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Solid Slab Design

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With Wisdom We Explore

Introduction

- 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.
- Type of slabs: One/two-way solid slabs, ribbed slabs, waffle slabs, flat slab with/without drop panel.

Introduction

One way slab with band beam

Flat slab w/o drop panel

Waffle slab

Precast concrete slab

Flat slab w drop panel

Solid slab

One way ribbed slab

Introduction

- 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.
- 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.

Procedure of Design

Step	Task	Standard
1	Determine design life, exposure class and 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 thickness of slab [√]	EN 1992-1-1: Table 7.4N EN 1992-1-2: Table 5.8
4	Calculate nominal cover, C_{nom}	EN 1992-1-1: Sec.4.4.1
5	Design actions, N_{Ed}	EN 1991-1-1
6	Moment, M_{Ed} and shear force, V_{Ed} [√]	EN 1992-1-1: Sec.5
7	Design flexural reinforcement [√]	EN 1992-1-1: Sec.6.1
8	Check shear resistance [√]	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

Thickness of Slab

- 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.
- Estimated for deflection control:

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

- This is based on the ratio of span/effective depth as in Table 7.4N BS EN 1992-1-1:2004.
- The minimum thickness for fire resistance is stated in Table 5.8 BS EN 1992-1-2.

Thickness of Slab

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)						
		One-way[a,b] spanning slab	Two-way spanning slab[a,b,c,d] $l_y/l_x \le 1.5$[f]	Two-way spanning slab[a,b,c,d] $1.5 < l_y/l_x \le 2$[f]	Ribs in a two-way spanning ribbed slab[e]			
REI 60	h_s =	80	80	80	b_{min} =	100	120	≥200
	a =	20	10[g]	15[g]	a =	25	15[g]	10[g]
REI 90	h_s =	100	100	100	b_{min} =	120	160	≥250
	a =	30	15[g]	20	a =	35	25	15[g]
REI 120	h_s =	120	120	120	b_{min} =	160	190	≥300
	a =	40	20	25	a =	45	40	30
REI 240	h_s =	175	175	175	b_{min} =	450	700	—
	a =	65	40	50	a =	70	60	

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.

The table is valid only if the detailing requirements are observed and in normal temperature design redistribution of bending moments does not exceed 15%.

The term two way slabs relates to slabs supported at all four edges. If this is not the case, they should be treated as one-way spanning slabs.

Moment and Shear Force

- Slab may be analyzed using the following methods:
  1) Elastic analysis covers three techniques:
     (a) idealization into one-way/two-way spanning
     (b) elastic plate analysis
     (c) finite element analysis
  2) 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.
- For slab, the analysis of moment and shear force may based on BS8110 for the following cases:
  - One-way simply supported/constrained slab
  - One-way continuous slab
  - Two-way simply supported slab
  - Two-way constrained slab

Moment and Shear Force

- Simply supported/Contraint one-way slab

  Similar to simply supported beam, for 1m slab width:

  Moment, $M_{max} = \dfrac{n_d L^2}{8}$; Shear, $V_{max} = \dfrac{n_d L}{2}$

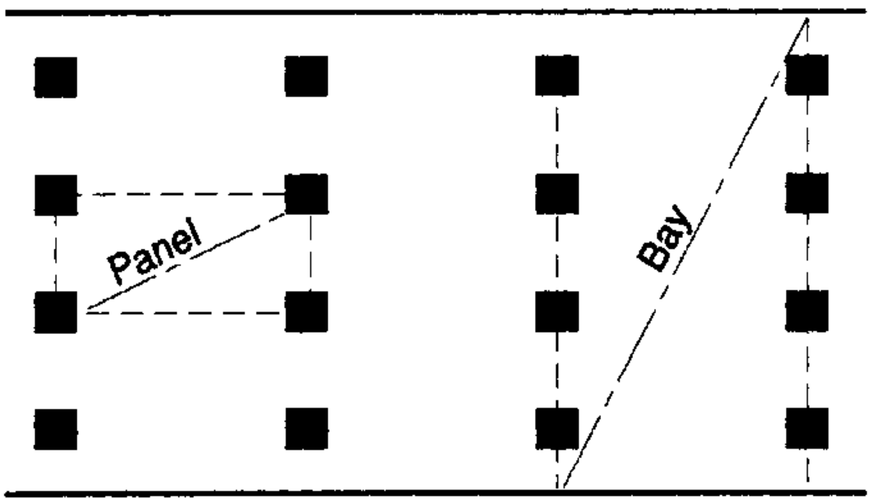
- One-way continuous slab

  Moment and shear force can be obtained from Table 3.12, BS8110:

<table>
<tr><th rowspan="3"></th><th colspan="4">End support condition</th><th colspan="3" rowspan="2"></th></tr>
<tr><th colspan="2">Pinned</th><th colspan="2">Continuous</th></tr>
<tr><th>Outer support</th><th>Near middle of end span</th><th>End support</th><th>End span</th><th>At 1st interior support</th><th>At middle of interior span</th><th>At interior support</th></tr>
<tr><td>Moment</td><td>0</td><td>0.086FL</td><td>-0.04FL</td><td>0.075FL</td><td>0.086FL</td><td>0.063FL</td><td>0.063FL</td></tr>
<tr><td>Shear</td><td>0.4F</td><td>-</td><td>0.46F</td><td>-</td><td>0.6FL</td><td>-</td><td>0.5FL</td></tr>
<tr><td colspan="8">L = effective span
F = total ultimate load = 1.35G_k + 1.5Q_k
*The use of this table must follow the applied conditions</td></tr>
</table>

Moment and Shear Force

- Table 3.12 only can be used of the slab fullfill the following requirement:
  - 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.



Moment and Shear Force

- Two-way simply supported slab

  Based on Table 3.13 BS8110:1:1:1997

  Moment at short span, $M_{sx} = \alpha_{sx} n_d L_x^2$

  Moment at long span, $M_{sy} = \alpha_{sy} n_d L_x^2$

  Shear force, $V_{Ed} = n_d L_x / 2$

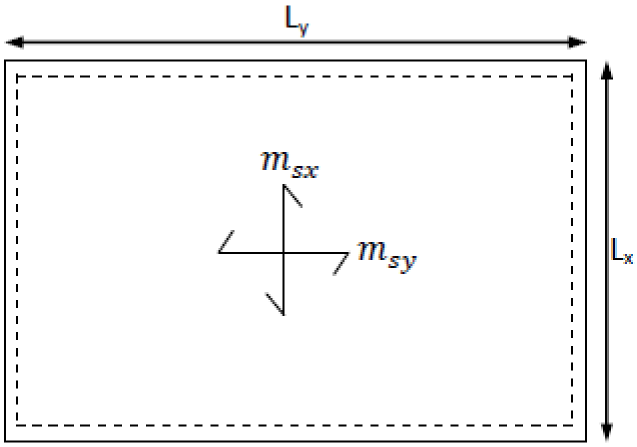


Table 3.13 — Bending moment coefficients for slabs spanning in two directions at right angles, simply-supported on four sides

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

Moment and Shear Force

- Two-way constrained slab

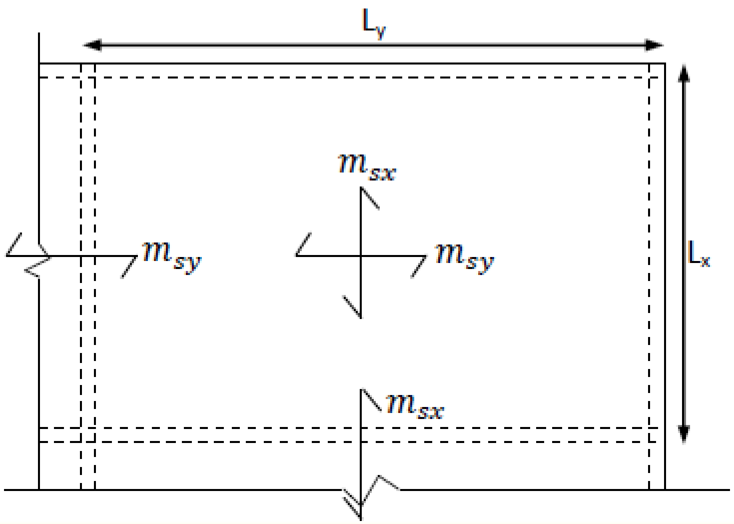
  Based on Table 3.14 and Table 3.15 BS8110:1:1:1997

