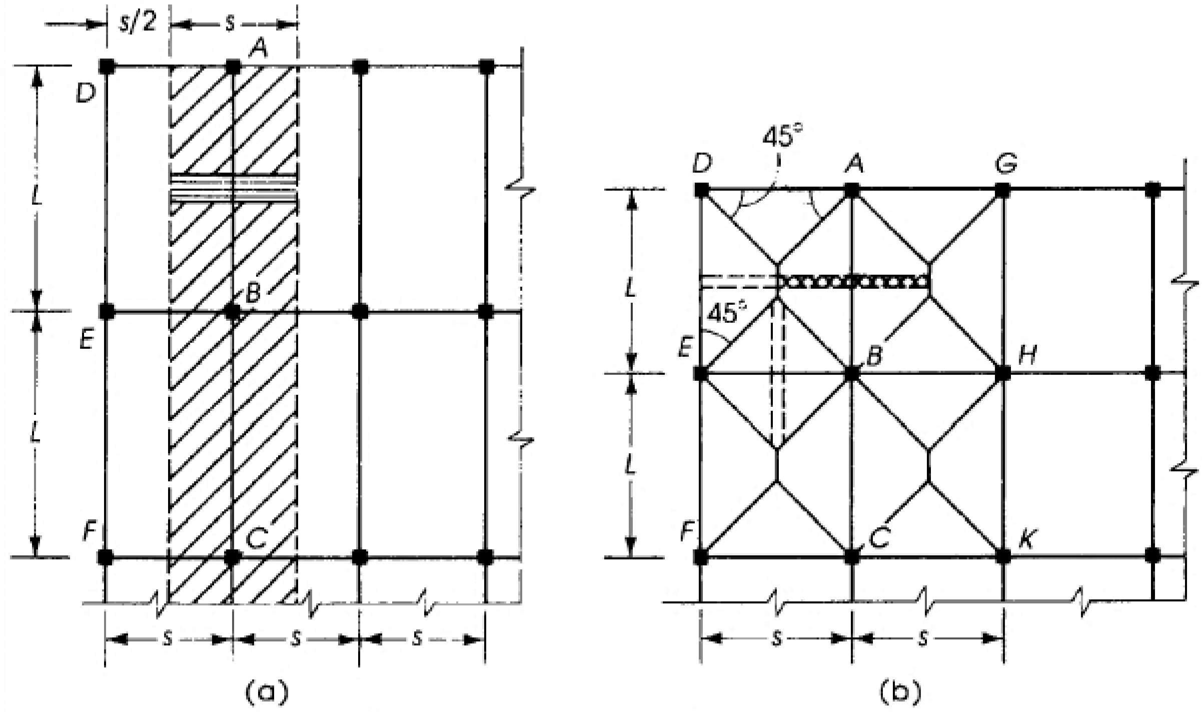
4. Two-Way Slabs

4.1 Introduction

When the slab is supported on all four sides and the length L , is less than twice the width, , the slab will deflect in two directions, and the loads on the slab are transferred to all four supports. This slab is referred to as a two-way slab. The bending moments and deflections in such slabs are less than those in one-way slabs; thus, the same slab can carry more load when supported on four sides. The load in this case is carried in two directions, and the bending moment in each direction is much less than the bending moment in the slab if the load were carried in one direction only.



Slab loads on supporting beams:

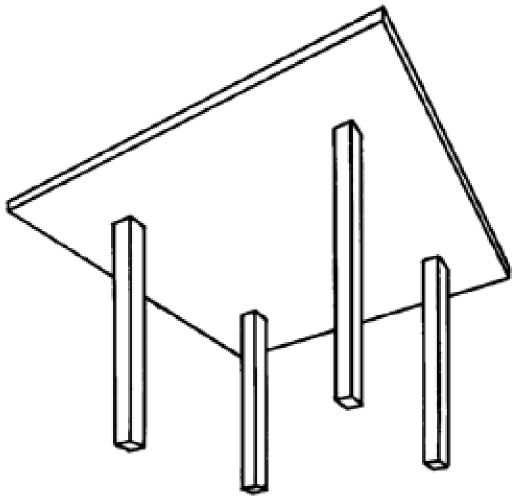
(*a*) one-way direction, $L/s > 2$; (*b*) two-way direction, $L/s \leq 2$.

