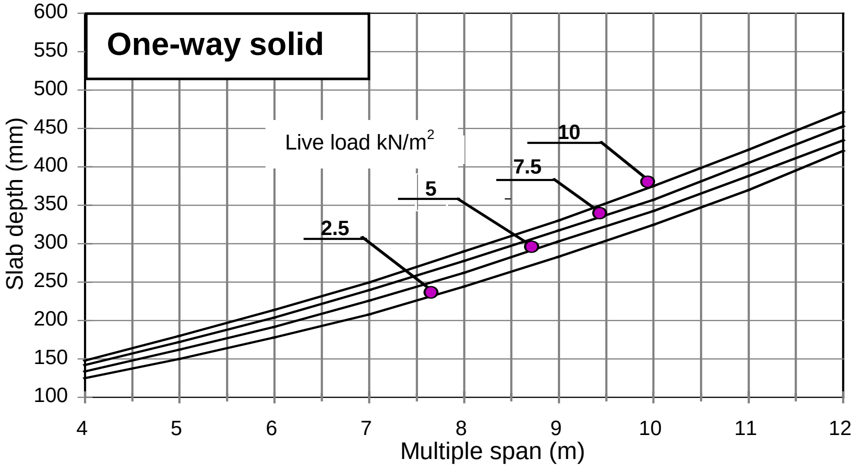
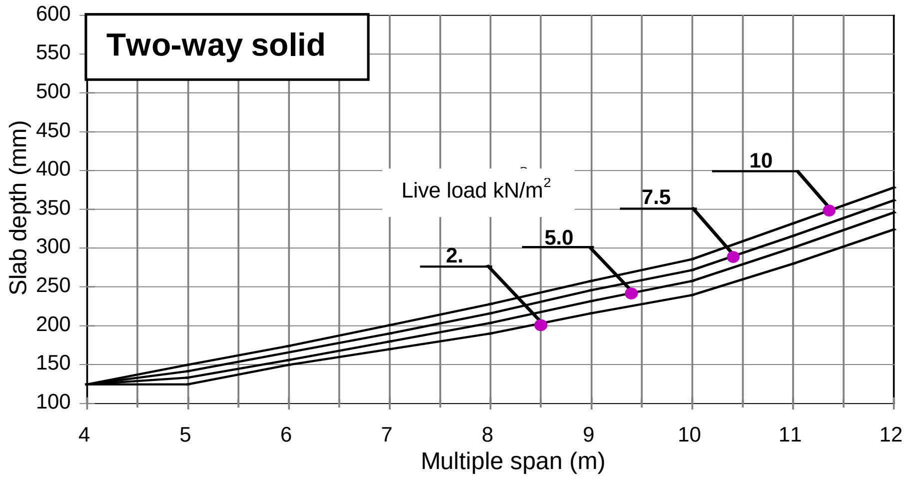
4.2 REINFORCED CONCRETE

4.2.1 RULES OF THUMB

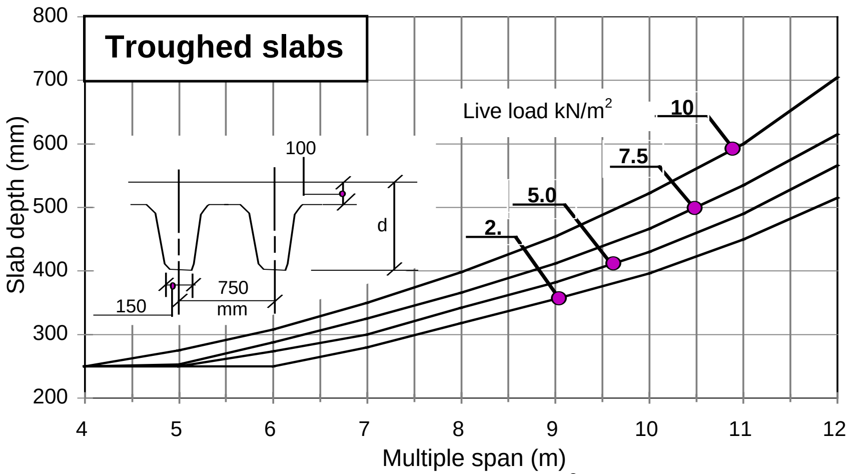
Span/depth ratios for slabs[1,7]

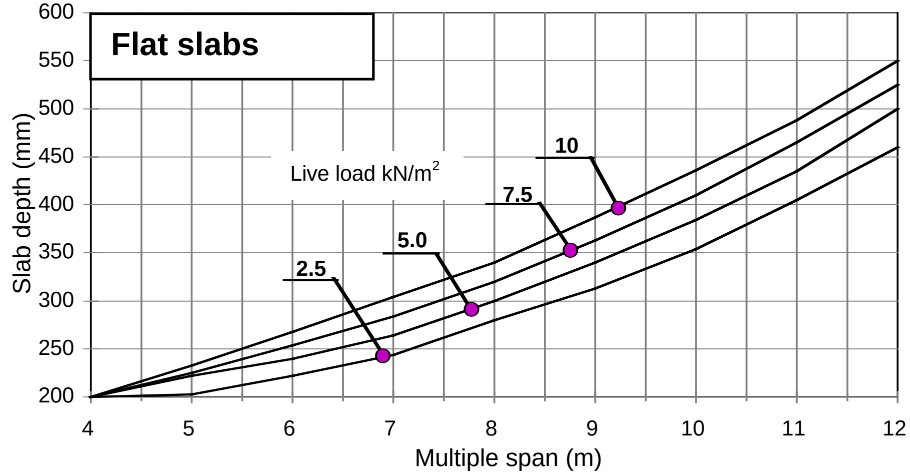
Slabs requiring support from beams





Slabs requiring support from columns only





Design assumptions : 3 spans. Loads: 1.5kN/m^2 has been allowed in addition to self-weight for finishes and services. Exposure: mild exposure conditions and one hour fire resistance. Materials in-situ: C35 concrete, main steel, fy = 460N/mm^2, mild steel links, fy = 250 N/mm^2

