046	0.035	0.051	0.058	0.040	0.029
0.75	0.061	0.028	0.040	0.043	0.033	0.048	0.051	0.036	0.031
0.80	0.056	0.026	0.034	0.039	0.032	0.045	0.045	0.032	0.029
0.85	0.050	0.024	0.029	0.036	0.031	0.042	0.040	0.029	0.028
0.90	0.045	0.022	0.025	0.033	0.029	0.039	0.035	0.025	0.026
0.95	0.040	0.020	0.021	0.030	0.028	0.036	0.031	0.022	0.024
1.00	0.036	0.018	0.018	0.027	0.027	0.033	0.027	0.020	0.023

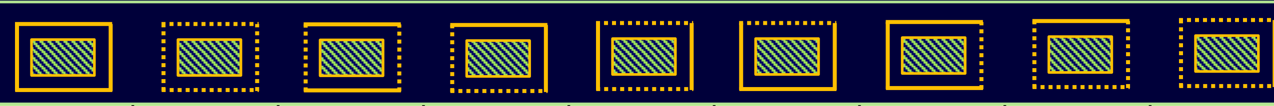
Note: Horizontal sides of the figure represents long side while vertical side represents short side.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A4: Coefficients ($C_{b,\ dl}$) For Dead Load Positive Moment in Slab along Long Direction



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.006	0.002	0.007	0.004	0.001	0.003	0.007	0.004	0.002
0.55	0.008	0.003	0.009	0.005	0.002	0.004	0.009	0.005	0.003
0.60	0.010	0.004	0.011	0.007	0.003	0.006	0.012	0.007	0.004
0.65	0.013	0.006	0.014	0.009	0.004	0.007	0.014	0.009	0.005
0.70	0.016	0.007	0.016	0.011	0.005	0.009	0.017	0.011	0.006
0.75	0.019	0.009	0.018	0.013	0.007	0.013	0.020	0.013	0.007
0.80	0.023	0.011	0.020	0.016	0.009	0.015	0.022	0.015	0.010
0.85	0.026	0.012	0.022	0.019	0.011	0.017	0.025	0.017	0.013
0.90	0.029	0.014	0.024	0.022	0.013	0.021	0.028	0.019	0.015
0.95	0.033	0.016	0.025	0.024	0.015	0.024	0.031	0.021	0.017
1.00	0.036	0.018	0.027	0.027	0.018	0.027	0.033	0.023	0.020

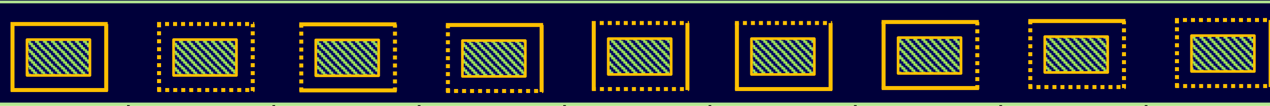
Note: Horizontal sides of the figure represents long side while vertical side represents short side.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A5: Coefficients ($C_{a, ll}$) For Live Load Positive Moment in Slab along Short Direction



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.095	0.066	0.088	0.077	0.067	0.078	0.092	0.076	0.067
0.55	0.088	0.062	0.080	0.072	0.063	0.073	0.085	0.070	0.063
0.60	0.081	0.058	0.071	0.067	0.059	0.068	0.077	0.065	0.059
0.65	0.074	0.053	0.064	0.062	0.055	0.064	0.070	0.059	0.054
0.70	0.068	0.049	0.057	0.057	0.051	0.060	0.063	0.054	0.050
0.75	0.061	0.045	0.051	0.052	0.047	0.055	0.056	0.049	0.046
0.80	0.056	0.041	0.045	0.048	0.044	0.051	0.051	0.044	0.042
0.85	0.050	0.037	0.040	0.043	0.041	0.046	0.045	0.040	0.039
0.90	0.045	0.034	0.035	0.039	0.037	0.042	0.040	0.035	0.036
0.95	0.040	0.030	0.031	0.035	0.034	0.038	0.036	0.031	0.032
1.00	0.036	0.027	0.027	0.032	0.032	0.035	0.032	0.028	0.030

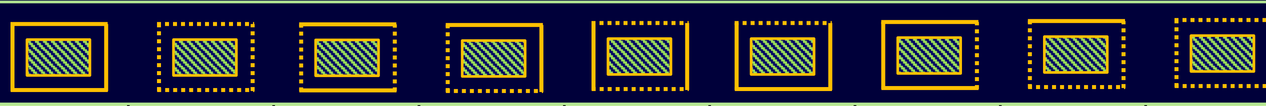
Note: Horizontal sides of the figure represents long side while vertical side represents short side.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A6: Coefficients ($C_{b,ll}$) For Live Load Positive Moment in Slab along Long Direction



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.006	0.004	0.007	0.005	0.004	0.005	0.007	0.005	0.007
0.55	0.008	0.006	0.009	0.007	0.005	0.006	0.009	0.007	0.006
0.60	0.010	0.007	0.011	0.009	0.007	0.008	0.011	0.009	0.007
0.65	0.013	0.010	0.014	0.011	0.009	0.010	0.014	0.011	0.009
0.70	0.016	0.012	0.016	0.014	0.011	0.013	0.017	0.014	0.011
0.75	0.019	0.014	0.019	0.016	0.013	0.016	0.020	0.016	0.013
0.80	0.023	0.017	0.022	0.020	0.016	0.019	0.023	0.019	0.017
0.85	0.026	0.019	0.024	0.023	0.019	0.022	0.026	0.022	0.020
0.90	0.029	0.022	0.027	0.026	0.021	0.025	0.029	0.024	0.022
0.95	0.033	0.025	0.029	0.029	0.024	0.029	0.032	0.027	0.025
1.00	0.036	0.027	0.032	0.032	0.027	0.032	0.035	0.030	0.08

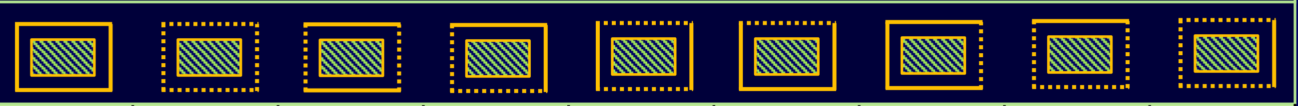
Note: Horizontal sides of the figure represents long side while vertical side represents short side.

Analysis of two-way Slabs

❑ Moment Coefficient Method

❖ ACI Moment Coefficients Tables

Table A7: Ratio of Load "w" in Short Direction for Shear in Slab and Load on Supports



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.94	0.94	0.76	0.94	0.99	0.97	0.86	0.89	0.97
0.55	0.92	0.92	0.69	0.92	0.98	0.96	0.81	0.85	0.95
0.60	0.89	0.89	0.61	0.89	0.97	0.95	0.76	0.80	0.94
0.65	0.85	0.85	0.53	0.85	0.96	0.93	0.69	0.74	0.92
0.70	0.81	0.81	0.45	0.81	0.95	0.91	0.62	0.68	0.89
0.75	0.76	0.76	0.39	0.76	0.94	0.88	0.56	0.61	0.86
0.80	0.71	0.71	0.33	0.71	0.92	0.86	0.49	0.55	0.83
0.85	0.66	0.66	0.28	0.66	0.90	0.83	0.43	0.49	0.79
0.90	0.60	0.60	0.23	0.60	0.88	0.79	0.38	0.43	0.75
0.95	0.55	0.55	0.20	0.55	0.86	0.75	0.33	0.38	0.71
1.00	0.50	0.50	0.17	0.50	0.83	0.71	0.29	0.33	0.67

Note: Horizontal sides of the figure represents long side while vertical side represents short side.

ACI Code Provisions for Two-way Slabs

❑ Minimum Slab Thickness (8.3.1.2)

- The Minimum thickness of two-way slabs with beams spanning between supports on all sides shall be as per ACI Table 8.3.1.2.

α_{fm}	Minimum h, in.
$\alpha_{fm} \leq 0.2$	Provisions of One-way slabs apply
$0.2 \leq \alpha_{fm} \leq 2.0$	Greater of $\left[\dfrac{l_n\left(0.8 + \dfrac{f_y}{200{,}000}\right)}{36 + 5\beta(\alpha_{fm} - 0.2)}, 5'' \right]$
$\alpha_{fm} > 2.0$	Greater of $\left[\dfrac{l_n\left(0.8 + \dfrac{f_y}{200{,}000}\right)}{36 + 9\beta}, 3.5'' \right]$

- α_{fm} is the average value of α_f for all beams on edges of a panel. $\alpha_f = E_{cb} I_b / E_{cs} I_s$
- l_n is the clear span in the long direction, measured face-to-face of beams (in.).
- β is the ratio of clear spans in long to short directions of slab.

ACI Code Provisions for Two-way Slabs

❑ Minimum Slab Thickness (8.3.1.2)

- If the beams are stiff enough, then α_{fm} can be taken greater than 2 and hence the third condition of the Table 8.3.1.2 would be governed.

$$h_{min} = \text{ Greater of } \left[\frac{l_n\left(0.8 + \frac{f_y}{200{,}000}\right)}{36 + 9\beta}, 3.5'' \right]$$

Setting $l_n = l_b$ and $\beta = l_b/_{la}$ the equation becomes

$$\boxed{h_{min} = max\left[\frac{l_b\left(0.8 + \frac{f_y}{200{,}000}\right)}{36 + 9(l_b/l_a)}, 3.5'' \right]}$$

- This equation will be used onward to calculate minimum slab thickness.

ACI Code Provisions for Two-way Slabs

Minimum Flexural Reinforcement (8.6.1)

- The minimum reinforcement requirement for two-way slabs is identical to that of one-way slabs.

$$A_{s,min} = 0.0018A_g$$

Spacing of Flexural Reinforcement (8.7.1)

- Maximum spacing *s* shall be the lesser of:
    - 2h and 18 in. at critical sections
    - 3h and 18 in. at other sections

Analysis of two-way Slabs

Moment Coefficient Method

Stepwise Procedure

- Calculate minimum slab depth
- Calculate loads
- Decide about case of slab
- Use tables to pick moment coefficients
- Calculate Moments
- Determine required reinforcement
- Apply reinforcement checks

Design Example 4.1

Design of Typical Single Story House

Design of Typical Single Story House

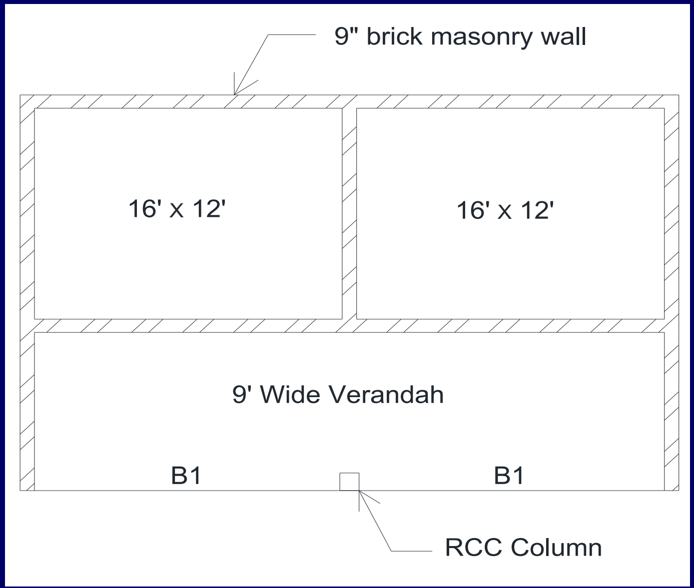
❑ Problem Statement

A single – story house with two bedrooms and a verandah is shown in figure on the next slide. The story height is 12 feet, and the thickness of the masonry wall is 9 inches. There is four inches of mud layer and two inches of tile brick over the slab. According to ASCE 7-10, the expected uniform service live load for the residential buildings is 40 psf. Material strengths are $f_c' = 3$ ksi and $f_y = 60$ ksi. The allowable bearing capacity of the foundation soil is 1.0ss TSF.

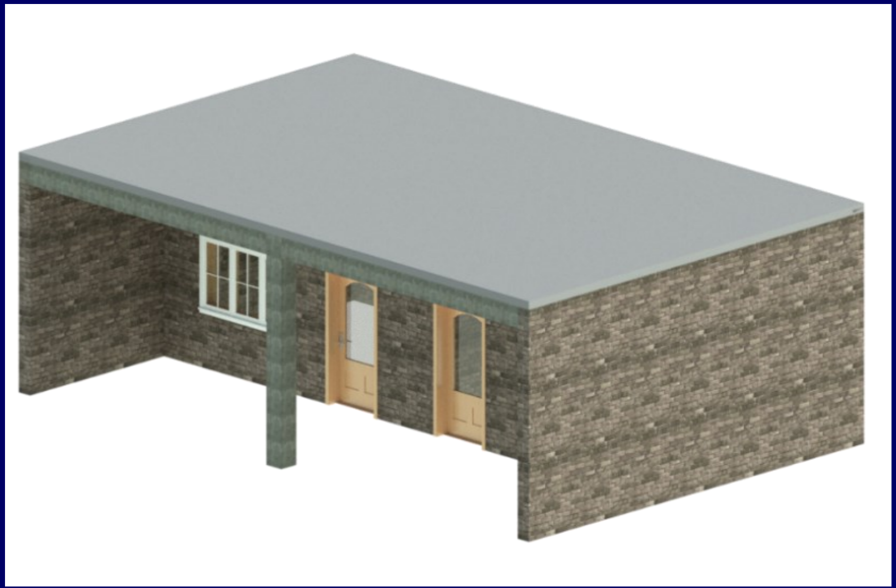
Design the slab, beam B1 and column

Design of Typical Single Story House

❑ Problem Statement



Floor Plan



3D Model

Design of Typical Single Story House

❑ Given Data

Dimensions of Rooms: 16′ x 12′ (interior)

Story height, h = 12′

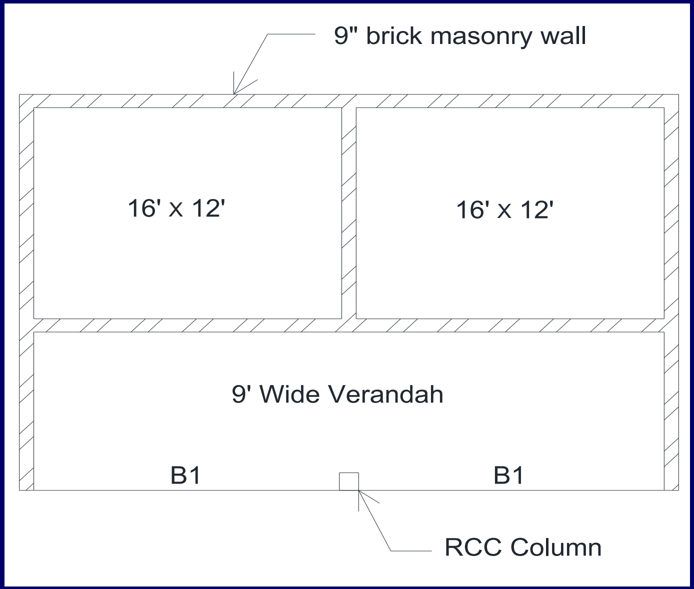
SDL: 4″ Mud layer and 2″ Tile layer

Live load: 40psf

$f_c' = 3$ ksi

$f_y = 60$ ksi

$q_a = 2.204$ ksf



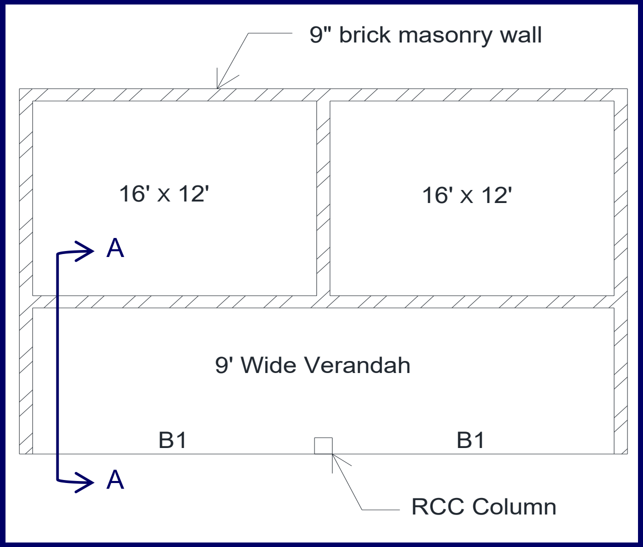
❑ Required Data

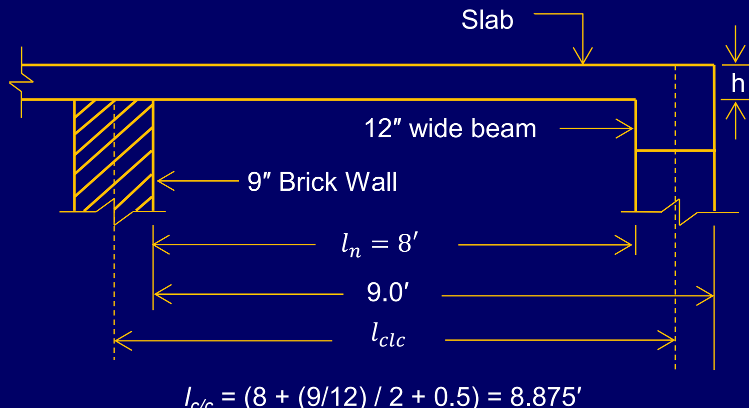
Design the Slab, Beam B1 and Column

Design of Typical Single Story House

❑ Solution

- As can be seen from the figure that the slab over the rooms is a two-way slab case whereas the verandah slab is a one-way slab.





