# NEW DESIGN TABLES FOR DEVELOPMENT AND LAP SPLICE LENGTHS IN ACCORDANCE WITH AS 3600–2009

**S. Munter**
Steel Reinforcement Institute of Australia (SRIA)
Sydney, New South Wales, Australia
scott.munter@sria.com.au

**R.I. Gilbert**
Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, Australia
i.gilbert@unsw.edu.au

**M. Patrick**
MP Engineers Pty Limited
Melbourne, Victoria, Australia
mp-engs@bigpond.net.au

## ABSTRACT

Design rules for stress development by end anchorage or lap splicing are important when detailing deformed steel reinforcing bars in concrete structures. They determine the amount of additional steel required to develop the required stress in the tensile or compressive bars at a critical cross-section, and thus can significantly affect detailing and economy. A recent survey of the minimum development and lap splice lengths for straight D500N bars specified by consulting engineering companies showed relatively large variations in values for the same types of members, when determined using the development length formula in AS 3600-2001. In the interpretation of the requirements of AS3600-2001, development length and lap length have often been assumed to be equal, despite the fact that the calculated value of both can depend on the clear distance between planar parallel bars developing stress and this may not be the same in each situation. With the advent of AS 3600-2009, new formulae are provided for computing basic and refined development and lap lengths, which incorporate design variables and factors that account directly for transverse pressure and/or reinforcement, and whether or not lapped bars are in contact with each other, staggered, or under high or low tensile stress. Comprehensive sets of general, bar-cover-controlled and bar-spacing-controlled design tables have been developed in accordance with AS 3600-2009, and their application to general design problems is explained. A unified approach for preparing project-specific design tables for structural drawings is also described.

## DESIGN TO AS 3600–2001 AND RESULTS OF AN INDUSTRY SURVEY

The formula in AS3600–2001 for calculating tensile development length, $L_{sy.t}$, was first introduced into the Standard in 1988 (AS3600–1988) and for reinforcing bars with characteristic yield stress $f_{sy}$ = 500 MPa was supposed to be given in Clause 13.1.2.1 as follows:

$$L_{sy.t} = \frac{k_1 k_2 f_{sy} A_b}{(2a + d_b)\sqrt{f'_c}} \geq 29 k_1 d_b \quad \text{.................................} \quad (1)$$

At the time Eq. 1 was developed, the characteristic yield stress, $f_{sy}$, of the available deformed bars (Y bars) was only 400 MPa. Patrick et al. (2008) have explained that for straight, deformed bars, the lower bound in Eq. 1 for D500N bars with characteristic yield stress, $f_{sy}$, equal to 500 MPa, should be $29k_1d_b$ instead of the originally specified value of $25k_1d_b$ for 400Y bars.

The factor $k_1$ accounts for the position of the bar, with $k_1$ = 1.25 when more than 300mm of concrete is cast below the bar (otherwise $k_1$ = 1.0); $k_2$ depends on the type of member, with $k_2$ =1.7 for slabs or walls with widely spaced bars (i.e. when the clear distance between the bars $s_c \geq$ 150 mm), $k_2$ = 2.2 for beams or columns with fitments, and $k_2$ = 2.4 for other cases; $A_b$ is the cross-sectional area of the bar being anchored; $d_b$ is the bar diameter; $f'_c$ is the characteristic concrete compressive strength; and $2a$ is the twice the clear cover to the bar, $c$, or the clear distance between adjacent parallel bars developing stress, $s_c$, whichever is less.

Patrick et al. (2008) also recommended that for lapped bars, the value of $2a$ used in Eq. 1 should not be less than $2d_b$, nor should it exceed $6d_b$, i.e. $3d_b \leq (2a + d_b) \leq 7d_b$.

The minimum concrete cover, $c$, required for corrosion protection of reinforcing steel depends on exposure classification and the compressive strength grade of the concrete, and for normal reinforced-concrete poured in situ using standard formwork and compaction, Table 4.10.3.2 of AS 3600–2001 applies (reproduced in part in Table 1). For proper placement and compaction of concrete, the cover should in no case be less than bar diameter, $d_b$, with standard bar sizes of 10, 12, 16, 20, 24, 28, 32, 36 and 40 mm. Cover to main bars in a beam, column, slab or wall is increased by the diameter of transverse bars (e.g. fitments) located closer to the exposed concrete surface.

