Notes on One Way Slab Design

-Dr. E. R. Latifee

Question: Define the term slab, one way slab, two way slab, Shrinkage and temperature reinforcement, main reinforcement.

Definition:
Slab is a common term used to describe the structural elements such as floors and roofs where the thickness of the element is very small compared to the length and width. Rectangular Slabs are mainly two types: one-way and two-way.

**One-way slab** means the load is transferred in one direction, therefore, the bending occurs in one direction only. When a rectangular slab is supported on all four sides, but the ratio of longer side, L, to shorter side, S, is two or more, L/S ≥ 2.0, then, the slab will act as a one-way slab, with bending primarily occurring in the short direction. Such slabs are designed as one-way slabs where the span length (L<sub>n</sub>) is equal to the length of short direction. Here, main reinforcement is placed in the shorter direction which is the span, while shrinkage reinforcement is provided in the longer direction to limit cracking.

**Note: Special case:** When the slab is supported on two sides only, which is uncommon, the load will be transferred to these sides regardless of its longer span to shorter span ratio, and it will be classified as one-way slab.

![One-way Slab Diagram](image)

**Two-way slab** means the load is transferred in two directions, therefore, the bending occurs in two directions. In this case, L/S is less than 2.0.

**Slab reinforcement:** **Main reinforcement:** Used to resist bending moment due to Live and dead load.
Shrinkage and temperature reinforcement: Used to prevent cracking from shrinkage/contraction of the concrete due to water loss from concrete mass at different stages, temperature variation and differential thermal gradient.

What are the assumptions for flexure theory in beam design?
There are three basic assumptions for flexure

I. Sections perpendicular to the axis of bending which are plane before bending remain plane after bending.

II. The strain in the reinforcement is equal to the strain in the concrete at the same level.

III. The stresses in the concrete and reinforcement can be computed from the strains using stress-strain curves for concrete and steel.

Additional

IV. The tensile strength of concrete is neglected in flexural strength calculations (ACI sec. 10.2.5).

V. Concrete is assumed to fail when the compressive strain reaches a limiting value.

VI. The compressive stress strain relationship for concrete may be assumed to be rectangular, trapezoidal, parabolic or any other shape that results in prediction of strength in substantial agreement with results of comprehensive tests (ACI 10.2.6).

What does it mean by beam design and beam analysis?
Design: Given a factored load effect such as Mu, select a suitable cross section, including dimensions, concrete strength, reinforcement detail and others.

Analysis: Given a cross section, concrete strength, reinforcement size, location and yield strength, compute the resistance or capacity.

ACI 318 -11- Building Code Requirements for Structural Concrete- by American Concrete Institute, ACI.

Minimum Thickness of One-way Slabs (ACI Code 9.5.2) (ACI 318-11)

These values are applicable for normal loading conditions and for slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections.

<table>
<thead>
<tr>
<th></th>
<th>$ln/20$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple span solid slabs*</td>
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<tr>
<td>Cantilever</td>
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</tr>
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<td>$ln/24$</td>
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<td>$ln/28$</td>
</tr>
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</table>

*Minimum thickness for cantilevers can be considered equal to twice that of for a simple span
Where, $l_n$ is the span length in the direction of bending.
What is positive moment and negative moment and reinforcement regarding beam?

Answer: A moment that causes compression on top surface of a beam and tension on the bottom surface will be called a positive moment. A moment that causes tension on top surface of a beam and compression on the bottom surface will be called a negative moment. The steel provided in the positive moment region is called positive reinforcement and the steel provided in the negative moment region is called negative reinforcement.

