CHAPTER TWO

2 .DESIGN OF SLABS

2.1 INTRODUCTION

- A slab is structural element whose thickness is **small** compared to its own length and width.
- Slabs are usually used in floor and roof construction.
- There are many types of slab. from these the followings are common.

1. Solid slab
2. Ribbed slab
3. Flat slab

Cont….

Types of Slab		
Solid slab 1. One way & 2. Two way	**Ribbed slab** 1. One way& 2. Two way (Waffle slab)	**Flat slab**

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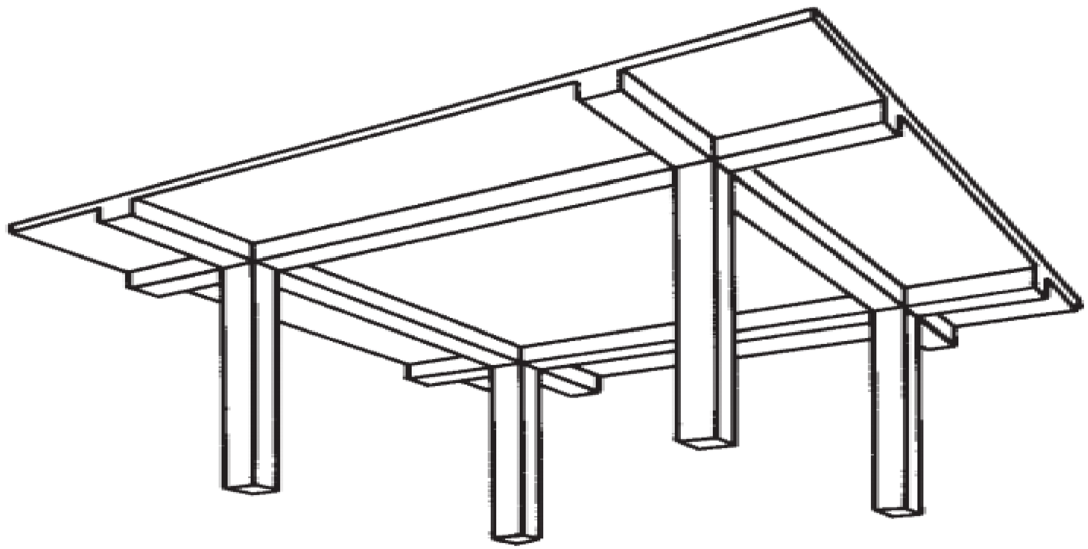
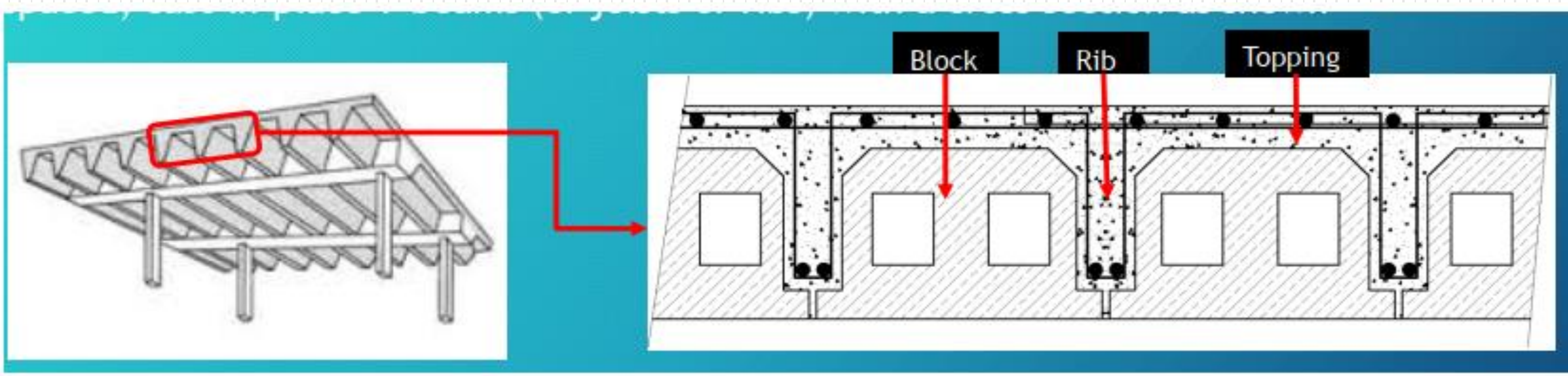


Solid slab



Ribbed Slab

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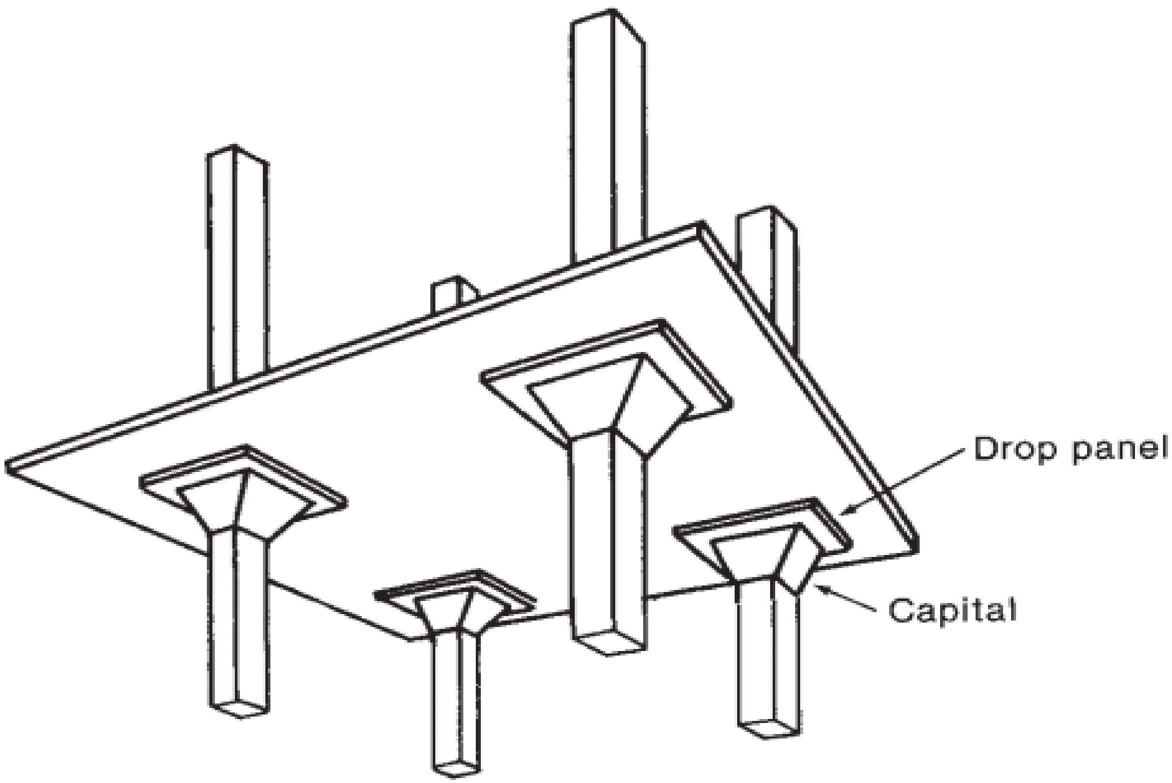

Flat slab

Cont….

- According to the way loads are transferred to supporting beams and columns, Solid slabs are classified into two types .These are:

1. **One way solid slab** and
2. **Two way solid slab.**

Cont….

One way solid slab

- Either supported on two opposite sides out of four sides or the ratio of longer span to shorter span is at least equal to 2.
- The bending is assumed typically in short direction.
- Main reinforcements are provided parallel to short direction.
- Secondary reinforcements are provided paralleled to long direction.

Two way solid slab

- The ratio of longer span to shorter span is less than or equal to 2.
- The bending is assumed both in short and longer direction .
- Main reinforcements are provided parallel to both shorter and longer direction.

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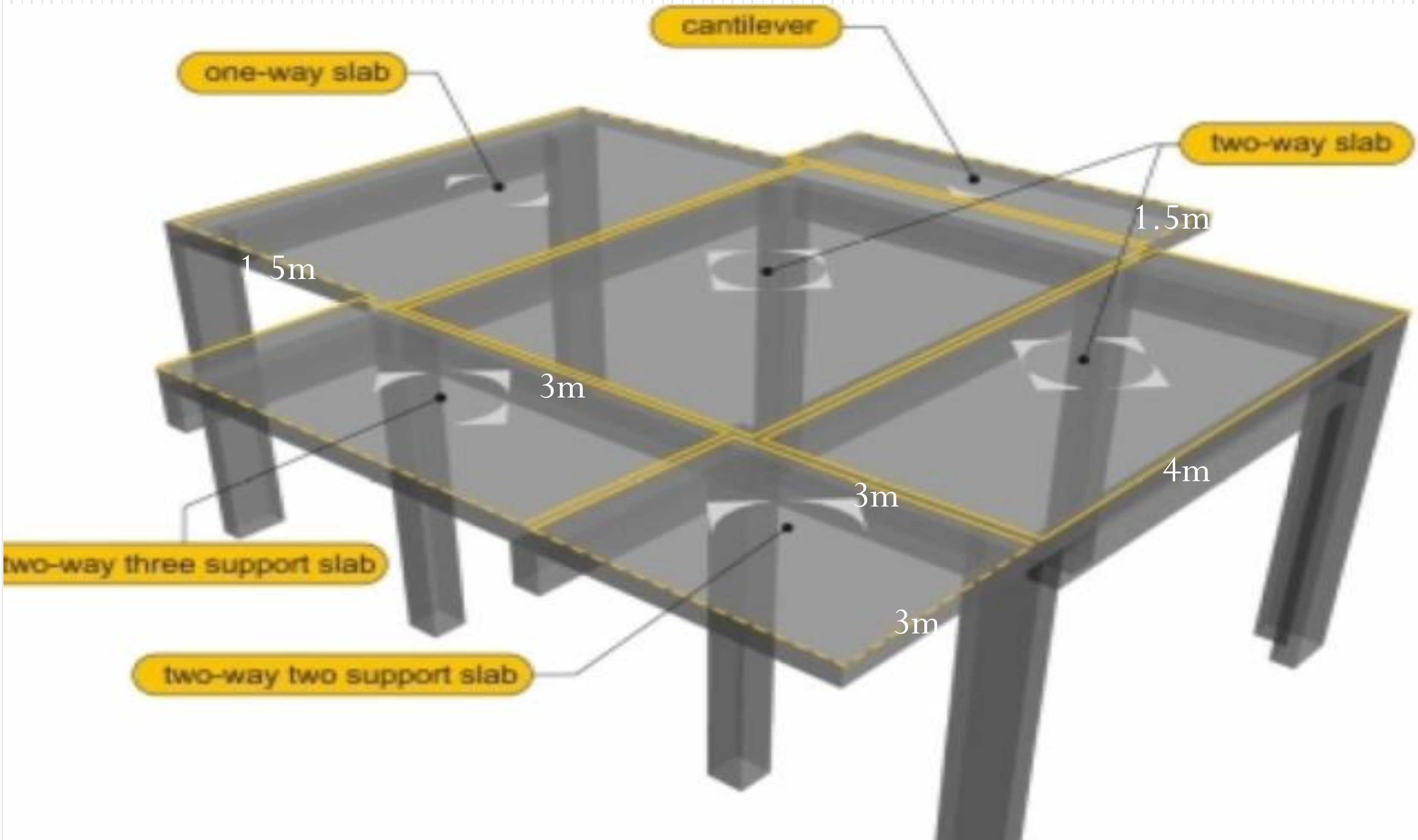

cantilever
one-way slab
two-way slab
1.5m
1.5m
3m
4m
3m
two-way three support slab
3m
two-way two support slab

Cont….

1. One-way slabs: They are those either supported on the two out of four opposite sides or the longer span to short span ratio is at least equal to 2.

2. Two-way slabs: They are those supported on all four sides and the longer span to short span ratio is less than 2

3. Cantilever slabs: They are those with a fixed support on only one out of four sides

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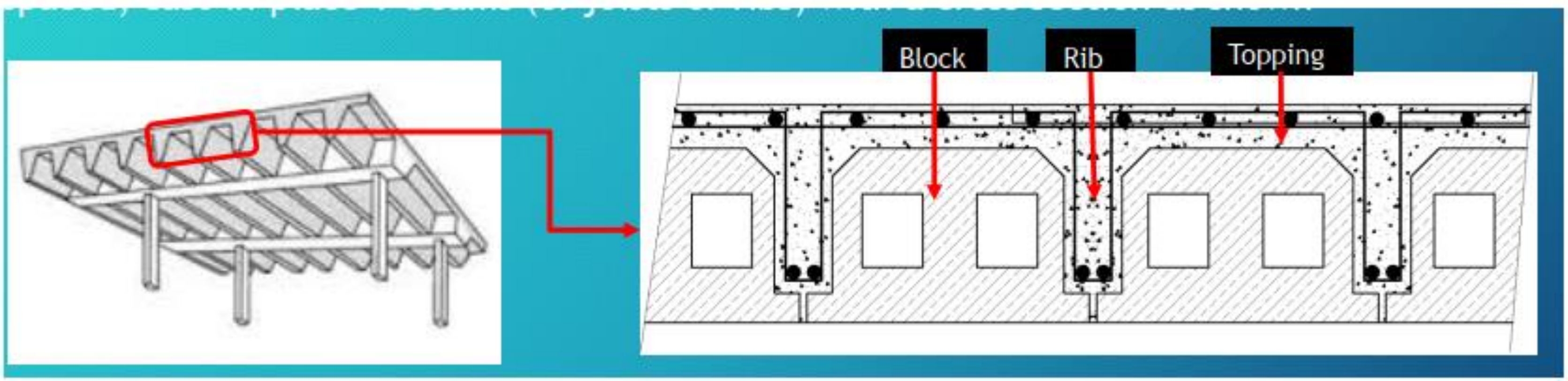
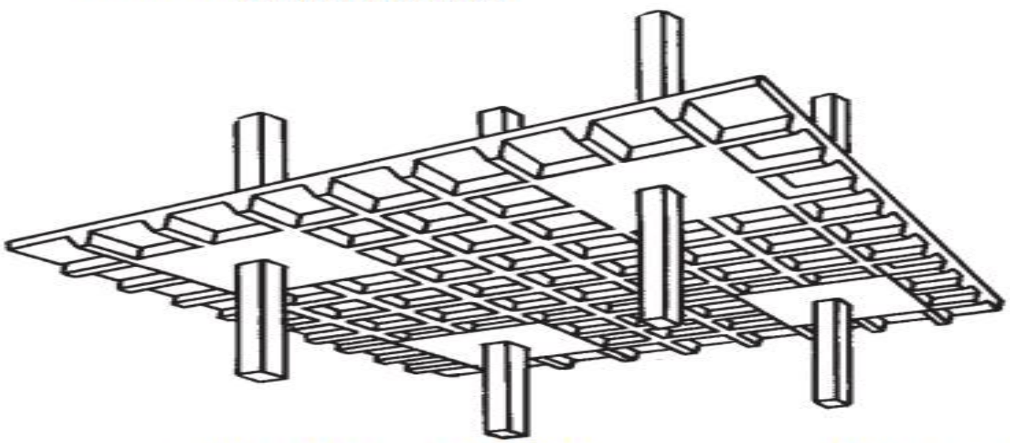
Types of Ribbed slab	
1. One way - Ribs runs only in one direction	**2. Two way** - Ribs runs on two orthogonal direction and are called waffle slab.

Cont….



One way Ribbed Slab



Waffle slab (Two way ribbed slab)

Cont….

1. **strength of concrete used for slab.**

- It depends on the exposure classes like that of beam.
- Most of the time minimum grade of concrete used for slab is C20/25.

2. Concrete cover for slab

- It is determined like that of beam.
- Most of the time 15mm or 20mm is recommended.

Cont….

3. Depth Determination for solid slab :

A. Serviceability requirement (Refer ES EN 1992 Section 7)

$$\frac{l}{d} = K\left[11 + 1{,}5\sqrt{f_{ck}}\frac{\rho_0}{\rho} + 3{,}2\sqrt{f_{ck}}\left(\frac{\rho_0}{\rho} - 1\right)^{3/2}\right] \quad \text{if } \rho \le \rho_0$$

$$\frac{l}{d} = K\left[11 + 1{,}5\sqrt{f_{ck}}\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho_0}}\right] \quad \text{if } \rho > \rho_0$$

where

l/d is the limit span/depth,

K is the factor to take into account the different structural systems,

Cont….

ρ_0 is the reference reinforcement ratio $= \sqrt{f_{ck}} \cdot 10^{-3}$,

ρ is the required tension reinforcement ratio at mid span to resist the moment due to the design loads (at support for cantilevers) and

ρ' is the required compression reinforcement ratio at mid span to resist the moment due to design loads (at support for cantilevers).

0.5%=0.005.

Cont....

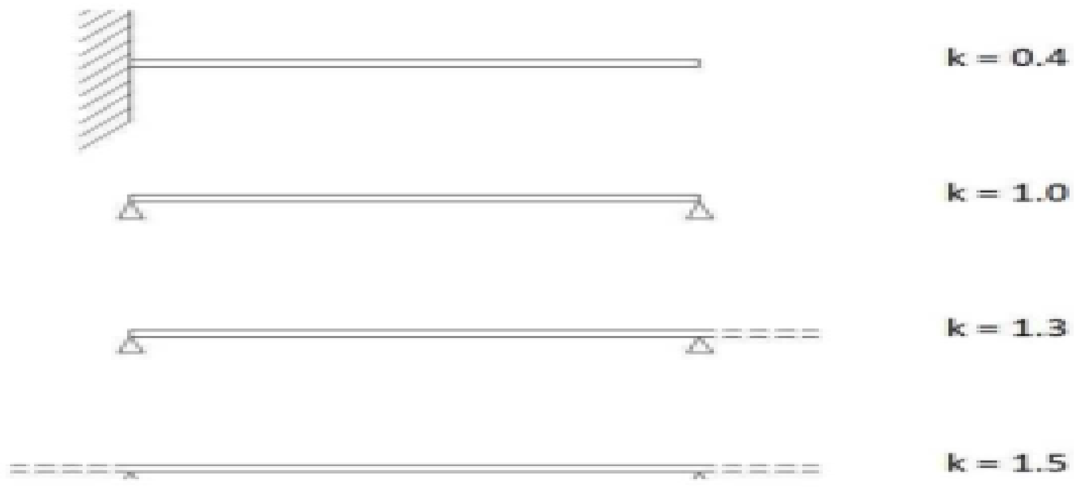


Fig.1.5.1 *K* values vs. structural systems

- For Fyk=500Mpa and C30/37 concrete, l/d values are as follows :

Cont….

Tabulated values for l/d

Structural system	Factor K	l/d	
		$\rho = 1,5\ \%$	$\rho = 0,5\ \%$
Simply supported slab/beam	1,0	14	20
End span	1,3	18	26
Interior span	1,5	20	30
Flat slab	1,2	17	24
Cantilever	0,4	6	8

d-effective depth and (l-shorter span length in case of solid slab
L-is longer span in case of flat slab)

Cont….

