Prestressed Concrete

Part 5

(Detailing of reinforcement)

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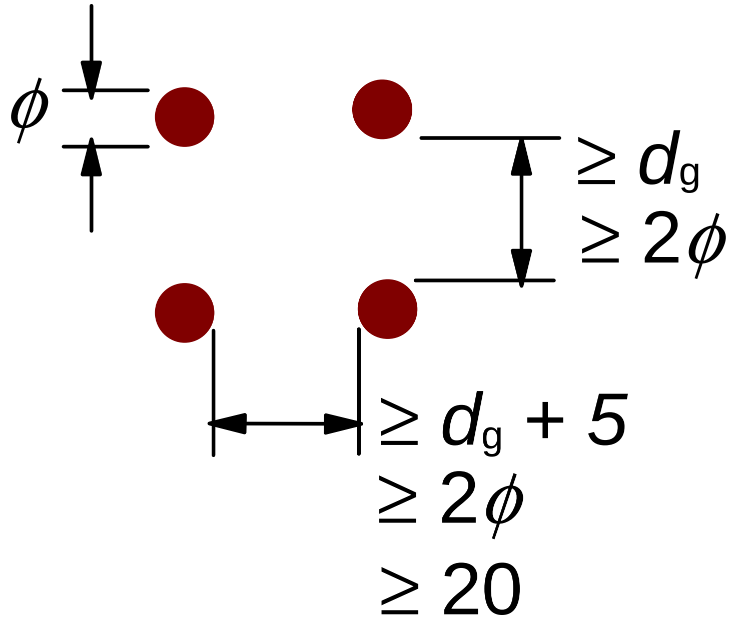
Arrangement of prestressing tendons and ducts

- The spacing of ducts or pre-tensioned tendons shall be such as to ensure:
  - satisfactory placing and compacting of the concrete
  - sufficient bond between the concrete and the tendons
  - durability with respect to danger of corrosion of the tendon at the end of elements
  - fire resistance of the prestressed element

Pre-tensioned tendons

- The minimum clear horizontal and vertical spacing of individual pre-tensioned tendons should be used provided that test results show satisfactory ultimate behaviour with respect to:
  - the concrete in compression at the anchorage
  - the spalling of concrete
  - the anchorage of pre-tensioned tendons
  - the placing of the concrete between the tendons.

Consideration should also be given to durability and the danger of corrosion of the tendon at the end of elements.



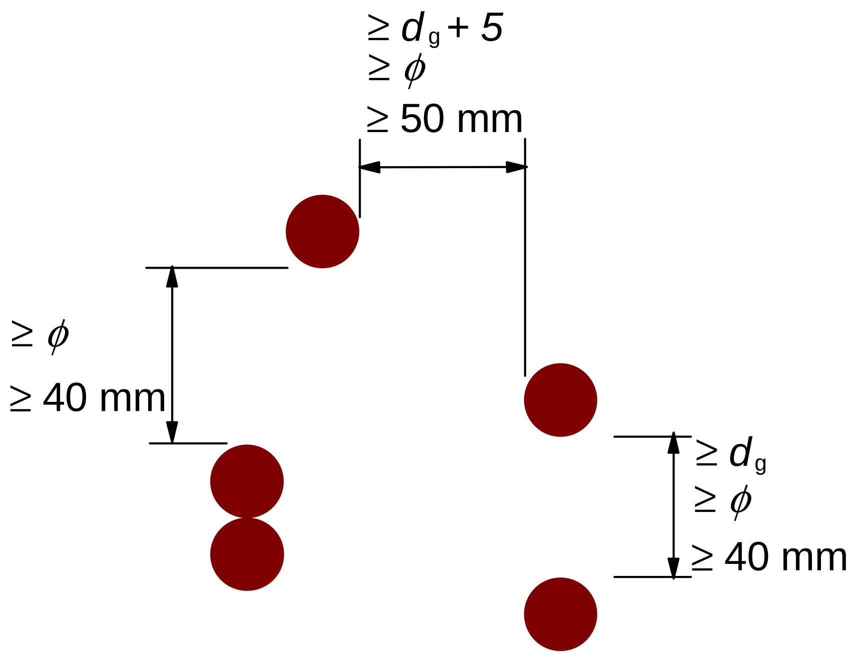
Note: Where ϕ is the diameter of pre-tensioned tendon and d_g is the maximum size of aggregate.

Minimum clear spacing between pre-tensioned tendons

Post-tension ducts

- The ducts for post-tensioned tendons shall be located and constructed so that:
  - the concrete can be safely placed without damaging the ducts;
  - the concrete can resist the forces from the ducts in the curved parts during and after stressing;
  - no grout will leak into other ducts during grouting process.