Q. Explain Tension, Compression & Balanced Failure:

Depending upon the properties of a beam, flexural failure may occur in three different ways:

1. Tension failure: Reinforcement yields before concrete crushes. (reaches its limiting compressive strain). Such a beam is said to be under-reinforced.
2. Compression failure: Concrete crushes before steel yields. Such a beam is said to be over-reinforced
3. Balanced failure: Concrete crushes (crushing strain) and steel yields (yield strain) simultaneously. Such a beam has balanced reinforcement.

\[
\rho_{\text{balance}} = (0.85) \beta_1 \times \frac{f'_c}{f_y} \times \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_y}
\]

Substitute, \(\varepsilon_{cu} = 0.003\) concrete compressive strain at failure,

\(E_s=\) Modulus of elasticity of steel=29000ksi,

Steel yield strain \(\varepsilon_y=\) stress/\(E_s = f_y/29,000,000\) psi

Now, substituting,

\[
\rho_{\text{balance}} = (0.85) \beta_1 \times \frac{f'_c}{f_y} \times \frac{87000}{87000 + f_y}
\]

\(\beta_1 = 0.85\) for \(f'_c \leq 4000\)psi
Design of a one-way slab

Step-1

Selection of thickness, h

**ACI 318 -11- Building Code Requirements for Structural Concrete- by American Concrete Institute, ACI.**

**Minimum Thickness of One-way Slabs** (ACI Code 9.5.2) (ACI 318-11)

These values are applicable for normal loading conditions and for slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections.

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</tr>
<tr>
<td>Solid Slabs Continuous at both Ends</td>
<td>( l_n/28 )</td>
</tr>
</tbody>
</table>

*Minimum thickness for cantilevers can be considered equal to twice that of for a simple span
Where, \( l_n \) is the span length in the direction of bending.
For the negative moment at the interior face of the exterior support, for positive moment, and for shear, \( l_n = \) clear span of the span in question.
For negative moment at interior supports, \( l_n = \) average of the clear spans of the adjacent spans.

(ACI Code 9.5.2 provided that slabs are of normal-weight concrete (wc=145 pcf) using Grade 60 reinforcement)

The total slab thickness \( h \) is usually rounded to the next higher ¼ inch for slabs up to 6 inch thickness and to the next higher ½ inch for thicker slabs. Best economy is often achieved when the slab thickness is selected to match nominal lumber dimensions.
The concrete protection below the reinforcement should follow the requirements of ACI code 7.7.1 calling for ¼ inch below the bottom of the steel. In a typical slab 1 inch below the centre of the steel may be assumed.

**Step-2**

Calculation of load

Two types of load-Dead load & Live load
a) Dead load calculation=
Self weight calculation=$\frac{\text{thickness}}{12}\times$ unit weight of concrete; where thickness is in inches

b) Live load calculation, assume
40 psf (residential), 100 psf (stair, lobby, public places etc.)

Note: 40 psf = 1.92 kN/m$^2$, 100 psf = 4.79 kN/m$^2$

BNBC Live Load:

<table>
<thead>
<tr>
<th>Table 2.3.1 Minimum Uniformly Distributed Live Loads, And Minimum Concentrated Live Loads (Contd.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penal Institutions</td>
</tr>
<tr>
<td>Cell blocks</td>
</tr>
<tr>
<td>Corridors</td>
</tr>
<tr>
<td>Residential</td>
</tr>
<tr>
<td>Dwellings (one- and two-family)</td>
</tr>
<tr>
<td>Uninhabitable attics without storage</td>
</tr>
<tr>
<td>Uninhabitable attics with storage</td>
</tr>
<tr>
<td>Habitable attics and sleeping areas</td>
</tr>
<tr>
<td>All other areas except stairs and balconies</td>
</tr>
<tr>
<td>Hotels and multifamily houses</td>
</tr>
<tr>
<td>Private rooms and corridors serving them</td>
</tr>
<tr>
<td>Public rooms and corridors serving them</td>
</tr>
</tbody>
</table>

Step-3

Determination of factored load
Factored dead load = calculated dead load $\times$ 1.2
Factored live load = calculated live load $\times$ 1.6
Calculate the factored load by magnifying service dead and live loads according to this equation $w_u = 1.20DL + 1.60LL$. The dead load includes own weight of the slab.

