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

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Synopsis: 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 critical cross-sections, and thus can significantly affect detailing and economy. In AS 3600–2009, new design formulae are included for computing basic or refined development and lap lengths incorporating design variables and factors that account directly for: transverse pressure and/or reinforcement; bar size and bar spacing; concrete cover; bar location; whether or not lapped bars are in contact with each other, staggered, or under high or low tensile stress; etc. A review of available test data on reinforced-concrete beams with transverse reinforcement is described, and amended design rules are proposed for AS 3600–2009 to cover circular columns with circular fitments, and rectangular columns, beams, walls or slabs using a weighted-average design approach so that all bars at a cross-section with transverse reinforcement may have the same development or lap length. In addition, the results of an SRIA industry survey of the minimum development and lap splice lengths for straight D500N bars specified by consulting engineering companies are described which show relatively large variations in values for the same types of members. In order to develop a unified approach for preparing project-specific design tables for structural drawings with the greatly increased range of design variables in AS 3600–2009, comprehensive sets of *general*, *bar-cover-controlled* and *bar-spacing-controlled design tables* prepared in accordance with AS 3600–2009 are described, and their application to general design problems is explained including a worked example with transverse reinforcement.

Keywords: deformed reinforcing bars, bond, anchorage, stress development, lap splice, design tables.

1. New Stress Development Design Rules in AS 3600–2009

1.1 Tensile Development Lengths (Basic or Refined)

As defined by Gilbert (1), in accordance with Clause 13.1.2.2 of AS 3600–2009 (2), for straight D500N bars anchored in normal-density concrete of characteristic compressive strength, f_c', between 20 and 100 MPa, basic development length, $L_{sy.tb}$, is calculated using Eq. 1 (f_c' not to exceed 65 MPa & bar diameter d_b not to exceed 40 mm):

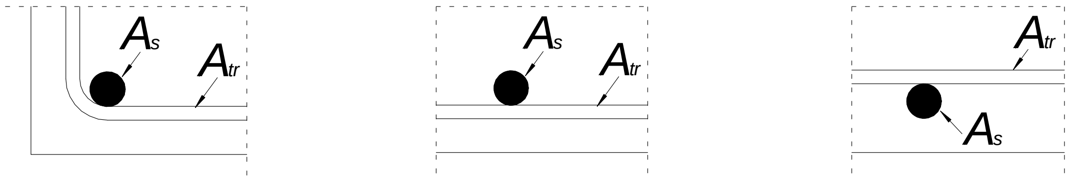
$$L_{sy.tb} = \frac{0.5 k_1 k_3 f_{sy} d_b}{k_2 \sqrt{f_c'}} \geq 29 k_1 d_b \qquad (1)$$

where: k_1 = 1.3 if 300 mm or more of concrete is cast below a non-vertical 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 minimum clear cover to the bars, c, or half the clear distance to the next bar being developed (a/2), whichever is the smaller. Characteristic yield stress, f_{sy}, equals 500 MPa, and is not a design variable despite appearing in the numerator. Unlike in AS 3600–2001 (3), neither is member or element type a design variable, although the rules distinguish between wide and narrow members or elements when determining the relevant minimum concrete cover, and also when designing non-contact lapped splices (see Section 1.2 below). The calculated value must be multiplied by 1.5 if bars are epoxy-coated, 1.3 if lightweight concrete is used, and 1.3 if construction uses slip-forms, each factor compounding if more than one case applies.

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. 2, using the basic development length ($L_{sy.tb}$) calculated from Eq. 1, where factors k_4 and k_5 account for the beneficial effects of transverse reinforcement and pressure, respectively:

$$L_{sy.t} = k_4 k_5 L_{sy.tb} \qquad (2)$$

Factor k_4 = 1.0 - $K\lambda$ (with 0.7 ≤ k_4 ≤ 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 in relation to the main bars being anchored or lapped. Term λ depends on the total cross-sectional area of transverse steel along the development or lap length (ΣA_{tr}), as well as the cross-sectional area of each individual 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, which is 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 as shown in Fig. 1 where: 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 reinforcing 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.