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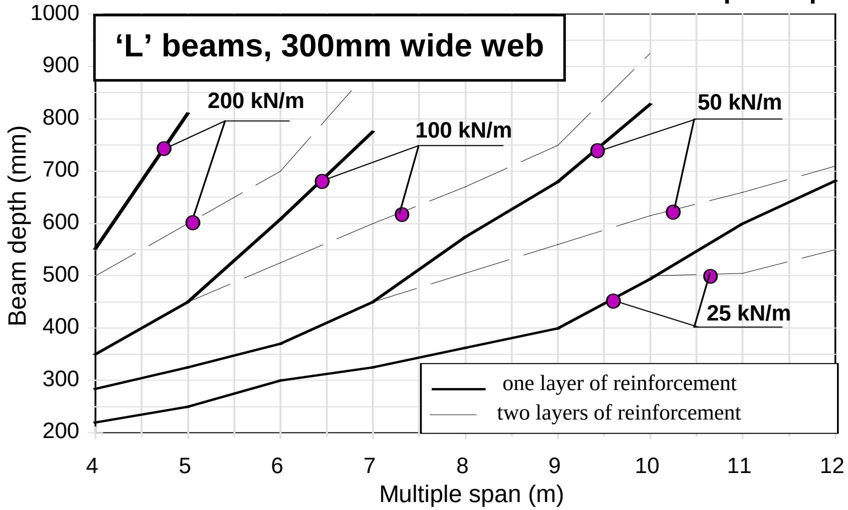
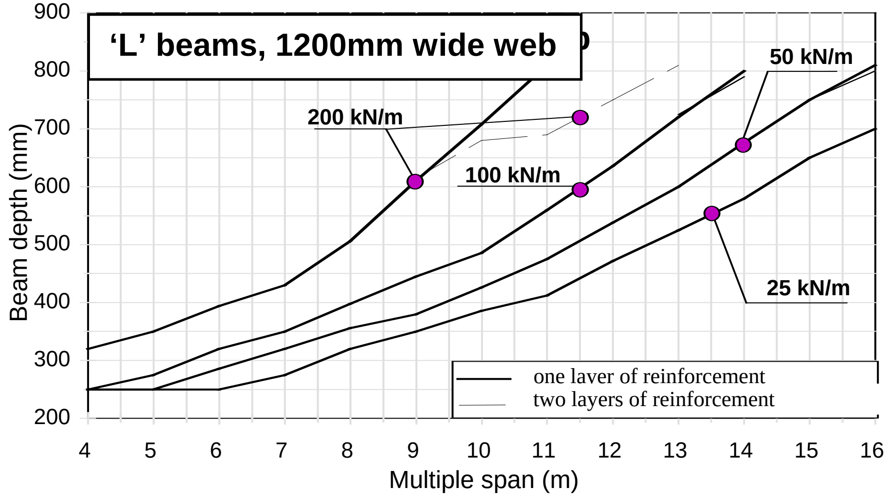
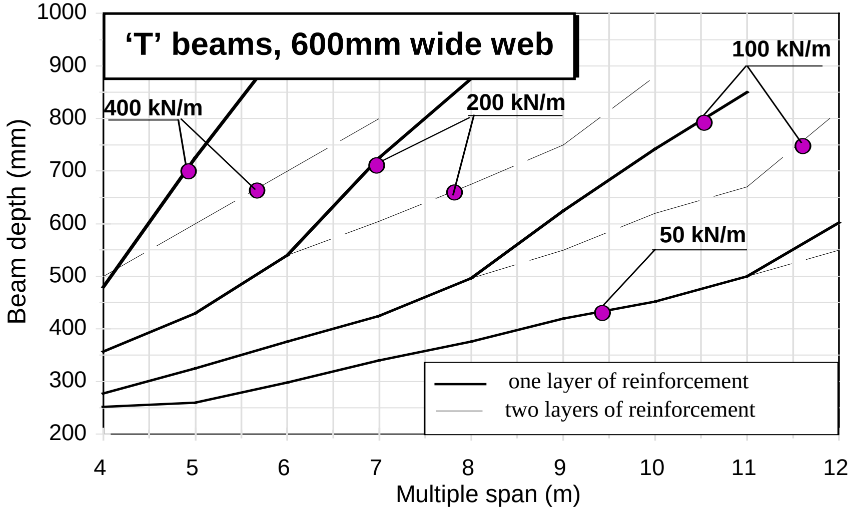
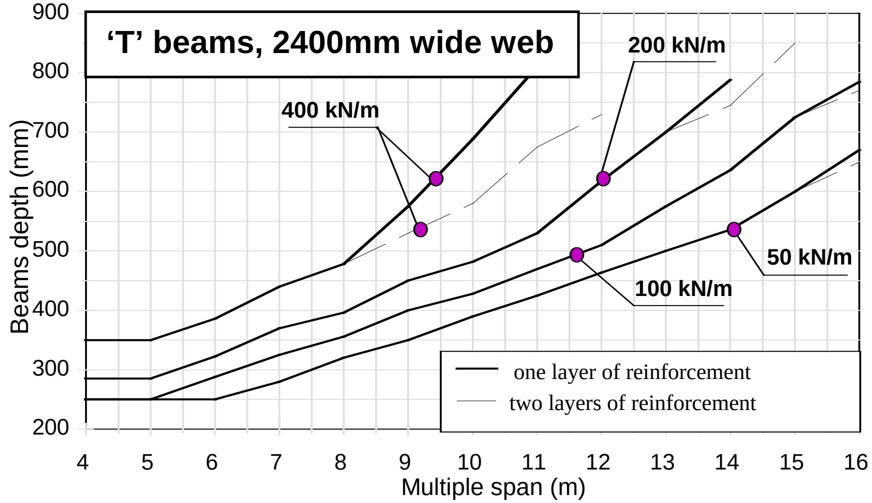
Span/depth ratios for beam[1,7]





