Semester 2 2017/2018

DESIGN OF REINFORCED CONCRETE PILE CAP

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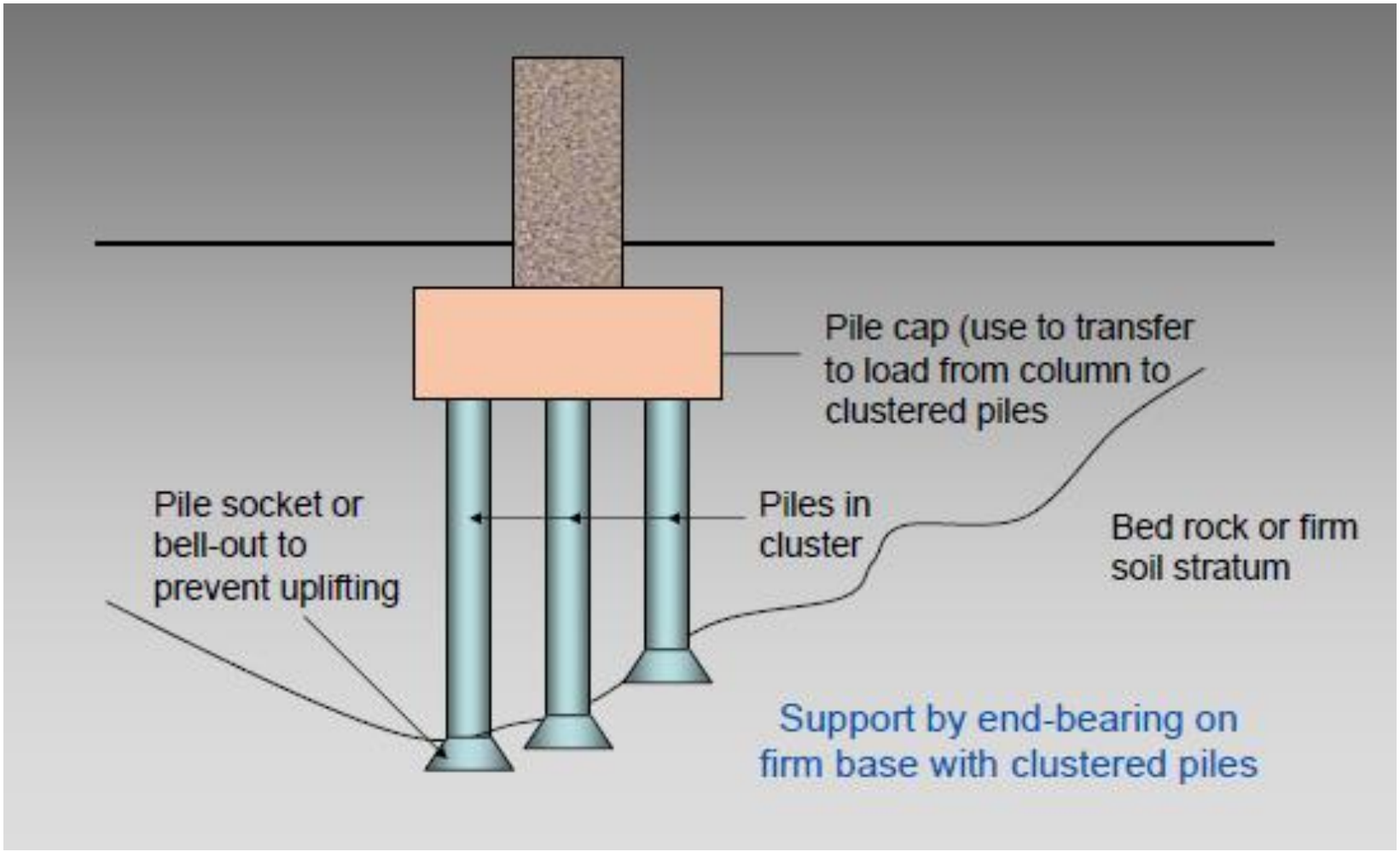
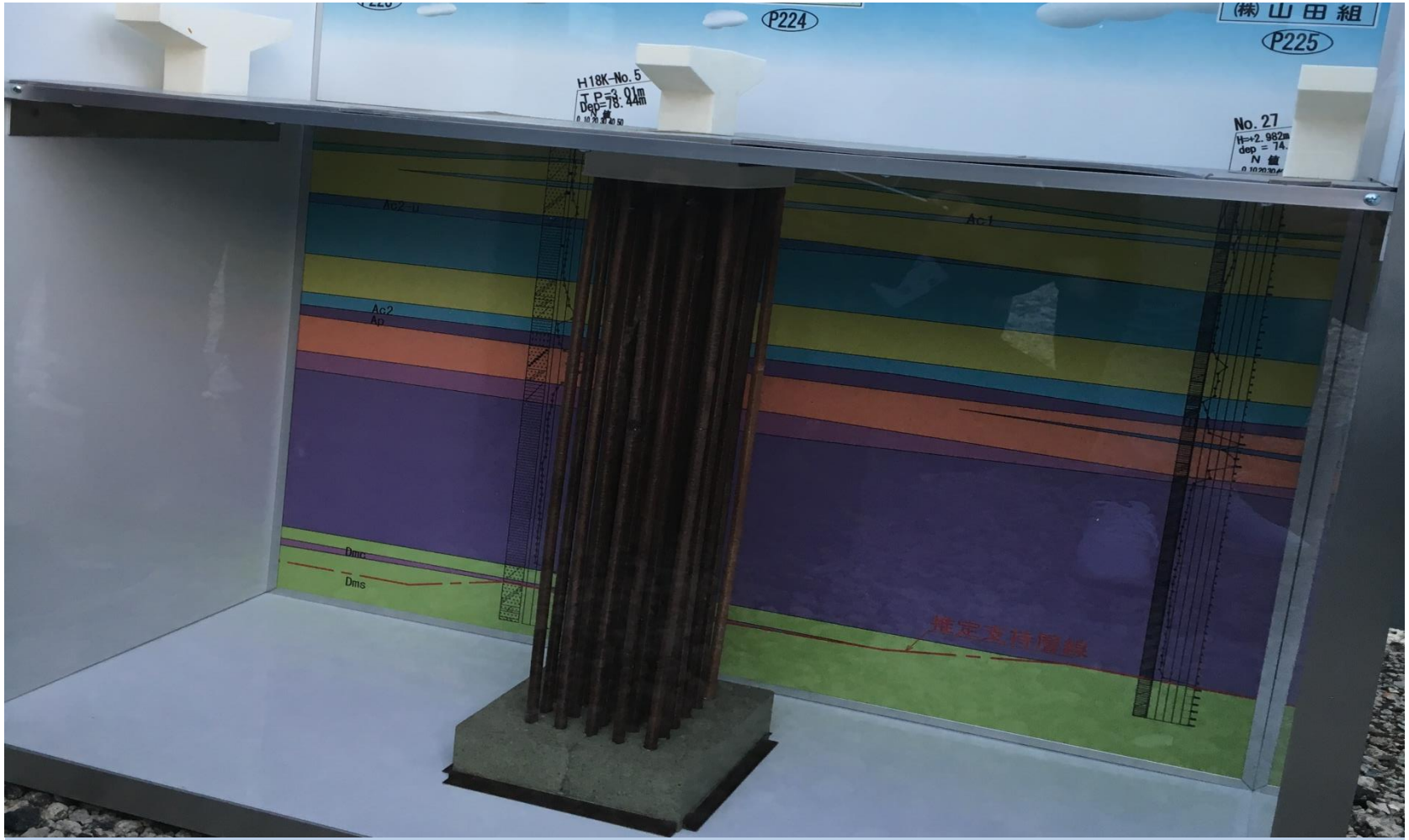
Introduction



