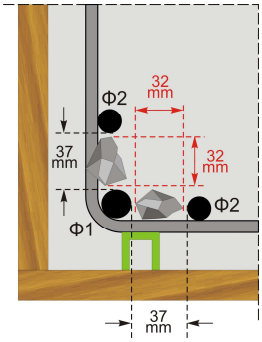
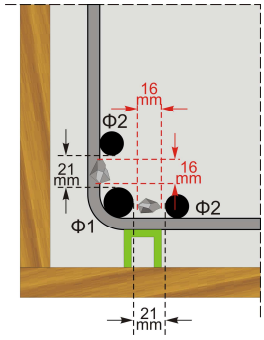
2.6.2 Minimum spacing between reinforcement bars

The distance among reinforcement bars must be such to allow the concrete's gravel to pass between them. In order to have properly anchored reinforcement, it is mandatory for rebars to be surrounded by concrete.

The minimum spacing between two reinforcement bars should be at least equal to the maximum aggregate grain dimension with a margin of 5 mm. For Greece, the maximum aggregate grains dimension for usual concrete, is 32 mm and for self compacting concrete is 16 mm.

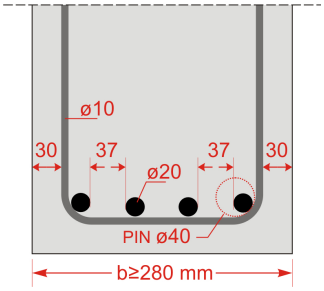


Usual Concrete



Self Compacting Concrete

Example:

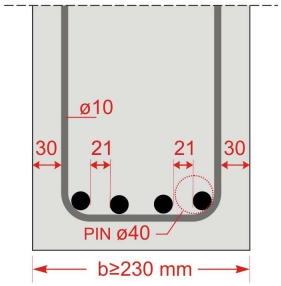


Usual Concrete

Beam **4Ø20**

Stirrups Ø10

Coating =30 mm



Self Compacting Concrete

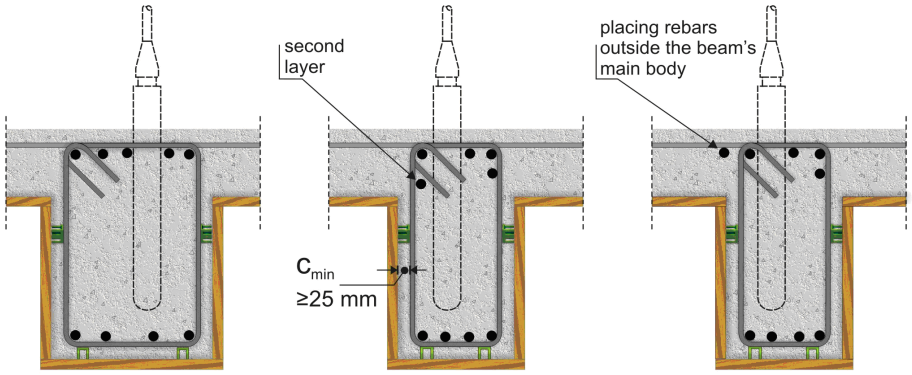
Beam **4Ø20**

Stirrups Ø10

Coating =30 mm

These spacing requirements are easily met in slabs and columns. However in beams extra attention must be paid mainly to the support and the joint areas. The problem in beams is related to the concrete's casting and it can be dealt with three different ways or in certain occasions with a combination of them.

For satisfactory results it is very important not only to use the vibrator in the proper way but also to avoid over-vibrating the concrete of the elements.