- L is shorter span length (Lx) in solid slabs.

B. For Fire Design Requirement.

Minimum dimensions and axis distances for reinforced concrete slabs

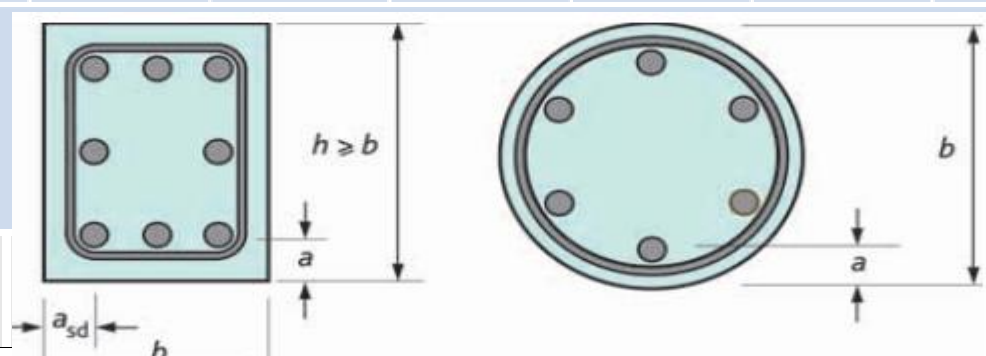
Standard fire resistance		Minimum dimensions (mm)							
		One-way spanning slab	Two-way spanning slab $l_y/l_x \le 1.5$	Two-way spanning slab $1.5 < l_y/l_x \le 2$	Flat slab	Ribs in a two-way spanning ribbed slab (b_{min} is the width of the rib)			
REI 60	h_s = a =	80 20	80 10	80 15	180 15	b_{min} = a =	100 25	120 15	≥200 10
REI 120	h_s = a =	120 40	120 20	120 25	200 35	b_{min} = a =	160 45	190 40	≥300 30
REI 240	h_s = a =	175 65	175 40	175 50	200 50	b_{min} = a =	450 70	700 60	—

Notes

1 Refer to BS EN 1992–1–2 for design limitations.

2 a is the axis distance (see Figure 4).

3 h_s is the slab thickness, including any non-combustible flooring.



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4. Minimum and Maximum area of reinforcement For solid slab

4.1 For main reinforcements

The area of longitudinal tension reinforcement should not be taken as less than $A_{s,min}$

$$A_{s,min} = 0.26 \frac{f_{ctm}}{f_{yk}} b_t d \quad \text{but not less than } 0.0013 b_t d \qquad (1\text{-}3)$$

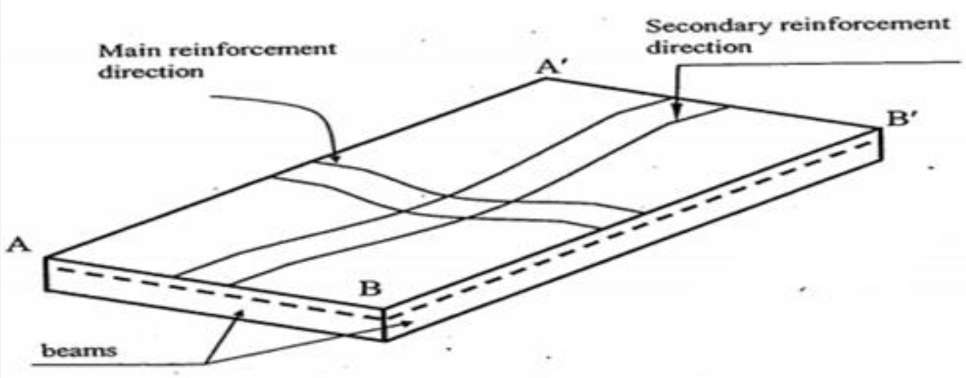
Where:

- The same as like that of beam. The only difference is b_t=width of beam considered during design of beam, b_t=1000 mm in Solid slabs.
- As max =0.04 Ac

Cont....

4.2 For Secondary Reinforcements

- Secondary transverse reinforcement of not less than 20% of the principal reinforcement should be provided in one way solid slabs.



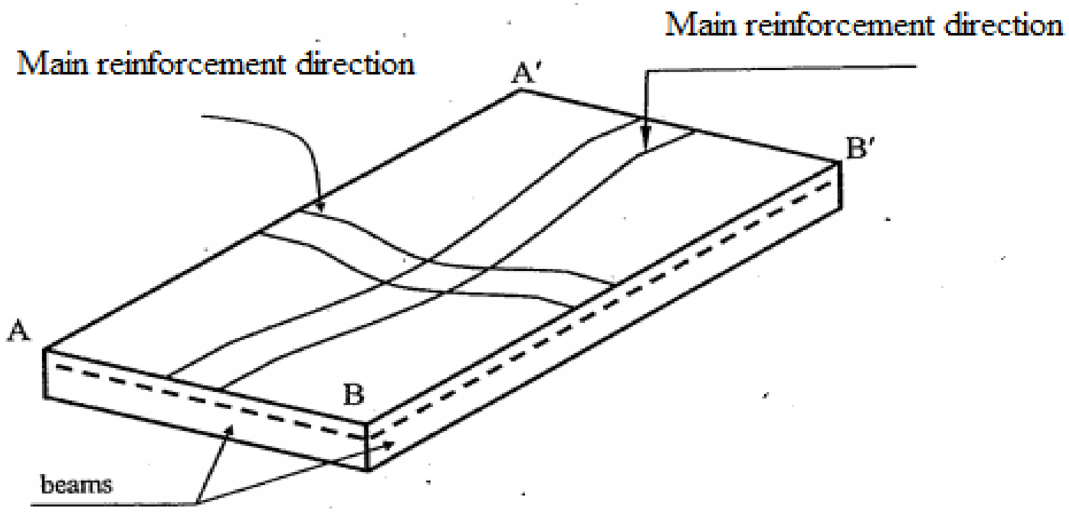
Structural action of one-way slabs

Cont….

- Longer span length (Ly) of the solid slab is AA’ or BB’.
- Shorter span length (Lx) of the solid slab is AB or A’B’.
- If Ly/Lx >2 , it is one way solid slab. But if Ly/Lx <=2 , it is two way solid slab.
- If the slab is one way solid slab main reinforcement were provided parallel to short direction and secondary reinforcements were provided parallel to longer direction .

Cont….

- If the slab is two way solid slab main reinforcement were provided parallel both in shorter and longer direction at tension region.



Struuctural action of Two way slab

Cont....

Spacing of bars

The spacing of bars should not exceed $s_{max,slabs}$.

Note: For the value of $s_{max,slabs}$, refer to the National Annex. The recommended value is:

- for the principal reinforcement, $3h \leq 400$ mm, where h is the total depth of the slab;
- for the secondary reinforcement, $3.5h \leq 450$ mm .

Cont…

Loads Assigned to Slabs

1. **Own weight of the slab(Self weight)**

- 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(γc).

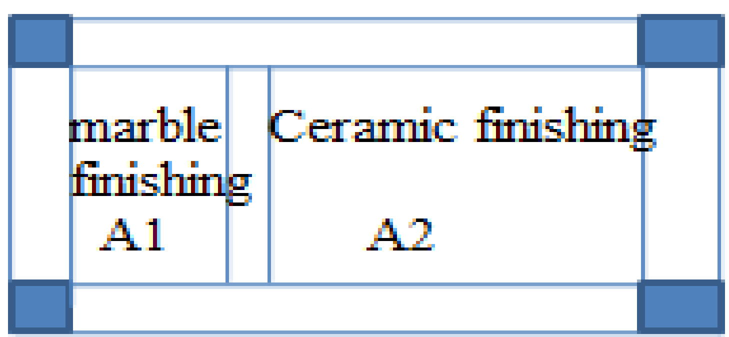
2. **Weight of slab covering materials (Finishing loads):**

- Calculated by multiplying Unit weight of finishing material by thickness of finishing material (If the finishing material is common and provided throughout of panel area) .

Cont….

- Sometimes more than one finishing materials are provided in single panel. In this case Load due to finishing material is calculated by using the following formula

$$\text{Finishing Load} = \frac{t_{f1} A_1 \gamma_{f1} + t_{f2} A_2 \gamma_{f2}}{pannel\ area} = \sum \frac{t_{fi} * A_i * \gamma_{fi}}{pannel\ area}$$



Cont….

3. Partition(Wall loads)

- If the partition exists on the panel but not on beams, the partition load is considered as distributed areal load. But if the partition exists on the beam, the partition on load is considered as it is on the beam.

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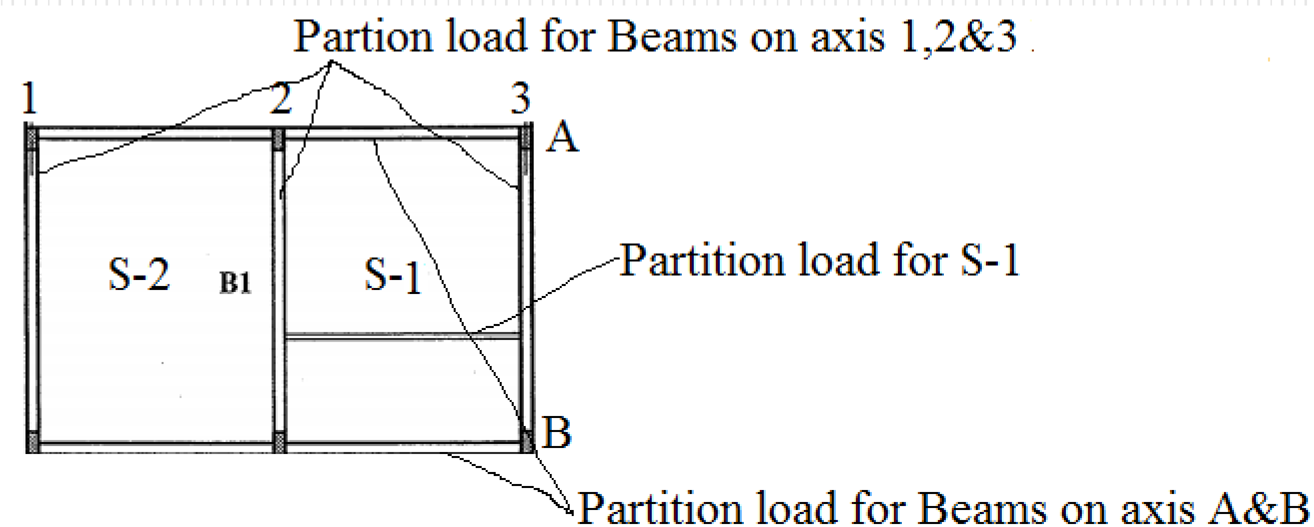

Cont….

- Calculated by using the following formula.

$$\text{Partition load} = \frac{\text{Wall volume} * \text{Wall unit weight}}{\text{Panel Area}}$$

- Wall volume=$t_w * h_w * L_W$

4. Live load

- It depends on the purpose for which the floor is constructed.

Cont….

Table **Flooring and Walling**

Materials	Density kN/m^3
Flooring	
clay tiling	21
Marble tiling	27
Parquet, timber board	9
PVC covering	16
Rubber covering	17
Granulithic, terrazzo paving	23
Walling	
Solid brick	22
Perfurated brick	19
Concrete hollow-block	
Stone aggregate	14-20*
Lightweight (pumice) aggregate	10-14*
Asoestos cement sheet	17
Fibrous plaster board	10

Cont….

Category	Specific Use	q_k [kN/m²]
A	Areas for domestic and residential activities (floors)	1.5 to **2.0**
B	Office areas	2.0 to **3.0**
C	Areas where people may congregate:	
	C1: Areas with tables (e.g. restaurants, cafés…)	2.0 to **3.0**
	C2: Areas with fixed seats (e.g. areas in churches, theatres or cinemas…)	3.0 to **4.0**
	C3: Areas without obstacles for moving people (e.g. museums, exhibition rooms…)	3.0 to **5.0**
	C4: Areas with possible physical activities (e.g. dance halls, gymnastic rooms…)	4.5 to **5.0**
	C5: Areas susceptible to large crowds (e.g. concert halls…)	**5.0** to 7.5

Cont….

-

D	Shopping areas:	
	D1: Areas in general retail shops	**4.0** to 5.0
	D2: Areas in department stores	4.0 to **5.0**

Cont….

Imposed laods on floors in Buildings

Loaded area		q_k (kN/m2)
Category A	- general	2.0
	- stairs	3.0
	- balconies	4.0
Category B		3.0
Category C	- C1	3.0
	- C2	4.0
	- C3	5.0
	- C4	5.0
	- C5	5.0
Category D	- D1	5.0
	- D2	5.0
Category E		6.0

Cont….

General procedures for one way solid slab design

Step-1 Determination of minimum depth for Serviceability and fire design.

Step-2 Determination of Design load by taking 1m strip width.

Step-3 Analysis (Determination of Action effects i.e Design moment and Design shear)

Step -4 Determine Design constants.

Step-5 Check depth a adequacy

a) For Flexure

b) For Shear

Cont….

Step-6 Reinforcement Design.

- Determination of As main and As secondary.
- Determination of spacing of main and secondary reinforcements.

6.1 Check minimum provision

6.1.1 Minimum area of reinforcement area (As_{min}) both for main and secondary reinforcements.

6.1.1.1 For main reinforcements

$$AS_{min} = Max \begin{cases} (0.26\ fctm/fyk)\ bd \\ 0.0013\ bd \end{cases}$$

Cont….

6.1.1.2 For Secondary reinforcements.

- $As_{min} = 0.2\ AS_{\text{main reinforcement}}$

6.1.2 Check maximum spacing of reinforcements

6.1.2.1 For main Reinforcements

$$S_{max} = \min \begin{cases} 3h \\ 400\ mm \end{cases}$$

6.1.2.2 For secondary reinforcement

$$S_{max} = \min \begin{cases} 3.5h \\ 450mm \end{cases}$$

Cont....

Step -7 Determine Anchorage length

7.1 Basic Anchorage length (lb)

7.2 Design Anchorage length(lbd)

Step -8 Reinforcement Layout (Detailing)

8.1 Overlapping length (lo) if any.

8.2 Number of bars.

- n=(Ln/s)+1,Ln is width of considered strip

8.3 Length of each bar.

Cont….

Reinforcement in slabs near supports

- Where partial fixity occurs along an edge of a slab, but is not taken into account in the analysis, the top reinforcement should be capable of resisting at least 25% of the maximum moment in the adjacent span. This reinforcement should extend at least 0,2 times the length of the adjacent span, measured from the face of the support. It should be continuous across internal supports and anchored at end supports. At an end support the moment to be resisted may be reduced to 15% of the maximum moment in the adjacent span.

Cont….

Two way slab system

Introduction

- Depending on the load transfer mechanism slabs can be classified as one way and two way slab systems, as discussed in the previous lesson.
- The analysis and design of one way slabs, especially for beam supported and one way ribbed slab system, was discussed in the previous lesson.
- Analysis and design of two way slab system is a lot more complex as load transfer is in two orthogonal directions and computing the design actions is not straight forward as in one way slab.
- For rectangular slabs with standard edge conditions and subjected to uniformly distributed load, normally the bending moments are obtained using tabulated coefficients are provided later in this section

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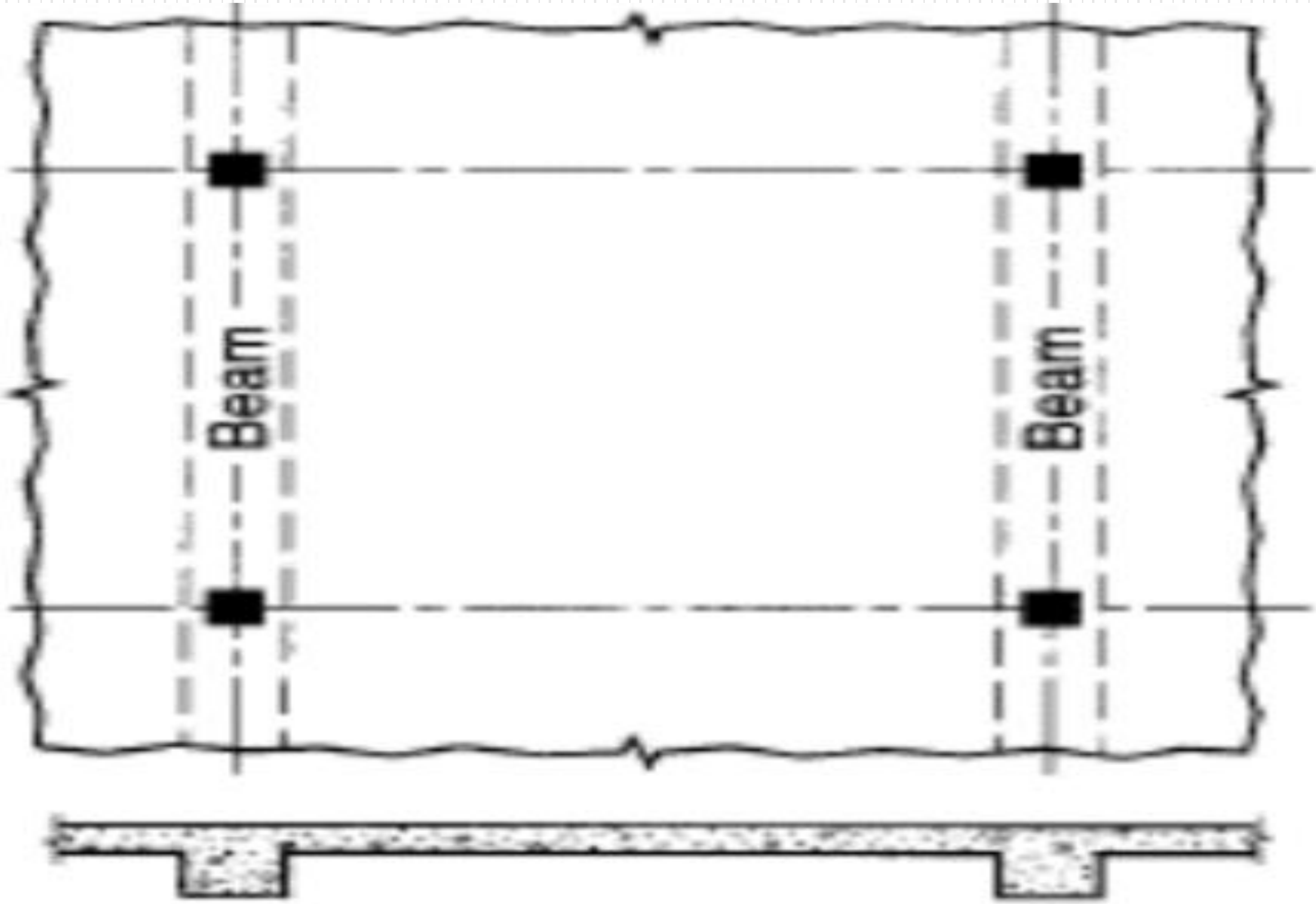

