New Design Tables for Development and Lap Splice Lengths in accordance with AS 3600–2009

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INNOVATIVE COMMUNITY BUILDING

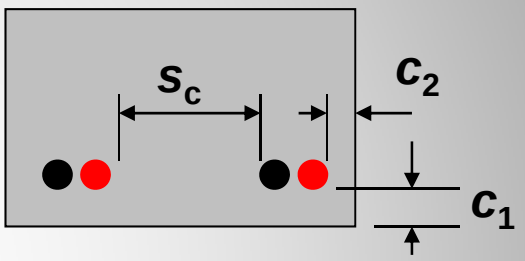
Overview

- **Design to AS 3600–2001**
- **SRIA Industry Survey of Engineering Drawings**
- **Design to AS 3600–2009:** ***Tensile Development Lengths***
- **Design to AS 3600–2009:** ***Tensile Lap Lengths***
- **SRIA Design Tables to AS 3600–2009**

Design to AS 3600–2001: $L_{sy.t}$

Tensile Development or Lap Length:

$$L_{sy.t} = \frac{k_1 k_2 f_{sy} A_b}{(2a + d_b)\sqrt{f_c'}} \geq 25 k_1 d_b$$



$2a$ = min. (2 x min. cover, clear distance s_c)

- **First included in AS 3600 – 1988**
- **Applicable for min. nominal 400 MPa deformed bars**
- **Formula can be used to calculate tensile development length or lap length (s_c modified)**
- **k_1 accounts for depth of concrete below bars**
- **k_2 accounts for wide bar spacing & any transverse bars**
- $f_c' \leq 65$ MPa

Design to AS 3600–2001: $L_{sy.t}$

Recommended improvements:

- **Increase minimum value of $L_{sy.t}$ for D500N reinforcing bars:**

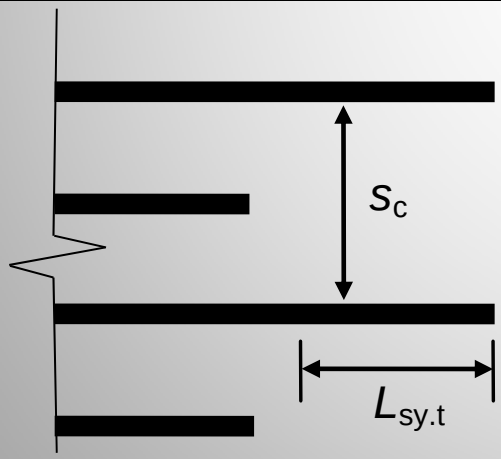
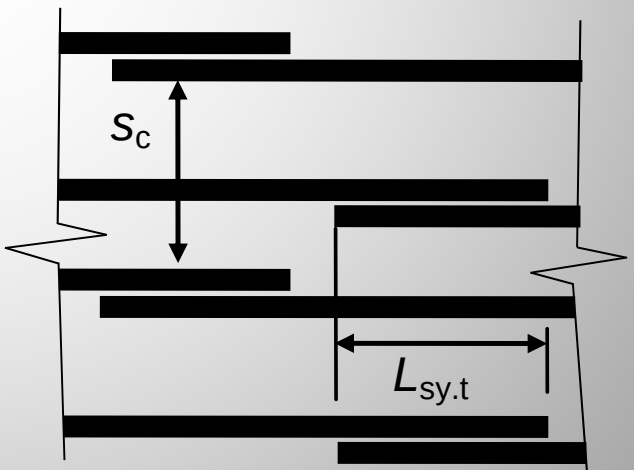
$$L_{sy.t} = \frac{k_1 k_2 f_{sy} A_b}{(2a + d_b)\sqrt{f_c'}} \geq 29 k_1 d_b$$

- **Place limits on 2*a*: $2d_b \leq 2a \leq 6d_b$ in particular the lower limit, so as to avoid excessively large $L_{sy.t}$ values**

Design to AS 3600–2001: $L_{sy.t}$

Definition of clear distance, s_c, between bars developing stress:

Figures unfortunately absent from Standard or Commentary:

Development	Lap splice
	

New Design Tables to AS 3600–2009

Design to AS 3600–2001: $L_{sy.t}$

Table A.19

Development Lengths[1], $L_{sy.t}$ (mm) for Grade D500N Bars in Beams and Columns with Fitments

For bars in columns with properly-designed fitments and bottom bars in beams with properly-designed fitments

$k_1 = 1.00$ $k_2 = 2.2$

s_b = clear distance between adjacent bars (or bundles of bars) developing stress