Section A-A

Design of Typical Single Story House

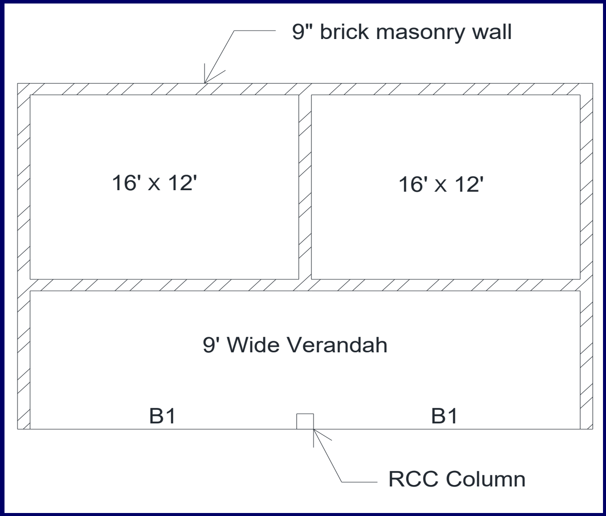
Solution

Slab Design

Step 1: Selection of Sizes

- **For Two-way Slabs:** Assuming $\alpha_{fm} > 2.0$, the minimum thickness is given by:

$$h_{min} = max\left[\frac{l_n\left(0.8 + \frac{f_y}{200{,}000}\right)}{36 + 9\beta}, 3.5''\right]$$



Substituting values, we get

$$h_{min} = max\left[\frac{16\left(0.8 + \frac{60{,}000}{200{,}000}\right)}{36 + 9\left(\frac{16}{12}\right)}, 3.5''\right] = 4.4''$$

Design of Typical Single Story House

Solution

Slab Design

Step 1: Selection of Sizes

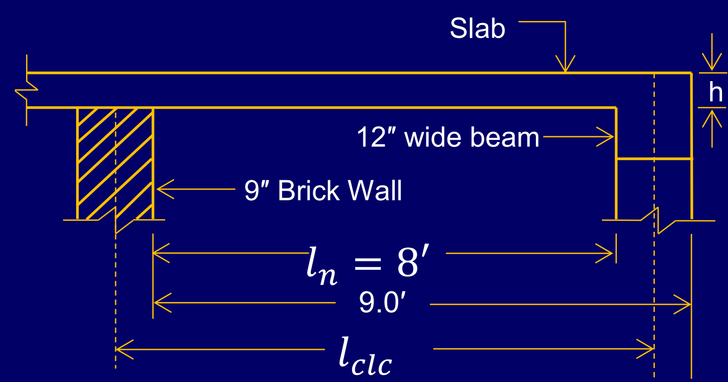
- **For One-way Slab:** For one-end continuous slabs, we have

$$h_{min} = \frac{l}{24}\left(0.4 + \frac{f_y}{100000}\right)$$

Substituting values, we get

$$h_{min} = \frac{8.875}{24}\left(0.4 + \frac{60,000}{100,000}\right) = 4.4''$$

Finally take h = 5″



$l_{c/c}$ = (8 + (9/12) / 2 + 0.5) = 8.875′

Section A-A

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 2: Calculation of loads

Material	Thickness h (in.)	Unit weight γ (kcf)	W = h x γ (ksf)
Concrete Slab	5	0.15	(5/12) × 0.15 = 0.0625
Mud	4	0.12	(4/12) × 0.12 = 0.04
Tile	2	0.12	(2/12) × 0.12= 0.02
Total dead load =			0.1225 ksf

$$w_{u,dl} = 1.2D = 1.2 \times 0.1225 = 0.147 \text{ ksf}$$

$$w_{u,ll} = 1.6 \times 0.04 = 0.064 \text{ ksf}$$

$$w_u = 0.147 + 0.064 = \mathbf{0.211\ ksf}$$

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- The given system consists of both one way and two-way slabs. A system where a two-way slab is continuous with a one-way slab or vice versa can be called as a mixed slab system.

- Strictly speaking, the ACI approximate analysis methods are not suitable for mixed systems.
  - In case of one-way slabs, the ACI approximate analysis is applicable where a one-way slab is continuous with a one-way slab.
  - In case of two-way slabs, the moment coefficient tables are applicable where a two-way slab is continuous with a two-way slab.

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- The best approach to analyze a mixed system is to use Finite Element software.
- However, such a system can also be analyzed manually by making certain approximations.
- We will analyze this system using both methods.

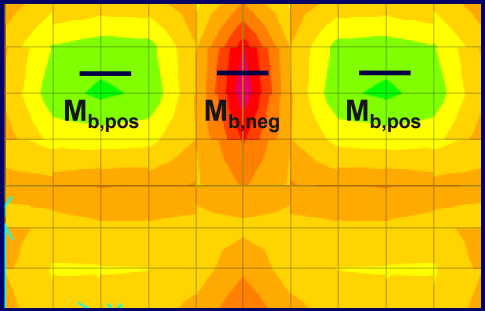
Design of Typical Single Story House

❑ Solution

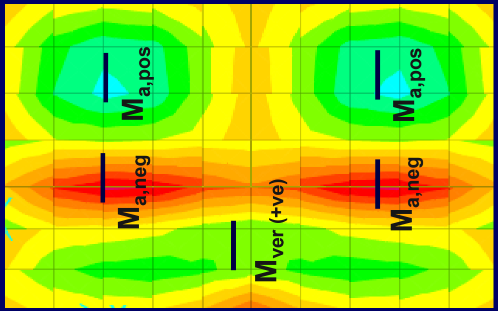
❖ Slab Design

➢ Step 3: Analysis (two-way slab)

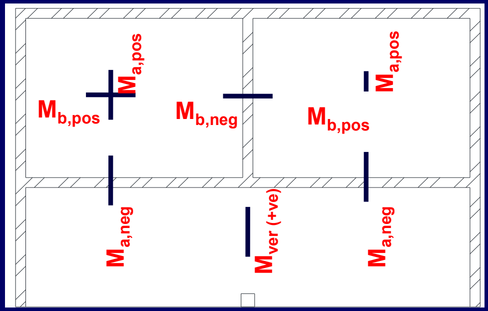
- Below are the Finite Element Analysis (FEA) results obtained using SAFE.



Moments in Long Direction



Moments in Short Direction



Two-way Slab Moments (in-kip/ft) for Rooms				One-way Slab Moment (in-kip/ft) for Verandah	
$M_{a(+)}$	$M_{b(+)}$	$M_{a(-)}$	$M_{b(-)}$	$M_{ver(+)}$	$M_{ver,ext(-)}$
19.0	14.0	25.2	20.0	13.2	4.6

Design of Typical Single Story House

❑ Solution

❖ Slab Design

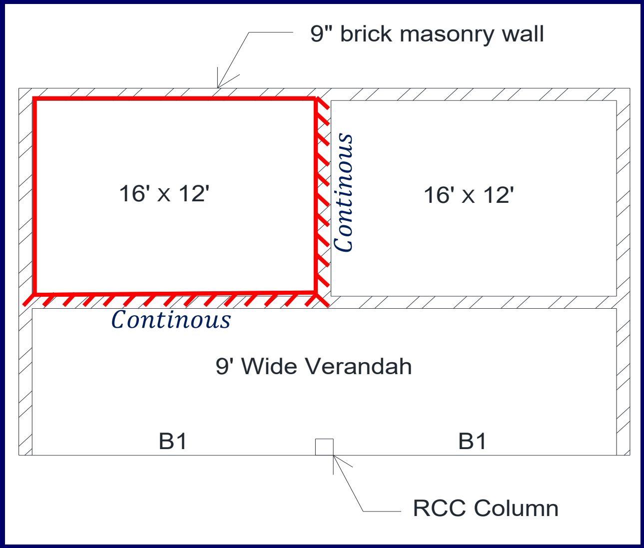
➢ Step 3: Analysis (two-way slab)

- Select slab case

From the figure, the slab case is 4

$$m = \frac{l_a}{l_b} = \frac{12}{16} = 0.750$$

Now, with m = 0.75 and slab case 4, pickup the moment coefficients from the relevant Tables



Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis (two-way slab)

Moment Coefficients

$$\boxed{C_{a,neg} = 0.076}$$

Table A1: Coefficients ($C_{a,\ Negative}$) For Negative Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.000	0.086	0.000	0.094	0.090	0.097	0.000	0.089	0.088
0.55	0.000	0.084	0.000	0.092	0.089	0.096	0.000	0.085	0.086
0.60	0.000	0.081	0.000	0.089	0.088	0.095	0.000	0.080	0.085
0.65	0.000	0.077	0.000	0.085	0.087	0.093	0.000	0.074	0.083
0.70	0.000	0.074	0.000	0.081	0.086	0.091	0.000	0.068	0.081
0.75	0.000	0.069	0.000	0.076	0.085	0.088	0.000	0.061	0.078
0.80	0.000	0.065	0.000	0.071	0.083	0.086	0.000	0.055	0.075
0.85	0.000	0.060	0.000	0.066	0.082	0.083	0.000	0.049	0.072
0.90	0.000	0.055	0.000	0.060	0.080	0.079	0.000	0.043	0.068
0.95	0.000	0.050	0.000	0.055	0.079	0.075	0.000	0.038	0.065
1.00	0.000	0.045	0.000	0.050	0.075	0.071	0.000	0.033	0.061

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis (two-way slab)

Moment Coefficients

$$C_{a,neg} = 0.076$$

$$\boxed{C_{b,neg} = 0.024}$$

Table A2: Coefficients ($C_{b,\,Negative}$) For Negative Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	**0.000**	**0.006**	**0.022**	**0.006**	**0.000**	**0.000**	**0.014**	**0.010**	**0.003**
0.55	0.000	0.007	0.028	0.008	0.000	0.000	0.019	0.014	0.005
0.60	0.000	0.010	0.035	0.011	0.000	0.000	0.024	0.018	0.006
0.65	0.000	0.014	0.043	0.015	0.000	0.000	0.031	0.024	0.008
0.70	0.000	0.017	0.050	0.019	0.000	0.000	0.038	0.029	0.011
0.75	0.000	0.022	0.056	**0.024**	0.000	0.000	0.044	0.036	0.014
0.80	0.000	0.027	0.061	0.029	0.000	0.000	0.051	0.041	0.017
0.85	0.000	0.031	0.065	0.034	0.000	0.000	0.057	0.046	0.021
0.90	0.000	0.037	0.070	0.040	0.000	0.000	0.062	0.052	0.025
0.95	0.000	0.041	0.072	0.045	0.000	0.000	0.067	0.056	0.029
1.00	0.000	0.045	0.076	0.050	0.000	0.000	0.071	0.061	0.033

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis (two-way slab)

Moment Coefficients

$$C_{a,neg} = 0.076$$

$$C_{b,neg} = 0.024$$

$$\boxed{C_{a,pos,dl} = 0.043}$$

Table A3: Coefficients ($C_{a,\,dl}$) For Dead Load Positive Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.095	0.037	0.080	0.059	0.039	0.061	0.089	0.056	0.023
0.55	0.088	0.035	0.071	0.056	0.038	0.058	0.081	0.052	0.024
0.60	0.081	0.034	0.062	0.053	0.037	0.056	0.073	0.048	0.026
0.65	0.074	0.032	0.054	0.050	0.036	0.054	0.065	0.044	0.028
0.70	0.068	0.030	0.046	0.046	0.035	0.051	0.058	0.040	0.029
0.75	0.061	0.028	0.040	**0.043**	0.033	0.048	0.051	0.036	0.031
0.80	0.056	0.026	0.034	0.039	0.032	0.045	0.045	0.032	0.029
0.85	0.050	0.024	0.029	0.036	0.031	0.042	0.040	0.029	0.028
0.90	0.045	0.022	0.025	0.033	0.029	0.039	0.035	0.025	0.026
0.95	0.040	0.020	0.021	0.030	0.028	0.036	0.031	0.022	0.024
1.00	0.036	0.018	0.018	0.027	0.027	0.033	0.027	0.020	0.023

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis (two-way slab)

Moment Coefficients

$C_{a,neg} = 0.076$

$C_{b,neg} = 0.024$

$C_{a,pos,dl} = 0.043$

$\boxed{C_{a,pos,ll} = 0.052}$

Table A4: Coefficients ($C_{a,\,ll}$) For Live Load Positive Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.095	0.066	0.088	0.077	0.067	0.078	0.092	0.076	0.067
0.55	0.088	0.062	0.080	0.072	0.063	0.073	0.085	0.070	0.063
0.60	0.081	0.058	0.071	0.067	0.059	0.068	0.077	0.065	0.059
0.65	0.074	0.053	0.064	0.062	0.055	0.064	0.070	0.059	0.054
0.70	0.068	0.049	0.057	0.057	0.051	0.060	0.063	0.054	0.050
0.75	0.061	0.045	0.051	0.052	0.047	0.055	0.056	0.049	0.046
0.80	0.056	0.041	0.045	0.048	0.044	0.051	0.051	0.044	0.042
0.85	0.050	0.037	0.040	0.043	0.041	0.046	0.045	0.040	0.039
0.90	0.045	0.034	0.035	0.039	0.037	0.042	0.040	0.035	0.036
0.95	0.040	0.030	0.031	0.035	0.034	0.038	0.036	0.031	0.032
1.00	0.036	0.027	0.027	0.032	0.032	0.035	0.032	0.028	0.030

Design of Typical Single Story House

Solution

Slab Design

Step 3: Analysis (two-way slab)

Moment Coefficients

$C_{a,neg} = 0.076$

$C_{b,neg} = 0.024$

$C_{a,pos,dl} = 0.043$

$C_{a,pos,ll} = 0.052$

$\boxed{C_{b,pos,dl} = 0.013}$

Table A5: Coefficients ($C_{b,dl}$) For Dead Load Positive Moment in Slab along Long Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.006	0.002	0.007	0.004	0.001	0.003	0.007	0.004	0.002
0.55	0.008	0.003	0.009	0.005	0.002	0.004	0.009	0.005	0.003
0.60	0.010	0.004	0.011	0.007	0.003	0.006	0.012	0.007	0.004
0.65	0.013	0.006	0.014	0.009	0.004	0.007	0.014	0.009	0.005
0.70	0.016	0.007	0.016	0.011	0.005	0.009	0.017	0.011	0.006
0.75	0.019	0.009	0.018	0.013	0.007	0.013	0.020	0.013	0.007
0.80	0.023	0.011	0.020	0.016	0.009	0.015	0.022	0.015	0.010
0.85	0.026	0.012	0.022	0.019	0.011	0.017	0.025	0.017	0.013
0.90	0.029	0.014	0.024	0.022	0.013	0.021	0.028	0.019	0.015
0.95	0.033	0.016	0.025	0.024	0.015	0.024	0.031	0.021	0.017
1.00	0.036	0.018	0.027	0.027	0.018	0.027	0.033	0.023	0.020

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 3: Analysis (two-way slab)