K=0.1 K=0.05 K=0

Figure 1. Values of *K* for different bar positions (according to Fig. 13.1.2.3(B) of AS 3600–2009)

Factor k_5 = 1.0 - 0.04ρ_p (with 0.7 ≤ k_5 ≤ 1.0) may reduce the development length if transverse pressure, ρ_p, exists along the development length perpendicular to the plane of splitting. As ρ_p increases from zero to 7.5 MPa, factor k_5 decreases linearly from 1.0 to a minimum of 0.7 which also applies if ρ_p exceeds 7.5 MPa.

Also, the product $k_3k_4k_5$ must not be less than 0.7. Therefore, depending on the degree of confinement provided by transverse reinforcement and/or pressure, the product of the *refining factors*, k_4k_5, must lie within the range 0.7/k_3 to 1.0. For a situation when c_d exceeds 3d_b, the factor k_3 = 0.7 and there is no benefit to be gained from Eq. 2, i.e. k_4k_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. 2 has the potential to reduce the development length by up to 30%. The variation between c_d and the product $(k_4k_5)_{min}$ is shown in tabular form in Table 1, which will be shown below to be a useful design aid, viz. values shown in bold italics indicate when refined design is possible, which clearly suits large bar diameters.

Table 1. Variation of minimum product of refining factors $(k_4k_5)_{min} = 0.7/k_3$ with c_d = min. (c, a/2)

c_d (mm)	D500N Bar Designation								
	N10	**N12**	**N16**	**N20**	**N24**	**N28**	**N32**	**N36**	**N40**
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***

Of particular relevance to this paper, during the derivation of Eqs 1 and 2, factors k_3, k_4 and k_5 were copied directly from Eurocode 2, Part 1.1 (4), as were their bounds and interrelationships defined above.

1.2 Tensile Lap Lengths (Basic or Refined)

In accordance with Clause 13.2.2 of AS 3600–2009, in wide members (such as slabs, walls and blade columns) when edge effects are insignificant, lap length, $L_{sy.t.lap}$, is calculated using Eq. 3:

$$L_{sy.t.lap} = k_7 L_{sy.t} \geq 29 k_1 d_b \qquad (3)$$

where $L_{sy.t}$ is calculated using Eq. 2 (with the value of c_d applicable to the specific arrangement of the lapped bars, rather than the anchored bars); and k_7 equals 1.25 unless the design stress in the lapped bars at the strength limit state does not exceed $0.5f_{sy}$ and no more than half the reinforcement at the section is lapped, in which case k_7 may be taken as 1.0. For bars lapped in the same plane, in order to calculate k_3 and therefore c_d, clear distance, *a*, shall be determined assuming contact splices, i.e. lapped bars shall be assumed to be touching each other, even if they are not.

When designing laps in narrow members or elements (such as columns and beam webs), an additional requirement applies to Eq. 3, viz.: $L_{sy.t.lap}$ is not less than $L_{sy.t} + 1.5s_b$, where s_b is the clear distance between bars of a lapped splice (of diameter d_b), and is zero for contact splices, and assumed to be zero if $s_b \leq 3d_b$.

2. Recommended Improvements to AS 3600–2009 Stress Development Design Rules

2.1 Recommended Improvements to Refined Design Procedure

As members of Standards Australia Subcommittee BD-002-04 "Materials and Construction" responsible for overseeing the drafting of design rules in Section 13 of AS 3600, the authors have recommended that the existing design rules in AS 3600–2009 be improved according to the details contained in the appendix to this paper. They relate to the calculation of factor k_4 (= 1.0 - $K\lambda$) used in the determination of either the refined development length $L_{sy.t}$ using Eq. 2, or the refined lap length $L_{sy.t.lap}$ using Eqs 2 and 3. Of course, refined design is only possible in cases when, as given by Table 1, $(k_4 k_5)_{min} < 1.0$.

2.2 Technical Reasons for Recommended Improvements

The technical reasons for proposing the corrections to AS 3600–2009 in the appendix are as follows.

1. The common case of a circular column with circular fitments is not included in the existing Figure 13.1.2.3(B) entitled "Values of K for different bar positions" (see Fig. 1 in this paper), and some guidance for this case is required.

   As shown in new Table 13.1.2.3 in the appendix, a longitudinal splitting crack that forms along a lap splice in the tensile face of a circular column must cross the circular fitment. This is the same as the corner case shown in existing Fig. 13.1.2.3(B) (Fig. 1 herein), and therefore K=0.1 is appropriate.

