DESIGN OF SLABS

Department of Structures and Materials Engineering
Faculty of Civil and Environmental Engineering
University Tun Hussein Onn Malaysia

Introduction

Types of Slab

- Slabs are plate elements forming floors and roofs in buildings which normally carry uniformly distributed loads.
- Slabs may be simply supported or continuous over one or more supports and are classified according to the method of support as follows:
  - Spanning one way between beams or walls
  - Spanning two ways between the support beams or walls
  - Flat slabs carried on columns and edge beams or walls with no interior beams
- Slabs may be solid of uniform thickness or ribbed with ribs running in one or two directions. Slabs with varying depth are generally not used.

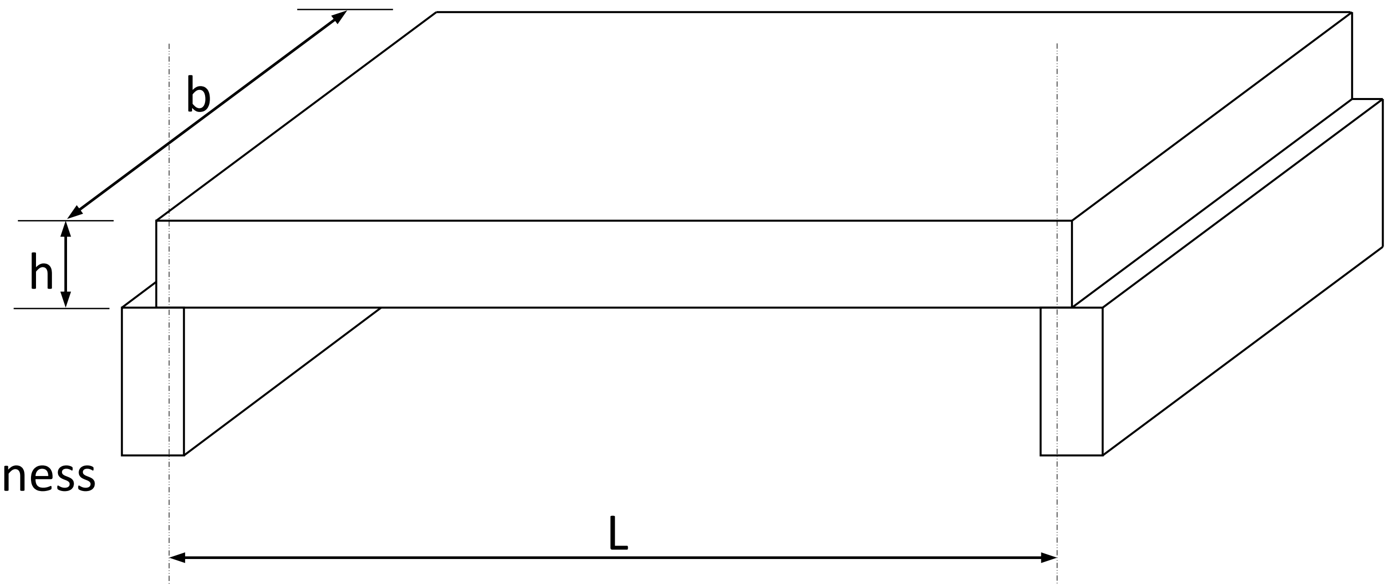
Introduction

- Slab are horizontal plate elements forming floor and roof in building and normally carry lateral actions.
- Slabs may be solid of uniform thickness or ribbed with ribs running in one or two direction.

L = Span

B = width

H = depth or thickness



Introduction

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  - Spanning one way between beams or walls
  - Spanning two ways between the support beams or walls
  - Flat slabs carried on columns and edge beams or walls with no interior beams
- Type of slab:
  - **One-way solid slab**: Slabs of uniform thickness bending and reinforced in one direction. **Suitable only for relatively short spans**.
  - **Two-way solid slab**: Slabs of uniform thickness bending and reinforced in two directions. **Economical for medium spans with intermediate to heavy loads**.

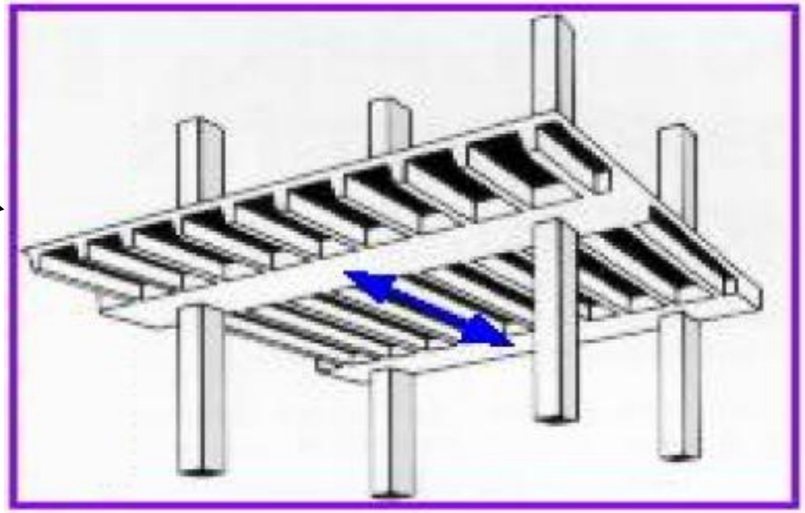
Introduction

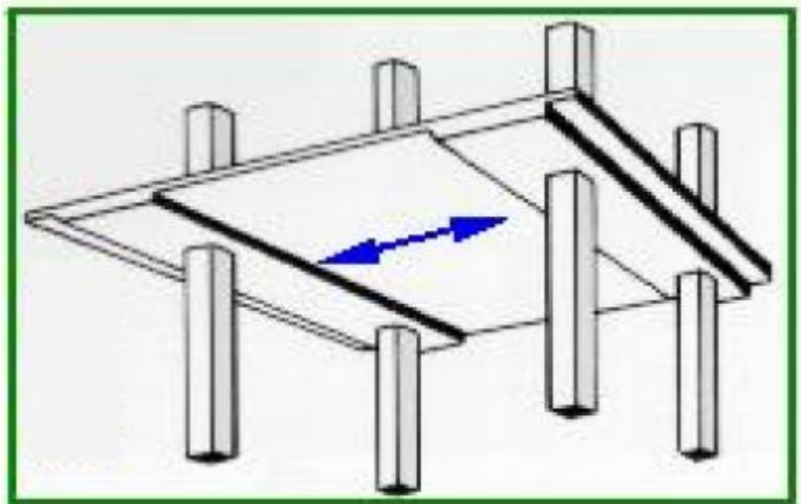
- **Ribbed slabs**: Slab cast integrally with a series of closely spaced joist which in turn are supported by a set of beams. Designed as a series of parallel T-beams **and economical for medium spans with light to medium live loads**.
- **Waffle slabs**: A two-way slab reinforced by ribs in two-dimensions. Able to **carry heavier loads and span longer than ribbed slabs**.
- **Flab slabs**: Slabs of uniform thickness bending and reinforced in two directions and supported directly by columns without beams.
- **Flat slabs with drop panel**: Flat slab thickness at its column supports with column capitals or drop panels to increase strength and moment-resisting capacity. **Suitable for heavily loaded span**.