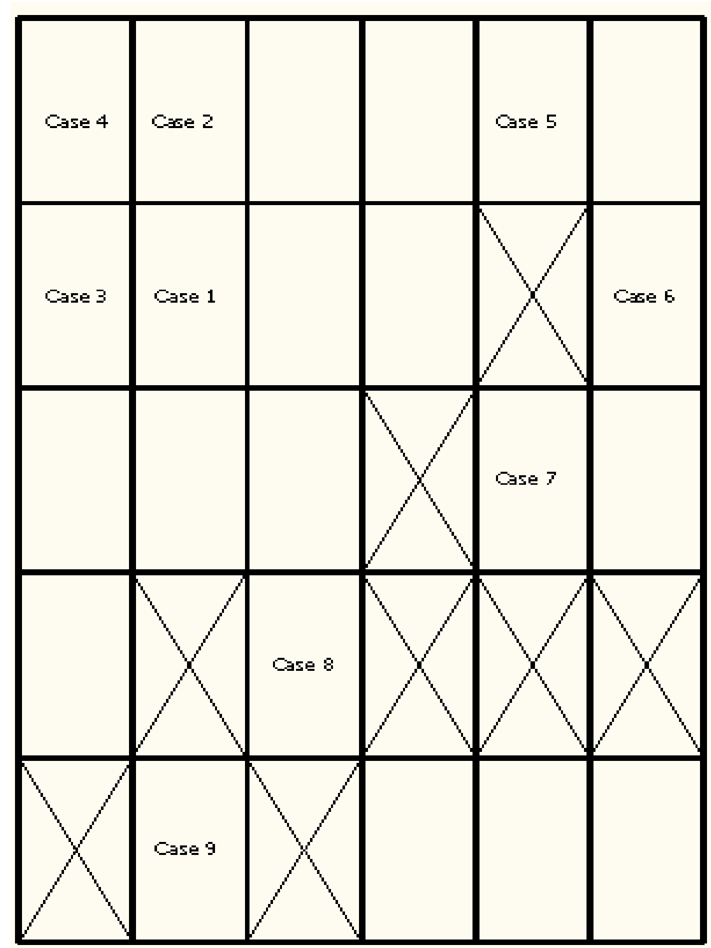
  Moment at short span, $M_{sx} = \beta_{sx} n_d L_x^{2}$