2. Rectangular columns, beams, walls or slabs can incorporate more than one of the details shown in Fig. 13.1.2.3(B) at a transverse cross-section through an anchorage or lap splice region. As currently shown, each case in Fig. 13.1.2.3(B) has to be treated differently, which results in different development or lap splice lengths for adjacent bars. Alternatively, the most conservative solution could be adopted for all the bars. A weighted-average design approach is the most practical solution and should be adopted, so that all of the bars in the same cross-section with the same diameter have the same development or lap splice length.

   The weighted-average formula [$K=0.05\times(1 + n_f / n_{bs}) \leq 0.10$] is based on the following assumptions (see the appendix for definitions of n_f and n_{bs}).

   (i) For longitudinal bars constrained by fitment corners, as shown in Fig. 13.1.2.3(B) (Fig. 1 herein) for the case when K=0.1, or as shown in proposed new Table 13.1.2.3 in the appendix for a slab or wall with internal fitments, the transverse reinforcement is assumed to be most effective, with K=0.1 applying. This is because a longitudinal splitting crack that forms between each longitudinal bar and the concrete tensile face passes through at least one leg of the fitment.

   (ii) For longitudinal bars located inside transverse bars, as shown in Fig. 13.1.2.3(B) for the case when K=0.05, or as shown in proposed new Table 13.1.2.3 in the appendix for a slab or wall without fitments, the longitudinal splitting cracks could either pass through adjacent longitudinal bars thus missing the transverse bars altogether, or across the transverse bars at each longitudinal bar as shown in proposed new Table 13.1.2.3 for a slab or wall without fitments. For simplicity, the design approach of Eurocode 2, Part 1.1 is to assume that at these locations, on average the transverse bars are 50% effective, i.e. K=0.05.

(iii) Consistent with the assumptions above, the potential splitting crack patterns shown for each case in proposed new Table 13.1.2.3 in the appendix yield the smallest value of ΣA_{tr} used in the formula for λ, and therefore the largest or most conservative value of k_4.

This weighted-average design approach is consistent with Clause 12.2.3 of ACI 318-08 (5), where in the formula for transverse reinforcement index $K_{tr}=40A_{tr}/(sn)$ in units of inches, A_{tr} = total cross-sectional area of all transverse reinforcement within spacing s that crosses the potential plane of splitting through the reinforcement being developed or lapped, and n = the number of bars being developed or lapped along the plane of splitting.

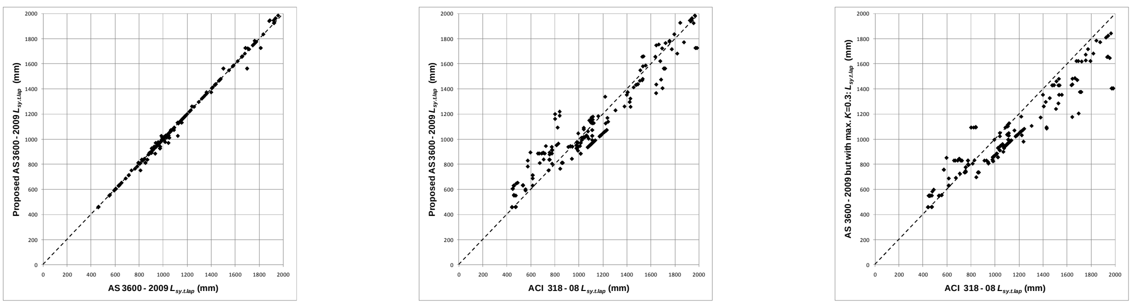
2.3 Review using ACI 408 Test Database

A database of bond test results maintained by ACI Committee 408 (6) has been used to examine the effect of the recommended improvements when transverse reinforcement is present. The individual database for bottom-cast bars (478 tests) is used here, except that test results are excluded if clear cover, c<max.(d_b, 20 mm) or clear distance, s_c < max.(1.5d_b, 40 mm), since these are outside normal practice. Tests specimens without transverse reinforcement are also irrelevant. Tests in which bars yielded are excluded too, as bond failure might not have occurred, and therefore not controlled ultimate strength.

