DESIGN OF ONE WAY SLAB

A reinforced concrete slab is built integrally with its supports and consists of three equal spans, each with a clear span of 15 ft. The service live load is 100 psf, and 4000 psi concrete is specified for use with steel with a yield stress equal to 60,000 psi. Design the slab, following the provisions of the ACI Code.

What is Effective Span of Slabs?

Effective span of slab shall be lesser of the two

1. l_{eff} = clear span + d (effective depth)

2. l_{eff} = Center to center distance between the support

What is Effective Depth of Slabs?

It is a distance measured from extreme compression face of concrete cross section to the center of tensile steel bars when the slab subjected to bending.

SOLUTION

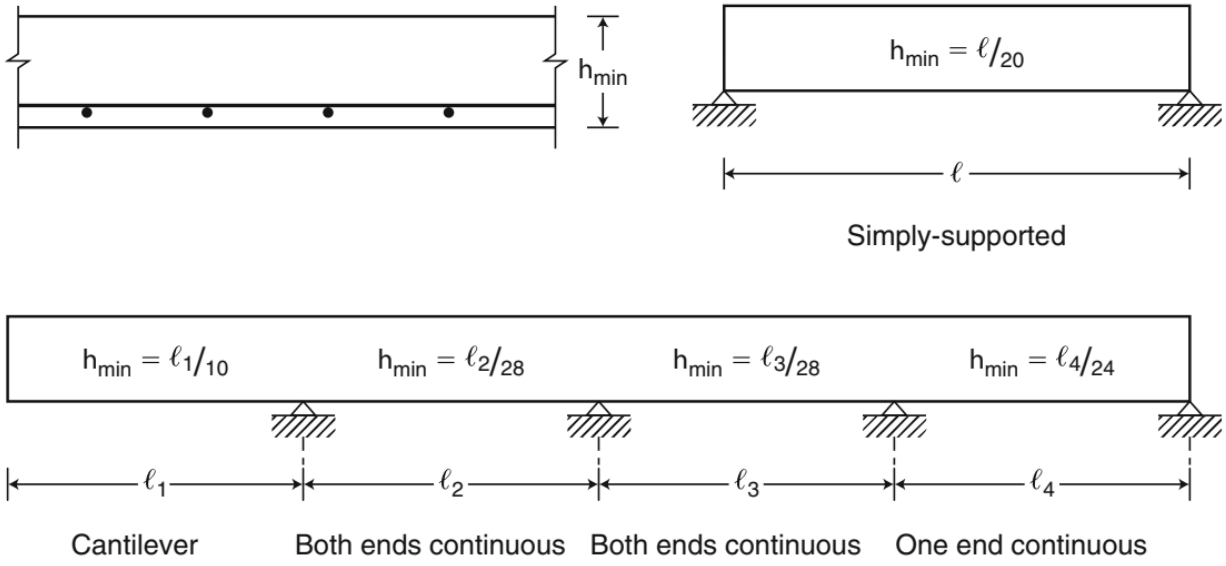
1. Assume minimum thickness (h) of the slab as per ACI Code.

$$h_{min} = \frac{l}{28} = \frac{15x12}{28} = 6.43 \text{ inch} = 6.5 \text{ inch}$$

Overall slab thickness (h_{min}) shall not be less than the limits in Table-12.1, unless the calculated deflection limits of 7.3.2 are satisfied as per ACI Code.

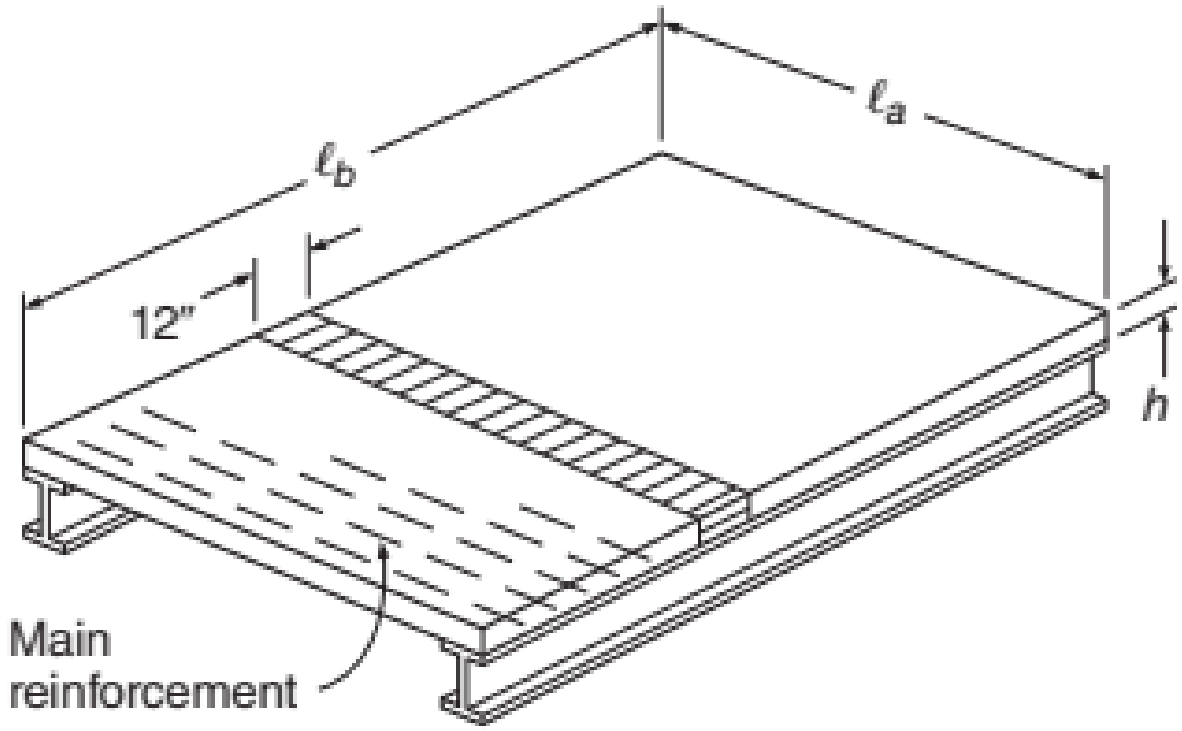
TABLE 12.1
Minimum thickness *h* of nonprestressed one-way slabs

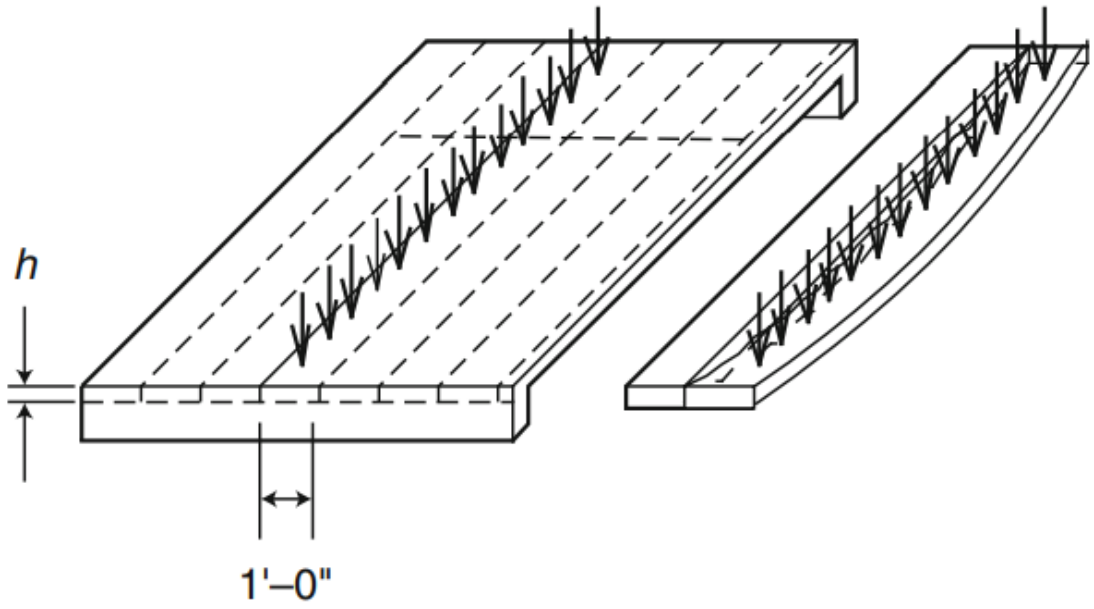
Simply supported	$\ell/20$
One end continuous	$\ell/24$
Both ends continuous	$\ell/28$
Cantilever	$\ell/10$



