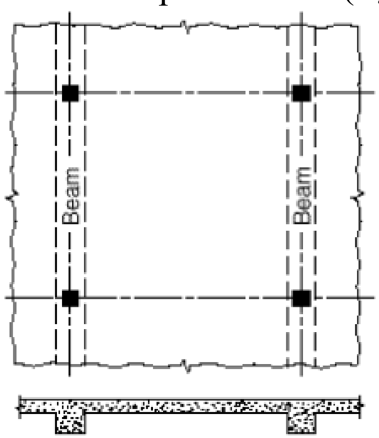
7 Design of One-Way Slabs

A RC slab is a broad, flat plate, usually horizontal, with top and bottom surfaces parallel. It may be supported by RC beams, by masonry or RC walls, by structural steel members, directly by columns, or continuously by the ground.

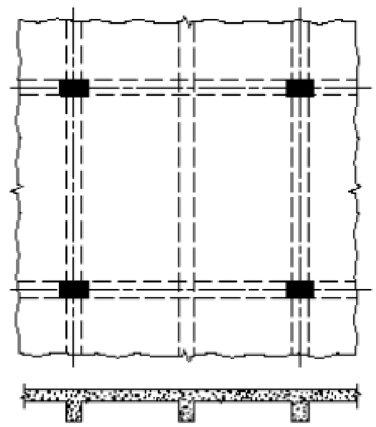
Types of Slabs

1. One-way slab:

A slab supported on two sides only (fig. a), or if the ratio of length to width of one slab panel is > 2 (fig. c)



(*a*) One-way slab

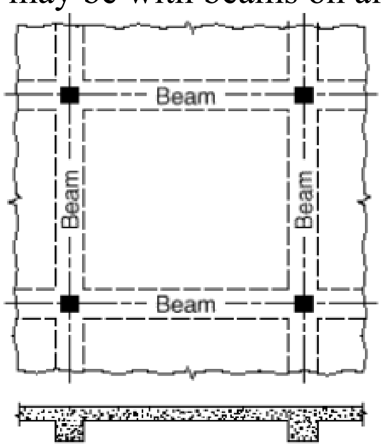

(*c*) One-way slab

In this type, loads are carried by the slab in *one* direction perpendicular to the supporting beam (in the short direction).

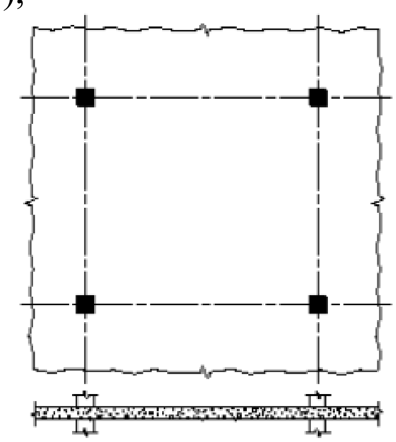
2. Two way slab:

The ratio of length to width of one slab panel is < 2

It may be with beams on all four sides (fig. b),



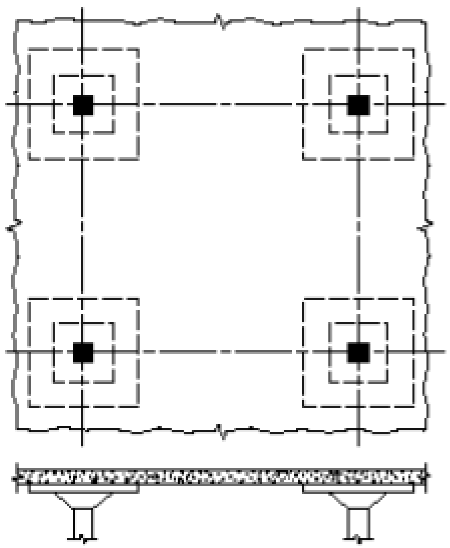
(*b*) Two-way slab


(*d*) Flat plate

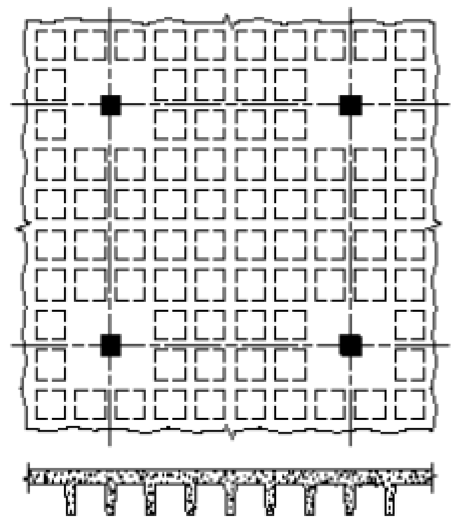
Or beamless:

- Flat plate, (fig. d), spans are not large and loads not heavy.

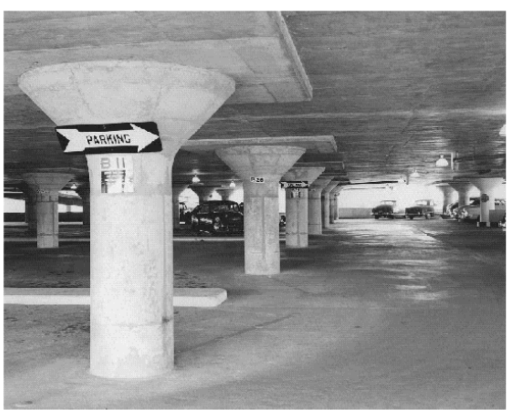
- Flat slab, (fig. e), incorporates drop panels and column capitals to reduce stresses due to shear and –ve bending around the columns, and
- Waffle (grid) slab, (fig. f), a two way joist (ribbed) slab in which voids are formed in a rectilinear pattern to reduce the dead load of a solid-slab construction.



(*e*) Flat slab



(*f*) Grid or waffle slab



Flat slab garage floor with drop panels and column capitals.

Two-way joist (ribbed) slab under construction with steel dome forms.

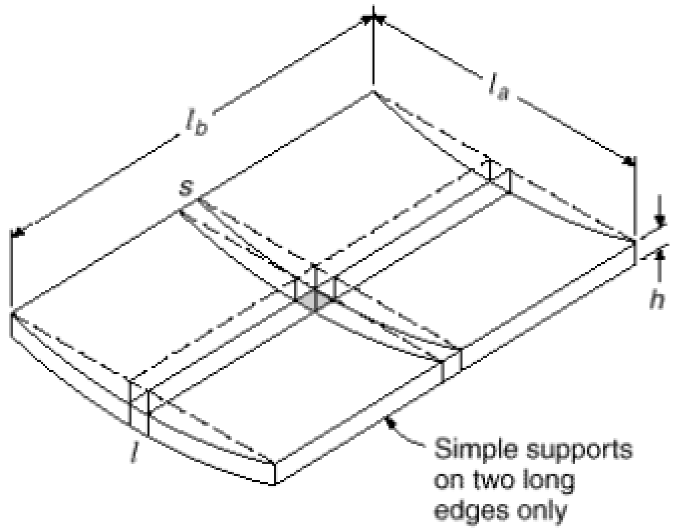
<u>*Note:*</u>

Design of Two-way slabs will be studied extensively in 4th year / 1st semester.

Design of One-Way Slabs

The Structural Behavior

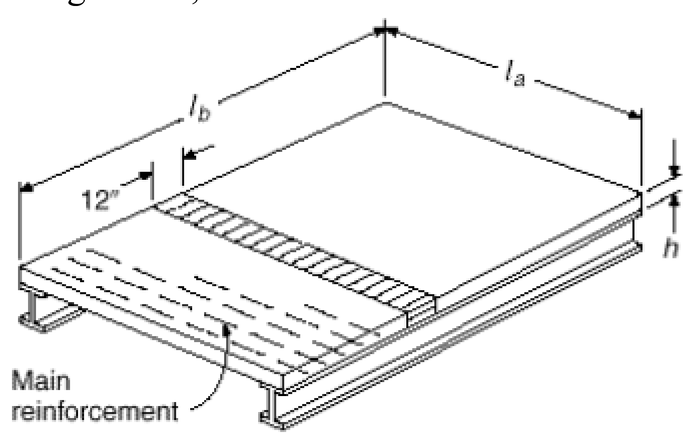
The structural action of a one-way slab may be visualized in terms of the deformed shape of the loaded surface. See Fig. below:



The deflected shape is shown by the solid lines. Curvatures, and consequently bending moments, are the same in all strips ***s*** spanning in the short direction between supported edges, whereas there is no curvature, hence no moments, in the long strips ***l***. The surface is approximately cylindrical.

Analysis Modeling

For purposes of analysis and design, a unit strip (**1 m** width) of slab cut out at right angles to the supporting beams, as shown below:



Use width = 1m (SI units), and 1 ft (12") in English units

It is considered as a rectangular beam of **1 m** width, with depth ***h*** equal to the thickness of the slab and a span l_a equal to the distance between supported edges. It follows that all the reinforcement should be placed in the short direction. Shrinkage and temperature reinforcement will be placed in the other direction.

Reinforcement ratio

$\boldsymbol{\rho = A_s / bd}$ ($\boldsymbol{b}$ **= 1000 mm**)

For e.g. assume a 125 mm slab with d = 100 mm, with No.13 bars (A_s = 129 mm^2) spaced 110 mm c.c.

The no. of bars = 1000 / 110 = 9.1

$A_s = 9.1 \times 129 = 1174$ mm^2/m

$\rho = 1174 / [1000 \times 100] = 0.0117$

Spacing of bars s = 1000 / no. of bars (≤ **3*h*** or **450 mm**) [ACI 7.6.5]

Shrinkage and Temperature Reinforcement

ACI Code 7.12 specifies minimum ratios of reinforcement area to gross concrete area (i.e. A_s / bh). This reinforcement shall be placed in the long direction. Also, this reinforcement represents the minimum permissible in the span direction of one-way slabs.

7.12.2 — Deformed reinforcement conforming to 3.5.3 used for shrinkage and temperature reinforcement shall be provided in accordance with the following:

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 280 or 350 deformed bars are used 0.0020

(b) Slabs where Grade 420 deformed bars or welded wire reinforcement are used....................................0.0018

(c) Slabs where reinforcement with yield stress exceeding 420 MPa measured at a yield strain of 0.35 percent is used .... $\dfrac{0.0018 \times 420}{f_y}$

7.12.2.2 — Shrinkage and temperature reinforcement shall be spaced not farther apart than five times the slab thickness, nor farther apart than 450 mm.

R7.12.2 — The amounts specified for deformed bars and welded wire reinforcement are empirical but have been used satisfactorily for many years. The area of reinforcement given by 7.12.2.1 may be distributed near the top or bottom of the slab, or may be allocated between the two faces of the slab as deemed appropriate for specific conditions. Splices and end anchorages of shrinkage and temperature reinforcement are to be designed for the full specified yield strength in accordance with 12.1, 12.15, 12.18, and 12.19.

Minimum Thickness

The ACI Code table 9.5a specifies the minimum thickness of one-way slabs.

TABLE 9.5(a) — MINIMUM THICKNESS OF NONPRESTRESSED BEAMS OR ONE-WAY SLABS UNLESS DEFLECTIONS ARE CALCULATED

	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	$\ell/16$	$\ell/18.5$	$\ell/21$	$\ell/8$

Notes:
Values given shall be used directly for members with normalweight concrete and Grade 420 reinforcement. For other conditions, the values shall be modified as follows:
a) For lightweight concrete having equilibrium density, w_c, in the range of 1440 to 1840 kg/m³, the values shall be multiplied by $(1.65 - 0.0003w_c)$ but not less than 1.09.
b) For f_y other than 420 MPa, the values shall be multiplied by $(0.4 + f_y/700)$.