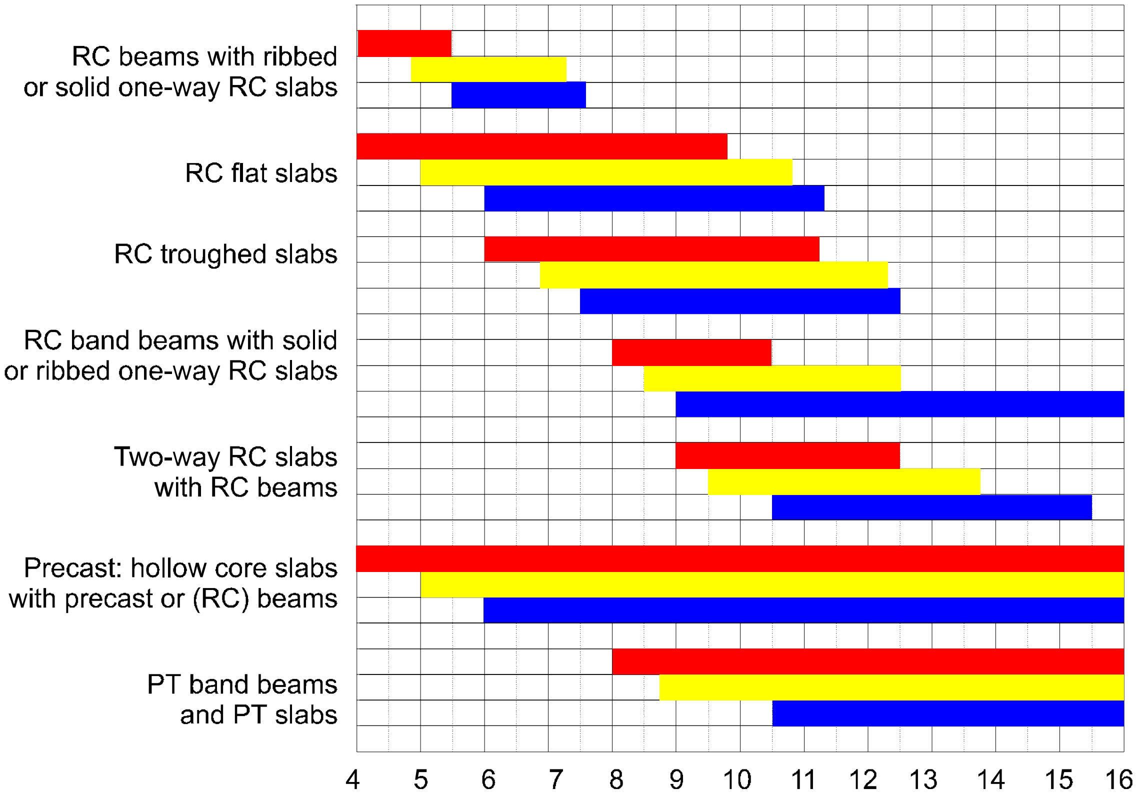




For the depth of a single span look up size at span +2%

Design assumptions : Beam self weight (extra over an assumed 200mm depth of slab) allowed for and included. Exposure: mild exposure conditions and one hour fire resistance. Materials in-situ: C35 concrete, main steel, fy = 460N/mm^2. T beam width = Beam span / 3.5. Loads are Ultimate.

Concrete Floor Slabs: Typical Econmic Span Ranger



Key

- Square panels, aspect ratio 1.0
- Rectangular panels, aspect ratio 1.25
- Rectangular panels, aspect ratio 1.5

Note
all subject to market conditions and project specific requirements
RC=Reinforced concrete   PT=Post-tensioned concrete

Typical column size[2] - also see section 4.2.6

Minimum column dimensions for 'stocky', braced column = clear height / 17.7

Column area where f_{cu} = 35 N/mm^2 and f_y = 460 N/mm^2 is as follows (N is axial force in Newtons):-

1% steel : Area = N/15
2% steel : Area = N/18
3% steel : Area = N/21

Approximate method for allowing for moments: multiply the axial load from the floor immediately above the column being considered) by:

1.25-interior columns
1.50-edge columns
2.00-corner columns

but keep the columns to constant size for the top two storeys.

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Typical wall thickness

At least 200mm thick (usually 300mm) for normal loads - if less than 1000mm high then 150mm thick is usually allowable.

Internal walls: Thickness > Height/15 (unrestrained at top)
Thickness > Height/30 (restrained at top)

Minimum size of elements[2]
Where different, values for Hong Kong[6] are in brackets.

Member	Minimum dimension, mm	Fire Rating		
		4h	2h	1h
Columns fully exposed to fire	width Cover	450 25 (35)	300 25 (35)	200 20 (25)
Beams	width cover	240 (280) 70 (80)	200 50	200 45
Slabs with plain soffit	thickness cover	170 45 (55)	125 35	100 35
Slabs with ribbed open soffit and no stirrups	thickness width of ribs cover	150 150 55	115 110 35	90 90 35

Cover to **main** reinforcement[2]

Conditions of exposure	Nominal cover				
Mild - protected from adverse conditions	25	20	20*	20*	20*
Moderate - condensation, soil	-	35	30	25	20
Severe - severe rain, occasional freezing	-	-	40	30	25
Very severe - sea water spray, severe freezing, salts	-	-	50†	40†	30
Extreme - abrasive action, acidic water, vehicles	-	-	-	60†	50
Maximum free water/cement ratio	0.65	0.60	0.55	0.50	0.45
Minimum cement content (kg/m^3)	275	300	325	350	400
Lowest grade of concrete	C30	C35	C40	C45	C50

Cover to **all** reinforcement[1]
*These covers may be reduced to 15mm provided that the nominal maximum size of aggregate does not exceed 15mm.
† Where concrete is subject to freezing whilst wet, air-entrainment should be used.
NOTE : This table relates to normal-weight aggregate of 20mm nominal size.

Reinforcement weights[2]

These values are approximate and should be used only as a check on the total estimated quantity:

Pile caps	-	110 - 150 kg/m^3
Rafts	-	60 - 70 kg/m^3
Beams	-	125 - 160 kg/m^3
Slabs	-	130 - 220 kg/m^3
Columns	-	220 - 300 kg/m^3
Walls	-	40 - 100 kg/m^3

Reinforcement availability

Standard sizes (mm): 6, 8, 10, 12, 16, 20, 25, 32, 40

Standard lengths: > 12mm diameter: 12 metres
< 12mm diameter: from a coil

4.2.2 LOAD FACTORS[3]

Partial safety factors for loads (Values in brackets are for H.K.)

Load combination (including earth and water loading where present)	Load type					
	Dead, G_k		Imposed, Q_k		Earth and water, E_n	Wind W_k
	adverse	beneficial	adverse	beneficial		
1. Dead and imposed	1.4 (1.5)	1.0	1.6 (1.7)	0	1.4*	-
2. Dead and wind	1.4	1.0	-	-	1.4*	1.4
3. Dead, wind and imposed	1.2	1.2	1.2	1.2	1.2	1.2

* For pressures arising from accidental head of water at ground level, a partial factor of 1.2 may be used.
Note : The HK dead & imposed factors can be reduced to 1.4 & 1.6 provided the procedure outlined in - PNAP 18F is followed.

The 'adverse' and 'beneficial' factors should be used so as to produce the most onerous condition.

4.2.3 BEAMS[3]

For high-tensile reinforcement: $f_y = 460$ N/mm^2
For mild steel: $f_y = 250$ N/mm^2

Bending

$M_u = 0.156 f_{cu} b d^2$

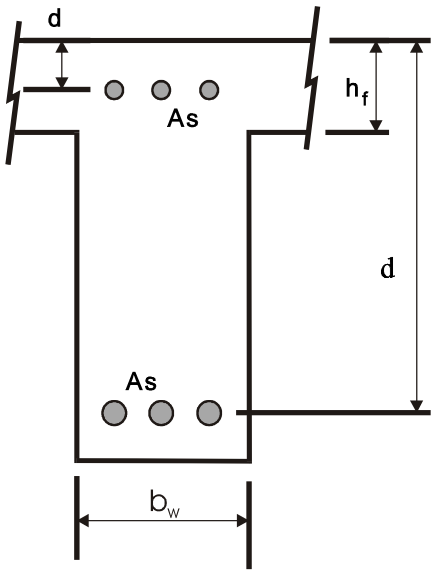
If: $M < M_u$ $\rightarrow$ no compression steel

$$A_s = \frac{M}{0.87 f_y 0.8 d}$$

If: $M > M_u$ $\rightarrow$ compression steel required

$$A_s' = \frac{M - 0.15 f_{cu} b d^2}{0.87 f_y (d - d')}$$

$$A_s = \frac{M_u}{0.87 f_y 0.8 d} + A_s'$$



where b equals:

	Simply supported	Continuous	Cantilever
T-Beam	$b_w + L / 5$	$b_w + L / 7.14$	b_w
L-Beam	$b_w + L / 10$	$b_w + L / 14.29$	b_w
and ≤ (i) actual flange width, (ii) beam spacing			

NOTE: If $M > 0.4 f_{cu} b_f h_f (d - 0.5 h_f)$ for flanged beams, then the neutral axis is in the web and the above formulae are not correct.

