9.4.2.4 Requirements for special exposure conditions

Concrete maximum water-binder ratios and minimum specified compressive strength should comply with specification of Table 15, according to conditions of exposure.

Table 15 — Requirements for special exposure conditions

Exposure condition	Maximum water-binder ratio by weight	Minimum f_c', MPa
Concrete intended to have low permeability when exposed to water	0,5	28
Concrete exposed to freezing and thawing in a moist condition or to de-icing chemicals	0,45	31,5
For corrosion protection of reinforcement in concrete exposed to chlorides from de-icing chemicals, salt, salt water, brackish water, seawater, or spray from these sources	0,4	35

9.4.2.5 Sulfate exposures

When water soluble sulfate (SO_4) is present in soil and has a concentration greater than 0,10 % by weight or is present in water with more than 0,015 % (150 ppm), concrete exposed to these sulfate-containing solutions or soils shall have a water-binder ratio less than or equal to 0,45 by weight and a minimum compressive strength, f_c', of 31 MPa. Calcium chloride as an admixture shall not be used in concrete exposed to sulfates.

9.4.2.6 Chloride-ion exposure

For corrosion protection of reinforcement in concrete, maximum water-soluble chloride-ion concentrations in hardened concrete at ages from 28 to 42 days contributed from the ingredients including water, aggregates, cement, and admixtures shall not exceed the limits of Table 16.

Table 16 — Maximum chloride ion content for corrosion protection of reinforcement

Type of member	Maximum water-soluble chloride-ion (Cl^-) in concrete, percent by weight of cement
Reinforced concrete exposed to chloride in service	0,15
Reinforced concrete that will be dry or protected from moisture in service	1
Other reinforced concrete construction	0,3

9.4.3 Required average compressive strength

Required average compressive strength, f_{cr}', for concrete shall be 10,5 MPa greater than the specified concrete compressive strength, f_c'.

9.4.4 Proportioning of the concrete mixture

The proportions of the concrete mixture shall be established from trial mixtures using combinations of materials for the proposed work, using at least three different water-binder ratios that comply with the durability requirements of 9.4.2 and the slump requirements from Table 17, and that encompass the required average strength, f_{cr}'. The trial mixtures shall be designed to produce slumps within ±20 mm of the maximum permitted.

Table 17 — Slumps for various types of construction

Member	Slump mm	
	Maximum	Minimum
Reinforced foundation walls, columns and footings	150	50
Plain footings, caissons, and substructure walls and columns	150	50
Beams and reinforced walls	210	80
Columns	210	80
Slabs	150	50
Pavements	75	25
Mass concrete	120	50

9.5 Concrete cover of reinforcement

9.5.1 Minimum concrete cover

The following minimum concrete cover should be provided for unprotected prestressing and reinforcing steel, even in non-seismic areas (see Figures 10 to 13).

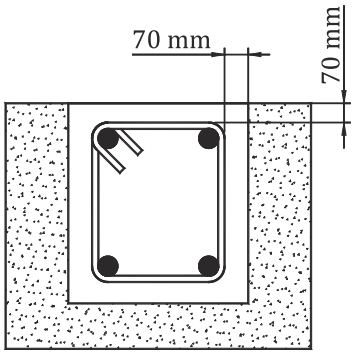


Figure 10 — All types of reinforcement of elements cast and permanently exposed to earth or water (Minimum concrete cover: 70 mm)

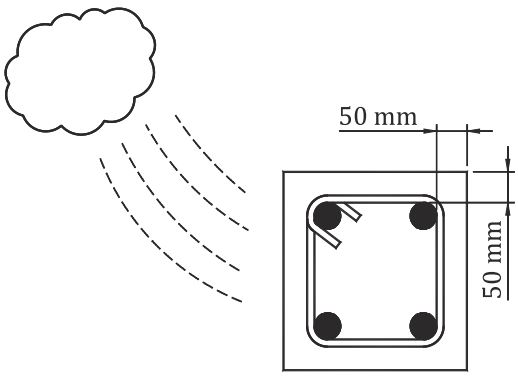


Figure 11 — All types of reinforcement of elements exposed to weather (Minimum concrete cover: 50 mm)