c = minimum cover to bar under consideration

f'_c (MPa)	a[2] (mm)	Bar size N12	N16	N20	N24	N28	N32	N36
20	20	530	880	1290	-	-	-	-
	25	450	750	1100	1500	-	-	-
	30	390	650	970	1320	1720	-	-
	35	340	580	860	1180	1550	1940	-
	40	300	520	770	1070	1400	1770	2160
	45	300	470	700	980	1280	1620	1990
	50	300	430	640	900	1180	1500	1840
	55	300	400	590	830	1100	1390	1710
	60	300	400	550	770	1020	1300	1600
	65	300	400	520	720	960	1220	1510
	70	300	400	500	680	900	1150	1420
	75	300	400	500	640	850	1090	1350
25	20	480	790	1150	-	-	-	-
	25	400	670	990	1340	-	-	-
	30	350	580	860	1180	1540	-	-
	35	300	510	770	1060	1380	1730	-
	40	300	460	690	960	1250	1580	1930
	45	300	420	630	870	1150	1450	1780
	50	300	400	580	800	1060	1340	1650
	55	300	400	530	740	980	1250	1530
	60	300	400	500	690	920	1160	1440
	65	300	400	500	650	860	1090	1350
	70	300	400	500	610	810	1030	1270
	75	300	400	500	600	760	970	1200
32	20	420	700	1020	-	-	-	-
	25	350	590	870	1190	-	-	-
	30	310	510	760	1050	1360	-	-
	35	300	450	680	940	1220	1530	-
	40	300	410	610	850	1110	1400	1710
	45	300	400	560	770	1010	1280	1570
	50	300	400	510	710	940	1180	1460
	55	300	400	500	660	870	1100	1360
	60	300	400	500	610	810	1030	1270
	65	300	400	500	600	760	970	1190
	70	300	400	500	600	710	910	1120
	75	300	400	500	600	700	860	1060
40	20	380	620	910	-	-	-	-
	25	320	530	780	1060	-	-	-
	30	300	460	680	940	1220	-	-
	35	300	410	610	840	1090	1370	-
	40	300	400	550	760	990	1250	1530
	45	300	400	500	690	910	1150	1410
	50	300	400	500	630	840	1060	1300
	55	300	400	500	600	780	990	1210
	60	300	400	500	600	720	920	1130
	65	300	400	500	600	700	860	1070
	70	300	400	500	600	700	810	1010
	75	300	400	500	600	700	800	950
50	20	340	560	810	-	-	-	-
	25	300	470	700	950	-	-	-
	30	300	410	610	840	1090	-	-
	35	300	400	540	750	980	1230	-
	40	300	400	500	680	890	1120	1370
	45	300	400	500	620	810	1030	1260
	50	300	400	500	600	750	950	1160
	55	300	400	500	600	700	880	1080
	60	300	400	500	600	700	820	1020
	65	300	400	500	600	700	800	950
	70	300	400	500	600	700	800	900
	75	300	400	500	600	700	800	900
65	20	300	490	710	-	-	-	-
	25	300	420	610	830	-	-	-
	30	300	400	540	730	950	-	-
	35	300	400	500	680	860	1080	-
	40	300	400	500	600	780	980	1200
	45	300	400	500	600	710	900	1100
	50	300	400	500	600	700	830	1020
	55	300	400	500	600	700	800	950
	60	300	400	500	600	700	800	900
	65	300	400	500	600	700	800	900
	70	300	400	500	600	700	800	900
	75	300	400	500	600	700	800	900
Minimum		300	400	500	600	700	800	900

NOTES:

(1) Development lengths have been calculated using the nominal areas as per AS/NZS 4761 and have been rounded, generally to the nearest 10 mm within the accuracy of normal design limits.

(2) Smaller of $0.5s_b$ and c.

New Design Tables to AS 3600–2009

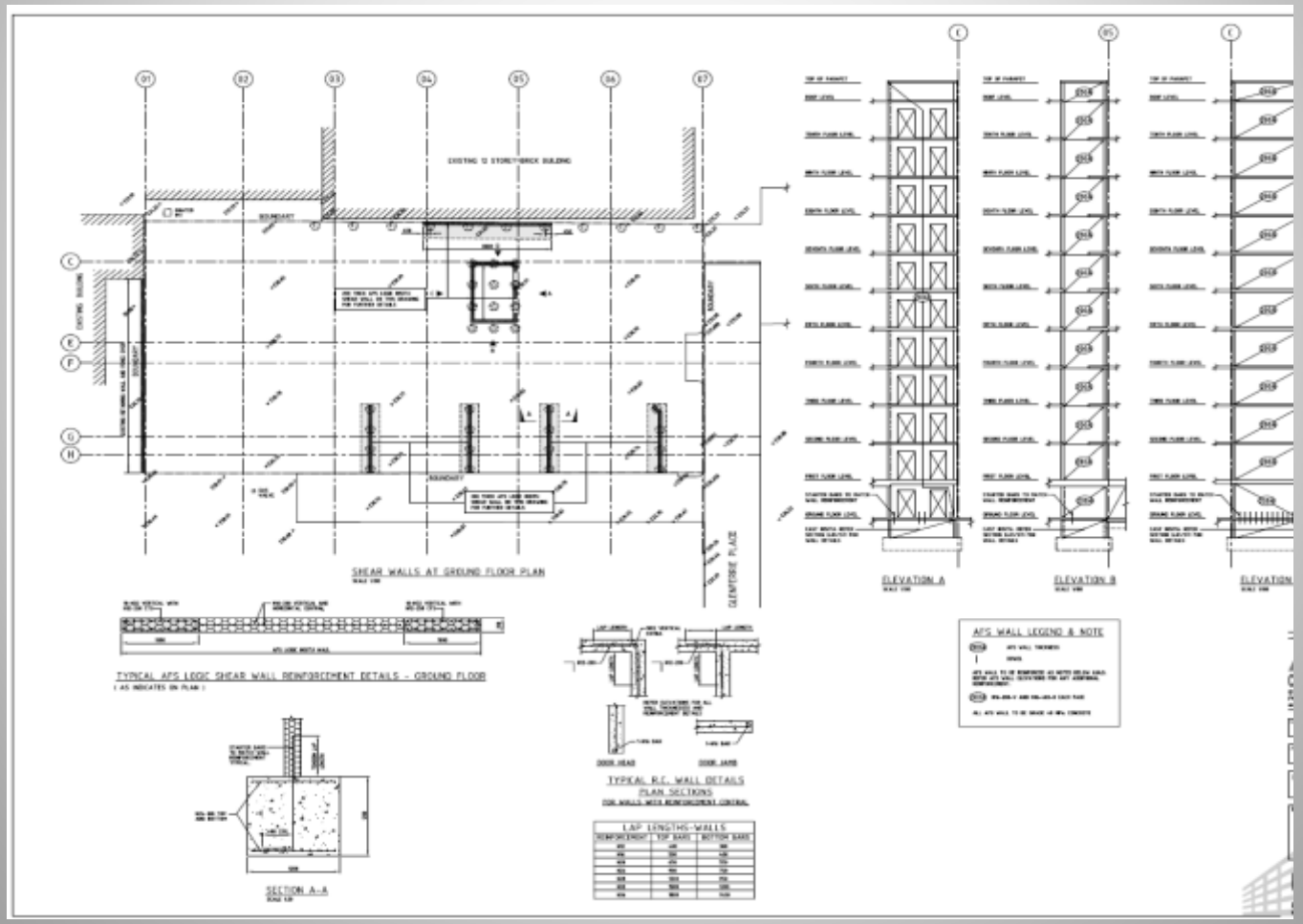
Design to AS 3600

f'_c (MPa)	a[2] (mm)	Bar size						
		N12	N16	N20	N24	N28	N32	N36
40	20	380	620	910	-	-	-	-
	25	320	530	780	1060	-	-	-
	30	300	460	680	940	1220	-	-
	35	300	410	610	840	1090	1370	-
	40	300	400	550	760	990	1250	1530
	45	300	400	500	690	910	1150	1410
	50	300	400	500	630	840	1060	1300
	55	300	400	500	600	780	990	1210
	60	300	400	500	600	720	920	1130
	65	300	400	500	600	700	860	1070
	70	300	400	500	600	700	810	1010
	75	300	400	500	600	700	800	950

(2) Smaller of $0.55f'_c$ and c.