Because of the quantities of concrete involved in floor slabs, their depths are rounded off to closer values than are used for beam depths. Slab thicknesses are usually rounded off to the nearest 1/4 inch on the high side for slabs of 6 inch or less in thickness and to the nearest 1/2 inch on the high side for slabs thicker than 6 inch.

2. Determine the Factored Loads on the Slab on a 1ft Wide Strip





DL = $\frac{6.5}{12}$ x 150 = 81 psf

LL = 100 psf

Factored load = 1.2 x 81 + 1.6 x100 = 257 psf = 0.257 ksf.

3. Determine Factored Moments at Critical Section using ACI Moment Coefficient Table

a. At Exterior Support, Negative Moment

b. At Mid Span, Positive Moment

c. At Interior Support, Negative Moment

At Exterior Support, Negative Moment, - M = $\frac{1}{16}\ x\ 0.257\ x\ 15^2$ = 3.61 k-ft.

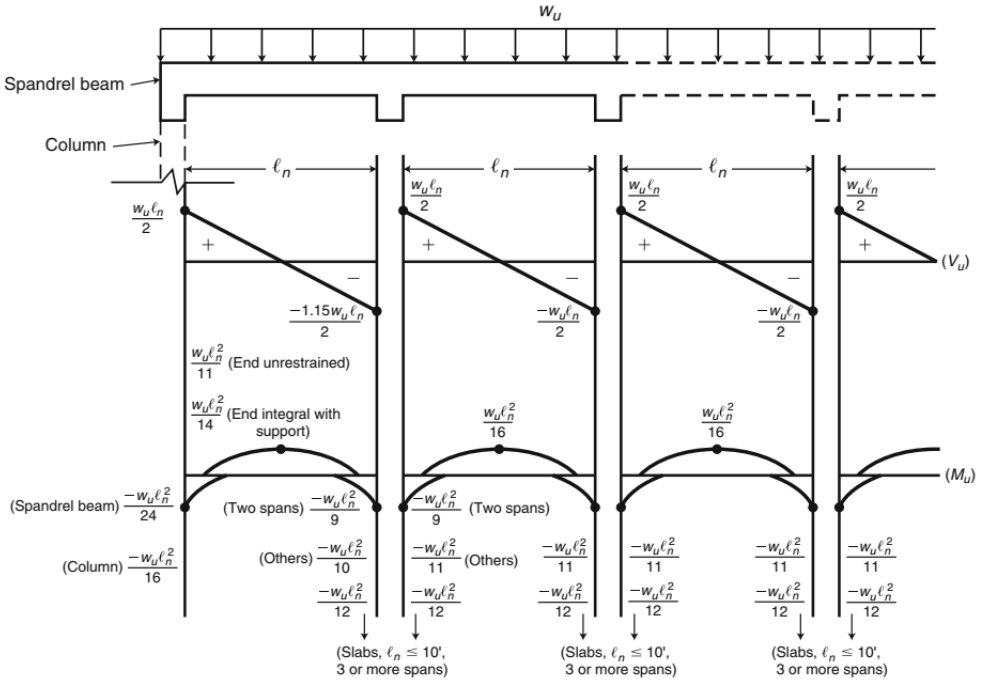
At Mid Span, Positive Moment, M = $\frac{1}{14}\ x\ 0.257\ x\ 15^2$ = 4.13 k-ft.

At Interior support, Negative moment, - M = $\frac{1}{10}\ x\ 0.257\ x\ 15^2$ = 5.78 k-ft.

Location and Conditions of Beams/Slabs to be considered while consulting this Table

Table A2.1 ACI approximate design moments and shears for beams and one-way slabs

Positive moment	End spans	
	Discontinuous end unrestrained	$w_u\ell_n^2/11$
	Discontinuous end integral with support	$w_u\ell_n^2/14$
	Interior spans	$w_u\ell_n^2/16$
Negative moment	At exterior face of the first interior support	
	Two spans	$w_u\ell_n^2/9$
	More than two spans	$w_u\ell_n^2/10$
	At other faces of interior supports	$w_u\ell_n^2/11$
	At the face of all supports for SLABS with spans not exceeding 10 ft; and BEAMS where ratio of sum of column stiffnesses to beam stiffness exceeds 8 at each end of the span	$w_u\ell_n^2/12$
	At interior face of exterior support for members built integrally with supports	
	Where support is a spandrel beam	$w_u\ell_n^2/24$
	Where support is a column	$w_u\ell_n^2/16$
Shear	In end members at the face of the first interior support	$1.15\,w_u\ell_n/2$
	At face of all other supports	$w_u\ell_n/2$



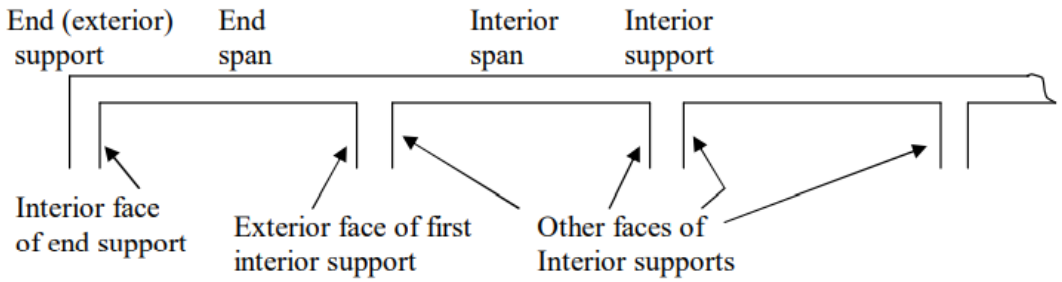
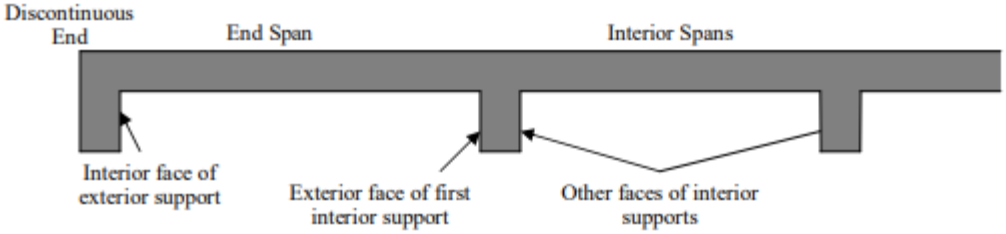


