New Design Rules and Tables for Development and Lap Splice Lengths to AS 3600–2009

Scott Munter – Steel Reinforcement Institute of Australia

Mark Patrick – MP Engineers

12 – 14 October 2011, Perth, WA.

CONCRETE 2011

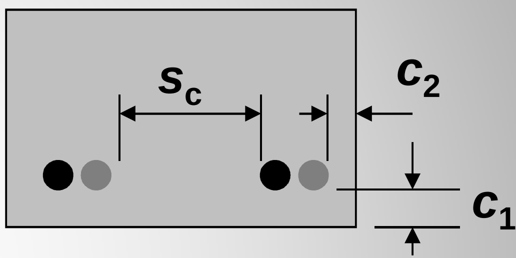
BUILDING A SUSTAINABLE FUTURE

Overview

- **Design to AS 3600–2001: *Tensile Development or Lap Length***
- **SRIA Industry Survey of Engineering Drawings**
- **Design to AS 3600–2009: *Tensile Development Lengths (Basic or Refined)***
- **Design to AS 3600–2009: *Tensile Lap Lengths (Basic or Refined)***
- **SRIA Design Tables to AS 3600–2009**

Design to AS 3600–2001: *Tensile Development or Lap Length*

$$L_{\mathrm{sy.t}} = \frac{k_1 k_2 f_{\mathrm{sy}} A_{\mathrm{b}}}{\left(2a + d_{\mathrm{b}}\right)\sqrt{f'_{\mathrm{c}}}} \geq 25 k_1 d_{\mathrm{b}}$$



2*a* = 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: *Tensile Development or Lap Length*

Recommended improvements:

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

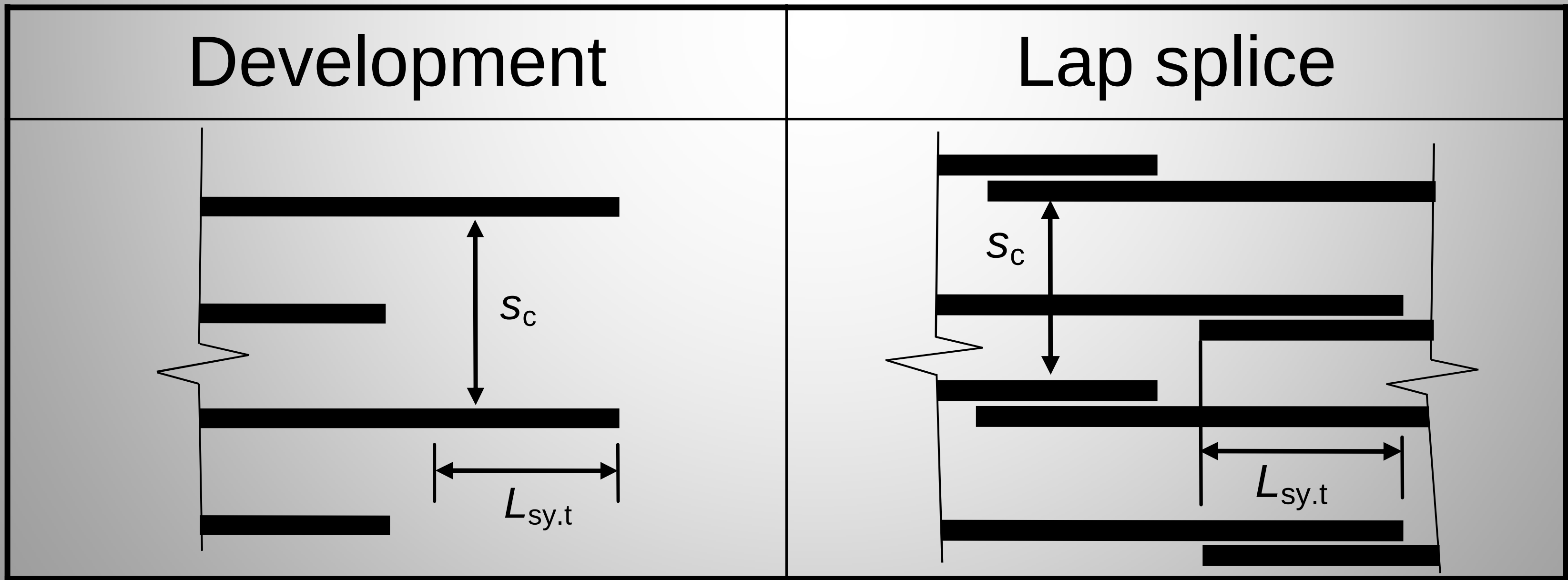
$$L_{sy.t} = \frac{k_1 k_2 f_{sy} A_b}{(2a + d_b)\sqrt{f'_c}} \geq \mathbf{29} k_1 d_b$$

- **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**

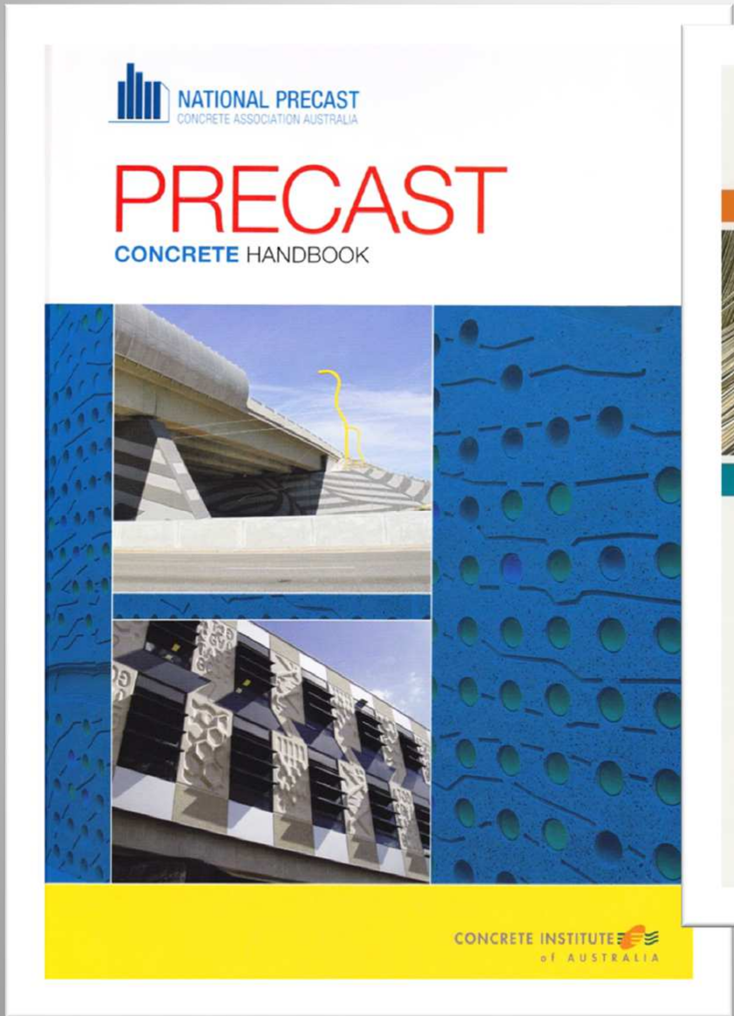
Design to AS 3600–2001: *Tensile Development or Lap Length*

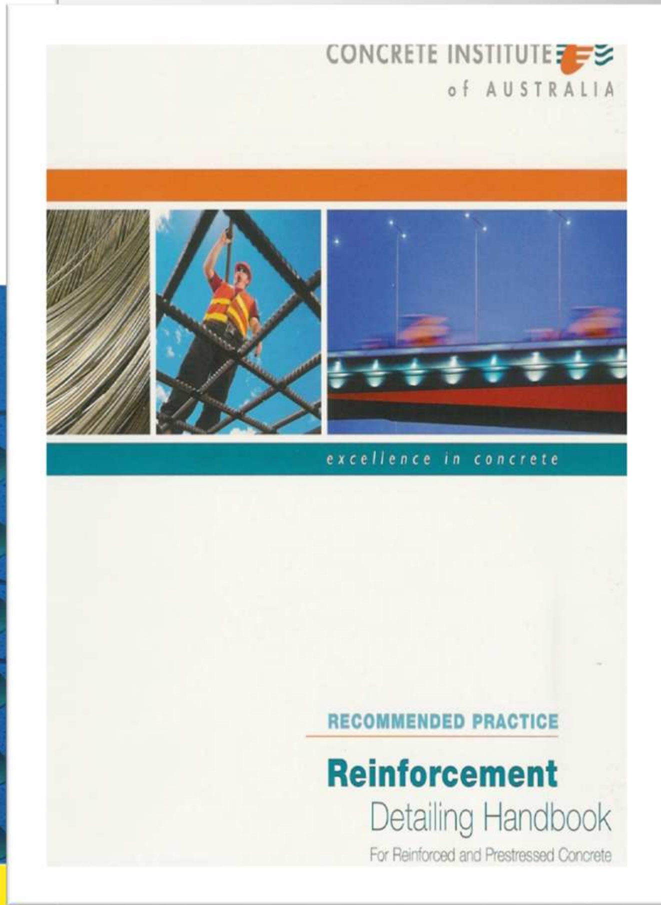
Definition of clear distance, s_c, between bars developing stress:

Figures unfortunately absent from Standard or Commentary:



Design to AS 3600–2001: *Tensile Development or Lap Length*



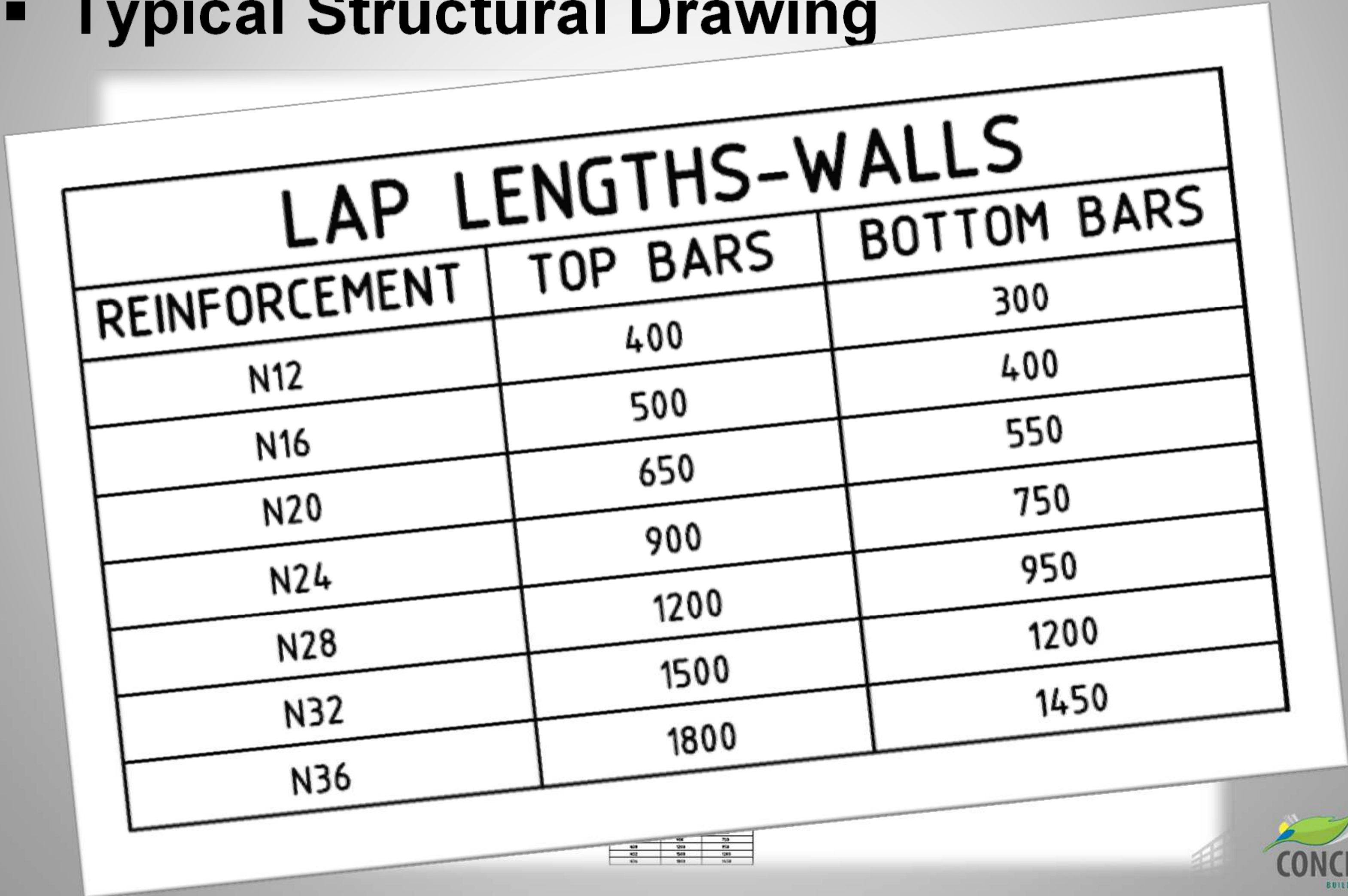


Design to AS 3600–200

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

SRIA Industry Survey of Engineering Drawings

- **Typical Structural Drawing**



LAP LENGTHS-WALLS

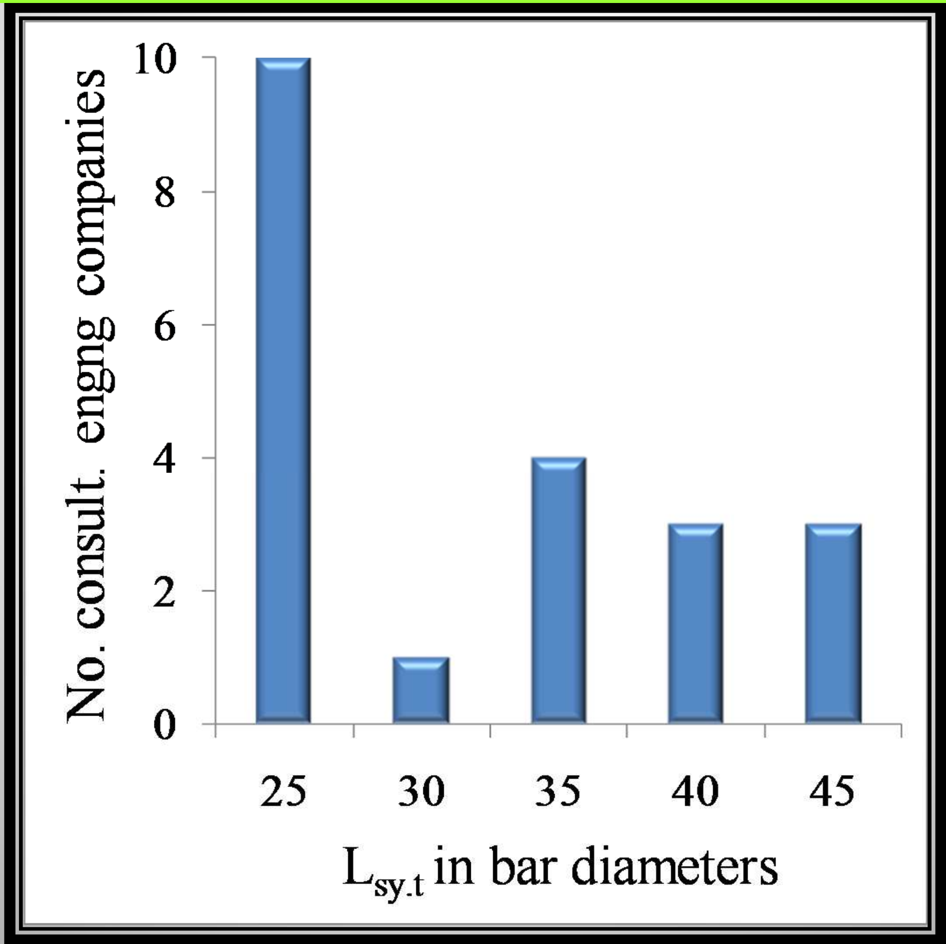
REINFORCEMENT	TOP BARS	BOTTOM BARS
N12	400	300
N16	500	400
N20	650	550
N24	900	750
N28	1200	950
N32	1500	1200
N36	1800	1450