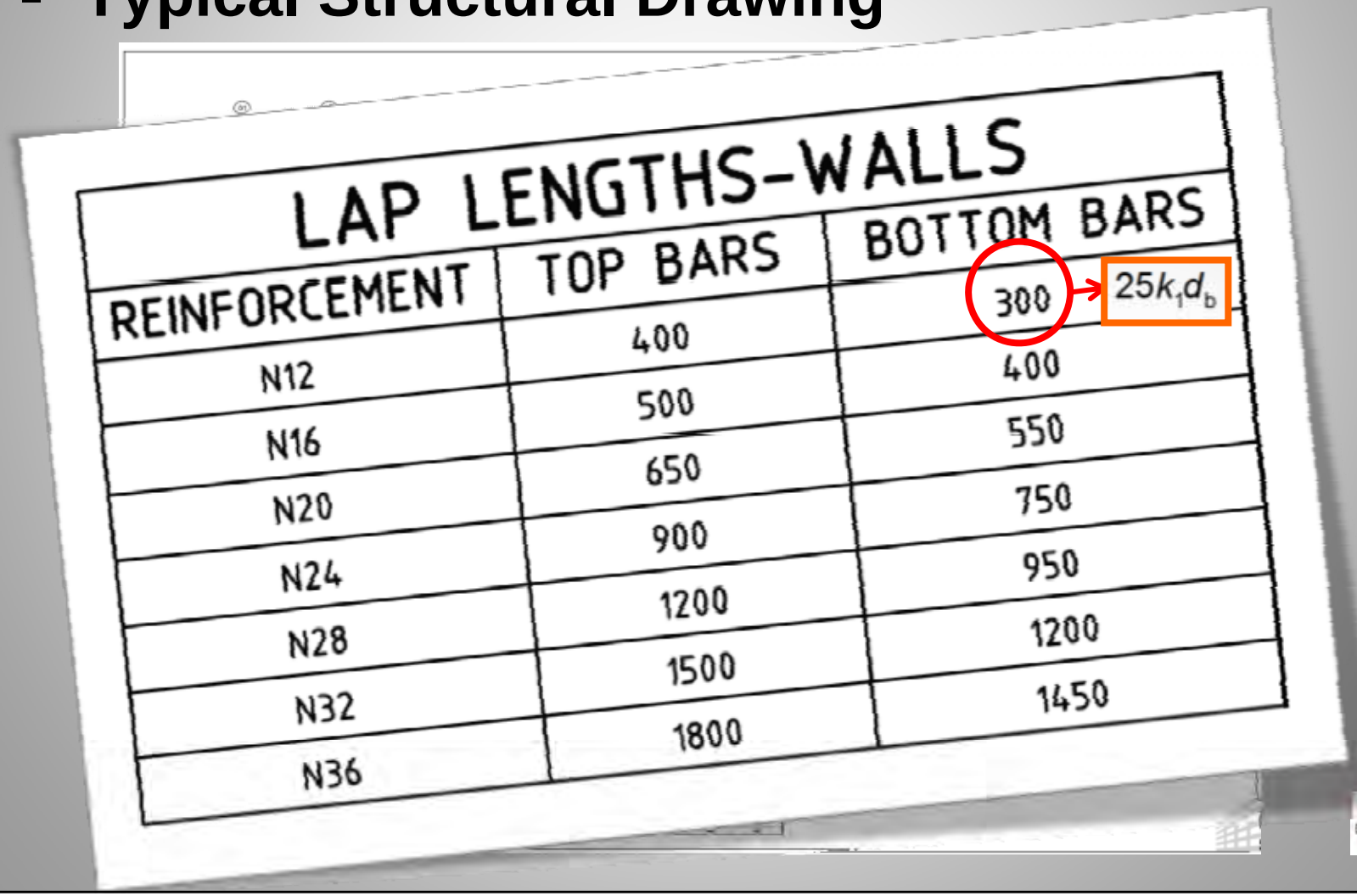
SRIA Industry Survey of Engineering Drawings

- **Typical Structural Drawing**



SRIA Industry Survey of Engineering Drawings

- **Typical Structural Drawing**



LAP LENGTHS-WALLS

REINFORCEMENT	TOP BARS	BOTTOM BARS
N12	400	300
N16	500	400
N20	650	550
N24	900	750
N28	1200	950
N32	1500	1200
N36	1800	1450