(a) One-way slab

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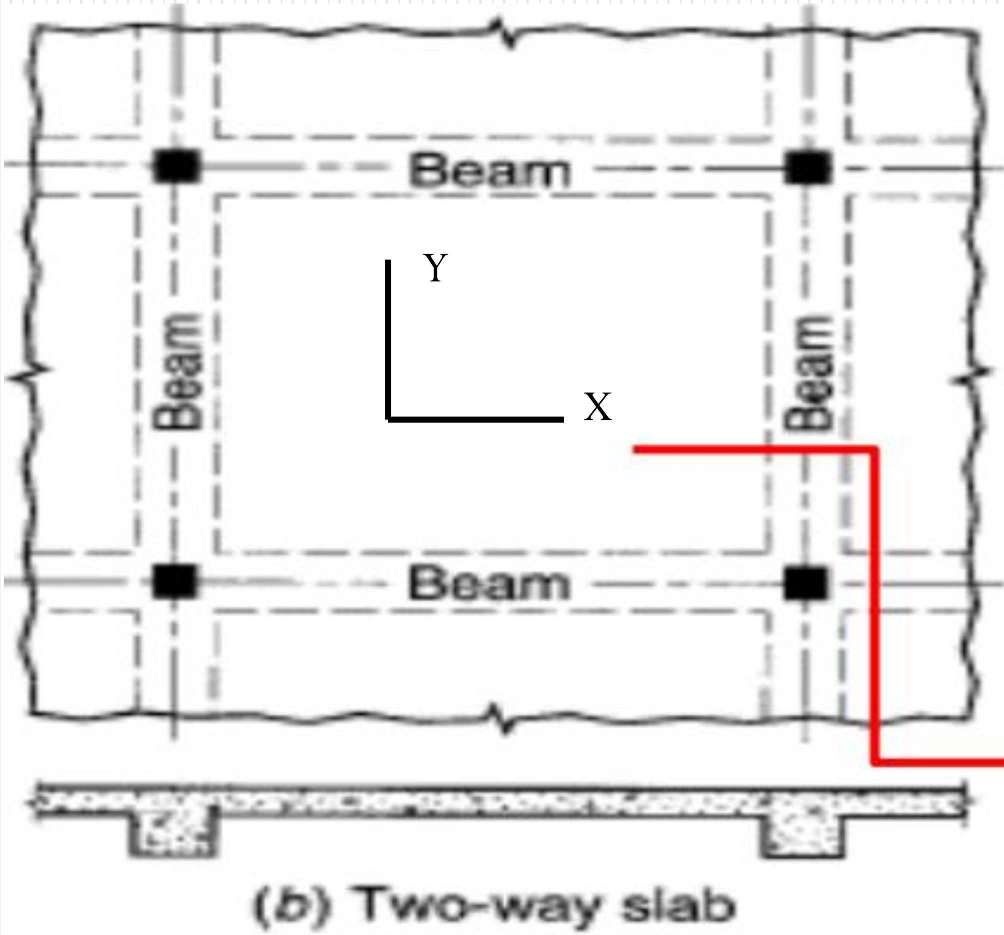

$LY / Lx \leq 2$

Two-way (Beam Supported) Slab System

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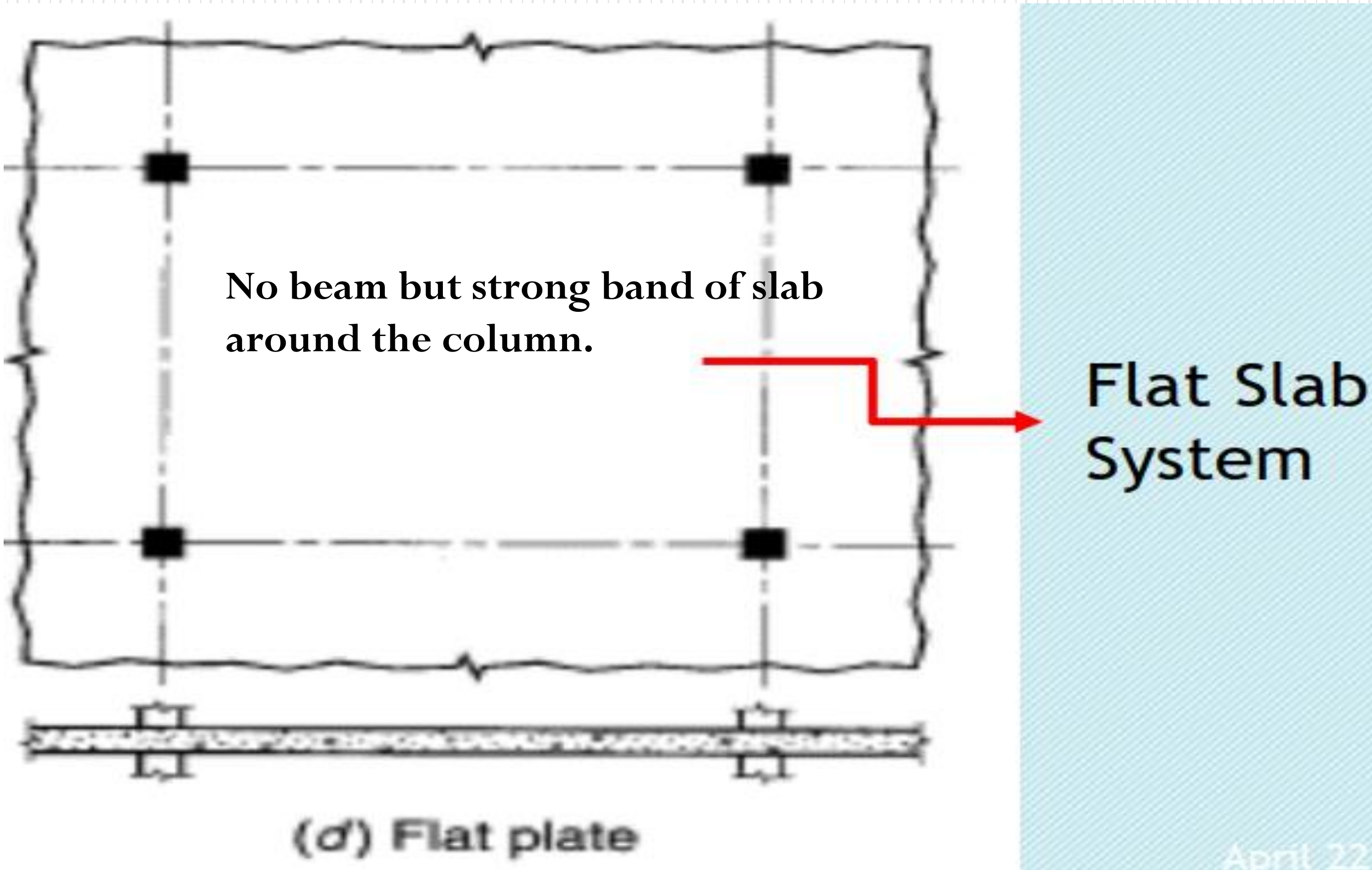
No beam but strong band of slab around the column.
Flat Slab System
(d) Flat plate
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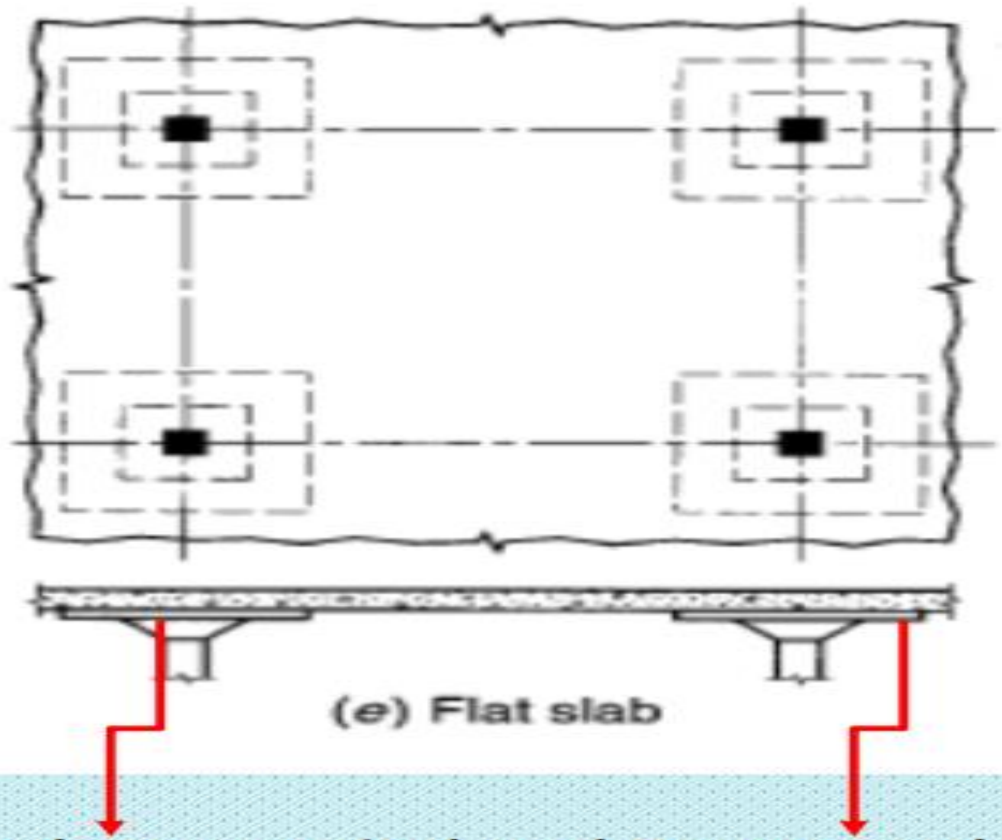

Column capital and Drop panel

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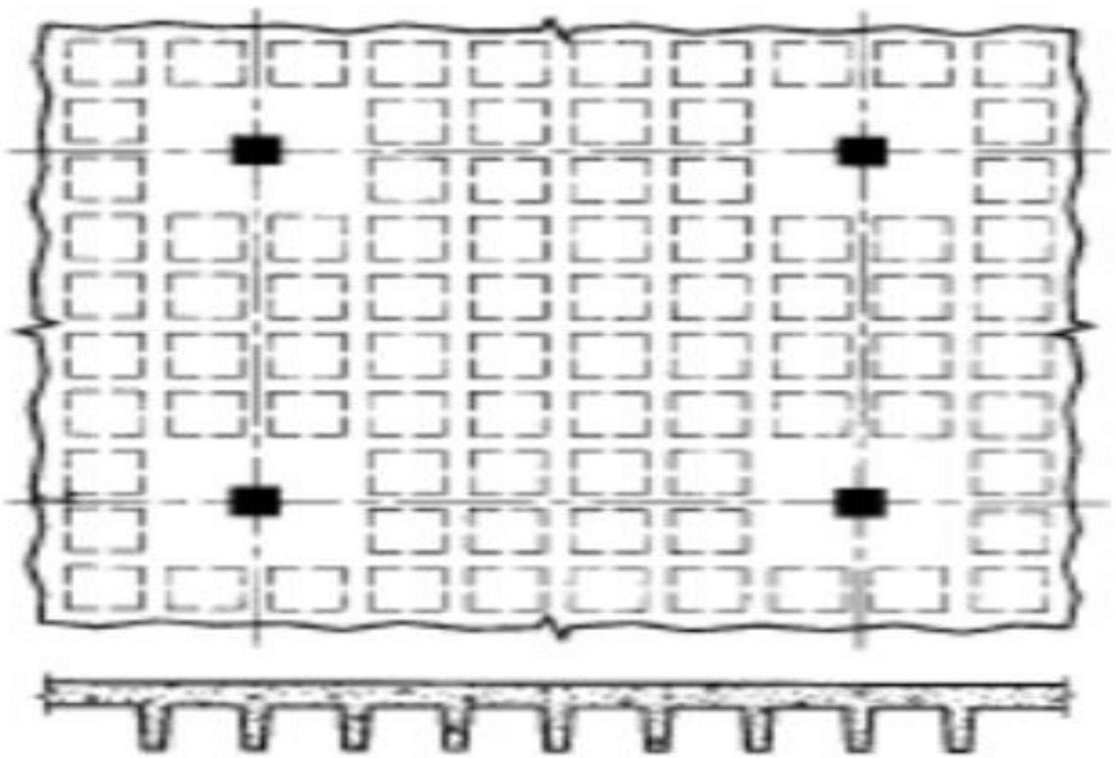

(f) Grid or waffle slab

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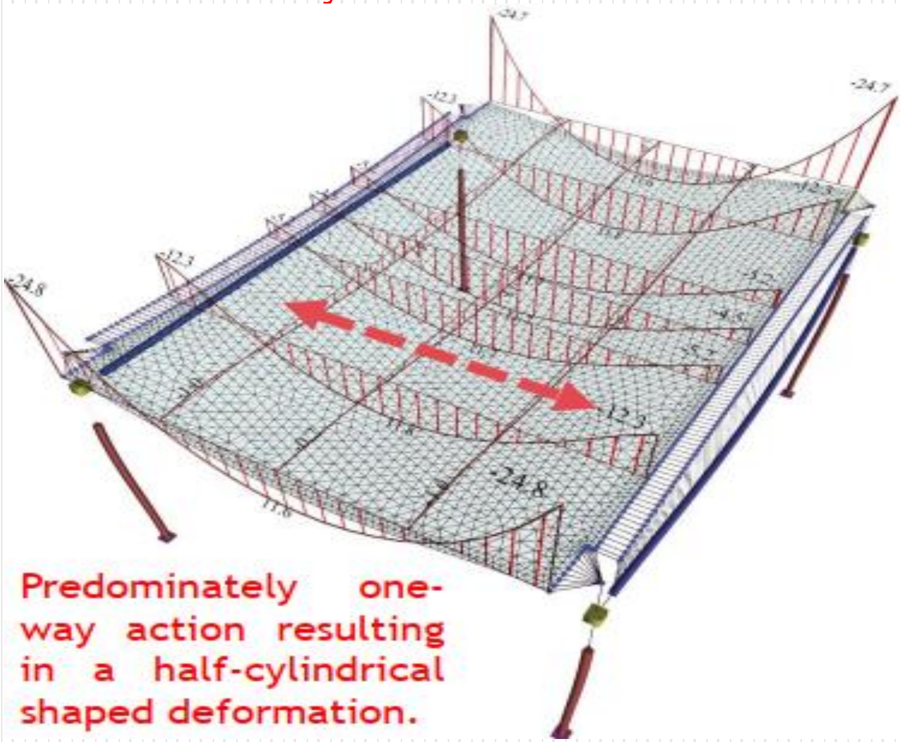
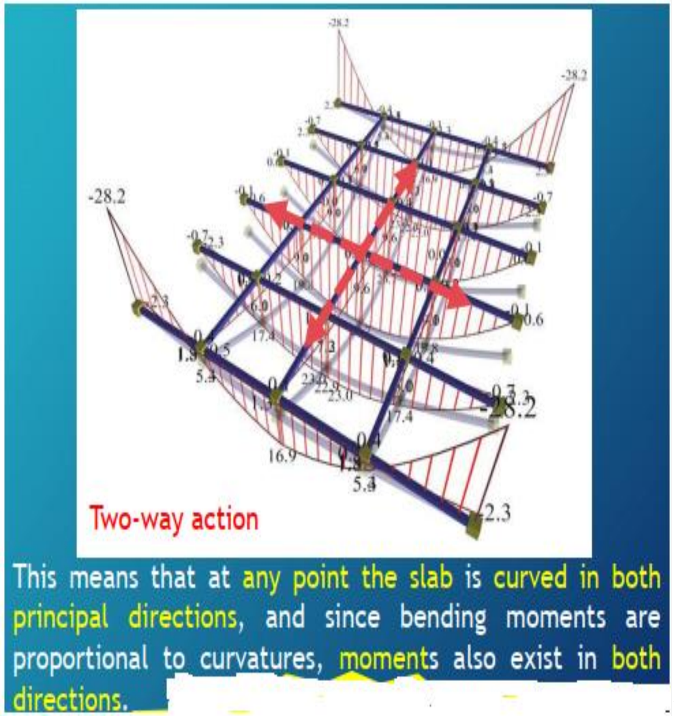
- In many cases rectangular slabs are of such proportions and are supported in such away that two way actions results. when loaded, such a slab bend in two a dished surface rather than a cylindrical one.





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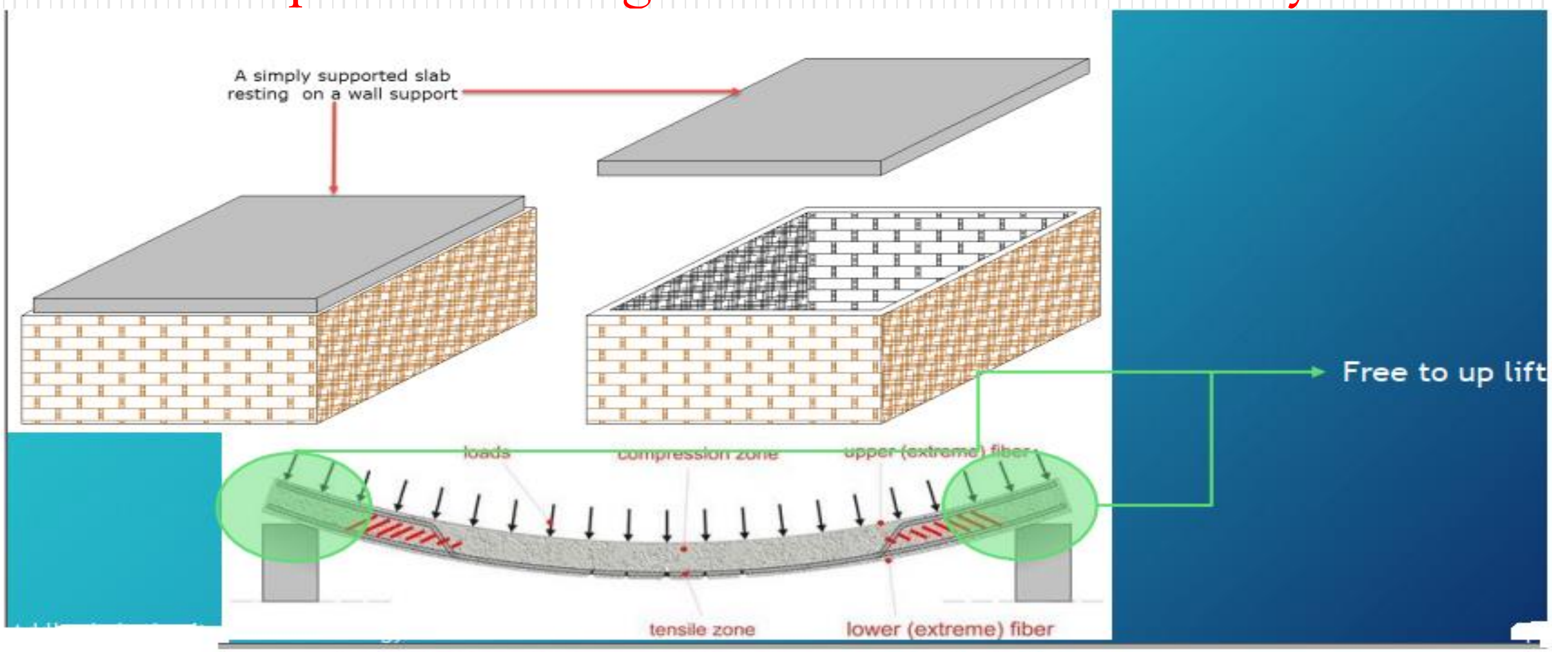
Analysis of rectangular panels with restrained edge

- Panels must had restrained edge in order to prevent lifting.

in order to prevent lifting reinforcement continuity must be



Unrestrained edge slab (Simply supported slab)

Cont….