Moment Coefficients

$C_{a,neg} = 0.076$

$C_{b,neg} = 0.024$

$C_{a,pos,dl} = 0.043$

$C_{a,pos,ll} = 0.013$

$C_{b,pos,dl} = 0.052$

$\boxed{C_{b,pos,ll} = 0.016}$

Table A6: Coefficients ($C_{b,ll}$) For Live Load Positive Moment in Slab along Long Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.006	0.004	0.007	0.005	0.004	0.005	0.007	0.005	0.007
0.55	0.008	0.006	0.009	0.007	0.005	0.006	0.009	0.007	0.006
0.60	0.010	0.007	0.011	0.009	0.007	0.008	0.011	0.009	0.007
0.65	0.013	0.010	0.014	0.011	0.009	0.010	0.014	0.011	0.009
0.70	0.016	0.012	0.016	0.014	0.011	0.013	0.017	0.014	0.011
0.75	0.019	0.014	0.019	0.016	0.013	0.016	0.020	0.016	0.013
0.80	0.023	0.017	0.022	0.020	0.016	0.019	0.023	0.019	0.017
0.85	0.026	0.019	0.024	0.023	0.019	0.022	0.026	0.022	0.020
0.90	0.029	0.022	0.027	0.026	0.021	0.025	0.029	0.024	0.022
0.95	0.033	0.025	0.029	0.029	0.024	0.029	0.032	0.027	0.025
1.00	0.036	0.027	0.032	0.032	0.027	0.032	0.035	0.030	0.08

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ **Step 3: Analysis (two-way slab)**

- Calculate bending Moments

$W_{u,dl} = 0.147ksf, W_{u,dl} = 0.064ksf, W_u = 0.211ksf, l_a = 12'$ *and* $l_b = 16'$

Coefficients	Moment formulae	Moment Values (in.kip)
$C_{a,neg} = 0.076$	$M_{a,neg} = C_{a,neg}W_u {l_a}^2$	27.7
$C_{b,neg} = 0.024$	$M_{b,neg} = C_{b,neg}W_u {l_b}^2$	15.6
$C_{a,pos,dl} = 0.043$ $C_{a,pos,ll} = 0.052$	$M_{a,pos} = C_{a,pos,dl}W_{u,dl}{l_a}^2 + C_{a,pos,ll}W_{u,ll}{l_a}^2$	16.7
$C_{b,pos,dl} = 0.013$ $C_{b,pos,ll} = 0.016$	$M_{b,pos} = C_{b,pos,dl}W_{u,dl}{l_b}^2 + C_{b,pos,ll}W_{u,ll}{l_b}^2$	9.0

Design of Typical Single Story House

Solution

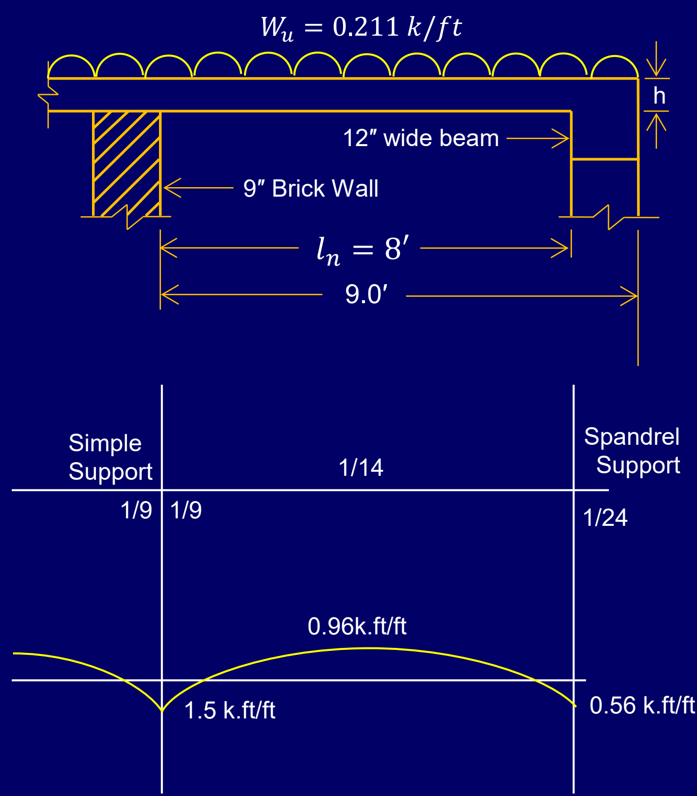
Slab Design

Step 4: Analysis (one-way slab)

$$M_{ver,int(-)} = \frac{w_u l_n^2}{9} = 18.0 \text{ in. kip/ft}$$

$$M_{ver(+)} = \frac{w_u l_n^2}{14} = 11.6 \text{ in. kip/ft}$$

$$M_{ver,ext(-)} = \frac{w_u l_n^2}{24} = 6.8 \text{ in. kip/ft}$$



Note:
For negative moment above the long wall common to rooms and veranda, maximum moment will be picked from both analyses.

Moment of 2.31 from two-way slab analysis is more than 1.5, therefore we will design for 2.31.

Design of Typical Single Story House

Solution

Slab Design

- Step 3: Analysis (comparison of results)

Analysis Method	Two – way Slab Moments (in-kip/ft) (Rooms)				One-way Slab Moment (in-kip/ft) (Verandah)		
	$M_{a(+)}$	$M_{b(+)}$	$M_{a(-)}$	$M_{b(-)}$	$M_{ver,int(-)}$	$M_{ver(+)}$	$M_{ver,ext(-)}$
FEA (SAFE)	19.0	14.0	25.2	20.0	25.2	13.2	4.6
Manual	16.7	9.0	27.7	15.6	18.0	11.6	6.8

- Analysis results from both approaches are almost similar.
- Hence the intelligent use of manual analysis yields reasonable results in most cases.

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ **Step 4: Determination of Flexural Steel Area**

The minimum reinforcement is given by

$$A_{s,min} = 0.0018bh = 0.0018(12)(5) = 0.108\ in^2/ft$$

Using #3 bars with $A_b = 0.11\ in^2$

$$S = \frac{12A_b}{A_s} = \frac{12 \times 0.11}{0.108} = 12.2''c/c$$

Calculated spacing shall not exceed S_{max} which is given by

$$S_{max} = min(2h\,, 18'') \Rightarrow\ min(2 \times 5\,, 18'') = 10''$$

Calculated spacing of 12.2″ exceeds 10″. Finally Provide #3@10″ c/c.

Design of Typical Single Story House

Solution

Slab Design

Step 4: Determination of Flexural Steel Area

With #3@10″ c/c, calculate moment capacity

$$A_{s,min} = \frac{12A_b}{S} = \frac{12(0.11)}{10} = 0.132 \text{ in}^2/\text{ft}$$

$$a = \frac{A_{s,min} f_y}{0.85 f_c' b} = \frac{0.132 \times 60}{0.85 \times 3 \times 12} = 0.26 \ in$$

Now,

$$\emptyset M_n = 0.9 \times 0.132 \times 60 \left(4 - \frac{0.26}{2}\right) = 27.6 \text{ in. kip/ft}$$

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 4: Determination of Flexural Steel Area

The flexural design summary is provided below.

Location	Moments (in.kip/ft)	$M_{n,min}$ (in. kip/ft)	A_s (in^2)	S using #3 bar (in)
$M_{a,neg}$	27.71	27.60	$\approx A_{s,min}$ governs	10
$M_{b,neg}$	15.56		$A_{s,min}$ governs	10
$M_{a,pos}$	16.67		$A_{s,min}$ governs	10
$M_{b,pos}$	9.02		$A_{s,min}$ governs	10
$M_{+,Ver}$	11.52		$A_{s,min}$ governs	10

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 5: Determination of temperature/shrinkage reinforcement

For one-way slab, the temperature reinforcement is given by

$$A_{s+T} = A_{min} = 0.108 \text{ in}^2/\text{ft}$$

$$S = \frac{12A_b}{A_s} = \frac{12 \times 0.11}{0.108} = 12.2'' c/c$$

Maximum spacing for shrinkage reinforcement is given by

$$s_{max} = min[\,5(5) \ or \ 18''] = 18'' \rightarrow OK!$$

Finally, provide #3 @10 in. c/c

Design of Typical Single Story House

Solution

Slab Design

Step 5: Determination of temperature/shrinkage reinforcement

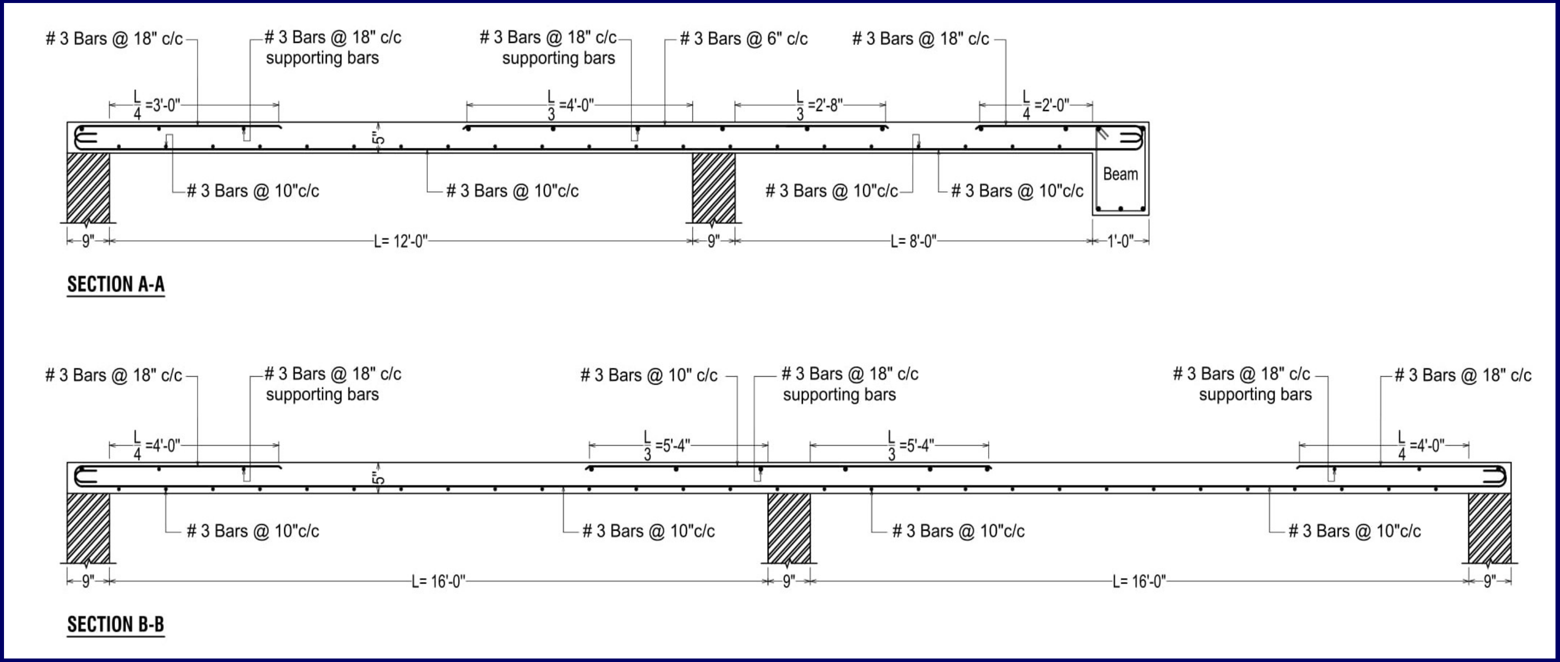
- **Reinforcement at discontinuous ends**
  - Reinforcement at discontinuous ends in a two – way slab is 1/3 of the positive reinforcement.
  - Positive reinforcement at midspan in this case is #3 @ 10″ c/c. Therefore, reinforcement at discontinuous end may be provided @ 30″ c/c.
  - However, in field practice, the spacing of reinforcement at discontinuous ends seldom exceeds 18″ c/c. The same is provided here as well.

Design of Typical Single Story House

❑ Solution

❖ Slab Design

➢ Step 6: Drafting



Design of Typical Single Story House

❑ Solution

❖ Beam Design

➢ Step 1: Selection of sizes

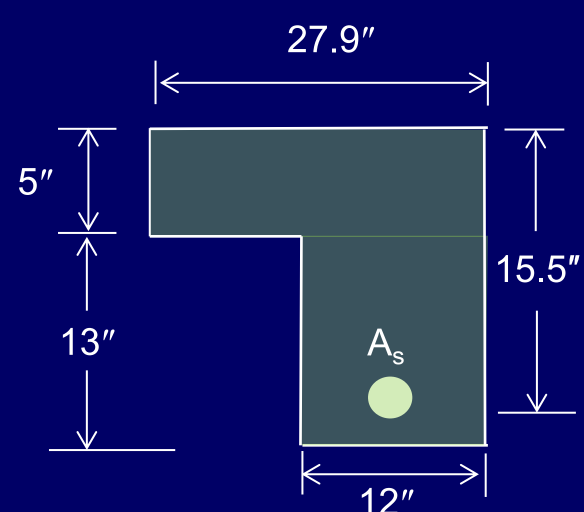
Assume $b_w = 12"$

$$h_{min,40} = \frac{16.75}{18.5} \times 12 = 10.9" \rightarrow Take\ h = 18''$$

Now,

$$b_{f,L} = min \begin{cases} b_w + 6h_f = 12 + 16 \times 5 = 92" \\ b_w + \frac{S_w}{2} = Not\ applicable \\ b_w + \frac{l_n}{12} = 12 + \frac{15.875}{12} \times 12 = 27.9" \end{cases}$$

$b_{f,L} = 27.9"$

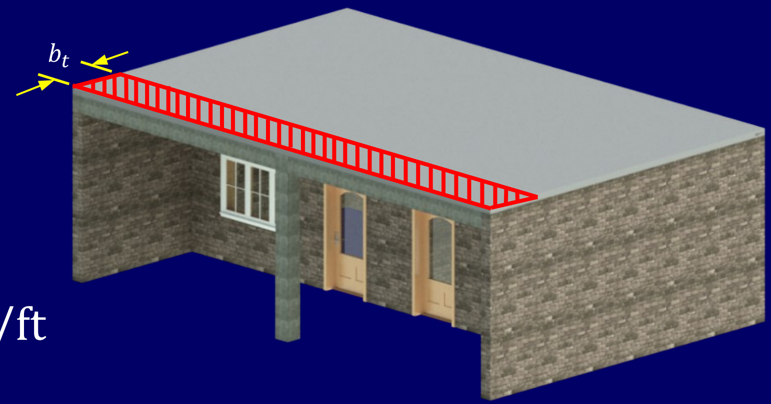


Design of Typical Single Story House

❑ Solution

❖ Beam Design

➢ Step 2: Calculation of loads



Self weight of beam is given by

$$SW = \frac{12(18-5)}{144} \times 0.150 = 0.163 \text{ k/ft}$$

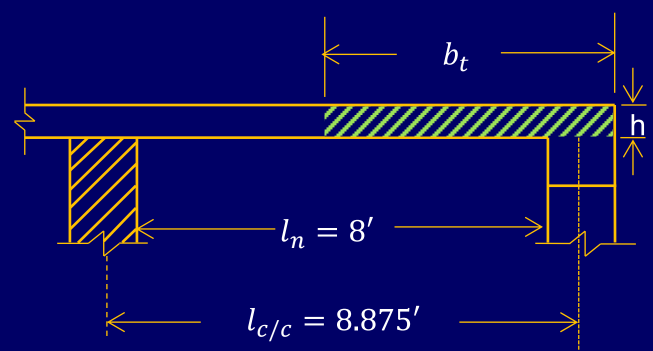
Now,

$$W_{u,beam} = w_{u,slab} \times b_t + 1.2SW$$

By putting values

$$W_{u,beam} = 0.211 \times 5 + 1.2(0.163)$$

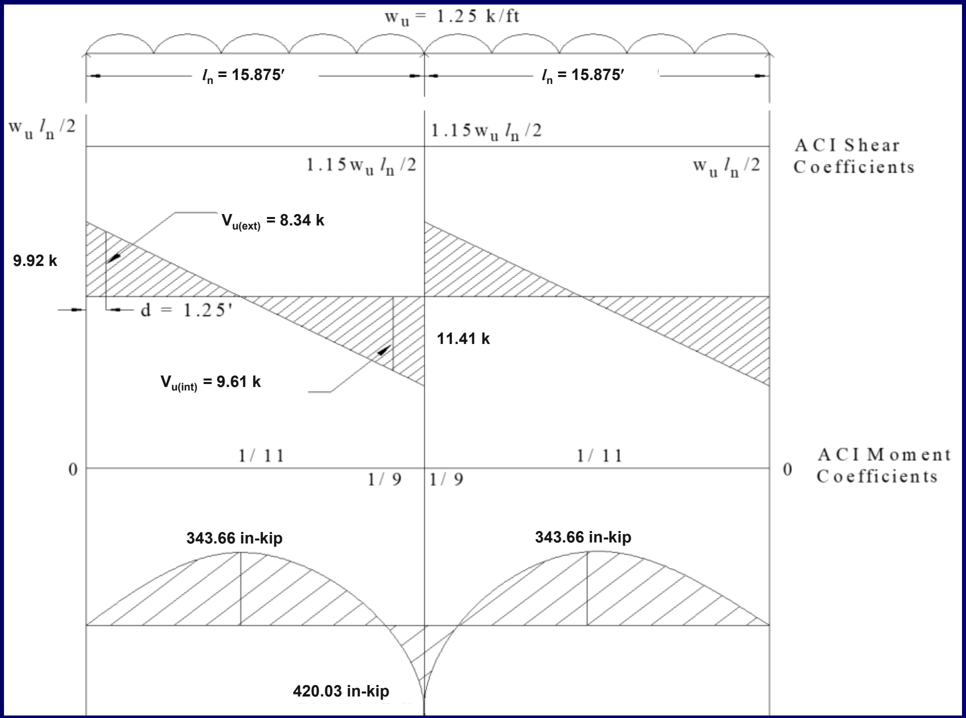
$$W_{u,beam} = 1.25 \text{ k/ft}$$



$$b_t = \frac{l_c}{2} + \frac{b_w}{2} = \frac{8.875'}{2} + \frac{1'}{2} = 4.9 \approx 5'$$