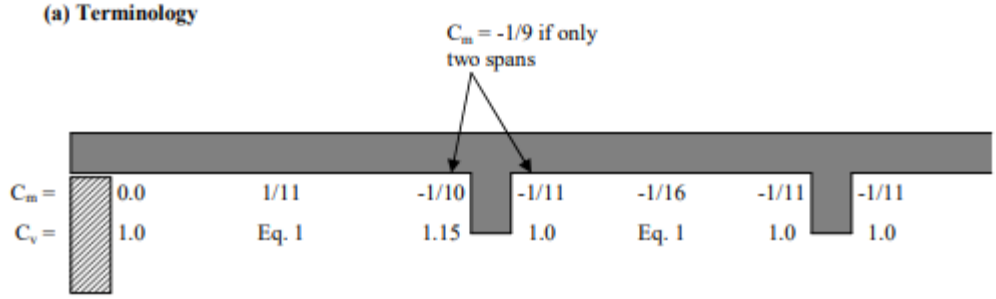
Figure above represents Location and Conditions for Approximate Moment and Shears in Continuous Beams and One Way Slabs

ACI Moment and Shear Coefficients

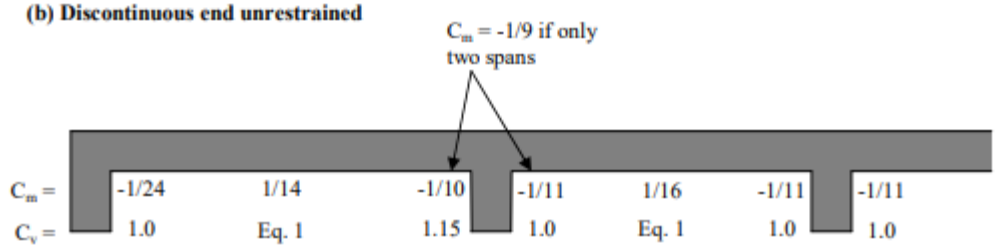
$M_u = C_m(w_u l_n^2)$; C_m : moment envelope coefficient
$V_u = C_v(w_u l_n/2)$; C_v : shear envelope coefficient
Where w_u is total factored load and l_n is clear span



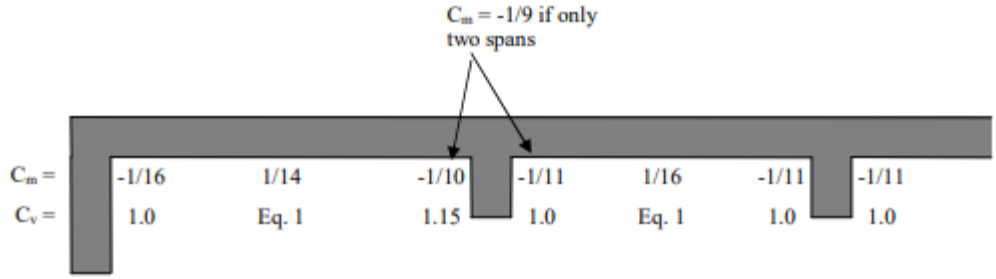
(a) Terminology



(b) Discontinuous end unrestrained



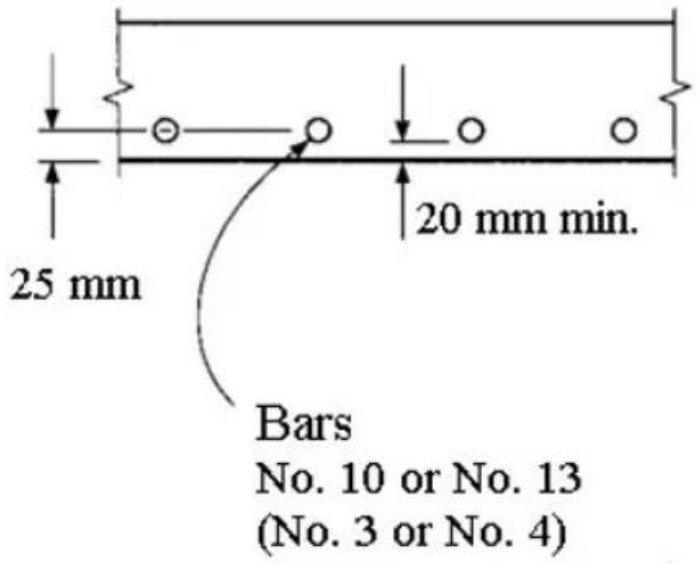
(c) Discontinuous end integral with support where support is spandrel beam

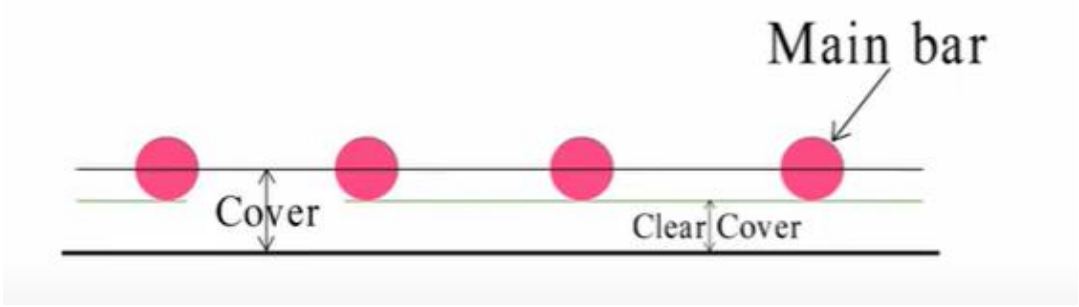


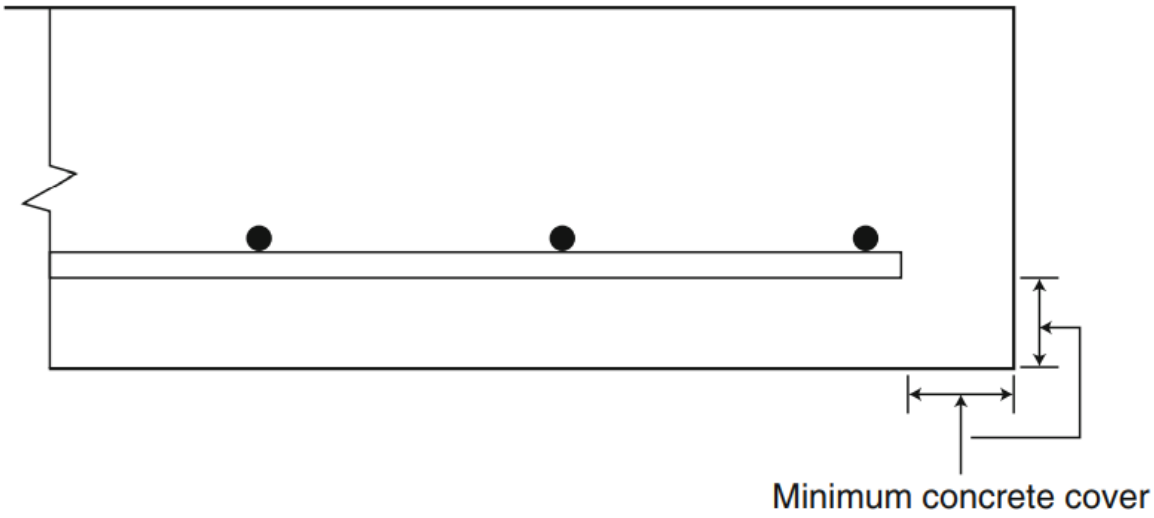
(d) Discontinuous end integral with support where support is a column

4. **Concrete Cover**

The concrete protection below the reinforcement should follow the requirements of ACI Code 20.5.1.3, calling for 20 mm below the bottom of the steel. In a typical slab, 25 mm below the center of the steel may be assumed.