Step-4

Determination of factored moment: **Moments for beams and one way slab**
Factored moment coefficient found in ACI Code section 8.3.3

Q. What are the criteria for using ACI moment coefficients for non pre-stressed continuous beams or one way slabs?

ACI MOMENT COEFFICIENT
Because the calculations necessary to derive the moment are tedious, approximate moment coefficients are presented in ACI Sec 8.3.3 which can be used to calculate the moment and shear envelopes for non pre-stressed continuous beams or one way slabs that meet the following criteria:

1. There are two or more spans
2. The spans are approximately equal with the longer of two adjacent spans not more than 1.2 times the length of the shorter one
3. The loads are uniformly distributed.
4. The unit live load does not exceed three times the unit dead load. The word ‘unit’ means the unfactored load per foot.
5. The beams must be prismatic.
6. The beam must be in a braced frame without significant moments due to lateral loads (not stated in ACI code but necessary for the coefficients to apply).

The maximum positive and negative moments and shears are computed from the following equations:

\[ M_u = C_n (w_u l_n^2) \]

The ACI Code 318-11 section 8.3.3 gives the moments at mid spans and at faces of supports, as follows.

**Positive moment**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>End spans</td>
<td>( w_u l_n^2 / 11 )</td>
</tr>
<tr>
<td>Discontinuous end unrestrained</td>
<td>( w_u l_n^2 / 14 )</td>
</tr>
<tr>
<td>Discontinuous end integral with support</td>
<td>( w_u l_n^3 / 16 )</td>
</tr>
</tbody>
</table>

Negative moments at exterior face of first interior support

<table>
<thead>
<tr>
<th>Span Configuration</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two spans</td>
<td>( w_u l_n^2 / 9 )</td>
</tr>
<tr>
<td>More than two spans</td>
<td>( w_u l_n^3 / 10 )</td>
</tr>
</tbody>
</table>

**Negative moment**

Negative moment at other faces of interior supports

<table>
<thead>
<tr>
<th>Condition</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slabs with spans not exceeding 10 ft; and beams where ratio of sum of column stiffness to beam stiffness exceeds eight at each end of the span</td>
<td>( w_u l_n^2 / 11 )</td>
</tr>
</tbody>
</table>

Negative moment at face of all supports for

<table>
<thead>
<tr>
<th>Condition</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where support is spandrel beam</td>
<td>( w_u l_n^2 / 2 )</td>
</tr>
<tr>
<td>Where support is column</td>
<td>( w_u l_n^2 / 16 )</td>
</tr>
</tbody>
</table>

Shear in end members at face of first interior support

<table>
<thead>
<tr>
<th>Condition</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear at face of all other supports</td>
<td>( V_u = 1.15 w_u l_d / 2 )</td>
</tr>
</tbody>
</table>
Determination of maximum reinforcement ratio, $\rho_{\text{max}}$, to ensure underreinforced behavior

$$\rho_{\text{max}} = (0.85) \beta_1 \left( \frac{f'_c}{f_y} \right) \frac{\varepsilon_u}{\varepsilon_u + \varepsilon_t}$$

For nonprestressed flexural members and nonprestressed members with factored axial compressive load less than $0.10f'cA_{\text{eff}}$, $\varepsilon_u$ at nominal strength shall not be less than 0.004.

Example:

$$\rho_{\text{max}} = 0.85 \beta_1 \left( \frac{f'_c}{f_y} \right) \left( \frac{0.003}{0.003 + 0.004} \right) = (0.85)^2 \cdot \left( \frac{4}{60} \right) \cdot \frac{0.003}{0.003 + 0.004} = 0.02064$$

Where,

- $f'_c =$ specified compressive strength of concrete cylinder (4” by 8”) at 28 days
- $f_y =$ yield strength of steel
\(\varepsilon_u=\text{compressive strain of concrete (observed failure at strain 0.003 to 0.004), take 0.003,}\)

\(\varepsilon_t=\text{minimum net tensile strain in steel, take 0.004 to ensure underreinforced behavior, i.e., tension failure.}\)

\[\rho_{\text{balance}}= (0.85) \beta_1 * \frac{f'_c}{f_y} * \frac{87000}{87000+f_y} = (0.85)^2 \cdot (4/60) \cdot \frac{87000}{87000+60000} = 0.0285\]

Limit: \(0.75 \cdot \rho_{\text{balance}} = 0.75 \cdot 0.0285 = 0.2138\)