Design of Typical Single Story House

- **Solution**
  - **Beam Design**
    - **Step 3: Analysis**



Design of Typical Single Story House

Solution

Beam Design

Step 4: Determination of Flexural Reinforcement

Flexural Design Summary

M_u (in-kip)	d (in.)	b (in.)	A_s (in^2)	A_{smin} (in^2)	A_{smax} (in^2)	A_s	Detailing
343.66 (+)	15	27.875	0.43	0.60	2.42	0.60	3 - #4
420.03 (-)	15	12	0.44	0.60	2.42	0.60	3 - #4

Shear Design Summary

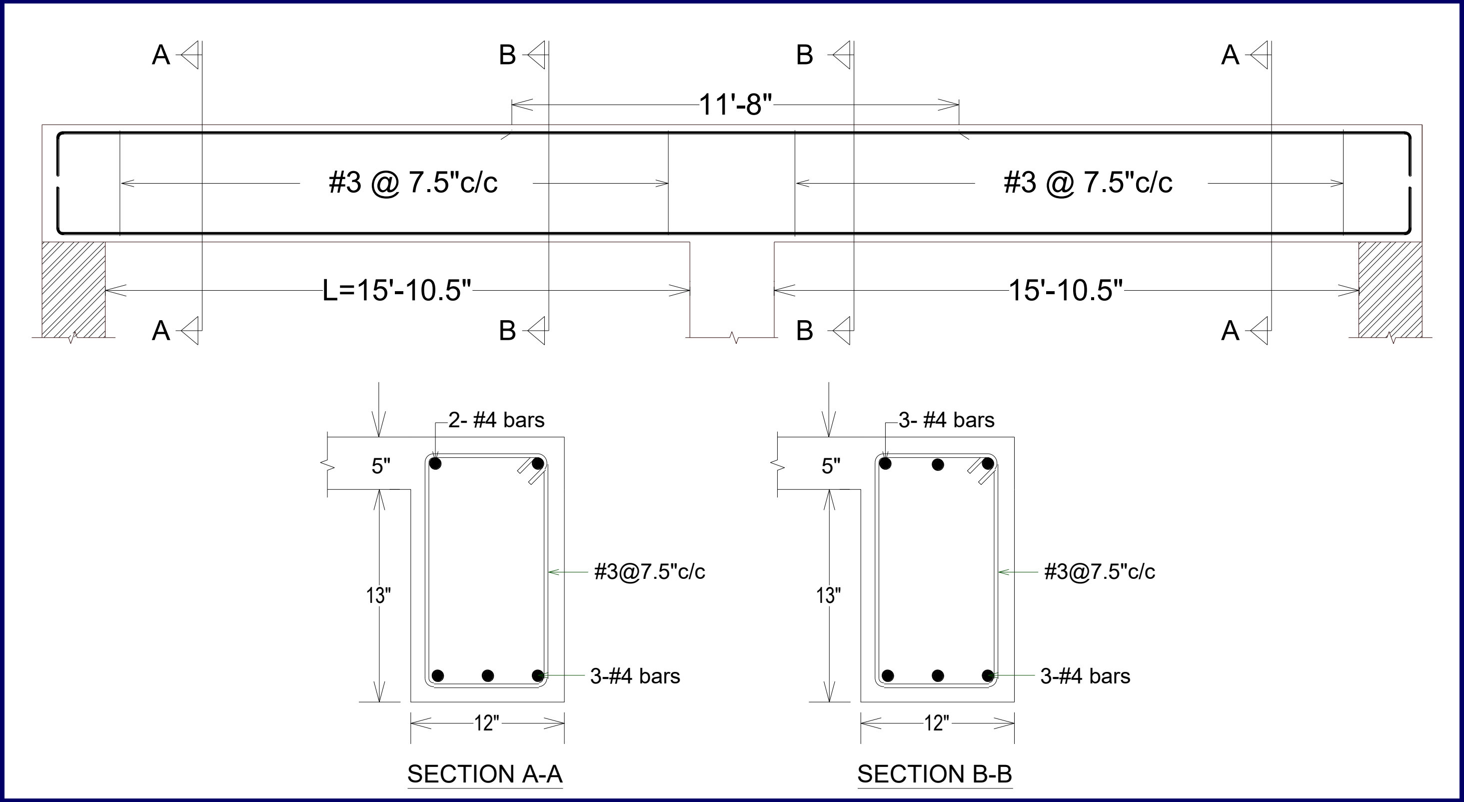
Location	V_u (@ d)(kip)	ΦV_c (kips)	S_{max} (in)	Detailing
Exterior	8.34	14.78	7.5″	2-legged #3 @7.5″ c/c
Interior	9.61	14.78	7.5″	2-legged #3 @7.5″ c/c

Design of Typical Single Story House

❑ Solution

❖ Beam Design

➢ Step No 5: Drafting



Design of Typical Single Story House

❑ Solution

❖ **Column Design**

➢ **Step 1: Selection of Sizes**

Assume column size = 12″ × 12″

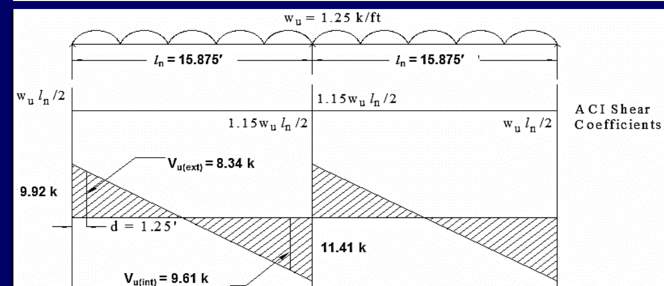
➢ **Step 2: Calculation of Loads**

P_u = 11.41 × 2 = 22.82 kip

➢ **Step 3: Longitudinal Reinforcement**

Assuming the column as concentric, the axial capacity is given by:

$$\alpha \emptyset P_n = 0.8 \times 0.65[0.85 f_c'(A_g - A_{st}) - A_{st} f_y]$$



Design of Typical Single Story House

❑ Solution

❖ Column Design

➢ Step 3: Longitudinal Reinforcement

Assuming $A_{st} = 0.01A_g = 0.01 \times 144 = 1.44\ in^2$

$\alpha \emptyset P_n = 0.8 \times 0.65[0.85 \times 3(144 - 1.44) - 1.44 \times 60]$

$= 144.10 > \mathrm{P_u} = 22.82\ \mathrm{kip} \rightarrow \mathrm{OK}$

Using #4 bar with $A_b = 0.20\ in^2$

No. of bars = 1.44/0.20 = 7.2 ≈ 8

Hence, Provide 8-#4 bars.

Design of Typical Single Story House

Solution

Column Design

Step 4: Determination of Spacing for Shear Reinforcement

Using #3 bar with $A_b = 0.11\ in^2, S_{max}$ is the least of:

i. $\dfrac{A_v f_y}{50b}$ = 0.22 x 60,000/ (50x12) = 22.0″

ii. $\dfrac{A_v f_y}{0.75\sqrt{f_c{}'}b}$ = 0.22 x 60,000 / (0.75$\sqrt{3000}$ x12) = 26.8″

iii. $16d_b$ of longitudinal bar = 16 x 4/8 = 8″

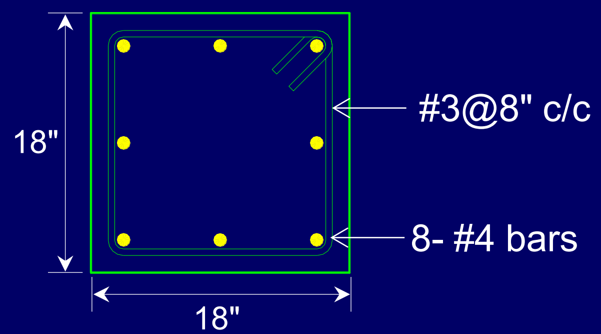
iv. 48 d_b of tie bar = 48 x 3/8 = 18″

v. Smallest dimension of member = 12″

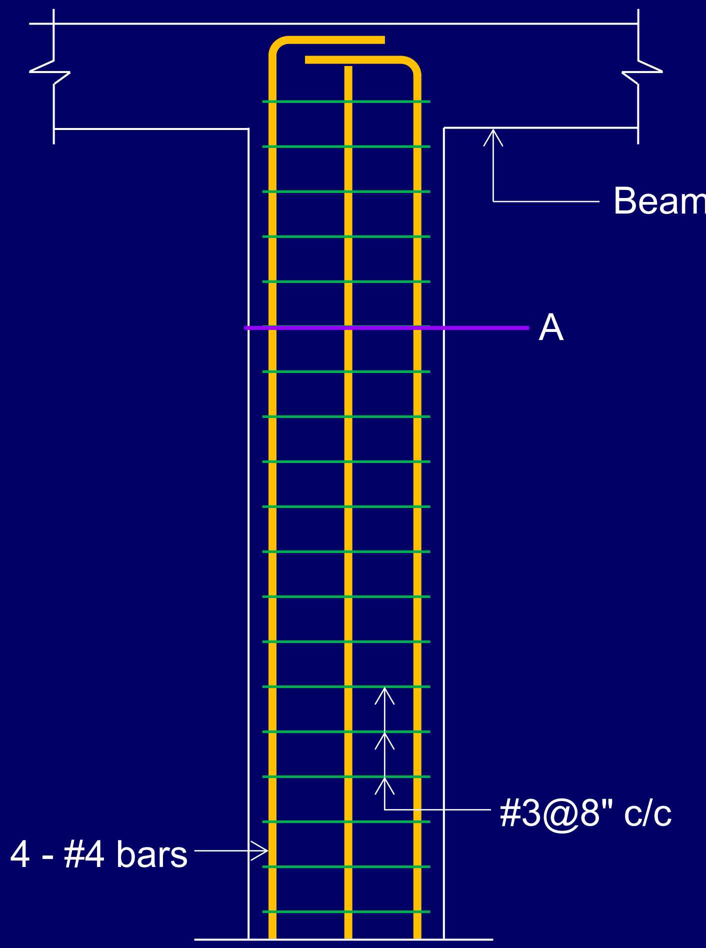
S_{max} = 8″. Provide #3 ties @ 8″ c/c

Design of Typical Single Story House

- **Solution**
  - **Column Design**
  - **Step 5: Drafting**



Section A-A



Design of Typical Single Story House

- Crack in slab in village house due to absence of negative reinforcement

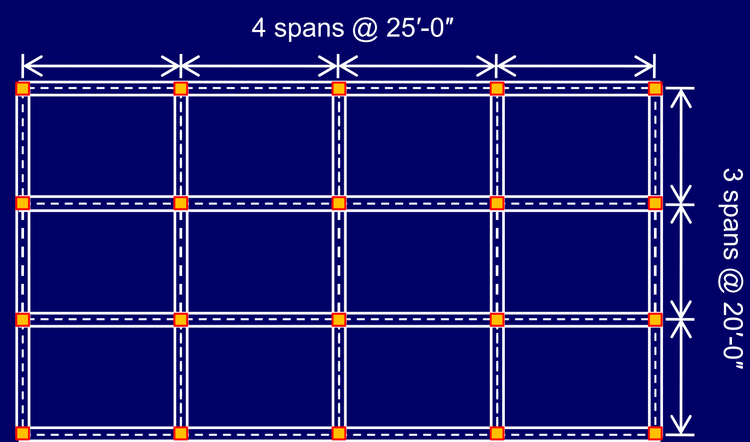
Design Example 4.2

Design of Three-story Commercial Building

Design of Three-story Commercial Building

❑ Problem Statement

- A 100′ x 60′ three-story 4 by 3 bay commercial building is shown below . The 7 in-thick floors are subjected to uniform service live load of 144psf. Taking $f_c{}' = 3ksi$ and $f_y = 40\ ksi$.
- ***Design*** slab and beams of one of the floors.



Floor Plan

3D Model

- All beams are 14″ x 20″
- All columns are 14″ x 14″

Design of Three-story Commercial Building

❑ Given Data

Dimensions of floor : 100′ x 60′ (center – to – center)

Story height, h = 12′

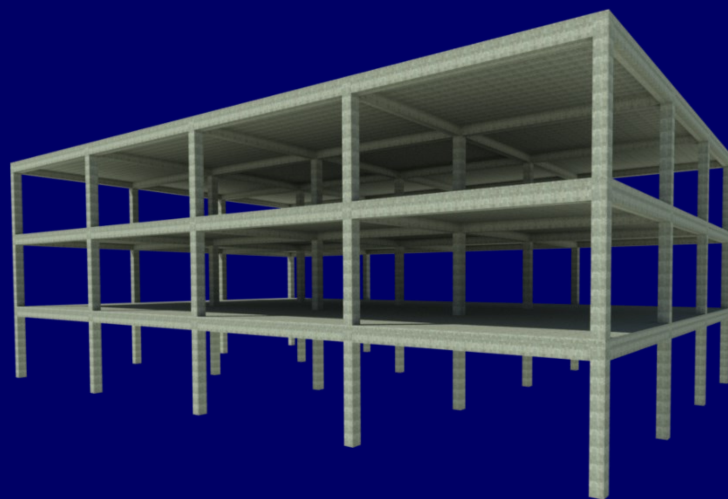
All beams are 14″ x 20″

All columns are 14″ x 14″

Superimposed Dead load : Nil

Live load: 144 psf

$f_c' = 3\ ksi\ \ \&\ \ f_y = 40\ ksi$



❑ Required Data

Design slab and beams of one of the floors

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 1 and 2: Selection of Structural Configuration and Sizes

Structural configuration and slab thickness are given, $h_f = 7$“

➢ Step 2: Calculation of Loads

Self weight of slab $= \frac{7}{12} \times 0.150 = 0.0875\ ksf$

$W_{u,dl} = 1.2(0.0875) = 0.105\ ksf$

$W_{u,ll} = 1.6(0.144) = 0.230\ ksf$

$W_u = 0.105 + 0.2304 = 0.335\ ksf$

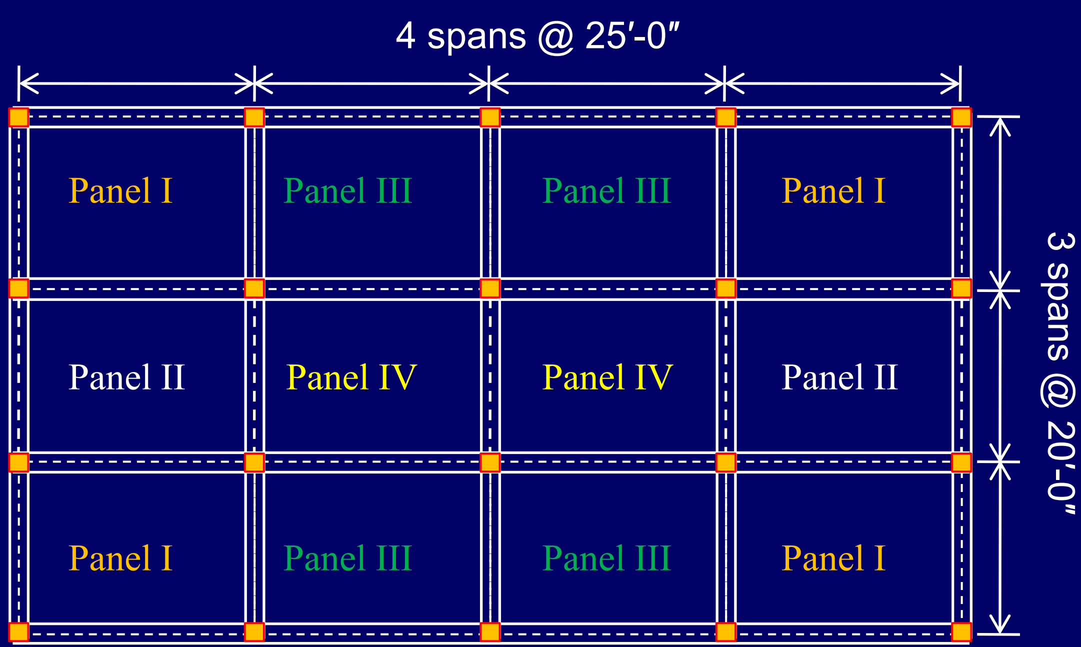
Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