$25k_1d_b$

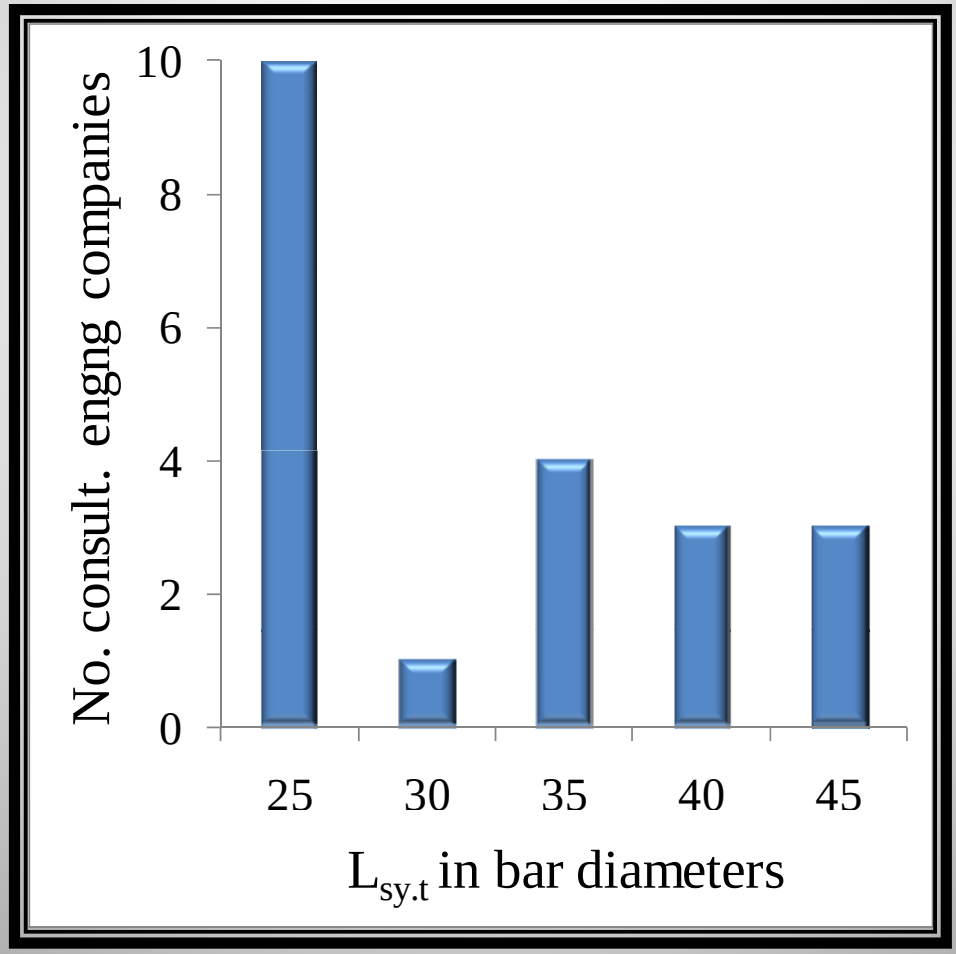
SRIA Industry Survey of Engineering Drawings

- **Sample of tensile development or lap lengths, $L_{sy.t}$ to AS 3600 – 2001, assuming:**
  - **clear distance, $a \geq 2\times$cover & at least 150 mm for slabs;**
  - **cover equals minimum required for durability;**
  - **cover not less than bar diameter, d_b, rounded up to nearest multiple of 5 mm; and**
  - **not more than 300 mm of concrete below bars.**

Exposure classification (EC) & strength grade f'_c	Element type	Bar diameter, d_b (mm)		
		12	16	28
A1 & f'_c = 25 MPa	Slab	30.8d_b	38.1d_b	42.5d_b
	Beam/Column	39.9d_b	49.4d_b	55.0d_b
A1 & $f'_c \geq$ 32 MPa	Slab	29.0d_b	33.7d_b	37.6d_b
	Beam/Column	35.2d_b	43.6d_b	48.6d_b
B1 & $f'_c \geq$ 32 MPa	Slab	29.0d_b	29.0d_b	30.6d_b
	Beam/Column	29.0d_b	29.0d_b	39.6d_b

SRIA Industry Survey of Engineering Drawings

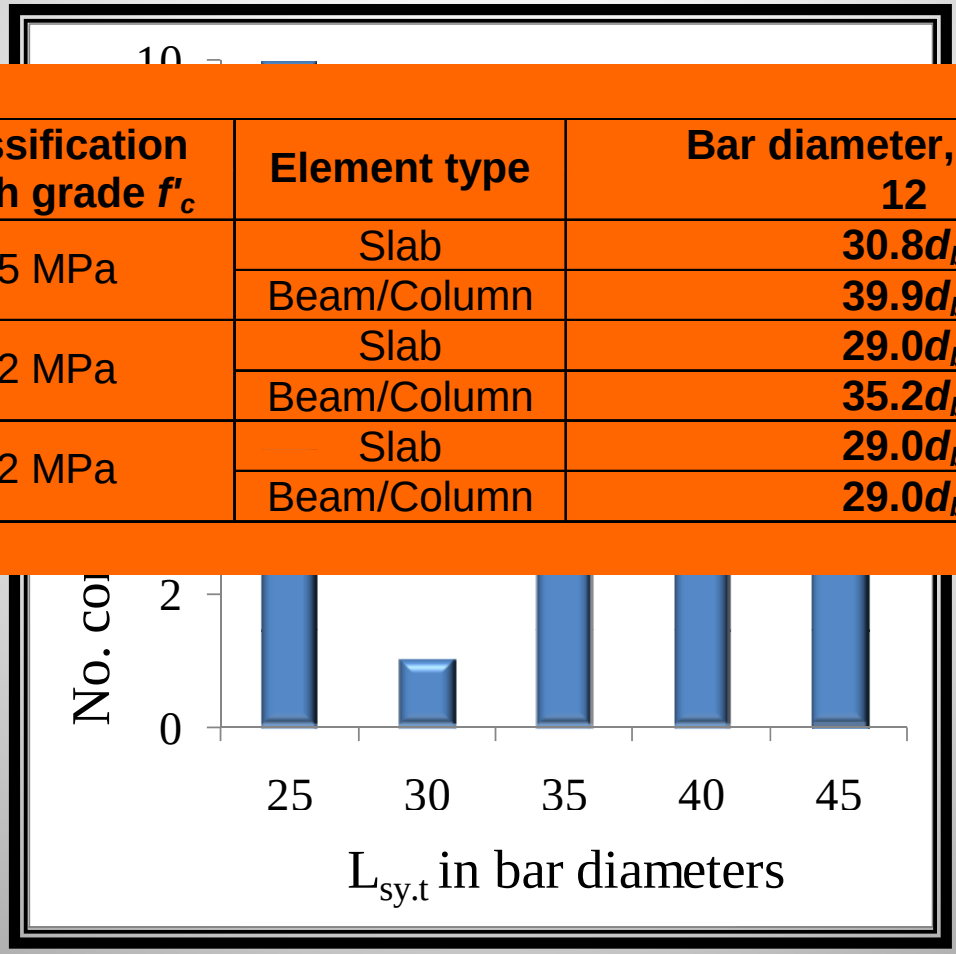
- $L_{sy.t}$ for D500N12 bars in slabs or beams