Tab. 1: Required cover for standard formwork and compaction to AS3600–2001.

| Exposure classification | Required concrete cover, $c_{req}$ (mm) | | | | |
|---|---|---|---|---|---|
| | Compressive strength grade, $f'_c$ (MPa) | | | | |
| | 20 | 25 | 32 | 40 | ≥50 |
| A1 | 20 | 20 | 20 | 20 | 20 |
| B1 | - | 60 | 40 | 30 | 25 |

It follows that Eq. 1 can provide design engineers with many different design solutions; examples of which are given in pages of tables of development lengths in the Concrete Institute of Australia's Reinforcement Detailing Handbook (CIA 2007).

However, to be practical, consulting engineers have historically only included very condensed tables of development and lap lengths on their structural drawing, with typically a single value for each bar size, and perhaps different sets for slabs, walls, beams and columns. Sometimes different values are specified for top bars and bottom bars in beams. These tables have tended to be reproduced project after project, and thus become standard, while project-specific design variables such as the exposure condition, concrete strength grade, concrete cover, and bar spacing have varied.

A systematic approach to establish condensed tables requires assumptions to be made, and the more general they are, the more conservative the solutions will be. Table 2 was generated for development or lapped splice lengths using Eq. 1 with $3d_b \leq (2a + d_b) \leq 7d_b$ applying and was based on the following assumptions:

(i) clear distance between bars, $s_c$, equals at least $2c$ (so $a = c$) for beams and columns ($k_2 = 2.2$) and is at least 150 mm for slabs (i.e. $k_2 = 1.7$);

(ii) cover, $c$, equals $c_{req}$ given in Table 1 corresponding to the exposure condition and $f'_c$ (ignoring transverse bars), but is not less than $d_b$ (rounded to the nearest multiple of 5mm above $d_b$);

(iii) not more than 300mm of concrete below the horizontal bars (i.e. $k_1 = 1.0$); and

(iv) lap splices may be contact or non-contact.

Tab. 2: Sample of tensile development or lap lengths, $L_{sy.t}$, to AS 3600–2001*.

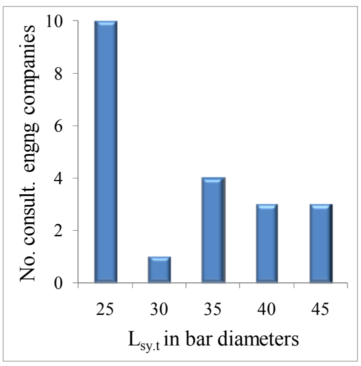
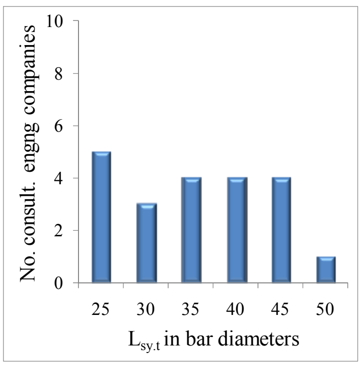
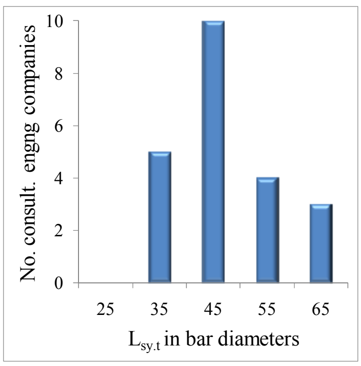
| Exposure classification (EC) & strength grade $f'_c$ | Element type | Bar diameter, $d_b$ (mm) | | |
|---|---|---|---|---|
| | | 12 | 16 | 28 |
| A1 & $f'_c$ = 25 MPa | Slab | $30.8d_b$ | $38.1d_b$ | $42.5d_b$ |
| | Beam/Column | $39.9d_b$ | $49.4d_b$ | $55.0d_b$ |
| A1 & $f'_c \geq$ 32 MPa | Slab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

* incorporating the limits imposed on ($2a + d_b$) by Patrick et al. (2008).