Complete analysis of the slab is done by analyzing four panels



Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- Moment Coefficients

$$\boxed{C_{a,neg} = 0.071}$$

Panel – I

Table A1: Coefficients ($C_{a,\ Negative}$) For Negative Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.000	0.086	0.000	0.094	0.090	0.097	0.000	0.089	0.088
0.55	0.000	0.084	0.000	0.092	0.089	0.096	0.000	0.085	0.086
0.60	0.000	0.081	0.000	0.089	0.088	0.095	0.000	0.080	0.085
0.65	0.000	0.077	0.000	0.085	0.087	0.093	0.000	0.074	0.083
0.70	0.000	0.074	0.000	0.081	0.086	0.091	0.000	0.068	0.081
0.75	0.000	0.069	0.000	0.076	0.085	0.088	0.000	0.061	0.078
0.80	0.000	0.065	0.000	0.071	0.083	0.086	0.000	0.055	0.075
0.85	0.000	0.060	0.000	0.066	0.082	0.083	0.000	0.049	0.072
0.90	0.000	0.055	0.000	0.060	0.080	0.079	0.000	0.043	0.068
0.95	0.000	0.050	0.000	0.055	0.079	0.075	0.000	0.038	0.065
1.00	0.000	0.045	0.000	0.050	0.075	0.071	0.000	0.033	0.061

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 4

$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- Moment Coefficients

$C_{a,neg} = 0.071$

$\boxed{C_{b,neg} = 0.029}$

Panel – I

Table A2: Coefficients ($C_{b,\ Negative}$) For Negative Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.000	0.006	0.022	0.006	0.000	0.000	0.014	0.010	0.003
0.55	0.000	0.007	0.028	0.008	0.000	0.000	0.019	0.014	0.005
0.60	0.000	0.010	0.035	0.011	0.000	0.000	0.024	0.018	0.006
0.65	0.000	0.014	0.043	0.015	0.000	0.000	0.031	0.024	0.008
0.70	0.000	0.017	0.050	0.019	0.000	0.000	0.038	0.029	0.011
0.75	0.000	0.022	0.056	0.024	0.000	0.000	0.044	0.036	0.014
0.80	0.000	0.027	0.061	0.029	0.000	0.000	0.051	0.041	0.017
0.85	0.000	0.031	0.065	0.034	0.000	0.000	0.057	0.046	0.021
0.90	0.000	0.037	0.070	0.040	0.000	0.000	0.062	0.052	0.025
0.95	0.000	0.041	0.072	0.045	0.000	0.000	0.067	0.056	0.029
1.00	0.000	0.045	0.076	0.050	0.000	0.000	0.071	0.061	0.033

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 4

$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- Moment Coefficients

$C_{a,neg} = 0.076$

$C_{b,neg} = 0.029$

$\boxed{C_{a,pos,dl} = 0.039}$

Panel – I

Table A3: Coefficients ($C_{a,dl}$) For Dead Load Positive Moment in Slab along Short Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.095	0.037	0.080	0.059	0.039	0.061	0.089	0.056	0.023
0.55	0.088	0.035	0.071	0.056	0.038	0.058	0.081	0.052	0.024
0.60	0.081	0.034	0.062	0.053	0.037	0.056	0.073	0.048	0.026
0.65	0.074	0.032	0.054	0.050	0.036	0.054	0.065	0.044	0.028
0.70	0.068	0.030	0.046	0.046	0.035	0.051	0.058	0.040	0.029
0.75	0.061	0.028	0.040	**0.043**	0.033	0.048	0.051	0.036	0.031
0.80	0.056	0.026	0.034	0.039	0.032	0.045	0.045	0.032	0.029
0.85	0.050	0.024	0.029	0.036	0.031	0.042	0.040	0.029	0.028
0.90	0.045	0.022	0.025	0.033	0.029	0.039	0.035	0.025	0.026
0.95	0.040	0.020	0.021	0.030	0.028	0.036	0.031	0.022	0.024
1.00	0.036	0.018	0.018	0.027	0.027	0.033	0.027	0.020	0.023

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80
Slab Case = 4
$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- Moment Coefficients

$C_{a,neg} = 0.071$

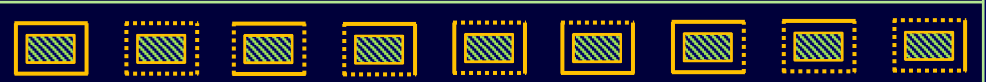
$C_{b,neg} = 0.029$

$C_{a,pos,dl} = 0.039$

$\boxed{C_{a,pos,ll} = 0.048}$

Panel – I

Table A4: Coefficients ($C_{a,ll}$) For Live Load Positive Moment in Slab along Short Direction



m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.095	0.066	0.088	0.077	0.067	0.078	0.092	0.076	0.067
0.55	0.088	0.062	0.080	0.072	0.063	0.073	0.085	0.070	0.063
0.60	0.081	0.058	0.071	0.067	0.059	0.068	0.077	0.065	0.059
0.65	0.074	0.053	0.064	0.062	0.055	0.064	0.070	0.059	0.054
0.70	0.068	0.049	0.057	0.057	0.051	0.060	0.063	0.054	0.050
0.75	0.061	0.045	0.051	0.052	0.047	0.055	0.056	0.049	0.046
0.80	0.056	0.041	0.045	0.048	0.044	0.051	0.051	0.044	0.042
0.85	0.050	0.037	0.040	0.043	0.041	0.046	0.045	0.040	0.039
0.90	0.045	0.034	0.035	0.039	0.037	0.042	0.040	0.035	0.036
0.95	0.040	0.030	0.031	0.035	0.034	0.038	0.036	0.031	0.032
1.00	0.036	0.027	0.027	0.032	0.032	0.035	0.032	0.028	0.030

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 4

$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- Moment Coefficients

$C_{a,neg} = 0.071$

$C_{b,neg} = 0.029$

$C_{a,pos,dl} = 0.039$

$C_{a,pos,ll} = 0.048$

$\boxed{C_{b,pos,dl} = 0.016}$

Panel – I

Table A5: Coefficients ($C_{b,dl}$) For Dead Load Positive Moment in Slab along Long Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.006	0.002	0.007	0.004	0.001	0.003	0.007	0.004	0.002
0.55	0.008	0.003	0.009	0.005	0.002	0.004	0.009	0.005	0.003
0.60	0.010	0.004	0.011	0.007	0.003	0.006	0.012	0.007	0.004
0.65	0.013	0.006	0.014	0.009	0.004	0.007	0.014	0.009	0.005
0.70	0.016	0.007	0.016	0.011	0.005	0.009	0.017	0.011	0.006
0.75	0.019	0.009	0.018	0.013	0.007	0.013	0.020	0.013	0.007
0.80	0.023	0.011	0.020	0.016	0.009	0.015	0.022	0.015	0.010
0.85	0.026	0.012	0.022	0.019	0.011	0.017	0.025	0.017	0.013
0.90	0.029	0.014	0.024	0.022	0.013	0.021	0.028	0.019	0.015
0.95	0.033	0.016	0.025	0.024	0.015	0.024	0.031	0.021	0.017
1.00	0.036	0.018	0.027	0.027	0.018	0.027	0.033	0.023	0.020

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80
Slab Case = 4
$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis

- Moment Coefficients

$C_{a,neg} = 0.071$

$C_{b,neg} = 0.029$

$C_{a,pos,dl} = 0.039$

$C_{a,pos,ll} = 0.048$

$C_{b,pos,dl} = 0.016$

$\boxed{C_{b,pos,ll} = 0.020}$

Panel – I

Table A6: Coefficients ($C_{b,ll}$) For Live Load Positive Moment in Slab along Long Direction

m	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
0.50	0.006	0.004	0.007	0.005	0.004	0.005	0.007	0.005	0.007
0.55	0.008	0.006	0.009	0.007	0.005	0.006	0.009	0.007	0.006
0.60	0.010	0.007	0.011	0.009	0.007	0.008	0.011	0.009	0.007
0.65	0.013	0.010	0.014	0.011	0.009	0.010	0.014	0.011	0.009
0.70	0.016	0.012	0.016	0.014	0.011	0.013	0.017	0.014	0.011
0.75	0.019	0.014	0.019	0.016	0.013	0.016	0.020	0.016	0.013
0.80	0.023	0.017	0.022	0.020	0.016	0.019	0.023	0.019	0.017
0.85	0.026	0.019	0.024	0.023	0.019	0.022	0.026	0.022	0.020
0.90	0.029	0.022	0.027	0.026	0.021	0.025	0.029	0.024	0.022
0.95	0.033	0.025	0.029	0.029	0.024	0.029	0.032	0.027	0.025
1.00	0.036	0.027	0.032	0.032	0.027	0.032	0.035	0.030	0.08

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 4

$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Design of Three-story Commercial Building

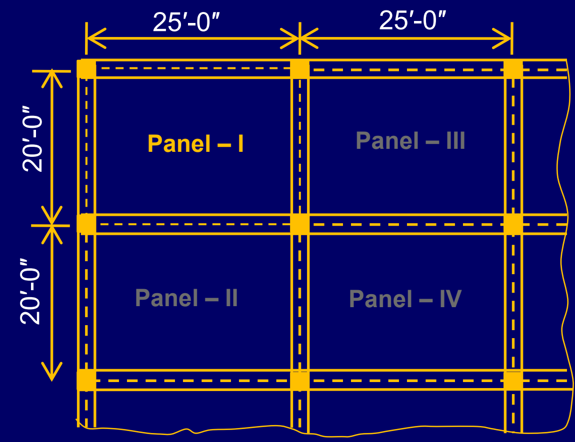
Solution

Slab Design

Step 3: Analysis (Panel – I)

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 4



$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Coefficients	Moment formulae	Moment Values (in.kip)
$C_{a,neg} = 0.071$	$M_{a,neg} = C_{a,neg} W_u {l_a}^2$	101.32
$C_{b,neg} = 0.029$	$M_{b,neg} = C_{b,neg} W_u {l_b}^2$	66.28
$C_{a,pos,dl} = 0.039$	$M_{a,pos} = C_{a,pos,dl} W_{u,dl} {l_a}^2 + C_{a,pos,ll} W_{u,ll} {l_a}^2$	64.48
$C_{a,pos,ll} = 0.048$		
$C_{b,pos,dl} = 0.016$	$M_{b,pos} = C_{b,pos,dl} W_{u,dl} {l_b}^2 + C_{b,pos,ll} W_{u,ll} {l_b}^2$	42.85
$C_{b,pos,ll} = 0.02$		

Design of Three-story Commercial Building

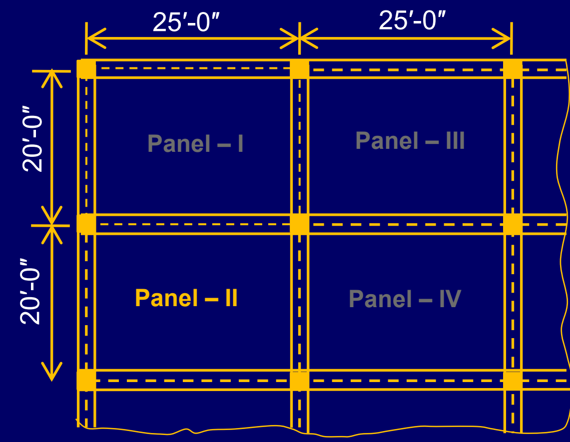
Solution

Slab Design

Step 3: Analysis (Panel – II)

$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 9



$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Coefficients	Moment formulae	Moment Values (in.kip)
$C_{a,neg} = 0.075$	$M_{a,neg} = C_{a,neg} W_u {l_a}^2$	107.03
$C_{b,neg} = 0.017$	$M_{b,neg} = C_{b,neg} W_u {l_b}^2$	38.85
$C_{a,pos,dl} = 0.029$	$M_{a,pos} = C_{a,pos,dl} W_{u,dl} {l_a}^2 + C_{a,pos,ll} W_{u,ll} {l_a}^2$	54.13
$C_{a,pos,ll} = 0.042$		
$C_{b,pos,dl} = 0.01$	$M_{b,pos} = C_{b,pos,dl} W_{u,dl} {l_b}^2 + C_{b,pos,ll} W_{u,ll} {l_b}^2$	33.85
$C_{b,pos,ll} = 0.017$		

Design of Three-story Commercial Building

Solution

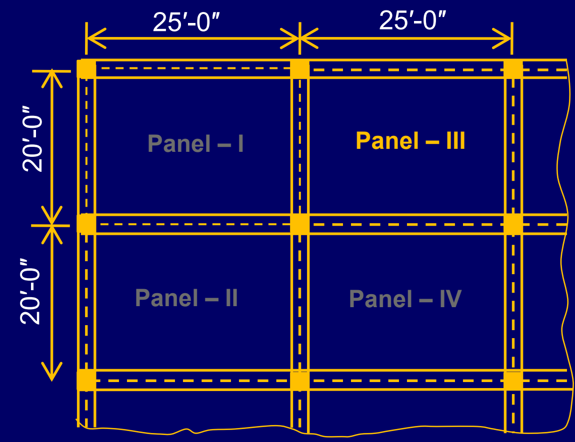
Slab Design

Step 3: Analysis (Panel – III)

$m = l_a/l_b = 18.83/23.83 = 0.78 \approx 0.80$

Slab Case = 8

$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$



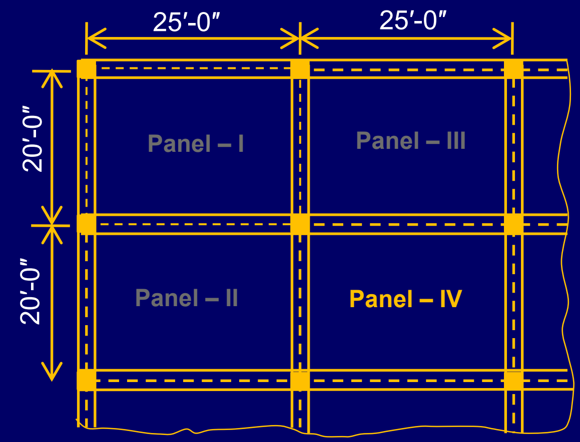
Coefficients	Moment formulae	Moment Values (in.kip)
$C_{a,neg} = 0.055$	$M_{a,neg} = C_{a,neg} W_u {l_a}^2$	78.49
$C_{b,neg} = 0.041$	$M_{b,neg} = C_{b,neg} W_u {l_b}^2$	93.71
$C_{a,pos,dl} = 0.032$ $C_{a,pos,ll} = 0.044$	$M_{a,pos} = C_{a,pos,dl} W_{u,dl} {l_a}^2 + C_{a,pos,ll} W_{u,ll} {l_a}^2$	57.43
$C_{b,pos,dl} = 0.015$ $C_{b,pos,ll} = 0.019$	$M_{b,pos} = C_{b,pos,dl} W_{u,dl} {l_b}^2 + C_{b,pos,ll} W_{u,ll} {l_b}^2$	40.56

Design of Three-story Commercial Building

Solution

- **Slab Design**

- **Step 3: Analysis (Panel – IV)**



$m = l_a/l_b$ = 18.83/23.83 = 0.78 ≈ 0.80

Slab Case = 2

$W_{u,dl} = 0.105ksf$ $W_{u,ll} = 0.230ksf$ and $W_u = 0.335ksf$

Coefficients	Moment formulae	Moment Values (in.kip)
$C_{a,neg} = 0.065$	$M_{a,neg} = C_{a,neg} W_u {l_a}^2$	92.76
$C_{b,neg} = 0.027$	$M_{b,neg} = C_{b,neg} W_u {l_b}^2$	61.71
$C_{a,pos,dl} = 0.026$	$M_{a,pos} = C_{a,pos,dl} W_{u,dl} {l_a}^2 + C_{a,pos,ll} W_{u,ll} {l_a}^2$	51.81
$C_{a,pos,ll} = 0.041$		
$C_{b,pos,dl} = 0.011$	$M_{b,pos} = C_{b,pos,dl} W_{u,dl} {l_b}^2 + C_{b,pos,ll} W_{u,ll} {l_b}^2$	34.56
$C_{b,pos,ll} = 0.017$		

