

Bundled bars:

IS CODE 456:2000

26.1.1 Bars may be arranged singly, or in pairs in contact, or in groups of three or four bars bundled in contact. Bundled bars shall be enclosed within stirrups or ties. Bundled bars shall be tied together to ensure the bars remaining together. Bars larger than 32 mm diameter shall not be bundled, except in columns.

26.2.1.2 Bars bundled in contact

The development length of each bar of bundled bars shall be that for the individual bar, increased by 10 percent for two bars in contact, 20 percent for three bars in contact and 33 percent for four bars in contact.

26.2.3.5 Curtailment of bundled bars

Bars in a bundle shall terminate at different points spaced apart by not less than 40 times the bar diameter except for bundles stopping at a support.

26.2.5.1 Lap splices

g) In case of bundled bars, lapped splices of bundled bars shall be made by splicing one bar at a time; such individual splices within a bundle shall be staggered.

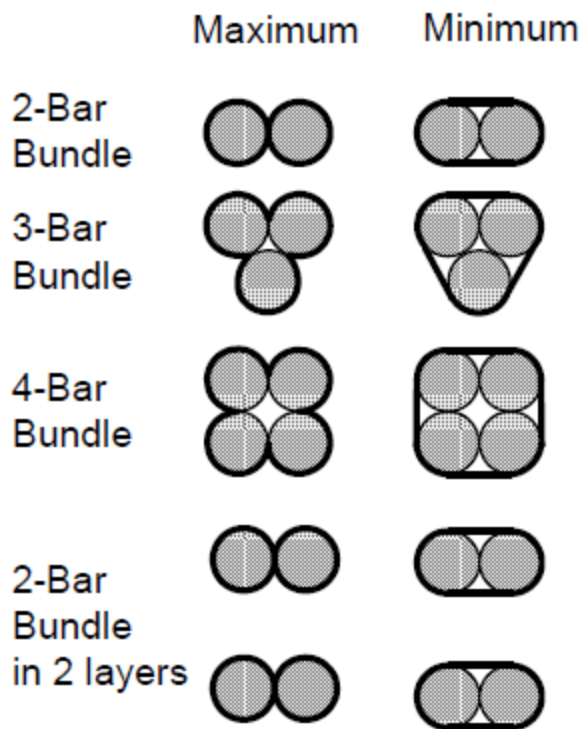
26.3 Spacing of Reinforcement

26.3.1 For the purpose of this clause, the diameter of a round bar shall be its nominal diameter, and in the case of bars which are not round or in the case of deformed bars or crimped bars, the diameter shall be taken as the diameter of a circle giving an equivalent effective area. Where spacing limitations and minimum concrete cover (see 26.4) are based on bar diameter, a group of bars bundled in contact shall be treated as a single bar of diameter derived from the total equivalent area.

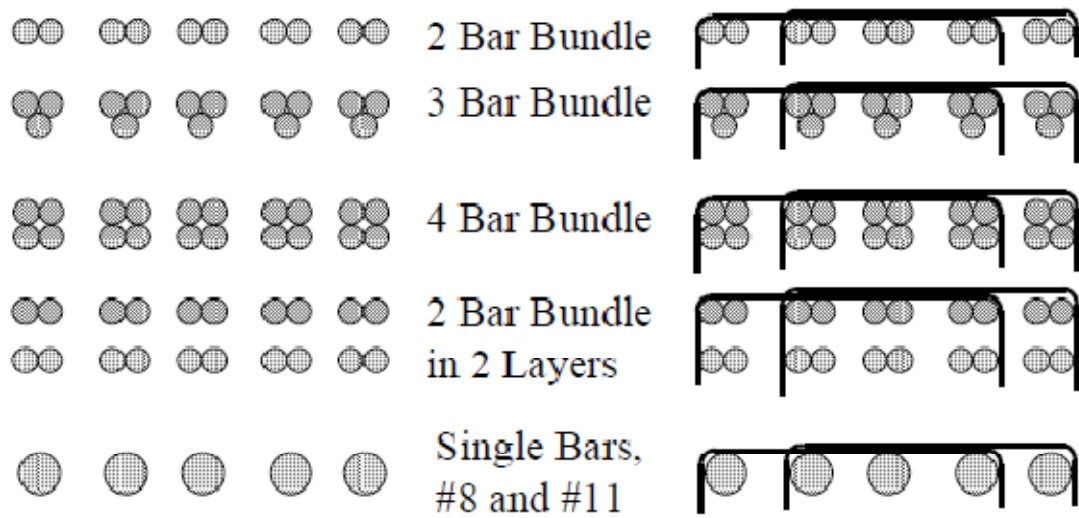
ACI-318-11-Clause 7.6.6.1 to 7.6.6.5 has specified some restrictions. Also see clause 7.7.4 for cover requirement.