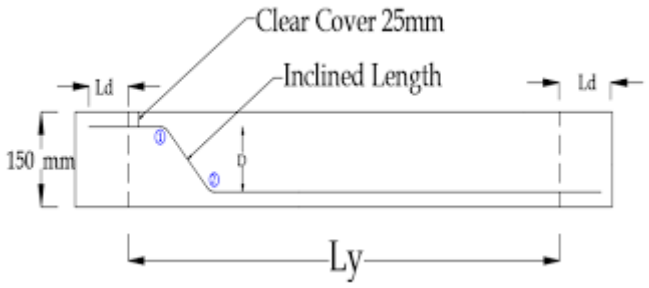




Minimum Concrete Cover for the Reinforcement in Slabs

A minimum concrete cover is needed for the reinforcement to prevent various detrimental effects of the environment on reinforcing bars. Concrete cover is always measured from the closest concrete surface to the first layer of reinforcing. This is shown in Figure 2.56. Section 20.6.1.3 of the **ACI Code requires a minimum concrete cover of ¾ in. for #11 and smaller bars, and 1.5 in. for #14 and #18 bars,**

provided that the concrete slab is not exposed to weather or not in contact with the ground.



One-way Slab Thickness=4"
Two-way Slab Thickness=3.5"
} Minimum Slab Thickness According to BNBC.

5. Determination of Reinforcement Ratio (ρ)

The maximum practical reinforcement ratio is

$$\rho_{0.005} = 0.85\beta_1 \frac{f_c'}{f_y} \frac{\epsilon_u}{\epsilon_u + 0.005}$$

$$= o.85\ x\ 0.85\ x\ \frac{4}{60}\ x\ \frac{0.003}{0.003 + 0.005}$$

$$= 0.0181$$

One-way slabs are normally designed with tensile reinforcement ratios well **below the maximum practical value of $\rho_{0.005}$. Typical reinforcement ratios range from about 0.004 to 0.008.** This is partially for reasons of economy, because the saving in reinforcement associated with increasing the effective depth more than compensates for the cost of the additional concrete, and partially because very thin slabs with high reinforcement ratios would be likely to permit large deflections.

Thus, flexural design may start with selecting a relatively low reinforcement ratio, say about 0.3 $\rho_{0.005}$. Alternatively, Table A.5 or Graph A.1 of Appendix A may be used. Table A.9 is also useful.

Select Minimum Required Effective Depth controlled by Maximum Negative Moment at the Interior Support by applying following formulae

Reinforcement for Negative Moment at Interior Support

If this value of ρ were actually used, the minimum required effective depth, controlled by negative moment at the interior support, would be found by

$$d^2 = \frac{M_u}{\emptyset \rho f_y b\ (1 - 0.59 \rho f_y / f_c^{/}}$$

$$= \frac{5.78\ x\ 12}{0.90\ x\ 0.0181\ x\ 60\ x\ 12\ [1 - 0.59\ x\ 0.0181\ x\ (60/4)]}$$

$$= 7.04\ in^2$$

d = 2.65 inch.

This is less than the effective depth of (6.50 – 1) inch = 5.50 inch.

At the interior support, considering the stress block depth a = 1inch, the area of steel required per foot width in the top of the slab

$$A_s = \frac{M_u}{\emptyset f_y\ (d - \frac{a}{2})}$$

$$= \frac{5.78\ x12}{0.90\ x\ 60\ (5.50 - \frac{1.00}{2})} = 0.26\ in^2/ft$$

Checking the assumed depth a, we get

$$a = \frac{A_s\ f_y}{0.85\ f_c^{/} b} = \frac{0.26\ x\ 60}{0.85\ x\ 4\ x12} = 0.38\ inch$$

If it is o.k. only then proceed. Otherwise increase the thickness of slab (h_{min}).

A second trial

$$A_s = \frac{M_u}{\emptyset f_y\ (d - \frac{a}{2})}$$

$$\frac{5.78\ x12}{0.90\ x\ 60\ (5.50 - \frac{0.38}{2})} = 0.24\ in^2/ft$$

For which a = 0.38 x 0.26/0.24 = 0.41 inch.

Reinforcement for Positive Moment at Mid Span

If this value of ρ were actually used, the minimum required effective depth, controlled by positive moment at the mid span

$$d^2 = \frac{M_u}{\emptyset \rho f_y b\,(1 - 0.59\rho f_y / f_c^{/}}$$

$$= \frac{4.13\ x\ 12}{0.90\ x\ 0.0181\ x\ 60\ x\ 12\ [1 - 0.59\ x\ 0.0181\ x\ (60/4)]}$$

$$= 5.03\ in^2$$

d = 2.24 inch.

This is less than the effective depth of (6.50 – 1) inch = 5.50 inch.

At the mid span, considering the stress block depth a = 1inch, the area of steel required per foot width in the bottom of the slab

$$A_s = \frac{M_u}{\emptyset f_y\ (d - \frac{a}{2})}$$

$$= \frac{4.13\ x12}{0.90\ x\ 60\ (5.50 - \frac{1.00}{2})} = 0.18\ in^2/ft$$

Checking the assumed depth a, we get

$$a = \frac{A_s\ f_y}{0.85\ f_c^{/} b} = \frac{0.18\ x\ 60}{0.85\ x\ 4\ x12} = 0.26\ inch$$

A second trial

$$A_s = \frac{M_u}{\emptyset f_y \ (d - \frac{a}{2})}$$

$$\frac{4.13\ x12}{0.90\ x\ 60\ (5.50 - \frac{0.26}{2})} = 0.17\ in^2/ft$$

For which a = 0.26 x 0.18/0.17 = 0.28 inch.

Reinforcement for Negative Moment at Exterior Support

If this value of ρ were actually used, the minimum required effective depth, controlled by negative moment at the exterior support, would be found by

$$d^2 = \frac{M_u}{\emptyset \rho f_y b\ (1 - 0.59 \rho f_y / f_c^{/}}$$

$$= \frac{3.61\ x\ 12}{0.90\ x\ 0.0181\ x\ 60\ x\ 12\ [1 - 0.59\ x\ 0.0181\ x\ (60/4)]}$$

$$= 4.39\ in^2$$

d = 2.09 inch.

This is less than the effective depth of (6.50 – 1) inch = 5.50 inch.

At the exterior support, considering the stress block depth a = 1inch, the area of steel required per foot width in the top of the slab

$$A_s = \frac{M_u}{\emptyset f_y \ (d - \frac{a}{2})}$$

$$= \frac{3.61\ x12}{0.90\ x\ 60\ (5.50 - \frac{1.00}{2})} = 0.16\ in^2/ft$$

Checking the assumed depth a, we get

$$a = \frac{A_s\ f_y}{0.85\ f_c^{/} b} = \frac{0.16\ x\ 60}{0.85\ x\ 4\ x12} = 0.24\ inch$$

A second trial

$$A_s = \frac{M_u}{\emptyset f_y \ (d - \frac{a}{2})}$$

$$\frac{5.78\ x12}{0.90\ x\ 60\ (5.50 - \frac{0.24}{2})} = 0.15\ in^2/ft$$

For which a = 0.24 x 0.16/0.15 = 0.26 inch.