  Moment at long span, $M_{sy} = \beta_{sy} n_d L_x^{2}$

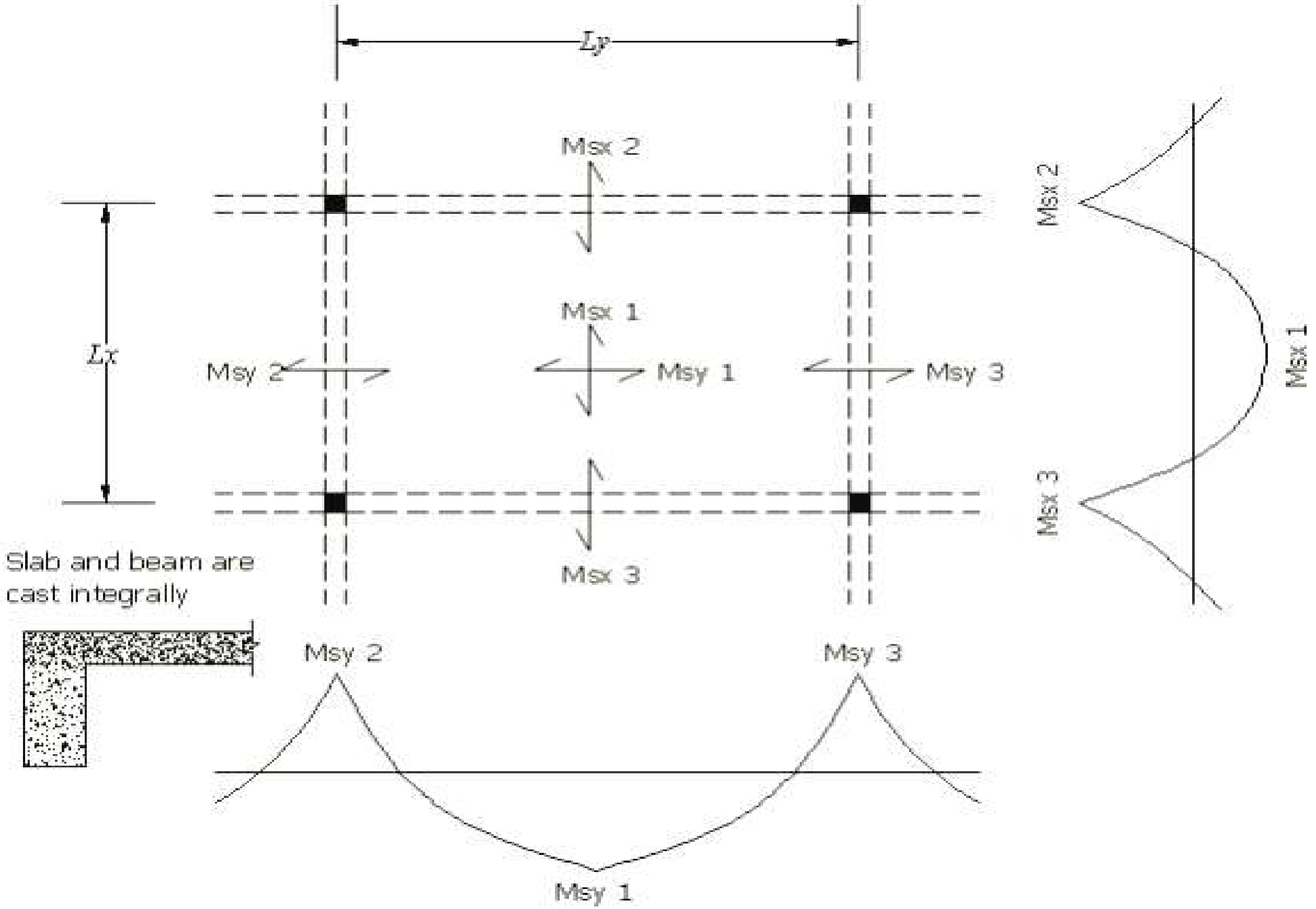
  Shear force at short span, $V_{sx} = \beta_{vx} n_d L_x$

  Shear force at long span, $V_{sy} = \beta_{vy} n_d L_x$





Moment and Shear Force



Moment and Shear Force

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}								Long span coefficients, β_{sy} for all values of l_y/l_x
		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