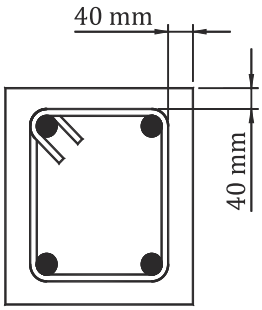


Figure 12 — All types of reinforcement of girders, beams, or columns, when not exposed to weather or in contact with ground (Minimum concrete cover: 40 mm)

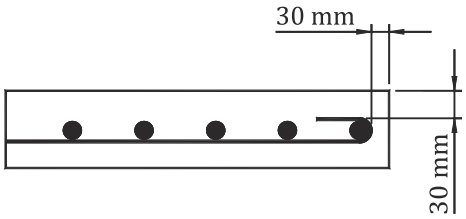


Figure 13 — All types of reinforcement of solid slabs, structural concrete walls or joists, when not exposed to weather or in contact with ground (Minimum concrete cover: 30 mm)

Cover for metal ducts for post-tensioned tendons shall not be less than:

— that specified for reinforcement; and

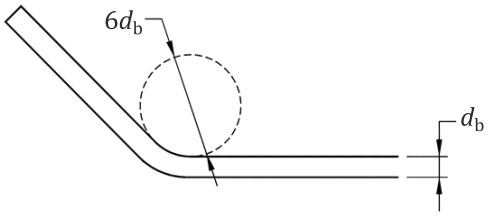
— one-half the diameter of the duct.

9.5.2 Special corrosion protection

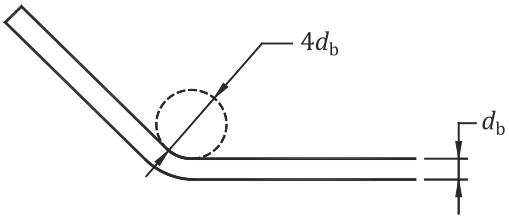
Protection against chloride-induced corrosion may be provided by epoxy coating or galvanizing of reinforcing steel, post-tensioning duct, and anchorage hardware and by epoxy coating of prestressing strand. This type of protection is beyond the scope of this document.

9.6 Minimum reinforcement bend diameter

The diameter of bend of the reinforcement, measured on the inside of the bar, should not be less than the values given in Figure 14.



a) Deformed reinforcing bars and plan reinforcing bars: $6d_b$



b) For stirrups and ties: $4d_b$

Figure 14 — Minimum reinforcement bend diameter

9.7 Standard hook dimensions

The term "standard hook" as used in this document should mean one of Figures 15 to 19.

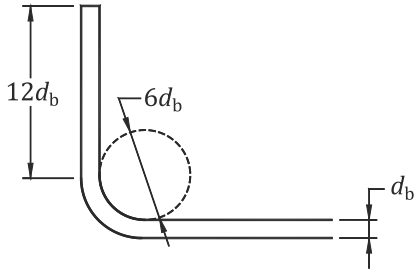


Figure 15 — 90° hook (90° bend plus $12d_b$ extension at free end of bar)

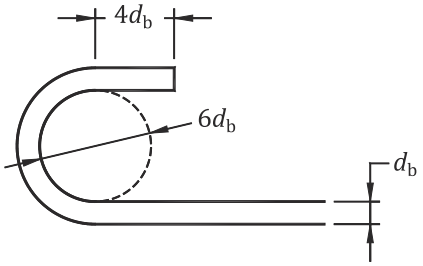
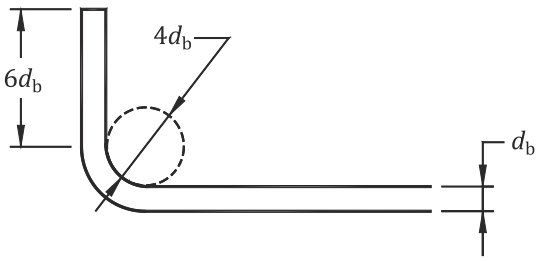
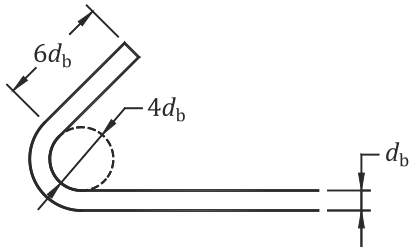