6. Calculation of Shrinkage and Temperature Reinforcement

Shrinkage and temperature reinforcements are provided to resist shrinkage and temperature stresses in concrete. Slabs are joined rigidly to other parts of the structure and cannot contract freely, this results in tension stresses known as shrinkage stresses.

A decrease in temperature relative to that at which the slab was cast, particularly in outdoor structures such as bridges, may have an effect similar to shrinkage. This means, the slab tends to contract and if restrained from doing so becomes subjected to tensile stresses.

According to ACI 318-19 section 24.4, the minimum temperature and shrinkage reinforcement can be at least equal to or greater than the steel area computed using the following Table:

TABLE 12.2
Minimum ratios of temperature and shrinkage reinforcement in slabs based on gross concrete area

Slabs where Grade 40 or 50 deformed bars are used	0.0020
Slabs where Grade 60 deformed bars or welded wire fabric (smooth or deformed) is used	0.0018
Slabs where reinforcement with yield strength exceeding 60,000 psi measured at yield strain of 0.35 percent is used	$\frac{0.0018 \times 60{,}000}{f_y}$

This is also the minimum of reinforcement required in shorter and longer direction. The usual minimums for flexural steel do not apply.

$A_s = 0.0018 \times 6.5 \times 12 = 0.14\ in^2/ft$

7. Find out Factored Shear force at a distance d from the face of interior support and nominal shear strength of concrete slab

$$V_u = C\, w_u l_n$$

$$V_n = V_c = 2\lambda \sqrt{f'_c}\, bd$$

λ = modification factor reflecting the reduced mechanical properties of lightweight concrete,

The value of λ varies from 0.75 to 1 depending on the particular blend of light weight and normal weight aggregate used in the concrete. λ equals to 1 for normal weight concrete, 0.85 for sand lightweight concrete, and 0.75 for all lightweight concrete.

Calculate

$$\varphi V_n = 0.75\, V_n$$

$$\varphi V_n > V_u$$

Using ACI Coefficient Table for the factored shear, the factored shear force at a distance d from the face of the interior support is

$$V_u = C\, w_u l_n$$

$$= 1.15\, x\, \frac{257\, x15}{2} - 257x\, \frac{5.50}{12} = 2100\, lb$$

The nominal shear strength of the concrete slab is

$$V_n = V_c = 2\lambda \sqrt{f_c'}\, bd$$

$$= 2\, x1\, \sqrt{4000}\, x\, 12\, x\, 5.50 = 8350\, lb$$

Thus the design strength of the concrete slab

$$\emptyset\, V_c = 0.75\, x\, 8350 = 6260\, lb$$

is well above the required strength in shear of $V_u = 2100\, lb$

8. **Detailing of Reinforcement**. **Maximum and Minimum Spacing between Steel bars**

1. The lateral maximum spacing of the bars, except those used only to control shrinkage and temperature cracks, should not exceed 3 times the thickness (h) or 450 mm, whichever is smaller.
2. The maximum spacing between shrinkage and temperature reinforcement bars is five times the slab thickness or 450 mm, whichever is smaller.
3. The minimum distance is 25 mm, the diameter of steel bar, or (4/3* maximum aggregate size).

a. **Main Reinforcement Spacing**

3h or 18 inch (Minimum of these two)

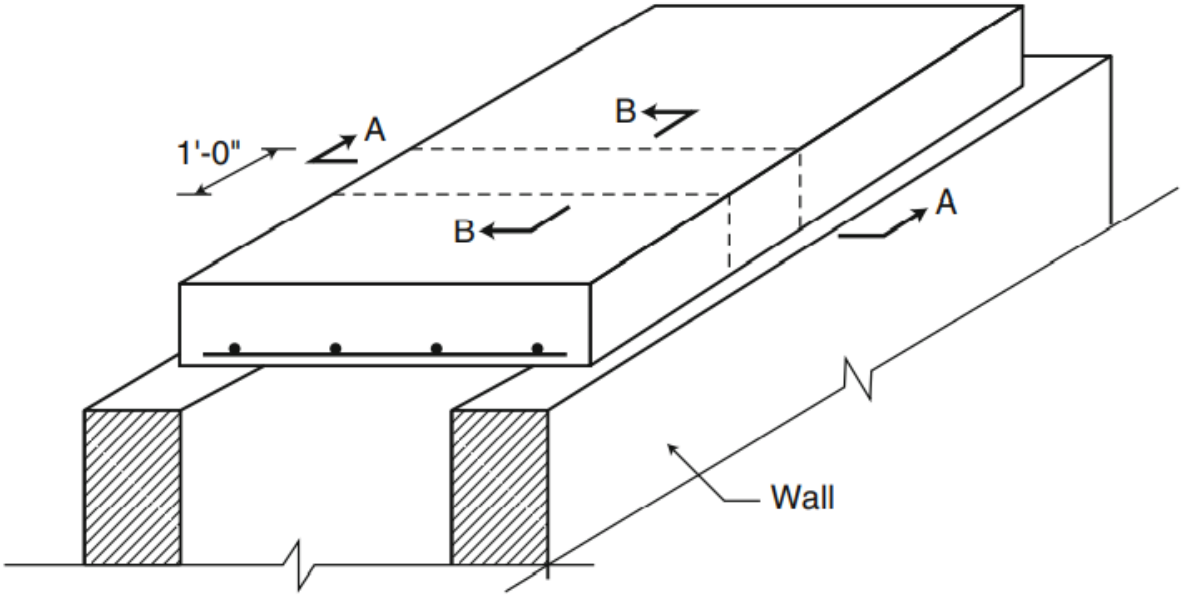
b. **Shrinkage and Temperature Reinforcement Spacing**

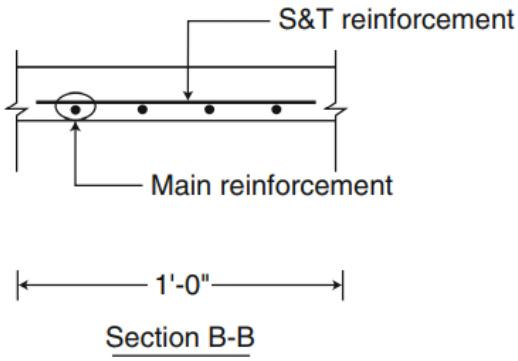
It should not be larger than 5h or 18 inch (Minimum of these two)

9. Bar Size

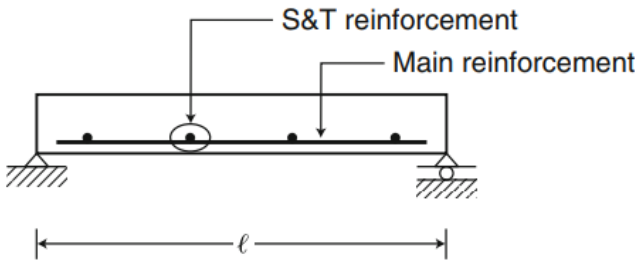
The bar size should be selected so that the actual spacing is not less than about 1.5 times the slab thickness, to avoid excessive cost for bar fabrication and handling. Also, to reduce cost,

straight bars are usually used for slab reinforcement.