Maximum and minimum areas of longitudinal reinforcement for beams[2]

Minimum tension reinforcement (f_y = 460 N/mm²)

Rectangular beams with overall dimensions b and h		0.002 bh
Flanged beams (web in tension) :	$b_w/b < 0.4$ $b_w/b \geq 0.4$	0.0018 b_wh 0.0013 b_wh
Flanged beams (flange in tension over a continuous support):	T - beam L - beam	0.0026 b_wh 0.0020 b_wh
Transverse reinforcement in flanges of flanged beams (may be slab reinforcement)		0.0015 h_f per metre width

Minimum compression reinforcement: Rectangular beam 0.002 bh

Flanged beam web in compression: 0.002 b_wh

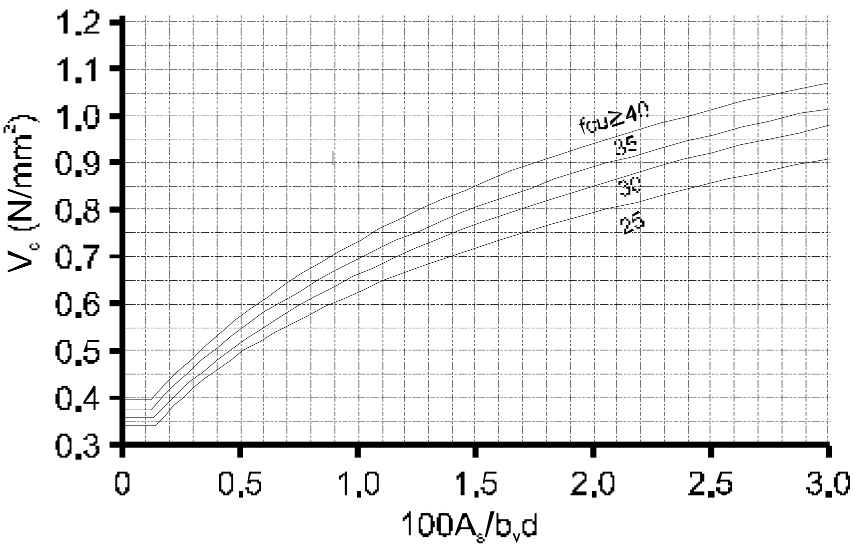
Maximum reinforcement (tension and compression): 0.04 b_wh

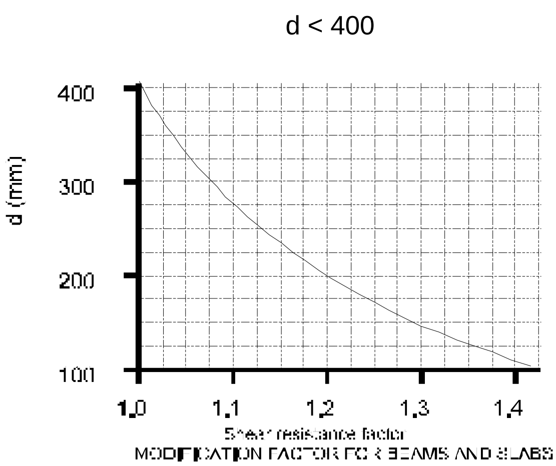
Normally main bars in beams should be not less than 16mm diameter.

Shear[3]

Minimum provision of links in beams	
Value of v (N/mm²)	Area of shear reinforcement
Less than $0.5v_c$	Grade 250 (mild steel) links equal to 0.18% of the horizontal section throughout the beam, except in members of minor structural importance such as lintels
$0.5v_c<v<(v_c+0.4)$	Minimum links for whole length of beam $A_{sv} > \frac{0.4 b_w s_v}{0.95 f_{yv}}$
$(v_c+0.4)<v$	Links only provided $A_{sv} > b_w \frac{s_v (v - v_c)}{0.95 f_{yv}}$
v< 0.8 $\sqrt{f_{cu}}$ and < 5 N/mm²	For beams 2.0 N/mm² typical maximum For ribs 0.6 N/mm² typical maximum

NOTE: A_{sv} is the total cross-section of the link(s) in mm² (2 legs for a single closed link, 4 legs for double closed). s_v is the link spacing along the member.





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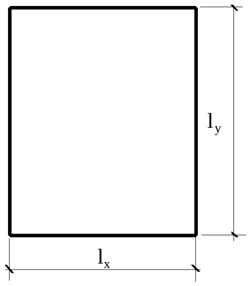
4.2.4 SLABS

Bending[3]

Simply supported on all sides:



$l_y > 1.5l_x$ then one-way spanning, else $M = \frac{wl_x l_y}{24}$ kNm/m

Design for bending as for beams (in 2 directions)

Continuous one-way spanning:

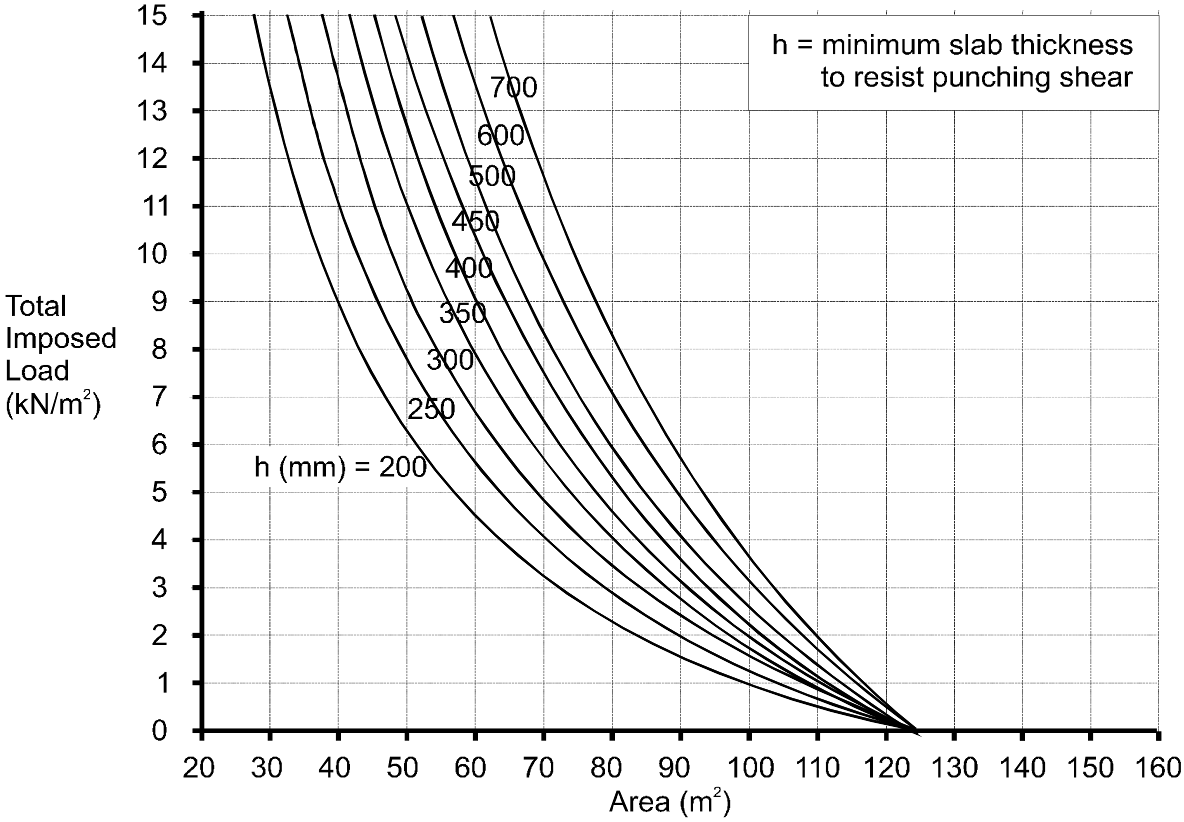
Bending moments and shear forces for one-way slabs					
	End support	End span	Penultimate support	Interior spans	Interior supports
Moment	0	0.086 Fl	-0.086 Fl	0.063 Fl	-0.063 Fl
Shear	0.4 F	-	0.6 F	-	0.5 F

Shear

Ultimate shear check at column face

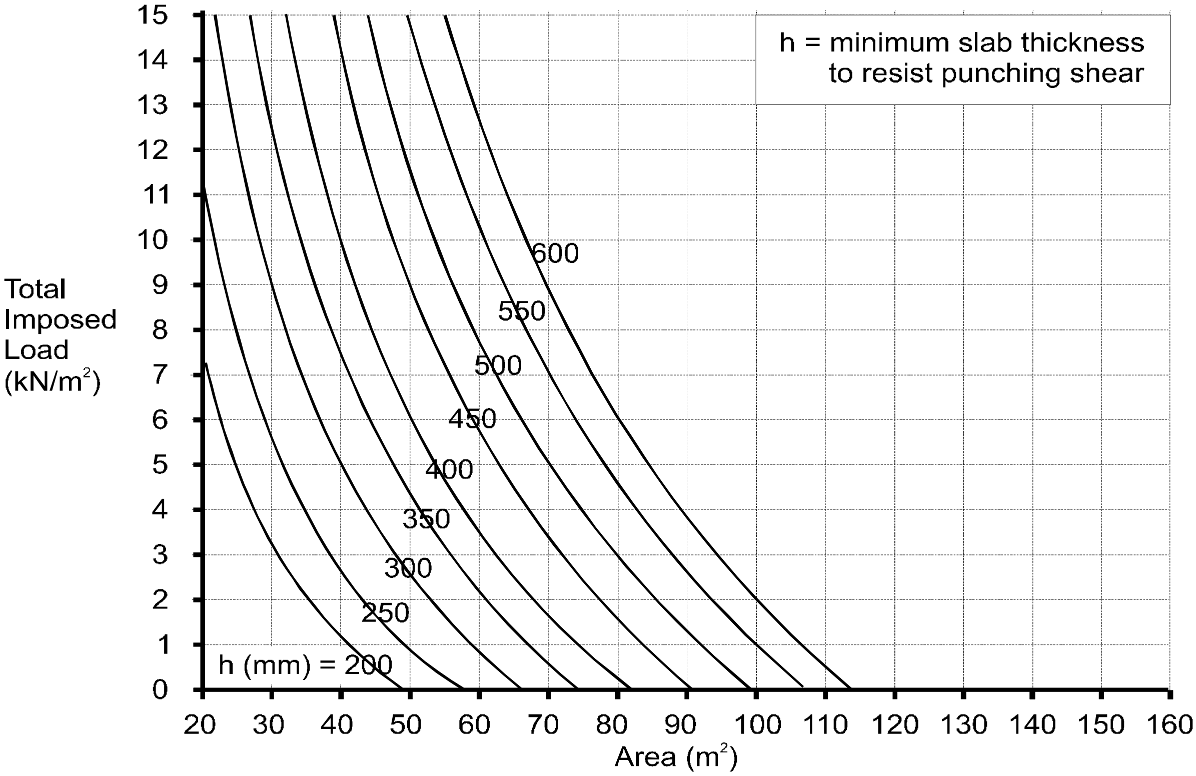
Column (inc. head) 300 x 300

Note: For column sizes other than 300 x 300 the slab depth should be multiplied by the factor = (column perimeter/1200)