Introduction

One-way slab

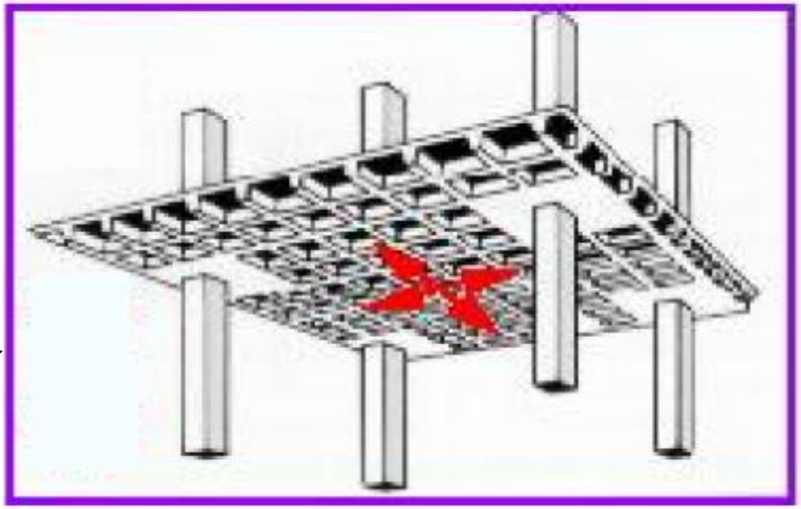
Ribbed slab





One-way slab

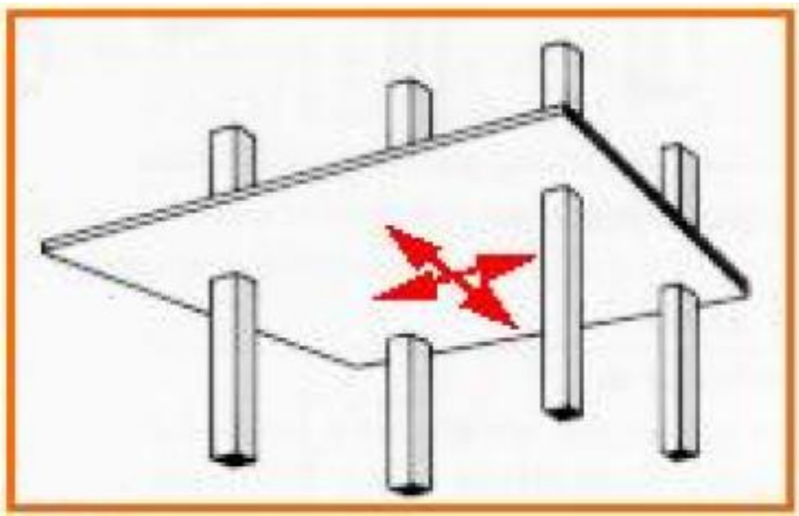
Waffle slab

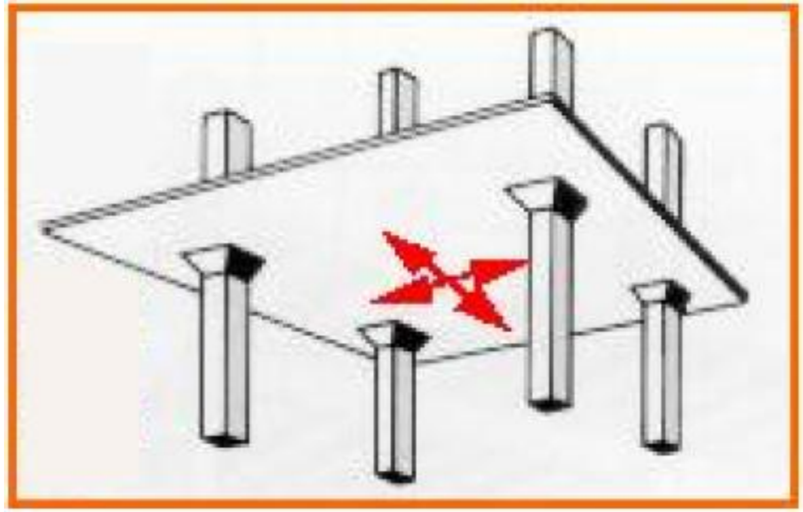


two-way slab

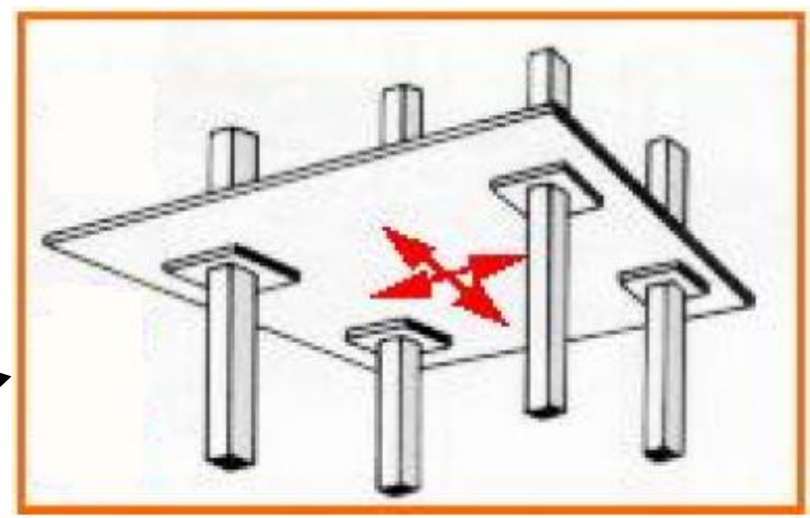
Introduction

Flat slab





Flat slab with drop panel



two-way slab

Introduction

This is a band beam and slab construction, where shallow band beams are used to minimise the depth

One-way slab

Introduction

Solid slab

Introduction

Flat slab without drop panel

Introduction

Drop panel

Flat slab with drop panel

Introduction

Waffle slab

Introduction

One-way Ribbed slab

Introduction

Precast concrete slab

Analysis of Slab

- Slabs may be analysed using the following methods.
  - **Elastic analysis** covers three techniques:

    (a) idealization into strips or beams spanning one way or a grid with the strips spanning two ways

    (b) elastic plate analysis

    (c) finite element analysis—the best method for irregularly shaped slabs or slabs with non-uniform loads
  - For the method of **design coefficients** use is made of the moment and shear coefficients given in the code, which have been obtained from yield line analysis.
  - The **yield line** and **Hillerborg strip methods** are limit design or collapse loads methods.