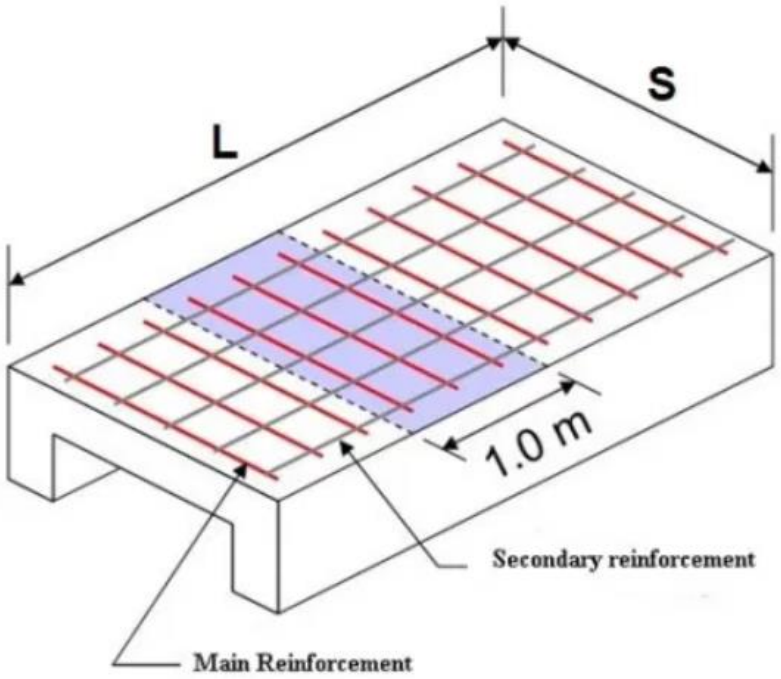


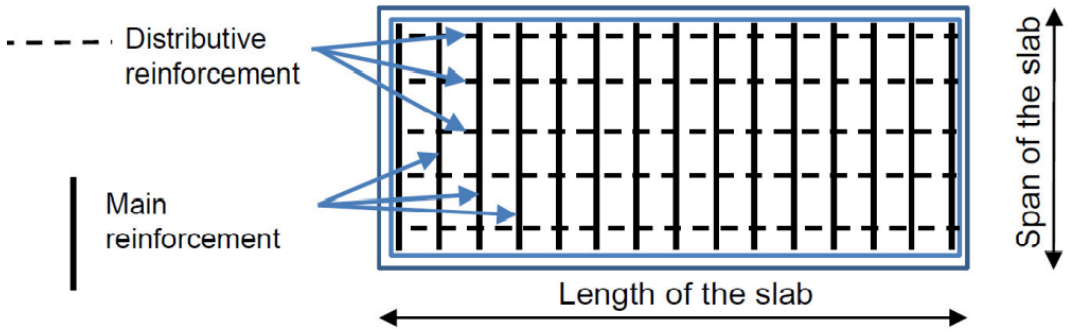


Section B-B



Section A-A





1. Straight-Bar System

Straight bars are used for the top and bottom reinforcement in all spans. The time and cost to produce straight bars are less than that required to

produce bent bars; thus, the straight-bar system is widely used in construction.

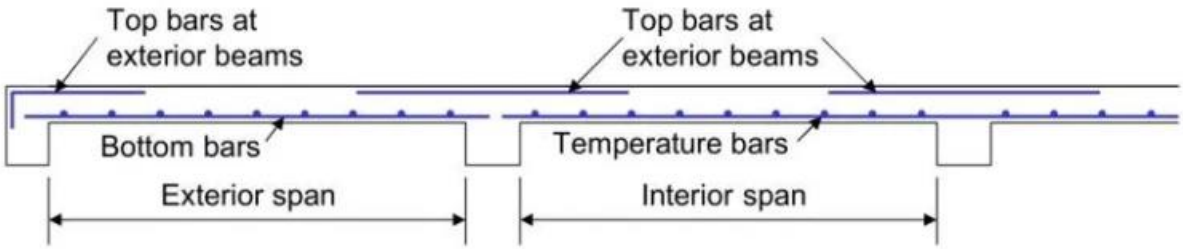


Figure 1: Top and Bottom Straight

2. Bent-Bar

Straight and bent bars are placed alternately in the floor slab. The location of bent points should be checked for flexural, shear, and development length requirements. For normal loading in buildings, the bar details at the end and interior spans of one-way solid slabs may be adopted.

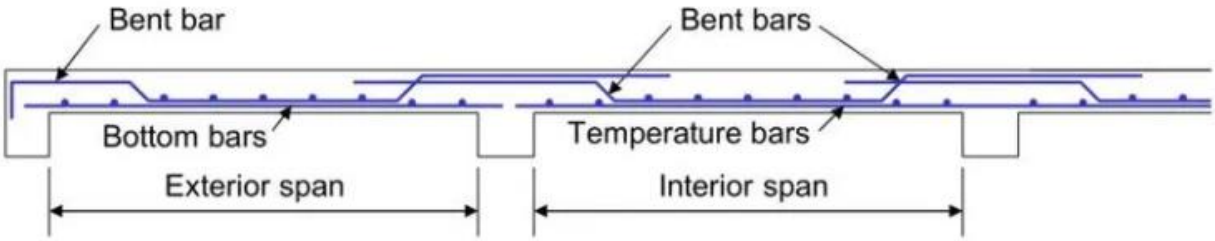


Figure 2: Bent Bar

Table A1.2 Steel bar sizes

Bar size	#3	#4	#5	#6	#7	#8	#9	#10	#11	#14	#18
Diameter (in.)	0.375	0.500	0.625	0.750	0.875	1.000	1.128	1.270	1.410	1.693	2.257
Area (in^2)	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56	2.25	4.00

Rebar Size		Linear Weight		Diameter		Lateral area	
U.S.	SI	lb/ft	kg/m	in	mm	in^2	mm^2
3	#10	0.38	0.56	0.38	9.53	0.11	71.00
4	#13	0.67	1.00	0.50	12.70	0.20	129.00
5	#16	1.04	1.56	0.63	15.88	0.31	200.00
6	#19	1.50	2.24	0.75	19.05	0.44	284.00
7	#22	2.04	3.05	0.88	22.23	0.60	387.00
8	#25	2.67	3.98	1.00	25.40	0.79	509.00
9	#29	3.40	5.07	1.13	28.65	1.00	645.00
10	#32	4.30	6.42	1.27	32.26	1.27	819.00
11	#36	5.31	7.92	1.41	35.81	1.56	1006.00
12	#38	5.99	8.93	1.50	38.10	1.77	1140.09
14	#43	7.65	11.41	1.69	43.00	2.25	1452.00
16	#50	10.65	15.88	2.00	50.80	3.14	2026.83
18	#57	13.60	20.28	2.26	57.33	4.00	2581.00
20	#64	16.63	24.82	2.50	63.50	4.91	3166.92

Bar for Positive Moment

Required $A_s = 0.17\ in^2/ft$, $A_{min} = 0.14\ in^2/ft$

Using # 4 bar

$$\text{Spacing of Bar} = \frac{Area\ of\ the\ bar\ used\ x\ Width\ of\ strip}{Required\ A_S} = \frac{0.20\ x\ 12}{0.17} = 14.12\ inch \approx 14\ inch$$

Crank 50 % bar to negative zone. Or 2 out of 3 will bent.

Bar for Negative Moment

Required $A_s = 0.24\ in^2/ft$, $A_{min} = 0.14\ in^2/ft$

Crank 50 % bar to negative zone

Already provided $A_s = \frac{0.20\ x\ 12}{28} = 0.085\ in^2$

Reqiured $A_s = 0.24 - 0.085 = 0.155\ in^2/ft$

$$\text{Spacing of Bar} = \frac{Area\ of\ the\ bar\ used\ x\ Width\ of\ strip}{Required\ A_S} = \frac{0.20\ x\ 12}{0.155} = 15.48\ inch \approx 15\ inch$$

FIGURE 12.4
One-way slab design example.