Design of Three-story Commercial Building

Solution

Slab Design

Step 3: Analysis

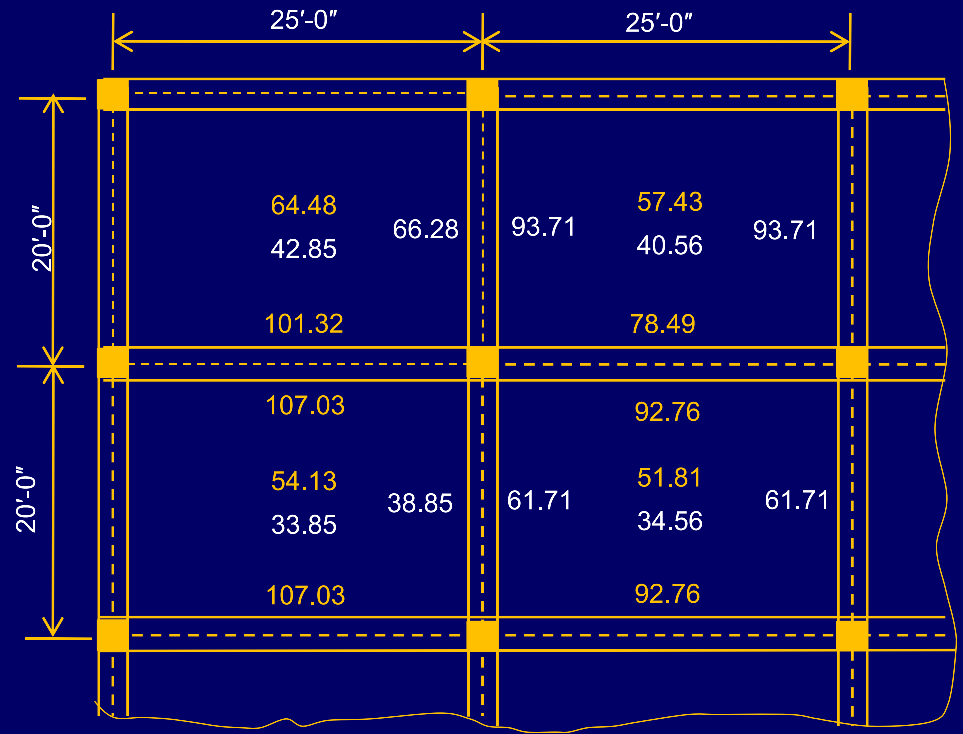
Summary of Analysis				
Location	Moment Values (in. kip/ft)			
	Panel – I	Panel - II	Panel - III	Panel - IV
$M_{a,neg}$	101.32	107.03	78.49	92.76
$M_{b,neg}$	66.28	38.85	93.71	61.71
$M_{a,pos}$	64.48	54.13	57.43	51.81
$M_{b,pos}$	42.85	33.85	40.56	34.56

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

➢ Step 3: Analysis



NOTE:

- All values are in in.kip/ft
- White values: Long Direction Moments
- Yellow values: Short Direction Moments

Design of Three-story Commercial Building

Solution

Slab Design

Step 4: Determination of Steel Area

- As there are several bending moments, making it exceedingly time-consuming and lengthy to calculate the steel area for each one.
- As a result, we shall use the "Unity Rule" in this situation.
- Calculate the area of steel for a unit moment and multiply it by the actual moments to obtain the necessary area of steel as described on the next slide.

Design of Three-story Commercial Building

Solution

Slab Design

Step 4: Determination of Steel Area

- For $M_u = 1\ in.kip$

$$a = d - \sqrt{d^2 - \frac{2.614M_u}{f_c{}'b}} = 6 - \sqrt{6^2 - \frac{2.614 \times (1)}{3 \times 12}} = 6.05 \times 10^{-3} in.$$

Now,

$$A_s = \frac{M_u}{0.9f_y\left(d - \frac{a}{2}\right)} = \frac{1}{0.9 \times 40\left(6 - \frac{6.05 \times 10^{-3}}{2}\right)} = 0.005\ in^2/ft$$

Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

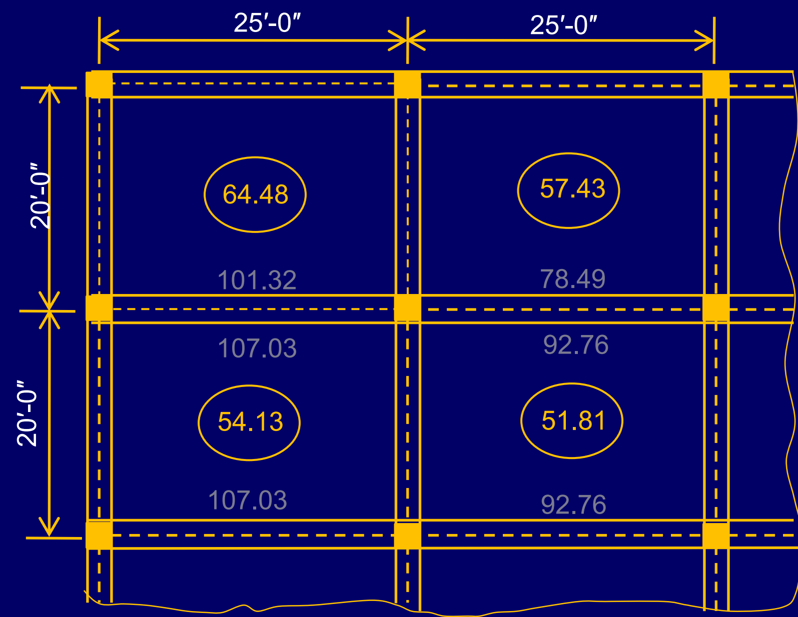
➢ Step 4: Determination of Steel Area

- For Positive Moments in Short Directions

$A_{s,min} = 0.0018(12)(7) = 0.151 in^2/ft$

$S_{max} = 2h \text{ or } 18" = 14''c/c$

M_u $(in.kip/ft)$	$A_s = 0.005M_u$ (in^2/ft)	S_{req} using #4	$Final\ S$
64.48	0.32> $A_{s,min}$	7.5″	7″
54.13	0.27> $A_{s,min}$	8.9″	7″
57.43	0.29> $A_{s,min}$	8.3″	7″
51.81	0.26> $A_{s,min}$	9.2″	7″



Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

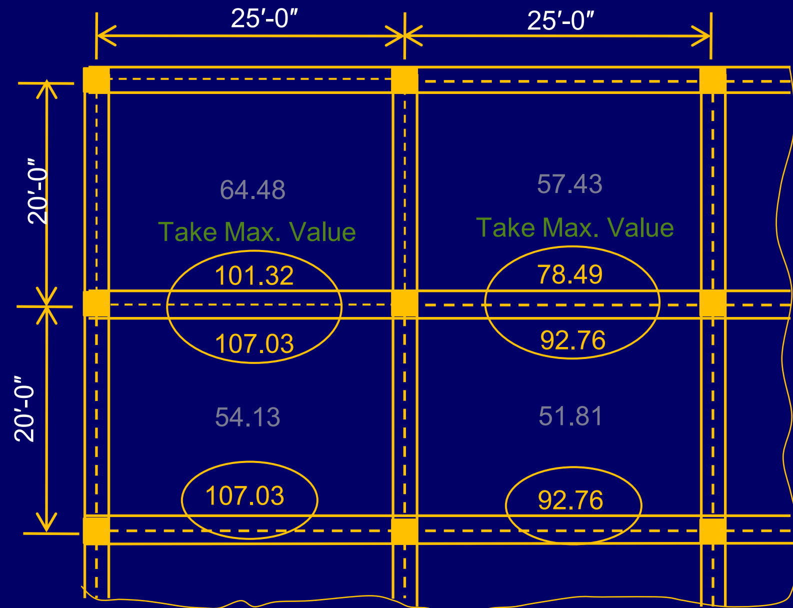
➢ Step 4: Determination of Steel Area

- For Negative Moments in Short Directions

$$A_{s,min} = 0.0018(12)(7) = 0.151 in^2/ft$$

$$S_{max} = 2h \text{ or } 18" = 14'' c/c$$

M_u $(in.kip/ft)$	$A_s = 0.005M_u$ (in^2/ft)	S_{req} using #4	$Final\ S$
107.03	0.54> $A_{s,min}$	4.4″	4″
92.76	0.46> $A_{s,min}$	5.2″	4″



Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

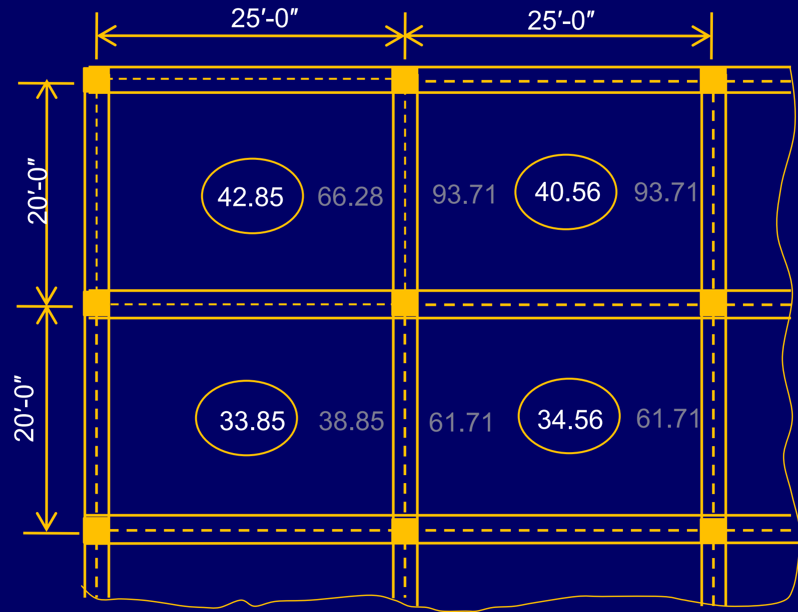
➢ Step 4: Determination of Steel Area

- For Positive Moments in Long Directions

$$A_{s,min} = 0.0018(12)(7) = 0.151 in^2/ft$$

$$S_{max} = 2h \text{ or } 18" = 14''c/c$$

M_u $(in.kip/ft)$	$A_s = 0.005M_u$ (in^2/ft)	S_{req} using #4	$Final\ S$
42.85	0.21> $A_{s,min}$	11.4″	10″
40.56	0.202> $A_{s,min}$	11.88″	10″
33.85	0.17> $A_{s,min}$	14.1″	10″



Design of Three-story Commercial Building

❑ Solution

❖ Slab Design

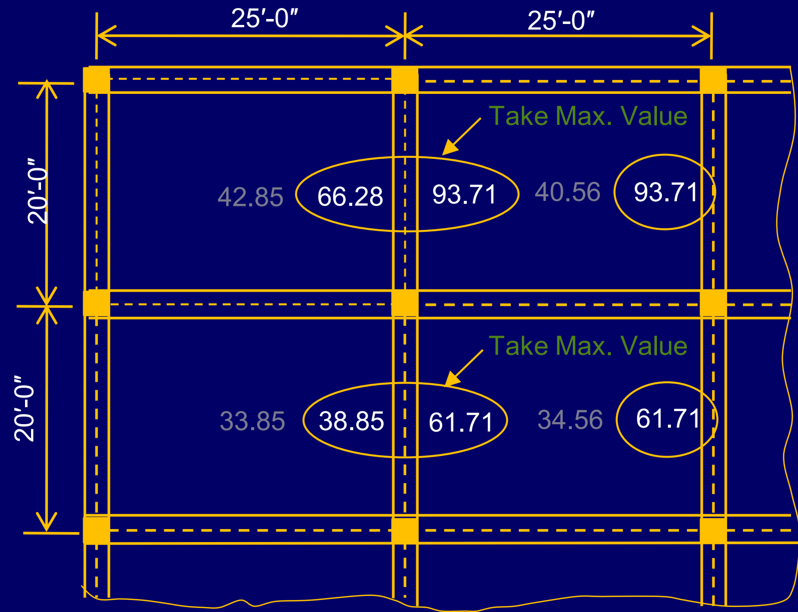
➢ Step 4: Determination of Steel Area

- For Negative Moments in Long Directions

$$A_{s,min} = 0.0018(12)(7) = 0.151in^2/ft$$

$$S_{max} = 2h \; or \; 18" = 14''c/c$$

M_u $(in.kip/ft)$	$A_s = 0.005M_u$ (in^2/ft)	S_{req} using #4	$Final\ S$
93.73	0.47> $A_{s,min}$	5.1″	4″
61.71	0.31> $A_{s,min}$	8.1″	7″



Design of Three-story Commercial Building

Solution

Slab Design

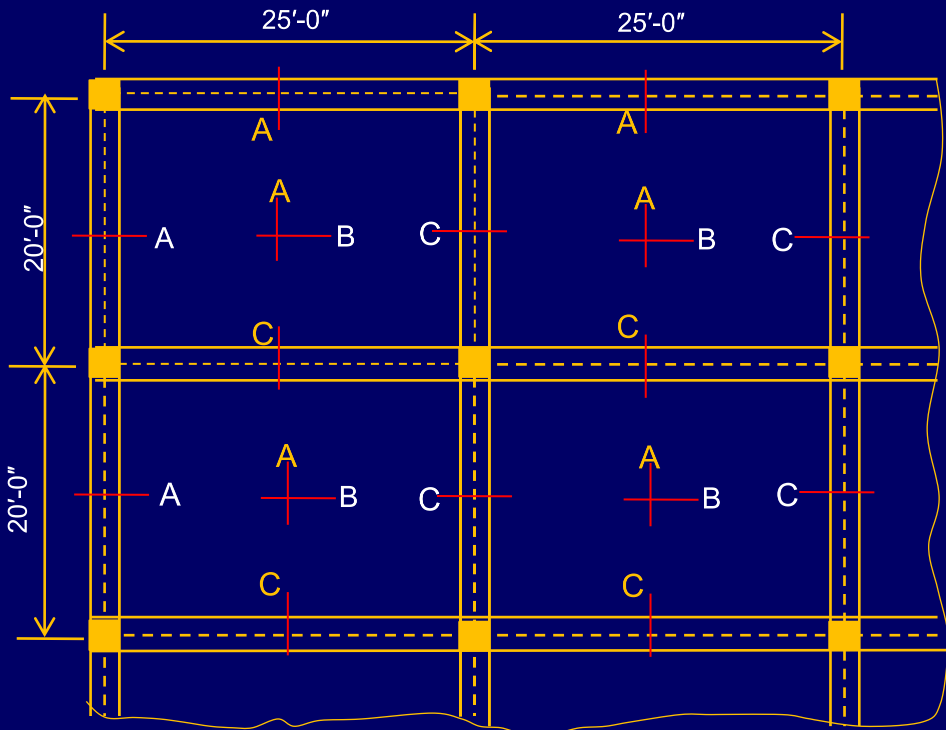
Step 5: Reinforcement Detailing

Finally, three set of spacings have been provided as shown.

$$A = \#4 @ 10'' c/c$$

$$B = \#4 @ 7'' c/c$$

$$C = \#4 @ 4'' c/c$$



Note:

- Reinforcement at discontinuous ends have been provided equal to 1/3 of the Positive reinforcement as per ACI Code.
- Yellow values: Short Direction
  White values : Long direction

Design of Three-story Commercial Building

Solution

Beam Design

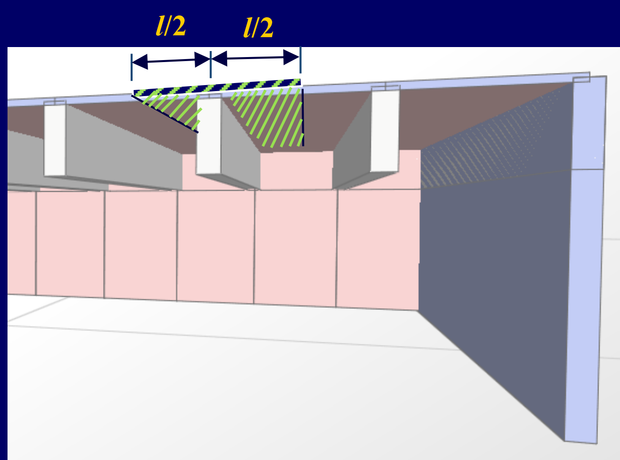
- In the following session, only the mechanism of load transfer from slabs to beams will be discussed; the analysis and design portions can be completed as usual.