SRIA Industry Survey of Engineering Drawings

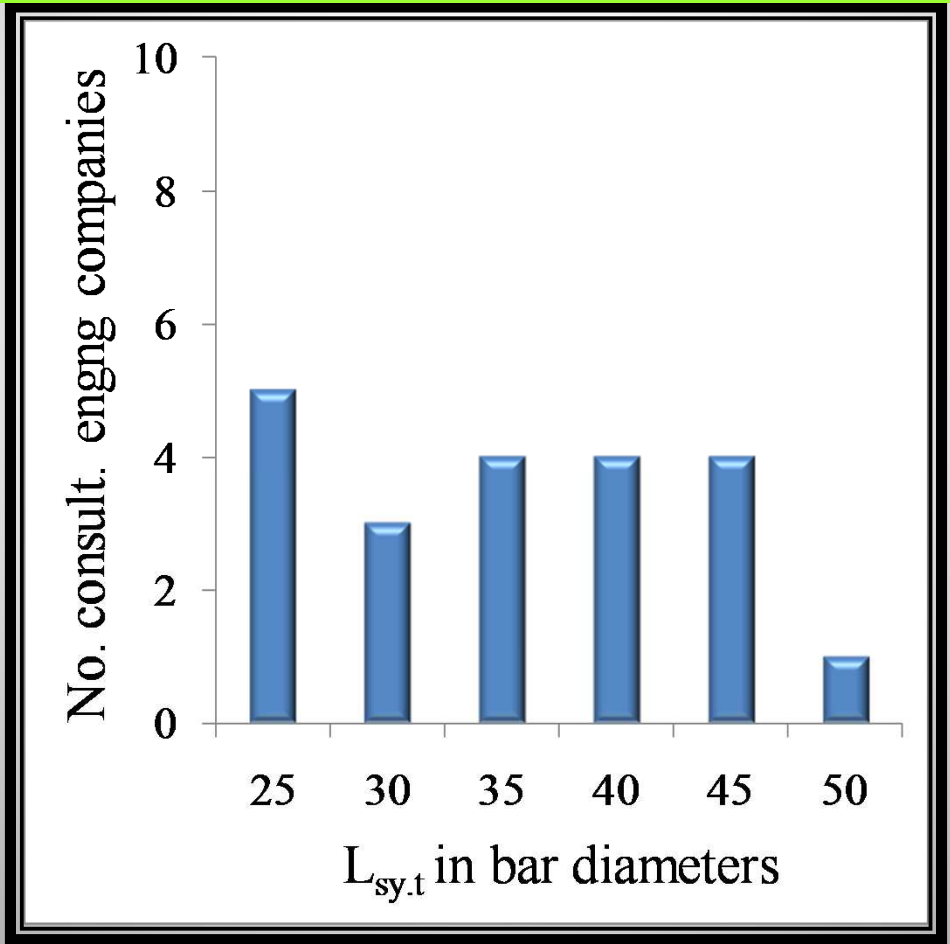
- **Sample of tensile development or lap lengths, $L_{sy.t}$, to AS 3600–2001, assuming:**
  - **clear distance, $a \geq 2\times$cover & at least 150 mm for slabs;**
  - **cover equals minimum required for durability;**
  - **cover not less than bar diameter, d_b, rounded up to nearest multiple of 5 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	$29.0d_b$	$29.0d_b$	$39.6d_b$

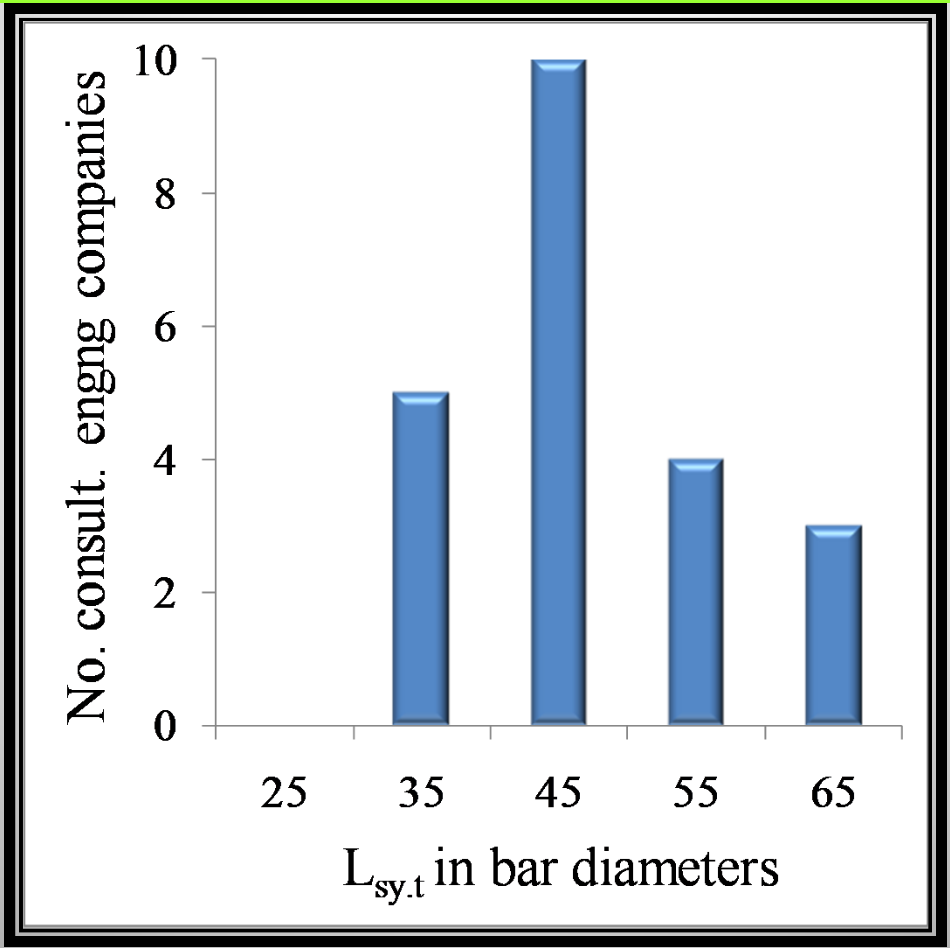
Exposure classification (EC) & strength grade f'_c	Element type	Bar diameter, d_b (mm) 12
A1 & $f'_c = 25$ MPa	Slab	**30.8d_b**
	Beam/Column	**39.9d_b**
A1 & $f'_c \geq 32$ MPa	Slab	**29.0d_b**
	Beam/Column	**35.2d_b**
B1 & $f'_c \geq 32$ MPa	Slab	**29.0d_b**
	Beam/Column	**29.0d_b**



Exposure classification (EC) & strength grade f'_c	Element type	Bar diameter, d_b (mm) 16
A1 & f'_c = 25 MPa	Slab	**38.1d_b**
	Beam/Column	**49.4d_b**
A1 & $f'_c \geq$ 32 MPa	Slab	**33.7d_b**
	Beam/Column	**43.6d_b**
B1 & $f'_c \geq$ 32 MPa	Slab	**29.0d_b**
	Beam/Column	**29.0d_b**



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**

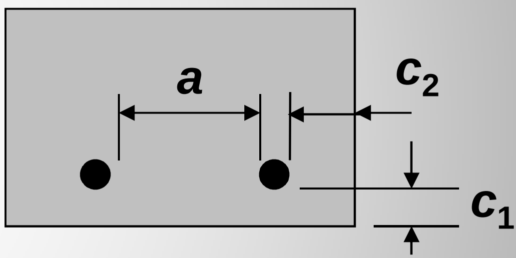


Design to AS 3600–2009: *Tensile Development Lengths*

Basic Tensile Development Length:

$$L_{\text{sy.tb}} = \frac{50k_1\left[\left(1.0 - 0.15(c_{\text{d}} - d_{\text{b}}\right)/d_{\text{b}}\right]f_{\text{sy}}d_{\text{b}}}{(132 - d_{\text{b}})\sqrt{f'_{\text{c}}}} \geq 29k_1d_{\text{b}}$$

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



Refined Tensile Development Length:

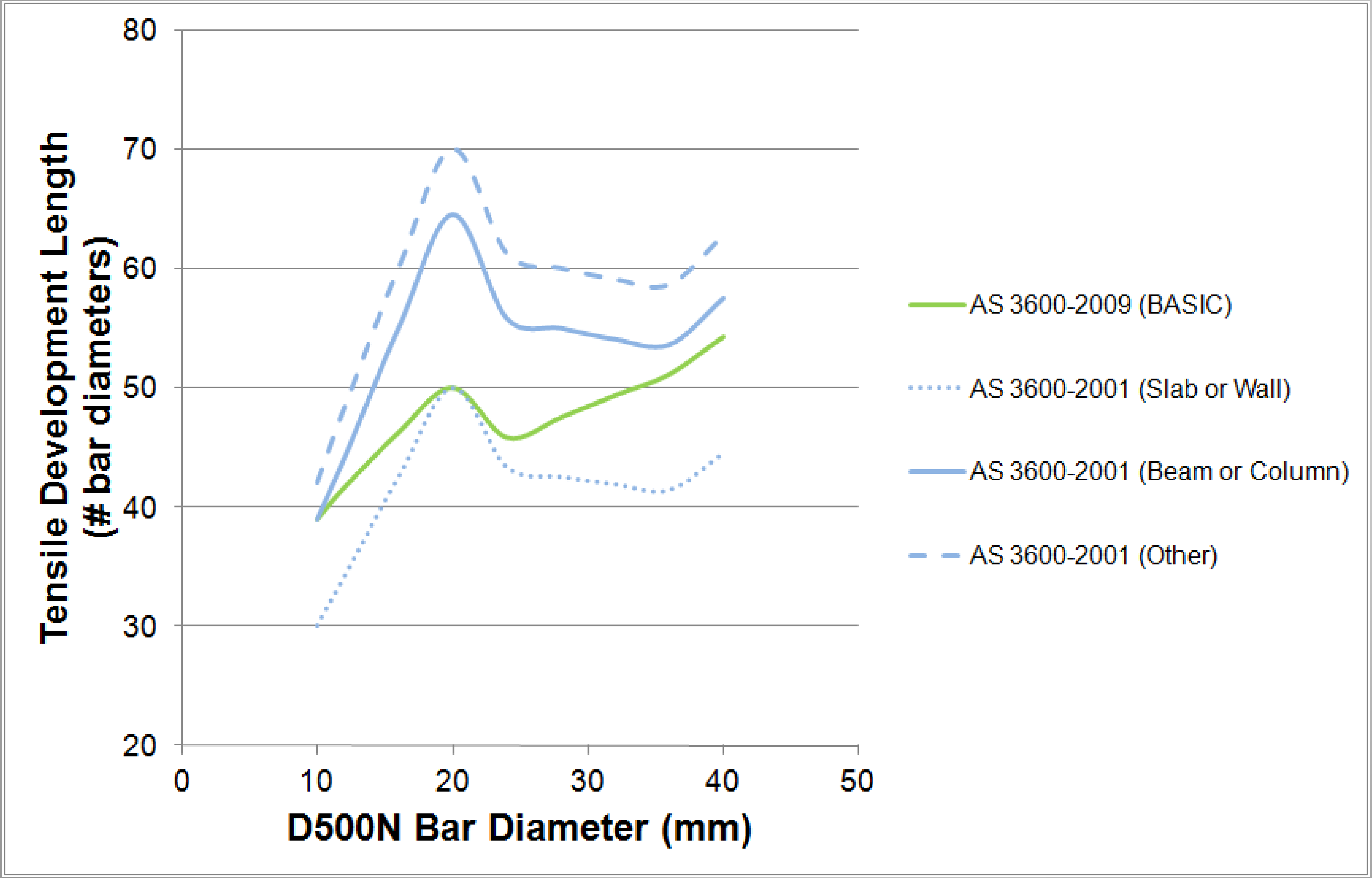
$$L_{\text{sy.t}} = [1.0 - K(\sum A_{\text{tr}} - \sum A_{\text{tr.min}})/A_{\text{s}}]\,[1.0 - 0.04\rho_{\text{p}}]L_{\text{sy.tb}} \geq (0.7/k_3)L_{\text{sy.tb}}$$

Transverse reinforcement term, k_4

Transverse pressure term, k_5

Design to AS 3600–2009: *Tensile Development Lengths*

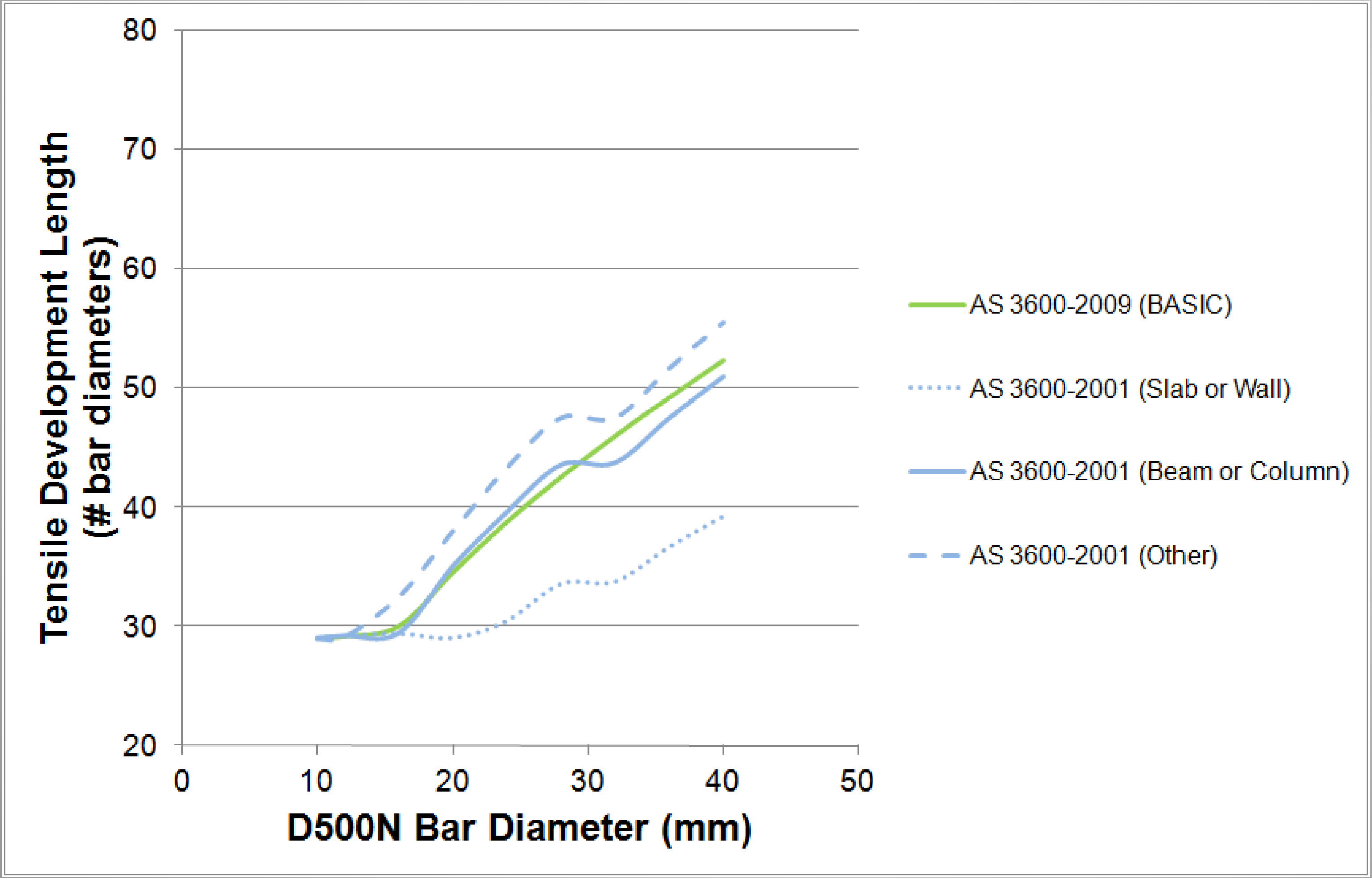
- **AS 3600–2001 vs AS 3600–2009: EC=A1 (f'_c=20,25 MPa)**