4.2 TYPES OF TWO-WAY SLABS

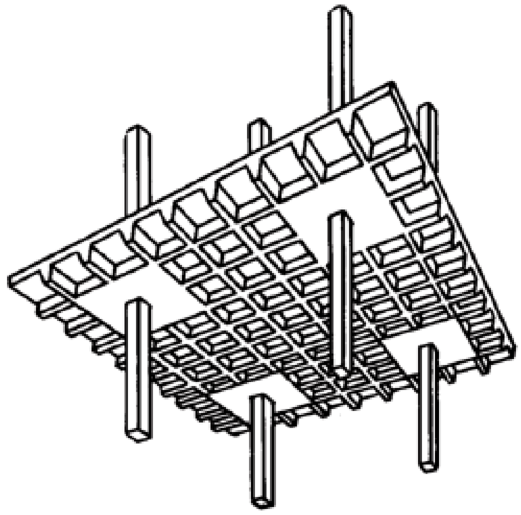
Structural two-way concrete slabs may be classified as follows:

1. **Two-Way Slabs on Beams:** This case occurs when the two-way slab is supported by beams on all four sides. The loads from the slab are transferred to all four supporting beams, which, in turn, transfer the loads to the columns.

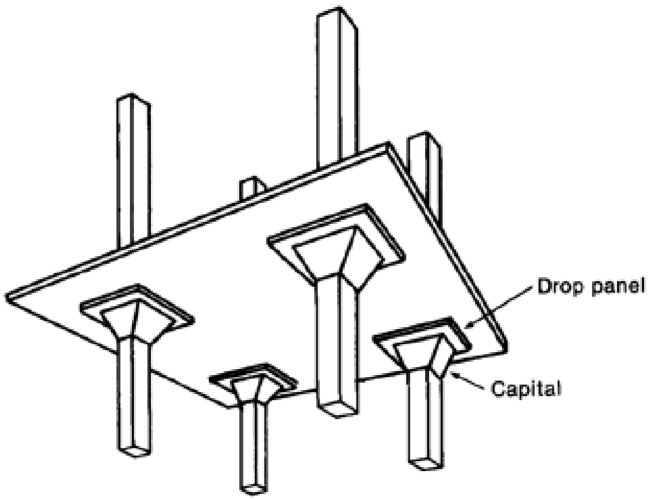
2. **Flat Slabs**: A flat slab is a two-way slab reinforced in two directions that usually does not have beams or girders, and the loads are transferred directly to the supporting columns. The column lends to punch through the slab, which can be treated by three methods:



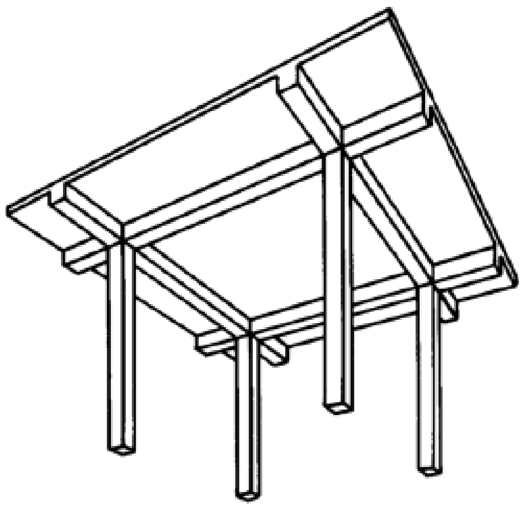
(a) Flat plate.



(b) Waffle slab.



(c) Flat slab.