a) *Large beam width*

b) *Use of the second layer, which is placed in contact with the stirrups.*

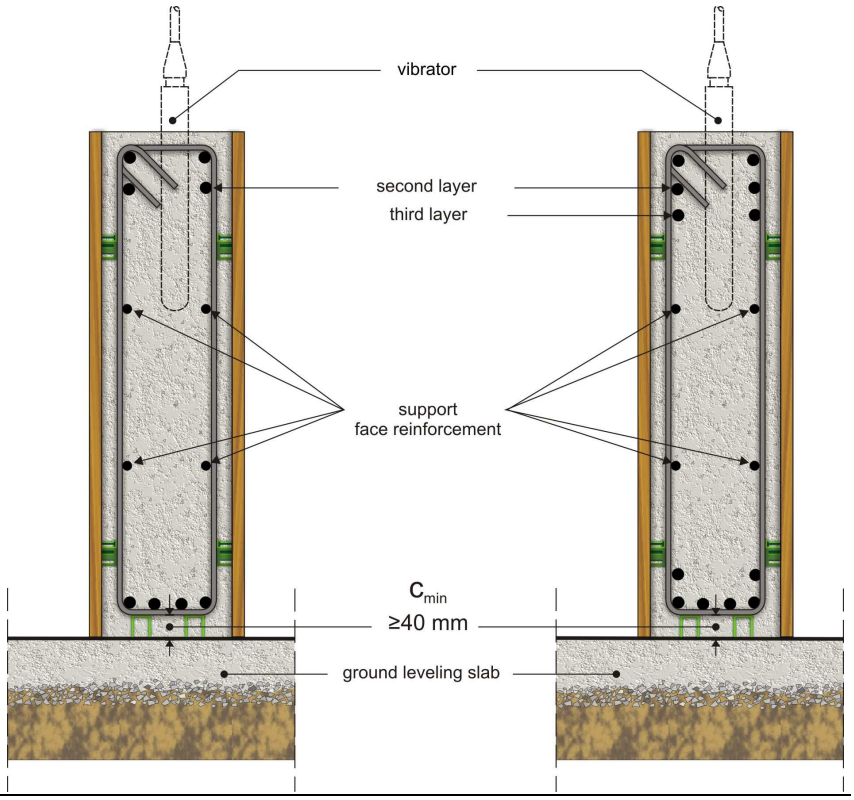
c) By placing rebars on both outer sides of the beam's main body.

It is allowed to place 25% of the total reinforcement outside the beam's main body.