- The above rectangular slab is simply supported or unrestrained edge slab b/c it is simply rest on supporting wall without reinforcement continuity b/n wall and slab.

Cont….

Approximate methods of analysis of two way edge restrained solid slab

1. Coefficient method
2. Yield line method and
3. Strip method.

A. Analysis by using coefficient method

Requirements for using coefficient method

1. The ratio of characteristic live load (Qk) to characteristic dead load (Gk) should be less than 1.25 or (Qk/Gk)<=1.25.
2. The characteristic live load (Qk) should be less than or equal to 5KN/m^2 or Qk<=5KN/m^2.

Cont….

3. The load should be uniformly distributed.

4. The slab should be rectangular.

5. The slab does not have large opening.

6. The slab should be Supported by beam in all edges.

Determination of support and field moment

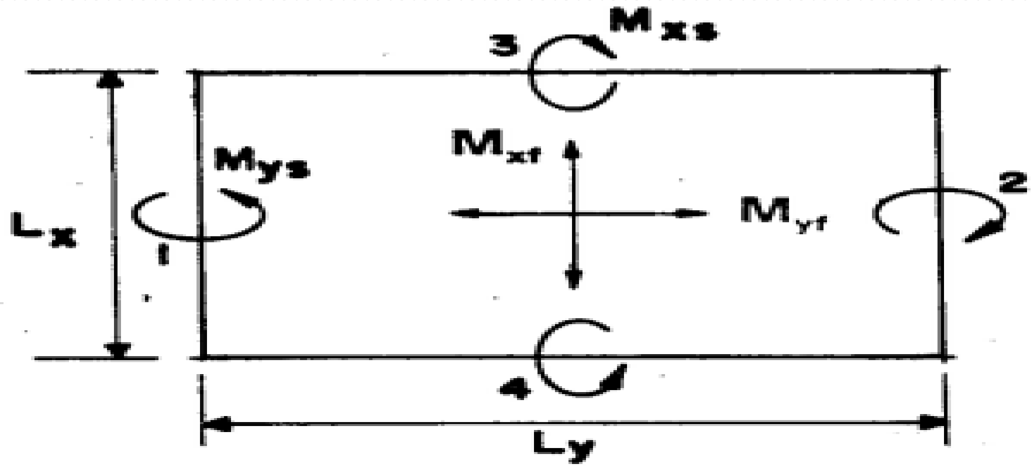


Figure A-3 Notations for Critical Moments

Cont….

- $M_i = \alpha_i * P_d * L_x^2$ i.e.

$M_{xf} = \alpha_{xf} * P_d * L_x^2$.

$M_{xs} = \alpha_{xs} * P_d * L_x^2$

$M_{yf} = \alpha_{yf} * P_d * L_x^2$

$M_{ys} = \alpha_{ys} * P_d * L_x^2$

Where as

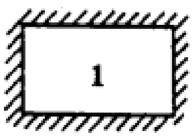
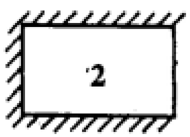
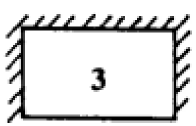
- f stands for field or span and s stands for support.
- αxf and αyf stands for coefficient of field or span moment along x and y direction respectively.
- αxs and αys stands for coefficient of support moment along x and y direction respectively.
- Pd stands for factored design load in one meter strip width of slab
- Lx stands for shorter span length of the slab.

Cont….

- The Values of αxf and αxs, were depend on Ly/Lx and supporting condition or continuity of the panel but the values of αyf and αys were depend on only supporting conditions. .
- Values of αxf, αyf, αxs and αys were obtained from the following table.

Cont…

Table A-1 Bending Moment Coefficients for Rectangular Panels Supported on Four Sides with Provision for Torsion at Corners

Support Condition	Coeff.	Values of L_y/L_x								Long span coefficients, αys & αyf for all values of L_y/L_x
		1.0	1.1	1.2	1.3	1.4	1.5	1.75	2.0	
 1	αxs αxf	0.032 0.024	0.037 0.028	0.042 0.032	0.046 0.035	0.050 0.037	0.053 0.040	0.059 0.044	0.063 0.048	0.032 0.024
 2	αxs αxf	0.039 0.029	0.044 0.033	0.048 0.036	0.052 0.039	0.055 0.041	0.058 0.043	0.063 0.047	0.067 0.050	0.039 0.029
 3	αxs αxf	0.039 0.030	0.049 0.036	0.056 0.042	0.062 0.047	0.068 0.051	0.073 0.055	0.082 0.062	0.089 0.067	0.039 0.030

Cont…

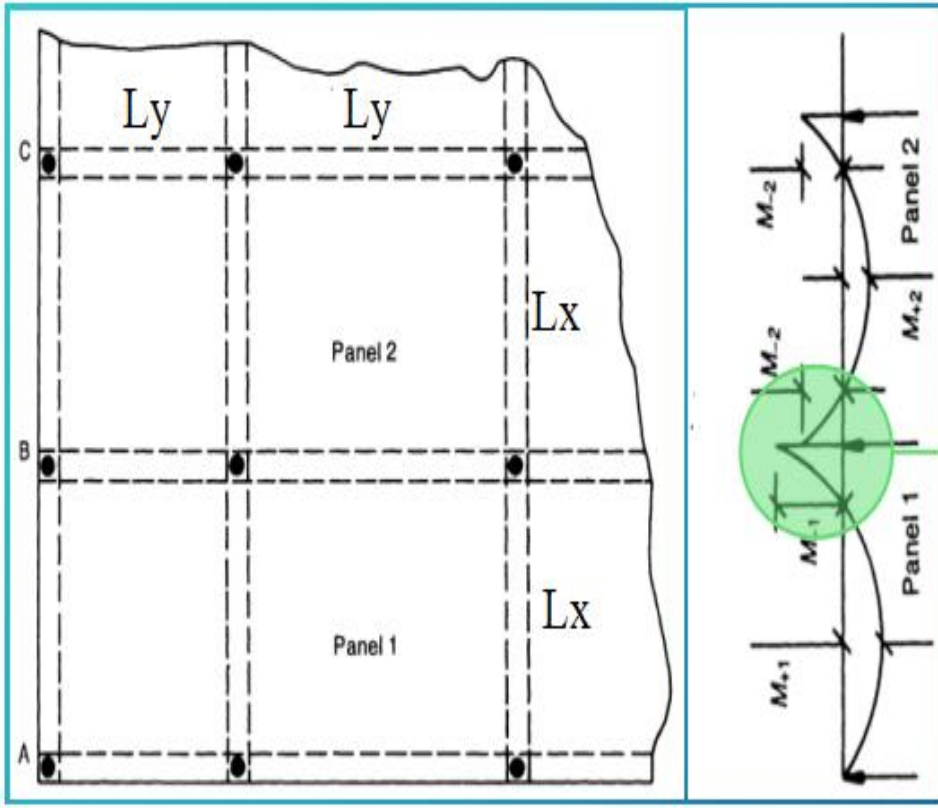
4	α_{sx}	0.047	0.056	0.063	0.069	0.074	0.078	0.087	0.093	0.047
	α_{sy}	0.036	0.042	0.047	0.051	0.055	0.059	0.065	0.070	0.036
5	α_{sx}	0.046	0.050	0.054	0.057	0.060	0.062	0.067	0.070	-
	α_{sy}	0.034	0.038	0.040	0.043	0.045	0.047	0.050	0.053	0.034
6	α_{sx}	-	-	-	-	-	-	-	-	0.045
	α_{sy}	0.034	0.046	0.056	0.065	0.072	0.078	0.091	0.100	0.034
7	α_{sx}	0.057	0.065	0.071	0.076	0.081	0.084	0.092	0.098	-
	α_{sy}	0.043	0.048	0.053	0.057	0.060	0.063	0.069	0.074	0.044
8	α_{sx}	-	-	-	-	-	-	-	-	0.058
	α_{sy}	0.044	0.054	0.063	0.071	0.078	0.084	0.096	0.105	0.044
9	α_{sy}	0.056	0.065	0.074	0.081	0.087	0.092	0.103	0.111	0.056

Cont….

Restrained slab with unequal conditions at adjacent panel

- In some cases, the bending moments at a common support, obtained by considering the two adjacent panels in isolation, may differ significantly because of the differing edge condition at the far supports or differing span lengths or loading.
- Consider panel 1 and 2 in figure bellow.

Cont….



Moments from the two panels is not the same ?

In these circumstances, the slab may be reinforced throughout for the worst case span and support moments.

However, this might be uneconomic in some cases. In such cases, the following distribution procedure may be used:

Cont….

Moment Adjustment

Support moment

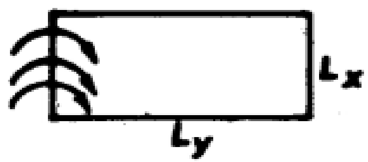
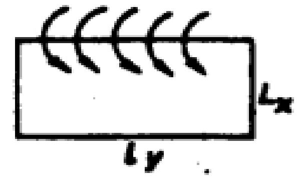
- Distributing of the moment by considering the stiffness of the two adjacent panels.

Span moment

- when the support moment decrease ,the span moments Mxf and Myf are then increased to allow for the changes of support moments. This increase is calculated as being equal to the change of the support moment multiplied by the factors given in table A-2.If a support moment is increased ,no adjustment shall be made to the span moments.

Cont….

Table A-2 Factors for Adjusting Span Moments m_{xf} and m_{yf}

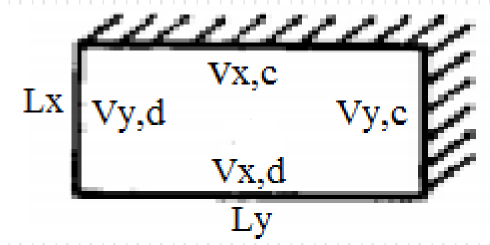
L_y/L_x				
	C_x	C_y	C_x	C_y
1.0	0.380	0.280	0.280	0.380
1.1	0.356	0.220	0.314	0.374
1.2	0.338	0.172	0.344	0.364
1.3	0.325	0.135	0.373	0.350
1.4	0.315	0.110	0.398	0.331
1.5	0.305	0.094	0.421	0.310
1.6	0.295	0.083	0.443	0.289
1.7	0.285	0.074	0.461	0.272
1.8	0.274	0.066	0.473	0.258
1.9	0.258	0.060	0.481	0.251
2.0	0.238	0.055	0.484	0.248

Cont....

- $\Delta Mxf = Cx*\Delta Mxs + Cx*\Delta Mys$
- $\Delta Myf = Cy*\Delta Mxs + Cy*\Delta Mys$

Loads on supporting beams (Load transfer from slab to beam)

- The design loads on beams supporting solid slabs spanning in two directions at right angles and supporting uniformly distributed load may be assessed from the following equation
- $Vi = \beta vi*Pd*Lx$ i.e
- $Vxc = \beta vx,c*Pd*Lx$
- Lx is shorter span



Cont….

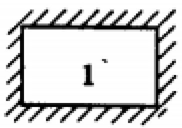
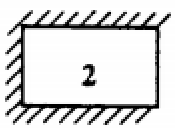
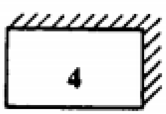
- $V_{xd} = \beta_{vx,d} * P_d * L_x$
- $V_{yc} = \beta_{vy,c} * P_d * L_x$
- $V_{yd} = \beta_{vy,d} * P_d * L_x$

Where as

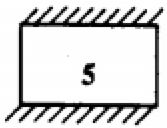
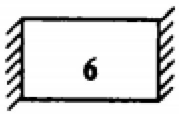
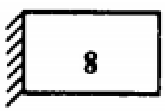
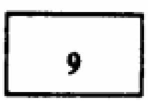
- c stands for continuous and d stands for discontinuous.
- V_i is the load transferred from slab to its supporting beam.
- β_{vi} is the coeffient of transferred load.
- P_d is the factored design load and
- L_x is the shorter span length of the slab.
- The values of coefficients obtained from the following table.

Cont….

Table A-3 Shear Force Coefficients for Uniformly Loaded Rectangular Panels Supported on Four Sides with Provision for Torsion at Corners

Type of panel and location	Edge	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	
	Continuous	0.33	0.36	0.39	0.41	0.43	0.45	0.48	0.50	0.33
	Continuous	0.36	0.39	0.42	0.44	0.45	0.47	0.50	0.52	0.36
	Discontinous	-	-	-	-	-	-	-	-	0.24
	Continuous	0.36	0.40	0.44	0.47	0.49	0.51	0.55	0.59	0.36
	Discontinous	0.24	0.27	0.29	0.31	0.32	0.34	0.36	0.38	-
	Continuous	0.40	0.44	0.47	0.50	0.52	0.54	0.57	0.60	0.40
	Discontinous	0.26	0.29	0.31	0.33	0.34	0.35	0.38	0.40	0.26

Cont….

 5	Continuous	0.40	0.43	0.45	0.47	0.48	0.49	0.52	0.54	-
	Discontinous	-	-	-	-	-	-	-	-	0.26
 6	Continuous	-	-	-	-	-	-	-	-	0.40
	Discontinous	0.26	0.30	0.33	0.36	0.38	0.40	0.44	0.47	-
 7	Continuous	0.45	0.48	0.51	0.53	0.55	0.57	0.60	0.63	-
	Discontinous	0.30	0.32	0.34	0.35	0.36	0.37	0.39	0.41	0.30
 8	Continuous	-	-	-	-	-	-	-	-	0.45
	Discontinous	0.30	0.33	0.36	0.38	0.40	0.42	0.45	0.48	0.30
 9	Discontinous	0.33	0.36	0.39	0.41	0.43	0.45	0.48	0.50	0.33

Cont….

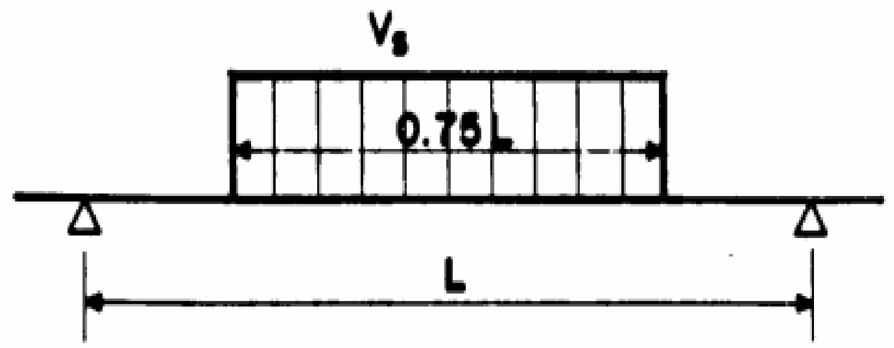


Figure A-5 Distribution of Load on a Beam Supporting a Two-Way Spanning Slab

Division of two way solid slab in to Middle strip and Edge strip.

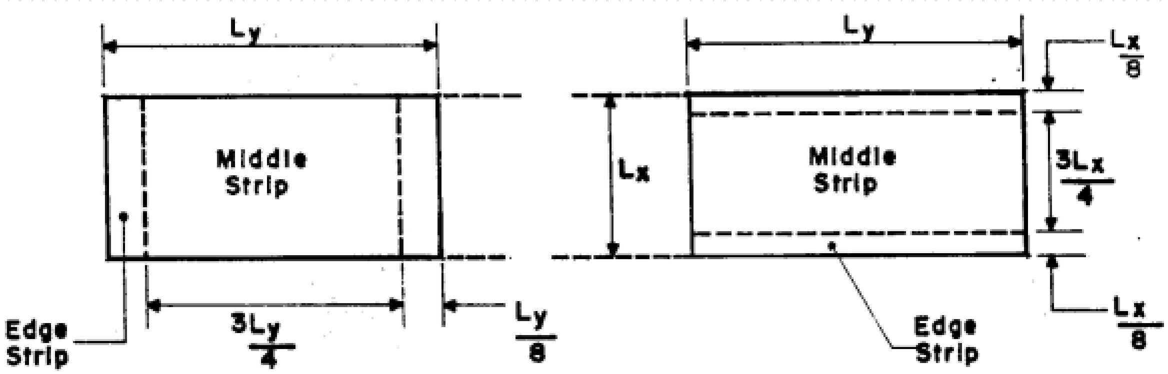


Figure A-4 Division of Slab into Middle and Edge Strips

Cont....

Minimum area of reinforcements(Asmin)

$$A_{S,min} = \max \begin{cases} (0.26\, f_{ctm}/f_{yk})\, bd \\ 0.0013\, bd \end{cases}$$

Maximum spacing

$$S_{max} = \min \begin{cases} 3h \\ 400\text{ mm} \end{cases}$$

Cont….

General procedures for two one way solid slab design

Step-1 Determination of minimum depth for Serviceability and fire design.

Step-2 Determination of Design load by taking 1m strip width.

Step-3 Analysis (Determination of field and support moment and shear transferred in to supporting beams) by using coefficient method.

Step-4 Adjusting support and field(span moments)

Step -5 Determine Design constants.

Step-6 Check depth a adequacy

a) For Flexure

b) For Shear

Cont....

Step-7 Reinforcement Design.

- Determination of As both in x and y direction.
- Determination of spacing reinforcements.

7.1 Check minimum provision

7.1.1 Minimum area of reinforcement (As_{min})

$$AS_{min} = Max \begin{cases} (0.26\ f_{ctm}/f_{yk})\ bd \\ 0.0013\ bd \end{cases}$$

Cont….

7.1.2 Check maximum spacing of reinforcements

$$S_{max} = \min \begin{cases} 3h \\ 400\ mm \end{cases}$$

Step -8 Determine Anchorage length

8.1 Basic Anchorage length (lb)

8.2 Design Anchorage length(lbd)

Step -9 Reinforcement Layout (Detailing)

9.1 Overlapping length (lo) if any.

Cont….