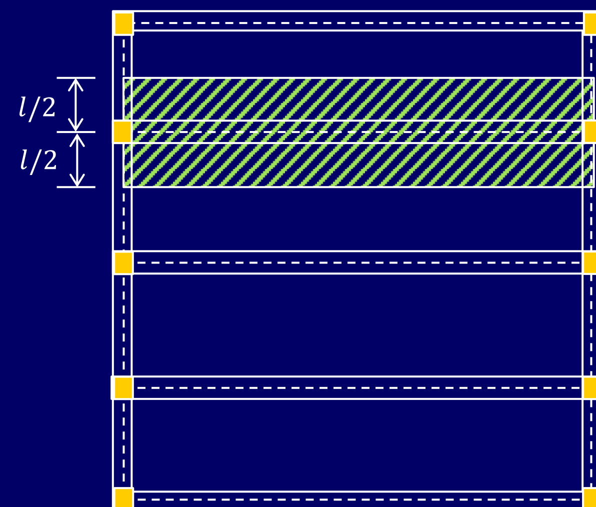
Design of Three-story Commercial Building

❑ Solution

❖ Beam Design

- **Load Transfer Mechanism**





- In case of one-way slab system the entire slab load is transferred in short direction.
- Load transfer in short direction = ($w_u \times \ell/2 \times 1$) + ($w_u \times \ell/2 \times 1$)
- Load transfer in long direction = $w_u \times \ell/2 \times 0$

Design of Three-story Commercial Building

❑ Solution

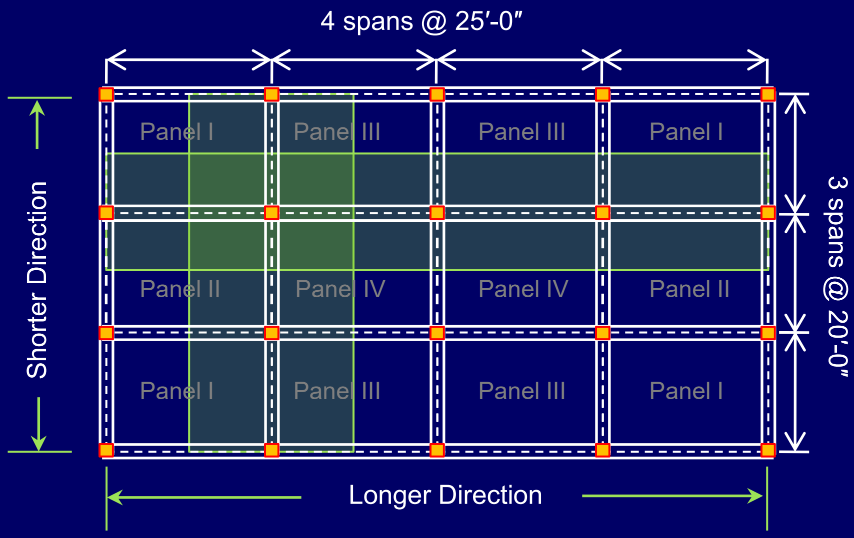
❖ Beam Design

- **Load Transfer Mechanism**
  - In case of two way slab system, entire slab load is NOT transferred in shorter direction.
    - Load in Shorter Direction

      $$= \frac{w_u l}{2} W_a + \frac{w_u l}{2} W_a$$

    - Load in Shorter Direction

      $$= \frac{w_u l}{2} W_b + \frac{w_u l}{2} W_b$$



NOTE:

$W_b = 1 - W_a$; *where* W_a *is NOT equal to 1. It is specified by ACI Table*

Design of Three-story Commercial Building

❑ Solution

❖ Beam Design

- **Load Transfer Mechanism**
  - The load transfer to B1 from Panels I and II in the short direction can be calculated as follows;

$$W_{a,Panel-I} = 0.71, \qquad W_{a,Panel-II} = 0.83 \quad and \quad w_u = 0.336$$

Now,

$$\frac{w_u l}{2} W_{a,Panel-I} + \frac{w_u l}{2} W_{a,Panel-II} = \frac{0.336 \times 20}{2} \times 0.71 + \frac{0.336 \times 20}{2} \times 0.83$$

$$Load\ on\ B_1 = 5.17k/ft$$

Design of Three-story Commercial Building

❑ Solution

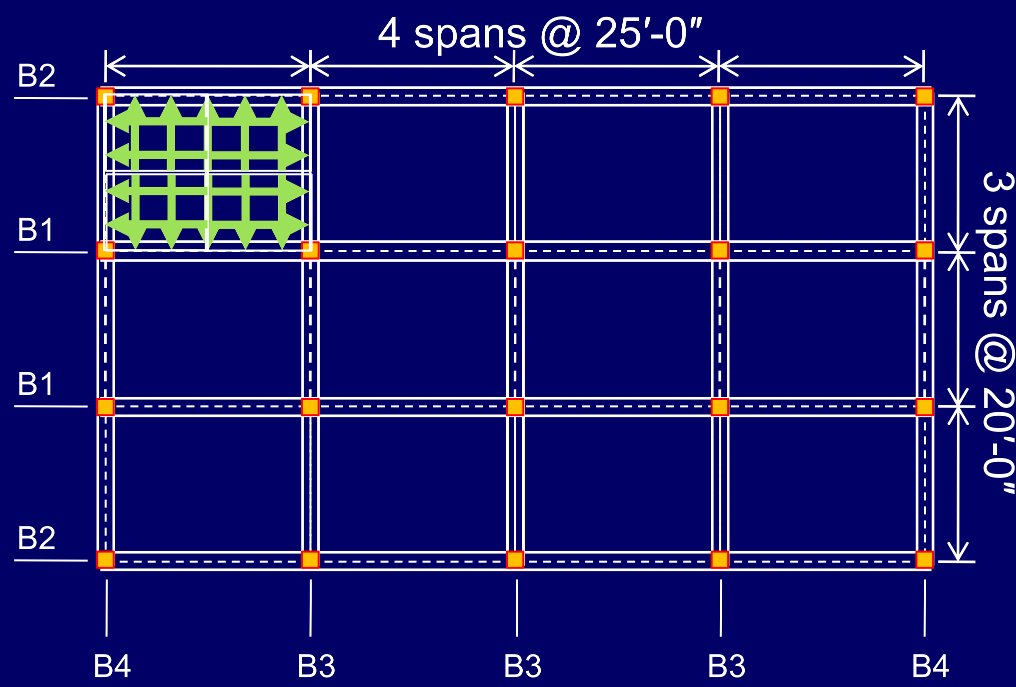
❖ Beam Design

- **Load On Beams from coefficient tables**

Panel I

Table: Load on beam in Panel I, using Coefficients (w_u = 0.336 ksf)

Beam	Length (ft)	Width (b_s) of slab panel supported by beam	W_a	W_b	Load due to slab, Ww_ub_s (k/ft)
B1	25	10	0.71	-	2.39
B2	25	10	0.71	-	2.39
B3	20	12.5	-	0.29	1.22
B4	20	12.5	-	0.29	1.22



Design of Three-story Commercial Building

❑ Solution

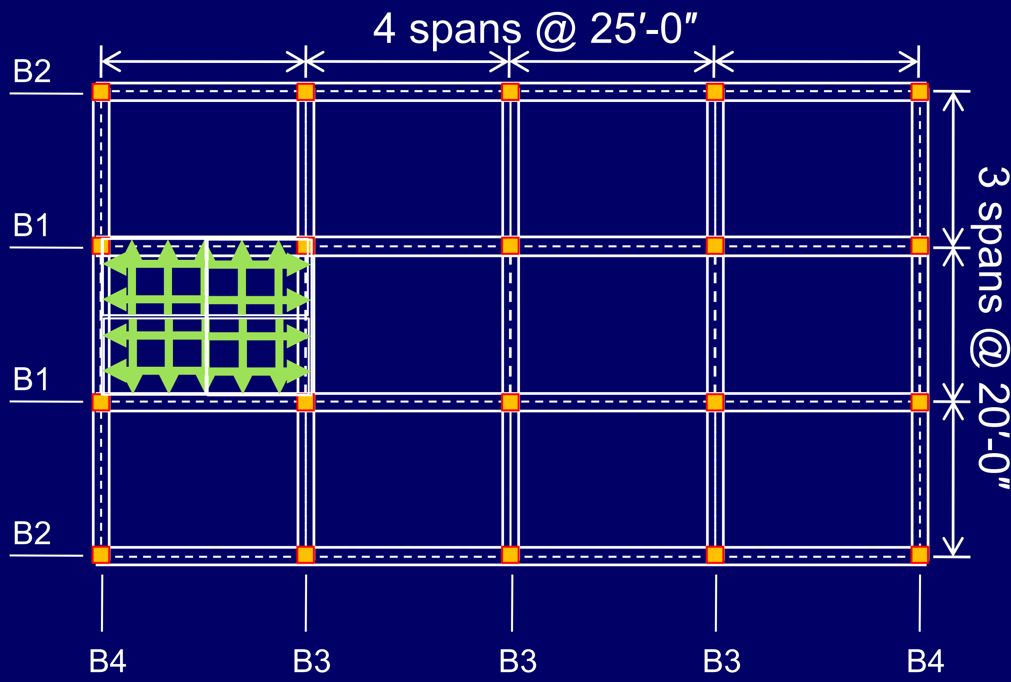
❖ Beam Design

- **Load On Beams from Coefficient Tables**

Panel II

Table: Load on beam in Panel I, using Coefficients (w_u = 0.336 ksf)

Beam	Length (ft)	Width (b_s) of slab panel supported by beam	W_a	W_b	Load due to slab, Ww_ub_s (k/ft)
B1	25	10	0.83	-	2.78
B3	20	12.5	-	0.17	0.714
B4	20	12.5	-	0.17	0.714



Design of Three-story Commercial Building

❑ Solution

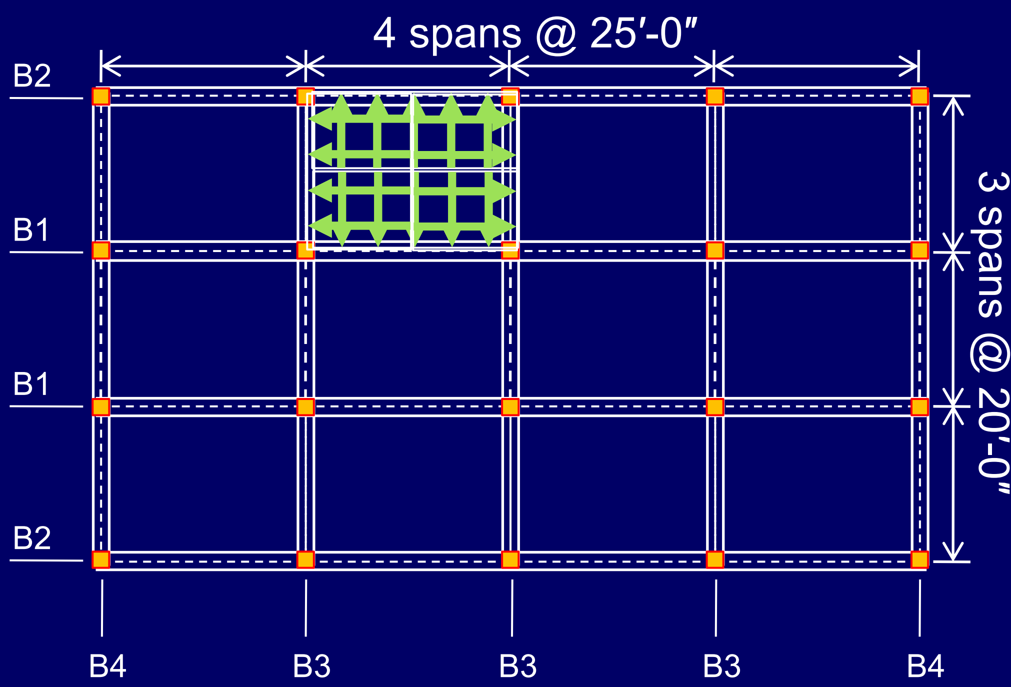
❖ Beam Design

- **Load On Beams from Coefficient Tables**

Panel III

Table: Load on beam in Panel I, using Coefficients (w_u = 0.336 ksf)

Beam	Length (ft)	Width (b_s) of slab panel supported by beam	W_a	W_b	Load due to slab, Ww_ub_s (k/ft)
B1	25	10	0.55	-	1.84
B2	25	10	0.55	-	1.84
B3	20	12.5	-	0.45	1.89



Design of Three-story Commercial Building

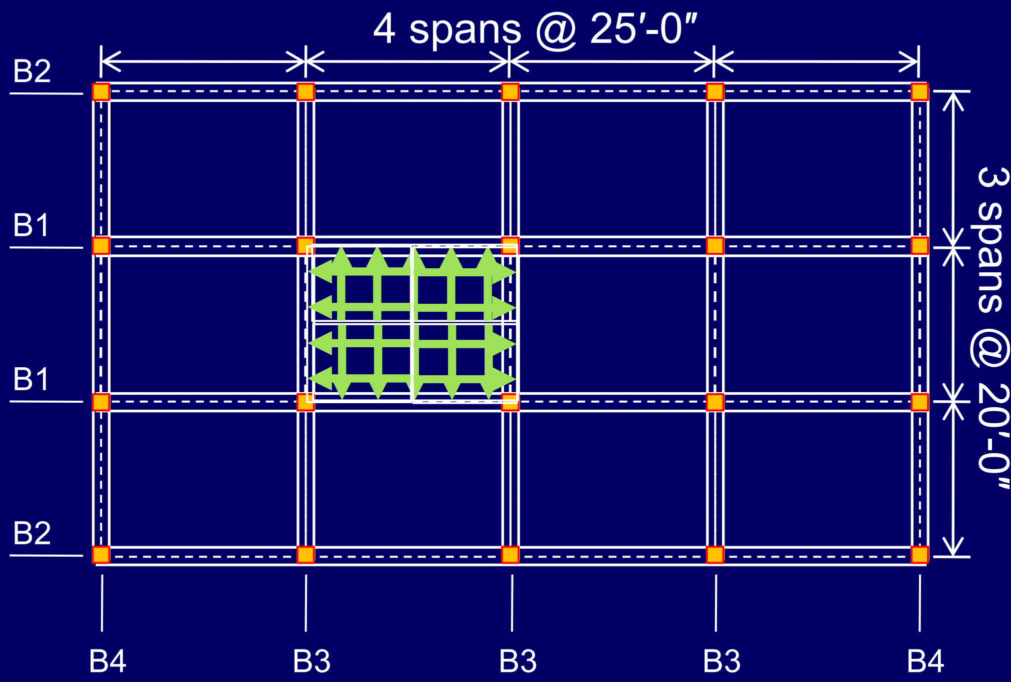
❑ Solution

❖ Beam Design

- **Load On Beams from Coefficient Tables**

Panel IV

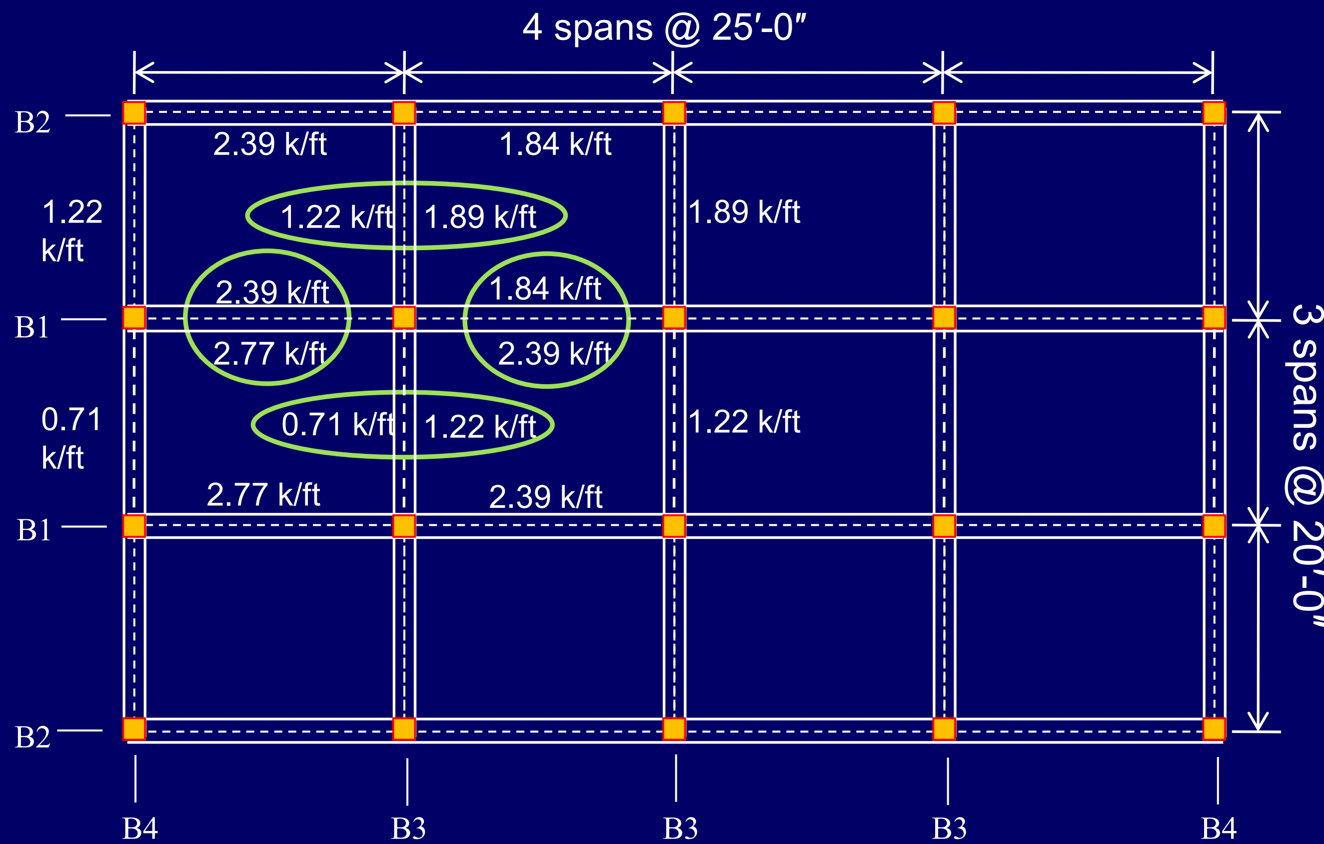
Table: Load on beam in Panel I, using Coefficients (w_u = 0.336 ksf)					
Beam	Length (ft)	Width (b_s) of slab panel supported by beam	W_a	W_b	Load due to slab, Ww_ub_s (k/ft)
B1	25	10	0.55	-	1.84
B2	25	10	0.55	-	1.84
B3	20	12.5	-	0.45	1.89