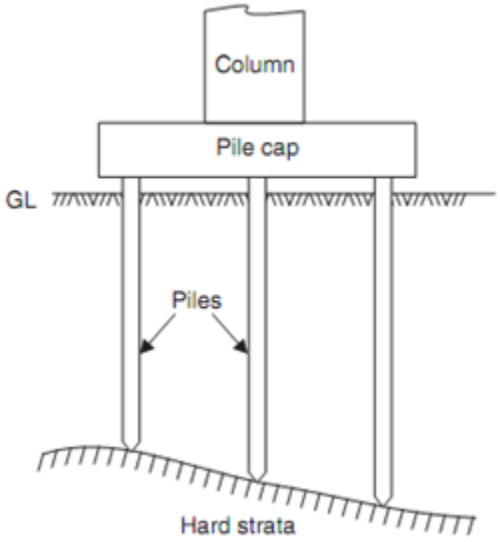
Introduction

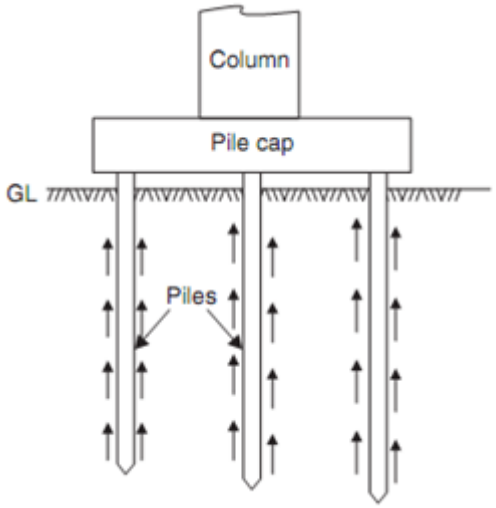


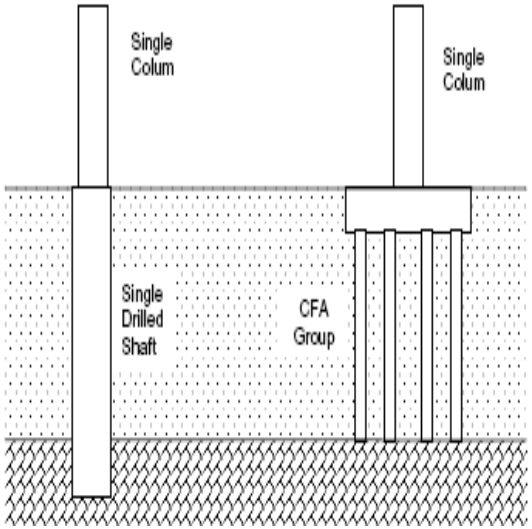
Nagoya Ring Road No. 2

Design of Pile Cap

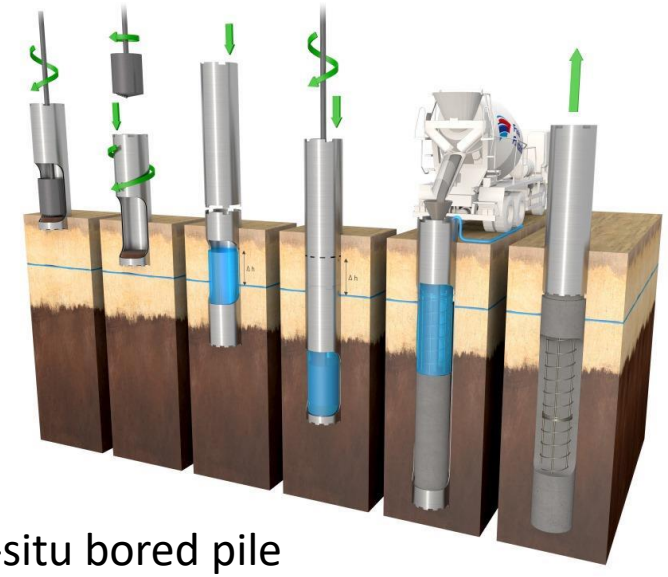
- Piles are used where the soil conditions are poor and it is uneconomical, or not possible to provide adequate spread foundations.
- The piles must extend down to firm soil so that the load is carried by either end bearing, friction along the length of pile, or a combination of both end bearing and friction.