New Design Rules and Tables to AS 3600–2009

Design to AS 3600–2009: *Tensile Development Lengths*

- **AS 3600–2001 vs AS 3600–2009: EC=B1 ($f'_c \geq 25$ MPa)**



Design to AS 3600–2009: *Tensile Development Lengths*

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

$$k_3 = 1.0 - 0.15(c_\mathrm{d} - d_\mathrm{b}) / d_\mathrm{b}$$

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

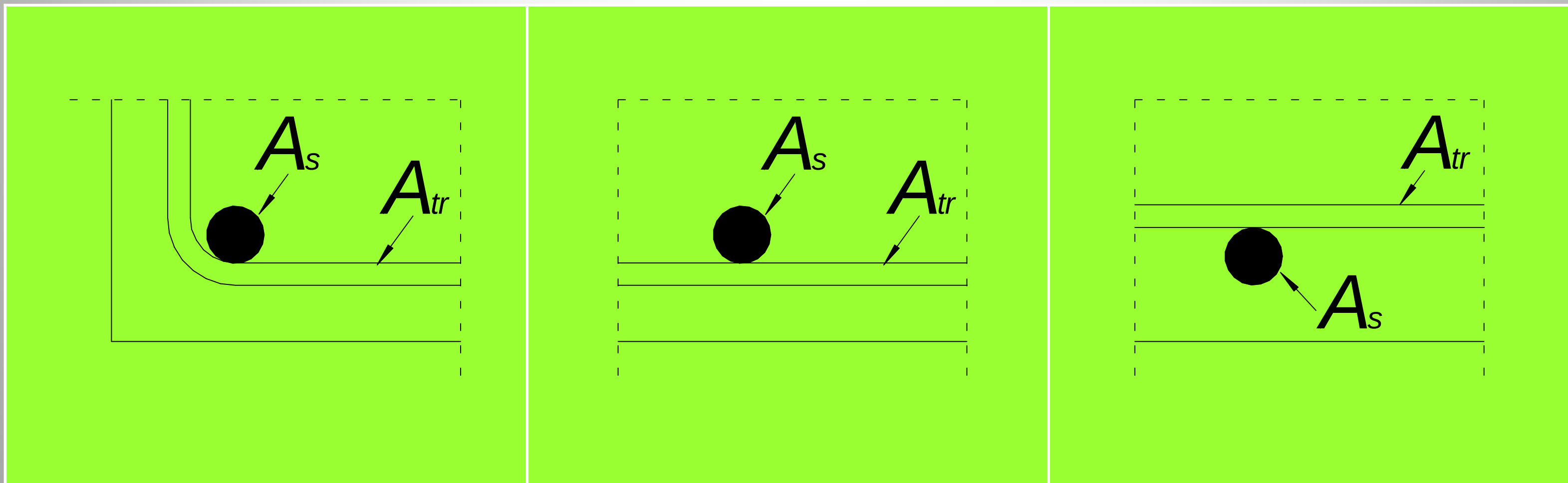
$$k_5 = 1.0 - 0.04\rho_\mathrm{p}$$

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

Design to AS 3600–2009: *Tensile Development Lengths*

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

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



K=0.1 (max.)	K=0.05	K=0

Design to AS 3600–2009: *Tensile Development Lengths*

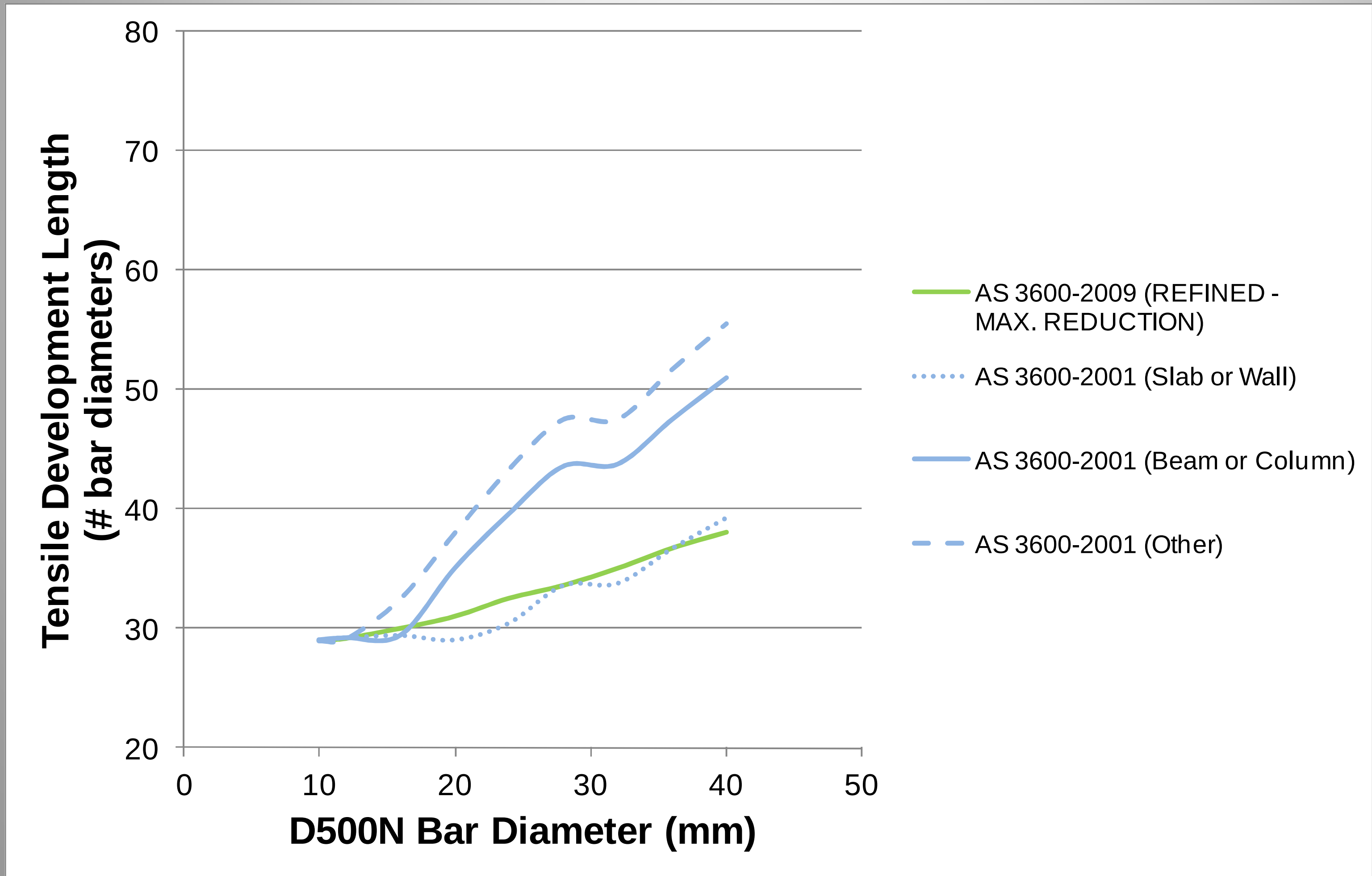
- **Maximum reduction to be gained from Refined Design:**

