CHAPTER 8: DESIGN OF ONE-WAY SLABS

8.1 Introduction

A slab is a structural element whose thickness is small compared to its own length and width. Slabs are usually used in floor and roof construction. According to the way loads are transferred to supporting beams and columns, slabs are classified into two types; one-way and two-way.

One-way slabs:
When the ratio of the longer to the shorter side \( L/S \) of the slab is at least equal to 2.0, it is called one-way slab, shown in Figure 8.1.a. Under the action of loads, it is deflected in the short direction only, in a cylindrical form. Therefore, main reinforcement is placed in the shorter direction, while the longer direction is provided with shrinkage reinforcement to limit cracking, as shown in Figure 8.1.b. When the slab is supported on two sides only, 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.
Two-way Slabs:

When the ratio \((L/S)\) is less than 2.0, it is called two-way slab, shown in Figure 8.2. Bending will take place in the two directions in a dish-like form. Accordingly, main reinforcement is required in the two directions.
8.2 One-way Slabs

In this section, two types will be discussed, one-way solid slabs and one-way ribbed slabs.

8.2.1 One-way Solid Slabs

8.2.1.1 Minimum Thickness

To control deflection, *ACI Code 9.5.2.1* specifies minimum thickness values for one-way solid slabs, shown in Table 8.1. 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 8.1: Minimum thickness of one-way solid slabs

<table>
<thead>
<tr>
<th>Element</th>
<th>Simply supported</th>
<th>One end continuous</th>
<th>Both ends continuous</th>
<th>Cantilever</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way solid slabs</td>
<td>( l/20 )</td>
<td>( l/24 )</td>
<td>( l/28 )</td>
<td>( l/10 )</td>
</tr>
</tbody>
</table>

where \( l \) is the span length in the direction of bending.

8.2.1.2 Minimum Concrete Cover

According to *ACI Code 7.7.1*, the following minimum concrete cover is to be provided:

a. Concrete not exposed to weather or in contact with ground:
   - Larger than \( \phi 36 \) mm bar: \( 4 \text{ cm} \)
   - \( \phi 36 \) mm and smaller bars: \( 2 \text{ cm} \)

b. Concrete exposed to weather or in contact with ground:
   - \( \phi 19 \) mm and larger bars: \( 5 \text{ cm} \)
   - \( \phi 16 \) mm and smaller bars: \( 4 \text{ cm} \)

c. Concrete cast against and permanently exposed to earth: \( 7.5 \text{ cm} \)

8.2.1.3 Design Concept

One-way solid slabs are designed as a number of independent 1 m wide strips which span in the short direction and supported on crossing beams.

8.2.1.4 Maximum Reinforcement Ratio

One-way solid slabs are designed as rectangular sections subjected to shear and moment. Thus, the maximum reinforcement ratio corresponds to a net strain in the reinforcement, \( \varepsilon_r \), of 0.004.

8.2.1.5 Shrinkage Reinforcement Ratio

According to *ACI Code 7.12.2.1* and for steels yielding at \( f_y = 4200 \text{ kg/cm}^2 \), the shrinkage reinforcement is taken not less than 0.0018 of the gross concrete area, or

\[
A_{\text{shrinkage}} = 0.0018 \times b \times h
\]

where, \( b = \) width of strip, and \( h = \) slab thickness.
8.2.1.6 Minimum Reinforcement Ratio

According to ACI Code 10.5.4, the minimum flexural reinforcement is not to be less than the shrinkage reinforcement, or \( A_{s,\text{min}} \geq 0.0018bh \).

8.2.1.7 Spacing Of Flexural Reinforcement Bars

Based on ACI 10.5.4, flexural reinforcement is to be spaced not farther than three times the slab thickness, nor farther apart than 45 cm, center-to-center.

8.2.1.8 Spacing Of Shrinkage Reinforcement Bars

Based on ACI 7.12.2.2, shrinkage reinforcement is to be spaced not farther than five times the slab thickness, nor farther apart than 45 cm, center-to-center.

8.2.1.9 Loads Assigned to Slabs

1. **Own weight of slab:**
   The weight of the slab per unit area is estimated by multiplying the thickness of the slab \( h \) by the density of the reinforced concrete, or \( h \gamma_c \).