The transverse reinforcement comprised stirrups, and for each test the database provides the number of spliced bars, n_{bs}, and the number of legs per stirrup, n_f, and their diameter and longitudinal spacing, which allows K (weighted-average) and λ to be calculated using the formulae in the appendix to this paper. In the tests with $n_{bs}=n_f$, all the longitudinal bars are corner bars whereby $K=0.05\times(1 + n_f/n_{bs})$ = 0.1, the same as for this case in Fig. 1. However, in a number of the tests $n_{bs}>n_f$, whereby not all longitudinal bars were corner bars. Therefore, according to Fig. 1, K=0.05 or 0.1 when using current AS 3600–2009. For example, a case is n_{bs}=5 and n_f=2, whereby the proposed weighted-average value for K is 0.07.

Assuming a bar design yield stress, f_{sy}, of 500 MPa, and a concrete compressive strength, f'_c, equal to the test compressive strength but not exceeding 65 MPa in accordance with Eq. 1, lap length, $L_{sy.t.lap}$, has been computed using Eq.3, either exactly as described above to give the values on the horizontal axis in Fig. 2(a), i.e. "AS 3600–2009 $L_{sy.t.lap}$ (mm) ", or with $K=0.05\times(1 + n_f/n_{bs})$ to give the values on the vertical axis in Fig. 2(a), i.e. "Proposed AS 3600–2009 $L_{sy.t.lap}$ (mm)". It should be noted that for tests with $n_{bs}>n_f$, two values of $L_{sy.t.lap}$ have been computed, viz. using K=0.05 or 0.1, and both are included in the graph for each such test. It can be seen that treating all the relevant tests in the ACI 408 database as design cases, that the values of $L_{sy.t.lap}$ calculated are hardly affected by the proposed change to AS 3600–2009. Its practical advantage is that corner bars and interior bars without a vertical leg at the same cross-section in a member can be assigned the same design lap or development length, and it is therefore recommended.

For interest, ACI 318-08 was used to calculate the design lap length of Type B laps (equivalent to k_7=1.3) for each relevant test specimen, and the graphs in Figs 2(b) & (c) show that on average AS 3600–2009 and ACI 318-08 give similar results provided K=0.1, confirming this Eurocode 2 upper limit is appropriate.



(a) Weighted-average K (Proposed) vs Fig. 1 (AS 3600–2009)

(b) Proposed AS 3600–2009 (max. K=0.1) vs ACI 318-08

(c) c.f. (b): AS 3600–2009 is unconservative for max. K=0.3 (arbitrary)

Figure 2. Analysis of bond tests with transverse reinforcement from ACI 408 database (6)

3. Results of an Industry Survey (Design to AS 3600–2001)

The formula in AS 3600–2001 for calculating tensile development length, $L_{sy.t}$, was first introduced into the Standard in 1988 (AS 3600–1988), and for reinforcing bars with characteristic yield stress f_{sy} = 500 MPa was supposed to be given in Clause 13.1.2.1 according to Eq. 4:

$$L_{sy.t} = \frac{k_1 k_2 f_{sy} A_b}{(2a + d_b)\sqrt{f'_c}} \geq 29 k_1 d_b \qquad (4)$$

At the time Eq. 4 was developed, the characteristic yield stress, f_{sy}, of the available deformed bars (Y bars) was only 400 MPa. Patrick et al. (7) have explained that for straight, deformed bars, the lower bound in Eq. 4 for D500N bars with characteristic yield stress, f_{sy}, equal to 500 MPa, should be $29k_1d_b$ (as in Eqs 1 and 3 for AS 3600–2009) 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 if 300 mm or more of concrete is cast below a non-vertical 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 bars being anchored (or lapped); d_b is their 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. (7) also recommended limits for anchored or lapped bars, viz. the value of 2a substituted into Eq. 4 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 uncoated reinforcing bars 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 2). 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 at least increased by the diameter of transverse bars (e.g. fitments) located closer to the exposed concrete surface.

Table 2. Required concrete cover for standard formwork and compaction to AS 3600–2001

Exposure classification (EC)	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. 4 can provide design engineers with many different design solutions; examples of which are given in pages of tables of development lengths in the superseded 2007 edition of Concrete Institute of Australia's Reinforcement Detailing Handbook (8).