	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

New Design Rules and Tables to AS 3600–2009

Design to AS 3600–2009: *Tensile Development Lengths*

- **AS 3600–2001 vs AS 3600–2009: EC=B1 ($f'_c \geq 25$ MPa)**



Design to AS 3600–2009: *Tensile Development Lengths*

- **Recommended amendment for transverse steel:**

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

$$Weighted - average:$$

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

n_f = no. of fitment bars that potential splitting crack crosses

n_{bs} = no. of longitudinal bars being anchored or spliced

BY THIS APPROACH, ALL BARS AT AN ANCHORAGE LOCATION HAVE THE SAME DEVELOPMENT LENGTH

New Design Rules and Tables to AS 3600–2009

Design to AS 3600–2009: *Tensile Development Lengths*

- **Recommended amendment for transverse steel:**

TABLE 13.1.2.3

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

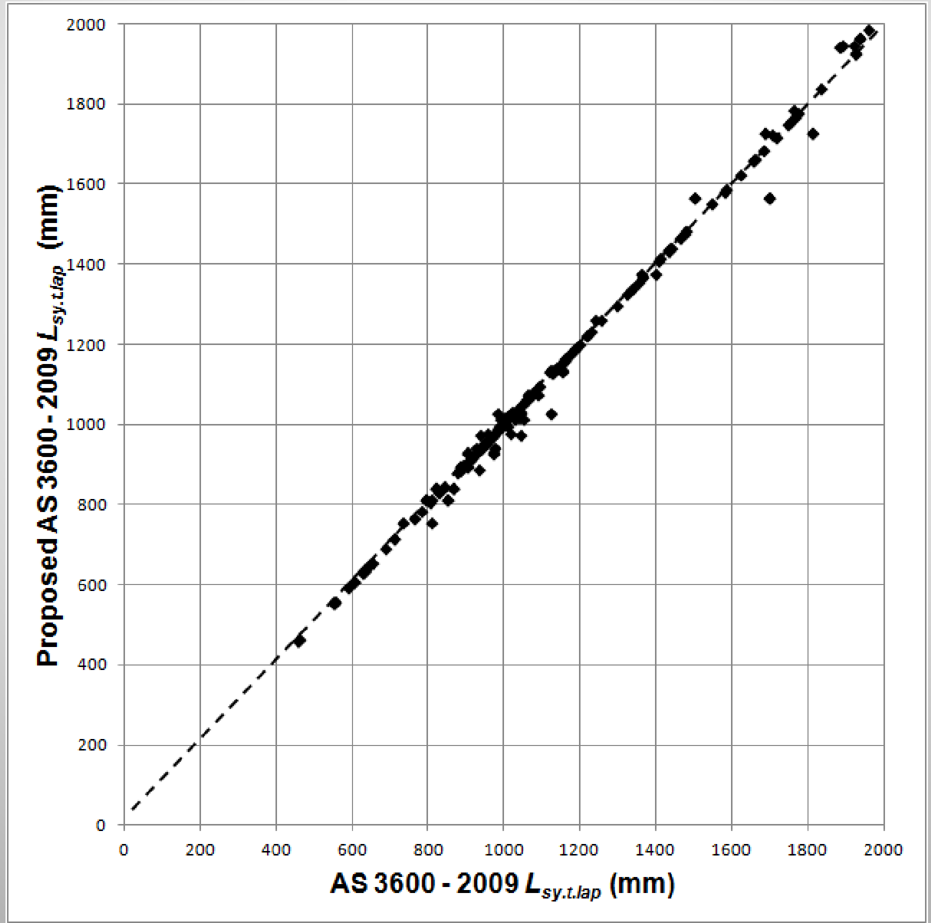
Member type	Examples of potential splitting cracks at a tensile face	n_f	n_{bs}	K (see Note 2)
Circular column	$A_{tr} = A_{b.fit}$	1	1	0.10
Rectangular column	$n_f = 2$, $n_{bs} = 2$ $\Rightarrow K=0.10$; $n_f = 2$, $n_{bs} = 3$ $\Rightarrow K=0.083$; $A_{tr} = A_{b.fit}$	≥1	≥1	$0.05 \le K \le 0.10$
Beam	$A_{tr} = A_{b.fit}$; $n_f = 2$, $n_{bs} = 4$ $\Rightarrow K=0.075$	≥1	≥1	$0.05 \le K \le 0.10$
Slab or wall (with fitments)	$A_{tr} = A_{b.fit}$; $n_f = n_{bs}$ $\Rightarrow K=0.10$	≥1	≥1	$0.05 \le K \le 0.10$
Slab or wall (without fitments)	A_{tr}	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.

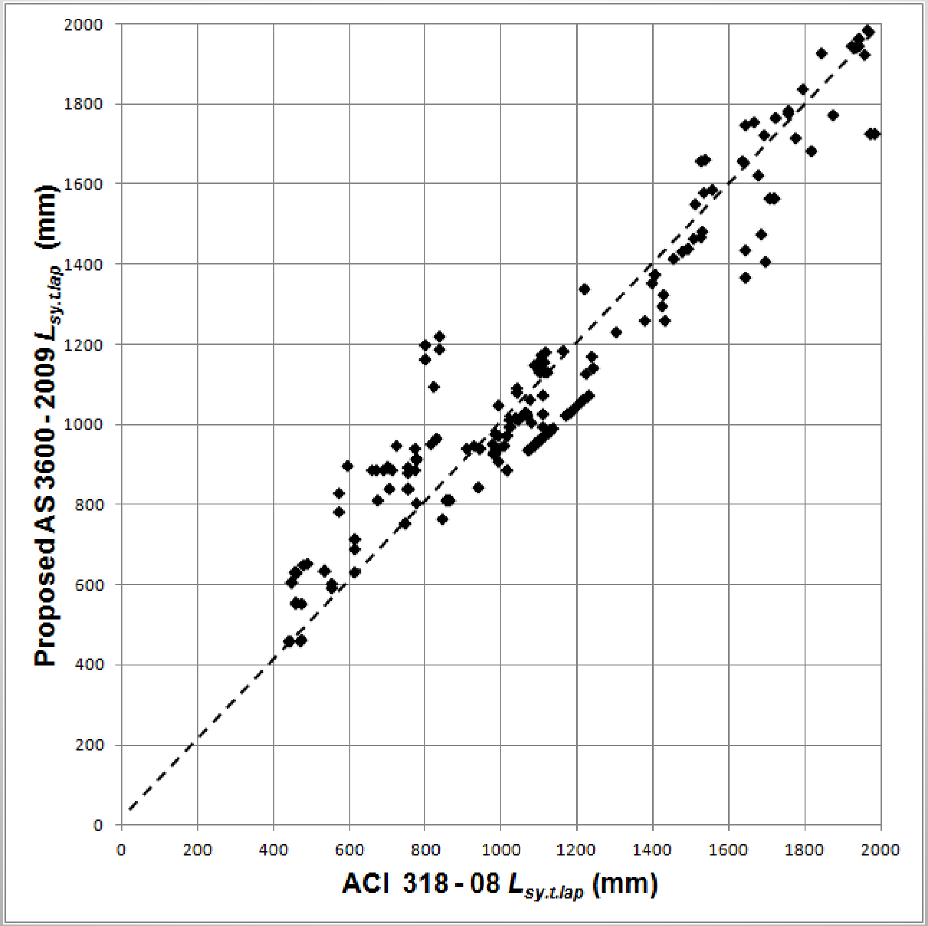
Design to AS 3600–2009: *Tensile Development Lengths*

- **Recommended amendment for transverse steel: ACI 408 database and max. *K*=0.1**



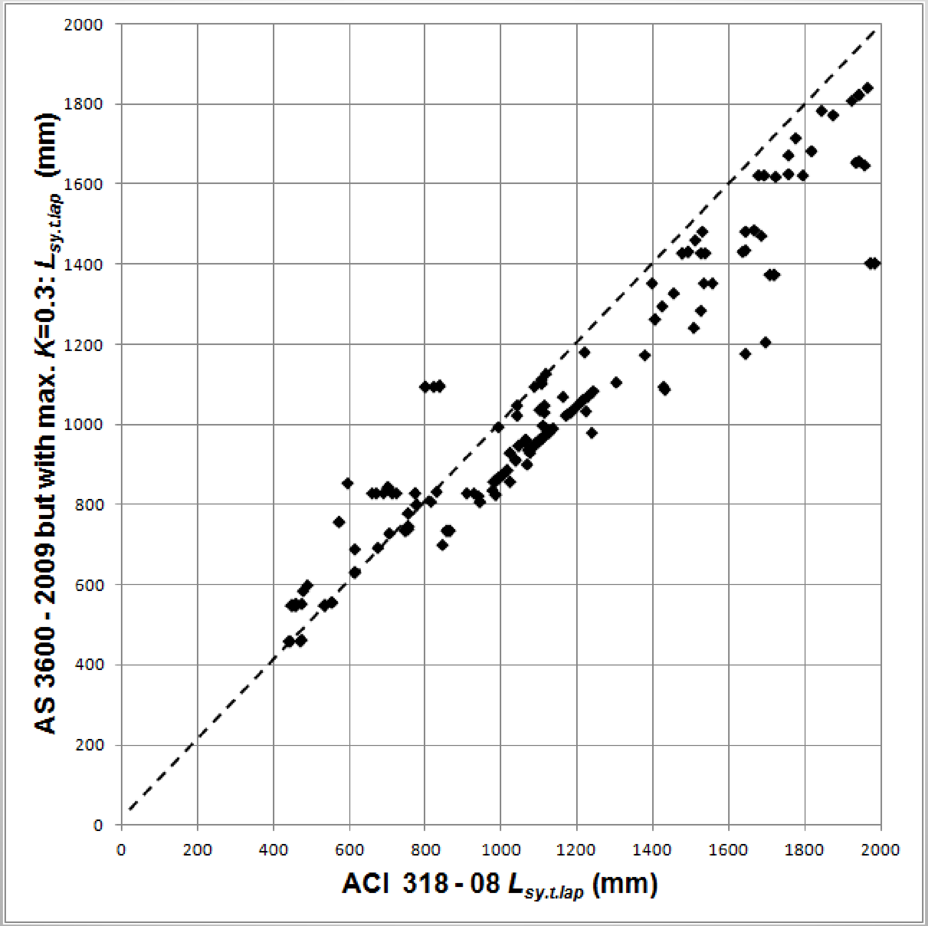
Design to AS 3600–2009: *Tensile Development Lengths*