\(\rho_{\text{max}} < 0.75 \cdot \rho_{\text{balance}} \) (OK, tension controlled, underreinforced)

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Step 6

Assume \(\rho = 0.5 \times \rho_{\text{max}} \) or, \(\rho = \rho_{\text{max}}\)

Check of effective depth, \(d\)

\[d^2 = \frac{M_u}{\phi \rho f_y b (1-0.59 \rho \left(\frac{f'_c}{f_c}\right))}\]

where, \(d=\text{effective depth of the slab}\)

\(d = \text{distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in., Chapters 7, 9-12, 14, 17, 18, 21,}\)

\(M_u=\text{factored moment}\)

Strength reduction factor, \(\phi=0.9\)

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Bangladesh National Building Code 2011
8.1.7.2 Cast-in-place Concrete:
(a) Minimum concrete cover for concrete cast against and permanently exposed to earth shall be 75 mm.
(b) Concrete exposed to earth or weather:

<table>
<thead>
<tr>
<th>Minimum cover, mm</th>
</tr>
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<tbody>
<tr>
<td>19 mm φ through 57 mm φ</td>
</tr>
<tr>
<td>16 mm φ bar and smaller</td>
</tr>
</tbody>
</table>

(c) The following minimum concrete cover may be provided for reinforcement for concrete surfaces not exposed to weather or in contact with ground:

<table>
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<tbody>
<tr>
<td>Slabs, Walls:</td>
</tr>
<tr>
<td>40 mm φ to 57 mm φ</td>
</tr>
<tr>
<td>36 mm φ bar and smaller</td>
</tr>
</tbody>
</table>

Thickness, \( h_1 = d \), effective thickness + \( \frac{1}{2} \) bar dia.+ 20 mm or \( \frac{3}{4} \) inches

**Minimum Thickness of One-way Slabs** (ACI Code 9.5.2) (ACI 318-11) –Deflection criterion

Say \( h_2 = l_n/24 \) or 28 etc., see table below.

These values are applicable for normal loading conditions and for slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections.

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<td>( l_n/28 )</td>
</tr>
</tbody>
</table>
Take the higher thickness between $h_1$ and $h_2 = \text{required } h$

Then, $d = h - 20 \text{ mm} - \frac{1}{2} \text{ bar dia.}$

Step-7

Determination of steel area, $A_s$

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

Checking the assumed depth, $a$

$$a = \frac{A_s f_y}{0.85 f'c \, b}$$

Iterate to find $A_s$.

**Minimum reinforcement area for slab in both short and long direction is equal to the Shrinkage and temperature reinforcement.**

**For slab - $A_s$, minimum = $A_s$, (S&T)**

**Minimum Reinforcement Ratio for Shrinkage and Temperature (S&T) Reinforcement:**

ACI Code 7.12.2.1 specifies the minimum ratios of Shrinkage and Temperature (S&T) Reinforcement area to gross concrete area (i.e. based on the), $\rho_{\text{minimum}} = \frac{A_s}{bh}$; $b =$ width of strip, such as 12 inches, $h =$ total depth of the slab, inches, but no less than 0.0014

<table>
<thead>
<tr>
<th>Type of reinforcement used</th>
<th>Minimum ratio of steel area to gross concrete area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slabs where Grade 40 or Grade 50 deformed bars are used</td>
<td>0.0020</td>
</tr>
<tr>
<td>Slabs where Grade 60 deformed bars or welded wire fabric (smooth or deformed) are used</td>
<td>0.0018</td>
</tr>
<tr>
<td>Slabs where reinforcement with yield strength exceeding 60,000 psi measured at yield strain of 0.35 percent is used</td>
<td>$\frac{0.0018 \times 60,000}{f_y}$</td>
</tr>
</tbody>
</table>

# Reinforcement for shrinkage and temperature stresses normal to the principal reinforcement should be provided in a structural slab in which the principal reinforcement extends in one direction only.
Step-8

Determining the spacing of the steel bars

\[
\text{Spacing} = \frac{\text{area of the bar used} \times \text{width of the strip}}{\text{required steel area}}
\]

Maximum spacing, S, for Main reinforcement for flexure, with slab thickness, h-

ACI 10.5.4: \( S \leq \) smaller of (3 h or 18 in.)