7.10.5.1 — All nonprestressed bars shall be enclosed by transverse ties, at least No. 10 in size for longitudinal bars No. 32 or smaller, and at least No. 13 in size for No. 36, No. 43, No. 57, and bundled longitudinal bars. Deformed wire or welded wire reinforcement of equivalent area shall be permitted.

Clause 12.4.1 to 12.4.2 for development length.



Bundle Size (#6 bars)	Maximum Perimeter (in.)	Minimum Perimeter (in.)	Δ (max-min/min) %
2-bar	4.72	3.86	22.30
3-bar	5.90	4.61	28.00
4-bar	7.08	5.36	32.10

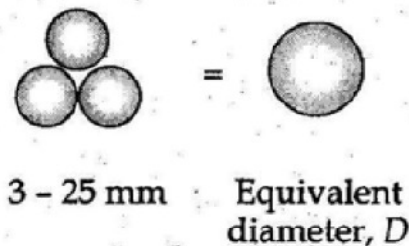


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BUNDLED BARS

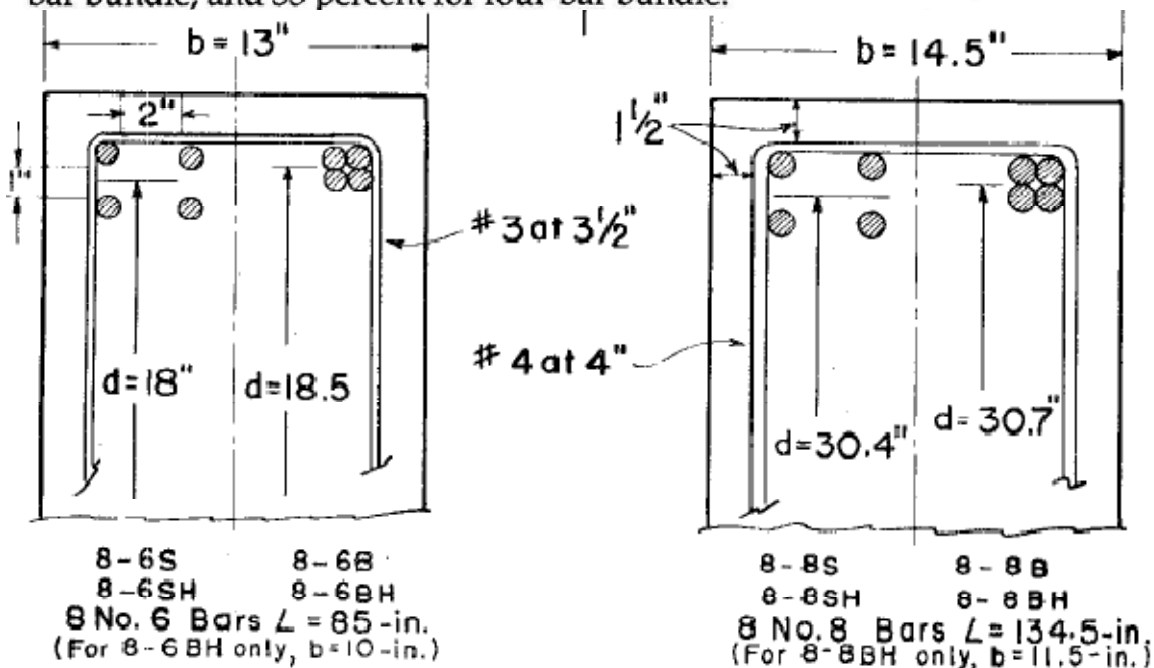
Groups of parallel reinforcing bars bundled in contact to act as a unit shall be limited to four in any one bundle. Bundled bars shall be enclosed within stirrups or ties and bars larger than 32 mm shall not be bundled in beams. The individual bars within a bundle terminated within the span of flexural members should terminate at different points with at least $40d_b$ stagger. Since spacing limitations and minimum concrete cover of most members are based on a single

Diameter of single bar equivalent to bundled bars according to NSCP to be used for spacing limitation and concrete cover.