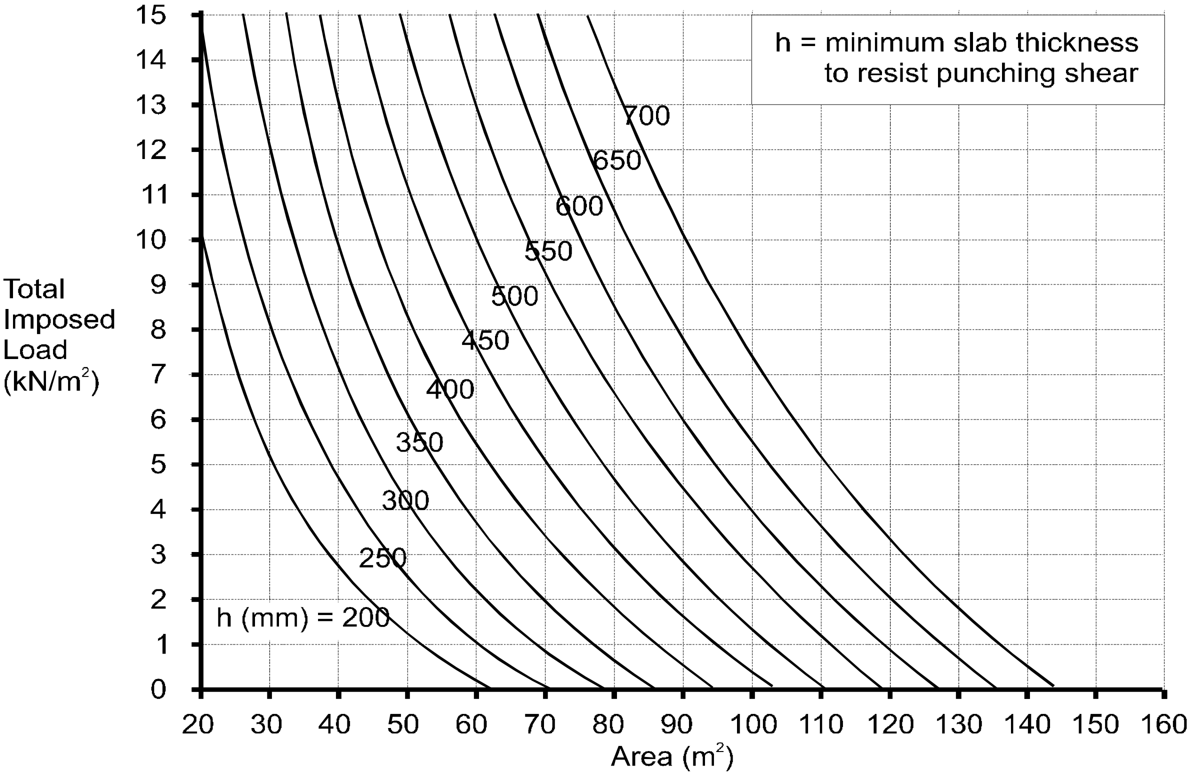


Notes: 1. f_{cu} = 35 N/mm²,
2. Dead load factor = 1.4,
3. Live load factor = 1.6,
4. The value of d/h is assumed to be 0.85,
5. The ratio of V_{eff}/V is assumed to be 1.15,

Column 300 x 300
Punching shear check at first perimeter for preliminary design (v_c = 0.6)



Column 500 x 500
Punching shear check at first perimeter for preliminary design (v_c = 0.6)



Notes:
1. f_{cu} = 35 N/mm²,
2. Dead load factor = 1.4,
3. Live load factor = 1.6,
4. The value of d/h is assumed to be 0.85,
5. The ratio of V_{eff}/V is assumed to be 1.15,

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4.2.5 STIFFNESS[3]

Typically require :	Total deflection	< span/250
	Live Load + creep	< span/350
	and	< 20mm

Criterion satisfied if span / effective depth < (Basic x C_1 x C_2 x C_3)

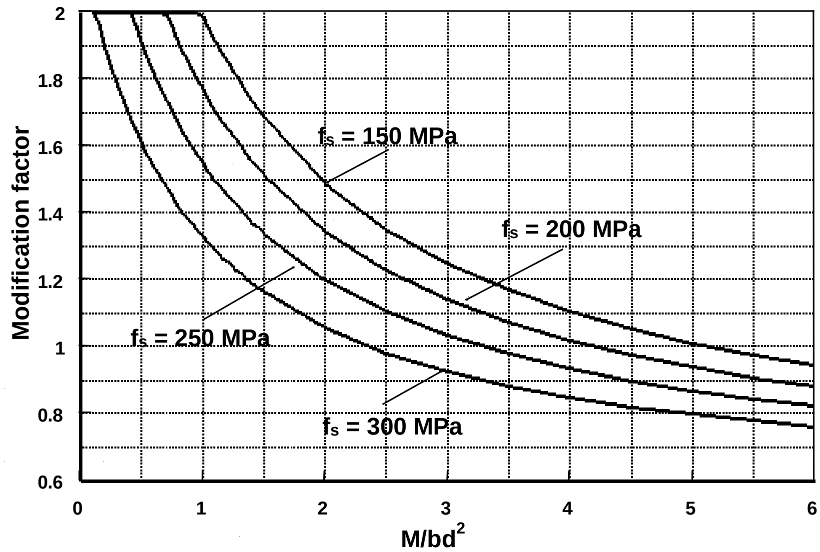
Typical multipliers (C1):
C1 = 0.8 for flanged beams with $b_w/b < 0.3$
C1 = 10/span(m) for spans beyond 10m
C1 = 0.9 for flat slabs (use longer span)

NOTE: For two-way slabs on continuous support, use shorter span.

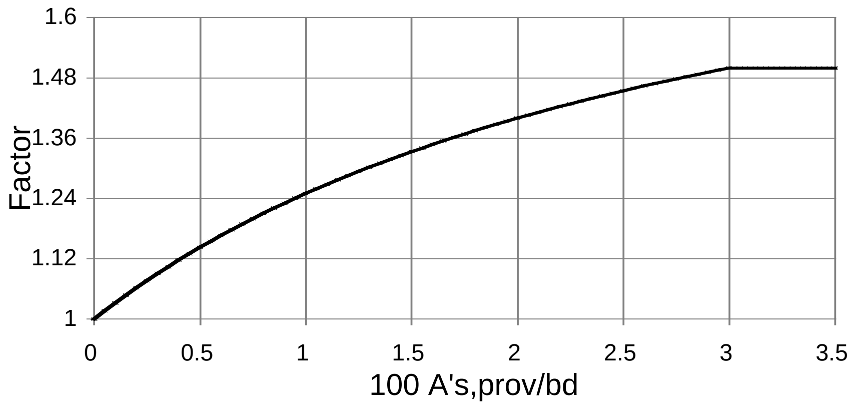
Basic span/effective depth ratios for rectangular beams	
Support conditions	Rectangular sections
Cantilever	7
Simple supported	20
Continuous	26

Tension reinforcement modification factor (C_2)[4]

f_S = service stress in reinforcement



Compression reinforcement modification factor (C_3)



4.2.6 COLUMNS

Typical design of columns[3]

For braced stocky columns use: $N_{cap} = 0.35\, f_{cu}A_c + 0.67\, f_yA_{sc}$

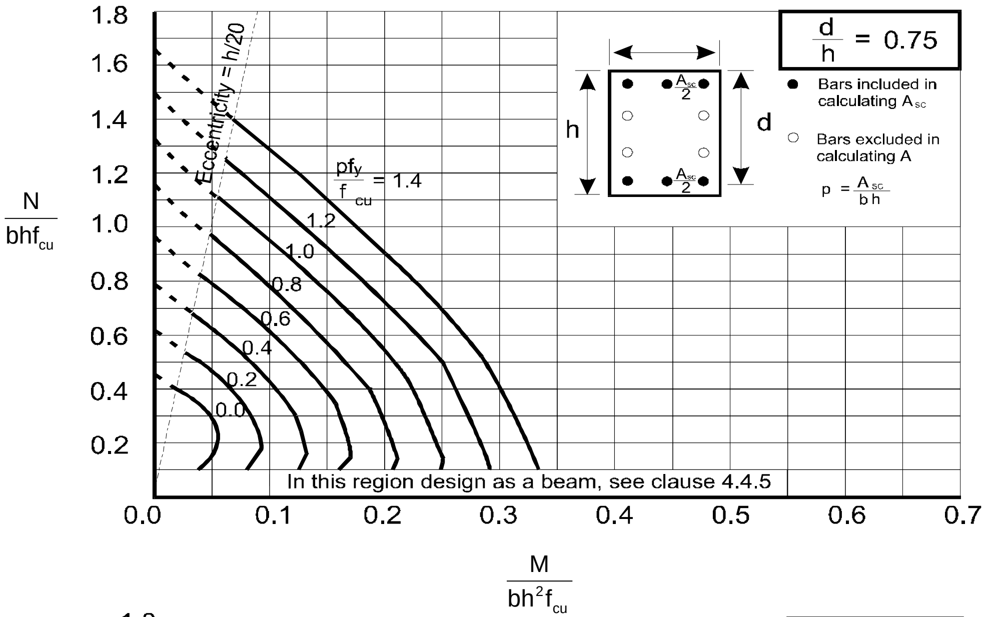
where: f_{cu} = characteristic strength of concrete (N/mm²)
A_c = area of concrete (mm²)
f_y = yield strength of reinforcement (N/mm²)
A_{sc} = area of rebars (mm²)