SRIA Industry Survey of Engineering Drawings

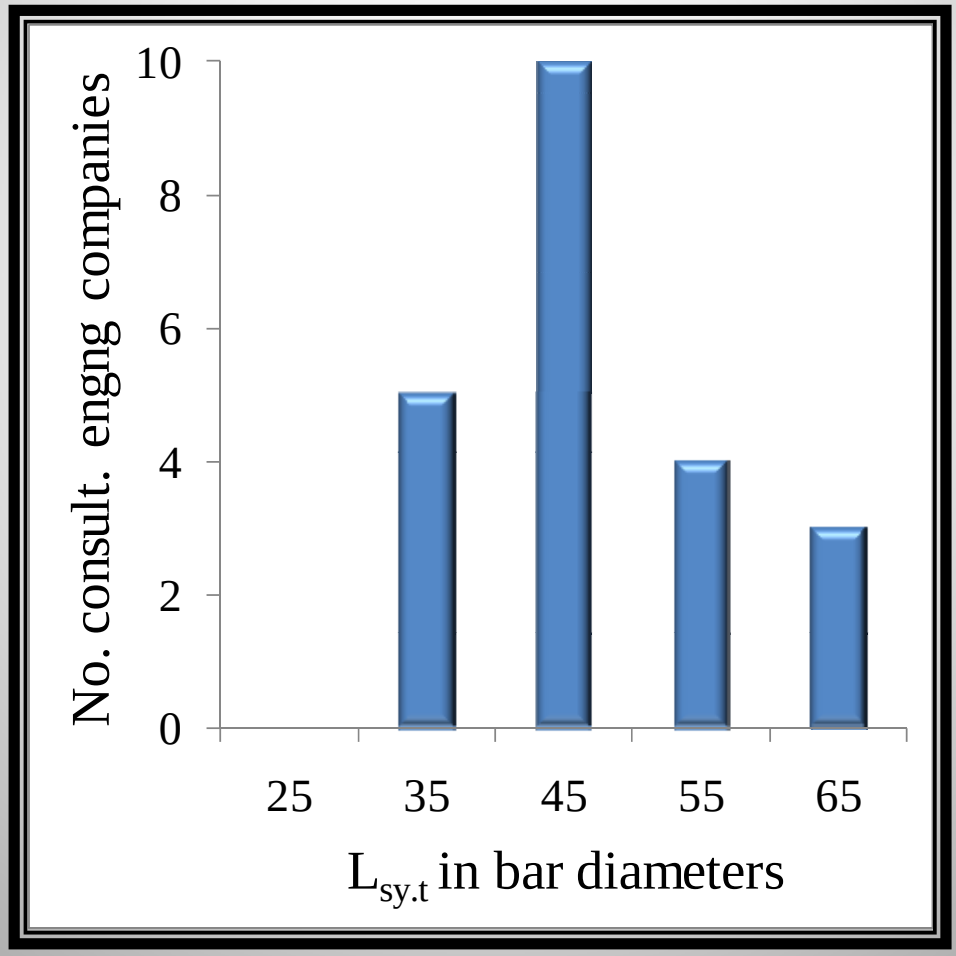
- $L_{sy.t}$ for D500N12 bars in slabs or beams

Exposure classification (EC) & strength grade f'_c	Element type	Bar diameter, d_b (mm) 12
A1 & f'_c = 25 MPa	Slab	**30.8d_b**
	Beam/Column	**39.9d_b**
A1 & $f'_c \geq$ 32 MPa	Slab	**29.0d_b**
	Beam/Column	**35.2d_b**
B1 & $f'_c \geq$ 32 MPa	Slab	**29.0d_b**
	Beam/Column	**29.0d_b**



SRIA Industry Survey of Engineering Drawings

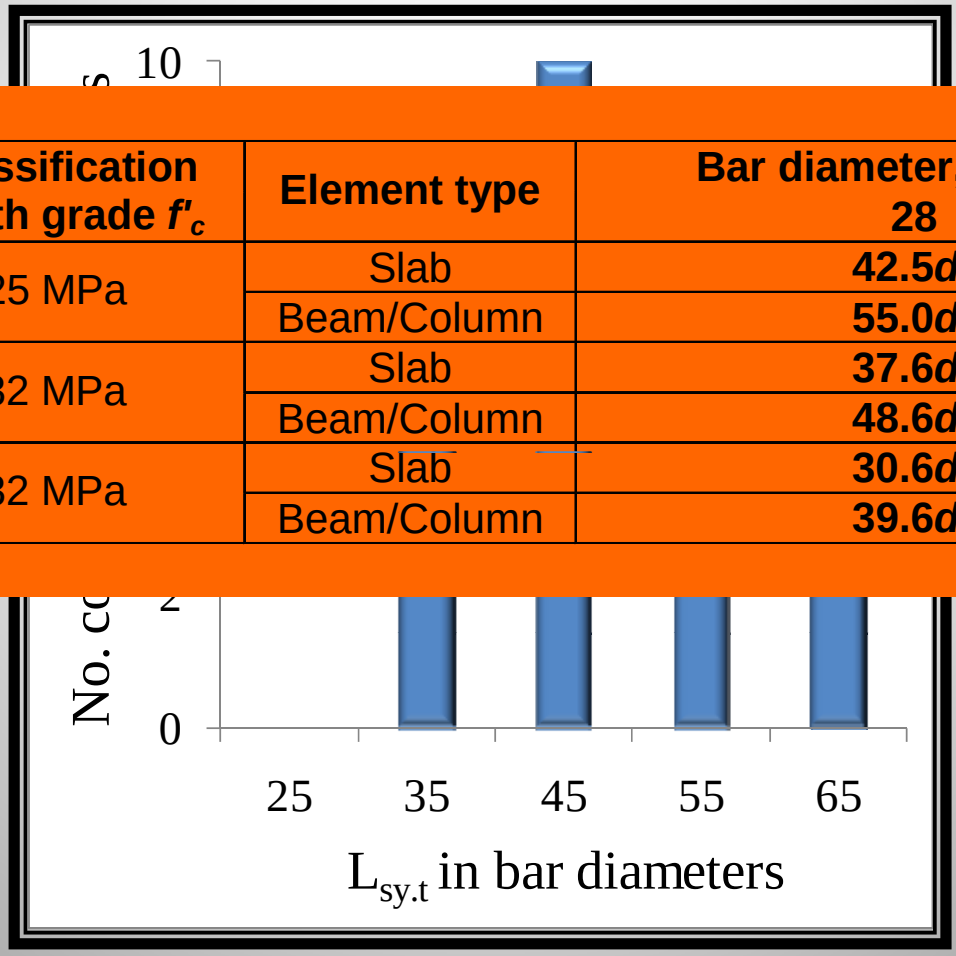
- $L_{sy.t}$ for D500N28 bars in slabs or beams