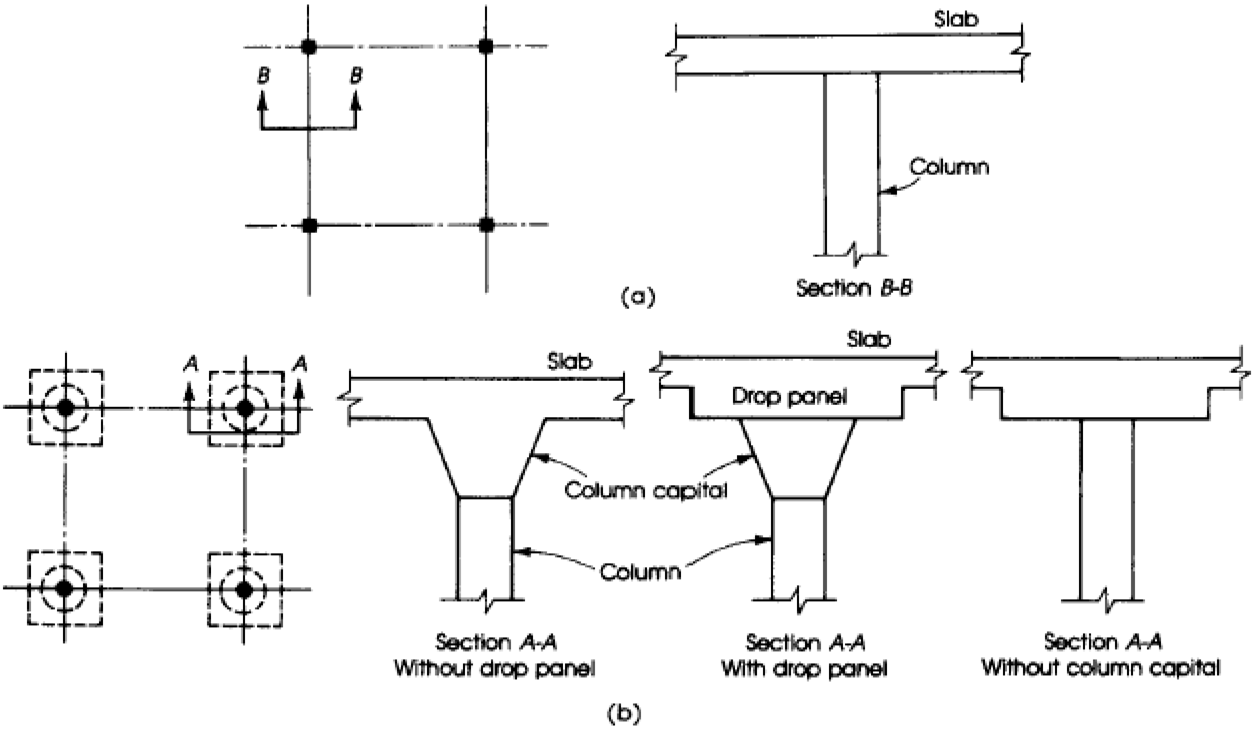
(d) Two-way slab with beams.

a. Using a drop panel and a column capital.

b. Using a drop panel without a column capital. The concrete panel around the column capital should be thick enough to withstand the diagonal tensile stresses arising from the punching shear.

c. Using a column capital without drop panel, which is not common.

3. **Flat-Plate Floors:** A flat-plate floor is a two-way slab system consisting of a uniform slab that rests directly on columns and does not have beams or column capitals (Fig. a). In this case the column tends to punch through the slab, producing diagonal tensile stresses. Therefore, a general increase in the slab thickness is required or special reinforcement is used.



Two-way slabs without beams:

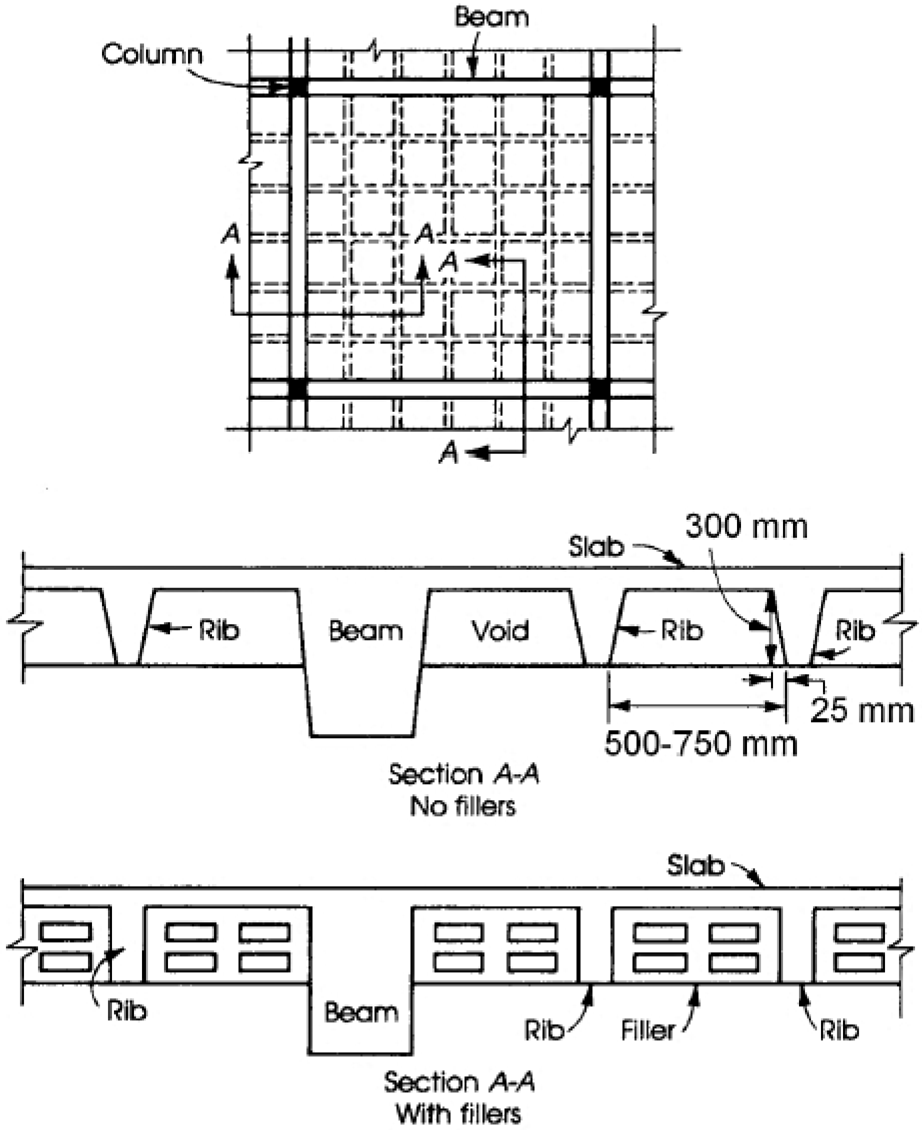
(*a*) flat plate floor and section; (*b*) flat slab floor and sections; (*c*) ribbed slab and sections.

4. **Two-Way Ribbed Slabs and the Waffle Slab System**: This type of slab consists of a floor slab with a length-to-width ratio less than 2. The thickness of the slab is usually 5 to 10 cm and is supported by ribs (or joists) in two directions. The ribs are arranged in each direction at spacing of about **50 cm** to **75 cm**, producing square or rectangular shapes. The ribs can also be arranged at **45° or 60°** from the centerline of slabs, producing architectural shapes at the soffit of the slab. In two-way ribbed slabs, different systems can be adopted:

a. **A two-way rib system with voids between the ribs**, obtained by using special removable and usable forms (pans) that are normally square in shape. The ribs are supported on four sides by girders that rest on columns. This type is called a two-way ribbed (joist) slab system.

b. **A two-way rib system with permanent fillers between ribs** that produce horizontal slab soffits. The fillers may be of hollow, lightweight or normal-weight concrete or any other lightweight material. The ribs are supported by girders on four sides, which in turn are supported by columns. This type is also called a two-way ribbed (joist) slab system or a hollow-block two-way ribbed system.

c. A two-way rib system with voids between the ribs with the ribs continuing in both directions without supporting beams and resting directly on columns through solid panels above the columns. This type is called a waffle slab system.



(c)

4.3 ECONOMICAL CHOICE OF CONCRETE FLOOR SYSTEMS

Various types of floor systems can be used for general buildings, such as residential, office, and institutional buildings. The choice of an adequate and economic floor system depends on the type of building, architectural layout, aesthetic features, and the span length between columns. In general, the superimposed live load on buildings varies between **4 and 7 kN/m^2**. A general guide for the economical use of floor systems can be summarized as follows:

1. **Flat Plates:** Flat plates are most suitable for spans of **6 to 8 m** and live loads between **3 and 5 kN/m^2**. The advantages of adopting flat plates include low-cost formwork, exposed flat ceilings, and fast construction. Flat plates have low shear capacity and relatively low stiffness, which may cause noticeable deflection. Flat plates are widely used in buildings either as reinforced or prestressed concrete slabs.