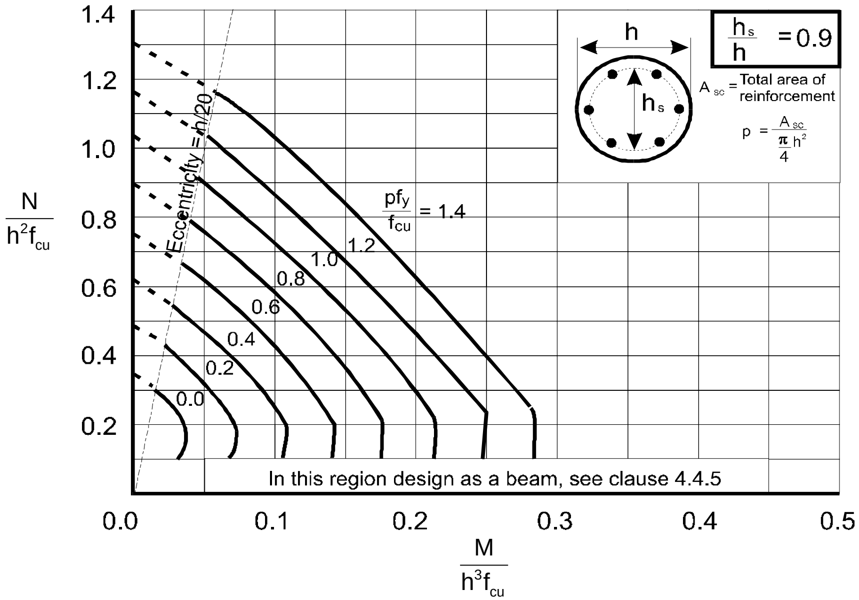
Ultimate resistance of braced stocky columns (f_{cu} = 35)

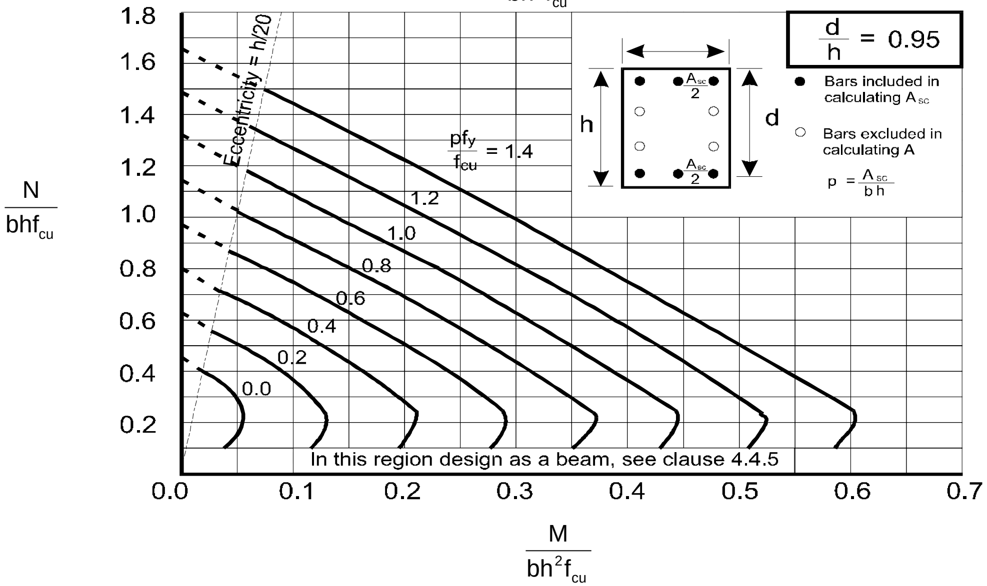
Column size & braced, clear storey height limit (mm)					Area of section ($mm^2 \times 10^3$)	p=1% (kN)	p=2% (kN)	p=3% (kN)	p=4%* (kN)
< 3530	< 4411	< 5294	< 6176	< 7059					
200 x 450	250 x 360	300 x 300			90	1369	1635	1901	2168
200 x 525	250 x 420	300 x 350			105	1597	1908	2218	2529
200 x 615	250 x 490	300 x 410	350 x 350		122.5	1863	2225	2588	2950
200 x 700	250 x 560	300 x 470	350 x 400		140	2129	2543	2958	3372
200 x 800	250 x 640	300 x 540	350 x 460	400 x 400	160	2433	2907	3380	3854
200 x 900	250 x 720	300 x 600	350 x 520	400 x 450	180	2737	3270	3803	4335
200 x1000	250 x 800	300 x 670	350 x 575	400 x 500	200	3041	3633	4225	4817
200 x1200	250 x 960	300 x 800	350 x 690	400 x 600	240	3650	4360	5070	5781

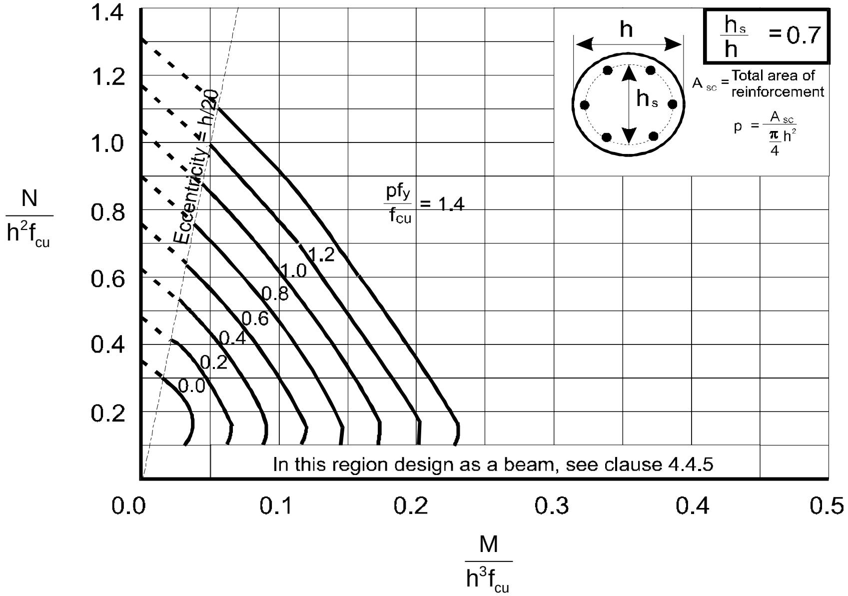
* Note : Scheme design based on 4% rebar should be avoided if possible.