2. **Weight of slab covering materials:**
   This weight per unit area depends on the type of finishing which is usually made of
   - Sand fill with a thickness of about 5 cm,
   \[ 0.05 \times 1.80 \, t/m^2 \]
   - Cement mortar, 2.5 cm thick.
   \[ 0.025 \times 2.10 \, t/m^2 \]
   - Tiling
   \[ 0.025 \times 2.30 \, t/m^2 \]
   - A layer of plaster about 2 cm in thickness.
   \[ 0.02 \times 2.10 \, t/m^2 \]

3. **Live Load:**
   It depends on the purpose for which the floor is constructed. Table 8.2 shows typical values used by the *Uniform Building Code (UBC)*.
Table 8.2: Minimum live Load values on slabs

<table>
<thead>
<tr>
<th>Type of Use</th>
<th>Uniform Live Load $kg/m^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>200</td>
</tr>
<tr>
<td>Residential balconies</td>
<td>300</td>
</tr>
<tr>
<td>Computer use</td>
<td>500</td>
</tr>
<tr>
<td>Offices</td>
<td>250</td>
</tr>
<tr>
<td>Warehouses</td>
<td></td>
</tr>
<tr>
<td>- Light storage</td>
<td>600</td>
</tr>
<tr>
<td>- Heavy Storage</td>
<td>1200</td>
</tr>
<tr>
<td>Schools</td>
<td></td>
</tr>
<tr>
<td>- Classrooms</td>
<td>200</td>
</tr>
<tr>
<td>Libraries</td>
<td></td>
</tr>
<tr>
<td>- Reading rooms</td>
<td>300</td>
</tr>
<tr>
<td>- Stack rooms</td>
<td>600</td>
</tr>
<tr>
<td>Hospitals</td>
<td>200</td>
</tr>
<tr>
<td>Assembly Halls</td>
<td></td>
</tr>
<tr>
<td>- Fixed seating</td>
<td>250</td>
</tr>
<tr>
<td>- Movable seating</td>
<td>500</td>
</tr>
<tr>
<td>Garages (cars)</td>
<td>250</td>
</tr>
<tr>
<td>Stores</td>
<td></td>
</tr>
<tr>
<td>- Retail</td>
<td>400</td>
</tr>
<tr>
<td>- Wholesale</td>
<td>500</td>
</tr>
<tr>
<td>Exit facilities</td>
<td>500</td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
</tr>
<tr>
<td>- Light</td>
<td>400</td>
</tr>
<tr>
<td>- Heavy</td>
<td>600</td>
</tr>
</tbody>
</table>

(4) Equivalent Partition Weight:

This load is usually taken as the weight of all walls carried by the slab divided by the floor area and treated as a dead load rather than a live load.

8.2.1.10 Loads Assigned to Beams

The beams are usually designed to carry the following loads:
- Their own weights.
- Weights of partitions applied directly on them.
- Floor loads.

The floor loads on beams supporting the slab in the shorter direction may be assumed uniformly distributed throughout their spans.
8.2.1.11 Approximate Structural Analysis

ACI Code 8.3.3 permits the use of the following approximate moments and shears for design of continuous beams and one-way slabs, provided:

- There are two or more spans.
- Spans are approximately equal, with the larger of two adjacent spans not greater than the shorter by more than 20 percent.
- Unfactored live load, \(L\) does not exceed three times unfactored dead load, \(D\).
-Loads are uniformly distributed.
- Members are prismatic (similar moment of inertia along their lengths).

For calculating negative moments, \(l_n\) is taken as the average of the adjacent clear span lengths.

The *ACI Code* gives the moments at mid spans and at faces of supports, as follows.

1. **Positive Moment:**
   
   a. **End Spans:**
      
      - When discontinuous end unrestrained, \(M_u = w_u l_n^2 / 11\)
      - When discontinuous end is integral with support, \(M_u = w_u l_n^2 / 14\)
      
      where \(l_n\) is the corresponding clear span length

   b. **Interior Spans:**
      
      - \(M_u = w_u l_n^2 / 16\)

2. **Negative Moment:**
   
   a. **Negative moment at exterior face of first interior support:**
      
      - Two spans, \(M_u = w_u l_n^2 / 9\)
      - More than two spans, \(M_u = w_u l_n^2 / 10\)
      
      where \(l_n\) is the average of adjacent clear span lengths.

   b. **Negative moment at other faces of interior supports:**
      
      - \(M_u = w_u l_n^2 / 11\)

   c. **Negative moment at interior face of exterior support:**
      
      - Support is edge beam, \(M_u = w_u l_n^2 / 24\)
      - Support is a column, \(M_u = w_u l_n^2 / 16\)
3. Shear:

   a. Shear in end members at face of first interior support:
      \[ V_u = 1.15 \frac{w_u l_n}{2} \]

   b. Shear at face of all other supports:
      \[ V_u = \frac{w_u l_n}{2} \]

   where \( l_n \) is the corresponding clear span length

See Figure 8.3 for shear force and bending moment coefficients.