However, to be practical, consulting engineers have historically only included very condensed tables of development and lap lengths on their structural drawings, 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 normally 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 3 was generated for development or lapped splice lengths using Eq. 4 with $3d_b \leq (2a + d_b) \leq 7d_b$ applying, 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 2 corresponding to the exposure condition and f'_c, ignoring transverse bars, but is not less than $d_{b.5mm}$ (d_b rounded to nearest multiple of 5 mm above d_b);

(iii) there is not more than 300mm of concrete below non-vertical bars (i.e. $k_1 = 1.0$); and

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

Table 3. Sample of tensile development or lap lengths, $L_{sy.t}$, to AS 3600–2001*

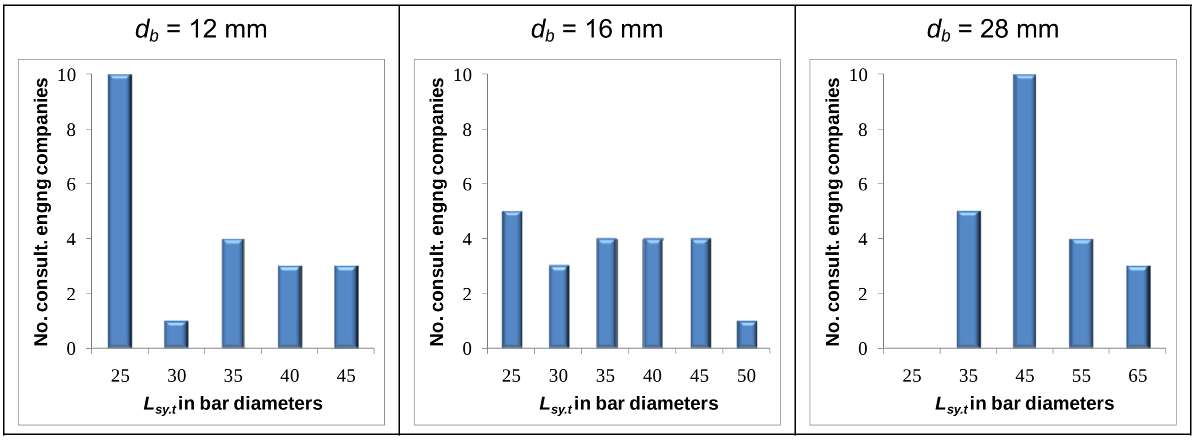
Exposure classification (EC) & concrete strength grade f'_c	Member type	Bar diameter, d_b (mm) 12	16	28	40
A1 & f'_c = 25 MPa	Slab	$30.8d_b$	$38.1d_b$	$42.5d_b$	-
	Beam/Column	$39.9d_b$	$49.4d_b$	$55.0d_b$	$57.6d_b$
A1 & f'_c ≥ 32 MPa	Slab	$29.0d_b$	$33.7d_b$	$37.6d_b$	-
	Beam/Column	$35.2d_b$	$43.6d_b$	$48.6d_b$	$50.9d_b$
B1 & f'_c ≥ 32 MPa	Slab	$29.0d_b$	$29.0d_b$	$30.6d_b$	-
	Beam/Column	$29.0d_b$	$29.0d_b$	$39.6d_b$	$50.9d_b$

* calculated using Eq. 4, incorporating the limits imposed on ($2a + d_b$) by Patrick et al. (7)

The SRIA (9) conducted a survey of the General Notes structural drawing from just over 20 Australian consulting engineering companies, with sample results applying to main bars in either slabs or beams shown in Table 4. 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 3), while the other half used values within the range of values for slabs and beams in Table 3, possibly also catering for bars in slabs with clear distance, s_c, less than 150 mm. For 16 mm diameter bars, only a quarter used the superseded minimum $25d_b$, and the rest again used values within the range of Table 3. For 28 mm diameter bars, most values effectively fall within the range of values in Table 3, 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 an urgent need for them to update their designs, and also rationalize them by adopting a more unified and consistent approach.

Table 4. Survey sample results of tensile development or lap lengths, $L_{sy.t}$, for slabs and beams designed to AS 3600–2001



4. Design Tables to AS 3600–2009

4.1 Tensile Development Lengths ($L_{sy.tb}$ & $L_{sy.t}$) & Tensile Lap Lengths ($L_{sy.tb.lap}$ & $L_{sy.t.lap}$)

To facilitate use of the new Standard by consulting engineers, an SRIA technical note (10) will contain three different sets of design tables of tensile development and tensile lap lengths. A key objective of the technical note is to provide sufficient information to enable structural designers to compile accurate, condensed design tables of development and lap lengths for inclusion on their General Notes structural drawing. (In the technical note, basic lap length $L_{sy.tb.lap}$ is calculated using Eqs 1 and 3 only, while refined lap length $L_{sy.t.lap}$ is calculated using Eqs 1, 2 and 3.)