Column interaction diagrams[2]









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4.2.7 CREEP & SHRINKAGE

Shrinkage

For normal situations, assume long term shrinkage strain of 300 x 10^{-6}

Creep

For normal situations, assume creep coefficient of ϕ = 2

Hence long term E value: $E = \frac{E_{28}}{1+\phi}$

4.2.8 BAR AND MESH AREAS AND WEIGHTS[5]

ϕ = diameter (mm); p = pitch (mm)

Sectional area (mm²) per m. width									
ϕ / p	6	8	10	12	16	20	25	32	40
50	566	1006	1570	2262	4022	6284	9818	16084	25132
75	376	669	1044	1504	2675	4179	6529	10696	16713
100	283	503	785	1131	2011	3142	4909	8042	12566
125	226	402	628	905	1609	2514	3927	6434	10053
150	189	335	523	754	1341	2095	3273	5361	8377
175	162	287	449	646	1149	1795	2805	4595	7180
200	142	252	393	566	1006	1571	2455	4021	6283
250	113	201	314	452	804	1258	1964	3217	5026
300	94	168	262	377	670	1047	1636	2681	4189

Weight (kg/m²)									
ϕ / p	6	8	10	12	16	20	25	32	40
50	4.44	7.90	12.32	17.76	31.58	49.32	77.08	126.26	197.28
75	2.96	5.27	8.21	11.84	21.05	32.88	51.39	84.17	131.52
100	2.22	3.95	6.16	8.88	15.79	24.66	38.54	63.13	98.64
125	1.78	3.16	4.93	7.10	12.63	19.73	30.83	50.50	78.91
150	1.48	2.63	4.11	5.92	10.53	16.44	25.69	42.09	65.76
175	1.27	2.26	3.52	5.07	9.02	14.09	22.02	36.07	56.36
200	1.11	1.98	3.08	4.44	7.90	12.33	19.27	31.57	49.32
250	0.89	1.58	2.46	3.55	6.32	9.86	15.42	25.25	39.46
300	0.74	1.32	2.05	2.96	5.26	8.22	12.85	21.04	32.88

Sectional Area (mm^2)									
ϕ / n	6	8	10	12	16	20	25	32	40
1	28	50	79	113	201	314	491	804	1257
2	57	101	157	226	402	628	982	1608	2513
3	85	151	236	339	603	943	1473	2413	3770
4	113	201	314	452	804	1257	1964	3217	5026
5	142	252	393	566	1006	1571	2455	4021	6283
6	170	302	471	679	1207	1885	2945	4825	7540
7	198	352	550	791	1408	2199	3436	5629	8796
8	226	402	628	905	1609	2514	3927	6434	10053
9	255	453	707	1018	1810	2828	4418	7238	11309
10	283	503	785	1131	2011	3142	4909	8042	12566
11	311	553	864	1244	2212	3456	5400	8846	13823
12	340	604	942	1357	2413	3770	5891	9650	15079
ϕ	6	8	10	12	16	20	25	32	40
Perim. (mm^2/mm)	18.8	25.1	31.4	37.7	50.2	62.8	78.5	100.5	125.6
Weight (kg/m)	0.222	0.395	0.616	0.888	1.579	2.466	3.854	6.313	9.864

n = number of bars

BS Fabric reference		Longitudinal wires			Cross wires			Nominal mass per square metre (kg)
		Nominal wire size (mm)	Pitch (mm)	Area (mm^2)	Nominal wire size (mm)	Pitch (mm)	Area (mm^2)	
Square mesh	A 393	10	200	393	10	200	393	6.16
	A 252	8	200	252	8	200	252	3.95
	A 193	7	200	193	7	200	193	3.02
	A 142	6	200	142	6	200	142	2.22
	A 98	5	200	98	5	200	98	1.54
Structural mesh	B 1131	12	100	1131	8	200	252	10.9
	B 785	10	100	785	8	200	252	8.14
	B 503	8	100	503	8	200	252	5.93
	B 385	7	100	385	7	200	193	4.53
	B 283	6	100	283	7	200	193	3.73
	B 196	5	100	196	7	200	193	3.05
Long mesh	C 785	10	100	785	6	400	70.8	6.72
	C 636	9	100	636	6	400	70.8	5.55
	C 503	8	100	503	5	400	49	4.34
	C 385	7	100	385	5	400	49	3.41
	C 283	6	100	283	5	400	49	2.61
Wrapping mesh	D 98	5	200	98	5	200	98	1.54
	D 49	2.5	100	49	2.5	100	49	0.77
Stock sheet size		Length 4.8m		Width 2.4m		Sheet area $11.52m^2$		

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Shear reinforcement A_{sv} / S_v values for links

No. of Legs	Bar Dia.---Area			Link Spacing Sv												
	8	10	12	100	125	150	175	200	225	250	275	300	325	350	375	400
2	101			1.005	0.804	0.670	0.574	0.503	0.447	0.402	0.366	0.335	0.309	0.287	0.268	0.251
		157		1.571	1.257	1.047	0.898	0.785	0.698	0.628	0.571	0.524	0.483	0.449	0.419	0.393
			226	2.262	1.810	1.508	1.293	1.131	1.005	0.905	0.823	0.754	0.696	0.646	0.603	0.565
3	151			1.508	1.206	1.005	0.862	0.754	0.670	0.603	0.548	0.503	0.464	0.431	0.402	0.377
		236		2.356	1.885	1.571	1.346	1.178	1.047	0.942	0.857	0.785	0.725	0.673	0.628	0.589
			339	3.393	2.714	2.262	1.939	1.696	1.508	1.357	1.234	1.131	1.044	0.969	0.905	0.848
4	201			2.011	1.608	1.340	1.149	1.005	0.894	0.804	0.731	0.670	0.619	0.574	0.536	0.503
		314		3.142	2.513	2.094	1.795	1.571	1.396	1.257	1.142	1.047	0.967	0.898	0.838	0.785
			452	4.524	3.619	3.016	2.585	2.262	2.011	1.810	1.645	1.508	1.392	1.293	1.206	1.131
6	302			3.016	2.413	2.011	1.723	1.508	1.340	1.206	1.097	1.005	0.928	0.862	0.804	0.754
		471		4.712	3.770	3.142	2.693	2.356	2.094	1.885	1.714	1.571	1.450	1.346	1.257	1.178
			679	6.786	5.429	4.524	3.878	3.393	3.016	2.714	2.468	2.262	2.088	1.939	1.810	1.696

4.2.9 REFERENCES

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