<table>
<thead>
<tr>
<th>Bar diameter</th>
<th>Area (mm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 mm</td>
<td>50.3</td>
</tr>
<tr>
<td>10 mm</td>
<td>78.5</td>
</tr>
<tr>
<td>12 mm</td>
<td>113.1</td>
</tr>
<tr>
<td>14 mm</td>
<td>153.86</td>
</tr>
</tbody>
</table>

In one way slab since all of the load on the slab must be transmitted to the two supporting beams, it follows that all of the reinforcement should be placed at right angles to these beams, with the exception of any bars that may be placed in the other direction to control shrinkage and temperature cracking.

# The lateral spacing of the bars, except those used to control shrinkage and temperature cracks should not exceed 3 times the thickness h or 18 inch, whichever is less, according to ACI Code 7.6.5.

# Generally, 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 \& handling. Also to reduce cost, straight bars are usually used for slab reinforcement.

**Spacing for Shrinkage and Temperature (S&T) Reinforcement: ;**

ACI 7.12.2.2 \( S_{\text{max}} \) (S&T) = min (5h or 18 in.)

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**Example 2.1: One way slab design:**

A reinforced concrete slab is to be built integrally with its supports and consists of two equal spans, each with a clear span of 15 ft. The service live load is 40 psf and 4000 psi concrete is specified with 60 grade steel (yield stress equal to 60,000 psi).
Solution:

Minimum thickness \( \frac{l_n}{28} = 15 \times 12/28 = 6.43 \text{ in.} \approx 6.50 \text{ in.} \)

Self-weight of slab = 150 X 6.50/12 = 81 psf \[ \text{[unit weight of concrete 150 lb/ft}^3] \]

The specified live load and computed dead load are multiplied by the Load factors:

\[
\begin{align*}
\text{Dead load} &= 81 \times 1.2 = 97 \text{ psf} \\
\text{Live load} &= 40 \times 1.6 = 64 \text{ psf} \\
\text{Total load} &= 161 \text{ psf}
\end{align*}
\]

Using ACI moment coefficient,

\[
\begin{align*}
&\text{At support: } -M = \frac{1}{9} \times 0.161 \times 15^2 = 4.025 \text{ ft-kip} \\
&\text{At mid-span: } +M = \frac{1}{14} \times 0.161 \times 15^2 = 2.5875 \text{ ft-kip} \\
&\text{At exterior support: } -M = \frac{1}{24} \times 0.161 \times 15^2 = 1.51 \text{ ft-kip}
\end{align*}
\]

\[
\begin{align*}
\rho_{\text{max}} &= 0.85 \beta_1 \left( \frac{f_y}{0.003 + 0.004} \right) = (0.85)^2 \frac{4/60}{0.003 + 0.004} = 0.021
\end{align*}
\]

Minimum effective depth = \((6.50-1) \text{ in.} = 5.50 \text{ in.}\)

[Note: minimum clear cover 20 mm or 0.75 inches for slab + ½ bar diameter \(\approx 1 \text{ inch.}\)]

Minimum required effective depth would be found from the equation

Now, we need to work only with one “d check” with Maximum moment,

since all through the slab, the same thickness will be given.

\[
d^2 = \frac{M_u}{\phi \rho f_y b (1 - 0.59 \rho (\frac{f_y}{f'_c}))}
\]
Now, \( d = 2.08 \text{ in.} \approx 2.1 \text{ in.} \lt \text{ minimum } 5.50 \text{ in.} \)

Therefore, deflection controls for depth of the slab.