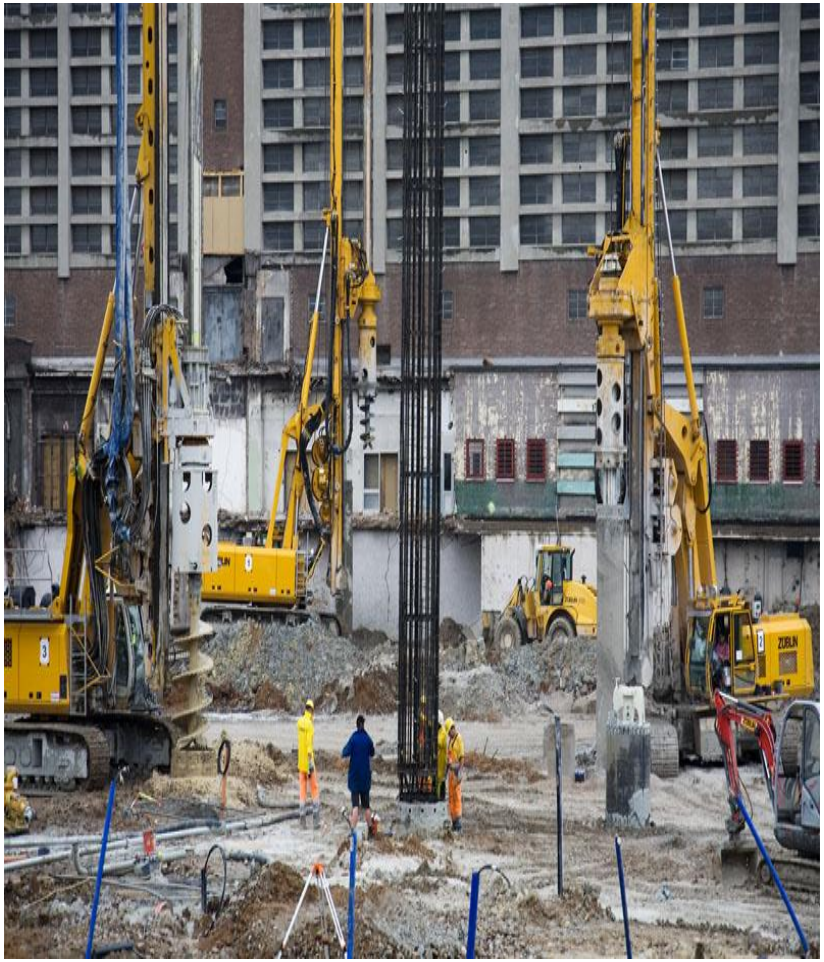


Design of Pile Cap



In-situ bored pile

Design of Pile Cap



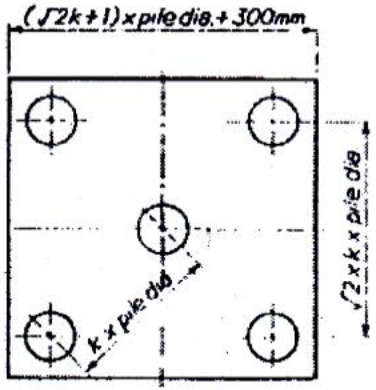
Design of Pile Cap

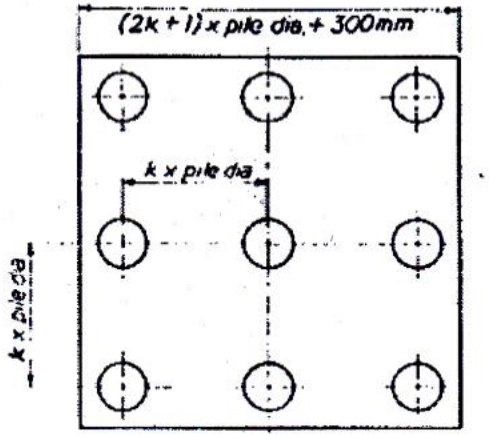
- Information from soils survey will provide a guide to the lengths of pile required and the probable safe load capacity of the piles.

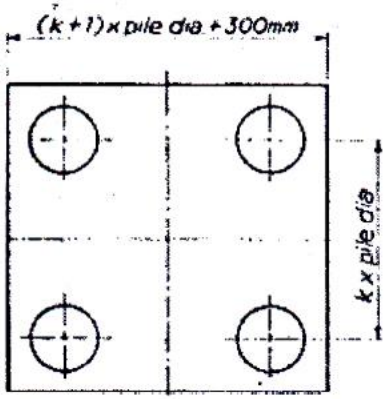
Pile Nominal Size A x C (mm x mm)	Pile Length L (m)	Concretre Grade (N/mm²)	Maximum Axial Working Load (kN)	JKR Recommended Axial Working Load (kN)	Nominal Pile Dimensions A (mm)	B (mm)	C (mm)	Main Reinforcement (No / Dia)	Links (Links Details to Table below or of Equivalent) Pile Head Wire Details	P1 (mm)	X (mm)	Transition P2 (mm)	Y (mm)	Pile Body Wire Details	P3 (mm)
150 X 150	3,6	45	332	200	153	147	150	4 T 10	R6.0	40	450	40 - 75	450	R6.0	75
175 X 175	3,6	45	455	300	178	172	175	4 T 12	R6.0	40	525	40 - 75	525	R6.0	75
200 X 200	3,6	45	570	350	203	197	200	4 T 12	2R6.0	65	600	65 - 85	600	R6.0	85
250 X 250	3,6,9,12	45	910	500	253	247	250	4 T 16	2R6.0	60	750	60 - 75	750	R6.0	75
300 X 300	3,6,9,12	45	1320	800	303	297	300	4 T 20	2R6.0	55	900	55 - 70	900	R6.0	70
350 X 350	3,6,9,12	45	1730	1150	353	347	350	4 T 20	2R6.5	55	1050	55 - 65	1050	R6.5	65
400 X 400	3,6,9,12	45	2310	1450	403	397	400	4 T 25	2R6.5	50	1200	50 - 60	1200	R6.5	60

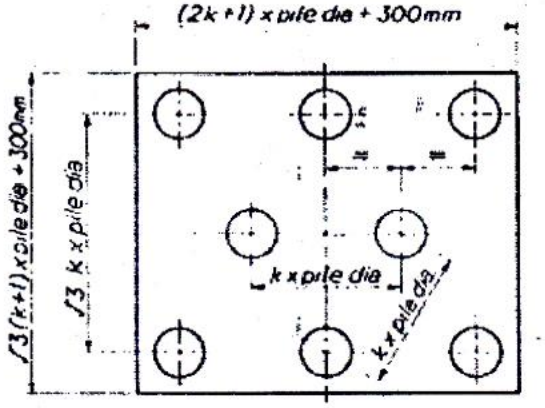
- Standard size of in-situ pile: 600mm – 1500mm.
- Precast driven pile: Micropile Ø < 150mm, Small 150mm < Ø < 550mm, Large Ø > 550mm.

Type of Pile Cap

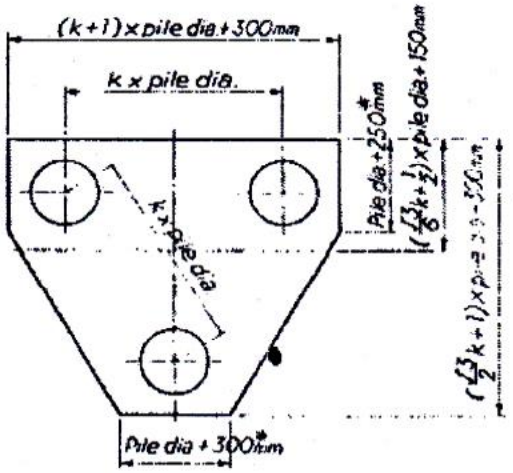


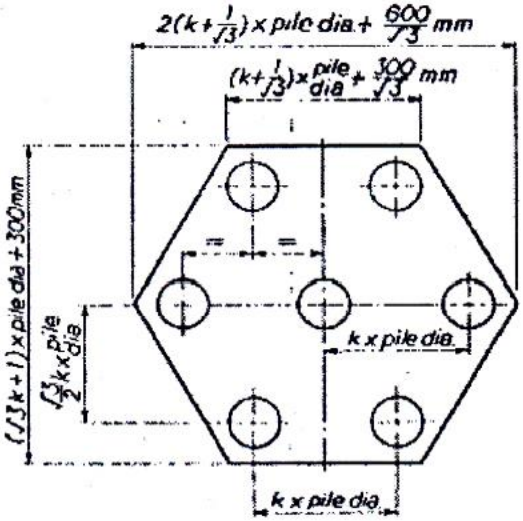


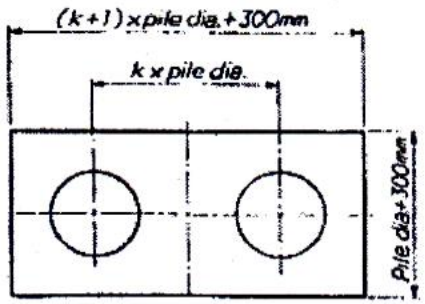


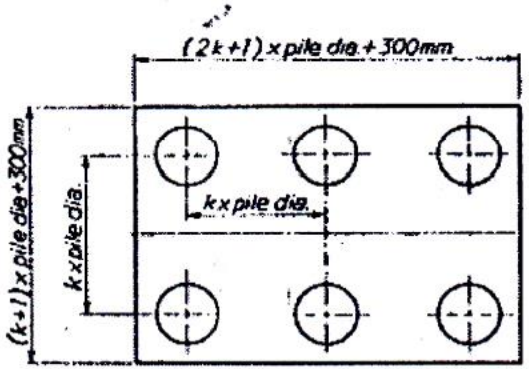


Type of Pile Cap









Procedure of Design

- General procedure of pile cap design:
  1. Selection of pile type
  2. Determination of pile capacity
  3. Determination of pile number and spacing
  4. Design of pile cap
     a) Size and thickness: diameter pile <550mm or >550mm
     b) Main reinforcement using
        - **Truss theory** >>> subjected to axial load only
        - **Beam theory** >>> subjected to axial load and moment
     c) Design for shear: punching shear is not necessary if $S \leq 3\emptyset_p$ and shear force < $V_{Rd,\,max}$
  5. Detailing
     a) Diameter bar not less than 12mm
     b) Spacing not greater than 250mm