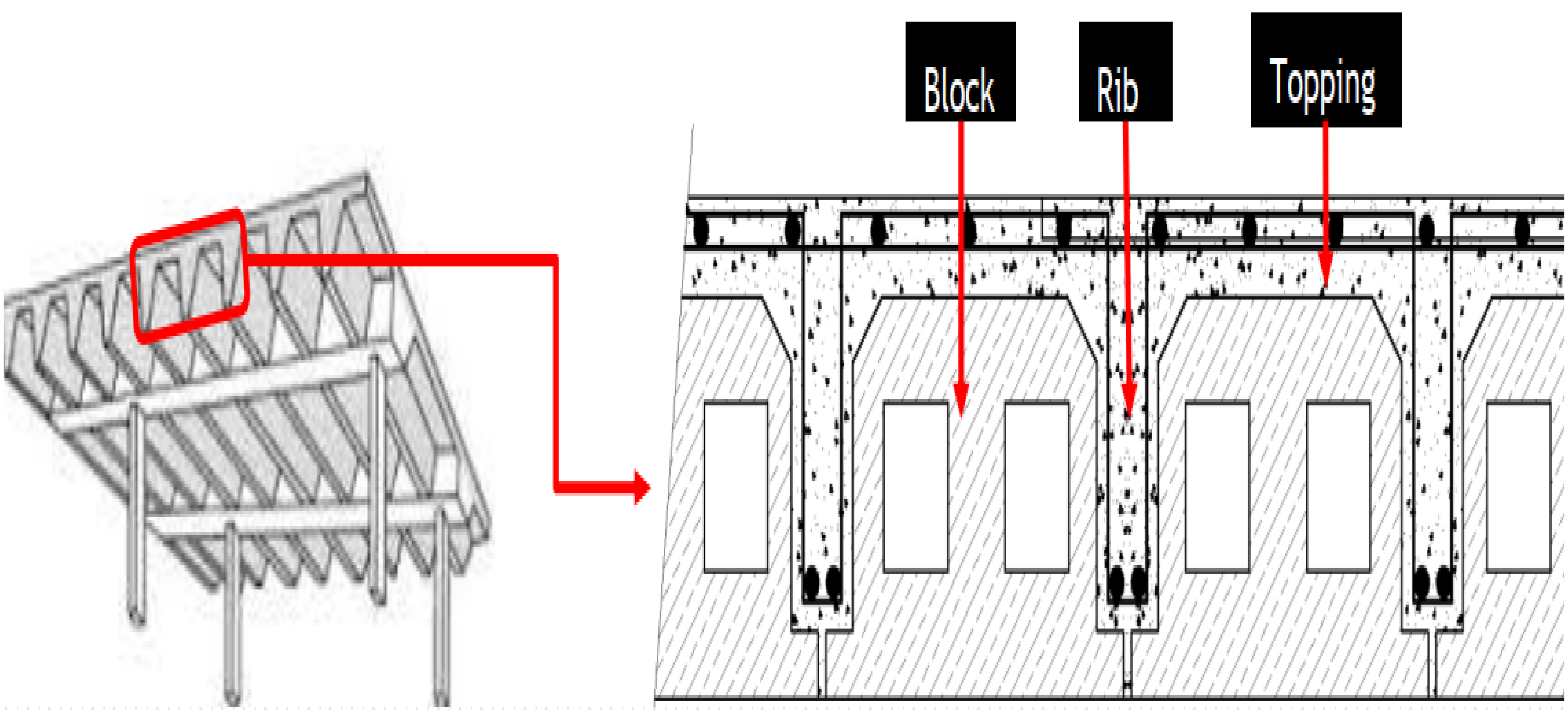
9.2 Number of bars.

- $n=(Ln/s)+1$

9.3 Length of each bar.

One way rib slab

- For long span floor relatively light live loads



Cont….

Design of one way ribbed slab

Introduction

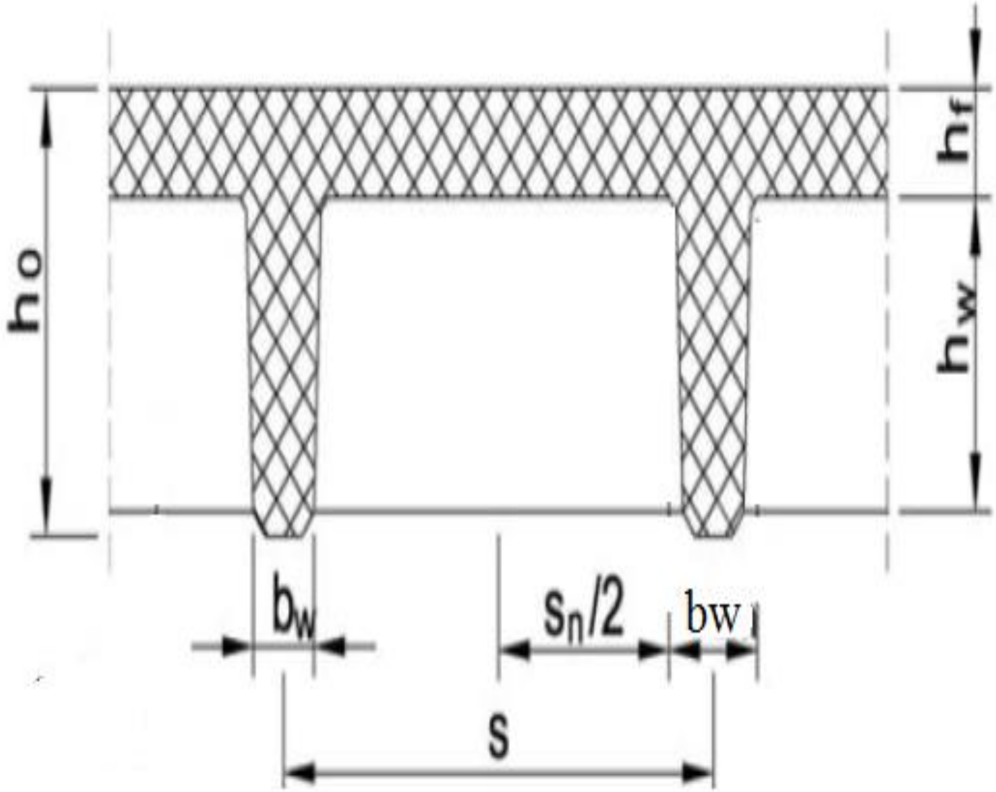
- Hollow block floors are formed typically using blocks made of concrete with light weight aggregate.
- The void in blocks reduces the total weight of the slab significantly.
- The main advantages of using hollow blocks is the reduction in weight by removing the part of the concrete bellow the neutral axis.
- Hollow block floors proved economical for spans of more than 5m with light or moderate live loads, such as hospitals, office or residential buildings.

Cont….

Requirements

- The c/c rib spacing doesn't exceed 1500mm.
- The depth of the rib bellow the flange doesn't exceed 4 times it's width.
- The depth of the flange is at least 1/10 of the clear distance between ribs or 50 mm.

Cont….



$s \leq 1500$ mm

$h_f \geq s_n/10$ or 50 mm

$h_w \leq 4 \cdot b_m$

$s_t \leq 10 \cdot h_0$

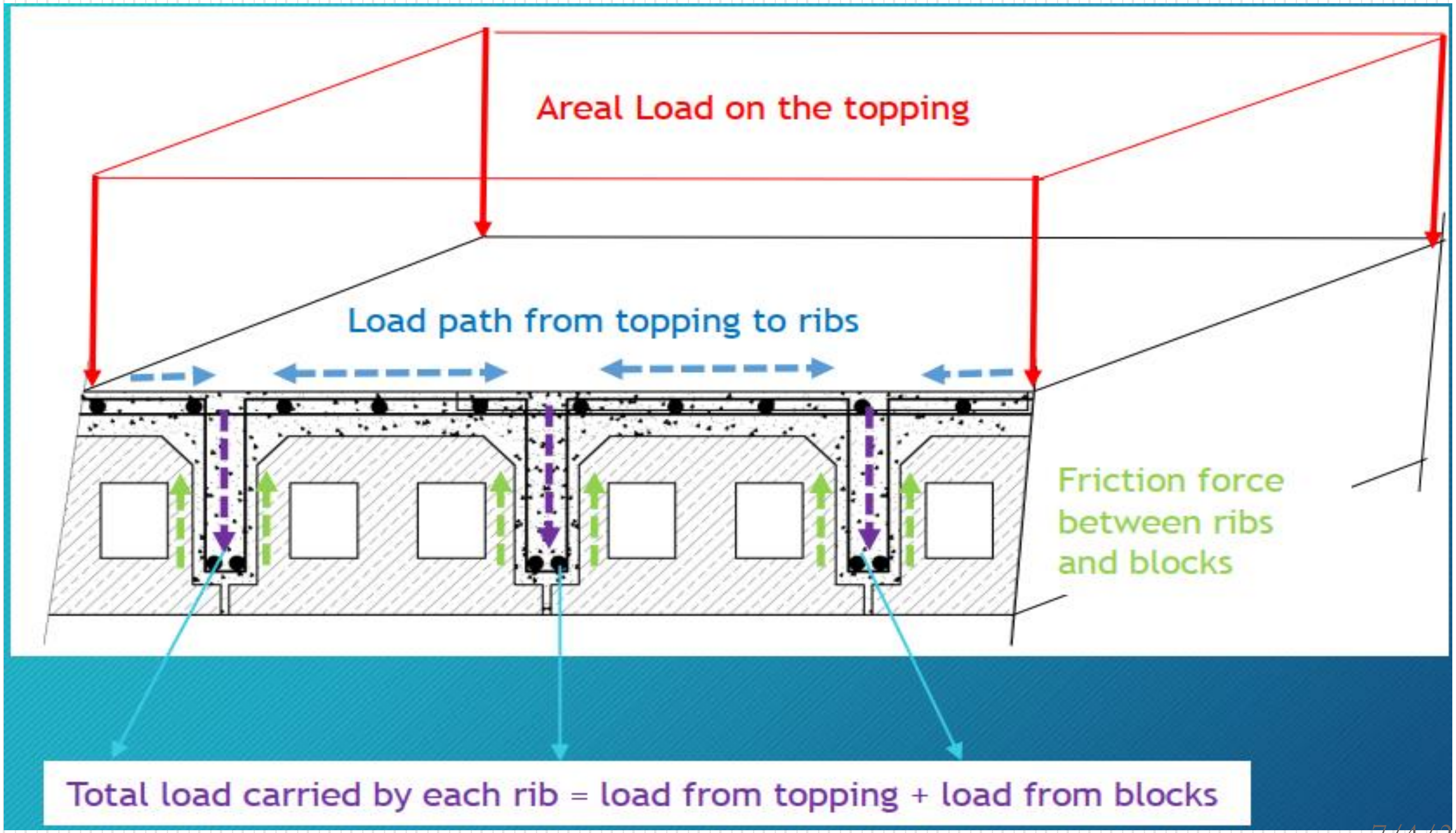
Cont….

Procedures

1. Shear force and moments for continuous rib slabs can be obtained by elastic analysis by considering live load variation.
2. The mid span section is designed as a T- beam with flange width equal to the distance between ribs. The support section is designed as a rectangular beam.
3. The shear verification is carried out for the critical section of the rib with the same procedure as in a rectangular beam section.
4. A mesh reinforcement with a cross sectional area of not less than 0.12% of the area of the topping in each direction should be provided.
5. $S_{max} \leq 0.5$ *c/c distance b/n ribs
6. If ribs are widely spaced ,topping should may be designed as one way slab between ribs.

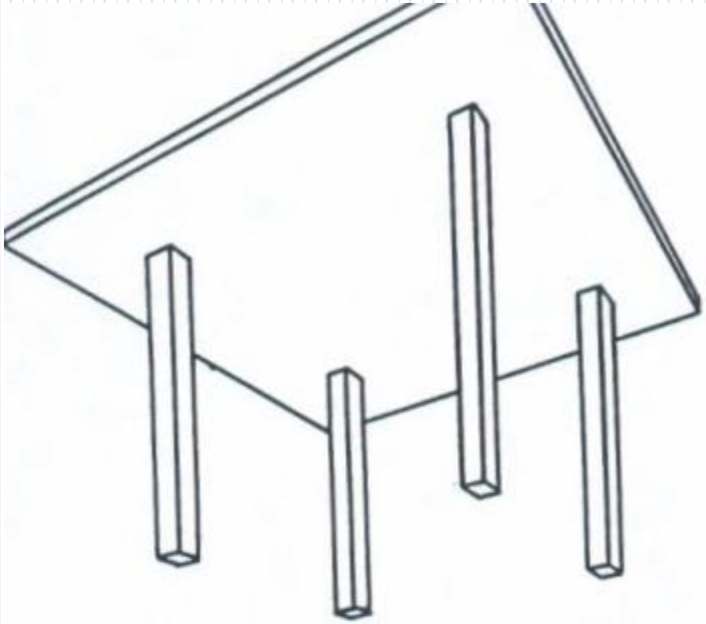
Cont....

Load transfer mechanisms in ribbed slab system

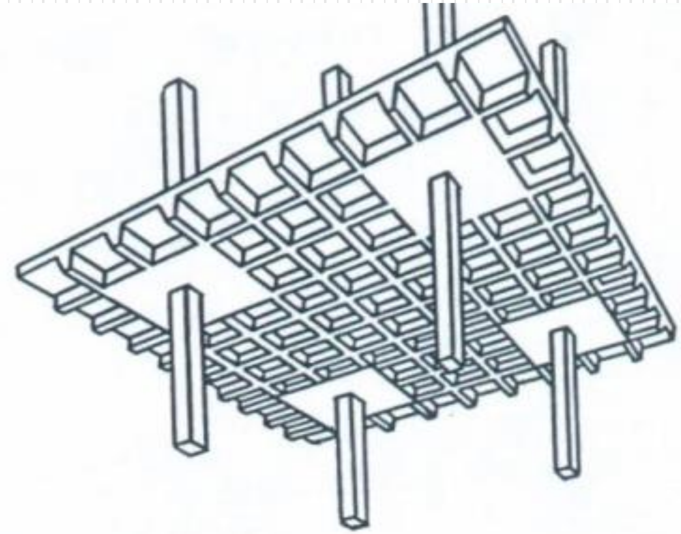


Flat slab

- The flat slab is a slab with or without drops, supported generally without beams by columns with or without column heads. The slab may be solid or have recesses formed on the soffit to give a waffle slab.



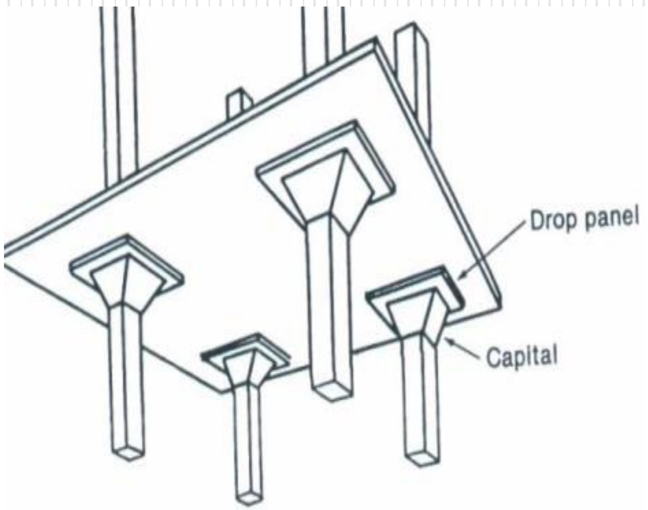
Flat Plate



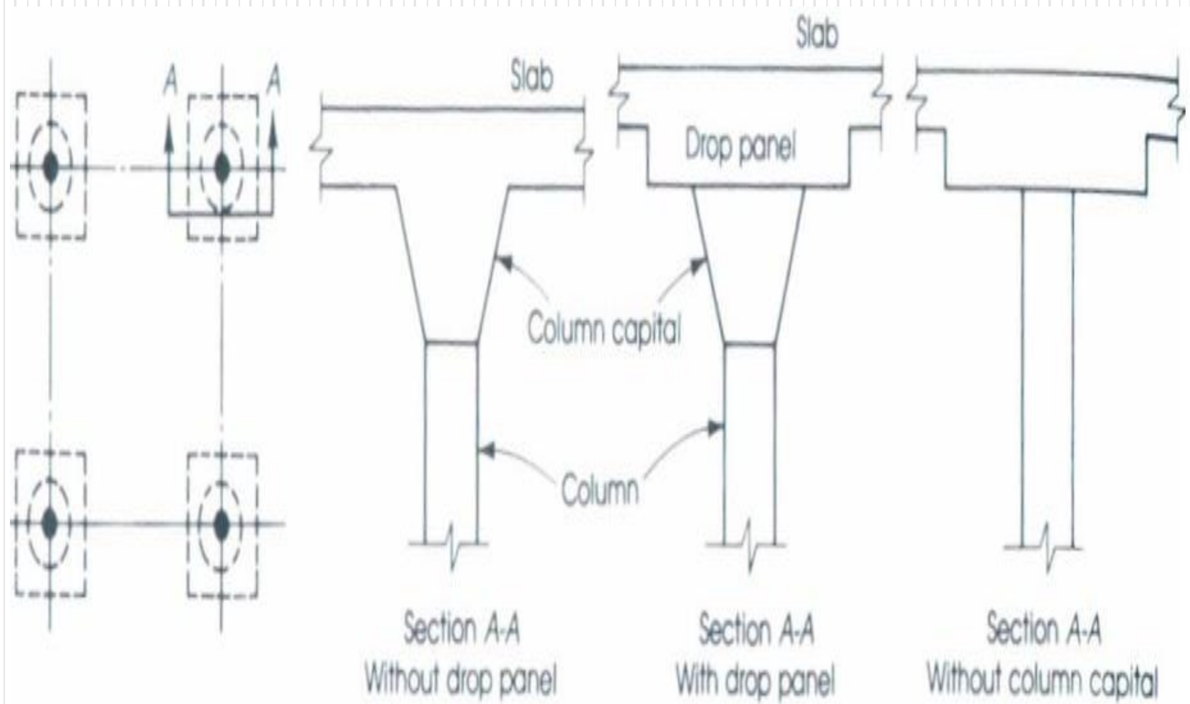
Waffle slab

Cont….

- Flat slabs can be constructed as one of the following illustrations

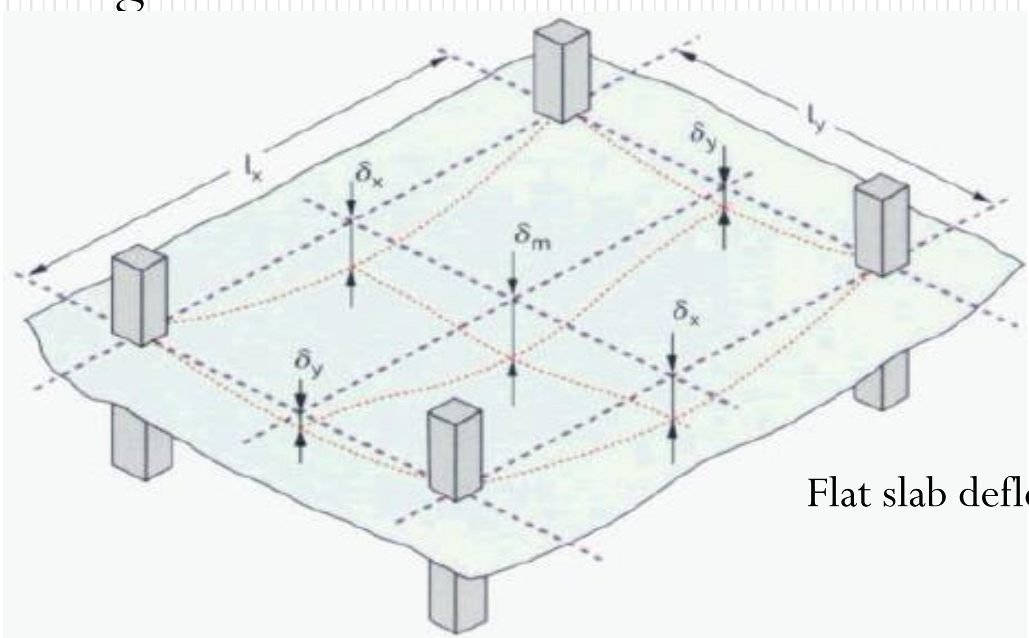


Flat slab



Cont.....