Design of Three-story Commercial Building

❑ Solution

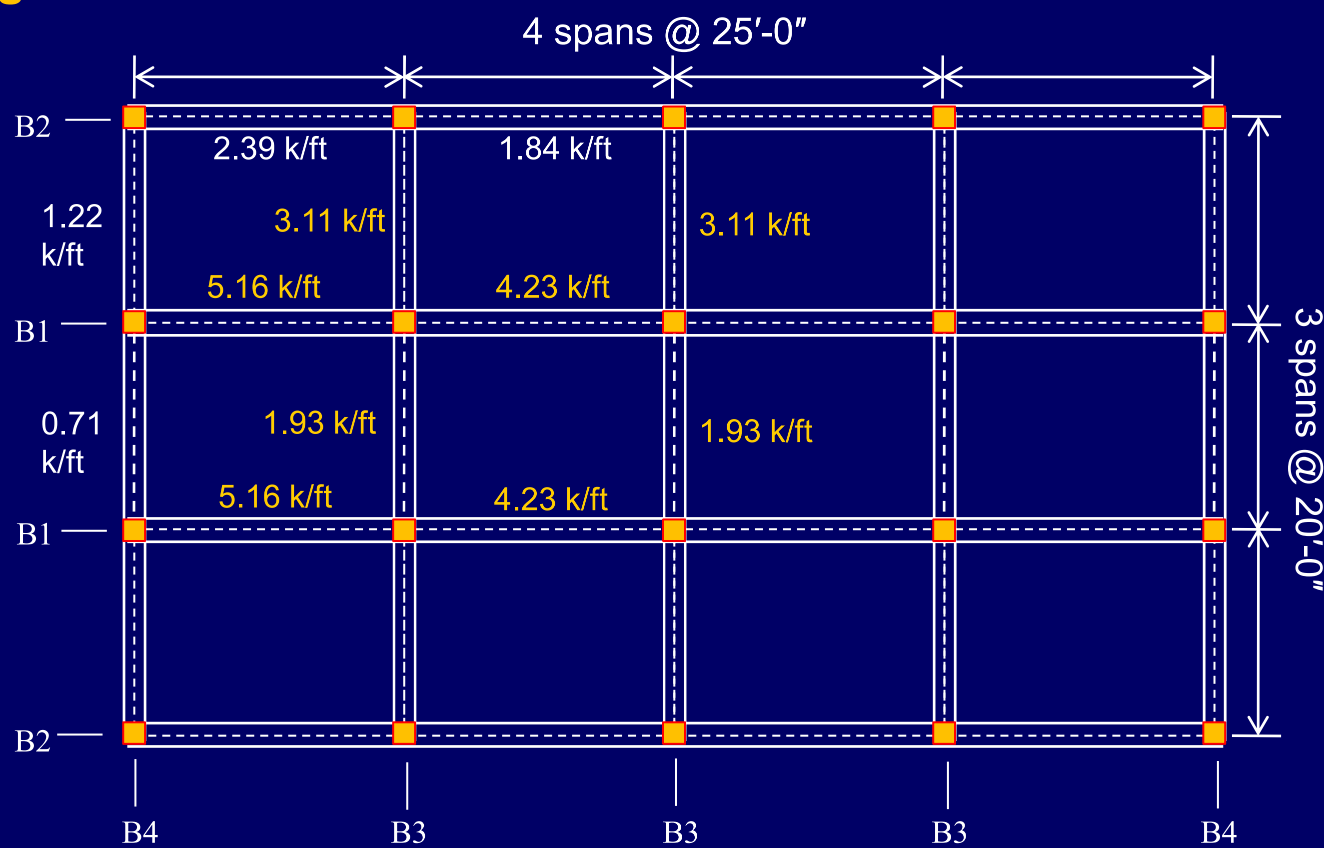
❖ Beam Design



Design of Three-story Commercial Building

❑ Solution

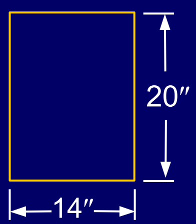
❖ Beam Design



Design of Three-story Commercial Building

❑ Solution

❖ Beam Design

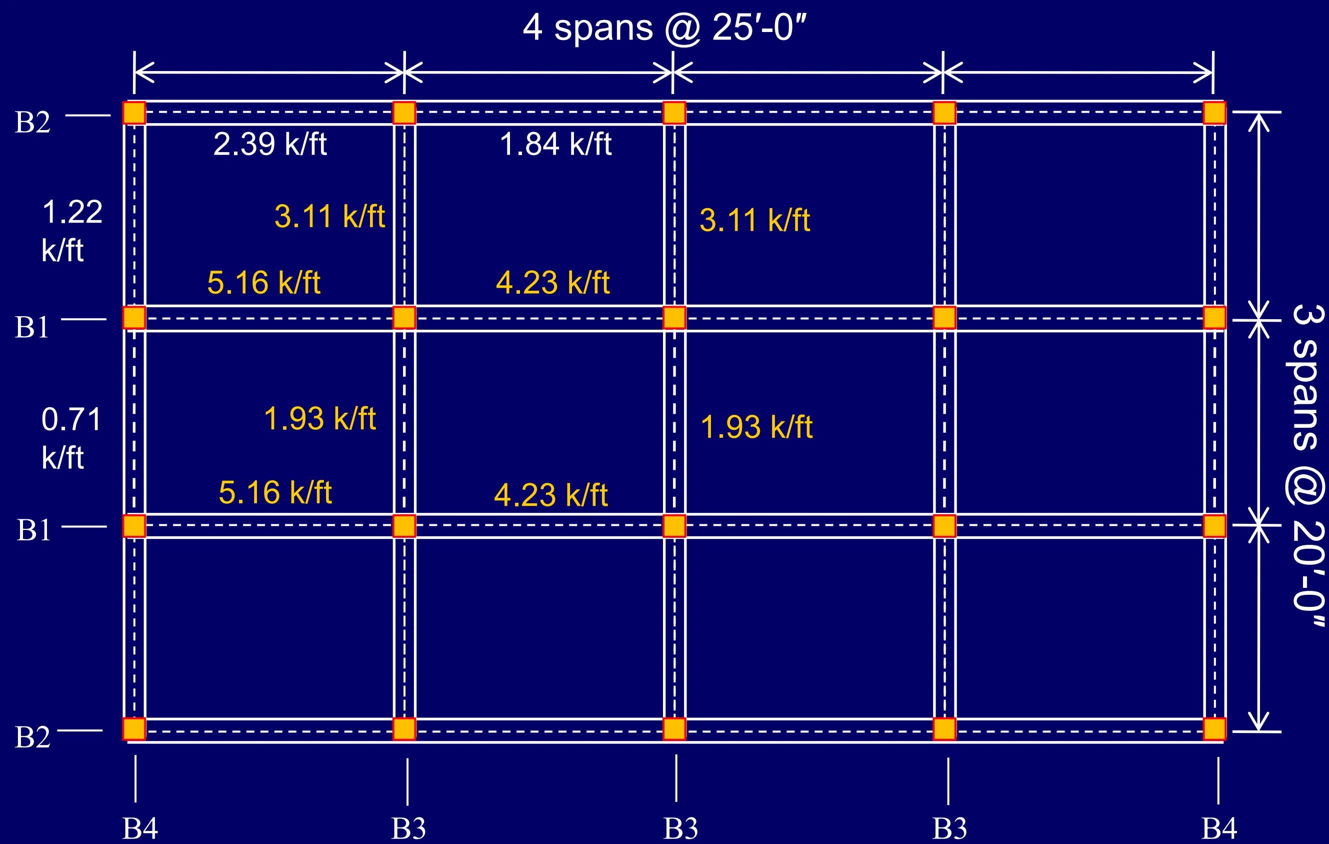


Self weight of beam

$= 1.2 \times \frac{14 \times 13}{144} \times 0.15$

$= 0.23\ kip/ft$

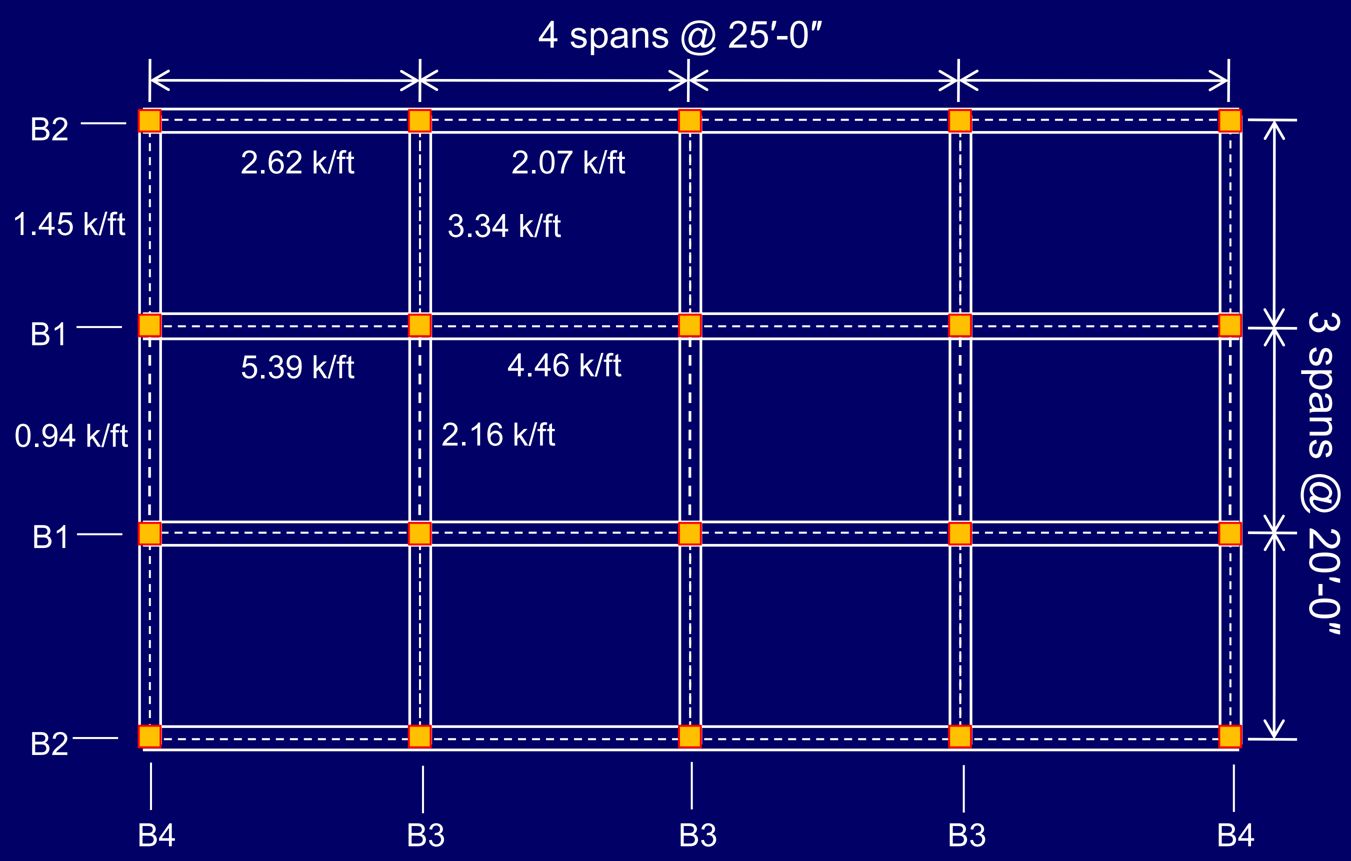
Adding this with the calculated loads on beams:



Design of Three-story Commercial Building

❑ Solution

❖ Beam Design (after including self-weight)



Design of Three-story Commercial Building

❑ Pictures of a Multi-story Commercial Building

Homework

Example 4.3

- Design the given slab system using the data provided.

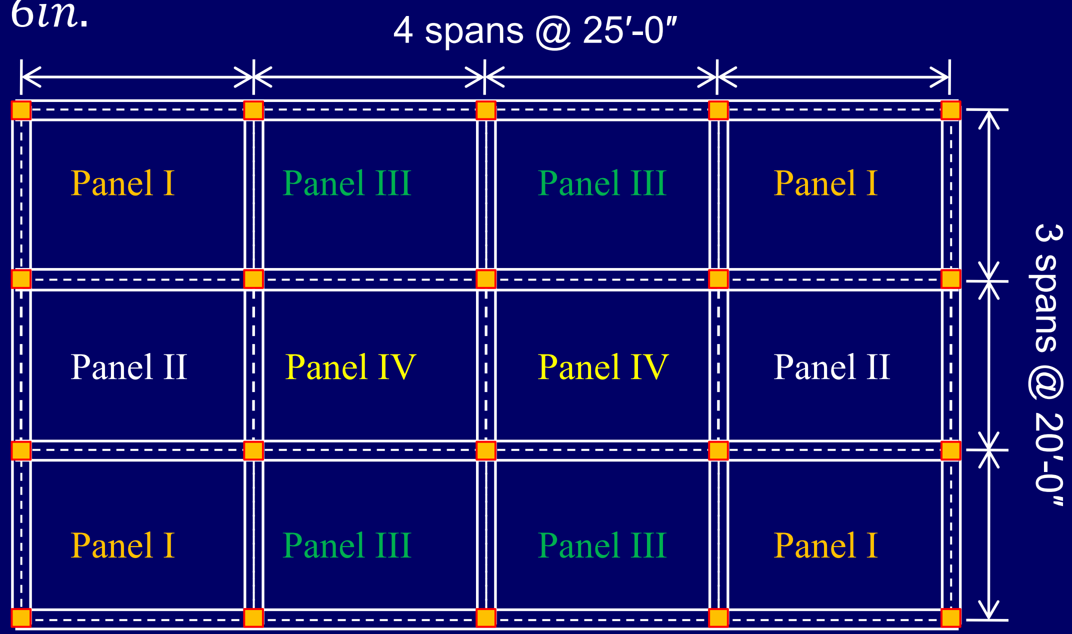
$Slab\ thickness, h_f = 6in.$

$SDL = 60\ psf$

$LL = 40\ psf$

$f_c' = 3\ ksi$

$f_y = 60\ ksi$



- All beams are 18″ x 24″
- All columns are 18″ x 18″

References

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