Procedure of Design

- Determine pile number and spacing

$$n = \frac{N + W}{P_{q,c}}$$

N = axial load from column
W = weight of pile cap
$P_{q,c}$ = service bearing capacity
n = number of piles
M = moment
x = distance from pile to centroid
I = moment of inertia, $4S^2$
$Ø_p$ = diameter of pile
h = depth of pile cap

- Size and thickness

if Øp ≤ 550mm >>> h = 2Øp + 100

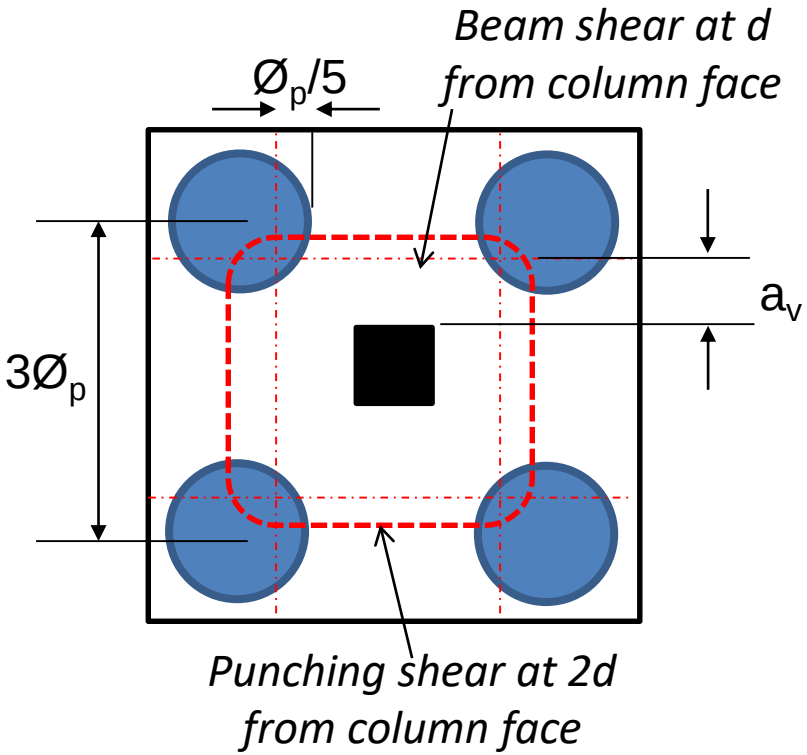
if Øp > 550mm >>> h = 1/3(8Øp – 600)

- Maximum service load per pile

F $F_a = \frac{N + W}{n}$; **F + M** $F_a = \frac{N + W}{n} \pm \frac{Mx_i}{I_y}$

Procedure of Design

- Design of shear
  - Shear capacity at the critical section, 20%$Ø_p$ or $Ø_p$/5 inside the face of pile.



For $S \leq 3Ø_p$
Shear resistance on vertical plane;
Shear enhancement, $V_c = v_c(2d/a_v)$

When $S > 3Ø_p$, punching shear must be checked

Shear force at column surface;
$V_{Rd,max} = 0.5u_o d_a v_1 (f_{ck}/1.5)$

$V_{Rd,max} > V_{Ed,max}$

Example 4.3:

Pile cap under axial load (Truss Theory)

Example 4.3

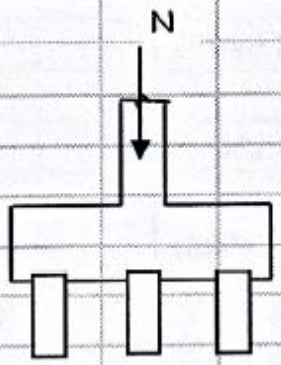
A pile foundation is required to support permanent axial load of 3200kN and variable load of 2500kN from a 500x500 mm rectangular reinforced concrete column.

The pile used is 500mm diameter reinforced concrete bored pile with service load capacity of 1800kN.

Determine the suitable number of pile and size of pile cap. Design the pile cap using grade C35/45 concrete, grade 500 steel reinforcement and concrete cover 75mm.

Example 4.3

SPECIFICATION



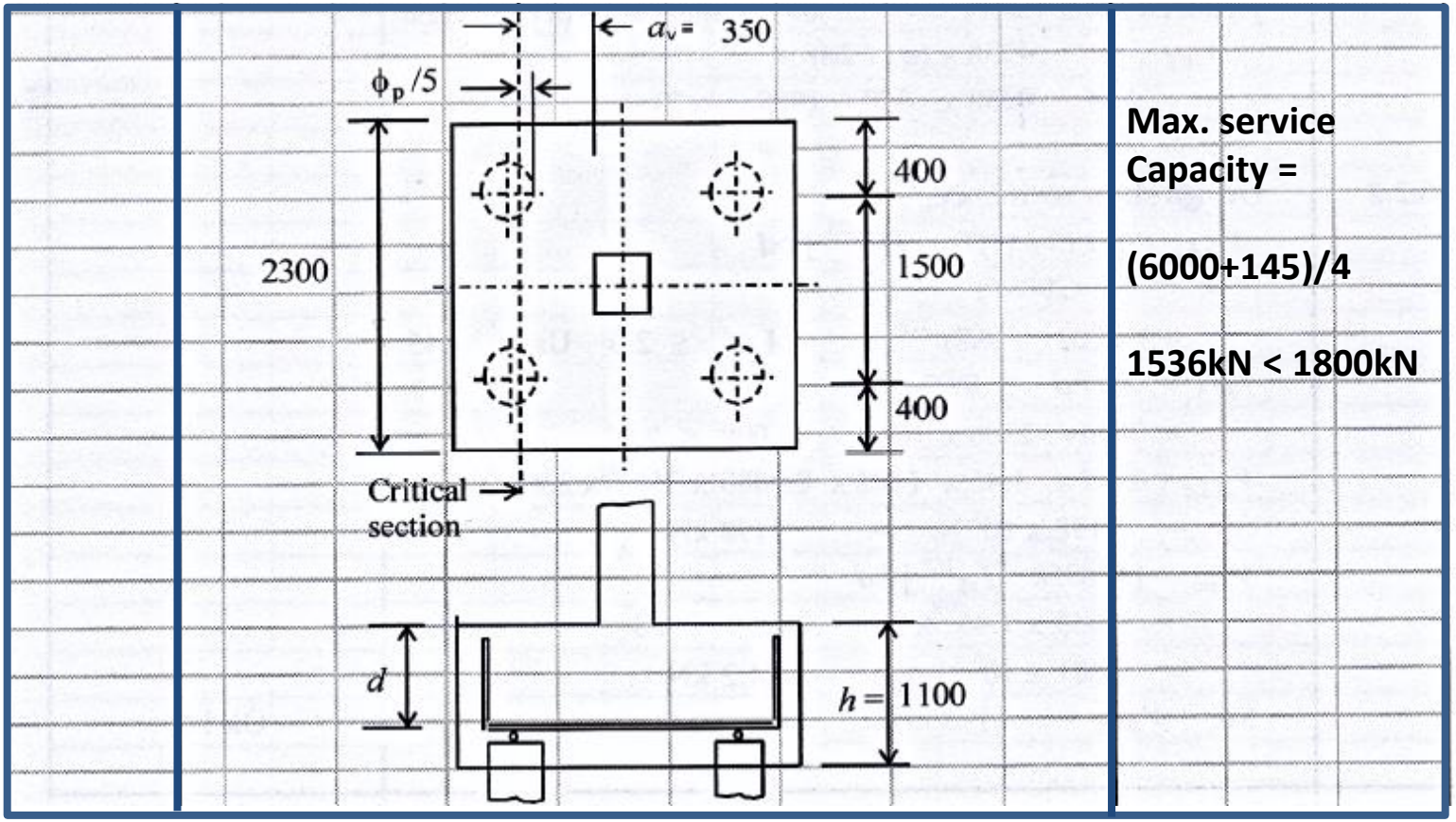
Axial Load, N ; G_k	=	3500	kN	Q_k =	2500	kN
Chac. Strength of concrete, f_{ck}	=			35		N/mm^2
Chac. Strength of steel, f_{yk}	=			500		N/mm^2
Assume bar size, ϕ_{bar}	=			25		mm
Nominal concrete cover, c	=			75		mm,
Column size	–	500	x	500		mm
Pile : Prestressed Spun pile	=			500		mm dia.
Service load	=			1800		kN