SRIA Industry Survey of Engineering Drawings

- $L_{sy.t}$ for D500N28 bars in slabs or beams

Exposure classification (EC) & strength grade f'_c	Element type	Bar diameter, d_b (mm) 28
A1 & f'_c = 25 MPa	Slab	**$42.5d_b$**
	Beam/Column	**$55.0d_b$**
A1 & $f'_c \geq$ 32 MPa	Slab	**$37.6d_b$**
	Beam/Column	**$48.6d_b$**
B1 & $f'_c \geq$ 32 MPa	Slab	**$30.6d_b$**
	Beam/Column	**$39.6d_b$**

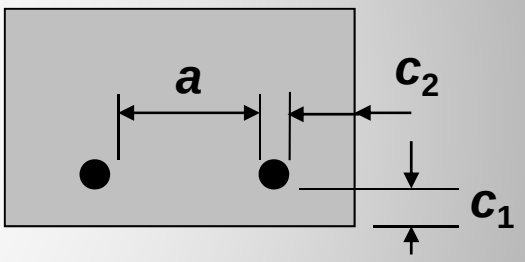


Design to AS 3600–2009: Tensile Development Lengths

Basic Tensile Development Length:

$$L_{sy.tb} = \frac{50k_1\left[(1.0 - 0.15(c_d - d_b)/d_b\right]f_{sy}d_b}{(132 - d_b)\sqrt{f_c'}} \geq 29k_1d_b$$

c_d = min. (c_1, c_2, $a/2$) and $d_b \leq c_d \leq 3d_b$



Refined Tensile Development Length:

$$L_{sy.t} = [1.0 - K(\sum A_{tr} - \sum A_{tr.min})/A_s]\,[1.0 - 0.04\rho_p]L_{sy.tb} \geq (0.7/k_3)L_{sy.tb}$$

Transverse reinforcement term, k_4

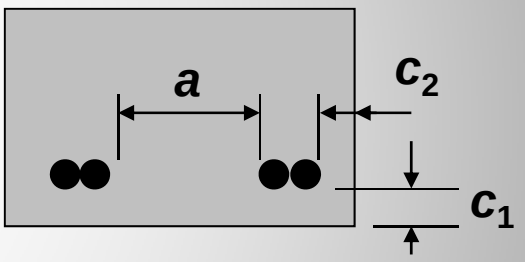
Transverse pressure term, k_5

Design to AS 3600–2009: Tensile Lap Lengths

Basic Tensile Lap Length:

$$L_{sy.tb.lap} = k_7 \frac{50k_1\left[\left(1.0 - 0.15(c_d - d_b)\right)/d_b\right]f_{sy}d_b}{(132 - d_b)\sqrt{f'_c}} \geq 29k_1d_b$$

c_d = min. (c_1, c_2, $al/2$) and $d_b \leq c_d \leq 3d_b$



Refined Tensile Lap Length:

$$L_{sy.t.lap} = [1.0 - K(\sum A_{tr} - \sum A_{tr.min})/A_s]\,[1.0 - 0.04\rho_p]L_{sy.tb.lap} \geq \max.[(0.7/k_3)L_{sy.tb.lap}, 29k_1d_b]$$

Transverse reinforcement term, k_4

Transverse pressure term, k_5

Design to AS 3600–2009: Tensile Development/Lap Lengths

- **Maximum benefit to be gained from Refined Design:**

$$k_3 = 1.0 - 0.15(c_d - d_b)/d_b$$

$$k_4 = 1.0 - K(\sum A_{tr} - \sum A_{tr.min})/A_s$$

$$k_5 = 1.0 - 0.04\rho_p$$

$$\left.\begin{array}{l} 0.7 \le k_3, k_4, k_5 \le 1.0 \\ k_3 k_4 k_5 \ge 0.7 \end{array}\right\} \Rightarrow k_4 k_5 \ge 0.7/k_3 \quad \text{OR} \quad (k_4 k_5)_{min} = 0.7/k_3$$

Design to AS 3600–2009: Tensile Development/Lap Lengths

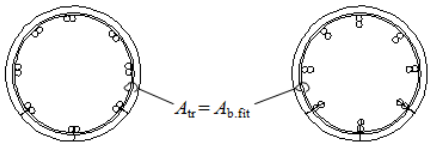
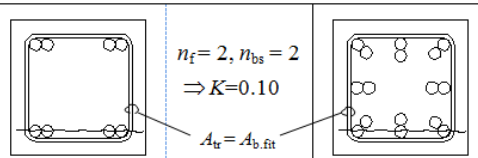
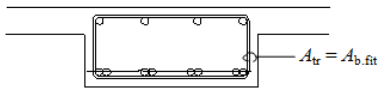
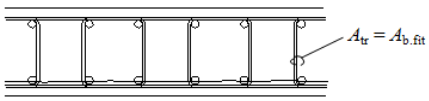
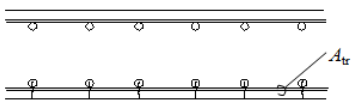
- **Maximum benefit to be gained from Refined Design:**