Figure 16 — 180° hook (180° bend plus $4d_b$ extension at free end of bar)



a) 90° bend plus $6d_b$ extension at free end of bar, or



b) 135° bend plus $6d_b$ extension at free end of bar

Figure 17 — For stirrup and tie hooks

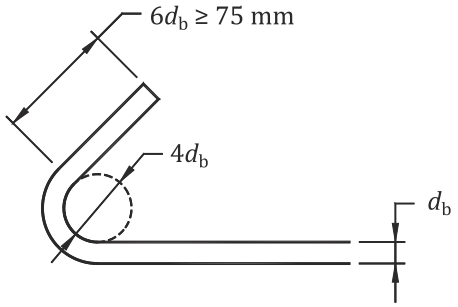


Figure 18 — For confinement stirrups and ties in seismic zones (135° bend plus $6d_b$ extension at free end of bar, but not less than 75 mm)

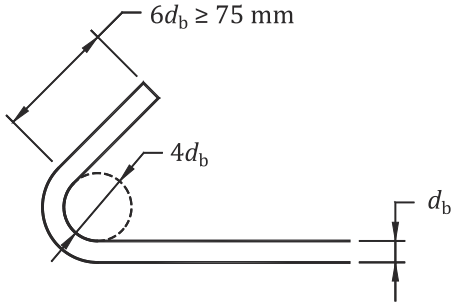


Figure 19 — For crossties in seismic zones (135° bend plus $6d_b$ extension at free end of bar, but not less than 75 mm)

9.8 Bar spacing and maximum aggregate size

9.8.1 General

The clear spacing between parallel bars in a layer and the maximum coarse aggregate size should be interrelated as follows.

9.8.2 Maximum nominal coarse aggregate size

Maximum nominal coarse aggregate size (see Figure 20) should not be larger than:

— 1/5 of the narrowest dimension between sides of forms;

— 1/3 of the depth of slabs; nor

— 3/4 the minimum clear spacing between parallel reinforcing bars or wires.

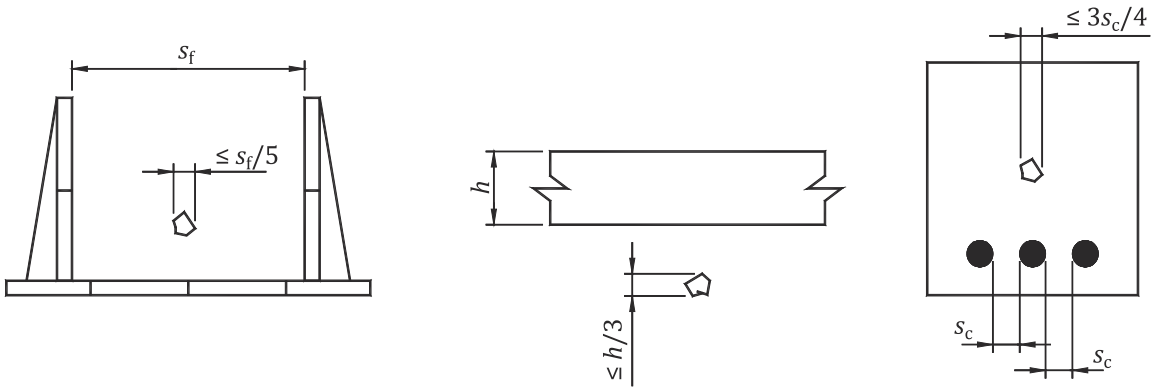


Figure 20 — Maximum nominal coarse aggregate size

9.8.3 Minimum clear spacing between parallel bars in a layer

In solid slabs, girders, beams and joists, the minimum clear spacing between parallel bars in a layer should be the largest nominal bar diameter, d_b, but not less than 25 mm (see Figure 21). This document should apply also for the spacing between parallel stirrups or ties.

9.8.4 Minimum clear spacing between parallel layers of reinforcement

In girders, beams and joists, where parallel reinforcement is placed in two or more layers, bars in the upper layer should be placed directly above bars in the bottom layer with clear distance between layers not less than 25 mm (see Figure 21).