SIZE OF PILE CAP

Service load =	3500	+ 2500	=	6000	kN	
Assume selfweight of pilecap, say W =				200	kN	
No. of pile required =	$(N + W)$ / pile capacity					
=	(6000 +200)	/ 1800	= 3.4	Use :	4	
Pile spacing = $k\phi_p$ =	3	ϕ_p				
Width = $(k + 1) \times \phi_p$ +	300					
=	(3 + 1)	(500)	+ 300	=	2300	mm
Length = $(k + 1) \times \phi_p$ +	300					
=	(3 + 1)	(500)	+ 300	=	2300	mm
Depth, h = $2\phi_p$ + 100	= 2	(500)	+100 =		1100	mm
Try size : $B \times H \times h$ =	2.3	x 2.3	x 1.1	m		
Selfweight =	25	x (2.3	x 2.3 x	1.1) =	145	kN

Ok

Example 4.3

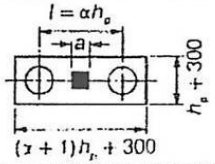
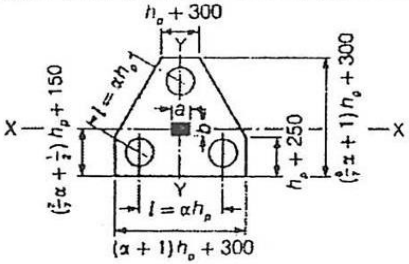
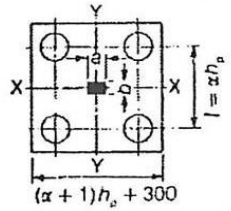
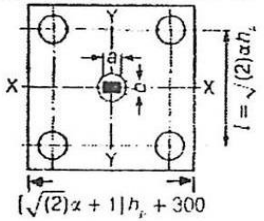


Max. service Capacity =

(6000+145)/4

1536kN < 1800kN

Example 4.3

Number of piles	Dimensions of pile cap	Tensile force to be resisted by reinforcement: Neglecting of column	Tensile force to be resisted by reinforcement: Taking size of column into consideration
2		$\frac{Nl}{4d}$	$\frac{N}{12ld}(3l^2 - a^2)$
3		$\frac{Nl}{9d}$	Parallel to X-X: $\frac{N}{36ld}(4l^2 + b^2 - 3a^2)$ Parallel to Y-Y: $\frac{N}{18ld}(2l^2 - b^2)$
4		$\frac{Nl}{8d}$	Parallel to X-X: $\frac{N}{24ld}(3l^2 - a^2)$ Parallel to Y-Y: $\frac{N}{24ld}(3l^2 - b^2)$
5		$\frac{Nl}{10d}$	Parallel to X-X: $\frac{N}{30ld}(3l^2 - a^2)$ Parallel to Y-Y: $\frac{N}{30ld}(3l^2 - b^2)$

Notation h_p diameter of pile; a, b dimensions of column; α spacing factor of piles (normally between 2 and 3 depending on ground conditions)

Example 4.3

	MAIN REINFORCEMENT		
	Effective depth, $d = h - c - 1.5(\phi_{bar})$		
	$= 1100 - 75 - (1.5 \times 25) =$ 988 mm		
	Ultimate load, $N = 1.35G_k + 1.5Q_k$		
	$= 1.35\,(3500) + 1.5\,(2500) =$ 8475 kN		
	From truss analogy,		
	Tension force, $T = NL/8d =$ 8475 x 1.5 / (8 x 0.988)		
	$=$ 1609 kN		
	Area of reinforcement, $A_s = T / 0.87 f_{yk}$		
	$=$ 1609 x 10^3 / 0.87 (500) = 3699 mm^2		
	For the whole width of pile cap,		
	$A_s =$ 2 x 3699 = 7399 mm^2		Use: 16 H25
			(7855 mm^2)
9.2.1.1	Minimum and maximum reinforcement area,		
	$A_{s,min} = 0.26(f_{ctm}/f_{yk})\,bd =$ 0.26 x (3.21 / 500) x bd		
	$= 0.0017\,bd =$ 0.0017 x2300 x 988 =3791 mm^2		
	$A_{s,max} = 0.04A_c =$ 0.04 x 2300 x 1100 = 101200 mm^2		