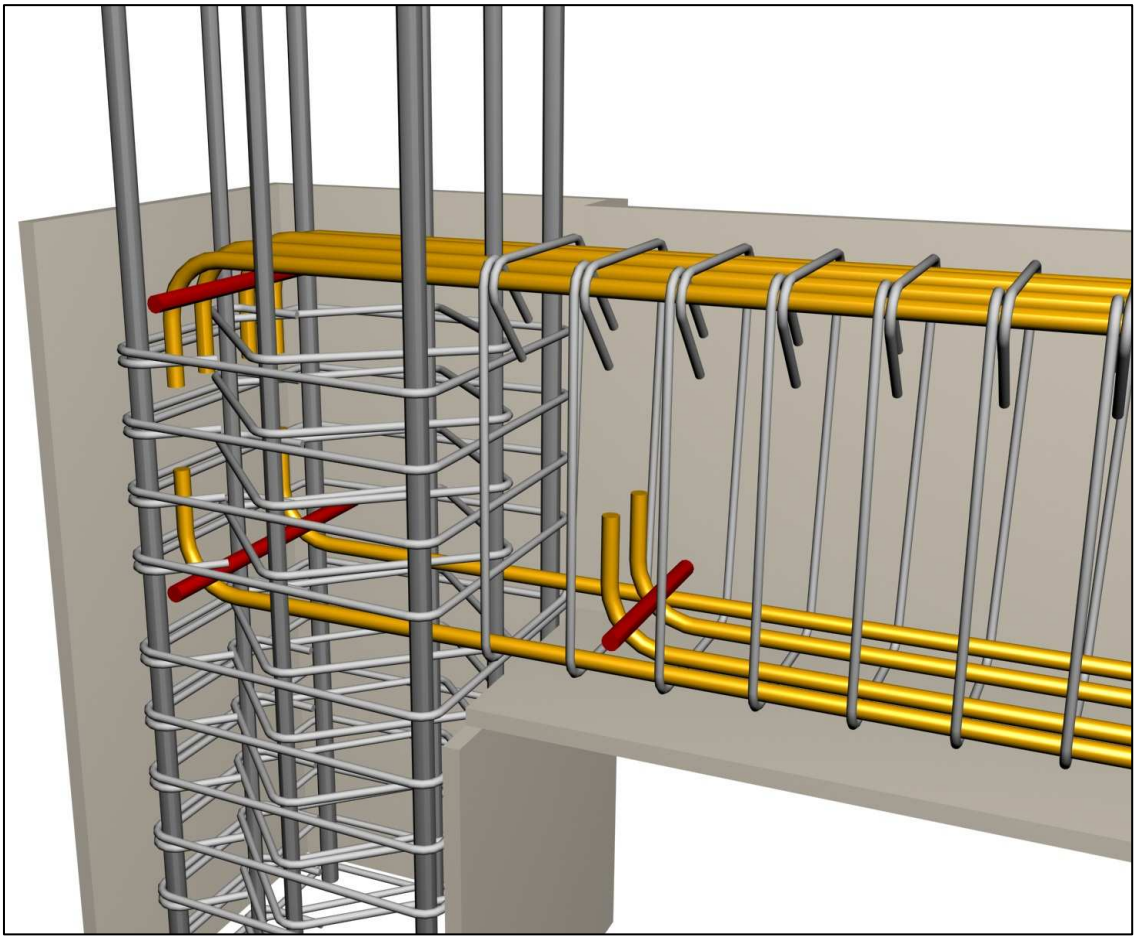
Connecting beams in foundation

Concrete casting in foundation connecting beams is not an easy procedure. These beams are not fixed together with a slab as are superstructure beams; consequently concrete has to be purred down the beam's tight top opening and reach the bottom side.

Because of the fact that connecting beams normally have a large height as well as a large internal lever, it is preferable to place rebars in two or even three layers along their height.

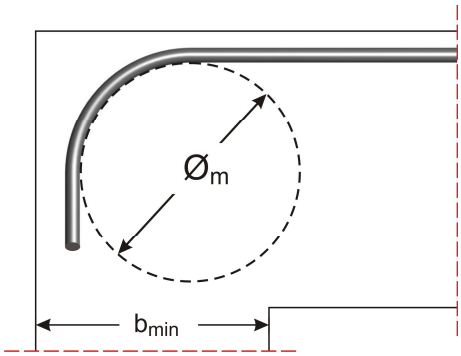


Simple hook anchorage



As far as the bar anchorage for slabs or beams is refereed to as 'simple hook anchorage' then metal pins should be placed in the bending areas with a diameter ≥Ø

Anchorage with drum

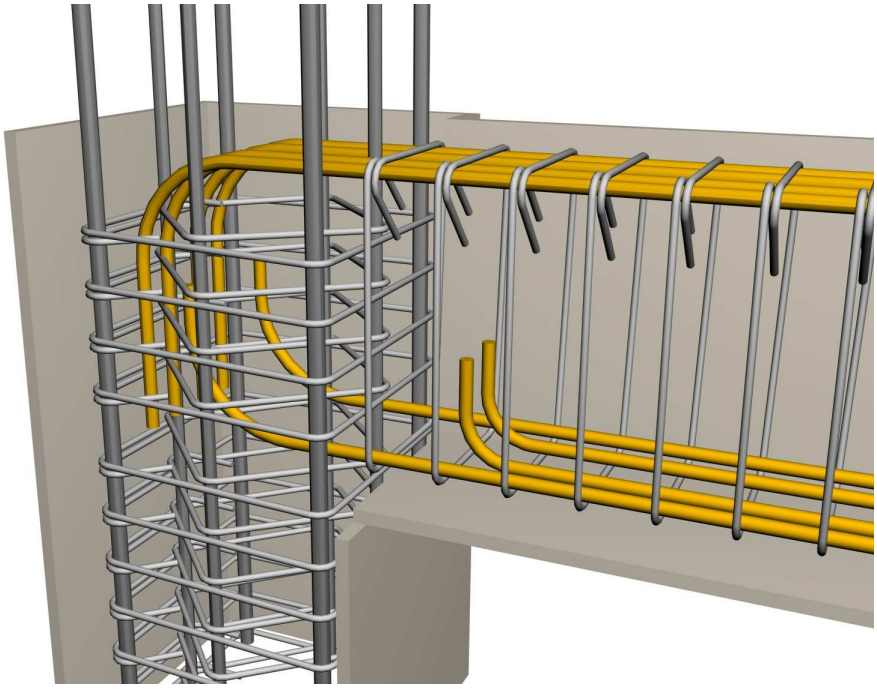


In columns that have a small dimension in the anchorage direction, (see the table below) the bending is implemented with the use of a large diameter drum.