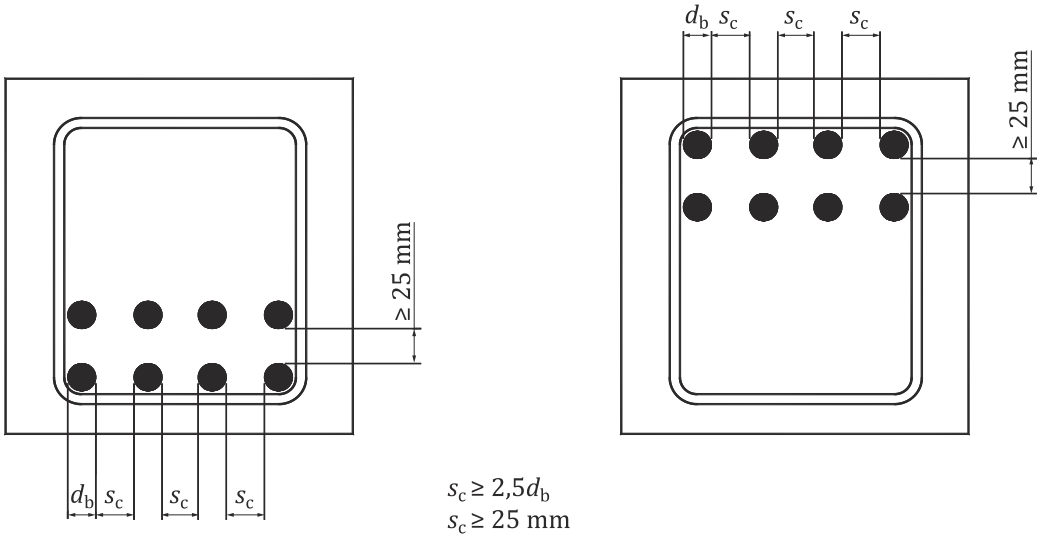


Figure 21 — Minimum clear spacing between parallel bars in a layer and clear distance between parallel layers of reinforcement

9.8.5 Minimum clear spacing between longitudinal bars in columns

In columns, clear distance between longitudinal bars should not be less than $1{,}5d_b$ or 40 mm (see Figure 22).

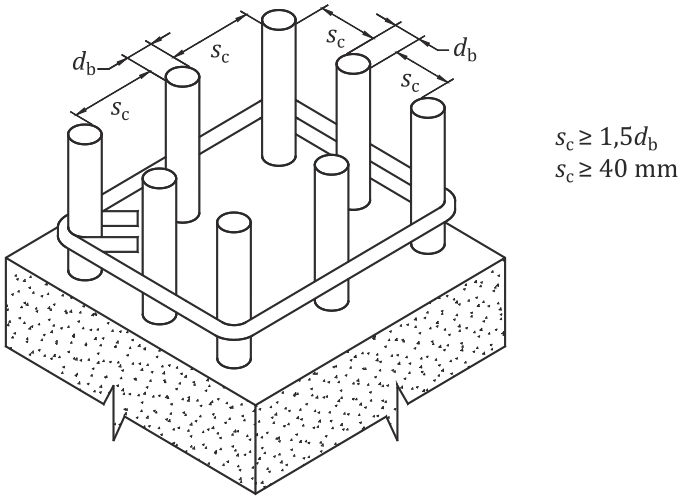


Figure 22 — Clear distance between longitudinal bars in columns

9.8.6 Clear spacing between parallel lap splices

Clear distance limitation between bars should apply also to the clear distance between a contact lap splice and adjacent splices or bars.

9.8.7 Maximum flexural reinforcement spacing in solid slabs

In solid slabs, primary flexural reinforcement should not be spaced farther apart than two times the slab thickness, nor more than 300 mm (see Figure 23).