![Figure 8.3: (a) Two spans, exterior edge unrestrained; (b) two spans, support is spandrel beam; (c) more than two spans, exterior edge unrestrained; (d) more than two spans, support is spandrel beam; (e) two spans, shearing force diagram](image)

8.2.1.12 Summary of One-way Solid Slab Design Procedure

Once design compressive strength of concrete and yield stress of reinforcement are specified, the next steps are followed:

1. Select representative 1 \( m \) wide design strip/strips to span in the short direction, as shown in Figure 8.4.a.

2. Choose a slab thickness to satisfy deflection control requirements. When several numbers of slab panels exist, select the largest calculated thickness.

3. Calculate the factored load \( w_u \) by magnifying service dead and live loads according to this equation \( w_u = 1.20 w_d + 1.60 w_l \). The dead load includes own weight of the slab in
addition to the covering materials it supports. The live load is dependent on the intended use of the slab.

Figure 8.4: (a) Representative strip and reinforcement; (b) strip and loads

4. Draw the shear force and bending moment diagrams for each of the strips as shown in Figure 8.4.b.

5. Check adequacy of slab thickness in terms of resisting shear by satisfying the following equation:

\[ V_u \leq 0.53 \Phi \sqrt{f_c} b d \]

where

\( V_u \) = factored shear force

\( V_c \) = shear force resisted by concrete alone

\( \Phi \) = strength reduction factor for shear is equal to 0.75.

\( b \) = width of strip = 100 cm

\( d \) = effective depth of slab

If the previous equation is not satisfied, go ahead and enlarge the thickness to do so.
6. Design flexural and shrinkage reinforcement:

Flexural reinforcement ratio is calculated from the following equation:

\[
\rho = \frac{0.85 f'_c}{f_y} \left[ 1 - \sqrt{1 - \frac{2.353 \times 10^5 M_u}{\Phi b d^2 f'_c}} \right]
\]

Make sure that the net tensile strain in the reinforcement, \( \varepsilon_t \), doesn't exceed 0.004.

Compute the area of shrinkage reinforcement, where \( A_{\text{min}} = 0.0018 b h \).

Select appropriate bar numbers and diameters for both, main and secondary reinforcement.

Check reinforcement spacing, modify your bar selection if needed.

7. Draw a plan of the slab and representative cross sections showing the dimensions and the selected reinforcement, as shown in Figure 8.4.a and Figure 8.4.c.

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8.2.2 One-Way Ribbed Slabs

Since resistance of concrete in tension is too small compared with that in compression, concrete in the tension zone may be gathered in regularly spaced ribs cast monolithically with topping slab on top of these ribs. Hollow blocks made of lightweight concrete or other materials are arranged between the ribs or the voids between ribs are left out without any filling material. The use of these blocks makes it possible to have smooth ceiling which is often required for architectural or hygienic considerations and have good sound and temperature insulating properties besides reducing the dead load of the slab greatly.

Ribbed slab floors are most economical for buildings such as hospitals, schools, hotels, and apartment construction where loads are somewhat small and the spans are relatively large.
There are two main types of ribbed floors (a) hollow block floors and (b) moulded floors as shown in Figure 8.5. Each type of floor consists of number of reinforced concrete ribs spanning in the short directions supporting a thin topping slab above. The hollow block floor is most suitable for small irregularly shaped floors as the hollow blocks can be easily fitted into the irregular shapes. On the other hand, for large symmetrically supported floors, the moulded type of floor is most suitable and economical. Steel or fiberglass moulds can be used for temporary formwork.

Ribbed slabs can be used in one-way and two-way edge supported slabs. Either drop or hidden beams can be used to support these slabs depending on the span.

If the ribs are provided in one direction only, the slab is classified as being one-way, regardless of the ratio of longer to shorter panel dimensions.