- **Recommended amendment for transverse steel: ACI 408 database and max. *K*=0.1**



Design to AS 3600–2009: *Tensile Development Lengths*

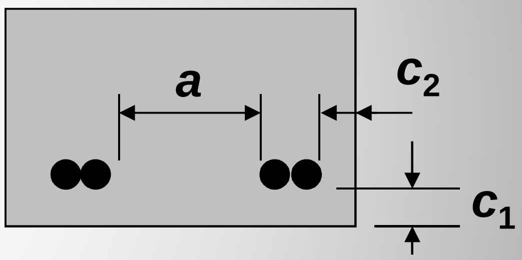
- **Recommended amendment for transverse steel: ACI 408 database but with max. *K*=0.3 (too high!)**



Design to AS 3600–2009: *Tensile Lap Lengths*

Basic Tensile Lap Length:

$$L_{\text{sy.tb.lap}} = k_7 \frac{50k_1\left[(1.0-0.15(c_\text{d}-d_\text{b})/d_\text{b}\right]f_{\text{sy}}d_\text{b}}{(132-d_\text{b})\sqrt{f'_\text{c}}} \geq 29k_1 d_\text{b}$$



c_d = min. (c_1, c_2, $a/2$)
and $d_\text{b} \leq c_\text{d} \leq 3d_\text{b}$

Refined Tensile Lap Length:

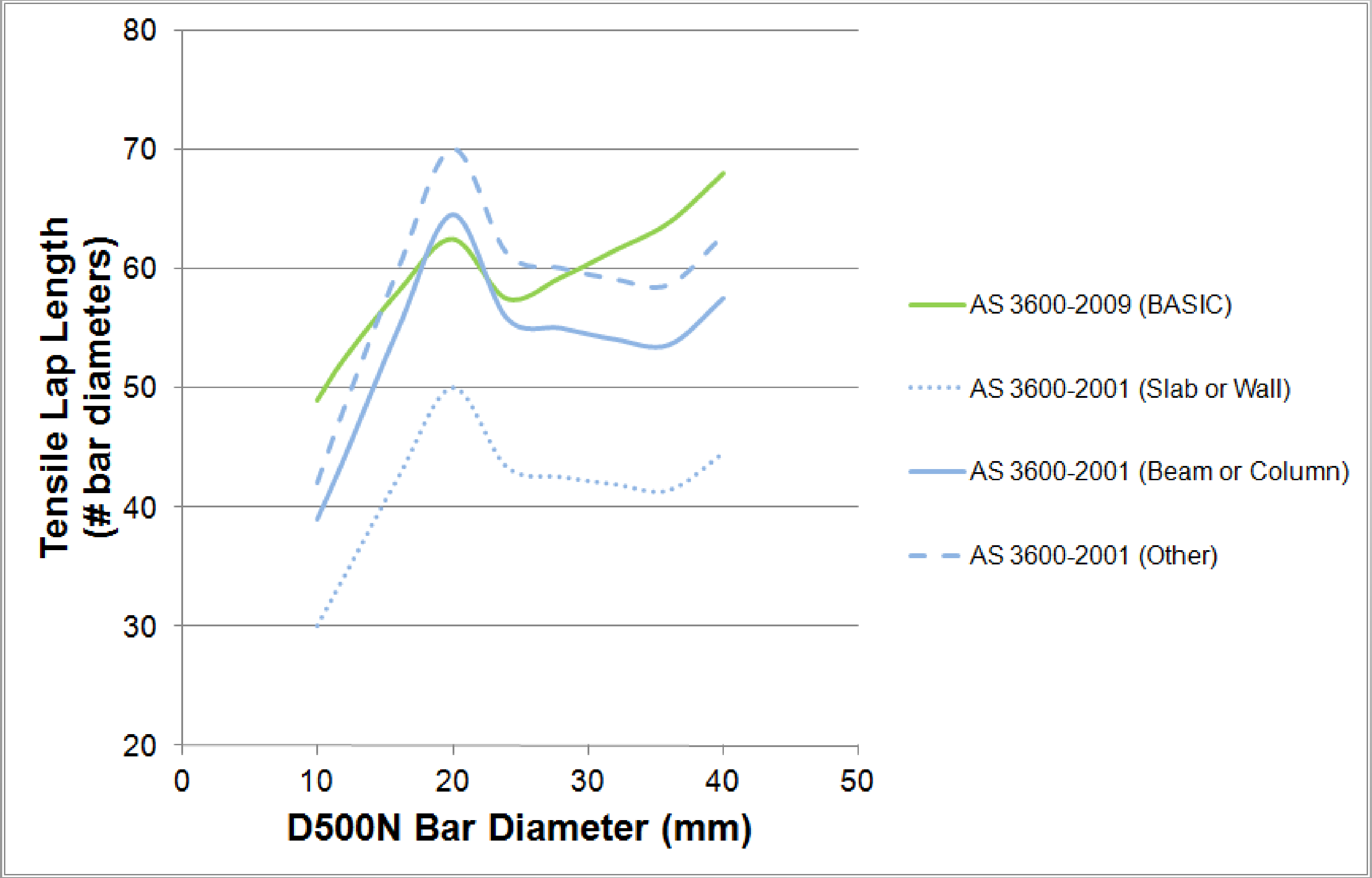
$$L_{\text{sy.t.lap}} = [1.0 - K(\sum A_{\text{tr}} - \sum A_{\text{tr.min}})/A_\text{s}]\,[1.0-0.04\rho_\text{p}]L_{\text{sy.tb.lap}} \geq \max.[(0.7/k_3)L_{\text{sy.tb.lap}}, 29k_1 d_\text{b}]$$

Transverse reinforcement term, k_4

Transverse pressure term, k_5

Design to AS 3600–2009: *Tensile Lap Lengths*

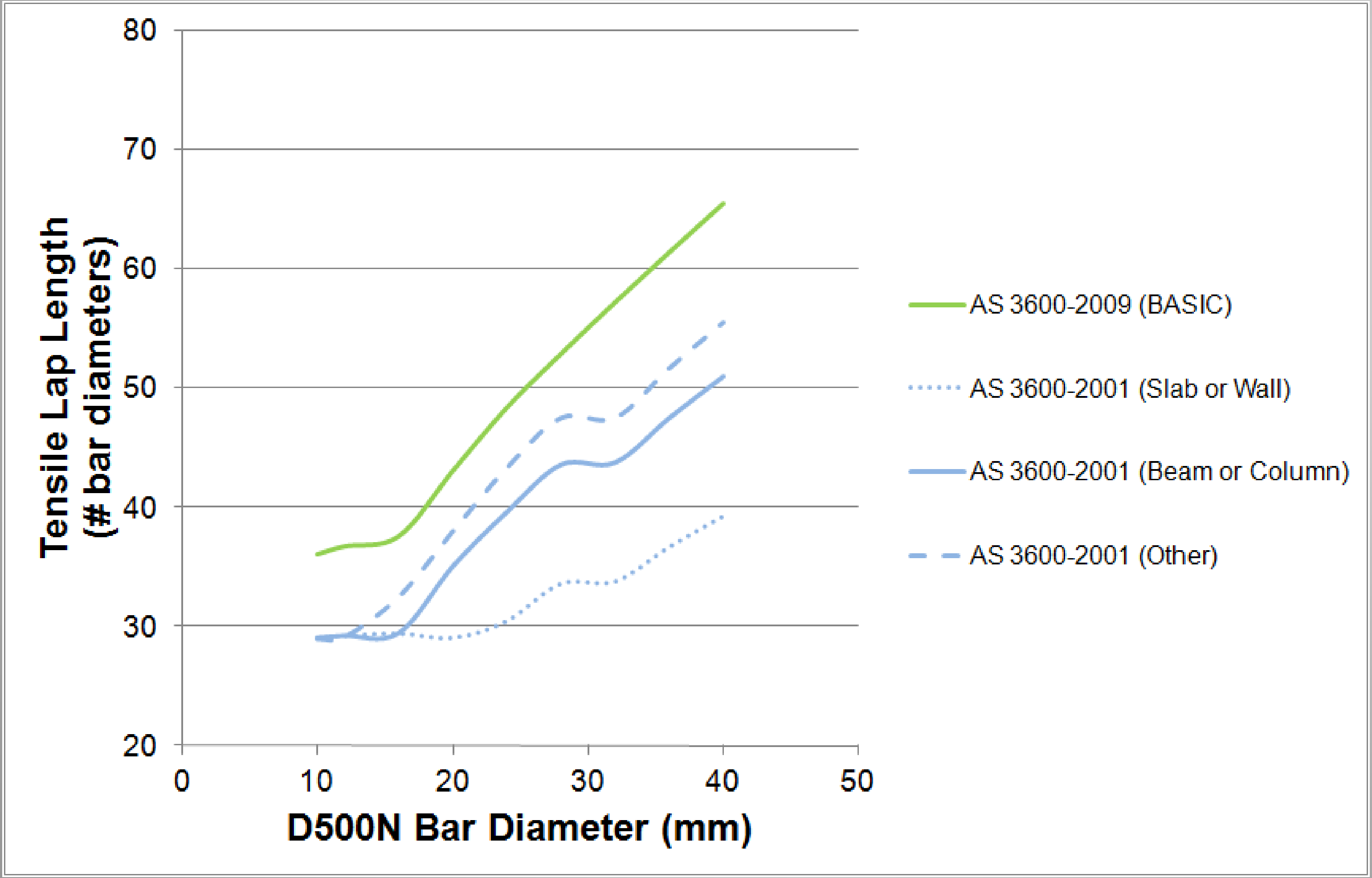
- **AS 3600–2001 vs AS 3600–2009: EC=A1 (f'_c=20,25 MPa)**