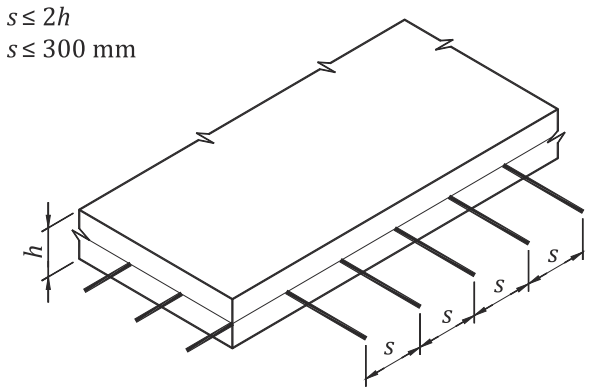


Figure 23 — Spacing between flexural reinforcement in solid slabs

9.8.8 Maximum shrinkage and temperature reinforcement spacing in solid slabs

In slabs, shrinkage and temperature reinforcement should not be spaced farther apart than three times the slab thickness, nor more than 300 mm (see Figure 24).

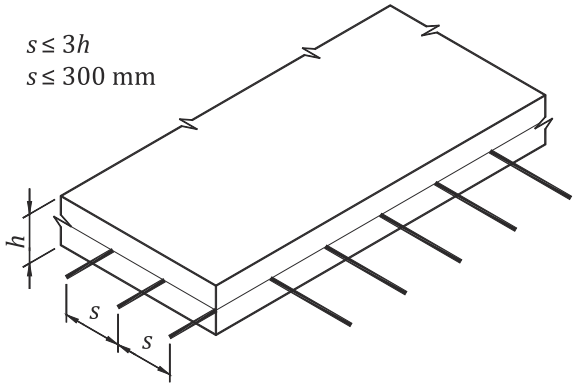


Figure 24 — Spacing between shrinkage and temperature reinforcement in slabs

9.8.9 Maximum reinforcement spacing in structural concrete walls

9.8.9.1 Vertical and horizontal reinforcement

In structural concrete walls, vertical and horizontal reinforcement should not be spaced farther apart than three times the structural concrete wall thickness, nor more than 300 mm (see Figure 25).

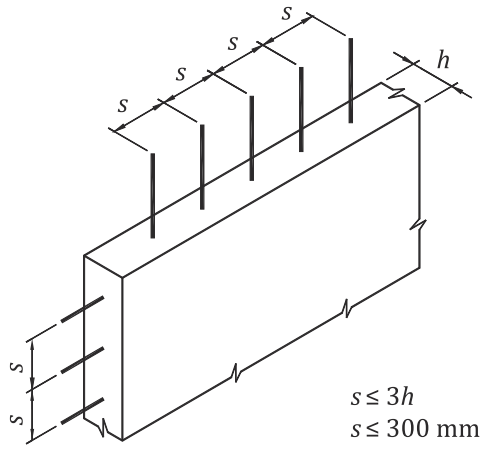


Figure 25 — Spacing between reinforcement in structural concrete walls

9.8.9.2 Number of layers of reinforcement

Structural concrete walls more than 250 mm thick should have vertical and horizontal reinforcement placed in two layers parallel with faces of wall. Each layer should have approximately half of the reinforcement in that direction. The layers should be placed no less than 30 mm nor more than one-third of the thickness of the wall from the surface of the wall. For exterior exposure, the exterior surface layer should be placed no less than 50 mm, instead of the 30 mm prescribed.

9.8.9.3 Special details per element type

The designer should comply with the additional reinforcement detail required for each individual element type.

9.8.10 Minimum spacing of prestressing tendons and ducts

9.8.10.1 Pretensioning strand

The distance between pretensioning strands, including shielded ones, at each end of a member within the transfer length, as specified in 9.9.1.3, shall not be less than a clear distance taken as 1,33 times the maximum size of the aggregate nor less than the centre-to-centre distances specified in Table 18.

Table 18 — Centre-to-centre spacings

Dimensions in millimetres

Strand size	Spacing
15,2	51
12,7 12,4 11,1 10,8	44
9,5 9,3	38

If justified by performance tests of full-scale prototypes of the design, the clear distance between strands at the end of a member may be decreased.

The minimum clear distance between groups of bundled strands shall not be less than 1,33 times the maximum size of the aggregate or 25 mm.

Pretensioning strands in a member may be bundled to touch one another in an essentially vertical plane at and between hold-down locations. Strands bundled in any manner, other than a vertical plane, shall be limited to four strands per bundle.