A survey was made of the general notes drawing from just over 20 consulting engineering companies (SRIA 2009), with sample results applying to main bars in either slabs or beams shown in Table 3. For 12 mm diameter bars, it is clear that about half of the consultants specified the published minimum value of $25d_b$ (cf. $29d_b$ in Table 2), while the other half used values within the range of values for slabs and beams in Table 2, possibly also catering for bars in slabs with clear distance, $s_c$, less than 150 mm. For 16 mm bars only a quarter used the minimum $25d_b$, and the rest again used values within the range of Table 2. For 28 mm bars, most values effectively fall within the range of values in Table 2, noting that the maximum survey value was $L_{sy.t} = 61.0d_b$.

Clearly, wide differences in specified minimum lap lengths exist in current Australian practice and, with many engineers specifying lap lengths as low as $25d_b$, there is a need for rationalisation and a more unified and consistent approach to this aspect of design.

Tab. 3: Survey sample results of tensile development or lap lengths, $L_{sy.t}$, for slabs and beams designed to AS 3600–2001.

| $d_b$ = 12 mm | $d_b$ = 16 mm | $d_b$ = 28 mm |
|---|---|---|
|  |  |  |

## DESIGN TO AS 3600–2009: TENSILE DEVELOPMENT LENGTHS

In accordance with Clause 13.1.2.2 of AS 3600–2009 (SA 2009), for D500N bars in normal-density concrete, basic development length ($L_{sy.tb}$) is calculated using Eq. 2:

$$L_{sy.tb} = \frac{0.5 k_1 k_3 f_{sy} d_b}{k_2 \sqrt{f'_c}} \geq 29 k_1 d_b \quad (2)$$

where: $k_1$ = 1.3 when more than 300 mm of concrete is cast below the bar (otherwise $k_1$ = 1.0); $k_2$=(132–$d_b$)/100 and $k_3$={1.0 − 0.15($c_d$ − $d_b$)/$d_b$} such that $0.7 \leq k_3 \leq 1.0$, with $c_d$ being either the cover to the bar or half the clear distance to the next bar being developed ($a$/2), whichever is the smaller. The element type is not a design variable, although the rules distinguish between wide and narrow elements.

In accordance with Clause 13.1.2.3 of AS 3600–2009, a refined development length ($L_{sy.t}$) may be determined according to Eq. 3, using the basic development length ($L_{sy.tb}$) calculated from Eq. 2, where coefficients $k_4$ and $k_5$ account for the beneficial effects of transverse reinforcement and transverse pressure, respectively:

$$L_{sy.t} = k_4 k_5 L_{sy.tb} \quad (3)$$

Factor $k_4 = 1.0 - K\lambda$ (where $0.7 \leq k_4 \leq 1.0$) accounts for the presence of transverse reinforcement, and equals 1.0 when there is no transverse steel between the anchored or lapped bars and the concrete tensile face, and may reduce to a minimum value of 0.7 depending on the amount and arrangement of the transverse steel. Term $\lambda$ depends on the total cross-sectional area of transverse steel along the development or lap length ($\Sigma A_{tr}$), as well as the cross-sectional area of the bar being developed or lapped ($A_s$), and is given by $\lambda = (\Sigma A_{tr} - \Sigma A_{tr.min})/A_s$, where $\Sigma A_{tr.min}$ is the cross-sectional area of the minimum transverse steel to be taken as $A_s/4$ for members with $K$>0, and zero when $K$=0. Factor $K$ accounts for the position of an anchored or lapped main bar with respect to the transverse steel, i.e.: $K$=0.1 if the main bar is in the corner of a fitment that crosses a potential splitting crack passing through the plane of the main bars; $K$ = 0.05 if the transverse steel lies between the main bar and the concrete tensile surface and crosses a potential splitting crack through the main bar perpendicular to the concrete tensile surface; otherwise $K$=0.

The factor $k_5$ (= $1.0 - 0.04\rho_p$ within the limits $0.7 \leq k_5 \leq 1.0$) reduces the development length when transverse pressure ($\rho_p$ in MPa) exists along the development length perpendicular to the plane of splitting. As $\rho_p$ increases from zero to 7.5 MPa, the factor $k_5$ decreases linearly from 1.0 to 0.7. When $\rho_p$ exceeds 7.5 MPa, $k_5$ = 0.7.