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

(i) basic development lengths (calculated using Eq. 1) and lap lengths (calculated using Eqs 1 and 3) are presented for a wide range of values of f'_c, d_b and c_d;

(ii) the potential level of refinement available from using Eq. 2 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 minimum value of the product of the refining factors $(k_4k_5)_{min}$ applies for each combination of c_d and d_b, as given by Table 1);

(iii) if $(k_4k_5)_{min} < 1.0$, a designer may choose to use Eq. 2 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 a designer, *general design tables* are provided in the SRIA technical note (10) 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 *bar-cover-controlled tables* are provided for non-vertical bars with more than 300 mm of concrete below them (k_1=1.3) and for other bars (k_1=1.0), in cases when cover, c, equals the larger of c_{req} from Table 2 (depending on concrete strength f'_c and exposure classification) and $d_{b.5\text{mm}}$, the nominal bar diameter, d_b, rounded upwards to the next multiple of 5 mm. For example, Table 5 contains typical information taken from these *bar-cover-controlled tables*. Values of k_1=1.0 and k_7=1.25 were used.

Table 5. Extracts from *Bar-Cover-Controlled Tables* (10)

Exposure classification (EC), strength f'_c and c_{req} (Table 2)	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)

The *bar-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 *bar-cover-controlled tables*, there are *bar-spacing-controlled tables* comprising solutions to Eqs 1, 2 and 3 for which the value of c_d is controlled by the clear distance between bars being anchored or lapped.

4.2 Example Design Table to AS 3600–2009

Consider the case of a building foundation (i.e. EC = B1 and f'_c = 32 MPa) incorporating two-way slabs with horizontal bars, supported by bored piles incorporating prefabricated cages with spiral fitments.

A conservative approach a designer could take is to assume that for the slabs, basic lengths $L_{sy.tb}$ and $L_{sy.tb.lap}$ apply, ignoring any confining effects from the transverse bars, even for the case shown in proposed new Table 13.1.2.3 in the appendix (see last figure for case K=0.05) with the main bars inside the transverse bars.

For the bored piles, refined lengths $L_{sy.t}$ and $L_{sy.t.lap}$ could be determined using Eq. 2, with the appropriate value of k_4k_5 at the least confined anchorage or splice location, and also confirming that $k_3k_4k_5 \geq 0.7$ at this location. For example, if the value of k_4k_5 for the bore piles in the structure in question equals the appropriate value of $(k_4k_5)_{min}$ given in Table 5, i.e. 0.75, a design table that could be included on the structural drawings for the project is given in Table 6. In this case, K=0.1 and since k_5=1, k_4=0.75, whereby $\lambda=(1-k_4)/K=(1-0.75)/0.1=2.5$. However, $\lambda=(\Sigma A_{tr} - \Sigma A_{tr.min})/A_s$ and $\Sigma A_{tr.min}=A_s/4$, whereby $\Sigma A_{tr} = (\lambda+0.25)A_s=2.75A_s$, where A_s is the cross-sectional area of an N28 bar =615 mm^2, and therefore ΣA_{tr} =1690 mm^2. For $L_{sy.t.lap}$ =1050 mm, if an N16 spiral were used, then its pitch, s, should not exceed $L_{sy.t.lap}\, A_{s.N16} / \Sigma A_{tr}$ =1050×200/1690=125 mm.

Table 6. 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) $L_{sy.t.lap}$ (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.

5. Conclusions

Amended design rules for AS 3600–2009 have been proposed to cover circular columns with circular fitments, and rectangular columns, beams, walls or slabs using a weighted-average design approach so that all bars at a cross-section may have the same development or lap length even with transverse reinforcement present. A unified approach for preparing project-specific design tables for inclusion on a General Notes structural drawing has been described using new design tables prepared in accordance with AS 3600–2009, which has been illustrated by a worked example involving transverse reinforcement.

6. Acknowledgement

The authors wish to acknowledge the support of their respective organisations to prepare this paper.