**Final slab thickness = 6.50 in.**

Assume, stress block depth \( a = 1 \text{ in.} \)

The area of steel required per foot width in the top of the slab is

\[
A_s = \frac{Mu}{\phi f_y (d-a/2)} = \frac{4.025 \times 12}{0.90 \times 60 \times (5.50 - 0.5)} = 0.178 \text{ in}^2
\]

Checking \( a \),

\[
a = \frac{0.178 \times 60}{0.85 \times 4 \times 12} = 0.2617 \text{ in.}
\]

Trail 2:

\[
a = 0.26 \text{ in.}
\]

\[
A_s = \frac{Mu}{\phi f_y (d-a/2)} = \frac{4.025 \times 12}{0.90 \times 60 \times (5.50 - 0.13)} = 0.166 \text{ in}^2
\]

Again checking \( a \),

\[
a = \frac{0.166 \times 60}{0.85 \times 4 \times 12} = 0.245 \text{ in.} \approx 0.26 \text{ in.} \text{ (ok)}
\]

**Minimum rebar for temperature and shrinkage, \( A_s, \text{min} = 0.0018 \times 12 \times 6.5 = 0.1404 \text{ in}^2/\text{ft} \)**

Negative Steel required,

\( A_s \) negative for interior support,

\[
A_s = \frac{Mu}{\phi f_y (d-a/2)} = \frac{4.025 \times 12}{0.90 \times 60 \times (5.50 - 0.125)} = 0.166 \text{ in}^2/\text{ft} > A_s, \text{min. OK}
\]

\( A_s \) negative at exterior support,

\[
A_s = \frac{1.51 \times 12}{0.90 \times 60 \times (5.50 - 0.125)} = 0.06 \text{ in}^2/\text{ft}0. < A_s, \text{min, use } A_s, \text{min}
\]

Positive \( A_s \) at mid span,

\[
A_s = \frac{2.588 \times 12}{0.90 \times 60 \times (5.50 - 0.125)} = 0.107 \text{ in}^2/\text{ft}, < A_s, \text{min, use } A_s, \text{min}
\]

**Spacing** = \( \frac{\text{area of the bar used} \times \text{width of the strip}}{\text{required steel area}} \)

\( S_{\text{max}} \) for main reinforcement

ACI 10.5.4: \( S_{\text{max}} \leq \text{smaller of (3 h or 18 in.)} = 3 \times 6.5 \) or 18, 18 inches governs

Shrinkage and temperature,

ACI 7.12.2.2 \( S_{\text{max}} \) (S&T) = min (5h or 18 in.), so 18 inches governs

Spacing, Let \# 4 bar, (Area of steel 0.2 in\(^2\))

\( A_s \) negative for interior support

\[
S = 0.2 \times 12/0.166 = 14.4 \text{ in, use 12 inches} < S_{\text{max}}, \text{OK}
\]

+ve Main rebar in short direction, \( S_{\text{main}} = 0.2 \times 12/0.1404 = 17.09 \text{ in, use 16 inches} < S_{\text{max}}, \text{OK} \)
Shrinkage and temperature, Spacing needed = $S_{S&T} = 0.2 \times 12/0.14 = 17.1$, use 16 inches < $S_{\text{max}}$, OK

<table>
<thead>
<tr>
<th>Position</th>
<th>Bar size</th>
<th>Spacing (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main rebar - $A_s$ positive short direction positive Moment-Bottom Bars</td>
<td>#4</td>
<td>16</td>
</tr>
<tr>
<td>Main rebar $A_s$ negative at exterior support - Top Bars</td>
<td>#4</td>
<td>16</td>
</tr>
<tr>
<td>Main rebar $A_s$ negative for interior support - Top Bars</td>
<td>#4</td>
<td>12</td>
</tr>
</tbody>
</table>

Shrinkage and temperature (S&T) reinforcement - Long direction.
Note that the depth within the slab is not critical for S&T steel. However, these are placed on top of main bottom bars below top bars.