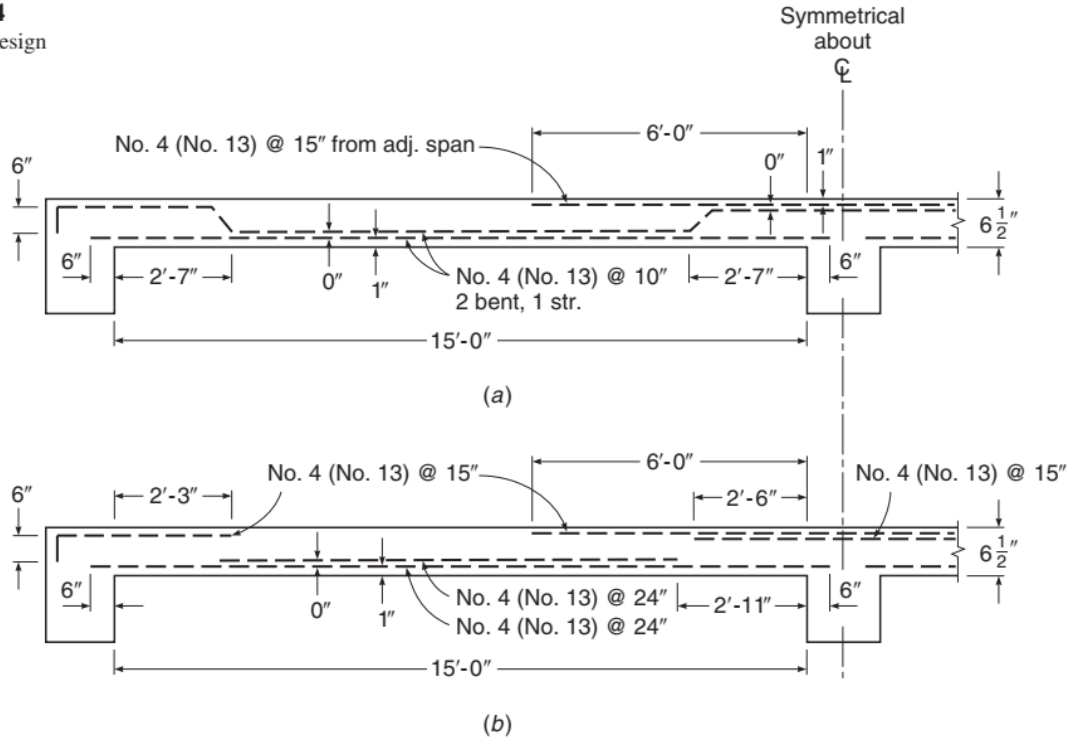
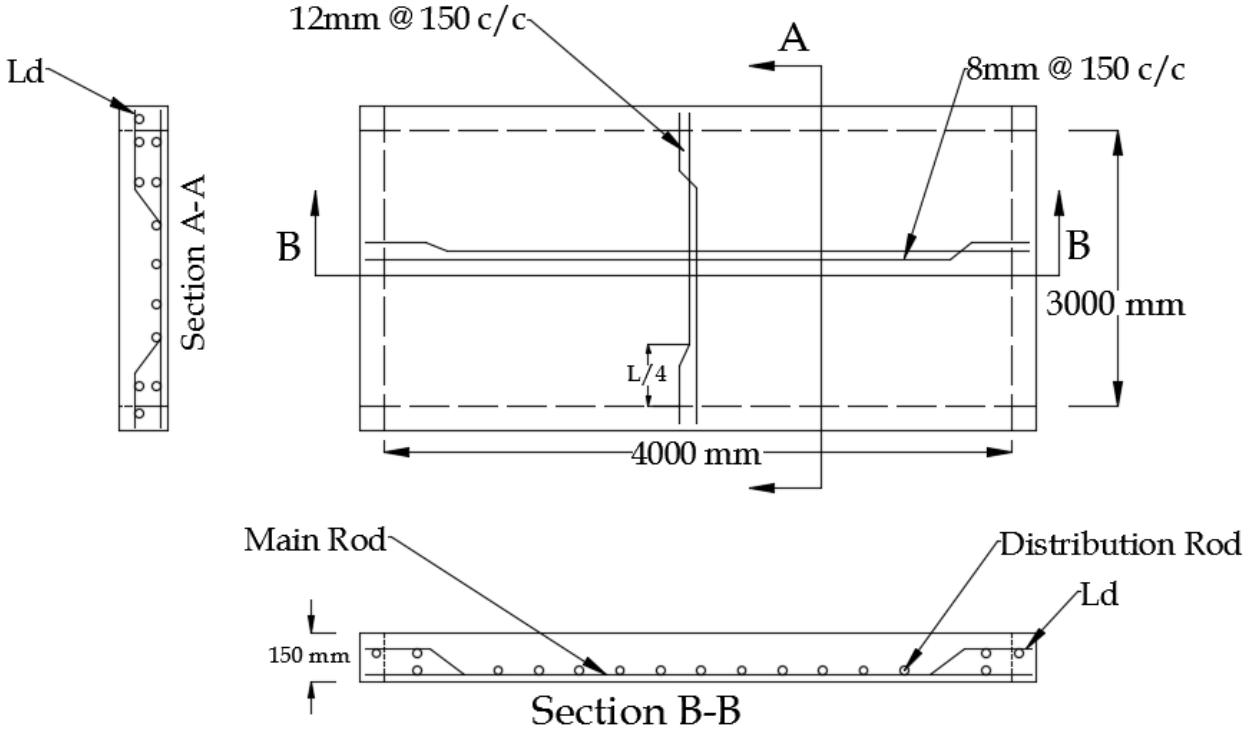
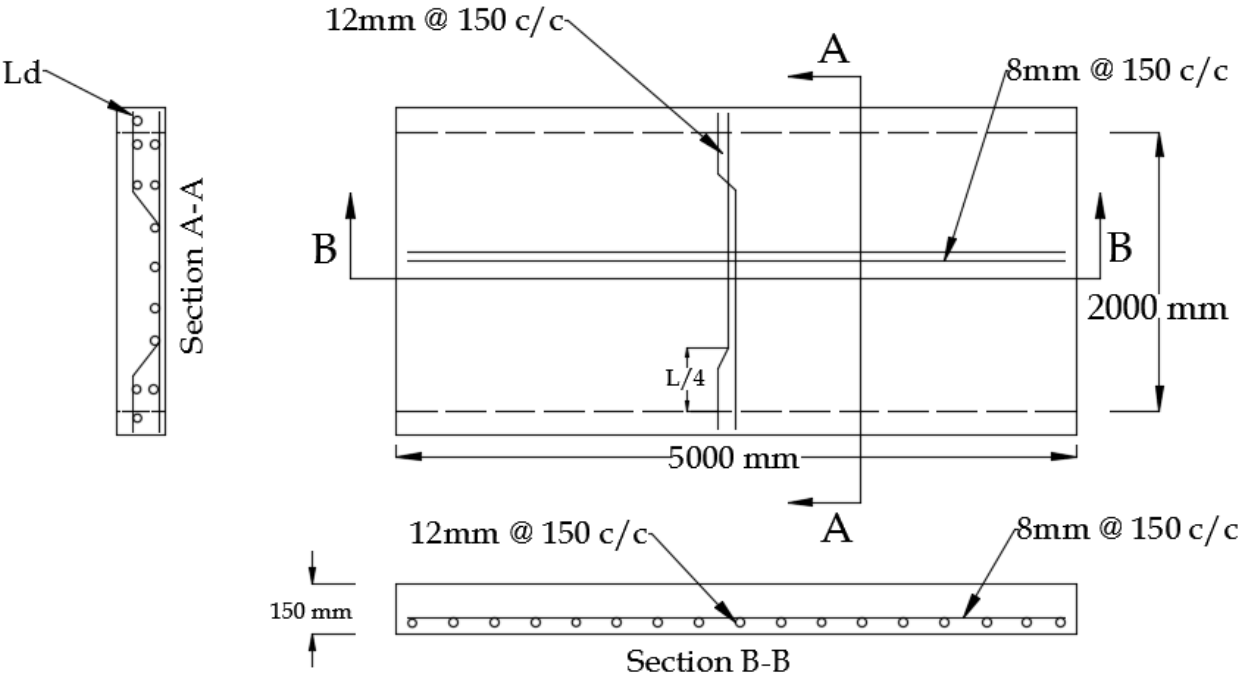