New Design Rules and Tables to AS 3600–2009

Design to AS 3600–2009: *Tensile Lap Lengths*

- **AS 3600–2001 vs AS 3600–2009: EC=B1 ($f'_c \geq$25 MPa)**



SRIA Design Tables to AS 3600–2009

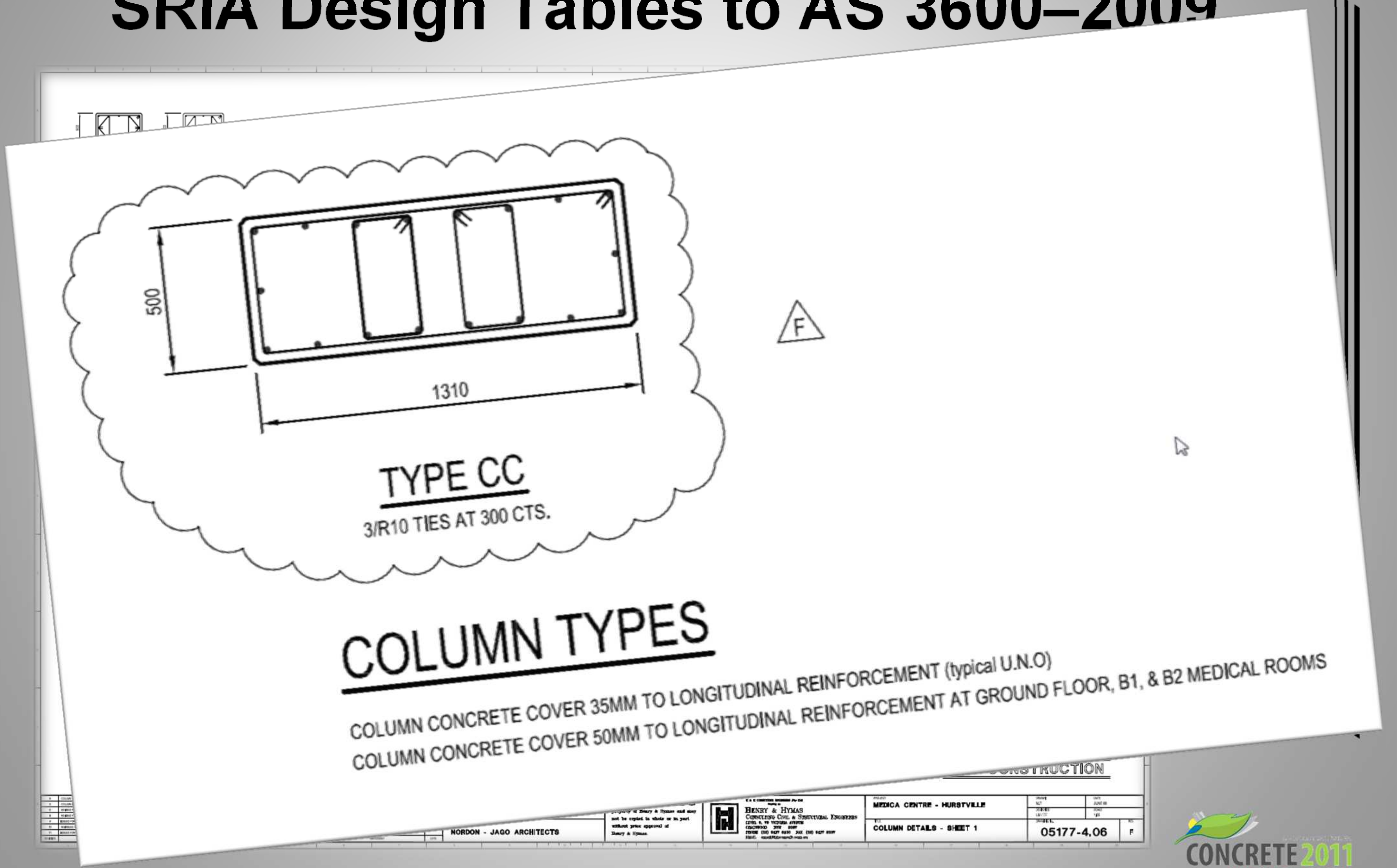
- **General Tables**
  - c_d is calculated directly by the designer
  - similar to existing tables
- **New Bar-Cover-Controlled Tables**
  - c_d is controlled by concrete cover to bars
- **New Bar-Spacing-Controlled Tables**
  - c_d is controlled by clear distance between bars
- **Commentary and Worked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

SRIA Design Tables to AS 3600–2009

- **Design Variables for Bar-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.

SRIA Design Tables to AS 3600–2009



CONCRETE 2011
BUILDING A SUSTAINABLE FUTURE

SRIA 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.

SRIA Design Tables to AS 3600–2009

- **Extracts from *Bar-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)

f_c'

SRIA Design Tables to AS 3600–2009

- **Example Design Table for Structural Dwgs**

(Worked example in paper:
building foundation EC=B1 and f'_c=32 MPa)

		N12 main bars	N16 main bars	N28 main bars
Slabs:	$L_{sy.t}$ (mm) $L_{sy.t.lap}$ (mm)	350 390	470 590	1120 1390
Bored Piles:	$L_{sy.t}$ (mm) $L_{sy.t.lap}$ (mm)	- -	- -	840 1050

Notes: (a) Exposure Classification B1 (exterior), f_c' = 32 MPa;
(b) min. concrete cover to main bars, c_{min} = 40 mm;
(c) min. centre-to-centre spacing of main bars = $2c_{min} + 2d_b$ assuming no staggering;
(d) N16 with max. 125 mm pitch or equivalent spiral in bored piles; and
(e) multiply slab values by 1.3 for top bars with 300^+ mm of concrete below.

Conclusions

- **Design to AS 3600–2001: *Tensile Development or Lap Length***
- **SRIA Industry Survey of Engineering Drawings**
- **Design to AS 3600–2009: *Tensile Development Lengths (Basic or Refined)***
- **Design to AS 3600–2009: *Tensile Lap Lengths (Basic or Refined)***
- **SRIA Design Tables to AS 3600–2009**


New Design Rules and Tables for Development and Lap Splice Lengths to AS 3600–2009
Scott Munter – Steel Reinforcement Institute of Australia
Mark Patrick – MP Engineers
12 – 14 October 2011, Perth, WA.
CONCRETE 2011
BUILDING A SUSTAINABLE FUTURE