9.8.10.2 Post-tensioning ducts not curved in the horizontal plane

Unless otherwise specified in this document, the clear distance between straight post-tensioning ducts shall not be less than 38 mm or 1,33 times the maximum size of the coarse aggregate. For precast segmental construction, when post-tensioning tendons extend through an epoxy joint between components, the clear spacing between post-tensioning ducts shall not be less than the greater of the duct internal diameter or 100 mm.

Ducts may be bundled together in groups not exceeding three, provided that the spacing, as specified between individual ducts, is maintained between each duct in the zone within 900 mm of anchorages.

For groups of bundled ducts in construction other than segmental, the minimum clear horizontal distance between adjacent bundles shall not be less than 100 mm. When groups of ducts are located in two or more horizontal planes, a bundle shall contain no more than two ducts in the same horizontal plan.

The minimum vertical clear distance between bundles shall not be less than 38 mm or 1,33 times the maximum size of coarse aggregate.

For precast construction, the minimum clear horizontal distance between groups of ducts may be reduced to 75 mm.

9.8.10.3 Curved post-tensioning ducts

The minimum clear distance between curved ducts shall be as required for tendon confinement as specified in 12.1. The spacing for curved ducts shall not be less than that required for straight ducts.

9.8.11 Maximum spacing of prestressing tendons in slabs

Pretensioning strands for precast slabs shall be spaced symmetrically and uniformly and shall not be farther apart than 1,5 times the total composite slab thickness or 450 mm.

Post-tensioning tendons for slabs shall not be farther apart, centre-to-centre, than 4,0 times the total composite minimum thickness of the slab.

9.8.12 Couplers in post-tensioning tendons

The contract documents shall specify that:

— not more than 50 % of the longitudinal post-tensioning tendons is coupled at one section; and

— the spacing between adjacent coupler locations is not closer than the segment length or twice the segment depth.

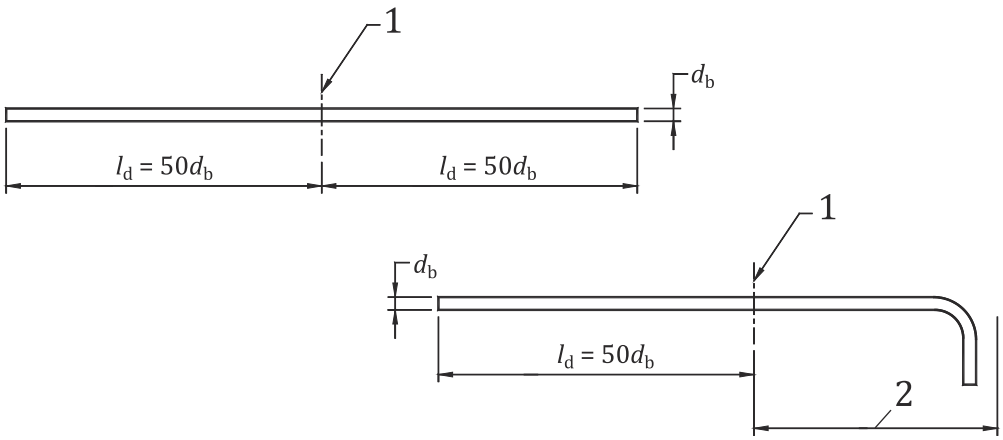
The void areas around couplers shall be deducted from the gross section area and second moment of area when computing stresses at the time post-tensioning force is applied.

9.9 Development length, lap splicing and anchorage of reinforcement

9.9.1 Development length

9.9.1.1 Reinforcing bars

The minimum embedment length, l_d, required on each side of a critical section, for a reinforcing bar to develop its full strength should be $50d_b$, for the bar diameters given in 9.3.11. It should be permitted to replace the development length in one side of the critical section by a length of bar ending in a standard hook complying with the minimum anchorage distance of 9.9.3 (see Figure 26).



Key

1 critical section

2 anchorage distance (see 9.9.3)

Figure 26 — Required development length for reinforcing bars

Whenever plain bars may be used instead of deformed bars, the development length specified here shall be multiplied by 1,8.