7. References

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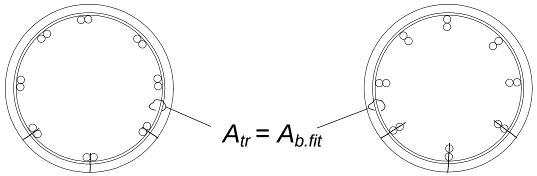
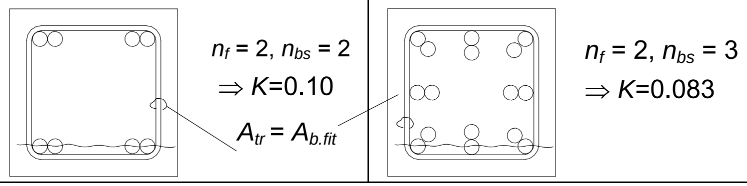
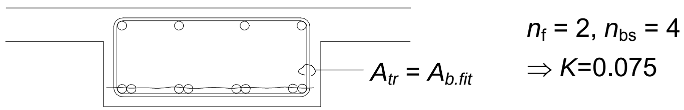
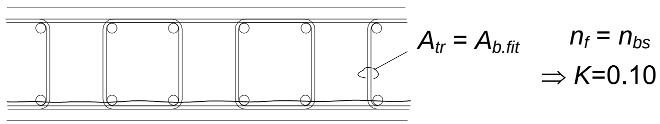
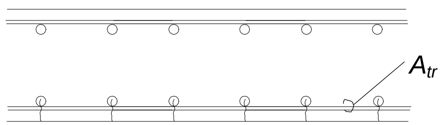
Appendix – Recommended Changes to Clauses 13.1.2.2 & 13.1.2.3 of AS 3600–2009

Page	Reference	Action	Comments
16	Clause 1.7 Notation	Add new symbols as follows: n_{bs} = number of longitudinal bars being developed or spliced at which a potential splitting crack can develop (see Table 13.1.2.3) n_f = number of fitment bars within longitudinal spacing or pitch *s* that a potential splitting crack has to cross (see Table 13.1.2.3) Correct existing notation as follows: A_s = cross-sectional area of reinforcement (see Clauses 3.4.3.2 and 13.2.2); or = cross-sectional area of a single bar of diameter d_b being anchored (see Clause 13.1.2.3) A_{tr} = cross-sectional area of a transverse reinforcing bar along a development or lap length (see Clause 13.1.2.3), through which a potential splitting crack can cross *K* = a factor that accounts for the weighted-average effectiveness of transverse reinforcement in controlling potential splitting cracks along a development or lap length (see Clause 13.1.2.3)	These support the proposed corrections to Clause 13.1.2.3 on p. 164 of AS 3600–2009.
163	Clause 13.1.2.2	Change definition of c_d to: c_d = a dimension (in millimetres), as shown in Fig. 13.1.2.2.	Figure number corrected.
164	Equation 13.1.2.3	Change definition of *K* to: *K* = a factor that accounts for the weighted-average effectiveness of transverse reinforcement in controlling potential splitting cracks along a development or lap splice length; = $0.05\times(1 + n_f/n_{bs}) \leq 0.10$, with values of n_f and n_{bs} given in Table 13.1.2.3 for typical arrangements of transverse reinforcement for different member types; and = 0, if transverse reinforcement is not located between the longitudinal bars and the concrete tensile face. Change definitions of λ, ΣA_{tr} and $\Sigma A_{tr.min}$ to: λ = $(\Sigma A_{tr} - \Sigma A_{tr.min})/A_s \geq 0$ ΣA_{tr} = sum of cross-sectional areas of the transverse bars along a development or lap length $\Sigma A_{tr.min}$ = sum of the cross-sectional areas of the transverse reinforcement when minimum steel is used, which shall be taken as $0.25A_s$ for members with $K > 0$, and 0 when $K = 0$	These are amendments to improve the procedures for calculating terms *K* and λ used in the formula for factor k_4, which accounts for the effects of transverse reinforcement. The value of *K* for each primary case in Fig. 13.1.2.3(B) remains the same.
164	Clause 13.1.2.3	Add new Table 13.1.2.3 given below.	Referenced in new definition of *K*.
165	Figure 13.1.2.3(A)	Change figure number to Figure 13.1.2.2.	Figure is referenced from Cls 13.1.2.2.
165	Figure 13.1.2.3(B)	Delete this figure.	Superseded by new Table 13.1.2.3.

PROPOSED NEW TABLE 13.1.2.3 FOR AS 3600–2009

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.