- In flat slab:
- Slab Carry the shear forces, which are concentrated around the column,
- Transmit the moment to the edge and corner columns,
- Suffer greater deflections.



Flat slab deflection illustration

Cont..

- ANALYSIS OF FLAT SLAB.

1.Direct design method (As per Design of reinforced concrete structures ,second edition-2008, volume 2)

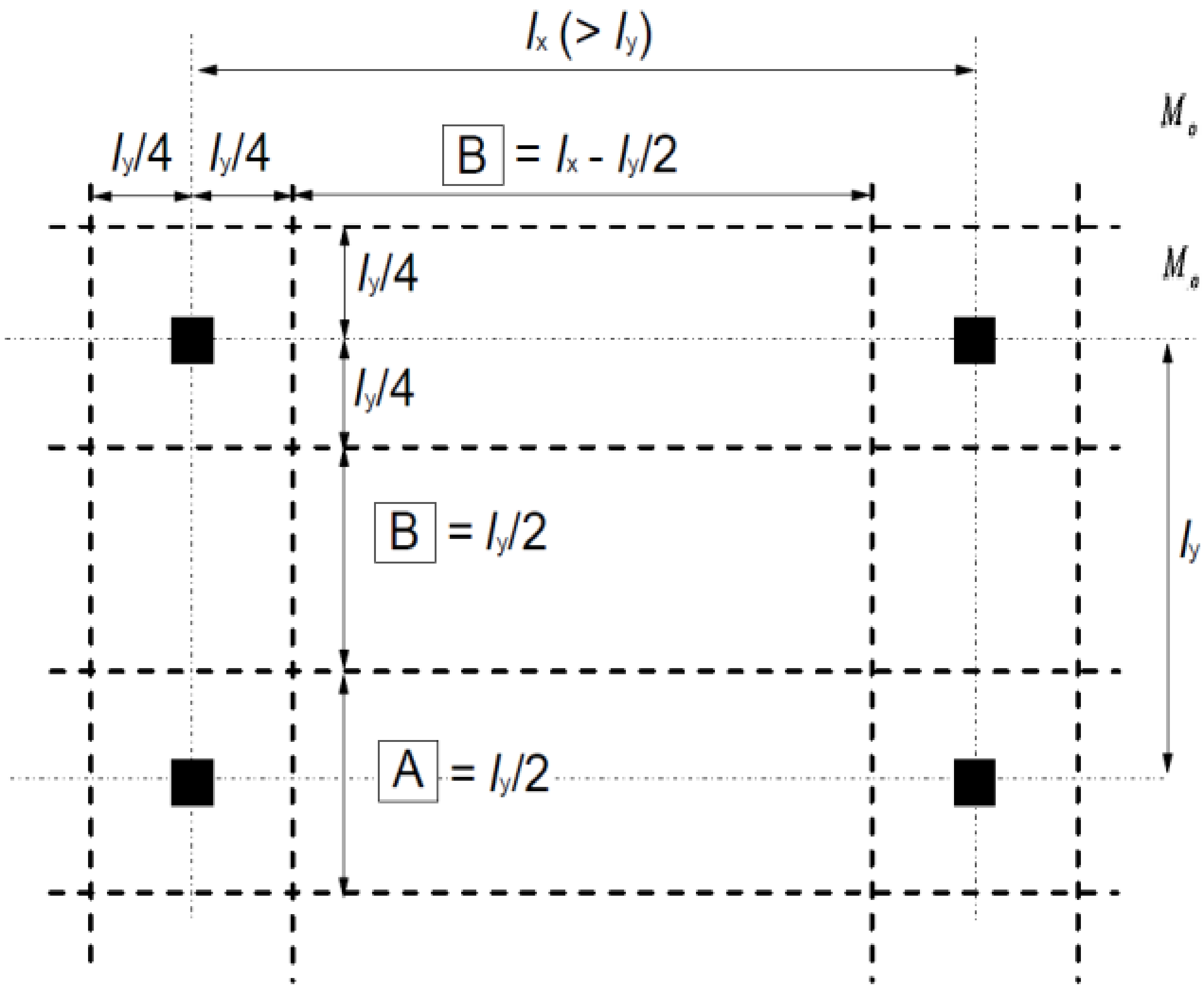
Limitation of the direct method

To ensure that the moments at the critical sections are adequate, the ECP 203 requires that the following design conditions be satisfied:

1. A minimum of three continuous spans in each direction.
2. The ratio of the longer to the shorter span within a panel should not exceed 1.3
3. Successive span lengths in each direction should not differ by more than 10%
4. Non-Successive span lengths in each direction should not differ by more than 20%

The slab is analyzed by dividing it as column (around the column) and middle strip (mid span of transverse span) as show the next slide.

Cont…



$$M_o = \frac{w_u \times L_2}{8} \times \left(L_1 - \frac{2 \times D}{3}\right)^2 \quad \text{(long direction)}.$$

$$M_o = \frac{w_u \times L_1}{8} \times \left(L_2 - \frac{2 \times D}{3}\right)^2 \quad \text{(short direction)}$$

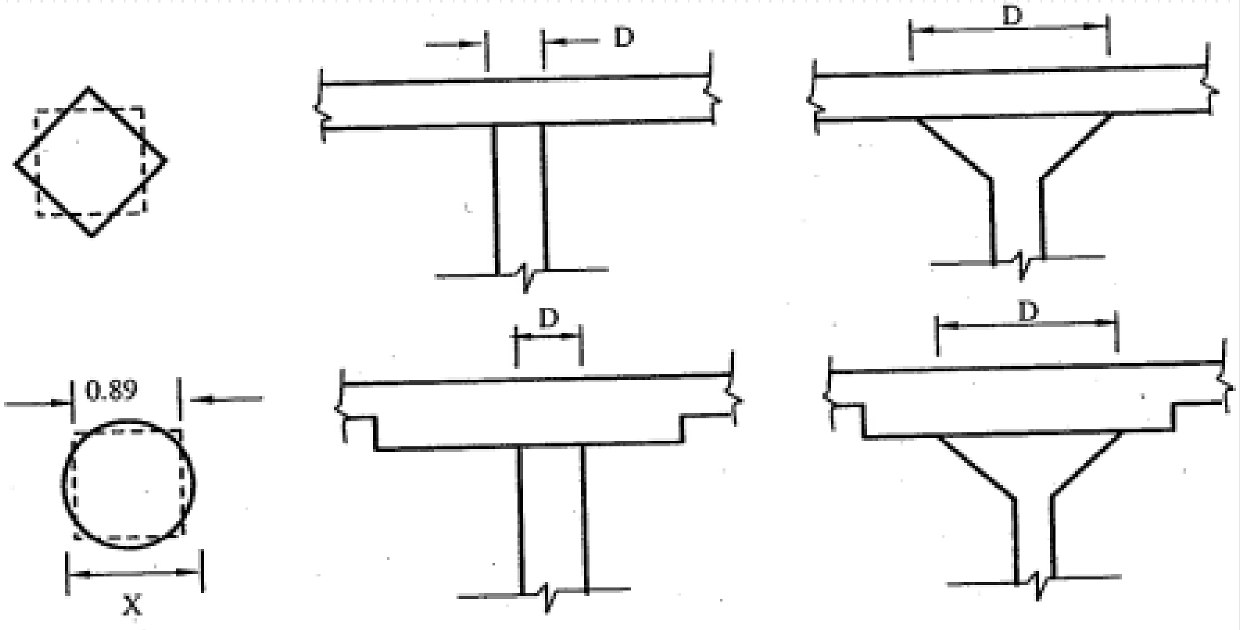
Here ly=L1 ans lx=L2

A - column strip

B - middle strip

Cont…

- D in the above slab is the smallest distance at the intersection of column and slab.

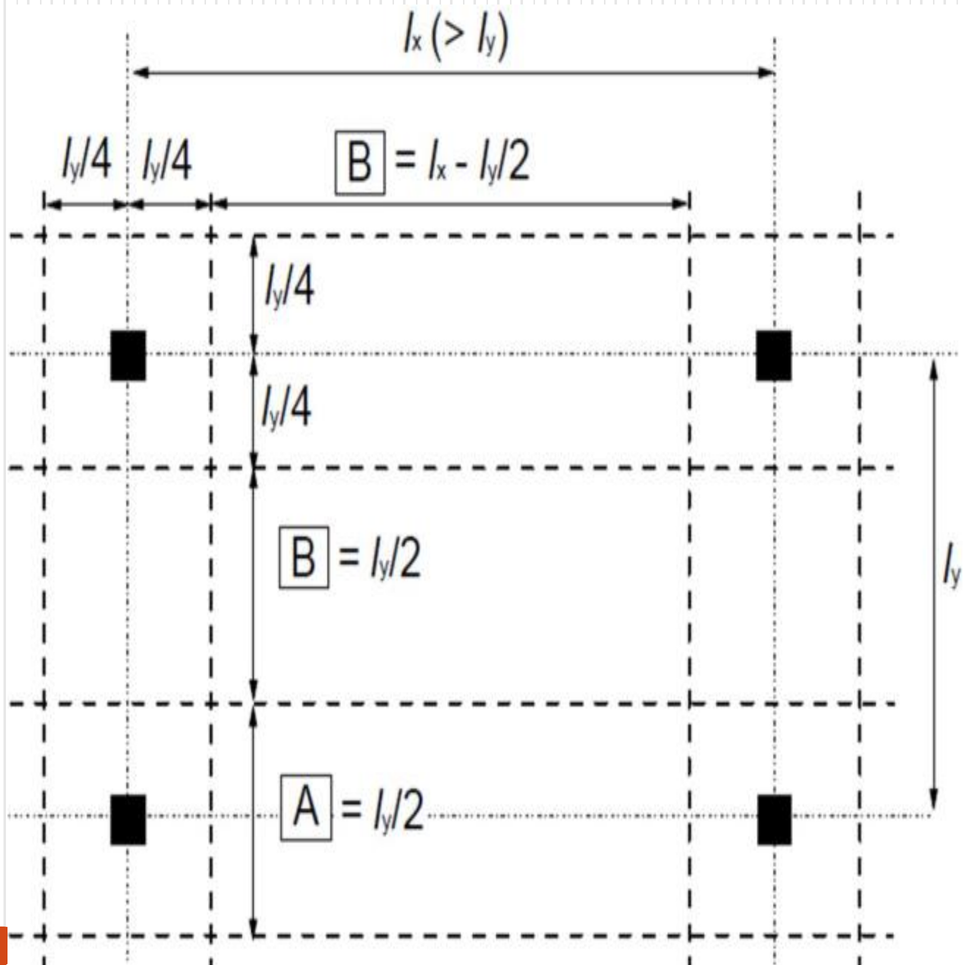


Definition of D for different flat slab systems

First total static moment is calculated which is is then divided in to support and span moments based on coefficients.

Support and span moments then divided in to column strip ad middle strip.

The static moment Mo is calculated as:



$$M_o = \frac{w_u \times L_2}{8} \times \left(L_1 - \frac{2 \times D}{3}\right)^2 \text{ (long direction)}.$$

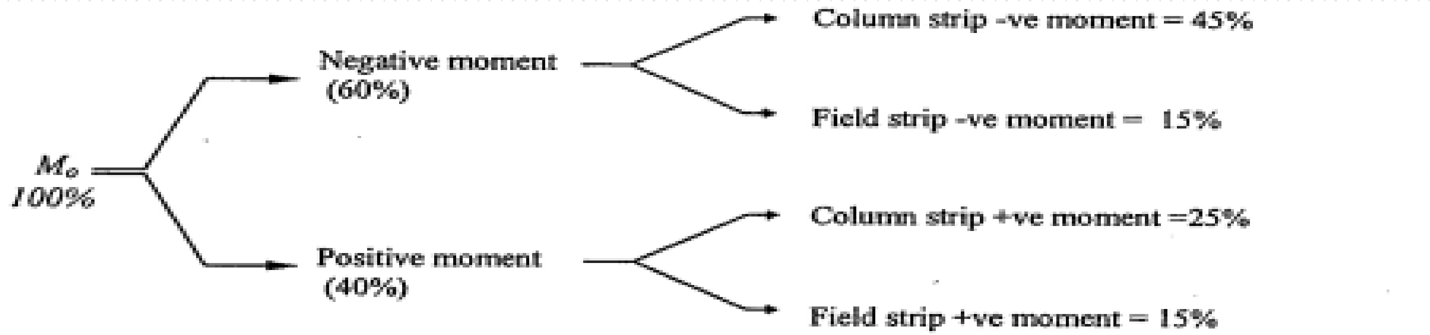
$$M_o = \frac{w_u \times L_1}{8} \times \left(L_2 - \frac{2 \times D}{3}\right)^2 \text{ (short direction)}$$

Here ly=L1 and lx=L2

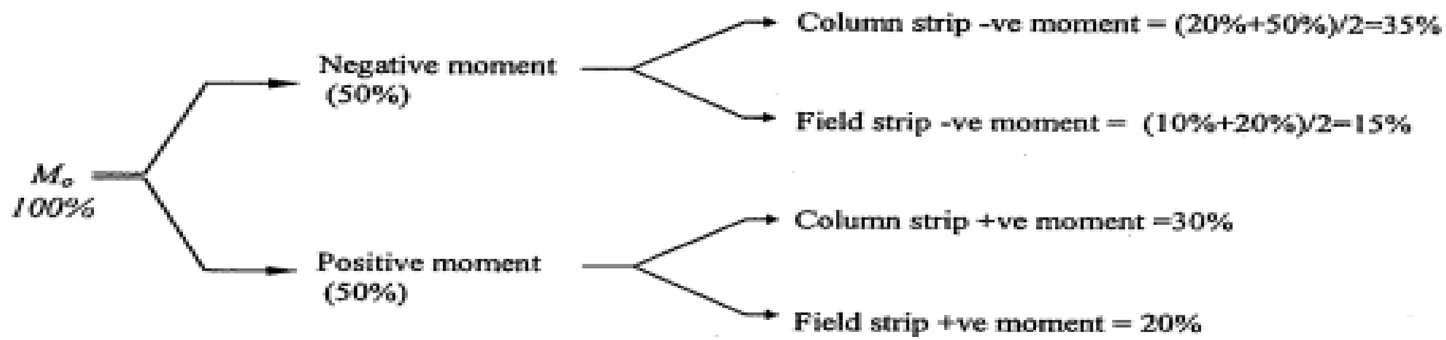
A - column strip

B - middle strip

Cont..



A: Moment distribution in interior panels (with or without marginal beam)



B: Moment distribution in exterior panels with marginal beam

Fig. 4.9 Distribution Moment in flat slabs using the direct design method

EQUIVALENT FRAM METHOD(As per ES EN 1992-1-1_2015)

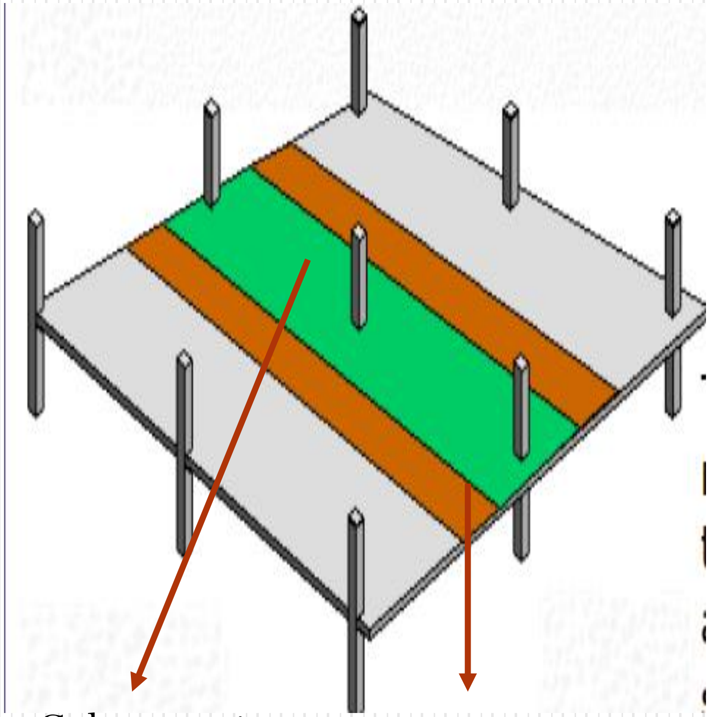
- The structure should be divided longitudinally and transversely into frames consisting of columns and sections of slabs contained between the centre lines of adjacent panels (area bounded by four adjacent supports).
- The stiffness of members may be calculated from their gross cross-sections. For vertical loading the stiffness may be based on the full width of the panels
- Total load on the panel should be used for the analysis in each direction.
- The total bending moments obtained from analysis should be distributed across the width of the slab.
- In elastic analysis negative moments tend to concentrate towards the centre lines of the columns.

CONT…

- The panels should be assumed to be divided into column and middle strips.

Simplified apportionment of bending moment for a flat slab

	Negative moments	Positive moments
Column Strip	60 – 80%	50 – 70%
Middle strip	40 – 20%	50 – 30%
Note: Total negative and positive moments to be resisted by the column and middle strips together should always add up to 100%.		



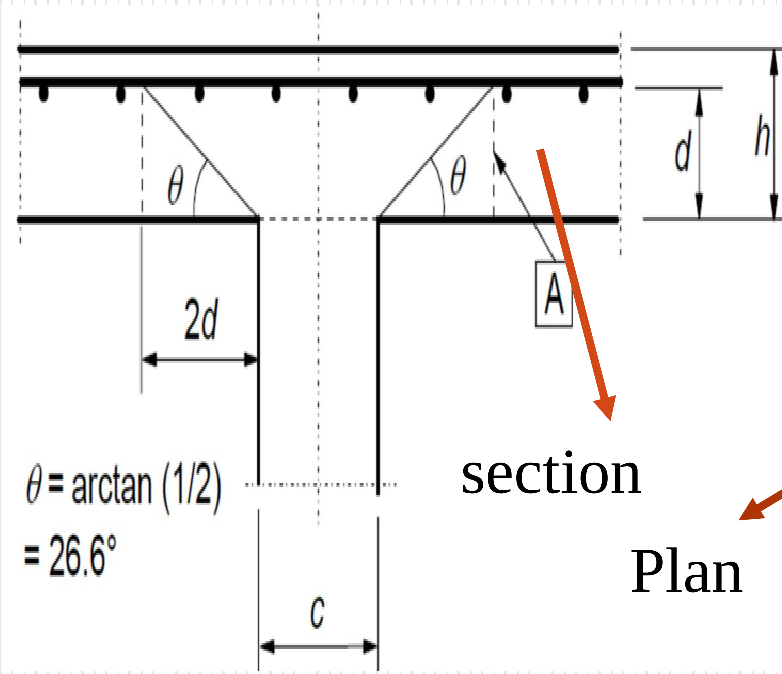
Punching shear

- Punching shear can result from a concentrated load or reaction acting on a relatively small area, called the loaded area A load of a slab or a foundation.
- Punching Shear Is the most common, and is a major design consideration, in flat slab construction.

Column is tending to punch the slab around it self due gravity loads including self weight.