2. **Flat Slabs:** Flat slabs are most suitable for spans of **6 to 9 m** and for live loads of **4 to 7 kN/m^2**. They need more formwork than flat plates, especially for column capitals. In most cases, only drop panels without column capitals are used.
3. **Waffle Slabs**: Waffle slabs are suitable for spans of **9 to 15 m** and for live loads of **4 to 7 kN/m^2**. They carry heavier loads than flat plates and have attractive exposed ceilings. Formwork, including the use of pans, is quite expensive.
4. Slabs on Beams: Slabs on beams are suitable for spans between **6 and 9 m** and live loads of **3 to 6 kN/m^2**. The beams increase the stiffness of the slabs, producing relatively low deflection. Additional formwork for the beams is needed.
5. **One-Way Slabs on Beams**: One-way slabs on beams are most suitable for spans of **3 and 6 m** and a live load of **3 to 5 kN/m^2**. They can be used for larger spans with relatively higher cost and higher slab deflection. Additional formwork for the beams is needed.
6. **One-Way Joist Floor System**: A one-way joist floor system is most suitable for spans of **6 to 9 m** and live loads of **4 to 6 kN/m^2**. Because of the deep ribs, the concrete and steel quantities are relatively low, but expensive formwork is expected. The exposed ceiling of the slabs may look attractive.

4.4 MINIMUM THICKNESS OF TWO-WAY SLABS.

The ACI Code, Section 9.5.3, specifies a minimum slab thickness in two-way slabs to control deflection. The magnitude of a slab's deflection depends on many variables, including the flexural stiffness of the slab, which in turn is a function of the slab thickness. By increasing the slab thickness, the flexural stiffness of the slab is increased, and consequently the slab deflection is reduced. Because the calculation of deflections in two-way slabs is complicated and to avoid excessive deflections, the ACI Code limits the thickness of these slabs by adopting the following three empirical limitations, which are based on experimental research. If these limitations are not met, it will be necessary to compute deflections.

1. For $0.2 \leq \alpha_{fm} \leq 2$

$$h = \frac{l_n\left(0.8 + \frac{f_y}{1400}\right)}{36 + 5\beta\left(\alpha_{fm} - 0.2\right)} \qquad (*)$$

but not less than 125 mm.

2. For $\alpha_{fm} > 2$

$$h = \frac{l_n\left(0.8 + \frac{f_y}{1400}\right)}{36 + 9\beta} \qquad (**)$$

but not less than 90 mm.

3. For $\alpha_{fm} < 0.2$

$$h = \textit{minimum slab thickness without interior beams } (Table\ 9.5(c))$$

where

$l_n -$ clear span in the long direction measured face to face of columns (or face to face of beams for slabs with beams).

$\beta -$ the ratio of the long to the short clear spans.

$\alpha_{fm} -$ the average value of α_f for all beams on the sides of a panel.

$\alpha_f -$ the ratio of flexural stiffness of a beam section $E_{cb}I_b$ to the flexural stiffness of the slab $E_{cs}I_s$, bounded laterally by the centerlines of the panels on each side of the beam.

$$\alpha_f = \frac{E_{cb}I_b}{E_{cs}I_s}$$

where E_{cb}, and E_{cs} are the moduli of elasticity of concrete in the beam and the slab, respectively, and

$I_b -$ the gross moment of inertia of the beam section about the centroidal axis (the beam section includes a slab length on each side of the beam equal to the projection of the beam above or below the slab, whichever is greater, but not more than four times the slab thickness)

$I_s -$ the moment of inertia of the gross section of the slab.

However, the thickness of any slab shall not be less than the following:

1. For slabs with $\alpha_{fm} \leq 2$ then thickness $\geq 125\ mm$.
2. For slabs with $\alpha_{fm} > 2$ then thickness $> 90\ mm$.

If no beams are used, as in the case of flat plates, then $\alpha_f = 0$ and $\alpha_{fm} = 0$. The ACI Code equations for calculating slab thickness, h, take into account the effect of the span length, the panel shape, the steel reinforcement yield stress, f_y, and the flexural stiffness of beams. When very stiff beams are used, Eq. ($*$) may give a small slab thickness, and Eq. ($**$) may control. For flat plates and flat slabs, when no interior beams are used, the minimum slab thickness may be determined directly from Table 9.5(c) of the ACI Code, which is shown here.