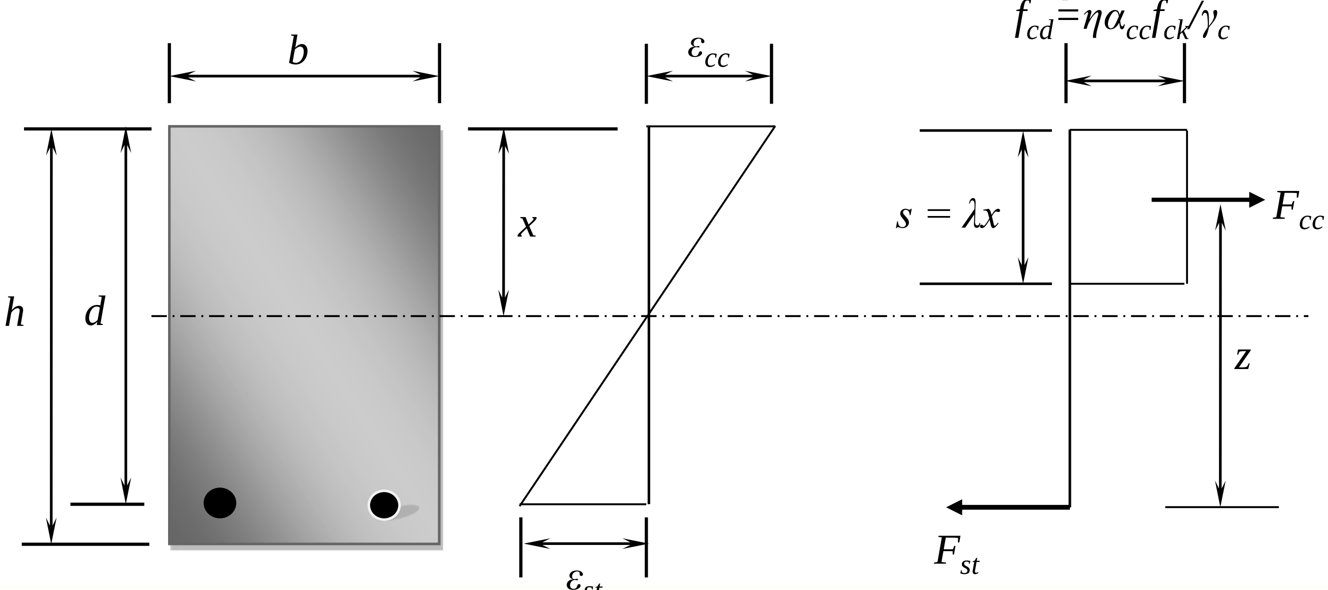
Moment and Shear Force

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

Flexural Reinforcement

- 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.
- The derived formula based on the simplified stress block:



f_{ck} < 50 N/mm²:

η = 1 (defining the effective strength),

ε_c = 0.0035,

α_{cc} = 0.85,

λ = 0.8,

γ_c = 1.5,

f_{cd} = 1.0x0.85xf_{ck}/ 1.5

= 0.567 f_{ck}

Flexural Reinforcement

- Follow a similar procedure to that use in beam design:

1) Calculate

$$K = \frac{M_{Ed}}{bd^2 f_{ck}}$$

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

$$z = d\left[0.5 + \sqrt{(0.25 - K/1.134)}\right] \leq 0.95d$$

$$A_s = \frac{M}{0.87 f_{yk} z}$$

3) Minimum and maximum reinforcement

$$A_{s,min} = 0.26(f_{ctm} / f_{yk})bd \geq 0.0013bd$$

$$A_{s,max} = 0.04A_c = 0.04bh$$

Flexural Reinforcement

- Secondary reinforcement is $20\% A_{s,req}$

Strength Classes for Concrete (BS EN 1992-1-1:2004) All unit in MPa												
f_{ck}	20	25	30	35	40	45	50	55	60	70	80	90
$f_{ck,cube}$	25	30	37	45	50	55	60	67	75	85	95	105
f_{cm}	28	33	38	43	48	53	58	63	68	78	88	98
f_{ctm}	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0

$$f_{ctm} = 0.30 \times f_{ck}^{(2/3)} \leq C50/60$$

$$f_{ctm} = 2.12 \ln\left[1 + \left(f_{cm}/10\right)\right] > C50/60$$

Shear Resistance

- 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, $V_{Rd,c}$.

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

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

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

$$V_{\min} = [0.35k^{3/2} f^{1/2}]bd$$

Deflection Control

- 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.
- Two equations are provided in Eq. 7.16.a and 7.16.b, Cl 7.4.2.(2):

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\frac{\rho_0}{\rho} + 3.2\sqrt{f_{ck}}\left(\frac{\rho_0}{\rho} - 1\right)^{3/2}\right] \quad \text{if } \rho \le \rho_0$$

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_0}}\right] \quad \text{if } \rho \le \rho_0$$

Deflection Control

- Percentage of required tension reinforcement

$$\rho = A_{s,req} / bd$$

- Reference reinforcement ratio

$$\rho_0 = (f_{ck})^{1/2} \times 10^{-3}$$

- Percentage of required compression reinforcement

$$\rho' = A_{s',req} / bd$$

- Factor for structural system, K must be referred in Table 7.4N
- Modification factor:
  - Span greater than 7m = 7/L
  - Steel area provided = $A_{s,prov}/A_{s,req} < 1.5$
- Deflection limited to span/250, span/500 or 20mm after installation.

Deflection Control

$$\left(\frac{l}{d}\right)_{allow} = \left(\frac{l}{d}\right) \times MF_i > \left(\frac{l}{d}\right)_{actual} = \frac{l_{eff}}{d_{eff}}$$

Table 7.4N: Basic ratio of span/effective depth for reinforced concrete members without axial compression

Structural System	K	Basic span-effective depth ratio	
		Concrete highly stressed, ρ = 1.5%	Concrete lightly stressed, ρ = 0.5%
1. Simply supported beam, one/two way simply supported slab	1.0	14	20
2. End span of continuous beam or one-way continuous slab or two way spanning slab continuous over one long side	1.3	18	26
3. Interior span of beam or one way or two way spanning slab	1.5	20	30
4. Slab supported on columns without beam (flat slab) based on longer span	1.2	17	24
5. Cantilever	0.4	6	8