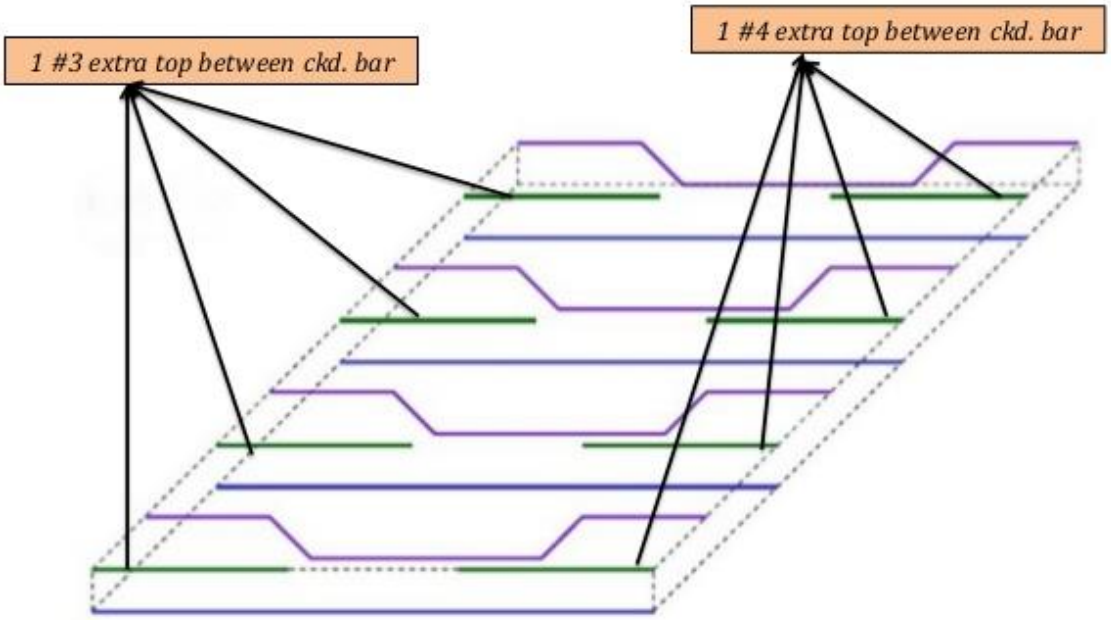
Table A1.2 Steel bar sizes

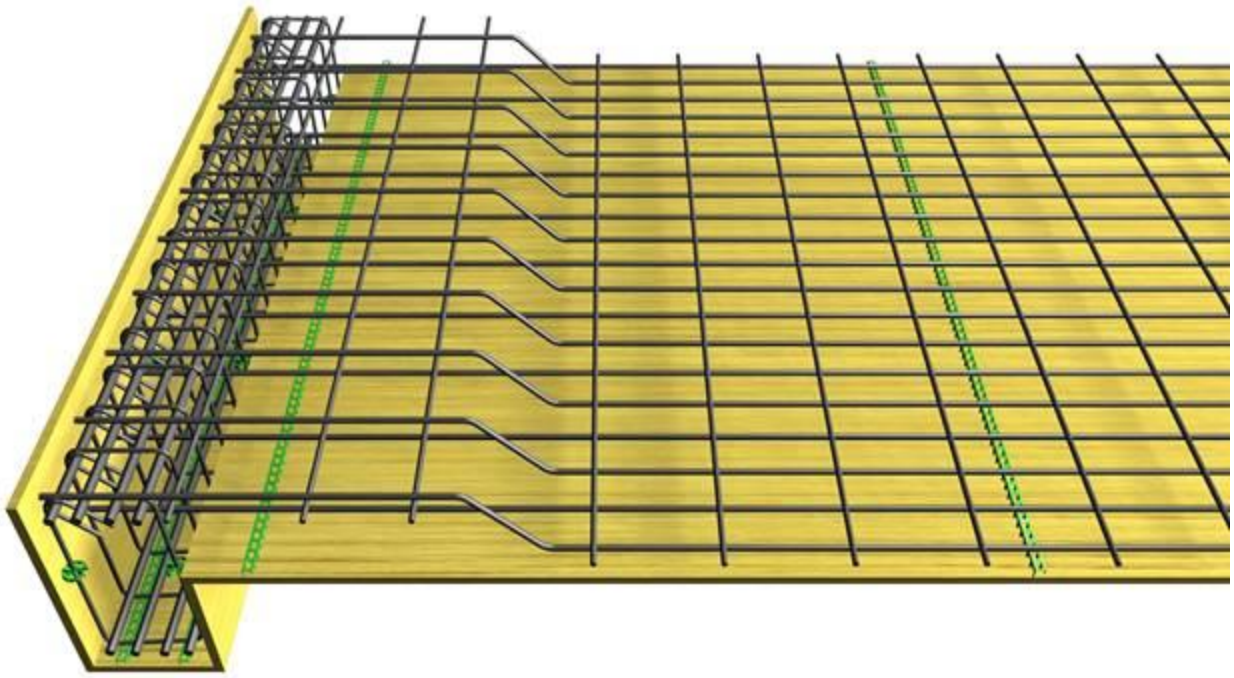
Bar size	#3	#4	#5	#6	#7	#8	#9	#10	#11	#14	#18
Diameter (in.)	0.375	0.500	0.625	0.750	0.875	1.000	1.128	1.270	1.410	1.693	2.257
Area (in^2)	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56	2.25	4.00

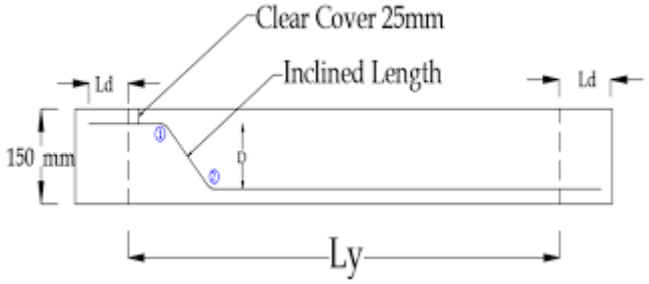

12mm @ 150 c/c
A
8mm @ 150 c/c
Ld
Section A-A
B
B
3000 mm
L/4
4000 mm
Main Rod
Distribution Rod
Ld
150 mm
Section B-B


12mm @ 150 c/c
A
8mm @ 150 c/c
Ld
Section A-A
B
B
2000 mm
L/4
5000 mm
A
12mm @ 150 c/c
8mm @ 150 c/c
150 mm
Section B-B

Example






Clear Cover 25mm
Inclined Length
Ld
Ld
150 mm
D
Ly