Ducts for post-tensioned members should not normally be bundled – except of a pair of ducts placed vertically one above the other

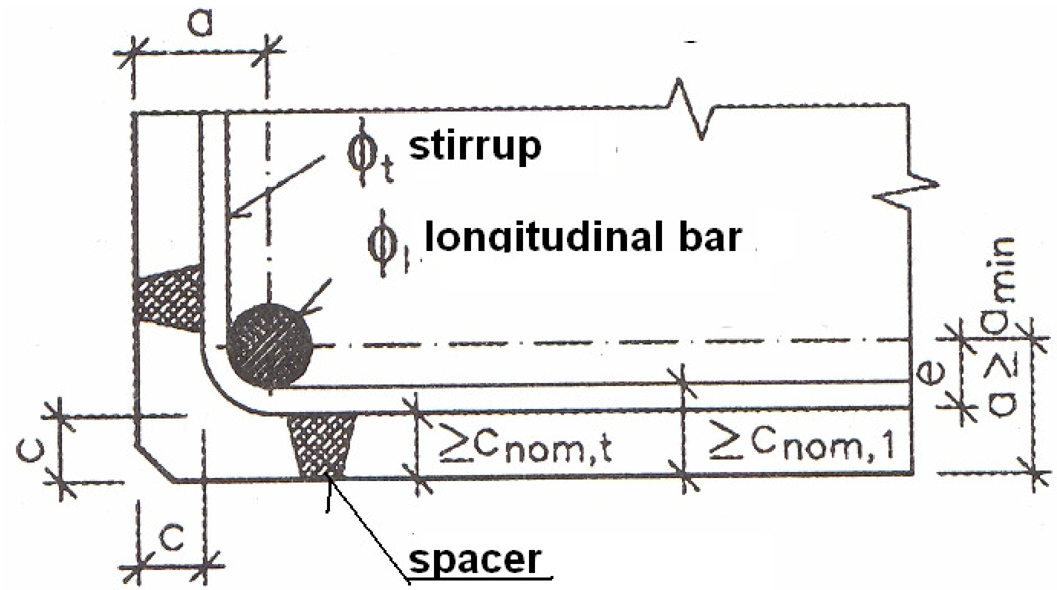


Note: Where ϕ is the diameter of post-tension duct and d_g is the maximum size of aggregate.

Minimum clear spacing between ducts

Durability and cover to reinforcement

Concrete cover – distance between the surface of the reinforcement closest to nearest concrete surface (including stirrups etc.)



$$c_{nom} = c_{min} + \Delta c_{dev}$$

Δc_{dev} - allowance in design for deviation ~ 10 mm

Check also fire resistance: $a \geq a_{min}$ – see EN 1992-1-2

$$c_{nom} = c_{min} + \Delta c_{dev}$$

- $c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10\text{ mm}\}$

where:

$c_{min,b}$ minimum cover due to bond requirement

$c_{min,dur}$ minimum cover due to environmental conditions

$\Delta c_{dur,\gamma}$ additive safety element, usually ≈ 0

$\Delta c_{dur,st}$ reduction of minimum cover for use of stainless steel, usually ≈ 0

$\Delta c_{dur,add}$ reduction of minimum cover for use of additional protection, usually ≈ 0

- The recommended values of $c_{min,b}$ minimum cover due to bond requirement:
- for post-tensioned circular and rectangular ducts:
  - circular ducts: diameter
  - rectangular ducts: greater of the smaller dimension or half the greater dimension

  There is no requirement for more than 80 mm for either circular or rectangular ducts.
- for pre-tensioned tendon:
  - 1,5 x diameter of strand or plain wire
  - 2,5 x diameter of indented wire.

The values for $c_{min,dur}$ - minimum cover due to environmental conditions

The minimum cover due to environmental conditions take account of the exposure classes (see Table A) and the structural classes.

Structural classification and values of $c_{min,dur}$ for use in a Country may be found in its National Annex.

The recommended Structural Class (design working life of 50 years) is S4 for the indicative concrete strengths given in Annex E (see Table E); the recommended modifications to the structural class is given in Table B. The recommended minimum Structural Class is S1.

The recommended values of $c_{min,dur}$ are given in Table C (reinforcing steel) and Table D (prestressing steel).