Shear Check:

$Vu = (1.15 \times w_u \times L_n) / 2 = (1.15 \times 0.161 \times 15) / 2 = 1.388$ kip

$V_c = 2 \sqrt{f_c'} b_w d$

$\phi V_c = 0.85 \times 2 \times (4000^{0.5}) \times 12 \times 5.5 / 1000 = 7.09$ kip

$\phi V_c \geq Vu$, therefore OK.
(a) Straight top and bottom bars

(b) Alternate straight and bent bars

greater of 0.3S_{ci} and 0.3S_{c2}
<table>
<thead>
<tr>
<th>Position</th>
<th>Bar size</th>
<th>Spacing (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main rebar- short direction positive Moment-Bottom Bars</td>
<td>#4</td>
<td>10</td>
</tr>
<tr>
<td>Main rebar- short direction negative Moment-Top Bars</td>
<td>#4</td>
<td>10</td>
</tr>
<tr>
<td>Shrinkage and temperature (S&amp;T) reinforcement.-Long direction.</td>
<td>#4</td>
<td>16</td>
</tr>
<tr>
<td>Note that the depth within the slab is not critical for S&amp;T steel.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>However, these are placed on top of main bottom bars below top bars.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Additional Notes:

Failure Scenario #1 (just right steel). The preferred order of flexure response events is: beam cracks, steel yields, concrete crushes

Failure Scenario #2 (too little steel). Mu < Mcr. In this case, the beam has so little steel, that when the beam does crack, it collapses. ACI 10.5.4 specifies a minimum area of steel, Asmin. For slabs, this is set equal to the reinforcement required to prevent excessive temperature and shrinkage cracking (ACI 7.12.2)

Failure Scenarios #3 (too much steel). es >> ey. In this case, the beam has so much steel that even at ultimate conditions (ec = 0.003) the steel has not yielded. ACI 10.3.5 specifies that the strain in the extreme tension steel must be well beyond yield (et > 0.004) to prevent crushing the concrete before observable deformation.

**Distribute reinforcement.** Stress transfer from the rebar to the surrounding concrete is more effective if smaller-diameter closely-spaced rebar is used, rather than larger-diameter, widely-spaced rebar.

**Determine slab thickness.** Slab thickness is usually controlled by deflection considerations or fire ratings. ACI sets minimum thicknesses for beams and one-way slabs not supporting partitions likely to be damaged by deflections unless deflections are calculated in ACI Table 9.5a. Another consideration when selecting a slab thickness is fire rating. For example, the minimum slab thickness for a two-hour fire rating is 4.75 inches. Finally, since shear reinforcement is not used in one-way slabs, the concrete must be able to resist the maximum shear force.
Example: Floor Slab reinforcement detail

```
<table>
<thead>
<tr>
<th>Imperial Bar Size</th>
<th>&quot;Soft&quot; Metric Size</th>
<th>Mass per unit length</th>
<th>Nominal Diameter</th>
<th>Nominal Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>lb/ft (kg/m)</td>
<td>(inch) (mm)</td>
<td>(inch²) (mm²)</td>
</tr>
<tr>
<td>#2</td>
<td>#6</td>
<td>0.167 (0.249)</td>
<td>0.250 = ⅛</td>
<td>0.05 (2)</td>
</tr>
<tr>
<td>#3</td>
<td>#10</td>
<td>0.376 (0.561)</td>
<td>0.375 = ⅜</td>
<td>0.11 (71)</td>
</tr>
<tr>
<td>#4</td>
<td>#13</td>
<td>0.668 (0.996)</td>
<td>0.500 = ½</td>
<td>0.20 (129)</td>
</tr>
<tr>
<td>#5</td>
<td>#16</td>
<td>1.043 (1.556)</td>
<td>0.625 = ⅝</td>
<td>0.31 (200)</td>
</tr>
<tr>
<td>#6</td>
<td>#19</td>
<td>1.502 (2.24)</td>
<td>0.750 = ⅞</td>
<td>0.44 (284)</td>
</tr>
<tr>
<td>#7</td>
<td>#22</td>
<td>2.044 (3.049)</td>
<td>0.875 = ⅚</td>
<td>0.60 (387)</td>
</tr>
<tr>
<td>#8</td>
<td>#25</td>
<td>2.670 (3.982)</td>
<td>1.000 = ⅝</td>
<td>0.79 (509)</td>
</tr>
<tr>
<td>#9</td>
<td>#29</td>
<td>3.400 (5.071)</td>
<td>1.128 = ⅞</td>
<td>1.00 (645)</td>
</tr>
</tbody>
</table>
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Last updated Wednesday, December 16, 2015