Cont…

- An appropriate verification model for checking punching failure at the ultimate limit state is shown in Figure below.



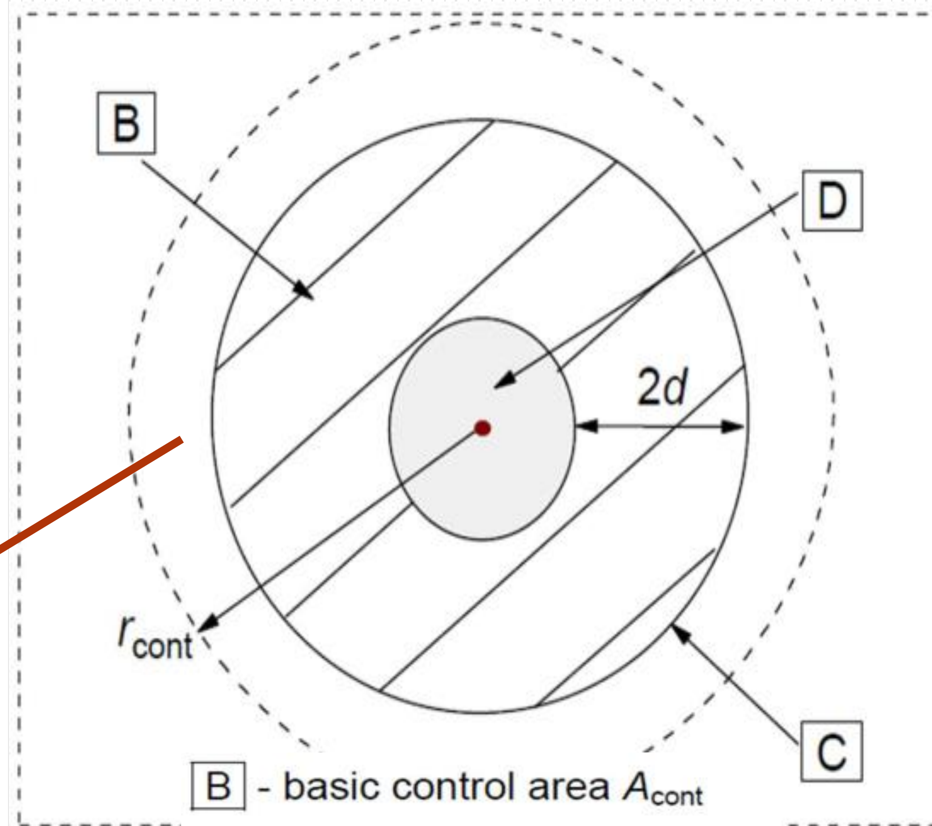


Figure Verification model for punching shear at the ultimate limit state

Cont...

- The effective depth of the slab is assumed constant and may normally be taken as: $D_{eff} = \frac{(d_y + d_z)}{2}$

where dy and dz are the effective depths of the reinforcement in two orthogonal directions.

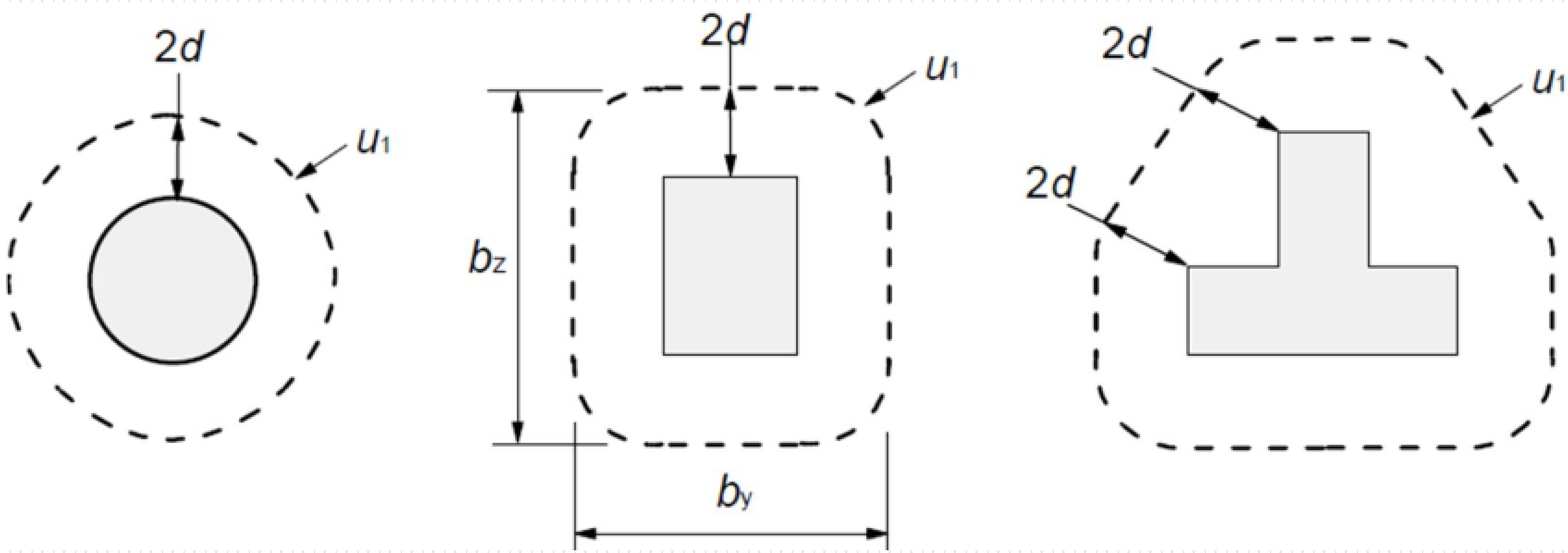
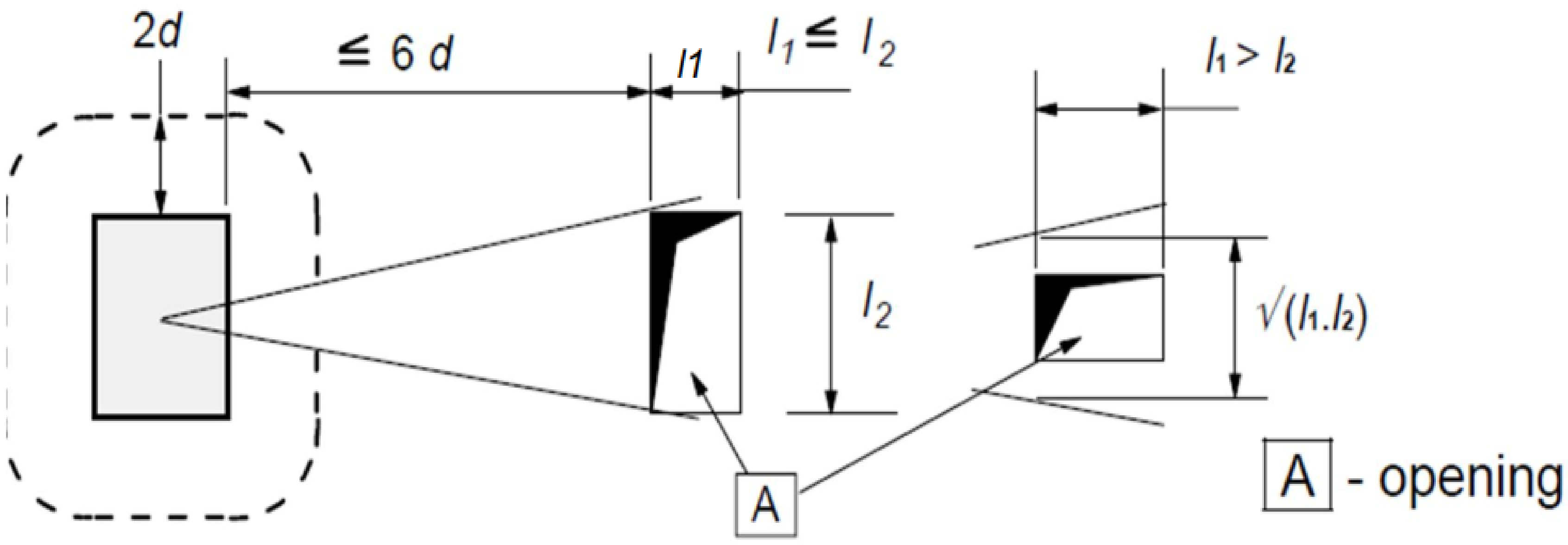


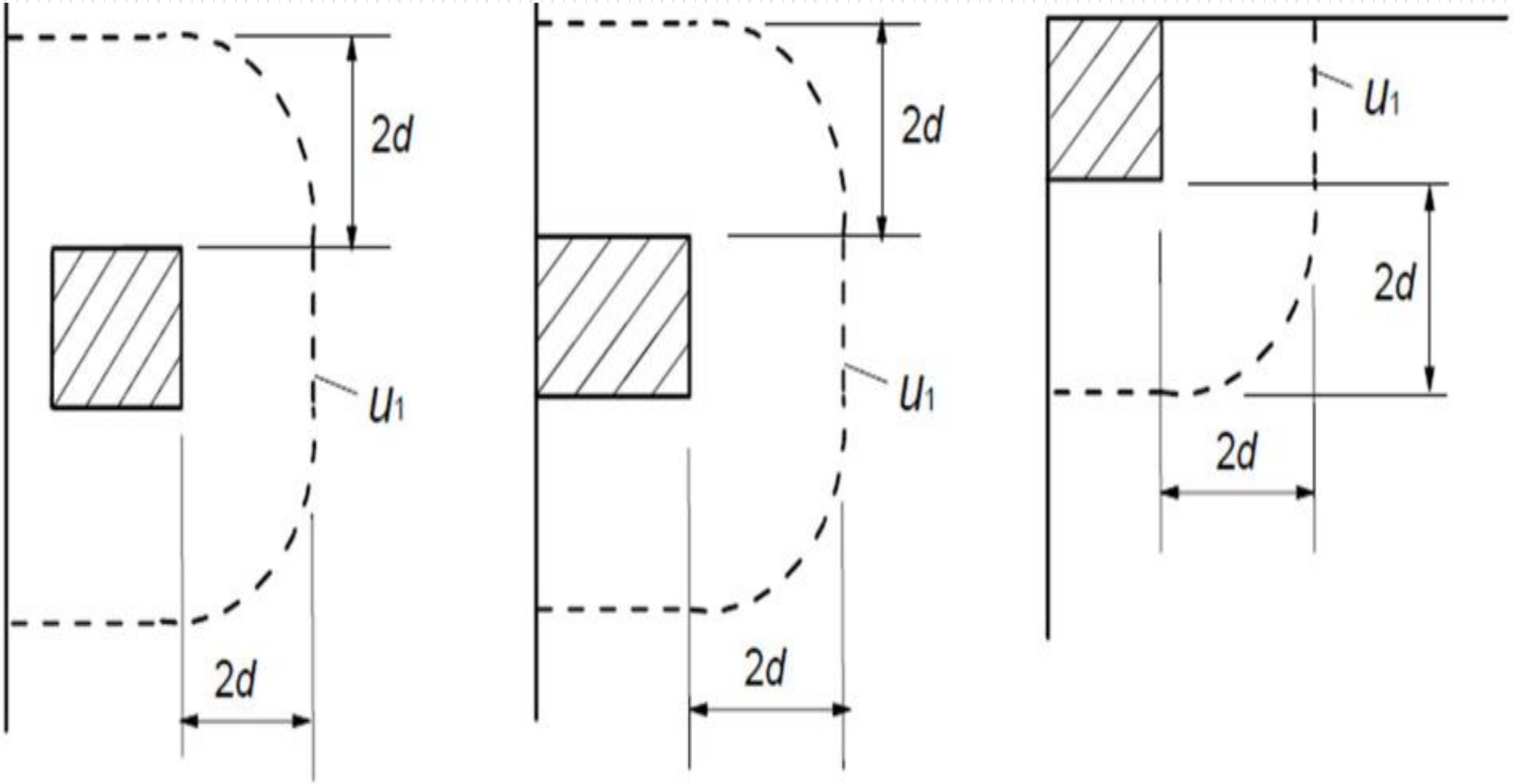
Figure Control perimeter near an opening

- For loaded areas situated near openings, if the shortest distance between the perimeter of the loaded area and the edge of the opening does not exceed 6d



Control perimeter near an opening

Cont…



Basic control perimeters for loaded areas close to or at edge or corner

- For slabs with circular column heads for which lH < 2hH a check of the punching shear stresses is only required on the control section outside the column head. The distance of this section from the centroid of the column rcont may be taken as:
- where: lH is the distance from the column face to the edge of the column head c is the diameter of a circular column

$$r_{cont} = 2d + l_H + 0.5c$$

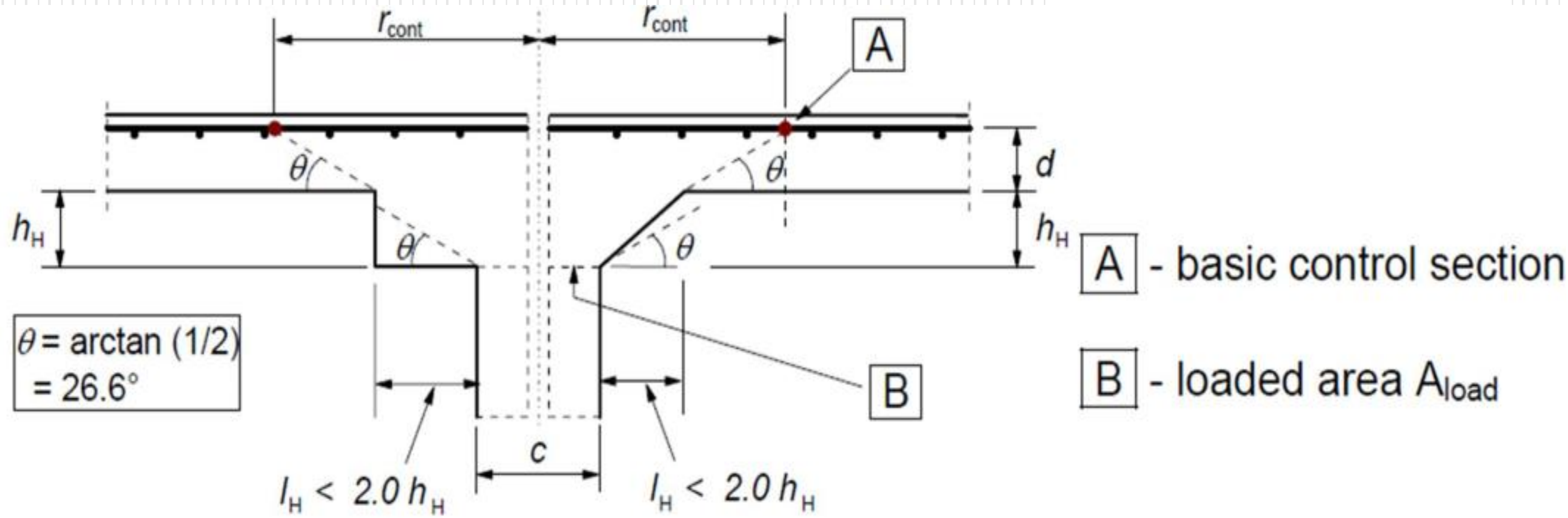


Figure **Slab with enlarged column head where $l_H < 2.0\, h_H$**

Punching shear calculation

The design procedure for punching shear is based on checks at the face of the column and at the basic control perimeter u1.

The following design shear stresses (MPa) along the control sections, are defined:

VRd,c is the design value of the punching shear resistance of a slab without punching shear reinforcement along the control section considered.

VRd,cs is the design value of the punching shear resistance of a slab with punching shear reinforcement along the control section considered.

VRd,max is the design value of the maximum punching shear resistance along the control section considered.

Cont..

- The following checks should be carried out:
- (a) At the column perimeter, or the perimeter of the loaded area, the maximum punching shear stress should not be exceeded: $V_{ed} \leq V_{Rd,max}$
- (b) Punching shear reinforcement is not necessary if:

  $V_{ed} \leq V_{Rd,c}$
- (c) Where V_{Ed} exceeds the value $V_{Rd,c}$ for the control section considered, punching shear reinforcement should be provided.
- **Where the support reaction is eccentric with regard to the control perimeter,look at the method of calculating maximum shear stress in ES EN 1992-1-1_2015 page 97**

A. Punching shear resistance of slabs and column bases without shear reinforcement

- The design punching shear resistance [MPa] may be calculated as follows:

$$v_{Rd,c} = C_{Rd,c} k (100 \rho f_{ck})^{1/3} + k_1 \sigma_{cp} \geq (v_{min} + k_1 \sigma_{cp})$$

f_{ck} is in MPa

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \quad d \text{ in mm}$$

$$\rho_l = \sqrt{\rho_{ly} \cdot \rho_{lz}} \leq 0.02$$

$$v_{Rd,max} = 0.5 \, \nu \, f_{cd}$$

$$\nu = 0.6 (1 - f_{ck} / 250)$$

ρly, ρlz relate to the bonded tension steel in y- and z- directions respectively.

The values ρlz and ρlz should be calculated as mean values taking into account a slab width equal to the column width plus 3d each side.

- σcp = (σcy + σcz)/2

Where σcy, σcz are the normal concrete stresses in the critical section in y- and z directions (MPa, positive if compression):

$$\sigma_{c,y} = \frac{N_{Ed,y}}{A_{cy}} \text{ and } \sigma_{c,z} = \frac{N_{Ed,z}}{A_{cz}}$$

CONT…

- N_{Edy}, N_{Edz} are the longitudinal forces across the full bay for internal columns and the longitudinal force across the control section for edge columns.
- The force may be from a load or prestressing action.

Ac is the area of concrete according to the definition of NEd

Note: The recommended value for CRd,c, is

$0.18/\gamma_c$, k1 is 0.1 $v_{min} = 0.035\, k^{3/2} \cdot fck^{1/2}$

For concentric loading the net applied force is

VEd,red = VEd - ΔVEd

where: VEd is the applied shear force

ΔVEd is the net upward force within the control perimeter considered i.e. upward pressure from soil minus self weight of base.

Cont…

- VEd = VEd, red / ud , VEd is applied shear stress
- $v_{Rd} = C_{Rd,c}k(100\,\rho_l\, f_{ck})^{1/3} \times 2d/a \geq v_{min} \times 2d/a$ resistance shear
- Where **a** is the distance from the periphery of the column to the control perimeter considered
- CRd,c ,vmin ,k are as described above slides 89 and 90.

For eccentric loading:

$$v_{Ed} = \frac{V_{Ed,red}}{u_d}\left[1 + k\frac{M_{Ed}u}{V_{Ed,red}W}\right] \qquad k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \quad d \text{ in mm}$$

W=W1 corresponds to a distribution of shear as function of the basic control perimeter u1

Cont…

$$W_i = \int_0^{u_i} |e| \, dl$$

- **dl** is a length increment of the perimeter and **e** is the distance of dl from the axis about which the moment MEd acts.

For a rectangular column:

$$W_1 = \frac{c_1^2}{2} + c_1 c_2 + 4c_2 d + 16d^2 + 2\pi d c_1$$

where: c1 is the column dimension parallel to the eccentricity of the load and c2 is the column dimension perpendicular to the eccentricity of the load.