The minimum diameter of the drum is inversely proportional to the strength of the concrete and proportional to the steel strength.

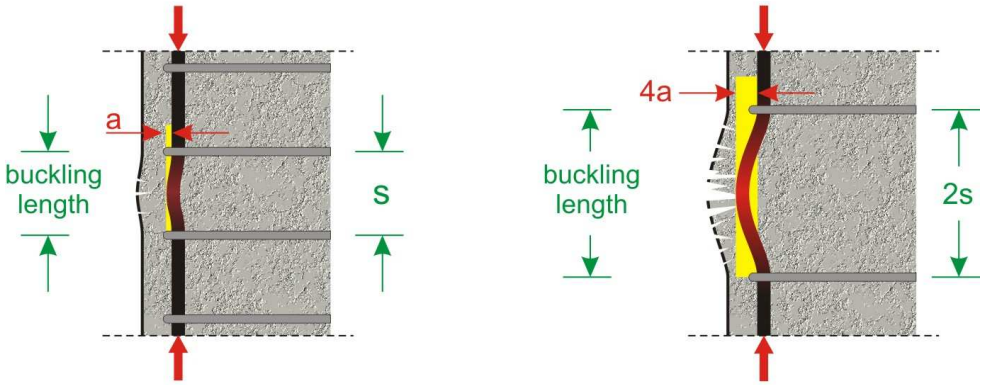
For grade C30/37 concrete and B500 steel, for various bar diameters, the minimum bending drum diameter and the minimum column dimension are displayed in the following table.

	Ø (mm)	14	16	18	20	22	25	28	32	40
C30/37	Minimum Drum Diameter $Ø_m$ (mm)	190	220	250	290	330	390	450	530	700
	Minimum Column Dimensions b_{min} (mm)	220	250	280	310	340	390	440	500	640



Anchorage with drum in a small sized column.

A column with 10% fewer rebars has around 10% lower capacity strength. However, if we remove even a single intermediate stirrup, the capacity strength of that same column will be lowered even by 50%. This happens because the stirrup's removal doubles the buckling length of the rebars previously enclosed by it.



In a seismic event, columns always fail in the same way:

a. When stirrups open, concrete disintegration in the column's head or foot occurs.

b. Once the stirrups' ends become apart, longitudinal reinforcement buckling and concrete disintegration take place.

That type of failure does not appear only to columns dimensioned according to old regulations and therefore have fewer rebars but also to newer columns with large amount of reinforcement, when they are not constructed according to the correct specifications:

a. with internal and external stirrup adequacy,

b. with correctly formed, antiseismic stirrups.

Throughout the world, structures collapse even when they have a large amount of reinforcement. The reason for this is always the same; lack of properly shaped and placed stirrups.

During a seismic event intense forces are applied to both concrete and reinforcement bars. These forces cause the lateral enlargement of the former and the buckling of the latter up to the point of their fracture.

Typical failure of a column's upper part.

The earthquake resistance of beams and columns depends mainly upon their vertical reinforcement. Stirrups ensure the confinement of the rebars fitted inside them and the integrity of the concrete that tends to spall due to lateral enlargement. If stirrups are not properly anchored they may open even in low intensity seismic events.

Failure of a column dimensioned according to old regulations that required a peripheral stirrup with its end bent in 90° instead of 135° (45°).

Generally column failure is induced by rebar buckling which leads to the fracture of longitudinal reinforcement. When there is adequate confinement, buckling length equals the distance between the stirrups. However in cases of loose end stirrups (open stirrups), according to the Greek Code, buckling length may reach twice or three times the stirrups' spacing in the critical duration of an earthquake.