Design Procedure

- RC slab behave primarily as flexural members with the design similar to that for beams.
- In general, the design of slab become more simpler because compression reinforcement are often not required and the shear stress are usually low except when there are heavy concentrated load.
- A design procedure for carrying out detail design of slab may be list out as follows;

Design procedure of slab

Step	Task	Standard
1	Determine design life, Exposure class & Fire resistance	EN 1990 Table 2.1 EN 1992-1-1: Table 4.1 EN 1992-1-2: Sec. 5.6
2	Determine material strength	BS 8500-1: Table A.3 EN 206-1: Table F1
3	Select size of thickness of slab	EN 1992-1-1: Table 7.4N EN 1992-1-2: Table 5.8
4	Calculate min. cover for durability , fire and bond requirements	EN 1992-1-1: Sec. 4.4.1
5	Estimate actions on slabs	EN 1991-1-1
6	Analyze structure to obtain critical moments and shear forces	EN 1992-1-1: Sec. 5
7	Design flexural reinforcement	EN 1992-1-1: Sec. 6.1
8	Check shear	EN 1992-1-1: Sec. 6.2
9	Check deflection	EN 1992-1-1: Sec. 7.4
10	Check cracking	EN 1992-1-1: Sec. 9.3
11	Detailing	EN 1992-1-1: Sec.8 & 9.3

Slab Thickness

- The selection of slab thickness from structural viewpoint is often dictated by deflection control criteria. In practice, the overall depths of slabs are often fixed in relation to their spans.

- Span to overall depth ratios of 20 to 30 are generally found to be economical in the case of simply supported and continuous slabs.

$$h = \frac{L}{20} \rightarrow \frac{L}{30}$$

- Beside of that, slab thickness also control by fire resistance as state in EC2-1-2 (Table 5.8).

Slab Thickness

Table 5.8: Minimum dimensions and axis distances for reinforced and prestressed concrete simply supported one-way and two-way solid slabs

Standard fire resistance	Minimum dimensions (mm)			
	slab thickness h_s (mm)	axis-distance a		
		one way	two way: $l_y/l_x \le 1,5$	two way: $1,5 < l_y/l_x \le 2$
1	2	3	4	5
REI 30	60	10*	10*	10*
REI 60	80	20	10*	15*
REI 90	100	30	15*	20
REI 120	120	40	20	25
REI 180	150	55	30	40
REI 240	175	65	40	50

l_x and l_y are the spans of a two-way slab (two directions at right angles) where l_y is the longer span.

For prestressed slabs the increase of axis distance according to 5.2(5) should be noted.

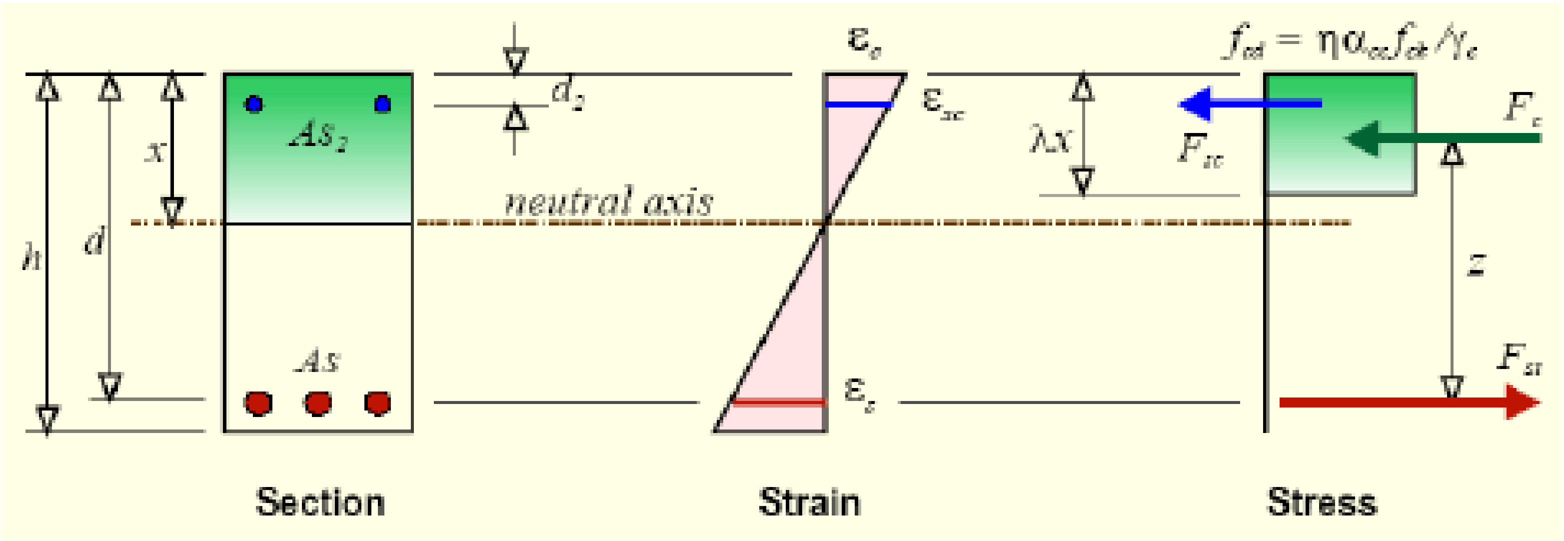
The axis distance a in Column 4 and 5 for two way slabs relate to slabs supported at all four edges. Otherwise, they should be treated as one-way spanning slab.