In addition, the product of $k_3 k_4 k_5$ must not be less than 0.7. This means that depending on the degree of confinement provided by transverse reinforcement and pressure, the product of the *refining coefficients*, $k_4 k_5$, must lie within the range 0.7/$k_3$ to 1.0. For a situation where $c_d$ exceeds 3$d_b$, the factor $k_3$ = 0.7 and there is no benefit to be gained from Eq. 3; $k_4 k_5$ must be taken equal to 1.0; and $L_{sy.t} = L_{sy.tb}$. When $c_d = d_b$, the factor $k_3$ = 1.0 and Eq. 3 has the potential to reduce the development length by up to 30%.

## DESIGN TO AS 3600–2009: TENSILE LAP LENGTHS

In accordance with Clause 13.2.2 of AS 3600–2009, in wide members (such as slabs, walls and blade columns), lap length ($L_{sy.t.lap}$) is calculated using Eq. 4:

$$L_{sy.t.lap} = k_7 L_{sy.t} \geq 29 k_1 d_b \qquad (4)$$

where $L_{sy.t}$ is calculated from Eq. 3; and $k_7$ shall be taken as 1.25 unless the stress in the lapped bar at the ultimate limit state is less than or equal to $0.5f_{sy}$ and no more than half the reinforcement at the section is spliced, in which case $k_7$ may be taken as 1.0. For bars lapped in the same plane, clear distance, $a$, shall be determined assuming contact lapped splices, i.e. lapped bars shall be assumed to be touching each other, even if they do not.

## DESIGN TABLES TO AS 3600–2009

In order to facilitate use of the new Standard by consulting engineers, Patrick and Gilbert (2010) have prepared a technical note for the SRIA in which three different sets of design tables of tensile development lengths and tensile lap splice lengths are presented. A key objective was to present sufficient information to enable structural designers to compile accurate, condensed design tables of development and lap lengths for inclusion in their general notes.

Some of the assumptions and conditions of use that apply to the tables are that:

(i) basic development lengths (Eq. 2) and lap lengths are presented for a wide range of values of $f'_c$, $d_b$ and $c_d$ ;

(ii) the potential level of refinement available from Eq. 3 is also presented as $(k_4k_5)_{\min} = 0.7/k_3$ (noting that $k_3$ is a function of $c_d$ and $d_b$, so that a unique value of $(k_4k_5)_{\min}$ applies for each combination of $c_d$ and $d_b$;

(iii) if $(k_4k_5)_{\min} < 1.0$, a designer may choose to use Eq. 3 to reduce the development (or lap) length below the basic value depending on the confinement provided by transverse reinforcement and pressure; and

(iv) clear concrete cover, $c$, should not be less than bar diameter, $d_b$.

When $c_d$ is calculated directly by the designer, general tables are provided by Patrick & Gilbert (2010) for numerous design solutions in which $f'_c$ ranges from 20 to ≥65 MPa and $d_b$ ranges from 12 mm to 40 mm. In addition, so-called cover-controlled tables are provided for both top ($k_1$=1.3) and bottom bars ($k_1$=1.0) for the situation where cover, $c$, equals the larger of $c_{req}$ from Table 1 (depending on the concrete strength and the exposure classification) and $d_{b.5mm}$, the nominal bar diameter, $d_b$, rounded upward to the next multiple of 5 mm. For example, Table 4 contains typical information taken from these cover-controlled tables. The values $k_1$=1.0 and $k_7$=1.25 have been used.

Tab. 4: Extracts from Cover-Controlled Tables (Patrick and Gilbert, 2010).

| Exposure classification (EC), strength $f'_c$ and $c_{req}$ (Table 1) | Development or lap length | Bar diameter, $d_b$ (mm) | | |
|---|---|---|---|---|
| | | 12 | 16 | 28 |
| A1<br>$f'_c$ = 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<br>$f'_c$ = 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<br>$f'_c$ = 32 MPa & $c_{req}$ = 40 mm<br>( $f'_c$ = 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) |

The cover-controlled tables are based on the assumptions that the centre-to-centre spacing, $s_{cc}$, of adjacent parallel, equi-sized bars being anchored or spliced, measured outside the anchorage or lap region, should satisfy the following:

For $L_{sy.tb}$: $s_{cc} \geq 2c_{min}+d_b$ when all bars terminate together (no staggering); or
$s_{cc} \geq c_{min}+d_b/2$ when every second bar terminates (50% staggering).