	N10	N12	N16	N20	N24	N28	N32	N36	N40
c_d			Values of $(k_4 k_5)_{min} = 0.7/k_3$						
20	0.82	0.78	0.73	0.70	0.70	0.70	0.70	0.70	0.70
25	0.90	0.84	0.76	0.73	0.70	0.70	0.70	0.70	0.70
30	1.00	0.90	0.81	0.76	0.73	0.71	0.70	0.70	0.70
35	1.00	0.98	0.85	0.79	0.75	0.73	0.71	0.70	0.70
40	1.00	1.00	0.90	0.82	0.78	0.75	0.73	0.71	0.70
45	1.00	1.00	0.96	0.86	0.81	0.77	0.75	0.73	0.71
50	1.00	1.00	1.00	0.90	0.84	0.79	0.76	0.74	0.73
55	1.00	1.00	1.00	0.95	0.87	0.82	0.78	0.76	0.74
60	1.00	1.00	1.00	1.00	0.90	0.84	0.81	0.78	0.76
65	1.00	1.00	1.00	1.00	0.94	0.87	0.83	0.80	0.77
70	1.00	1.00	1.00	1.00	0.98	0.90	0.85	0.82	0.79
75	1.00	1.00	1.00	1.00	1.00	0.94	0.88	0.84	0.81
80	1.00	1.00	1.00	1.00	1.00	0.97	0.90	0.86	0.82
85	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.88	0.84
90	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.90	0.86
95	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.93	0.88
100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90

Design to AS 3600–2009: Tensile Development/Lap Lengths

- **Recommended amendment for transverse steel:**

TABLE 13.1.2.3
VALUES OF *K* FOR TYPICAL ARRANGEMENTS OF TRANSVERSE REINFORCEMENT FOR DIFFERENT MEMBER TYPES

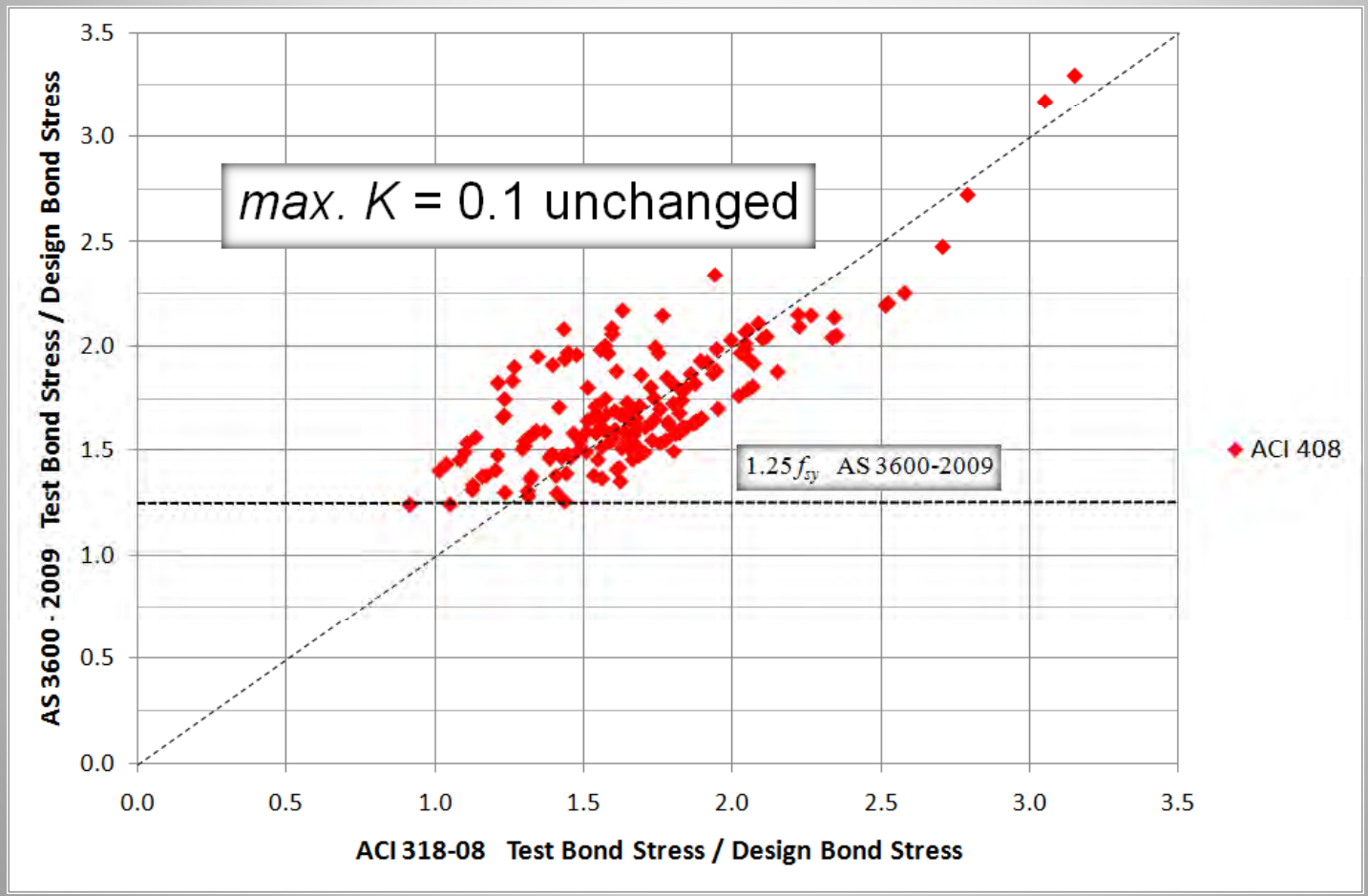
Member type	Examples of potential splitting cracks at a tensile face	n_f	n_{bs}	K (see Note 2)
Circular column		1	1	0.10
Rectangular column		≥1	≥1	$0.05 \le K \le 0.10$
Beam		≥1	≥1	$0.05 \le K \le 0.10$
Slab or wall (with fitments)		≥1	≥1	$0.05 \le K \le 0.10$
Slab or wall (without fitments)		0	1 per main bar spacing	0.05 (see Note 3)

NOTES:
1 Fitments are a type of transverse reinforcement.
2 The same value of K applies to all of the longitudinal bars being either anchored or lap spliced, i.e. it is a weighted average value.
3 To be effective, the transverse reinforcement must be located between the longitudinal bars and the concrete tensile face as shown, otherwise $K=0$.