Concrete cover = **20 mm**. (ACI 7.7)

Shear

Shear will seldom control the design. The shear capacity φV_c mostly will be well above V_u.

Example:

A RC slab is built integrally with its supports and consists of two equal spans, each with a clear span of **4.5 m**. The service live load is **4.8 kN/m²**. f'_c **= 28 MPa** and f_y **= 420 MPa**.
Design the slab following the ACI provisions.

Solution:

1. Slab thickness:
   Table 9.5a: $h = l / 28 = 4500 / 28 = 161$ mm. Try $\boldsymbol{h = 160}$ **mm**
2. Loads
   $D = 0.160 \times 24 = 3.84$ kN/m², $1.2D = 4.61$ kN/m²
   $L = 4.8$ kN/m², $1.6L = 7.68$ kN/m²
   Total $w_u = 12.29$ kN/m²
3. Bending moments (ACI moment coefficients):
   At interior support: $-M = (1/9)\, w_u l_n^2 = 12.29(4.5)^2/9 = 27.7$ kNm / m
   At midspan: $+M = (1/14)\, w_u l_n^2 = 12.29(4.5)^2/14 = 17.8$ kNm / m
   At exterior support: $-M = (1/24)\, w_u l_n^2 = 12.29(4.5)^2/24 = 10.4$ kNm / m

4. Reinforcement

$\boldsymbol{d}$ = 160 – 25 = 135 mm

For interior support:

Assume a = 20 mm, $\boldsymbol{A_s = M_u / [\varphi f_y (d - a/2)]}$

$= 27.7(10)^6 / [0.9\times420\times125] = 587\ mm^2$

Check $\boldsymbol{a = A_s f_y / 0.85 f'_c\, b}$ = 587×420/(0.85×28×1000) = 10.3 mm

Use new a = 10 mm, $A_s = 27.7(10)^6 / [0.9\times420\times129.8] = 565\ mm^2$

Check new $\boldsymbol{a}$ = (565/587)×10.3 = <u>10.0 mm</u> use

$-A_s = 565\ mm^2$ / m (ρ = 565/ [1000×135] = 0.0042)

For midspan: (use the same a = 10 mm)

$\boldsymbol{+A_s = M_u / [\varphi f_y (d - a/2)]}$

$= 17.8\ (10)^6 / [0.9\times420\times130] = 363\ mm^2$ / m

For exterior support:

$\boldsymbol{+A_s = M_u / [\varphi f_y (d - a/2)]}$

$= 10.4\ (10)^6 / [0.9\times420\times130] = 212\ mm^2$ / m <u>(use min A_s = 288 mm^2 / m)</u>

Check max practical $\boldsymbol{\rho}$

$\boldsymbol{\rho_{0.005} = 0.85\, \beta_1 (f'_c / f_y)[\varepsilon_u / (\varepsilon_u + 0.005)]}$

= 0.85×0.85 (28/420)[0.003 /(0.003 + 0.005)] = 0.0181 > 0.0042 OK

Check min A_s (shrinkage and temperature)

$\boldsymbol{A_{s,min} = 0.0018\, b\, h}$ **(for f_y = 420 MPa)**

$= 0.0018 \times1000\times160 = 288\ mm^2$ / m

5. Shear

At distance $\boldsymbol{d}$ from face of interior support

$\boldsymbol{V_{u,d} = (1.15 / 2)\, w_u l_n - w_u\, d}$

= (1.15/2)(12.29×4.5) – (12.29×0.135) = 34.9 kN / m

$\boldsymbol{\varphi V_c = \varphi[0.17 \sqrt{f'_c}\, b_w\, d\,]}$

$= 0.75[0.17\sqrt{28}\ (1000)\ (135)](10^{-3})$ = 91.1 kN / m > 34.9 kN / m OK

6. Reinforcement spacing and sketch

<u>For the interior support:</u>

The number of **No.13 bars** = 565 / 129 = 4.38

Spacing of bars $\boldsymbol{s}$ = 1000 / no. of bars (**≤ 3*h*** or **450 mm**)