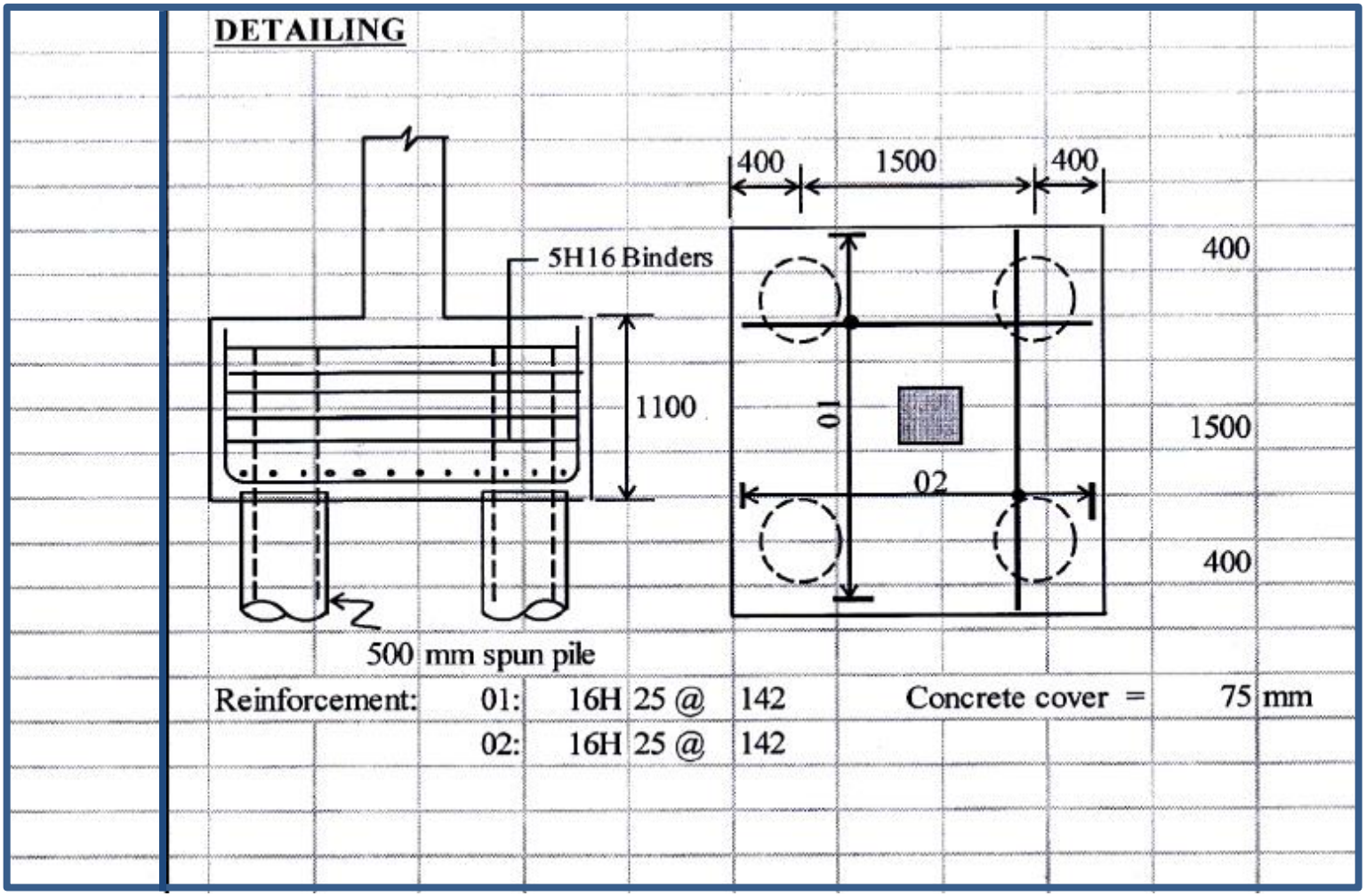
Example 4.3

	SHEAR										
	(i). Vertical shear - at $\phi/5$ section inside pile										
	Load per pile =	8475	/ 4 =	2119	kN						
3.11.4.3	2 pile outside the critical section.										
	Shear force, V_{Ed}	=	2	(2119)	=	4238	kN				
	Pile spacing	<	$3\phi_{pile}$	Consider shear enhancement							
	Reduced shear force,			on the whole width of the section							
	V_{Ed} =	4238 x	$(a_v / 2d)$ =								
	=	4238 x	350 /	(988	x 2) =	751	kN				
6.2.2	Design shear resistance,										
	$V_{Rd,c} = [\ 0.12\, k\, (100\rho_1 f_{ck})^{1/3}\ ]\, bd$										
	$k = 1 + (200/d)^{1/2} \leq 2.0$										
	=	1+(200	/ 988)	$^{1/2}$	= 1.45	$\leq$ 2.0	Use :	1.45			
	$\rho_1 = A_{sl}/bd \leq 0.02$										
	=	7855 /	2300 x	988 =	0.008	$\leq$ 0.02					
	$V_{Rd,c}$ =	0.12 x	1.45 x	(100 x	0.0080	x 35) $^{1/3}$	x 2300	x 988			
	=	1198	x 10^3 N	=	1198	kN					
	$V_{min} = [\ 0.035 k^{3/2} f_{ck}^{1/2}\ ]\, bd$										
	=	0.035	x $1.45^{3/2}$	x $35^{1/2}$	x 2300	x 988					
	=	821	x 10^3 N	=	821.2	kN					
	So, $V_{Rd,c}$ =	1198	kN	>	V_{Ed}					Ok !	

Example 4.3

6.4	(ii). Punching Shear at perimeter 2.0d from column face Pile spacing $<$ $3\phi_{pile}$ No punching shear check is necessary	Ok !
	(iii). Maximum Punching Shear at column perimeter. Maximum shear resistance, $V_{Rd,max} = 0.5ud\ [0.6(1 - f_{ck}/250)]\ f_{ck}/1.5$ $= 0.5(4 \times 500) \times 988\ [0.6\ (1 - 35 / 250)]\ (35/1.5)$ $= 11890$ kN $>$ $V_{Ed,max} = 8475$ kN	Ok !
	CRACKING	
7.3.3	$h =$ 1100 mm $>$ 200 mm	Need spesific measure !
	Assume steel stress under quasi permanent loading , $= 0.55\ (f_{yk}/1.15)(A_{s.req}/A_{s.prov})$ $= 0.55\ (500 / 1.15)\ (7399 / 7855)$ $= 225$ N/mm^2	
Table 7.3N	For design crack width = 0.3 mm Max. allowable bar spacing = 200 mm Max. bar spacing $= [2300 - 2(75) - 25] / 15$ $= 142$ mm $>$ 200 mm	Ok !

Example 4.3


DETAILING
400
1500
400
5H16 Binders
1100
400
01
1500
02
400
500 mm spun pile
Reinforcement: 01: 16H 25 @ 142
02: 16H 25 @ 142
Concrete cover = 75 mm

Pile Cap Design

Example 4.4:

Pile cap under axial + moment (Beam Theory)

Example 4.4

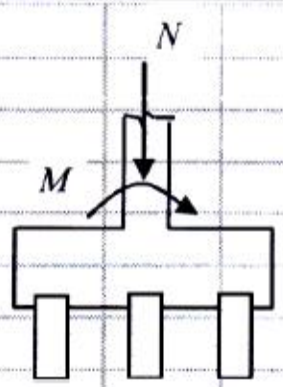
A pile foundation is required to support an ultimate axial load of 4200kN and an ultimate bending moment of 75kNm from a 400x400 mm rectangular reinforced concrete column.

The pile used is 300x300mm precast RC piles with service load capacity of 600kN.

Determine the suitable number of pile and size of pile cap. Design the pile cap using grade C35/45 concrete, grade 500 steel reinforcement and concrete cover 75mm.