* Normally the cover required by EN 1992-1-1 will control.

Design of Flexural Reinforcement

The design procedure for flexural design in Figure 2. The derived formula is based on the following simplified stress block.

EN 1992-1-1: Sec. 6.1



f_{ck} = characteristic concrete cylinder strength (*equivalent to 80% cube strength*).

Design of Flexural Reinforcement

- The calculations for flexural reinforcement follow a similar procedure to that use in beam design.

1) Calculate $K = \dfrac{M}{bd^2 f_{ck}}$

2) If $K \leq K_{bal}$ (= 0.167), compression reinforcement is not required, and

   i. $z = d\left[0.5 + \sqrt{(0.25 - K/1.134)}\right]$

   ii. $A_s = \dfrac{M}{0.87 f_{yk} z}$

Shear

- Shear stress in slabs subjected to uniformly distributed loads are generally small. It is not usual for a slab to provide shear reinforcement.
- It is necessary to ensure that design ultimate shear force, V_{ed} is less than shear strength of the unreinforced section, $V_{Rd,c}$.

$$V_{Rd,c} = [0.12k(100\rho_1 f_{ck})^{1/3}]b_w d \geq [0.035k^{3/2} f_{ck}^{1/2}]b_w d$$

$$k = [1 + (200/d)^{1/2}] \leq 2.0 \; d \; in \; mm$$

$$\rho_1 = (A_{s1}/b_w d) \leq 0.02$$

A_{s1} = the area of tensile reinforcement that extends $\geq (l_{bd} + d)$ beyond the section considered.

b_w = the smallest width of the section in tensile area (mm)

Deflection

- Excessive deflection of slabs will cause damage to the ceiling, floor finishes or other architectural finishes.

- To avoid this, limit are set on the span-depth ratio. These limit are similarly to limit for beams.

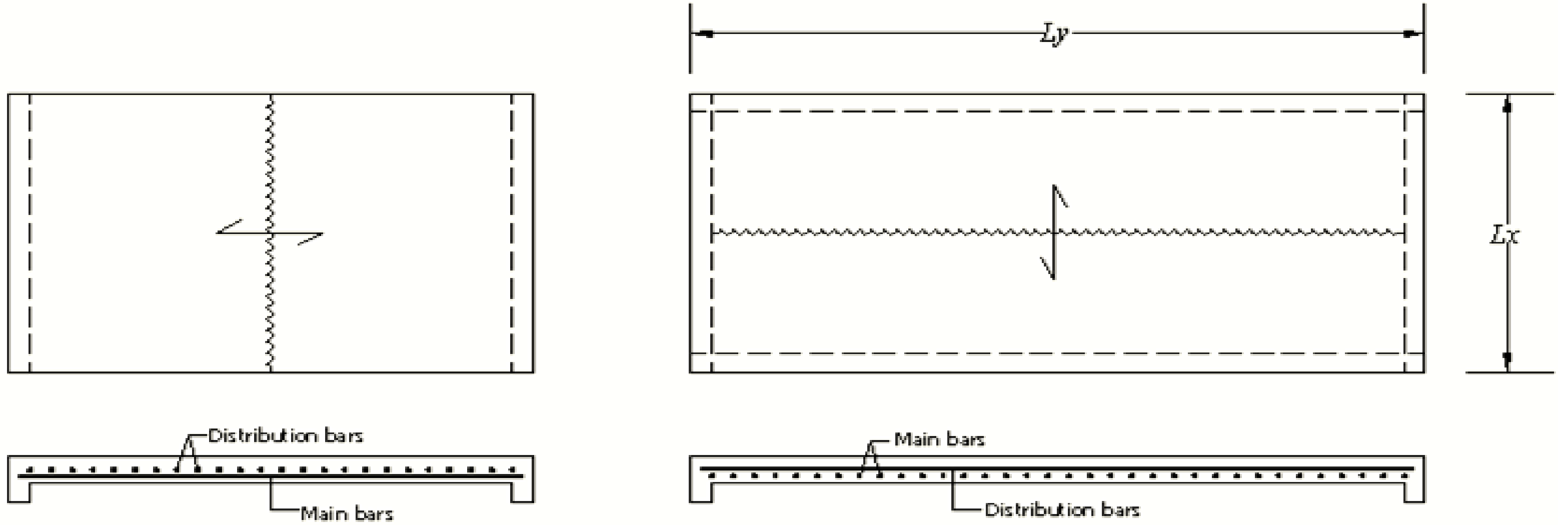
- As a slab is usually a slender member, the restrictions on the span-depth ratio become more important and this can often control the depth of slab required.

Cracking

- To resist cracking of the concrete slabs, EC2 (Sec. 7.3.3) specify details such as minimum area of reinforcement required in a section and limits to the maximum and minimum spacing of bar.
- The minimum area of principal reinforcement is $A_{s,min} = 0.26 f_{ctm} b_t d / f_{yk}$ but not less than $0.0013 b_t d$, where b_t is the mean width of the tension zone.
- The minimum area of secondary reinforcement is 20% $A_{s,min}$. In areas near support, transverse reinforcement is not necessary where there is no transverse bending moment.
- The spacing of principal reinforcement bars should not exceed three times the overall depth of slab (3h) or 400 mm whichever is the lesser. For secondary reinforcement the spacing should not exceed 3.5h or 450 mm whichever the lesser. These rules apply for slabs not exceeding 200 mm thick.