DEVELOPMENT OF BUNDLED BARS

Development length of individual bars within a bundled, in tension or compression, shall be that for the individual bar, increased 20 percent for three-bar bundle, and 33 percent for four-bar bundle.



AUSTRALIAN CODE AS3600:

The lengths below rationalise the values given in AS3600. If both tension and compression can act at different times on the same cross-section, anchorage must be designed for the worst case situation.

If the factors given in Clause 13.1.7 for bundled are applied directly to compression development length given in Clause 13.1.5.2, for $f'_c = 25$ MPa and $f_{sy} = 500$ MPa ($22d_b$) they become $26.4d_b$ and $29.3d_b$ respectively.

Bundled bars in compression are not commonly used other than in columns of very high buildings so that, for practical use, all development lengths have been rounded up to $30d_b$. This value will decrease as f'_c increases.

The lap splice for a single bar in compression is a minimum $40d_b$ (Clause 13.2.4(a)) and rounded up to $54d_b$ for a bundled bar (Clause 13.2.5).

Lap splices are always based on full yield strength f_{sy} . To permit other values would create uncertainty in the mind of fixers and inspectors, and would certainly require more work from detailers. AS3600-2009 Clause 13.2.4 does not allow reductions in compression lap lengths.

Application		Lengths for Grade 500N single and bundled bars, $f'_c = 25$ MPa						
		N12	N16	N20	N24	N28	N32	N36
$L_{sy.tb}$	$29d_b$ Tensile development length (Clause 13.1.2.2 - bottom bars) minimum	350	460	580	700	810	930	1040
$L_{sy.tb}$	$38d_b$ Tensile development length (Clause 13.1.2.2 - top bars) minimum	450	600	750	900	1060	1210	1360
$L_{sy.cb}$	$22d_b$ Compression development length (Clause 13.1.5.2) for single bar	260	350	440	530	620	700	790
$L_{sy.cb}$	$40d_b$ Compression splice for single bar (Clause 13.2.4(a))	480	640	800	960	1120	1280	1440
$L_{sy.cb}$	$30d_b$ Compression development length (Clause 13.1.5.2) for 3 and 4 bar bundles	360	480	600	720	840	960	1080
$L_{sy.cb}$	$54d_b$ Compression splice for 3 and 4 bar bundles (Clause 13.2.5)	650	860	1080	1300	1510	1730	1940

Compression Development Length for Single Bars, $L_{sy,c}$ (Clause 13.1.5)

Although it is not stated in Clause 13.1.5, the minimum cover and spacing rules still apply. Compression causes splitting of the cover in a different way to tensile forces. A realistic spacing is required to ensure concrete can be consolidated properly. Encircling ties may also be advisable in zones of heavy reinforcement.

Compression bars must not be hooked.

Compression Lap Splices for Single Bars (Clause 13.2.4)

For 500 MPa bars in a compression zone of the concrete, the lap length is $41d_b$. This is twice the compressive stress development length. This value also applies to lap splice lengths for column bars.

Compression bars must not be hooked. This is not restricted to columns and walls. It applies to all members.

Where the concrete at the bottom of a beam over a column carries an excessively large compression load, extra bars lapped for compressive stress transfer will be required there.

Development Length of Bundled Bars in Compression (Clauses 8.10.8, 10.7, 13.1.6, 13.1.7)

When two bars are tied together over their full length, to form a two-bar bundle, an increase in development length is not required.

Three or four bars can be tied tightly together to form a bundle. Each bar of the “unit” therefore presents a smaller surface in contact with the surrounding concrete. This requires an increased development length for bundled bars (Clauses 13.1.6, 13.1.7).

In beams, the bar cut-off point of each bar in a bundle must be staggered by $40d_b$ (Clause 8.10.8).