Example 4.4

SPECIFICATION



Axial Load, $N_{ultimate}$	=	4200	kN	
Moment , $M_{ultimate}$	=	75	kNm	
Chac. Strength of concrete, f_{ck}	=	35	N/mm^2	
Chac. Strength of steel, f_{yk}	=	500	N/mm^2	
Cover, c = 75 mm	ϕ_{bar} =	16	mm	
Column size =	=	400	x 400	mm
Pile : Precast RC pile		300	x 300	mm
Working load	=	600	kN	
Safety factor	=	1.40		

SIZE OF PILE CAP

Service load = (4200 /1.40) = 3000 kN

Assume selfweight of pilecap, say W = 200 kN

No. of pile required = $(N + W)$ / pile capacity

= (3000 + 200) / 600 = 5.3 Use : 6

Pile spacing = $k\phi_p$ = $3\phi_p$

Width, $B = (k + 1) \times \phi_p + 300$

= (3 + 1) (300)+ 300 = 1500 mm

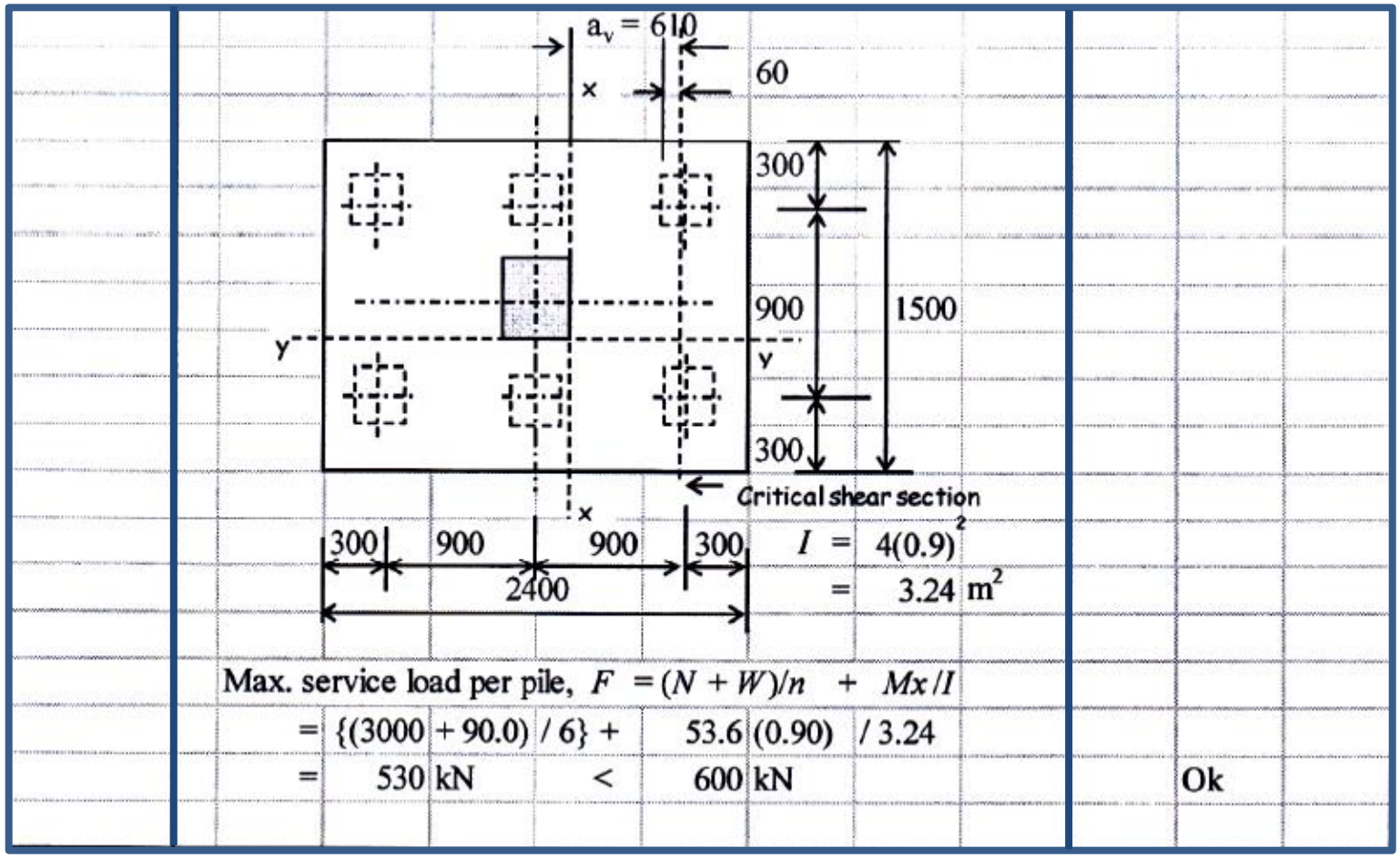
Length, $L = (2k + 1) \times \phi_p + 300$

= [2(3) + 1] (300)+ 300 = 2400 mm

Depth, $h = 2\phi_p +$ 400 = 2(300) +400 = 1000 mm

Selfweight = 25(1.5 x 2.4 x 1.0) = 90 kN

Example 4.4



Max. service load per pile, $F = (N + W)/n + Mx/I$

$= \{(3000 + 90.0)/6\} + 53.6\ (0.90)\ /\ 3.24$

$= 530$ kN $<$ 600 kN Ok

Example 4.4

Analysis

Ultimate load per pile, $F = P/n + Mx/I$

$= (4200 / 6) + 75.0\ (0.90)\ / 3.24$

$= 700.0 + 20.8$

$= 721$ kN

Maximum moment at column face,

$M_{xx} = 2\ \{\ 721 \times (0.90 - 0.20)\ \} = 1009$ kNm

$M_{yy} = 3\ \{\ 700 \times (0.45 - 0.20)\ \} = 525$ kNm

6.1 **MAIN REINFORCEMENT**

Effective depth,

$d_x = h - C_{nom} - 0.5\phi_{bar} = 1000 - 75 - 0.5 \times 16 = 917$ mm

$d_y = h - C_{nom} - 1.5\phi_{bar} = ##### - 75 - 1.5 \times 16 = 901$ mm

Longitudinal bar

Bending Moment, $M = 1009$ kNm

$K = M / bd^2 f_{ck}$

$= 1009 \times 10^6 / (1500 \times 917^2 \times 35)$

$= 0.023 < K_{bal} = 0.167$

Compression reinforcement is not required

$z = d\ [\ 0.5 + \sqrt{0.25 - K/1.134}\ ] = 0.98\ d \leq 0.95d$

$A_s = M / 0.87 f_{yk} z$

$= 1009 \times 10^6 / (0.87 \times 500 \times 0.95 \times 917)$

$= 2663$ mm^2/m

Use: 14 H16

(2815 mm^2)

Example 4.4

9.2.1.1	Minimum and maximum reinforcement area,										
	$A_{s,min}$ =	$0.26(f_{ctm}/f_{yk})\,bd$ =			0.26 x	(3.21 /	500) x	bd			
	=	0.0017	bd =	0.0017	x1500	x 917	=2296	mm^2			
	$A_{s,max}$ =	$0.04A_c$	=	0.04 x	1500 x	1000 =	60000	mm^2			
	Transverse bar										
	Bending Moment, M		=	525	kNm						
	$K = M / bd^2 f_{ck}$										
	=	525	x 10^6 /	(2400	x 901^2	x 35)					
	=	0.008	<	K_{bal} =	0.167						
	Compression reinforcement is not required										
	z =	$d\,[\,0.5 + \sqrt{0.25 - K/1.134}\,]$	=	0.99	d	≤	0.95d				
	A_s =	$M / 0.87 f_{yk} z$									
	=	525	x 10^6 /	(0.87 x	500 x	0.95 x	901)		Use:	16	H16
	=	1410	mm^2/m							(3217	mm^2)
9.2.1.1	Minimum and maximum reinforcement area,										
	$A_{s,min}$ =	$0.26(f_{ctm}/f_{yk})\,bd$ =			0.26 x	(3.21 /	500) x	bd			
	=	0.0017	bd =	0.0017	x2400	x 901	=3609	mm^2			
	$A_{s,max}$ =	$0.04A_c$	=	0.04 x	2400 x	1000 =	96000	mm^2			