For $L_{sy.tb.lap}$: $s_{cc} \geq 2(c_{min}+d_b)$ when all bars are lapped together (no staggering); or
$s_{cc} \geq c_{min}+d_b$ when every second bar is lapped (50% staggering).

In addition to the cover-controlled tables, Patrick and Gilbert (2010) provide spacing-controlled tables comprising solutions using Eqs 2 and 3 for which the value of $c_d$ is controlled by the clear distance between bars being anchored or lapped.

## Example Design Table to AS 3600–2009

Consider the case of an interior of a building (i.e. EC = A1 and $f'_c$ = 25 MPa) with relatively lightly reinforced slabs, and normal beams and columns with transverse fitments. An approach a designer could take is to assume that for the slabs $L_{sy.tb}$ and $L_{sy.tb.lap}$ apply, while for the beams and columns, $L_{sy.t}$ and $L_{sy.t.lap}$ could be determined using Eq. 3 with the appropriate value of $k_4k_5$ at the least confined development or splice location and confirming that $k_3k_4k_5 \geq 0.7$ at this location. For example, if the value of $k_4k_5$ for the beams and columns in the structure in question equals the appropriate value of $(k_4k_5)_{min}$ given in Table 4, a design table that might be included on the structural drawings for the project is given in Table 5.

Tab. 5: Example design table for inclusion on a general notes structural drawing.

| | | N12 main bars | N16 main bars | N28 main bars |
|---|---|---|---|---|
| Slabs: | $L_{sy.t}$ (mm)<br>$L_{sy.t.lap}$ (mm) | 450<br>560 | 660<br>830 | -<br>- |
| Beams and Columns: | $L_{sy.t}$ (mm)<br>$L_{sy.t.lap}$ (mm) | -<br>- | 480<br>600 | 950<br>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 bard with $300^+$ mm of concrete below.

## REFERENCES

Concrete Institute of Australia (2007). Recommended Practice – Reinforcement Detailing Handbook for Reinforced and Prestressed Concrete.

Patrick, M., Gilbert, R.I. (2010). Stress Development and Lap Splicing of Straight D500N Reinforcing Bars to AS 3600-2009. Technical Note No. TN7. Steel Reinforcement Institute of Australia. August.

Patrick, M., Turner, M., Keith, J. (2008).A Review of Australian Design and Construction Practices Concerning Anchorage and Lap Splicing of Reinforcing Bars, with Particular Emphasis on Slabs and Walls. ASEC 2008.

Steel Reinforcement Institute of Australia (SRIA) (2009). Current practice survey of development and lap lengths in consulting engineer's General Notes and Specifications

Standards Australia (2009). Concrete Structures. AS 3600–2009. Includes Amdt 1.

## PRESENTERS' BIOGRAPHIES

**Scott Munter** is a structural engineer and Executive Director for the Steel Reinforcement Institute of Australia (SRIA). Previously Scott worked for BlueScope Steel for almost 3 years as the Lysaght National Structural Decking Manager then High-Rise Business & Engineering Manager for BlueScope Buildings.

Scott served for 7 years with Australian Steel Institute as the State Manager-NSW then National Engineering Construction Manager working on a variety of key projects such as the Steel Connection Design Series. Scott also has a broad 15 year commercial, industrial and residential track record as a Civil & Structural Consulting Engineer with SCP Consulting in the Engineering Design and Construction field.

He graduated with a Bachelor of Structural Engineering (under the part-time attendance program, 6 year degree) from the University of Technology, Sydney in 1991 with 1st Class Honours, University Medal and the Engineers Australia Medal. As a Member of Engineers Australia he holds Charter Professional Engineer & NPER (Structural) status. He is a member of a number of Standards Australia committees including BD-002 Concrete Structures.

**Mark Patrick** holds BE and MEngSc degrees from Melbourne University and a PhD from Sydney University. For 6 years he was a consulting structural engineer; researched composite and concrete construction at BHP Melbourne Research Laboratories for 15 years; held a professorial position at the University of Western Sydney for 5 years; before starting a specialist structural engineering consultancy practice six years ago. He is a member of several Standards Australia committees including BD-002 Concrete Structures.