8.2.2.1 Key Components

The ribbed slab consists of the following key components, shown in Figure 8.6:

a. Topping slab:

According to ACI Code 8.13.6.1, topping slab thickness is not to be less than 1/12 the clear distance between ribs, nor less than 5.0 cm. The topping slab is designed as a continuous beam supported by the ribs. Due to the large number of supporting ribs, the maximum
bending moment is taken as \( \frac{w_u l_c^2}{12} \) where \( w_u \) is the factored load resisted by the topping slab and \( l_c \) is the clear distance between ribs.

The topping slab thickness \( t \) is evaluated by conservatively considering it made of plain concrete and subjected to the maximum moment given above.

The modulus of rupture \( f_r \) is given by \( f_r = 2 \sqrt{f_c} = \frac{M_u (t/2)}{\Phi b (t^3/12)} \) or

\[
t = \frac{3 M_u}{\Phi b \sqrt{f_c} t^3/12}
\] (8.1)

where

\( t \) = topping slab thickness

\( M_u \) = factored bending moment

\( \Phi \) = strength reduction factor for flexure

\( b \) = web width

Shrinkage reinforcement is provided in the topping slab in both directions in a mesh form.

b. Regularly spaced ribs:

Minimum dimensions:

According to \( ACI \) Code 8.13.2, ribs are not to be less than 10 cm in width, and a depth of not more than 3.5 times the minimum web width. Clear spacing between ribs is not to exceed 75.0 cm as specified by \( ACI \) Code 8.13.3.

Loads:

The load on ribs consists of dead and live loads. The dead load includes own weight of the slab, weight of the surface finish, and equivalent partition load. The live load is dependant on the intended use of the building.

Direction:

In one-way ribbed slabs ribs may be arranged in any of the two principal directions. Two options are possible; the first is by providing ribs in the shorter direction as shown in Figure 8.7.a, which leads to smaller amounts of reinforcement in the ribs, while large
amounts of reinforcement are required in the supporting beams, associated with large deflections. The second option is by providing ribs in the longer direction as shown in Figure 8.7.b, which leads to larger amount of reinforcement in the ribs, while smaller amounts of reinforcement are required in the supporting beams associated with smaller deflections compared to the first option.

Figure 8.7: Arrangement of ribs: (a) ribs are arranged in the shorter direction; (b) ribs are arranged in the longer direction
The designer has to make up his mind regarding the option he prefers. Some designers opt to run the ribs in a direction that leads to smaller moments and shears in the supporting beams which means much more reinforcement in the ribs. Other designers opt to run the ribs in the shorter direction which leads to much more reinforcement in the supporting beams. The later option leads to more economical design.

Shear strength:
According to *ACI Code* 8.13.8, shear strength provided by rib concrete $V_c$ may be taken 10% greater than those for beams. It is permitted to increase shear strength using shear reinforcement or by widening the ends of ribs.

Although shear reinforcement is not often required, it is recommended to use 4 φ 6 mm stirrups per meter run,

Flexural strength:
Ribs are designed as rectangular beams in the regions of negative moment at the supports and as T-shaped beams in the regions of positive moments between the supports. Effective flange width $b_e$ is taken as half the distance between ribs, center-to-center.

c. Hollow blocks:
Hollow blocks are made of lightweight concrete or other lightweight materials. They are commercially available in standard sizes and shapes. The most common concrete hollow block sizes are $40 \times 25 \text{ cm}$ in plan and heights of 14, 17, 20, and 24 cm.

### 8.2.2.2 Minimum Thickness
To control deflection, *ACI Code* 9.5.2.1 specifies minimum thickness values for one-way ribbed slabs, shown in Table 8.3. 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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<thead>
<tr>
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<th>Both ends continuous</th>
<th>Cantilever</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-way ribbed slabs</td>
<td>l/16</td>
<td>l/18.5</td>
<td>l/21</td>
<td>l/8</td>
</tr>
</tbody>
</table>
8.2.2.3 Summary of One-way Ribbed Slab Design Procedure

Once design compressive strength of concrete and yield stress of reinforcement are specified, the next steps are followed:

1. The direction of ribs is chosen.
2. The overall slab thickness $h$ is determined based on deflection control requirement. Also, thickness of topping slab $t$, rib width $b$, and hollow block size, if any, are to be determined based on code requirements.
3. The factored load on each of the ribs is computed.
4. The shear force and bending moment diagrams using the load evaluated in step 3 are drawn.
5. The strength of web in shear is checked.
6. Design positive and negative moment reinforcement. Clear distance between bars is to be checked to guarantee a free flow of concrete.
7. Neat sketches showing arrangement of ribs and details of the reinforcement are to be prepared.