Compression Lap Splices for Bundled Bars (Clauses 13.2.4, 13.2.5)

Lap splicing of bundled bars is messy, complicated, uses excessive steel, and causes overcrowding of the column area. These lap splices must be avoided.

Wherever possible bundled bars should be spliced by end bearing (no laps) or by mechanical splice because these give a simpler solution.

The values in the table also apply to an extra splice bar added to a bundle which did not have a sawn-end preparation for an end-bearing splice. The splice bar must be at least twice the lap length given above, and located centrally about the section where the splice is.

Spalling of the concrete

Where the main reinforcement is made up of:

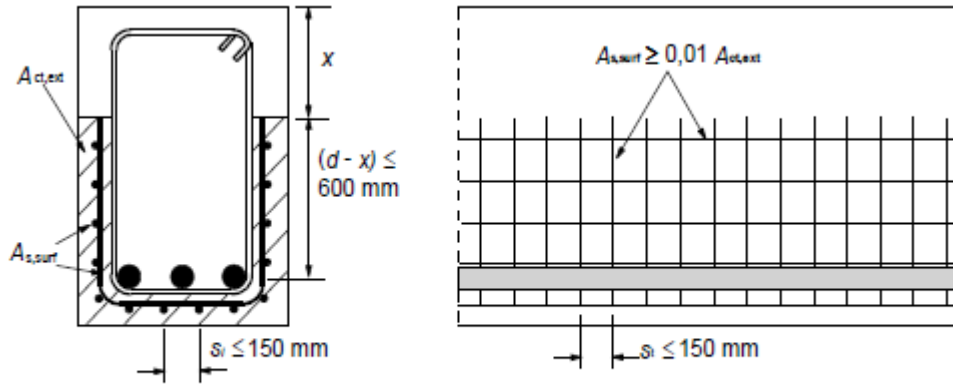
- bars with diameter greater than 32 mm or
- bundled bars with equivalent diameter greater than 32 mm,

the cover/surface reinforcement $A_{s,surf}$ should be used – **to avoid spalling.**

The **minimal area** of the surface reinforcement $A_{s,surfmin}$ **in each direction, parallel** $A_{s,surfmin,l}$ and **orthogonal** $A_{s,surfmin,t}$ to the tension reinforcement in the beam is recommended (according to [EN 1992-1-1: Eurocode 2: *Design of Concrete Structures* – Part 1-1: General rules and rules for buildings] as follows:

$$A_{s,surf} \geq A_{s,surfmin} \quad A_{s,surfmin} = A_{s,surfmin,l} = A_{s,surfmin,t} = 0,01 A_{ct,ext},$$

where: $A_{ct,ext}$ the area of the tensile concrete external to the links (see **Fig. 1**).



x is the depth of the neutral axis at ULS

Fig. 1 Position and terminology of the surface reinforcement

PCA :

Bundling of bars (parallel reinforcing bars in contact, assumed to act as a unit) is permitted, but only if such bundles are enclosed by ties or stirrups. Some limitations are placed on the use of bundled bars as follows:

1. No. 14 and No. 18 bars cannot be bundled in beams.
2. If individual bars in a bundle are cut off within the span of beams, such cutoff points must be staggered at least 40 bar diameters.
3. A maximum of two bundled bars in any one plane is implied (three or four adjacent bars in one plane are not considered as bundled bars).
4. For spacing and concrete cover, a unit of bundled bars must be treated as a single bar with an area equivalent to the total area of all bars in the bundle. Equivalent diameters of bundled bars are given in Table 3-7.
5. A maximum of four bars may be bundled (See Fig. 3-2).



Figure 3-2 Possible Reinforcing Bar Bundling Schemes

6. Bundled bars must be enclosed within stirrups or ties.

Table 3-7 Equivalent Diameters of Bundled Bars, in.

Bar Size	Bar Diameter	2-Bar Bundle	3-Bar Bundle	4-Bar Bundle
#6	0.750	1.06	1.30	1.50
#7	0.875	1.24	1.51	1.75
#8	1.000	1.42	1.74	2.01
#9	1.128	1.60	1.95	2.26
#10	1.270	1.80	2.20	2.54
#11	1.410	1.99	2.44	2.82
#14	1.693	2.39	2.93	3.39

Compiled by Er.T.RangaRajan.