= 1000 / 4.38 = **228 mm** (< 3×160 or <u>450 mm</u>)

<u>For the midspan:</u>

The number of **No.13 bars** = 363 / 129 = 2.81

Spacing of bars $\boldsymbol{s}$ = 1000 / no. of bars (**≤ 3*h*** or **450 mm**)

= 1000 / 2.81 = **355 mm** (< 3×160 or <u>450 mm</u>)

<u>For the exterior support:</u>

The number of **No.13 bars** = 212 / 129 = 1.64

Spacing of bars s = 1000 / no. of bars (**≤ 3*h*** or **450 mm**)

= 1000 / 1.64 = *608 mm* (> 3×160 or **<u>450 mm</u>**)

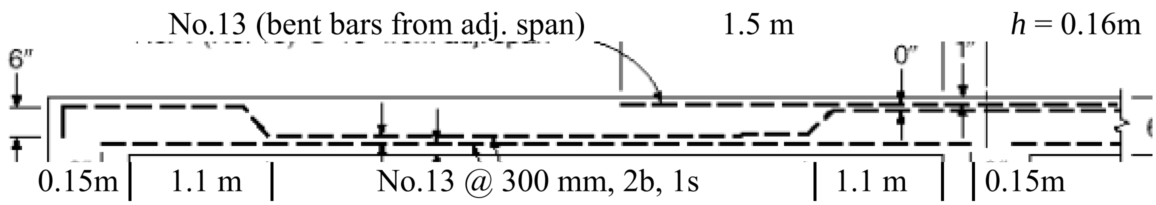
Two methods can be used for bars arrangements

a) Straight and bent bars.

b) Straight bars only.

Whatever the selection, the arrangement should be such that the steel can be placed rapidly with the minimum of labor costs.

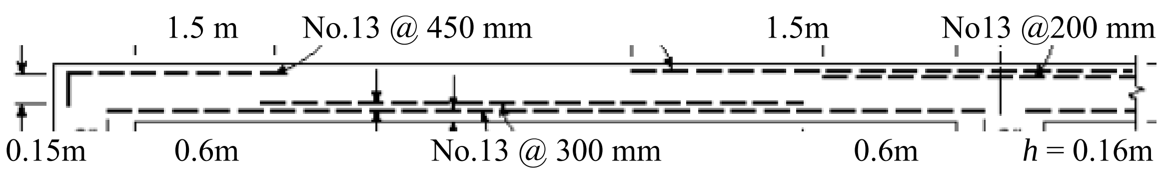
(a) **Arrangement by straight and bent bars**;



At midspan; No.13 @ 300 mm, 2b, 1s is furnished (A_s = 430 mm²/m > 363 mm²/m OK) 2/3 of bars are bent upward for –ve reinf over interior support: (2/3)430 = 286 mm²/m. Identical pattern of bars is bent from other side (286 mm²/m). Thus the total area *over interior support* is 2×286 = 572 mm² /m > 565 mm²/m required OK, and average spacing is 1000 / [572 / 129] = 225 mm (< 228 mm required OK)
Over exterior support, A_s = 286 mm²/m > 212 mm²/m OK, and average spacing is 1000 / [286 / 129] = 450 mm (= max allowed OK)

Bars are bent at ***l* / 4** = 4.5 / 4 = 1.1m, and top bars are cut at ***l* / 3** = 1.5 m

(b) **Arrangement by straight bars only**;



At midspan; No.13 @ 300 mm is furnished (A_s = 430 mm²/m > 363 mm²/m, and spacing 300 mm < 355 mm required OK).
Over interior support, No.13 @ 200 mm is furnished (A_s = 645 mm²/m > 565 mm²/m, and spacing 200 mm < 228 mm required OK).
Over exterior support, No.13 @ 450 mm is furnished (A_s = 286 mm²/m > 212 mm²/m, and spacing = max allowed OK).

Bottom bars are cut at ***l* / 8** = 4.5 / 8 = 0.6 m, and top bars are cut at ***l* / 3** = 1.5 m.