B.Punching shear resistance of slabs and column bases with shear reinforcement

- Where shear reinforcement is required it should be calculated in accordance with Expression:

$$v_{Rd,cs} = 0.75\, v_{Rd,c} + 1.5\,(d/s_r)\, A_{sw}\, f_{ywd,ef}(1/(u_1 d))\sin\alpha$$

- Where -A_{sw} is the area of one perimeter of shear reinforcement around the column [mm]^2

-s_r is the radial spacing of perimeters of shear reinforcement [mm]

-$f_{ywd,ef}$ is the effective design strength of the punching shear reinforcement, according to $f_{ywd,ef} = 250 + 0.25\, d \leq fywd$ [MPa]

-d is the mean of the effective depths in the orthogonal directions [mm]

-α is the angle between the shear reinforcement and the plane of the slab

-u1-basic control perimeter

Cont…

- Adjacent to the column the punching shear resistance is limited to a maximum of:

$$v_{Ed} = \frac{\beta V_{Ed}}{u_0 d} \leq v_{Rd,max}$$

$$v_{Rd,max} = 0.5\, \nu\, f_{cd}$$
$$\nu = 0.6\,(1 - f_{ck} / 250)$$

For an interior column, u0 = enclosing minimum periphery [mm]

for an edge column, u0 = c2 + 3d ≤ c2 + 2c1[mm]

for a corner column, u0 = 3d ≤c1 + c2 [mm]

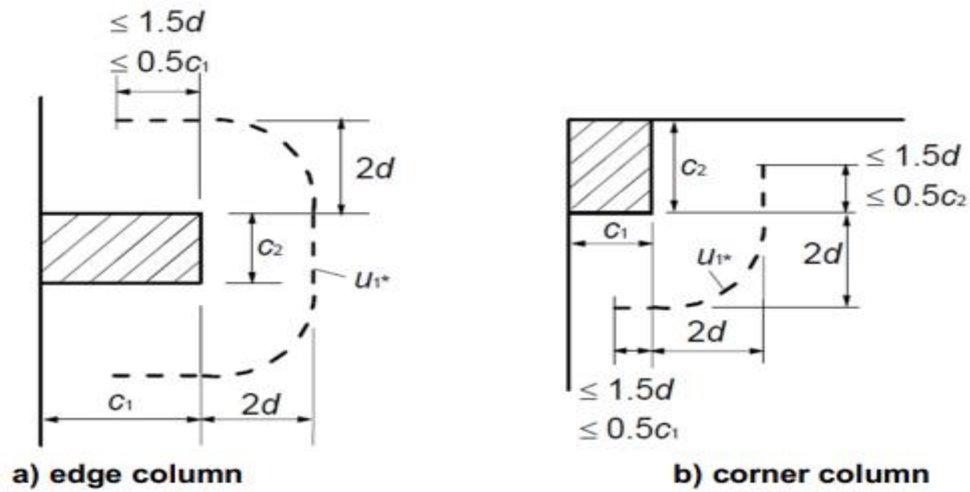


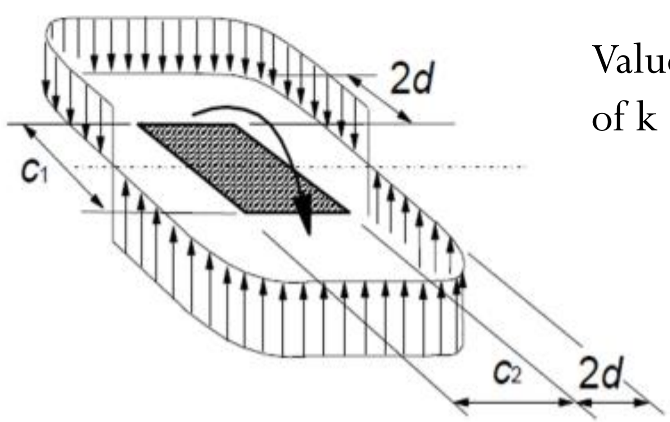
Fig:c1, c2 are the column dimensions

Cont…

- Where the support reaction is eccentric with regard to the control perimeter $\beta = 1 + k\frac{M_{Ed}}{V_{Ed}}\cdot\frac{u_1}{W_1}$ W1 is expressed in slide 91

Table 6.1: Values of *k* for rectangular loaded areas

c_1/c_2	≤ 0.5	1.0	2.0	≥ 3.0
k	0.45	0.60	0.70	0.80



Values of k

For a rectangular column:

$$W_1 = \frac{c_1^2}{2} + c_1c_2 + 4c_2d + 16d^2 + 2\pi dc_1$$

where:

c_1 is the column dimension parallel to the eccentricity of the load

c_2 is the column dimension perpendicular to the eccentricity of the load

Cont…

For internal circular columns β follows from:

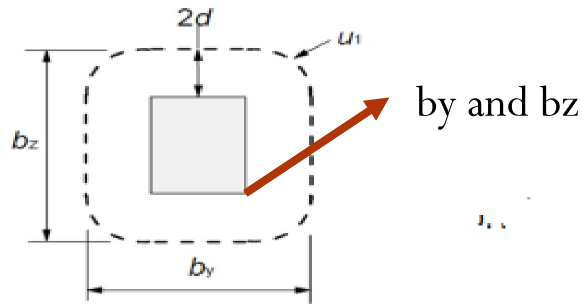
$$\beta = 1 + 0.6\pi \frac{e}{D + 4d}$$

where D is the diameter of the circular column

e is the eccentricity of the applied load $e = M_{Ed}/V_{Ed}$

For an internal rectangular column where the loading is eccentric to both axes, the following approximate expression for β may be used:

$$\beta = 1 + 1.8\sqrt{\left(\frac{e_y}{b_z}\right)^2 + \left(\frac{e_z}{b_y}\right)^2}$$



where:

e_y and e_z are the eccentricities M_{Ed} / V_{Ed} along y and z axes respectively

b_y and b_z is the dimensions of the control perimeter …

Note: e_y results from a moment about the z axis and e_z from a moment about the y axis.

Simplified values of β for effective shear force	
Condition	**β**
Internal column	1.15
Edge column	1.40
Corner column	1.50

- The control perimeter at which shear reinforcement is not required, $u_{out,ef}$ (or $u_{out,ef}$) $u_{out,ef} = \beta V_{Ed} / (v_{Rd,c}\, d)$
- The outermost perimeter of shear reinforcement should be placed at a distance not greater than kd within $u_{out,ef}$ (or $u_{out,ef}$).
- The outermost perimeter of shear reinforcement should be placed at a distance not greater than kd within $u_{out,ef}$
- (or $u_{out,ef}$) **.see next slide.**

$$k = 1 + \sqrt{\frac{200}{d}} \le 2.0 \quad d \text{ in mm}$$

C. Detailing requirements for punching shear reinforcement

Where punching shear reinforcement is required it should be placed between the loaded area/column and kd inside the control perimeter at which shear reinforcement is no longer required.

It should be provided in at least two perimeters of link legs

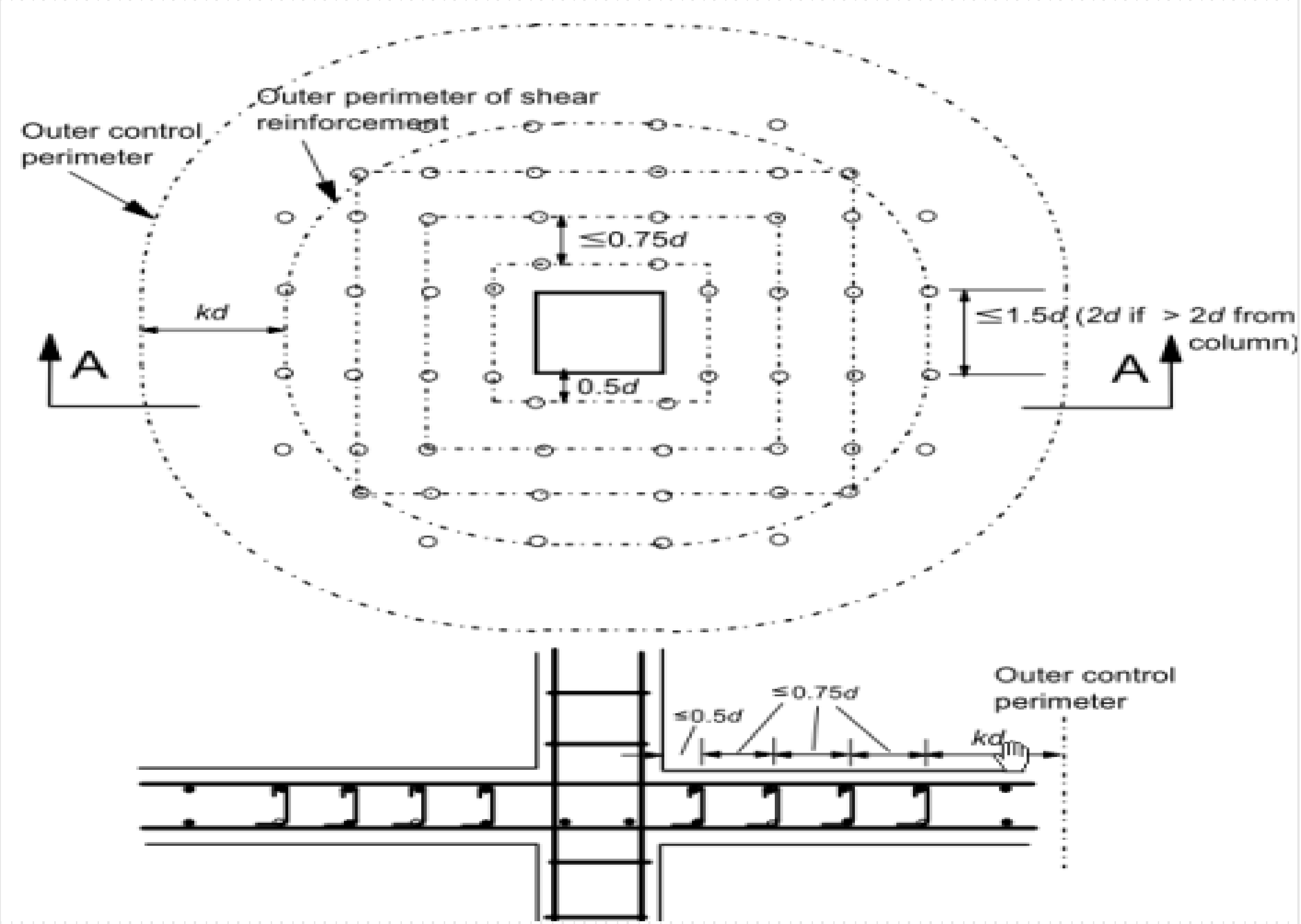
The spacing of the link leg perimeters should not exceed 0.75d

The spacing of link legs around a perimeter should not exceed 1.5d within the first control perimeter (2d from loaded area), and should not exceed 2d for perimeters outside the first control perimeter where that part of the perimeter is assumed to contribute to the shear capacity .

For bent down bars as arranged in Figure of next slide) one perimeter of link legs may be considered sufficient

CONT…

- Punching shear reinforcement



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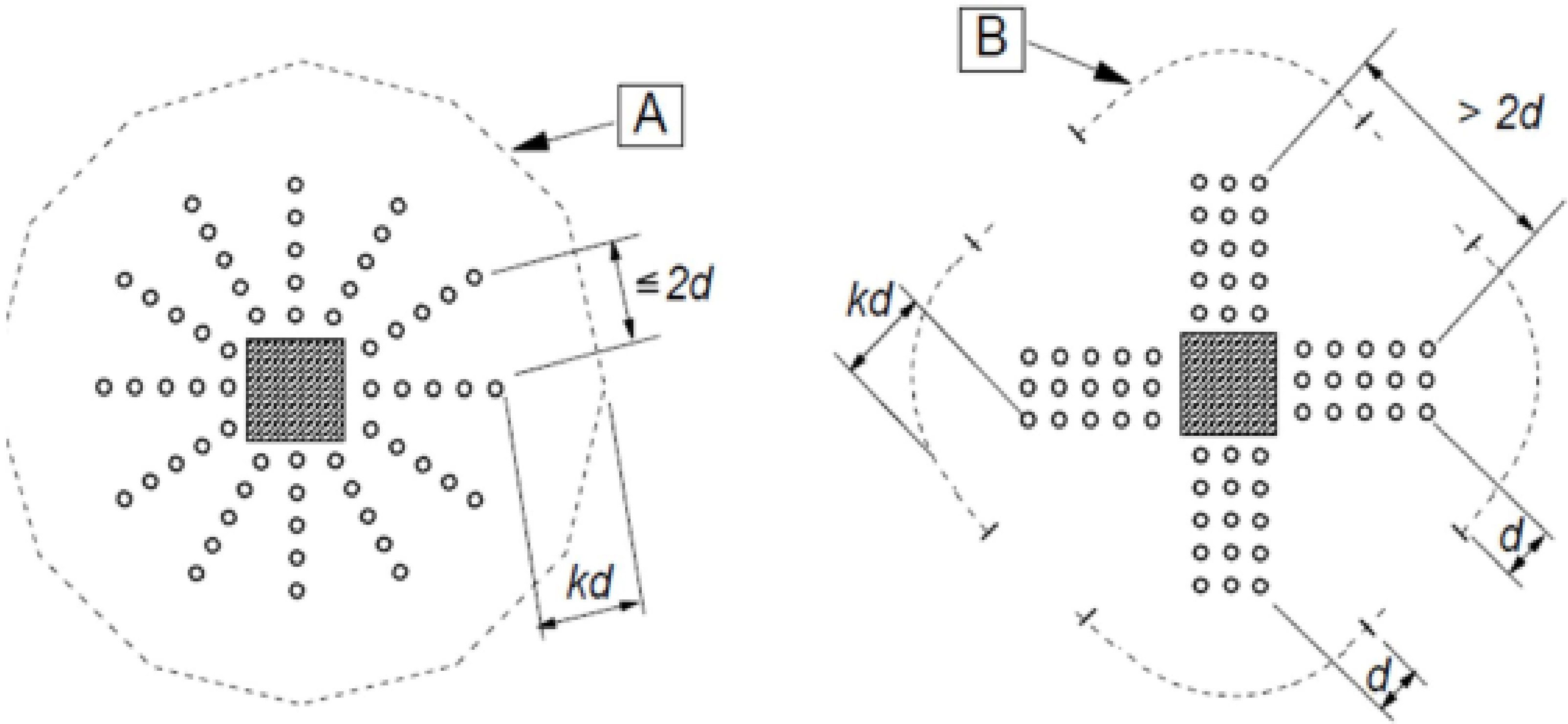


A Perimeter u_{out} B Perimeter $u_{out,ef}$

Figure Control perimeters at internal columns

Cont…

- Where shear reinforcement is required the area of a link leg (or equivalent), $A_{sw,min}$, is given as

$$A_{sw,min} \cdot (1.5 \sin\alpha + \cos\alpha)/(s_r \cdot s_t) \geq 0.08 \cdot \frac{\sqrt{f_{ck}}}{f_{yk}}$$

where:

α is the angle between the shear reinforcement and the main steel (i.e. for vertical links
$\alpha = 90°$ and $\sin \alpha = 1$)

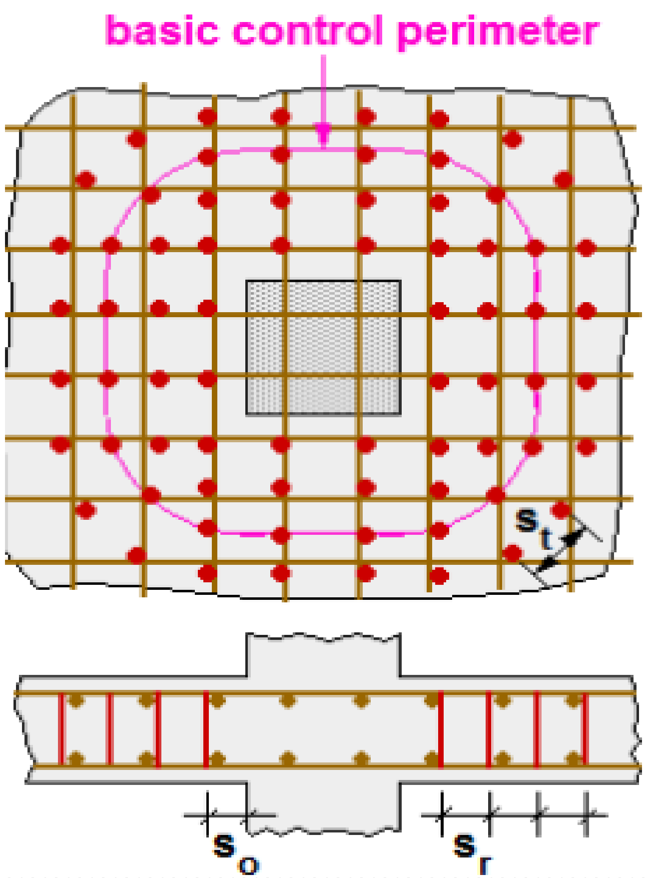
s_r is the spacing of shear links in the radial direction

s_t is the spacing of shear links in the tangential direction

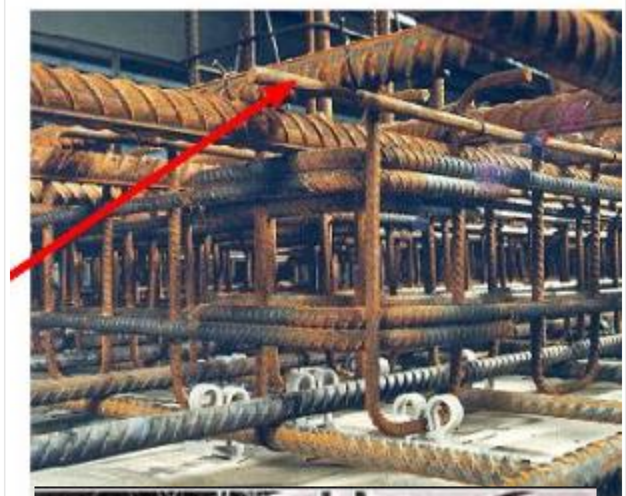
f_{ck} is in MPa

Look next slide for sr and st

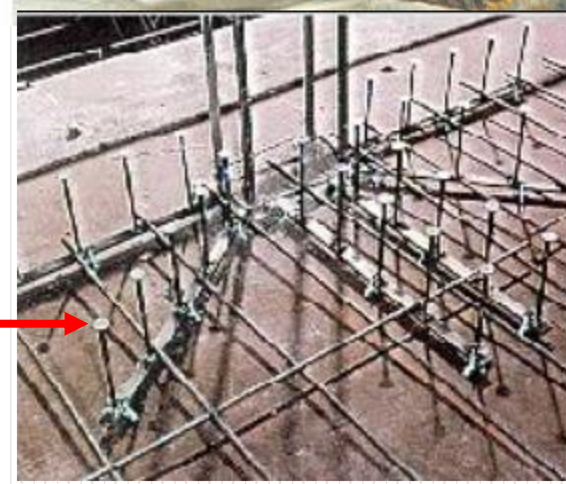
Cont…



Link hanger
Additional longitudinal bar



Stud rails



THANK YOU