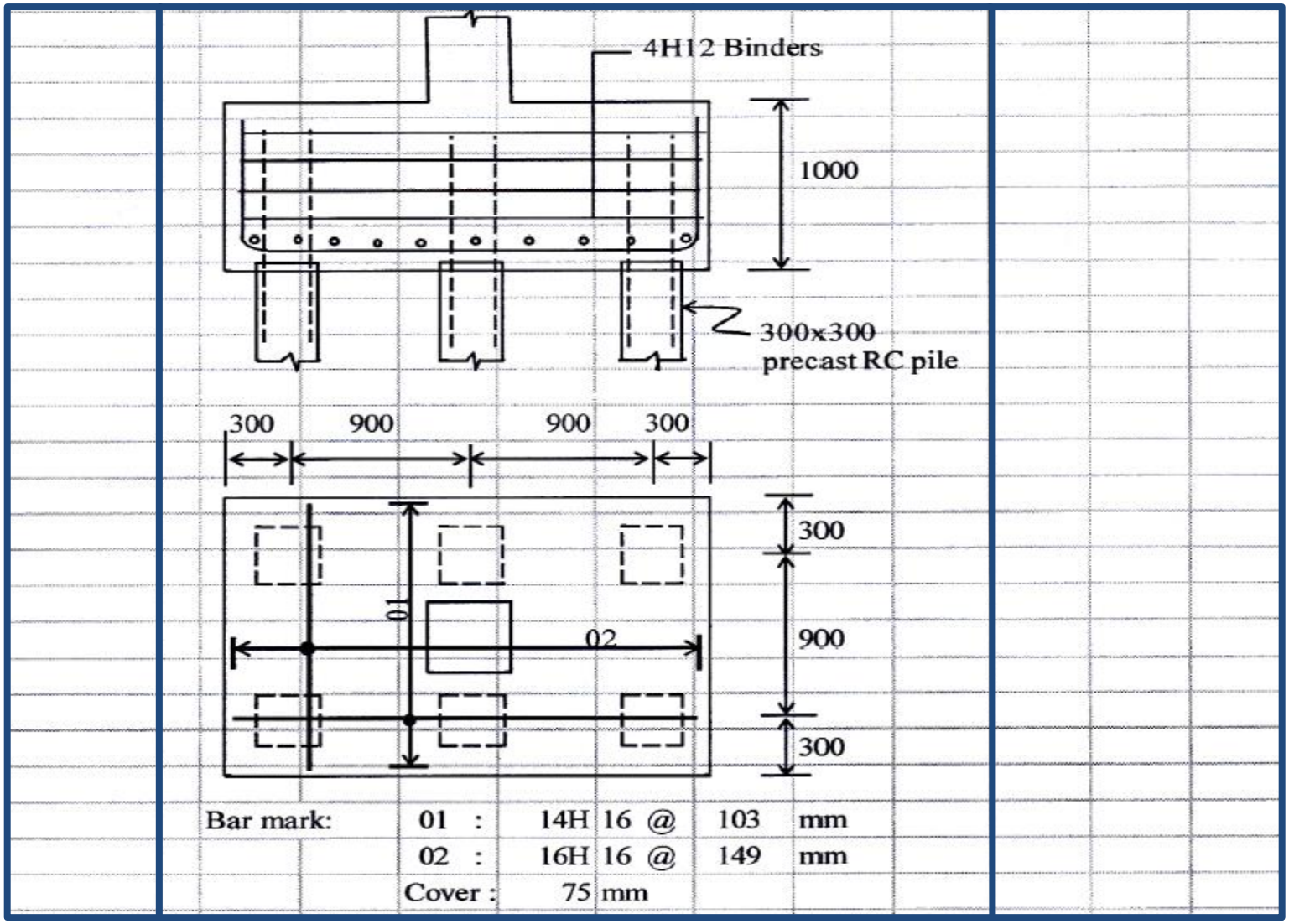
Example 4.4

	SHEAR	
	(i). Vertical shear - at $\phi/5$ section inside pile	
3.11.4.3	2 pile outside the critical section.	
	Shear force, V_{Ed} = 2 (721) = 1442 kN	
	Pile spacing < $3\phi_{pile}$	
	Consider shear enhancement over the whole width of pile cap	
	Reduced shear force,	
	V_{Ed} = 1442 x $(a_v / 2d)$	
	= 1442 x 610 / (917 x 2) = 480 kN	
6.2.2	Design shear resistance,	
	$V_{Rd,c} = [\, 0.12\, k\, (100\rho_1 f_{ck})^{1/3}\,]\, bd$	
	$k = 1 + (200/d)^{1/2} \leq 2.0$	
	$= 1+(200 / 917)^{1/2} = 1.47 \leq 2.0$	
	$\rho_1 = A_{sl}/bd \leq 0.02$	
	= 2815 / 1500 x 917 = 0.0031 $\leq$ 0.02	
	$V_{Rd,c}$ = 0.12 x 1.47 x (100 x 0.0031 x 35) $^{1/3}$ x 1500 x 917	
	= 534 x 10^3 N = 534 kN	
	$V_{min} = [\, 0.035 k^{3/2} f_{ck}^{1/2}\,]\, bd$	
	= 0.035 x $1.47^{3/2}$ x $35^{1/2}$ x 1500 x 917	
	= 506 x 10^3 N = 506 kN	
	So, $V_{Rd,c}$ = 534 kN > V_{Ed}	Ok !

Example 4.4

6.4	(ii). Punching Shear : Critical at perimeter 2.0d from column face.	
	Pile spacing < $3\phi_{pile}$	
	No punching shear check is necessary	Ok !
	(iii). Maximum Punching Shear at column perimeter.	
	Maximum shear resistance,	
	$V_{Rd,max}$ = $0.5ud$ [$0.6(1 - f_{ck}/250)] f_{ck}/1.5$	
	= 0.5(4 x 400) x 909 [0.6 (1 - 35 / 250)] (35/1.5)	
	= 8755 kN > $V_{Ed,max}$ = 4200 kN	Ok !
	CRACKING	
7.3.3	h = 1000 mm > 200 mm	Need spesific measure !
	Assume steel stress under quasi permanent loading ,	
	= $0.55 (f_{yk}/1.15)(A_{s.req}/A_{s.prov})$	
	= 0.55 (500 / 1.15) (2663 / 2815)	
	= 226 N/mm^2	
Table 7.2N	For design crack width = 0.3 mm	
	Max. allowable bar spacing = 200 mm	
	Max. bar spacing 1 = 1500 - 2(75) - 16] / 13	
	= 103 mm < 200 mm	Ok !
	Max. bar spacing 2 = 2400 - 2(75) - 16] / 15	
	= 149 mm < 200 mm	Ok !

Example 4.4



Bar mark:	01 :	14H	16 @	103	mm
	02 :	16H	16 @	149	mm
	Cover :	75	mm		