Table A: Exposure classes related to environmental conditions in accordance with EN 206-1

Corrosion of reinforcement

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2

Table A - continue

Corrosion of reinforcement

3 Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Car park slabs
4 Corrosion induced by chlorides from sea water		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures

Table A - continue

Damage of concrete

5. Freeze/Thaw Attack		
XF1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agents	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation with de-icing agents or sea water	Road and bridge decks exposed to de-icing agents Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zone of marine structures exposed to freezing
6. Chemical attack		
XA1	Slightly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA2	Moderately aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA3	Highly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water

Table A – Notes

Note: The composition of the concrete affects both the protection of the reinforcement and the resistance of the concrete to attack. Annex E gives indicative strength classes for the particular environmental exposure classes. This may lead to the choice of higher strength classes than required for the structural design. In such cases the value of f_{ctm} should be associated with the higher strength in the calculation of minimum reinforcement and crack width control.

Table E: Indicative strength classes

	Exposure Classes according to Table 4.1									
Corrosion of reinforcement										
	Carbonation-induced corrosion				Chloride-induced corrosion			Chloride-induced corrosion from sea-water		
	XC1	XC2	XC3	XC4	XD1	XD2	XD3	XS1	XS2	XS3
Indicative Strength Class	C20/25	C25/30	C30/37		C30/37		C35/45	C30/37	C35/45	
Damage to Concrete										
	No risk	Freeze/Thaw Attack			Chemical Attack					
	X0	XF1	XF2	XF3	XA1	XA2	XA3			
Indicative Strength Class	C12/15	C30/37	C25/30	C30/37	C30/37		C35/45			

Table B: Recommended modification of structural classification

•Structural Class							
Criterion	Exposure Class according to Table A						
	X0	XC1	XC2 / XC3	XC4	XD1	XD2 / XS1	XD3 / XS2 / XS3
Design Working Life of 100 years	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2
Strength Class [1) 2)]	≥ C30/37 reduce class by 1	≥ C30/37 reduce class by 1	≥ C35/45 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C45/55 reduce class by 1
Member with slab geometry (position of reinforcement not affected by construction process)	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1
Special Quality Control of the concrete production ensured	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1

Notes to Table B:

1. The strength class and w/c ratio are considered to be related values. A special composition (type of cement, w/c value, fine fillers) with the intent to produce low permeability may be considered.
2. The limit may be reduced by one strength class if air entrainment of more than 4% is

Table C: Values of minimum cover, $c_{min,dur}$, requirements with regard to durability for reinforcement steel in accordance with EN 10080

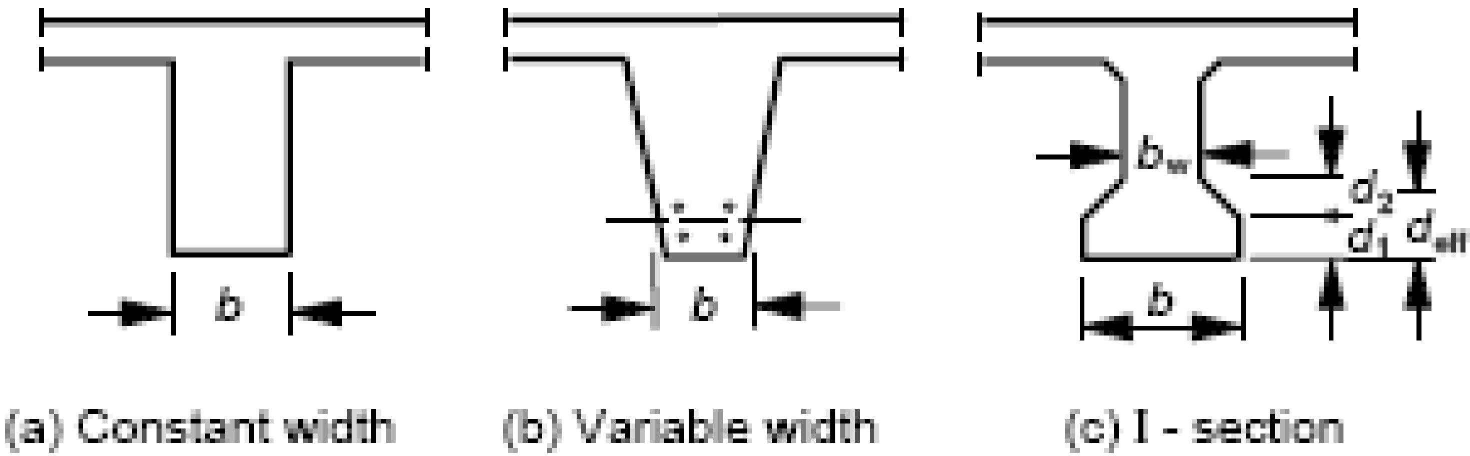
Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table A						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4	10	15	25	30	35	40	45
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

Table D: Values of minimum cover, $c_{min,dur}$, requirements with regard to durability for prestressing steel in accordance with EN 10138