TABLE 9.5(c)—MINIMUM THICKNESS OF SLABS WITHOUT INTERIOR BEAMS*

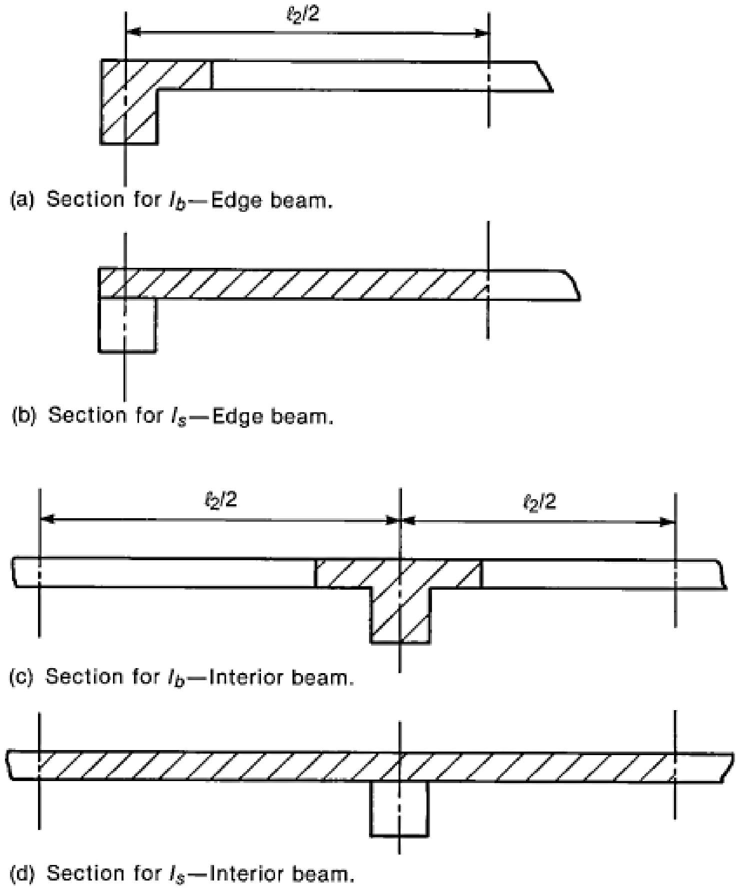
	Without drop panels‡			With drop panels‡		
	Exterior panels		Interior panels	Exterior panels		Interior panels
f_y, MPa†	Without edge beams	With edge beams§		Without edge beams	With edge beams§	
280	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$	$\ell_n/36$	$\ell_n/40$	$\ell_n/40$
420	$\ell_n/30$	$\ell_n/33$	$\ell_n/33$	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$
520	$\ell_n/28$	$\ell_n/31$	$\ell_n/31$	$\ell_n/31$	$\ell_n/34$	$\ell_n/34$

*For two-way construction, ℓ_n is the length of clear span in the long direction, measured face-to-face of supports in slabs without beams and face-to-face of beams or other supports in other cases.

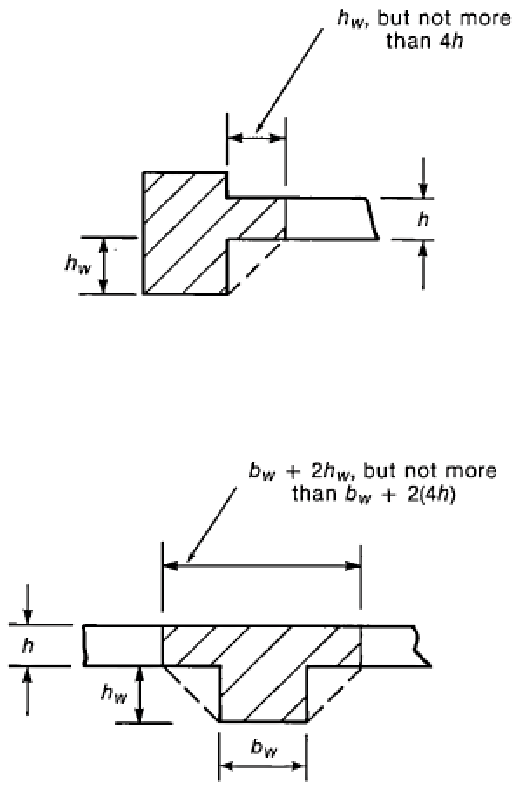
†For f_y between the values given in the table, minimum thickness shall be determined by linear interpolation.

‡Drop panels as defined in 13.2.5.

§Slabs with beams between columns along exterior edges. The value of α_f for the edge beam shall not be less than 0.8.



Beam and slab sections for calculations of α_f



Cross section of beams as defined in ACI Code Section 13.2.4.