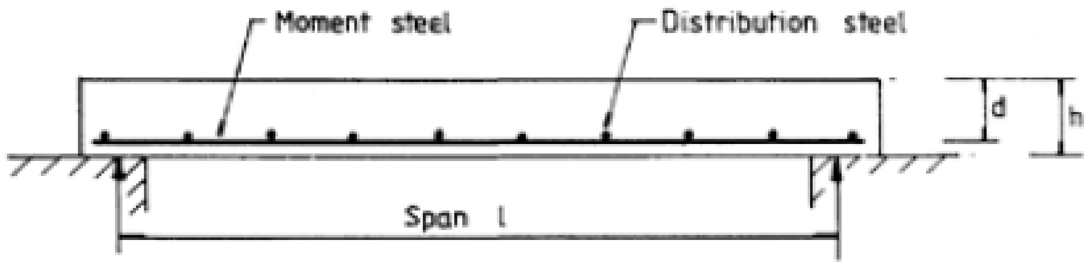
Design of One-Way Slab

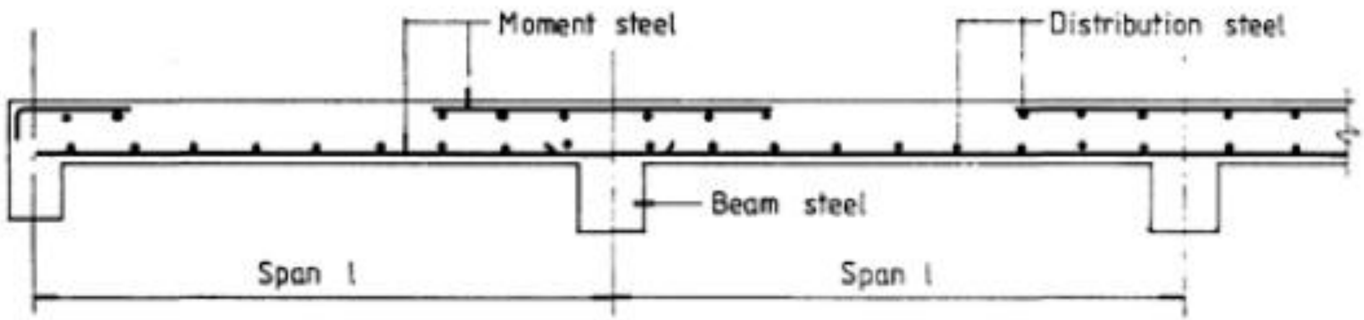
- Slab are considered as one-way if the main reinforcement is designed only in one direction. This condition occur if the slab supported by two side of beam or walls.
- If slab supported by four side of beams or walls, the slab is considered one-way if ratio of long span (Ly) to short span (Lx) **greater than 2**. Otherwise, the slab is state as two-way slab.



Design of One-Way Slab

- One-way slabs carrying predominantly uniform load are designed on the assumption that they consist of a series of rectangular beams 1 m wide spanning between supporting beams or walls. The sections through a simply supported slab and a continuous slab are shown in figure below.





One-way simply supported slab

- Analysis and design of the slab similar to design of simply supported beam as indicate in the previous chapter. For 1m slab width,
- Moment, $$M_{max} = \frac{wL^2}{8}$$ Shear Force, $$V_{max} = \frac{wL}{2}$$

One-way Continuous slab

- For continuous slab, moment and shear force can be obtained from Table 3.12: BS 8110 if the following conditions applied.

Table 3.12 — Ultimate bending moment and shear forces in one-way spanning slabs

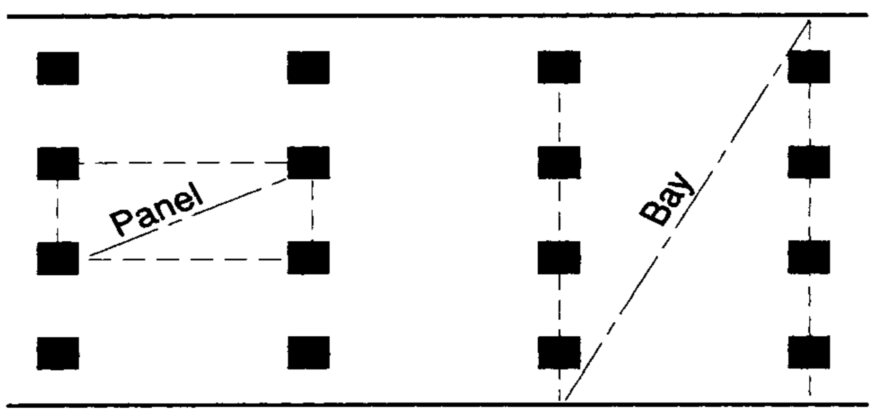
	End support/slab connection				At first interior support	Middle interior spans	Interior supports
	Simple		Continuous				
	At outer support	Near middle of end span	At outer support	Near middle of end span			
Moment	0	$0.086Fl$	$-0.04Fl$	$0.075Fl$	$-0.086Fl$	$0.063Fl$	$-0.063Fl$
Shear	$0.4F$	—	$0.46F$	—	$0.6F$	—	$0.5F$

NOTE F is the total design ultimate load 1.35Gk + 1.5Qk
l is the effective span.

Design of One-Way Slab

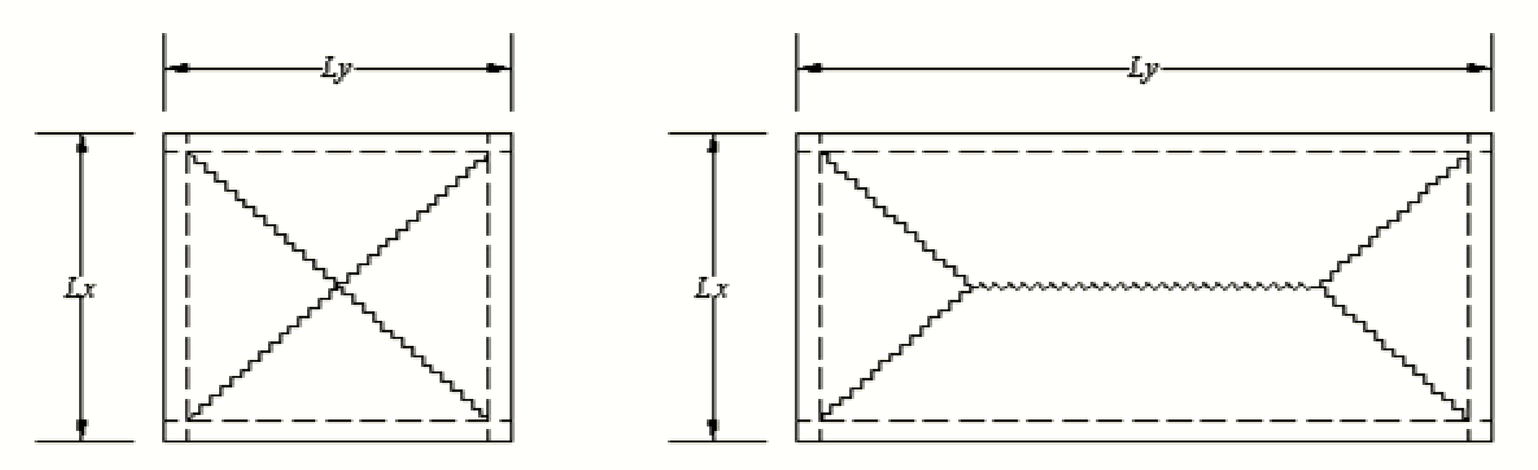
- The area of each bay, i.e. the building width × column spacing, exceeds 30 m^2.
- The ratio of characteristic imposed load to characteristic dead load does not exceed 1.25.
- The characteristic imposed load does not exceed 5 kN/m^2 excluding partitions.