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table A						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	15	20	25	30	35	40
S2	10	15	25	30	35	40	45
S3	10	20	30	35	40	45	50
S4	10	25	35	40	45	50	55
S5	15	30	40	45	50	55	60
S6	20	35	45	50	55	60	65

Fire resistance of the prestressed elements
- tabulated data

b



a

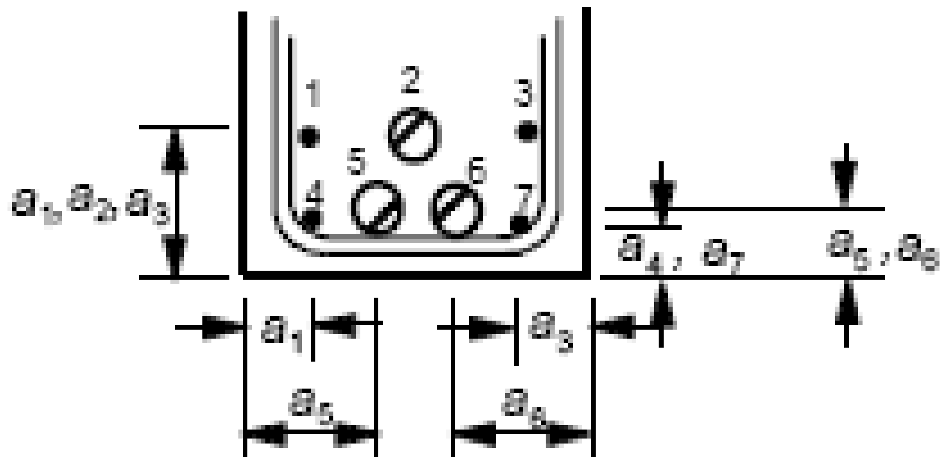


Table 5.5: Minimum dimensions and axis distances for simply supported beams made with reinforced and prestressed concrete

Standard fire resistance	Minimum dimensions (mm)						
	Possible combinations of a and b_{min} where a is the average axis distance and b_{min} is the width of beam				Web thickness b_w		
					Class A	Class B	Class C
1	2	3	4	5	6	7	8
R 30	b_{min}= 80 a = 25	120 20	160 15*	200 15*	80	80	80
R 60	b_{min}= 120 a = 40	160 35	200 30	300 25	100	100	100
R 90	b_{min}= 150 a = 55	200 45	300 40	400 35	110	100	100
R 120	b_{min}= 200 a = 65	240 60	300 55	500 50	130	120	120
R 180	b_{min}= 240 a = 80	300 70	400 65	600 60	150	150	140
R 240	b_{min}= 280 a = 90	350 80	500 75	700 70	170	170	160
a_{sd} = a + 10mm (see note below)							

For prestressed beams the increase of axis distance according to 5.2(5) should be noted.

a_{sd} is the axis distance to the side of beam for the corner bars (or tendon or wire) of beams with only one layer of reinforcement. For values of b_{min} greater than that given in Column 4 no increase of a_{sd} is required.

* Normally the cover required by EN 1992-1-1 will control.

Brittle failure should be avoided

by one or more of the following methods:

Method A: Provide minimum reinforcement.

Method B: Provide pretensioned bonded tendons.

Method C: Provide easy access to prestressed concrete members in order to check and control the condition of tendons by non-destructive methods or by monitoring.

Method D: Provide satisfactory evidence concerning the reliability of the tendons.

Method E: Ensure that if failure were to occur due to either an increase of load or a reduction of prestress under the frequent combination of actions, cracking would occur before the ultimate capacity would be exceeded, taking account of moment redistribution due to cracking effects.

Note: The selection of Methods to be used in a Country may be found in its National Annex.

The minimum reinforcement

$$A_{s,min} = M_{rep} /(z_s.f_{yk})$$

M_{rep} is the cracking moment calculated assuming a tensile stress equal to f_{ctm} at the extreme tension fibre of the section, ignoring any effect of prestressing,

z_s the lever arm at ULS related to the reinforcing steel.

a) Tendons with concrete cover $k_{cm}.c$ are considered as effective in $A_{s,min}$. A value of z_s based on effective strands is used and f_{yk} is replaced with $f_{p0,1k}$. The recommended value $k_{cm} = 2$.

b) Tendons subjected to stresses lower than $0,6f_{pk}$ after losses under characteristic combination of actions are considered as fully active. In this case

$$A_{s,min}f_{yk} + A_p \Delta\sigma_p \geq M_{rep} / z_s$$

where $\Delta\sigma_p$ is the smaller of $0,4\,f_{pk}$ and 500 MPa.