$$K = 0.05(1 + n_f / n_{bs}) \le 0.1$$

Design to AS 3600–2009: Tensile Development/Lap Lengths

- **Recommended amendment for transverse steel:**



Design Tables to AS 3600–2009

- **General Tables**
  - c_d is calculated directly by the designer
  - similar to existing tables
- **New Cover-Controlled Tables**
  - c_d is controlled by concrete cover
- **New Spacing-Controlled Tables**
  - c_d is controlled by clear distance between bars
- **Commentary and Worked Examples**

Design Tables to AS 3600–2009

Design Variables for Cover-Controlled Tables

Design Variable	Description	Range
EC	Exposure classification for durability	*EC* = A1, A2 or B1, with concrete assumed to be cast in standard formwork
k_1	Constant that accounts for depth of concrete below bars	k_1 = 1.3 for horizontal anchored or lapped bars with more than 300 mm concrete below; or = 1.0 otherwise
k_7	Constant that accounts for effects of staggered laps and bar stress levels	k_7 = 1.0 if the cross-sectional area of the bars outside the laps equals at least twice the area required for strength, and no more than half the bars are lapped at any section; or = 1.25 otherwise.

Design Tables to AS 3600–2009

- **Required concrete cover, c_{req}**

TABLE 4.10.3.2

REQUIRED COVER WHERE STANDARD FORMWORK AND COMPACTION ARE USED

Exposure classification	Required cover, mm				
	Characteristic strength (f'_c)				
	20 MPa	25 MPa	32 MPa	40 MPa	≥ 50 MPa
A1	20	20	20	20	20
A2	(50)	30	25	20	20
B1	—	(60)	40	30	25
B2	—	—	(65)	45	35
C1	—	—	—	(70)	50
C2	—	—	—		65

NOTE: Bracketed figures are the appropriate covers when the concession given in Clause 4.3.2, relating to the strength grade permitted for a particular exposure classification, is applied.

Design Tables to AS 3600–2009

- **Extracts from Cover-Controlled Tables**

Exposure classification (EC), strength f'_c and c_{req}	Development or lap length	Bar diameter, d_b (mm)		
		12	16	28
A1 f'_c = 20 MPa & c_{req} = 20 mm	$L_{sy.tb}$	$41.9d_b$	$46.4d_b$	$53.2d_b$
	$L_{sy.tb.lap}$	$52.4d_b$	$58.0d_b$	$66.5d_b$
	$(k_4k_5)_{min}$	0.78	0.73	0.71
A1 f'_c = 25 MPa & c_{req} = 20 mm	$L_{sy.tb}$	$37.5d_b$	$41.5d_b$	$47.6d_b$
	$L_{sy.tb.lap}$	$46.9d_b$	$51.9d_b$	$59.5d_b$
	$(k_4k_5)_{min}$	0.78	0.73	0.71
B1 f'_c = 32 MPa & c_{req} = 40 mm (f'_c = 25 MPa & c_{req} = 60 mm)	$L_{sy.tb}$	$29.0d_b$ ($29.2d_b$)	$29.5d_b$ ($30.2d_b$)	$39.8d_b$ ($39.8d_b$)
	$L_{sy.tb.lap}$	$32.2d_b$ ($36.5d_b$)	$36.9d_b$ ($37.7d_b$)	$49.7d_b$ ($49.8d_b$)
	$(k_4k_5)_{min}$	1.0 (1.0)	0.90 (1.0)	0.75 (0.85)

Design Tables to AS 3600–2009

- **Example Design Table for Structural Dwgs**

		N12 main bars	N16 main bars	N28 main bars
Slabs:	$L_{sy.t}$(mm)	450	660	-
	$L_{sy.t.lap}$(mm)	560	830	-
Beams and	$L_{sy.t}$(mm)	-	480	950
columns:	$L_{sy.t.lap}$(mm)	-	600	1190

Notes: (a) Expos. Class. A1 (interior), f'_c = 25 MPa;

(b) min. concrete cover, c_{min} = 20 mm for N12 & N16 bars; = 30 mm for N28;

(c) min. centre-to-centre bar spacing = $2c_{min} + 2d_b$ assuming no staggering; and

(d) multiply the above by 1.3 for horizontal bars with 300$^+$ mm of concrete below.

Design Tables to AS 3600–2009

...ural Dwgs

Exposure classification (EC), strength f'_c and c_{min}	Development or lap length	Bar diameter, d_b (mm) 12	16	28
A1	$L_{sy.t}$	$37.5d_b$	$41.5d_b$	$47.6d_b$
f'_c = 25 MPa & c_{min} = 20 mm	$L_{sy.t.lap}$	$46.9d_b$	$51.9d_b$	$59.5d_b$
	$(k_4k_5)_{min}$	0.78	0.73	0.71
B1	$L_{sy.t}$	$29.0d_b$ ($29.2d_b$)	$29.5d_b$ ($30.2d_b$)	$39.8d_b$ ($39.8d_b$)
f'_c = 32 MPa & c_{min} = 40 mm	$L_{sy.t.lap}$	$32.2d_b$ ($36.5d_b$)	$36.9d_b$ ($37.7d_b$)	$49.7d_b$ ($49.8d_b$)
(f'_c = 25 MPa & c_{min} = 60 mm)	$(k_4k_5)_{min}$	1.0 (1.0)	0.90 (1.0)	0.75 (0.85)

				N28 main bars
				-
Beams and columns:	$L_{sy.t}$ (mm)	-	480	950
	$L_{sy.t.lap}$ (mm)	-	600	1190

Notes: (a) Expos. Class. A1 (interior), f'_c = 25 MPa;

(b) min. concrete cover, c_{min} = 20 mm for N12 & N16 bars; = 30 mm for N28;

(c) min. centre-to-centre bar spacing = $2c_{min} + 2d_b$ assuming no staggering; and

(d) multiply the above by 1.3 for horizontal bars with 300+ mm of concrete below.

Conclusions

- **Design to AS 3600–2001**
- **SRIA Industry Survey of Engineering Drawings**
- **Design to AS 3600–2009:** ***Tensile Development Lengths***
- **Design to AS 3600–2009:** ***Tensile Lap Lengths***
- **SRIA Design Tables to AS 3600–2009**

New Design Tables for Development and Lap Splice Lengths in accordance with AS 3600–2009

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