- If the above conditions are not satisfied, the slab can be analyzed using elastic analysis as performed for continuous beams.



Design of Two-Way Slab

- The main reinforcement for two-way slab are designed in two directions which are x-direction and y-direction.
- This condition occur when the slab are supported at four side of the beams or walls and the ratio of long span to short span is **equal or less than 2.**
- Bending moment and shear force of two-way slab are depend on L_y/L_x ratio and support condition either simply supported or end restraint.



Two-Way Simply Supported Slab

- If the slab consist of one panel and end support are not restrained, (the slab and beam are not connected monolithically) the slab are classify as two-way simply supported slab.
- When simply-supported slabs do not have adequate provision to resist torsion at the corners, and to prevent the corners from lifting, the maximum moments per unit width are given by the following equations:

Moment at short span; $$M_{sx} = \alpha_{sx}.n.L_x^2$$

Moment at long span; $$M_{sy} = \alpha_{sy}.n.L_x^2$$

Where; α_{sx}, α_{sy} = *moment coefficient from Table 3.13 (BS8110:1:1997).*

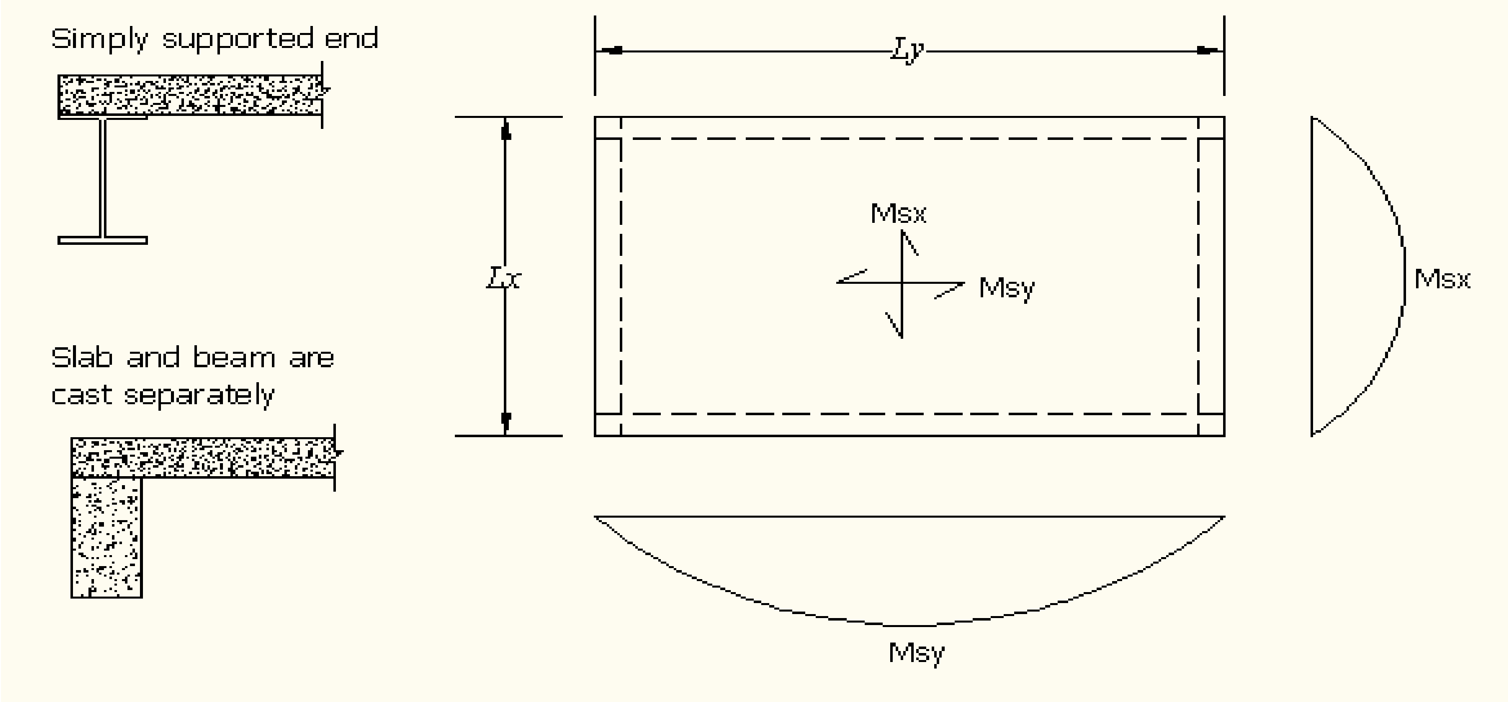
n = *design load (kN/m²)*

L_x = *short span (m)*

Design of Two-Way Slab

Table 3.13 — Bending moment coefficients for slabs spanning in two directions at right angles, simply-supported on four sides

l_y/l_x	1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0
α_{sx}	0.062	0.074	0.084	0.093	0.099	0.104	0.113	0.118
α_{sy}	0.062	0.061	0.059	0.055	0.051	0.046	0.037	0.029



Two-Way Restrained Slab

- If the slabs consist more than one panel or corner of the slab are prevent against lifting it is define as two-way restrained slab.
- This condition occur when the slabs are connected monolithically with support.
- The design bending moment of two-way restrained slab can be calculated as follows;