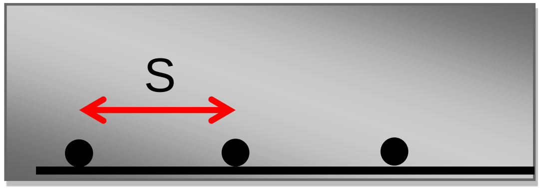
Cracking Control

- To resist cracking of the concrete slabs, Cl.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.
- For thickness less than 200mm, the crack control is based on the limitation of spacing as:
  - for main bar:

    $S_{max,slab}$ = 3h or 400mm (use the smaller)
  - for secondary bar:

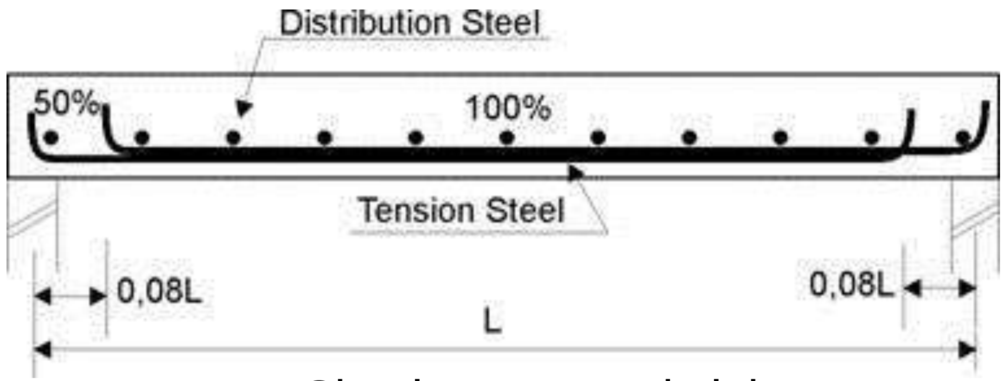
    $S_{max,slab}$ = 3.5h or 450mm (use the smaller)
- Maximum bar spacing:

  $S_{max} = [L_y - 2C_{nom} - Ø_{bar}] / [\text{No. bar} - 1]$

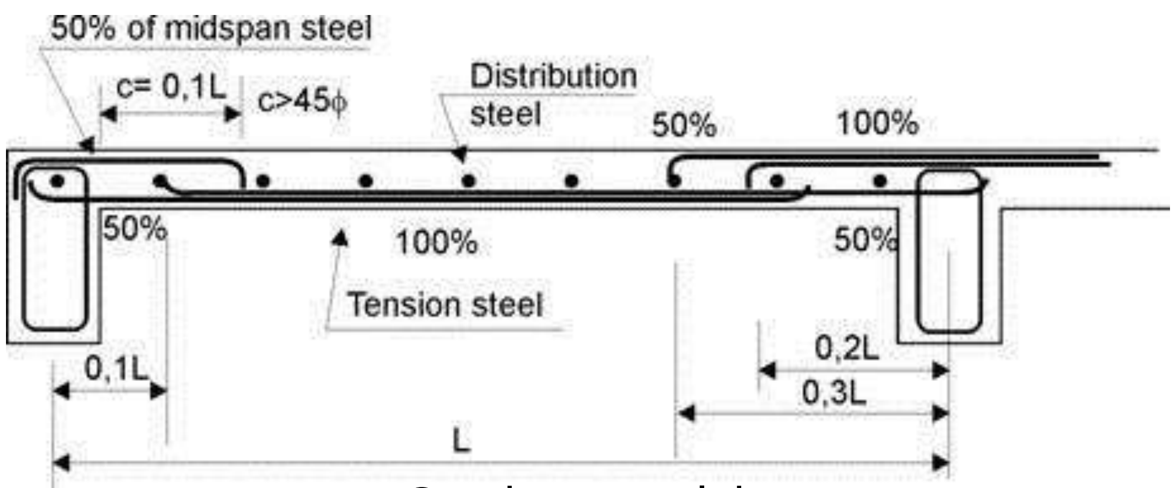


Detailing

- Simplified rules for curtailment, Cl. 9.3



Simply supported slab



Continuous slab