Moment at short span,

Moment at long span,

$$M_{sx} = \beta_{sx}.n.L_x^{\ 2}$$

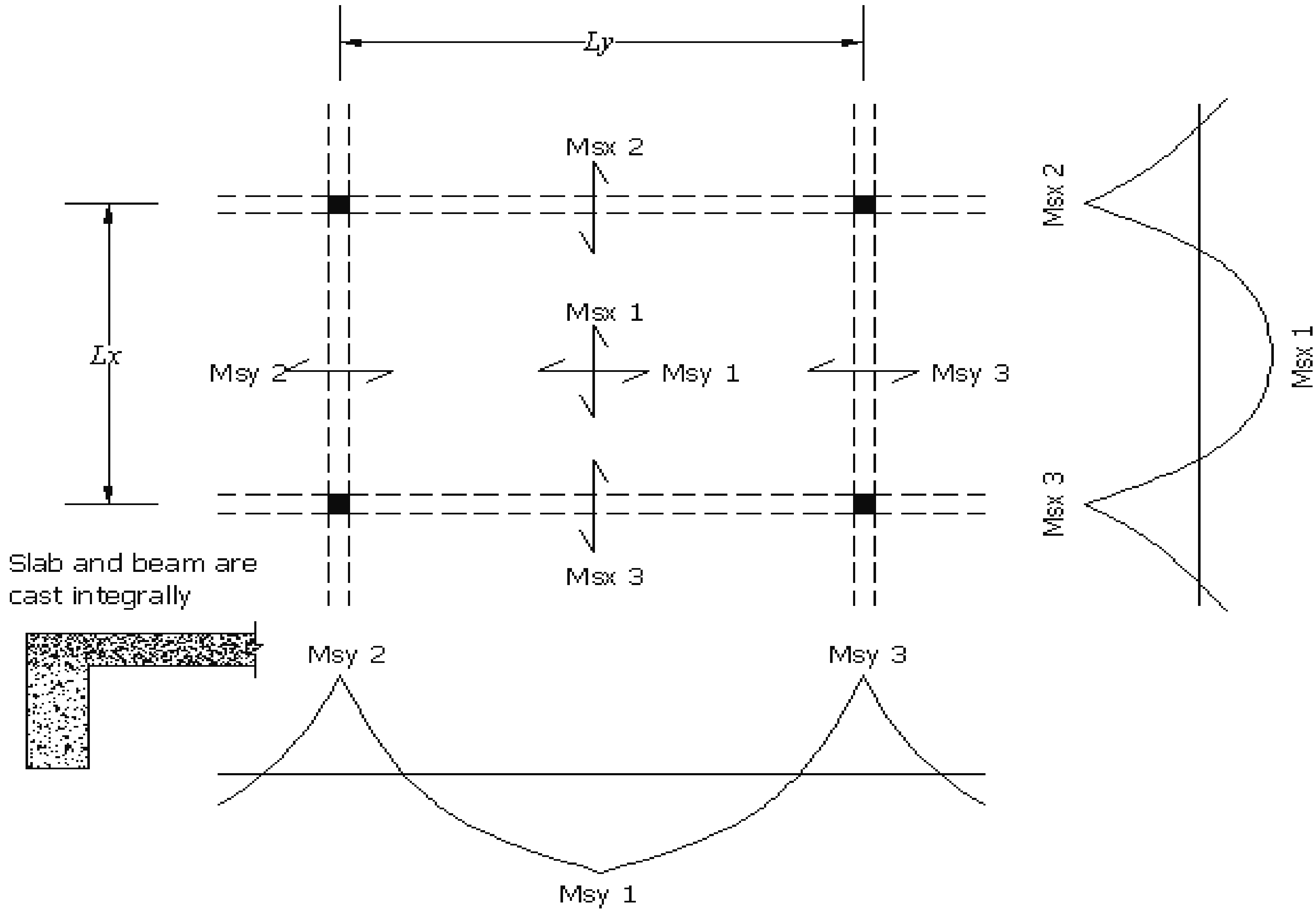
$$M_{sy} = \beta_{sy}.n.L_x^{\ 2}$$

Where; β_{sx}, β_{sy} = *moment coefficient from Table 3.14 (BS8110:1:1997)*

n = *design load (kN/m²)*

L_x = *short span (m)*

Design of Two-Way Slab



Design of Two-Way Slab

- Bending moment of two-way restrained slab depends on the ratio of L_y/L_x and continuity of slab edges.
- There are 9 cases of slab edge continuity that may be exist as shown in figure below.
- The design shear force of two-way restrained slab can be calculated as follows;

Shear force at short span,

Shear force at long span,

$$V_{sx} = \beta_{vx} . n . L_x$$

$$V_{sy} = \beta_{vy} . n . L_x$$

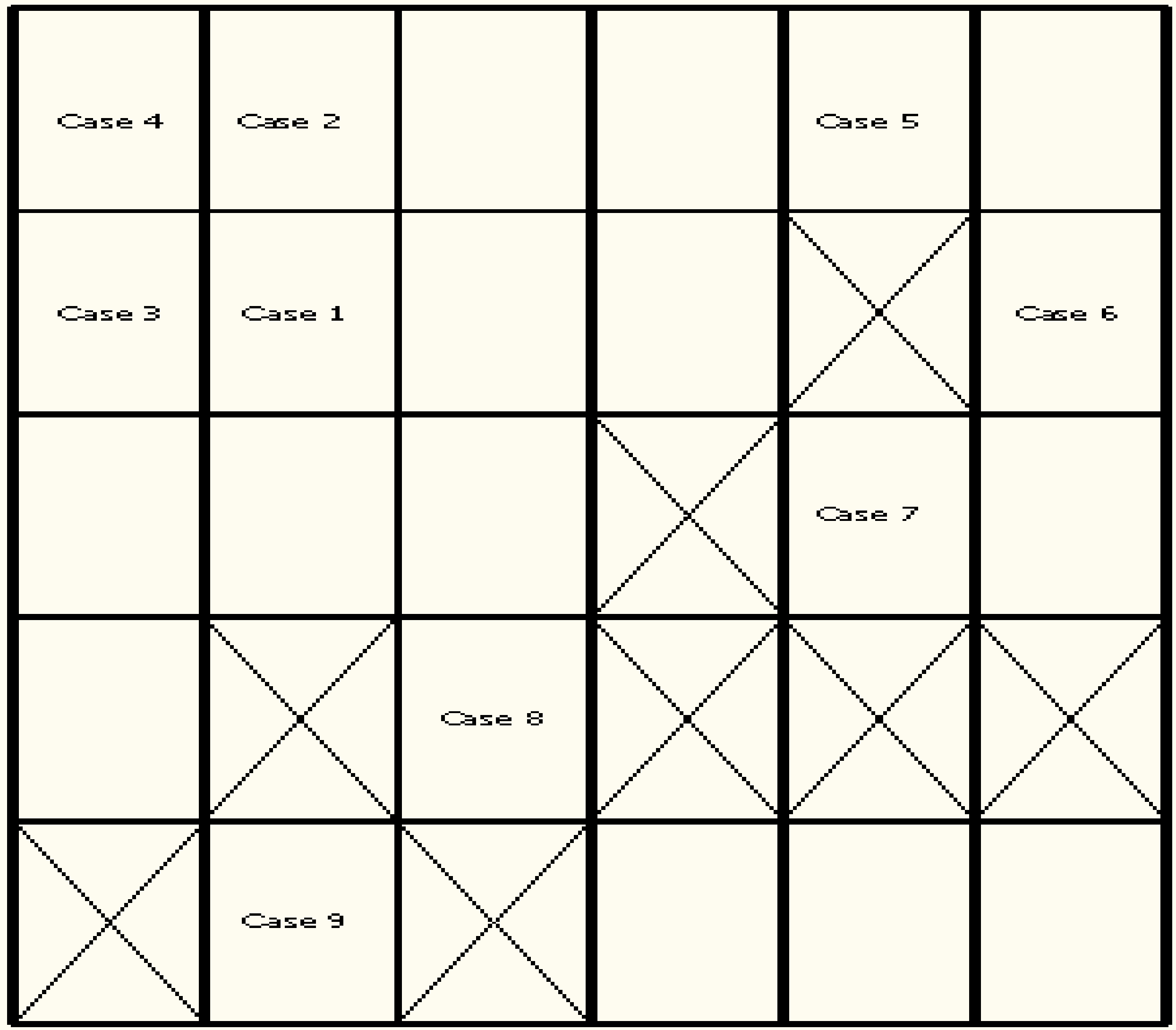
Where; β_{vx}, β_{vy} = moment coefficient from Table 3.15 (BS8110:1:1997)

n = design load (kN/m^2)

L_x = short span (m)

Design of Two-Way Slab

- Cases of Two- Way restrained slab



Design of Two-Way Slab

Table 3.14 — Bending moment coefficients for rectangular panels supported on four sides with provision for torsion at corners

	Type of panel and moments considered	Short span coefficients, β_{sx} Values of l_y/l_x								Long span coefficients, β_{sy} for all values of l_y/l_x
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
Case 1	**Interior panels**									
	Negative moment at continuous edge	0.031	0.037	0.042	0.046	0.050	0.053	0.059	0.063	0.032
	Positive moment at mid-span	0.024	0.028	0.032	0.035	0.037	0.040	0.044	0.048	0.024
Case 2	**One short edge discontinuous**									
	Negative moment at continuous edge	0.039	0.044	0.048	0.052	0.055	0.058	0.063	0.067	0.037
	Positive moment at mid-span	0.029	0.033	0.036	0.039	0.041	0.043	0.047	0.050	0.028
Case 3	**One long edge discontinuous**									
	Negative moment at continuous edge	0.039	0.049	0.056	0.062	0.068	0.073	0.082	0.089	0.037
	Positive moment at mid-span	0.030	0.036	0.042	0.047	0.051	0.055	0.062	0.067	0.028
Case 4	**Two adjacent edges discontinuous**									
	Negative moment at continuous edge	0.047	0.056	0.063	0.069	0.074	0.078	0.087	0.093	0.045
	Positive moment at mid-span	0.036	0.042	0.047	0.051	0.055	0.059	0.065	0.070	0.034
Case 5	**Two short edges discontinuous**									
	Negative moment at continuous edge	0.046	0.050	0.054	0.057	0.060	0.062	0.067	0.070	—
	Positive moment at mid-span	0.034	0.038	0.040	0.043	0.045	0.047	0.050	0.053	0.034
Case 6	**Two long edges discontinuous**									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.045
	Positive moment at mid-span	0.034	0.046	0.056	0.065	0.072	0.078	0.091	0.100	0.034
Case 7	**Three edges discontinuous (one long edge continuous)**									
	Negative moment at continuous edge	0.057	0.065	0.071	0.076	0.081	0.084	0.092	0.098	—
	Positive moment at mid-span	0.043	0.048	0.053	0.057	0.060	0.063	0.069	0.074	0.044
Case 8	**Three edges discontinuous (one short edge continuous)**									
	Negative moment at continuous edge	—	—	—	—	—	—	—	—	0.058
	Positive moment at mid-span	0.042	0.054	0.063	0.071	0.078	0.084	0.096	0.105	0.044
Case 9	**Four edges discontinuous**									
	Positive moment at mid-span	0.055	0.065	0.074	0.081	0.087	0.092	0.103	0.111	0.056

Design of Two-Way Slab

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Table 3.15 — Shear force coefficient for uniformly loaded rectangular panels supported on four sides with provision for torsion at corners

	Type of panel and location	β_{vx} for values of l_y/l_x								β_{vy}
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
Case 1	**Four edges continuous**									
	Continuous edge	0.33	0.36	0.39	0.41	0.43	0.45	0.48	0.50	0.33
Case 2	**One short edge discontinuous**									
	Continuous edge	0.36	0.39	0.42	0.44	0.45	0.47	0.50	0.52	0.36
	Discontinuous edge	—	—	—	—	—	—	—	—	0.24
Case 3	**One long edge discontinuous**									
	Continuous edge	0.36	0.40	0.44	0.47	0.49	0.51	0.55	0.59	0.36
	Discontinuous edge	0.24	0.27	0.29	0.31	0.32	0.34	0.36	0.38	—
Case 4	**Two adjacent edges discontinuous**									
	Continuous edge	0.40	0.44	0.47	0.50	0.52	0.54	0.57	0.60	0.40
	Discontinuous edge	0.26	0.29	0.31	0.33	0.34	0.35	0.38	0.40	0.26
Case 5	**Two short edges discontinuous**									
	Continuous edge	0.40	0.43	0.45	0.47	0.48	0.49	0.52	0.54	—
	Discontinuous edge	—	—	—	—	—	—	—	—	0.26
Case 6	**Two long edges discontinuous**									
	Continuous edge	—	—	—	—	—	—	—	—	0.40
	Discontinuous edge	0.26	0.30	0.33	0.36	0.38	0.40	0.44	0.47	—
Case 7	**Three edges discontinuous (one long edge discontinuous)**									
	Continuous edge	0.45	0.48	0.51	0.53	0.55	0.57	0.60	0.63	—
	Discontinuous edge	0.30	0.32	0.34	0.35	0.36	0.37	0.39	0.41	0.29
Case 8	**Three edges discontinuous (one short edge discontinuous)**									
	Continuous edge	—	—	—	—	—	—	—	—	0.45
	Discontinuous edge	0.29	0.33	0.36	0.38	0.40	0.42	0.45	0.48	0.30
Case 9	**Four edges discontinuous**									
	Discontinuous edge	0.33	0.36	0.39	0.41	0.43	0.45	0.48	0.50	0.33