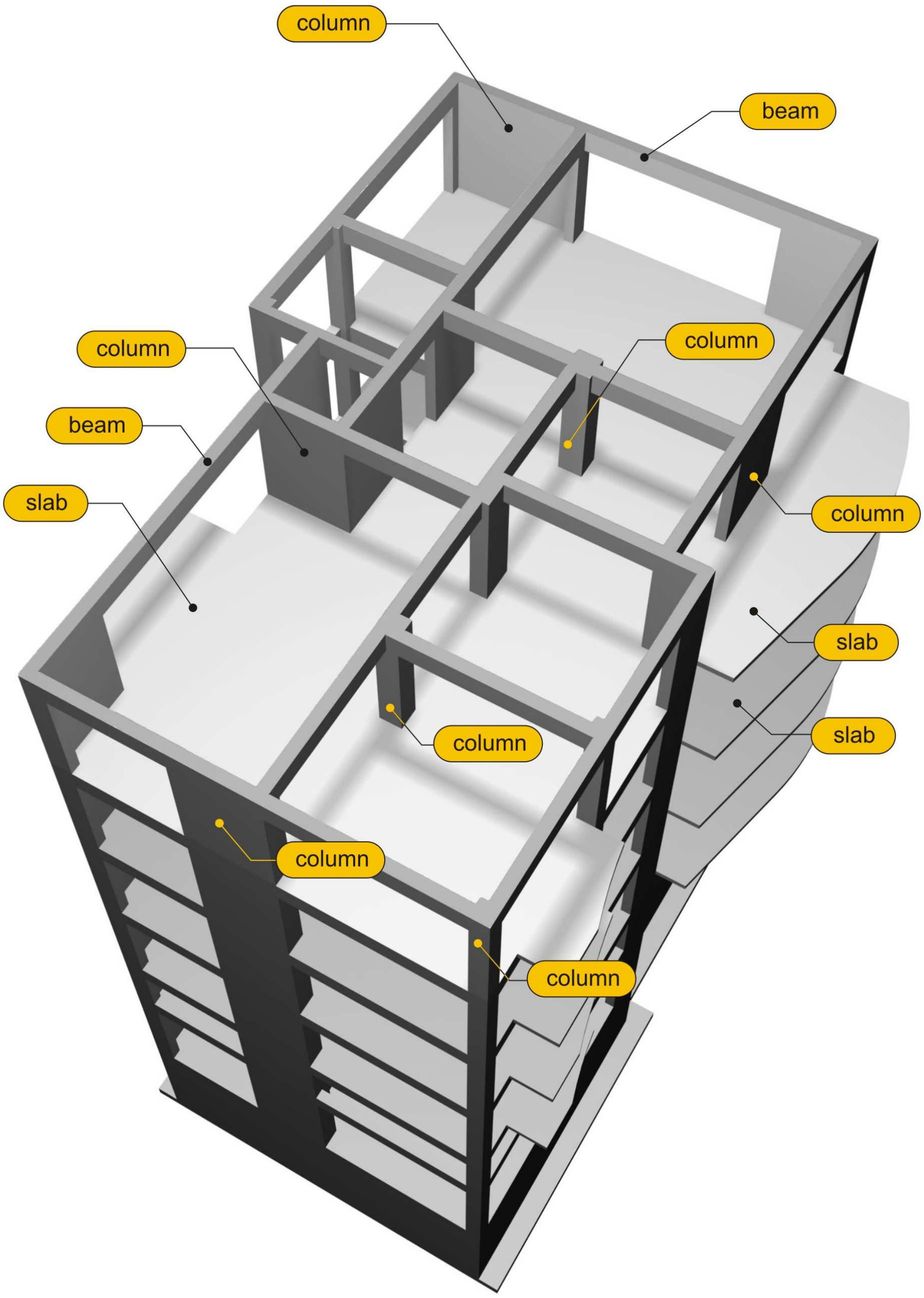
The following photorealistic figure shows the structural frame of the above building (the slabs of the upper storey have been removed in order to allow for the optical presentation of all elements.

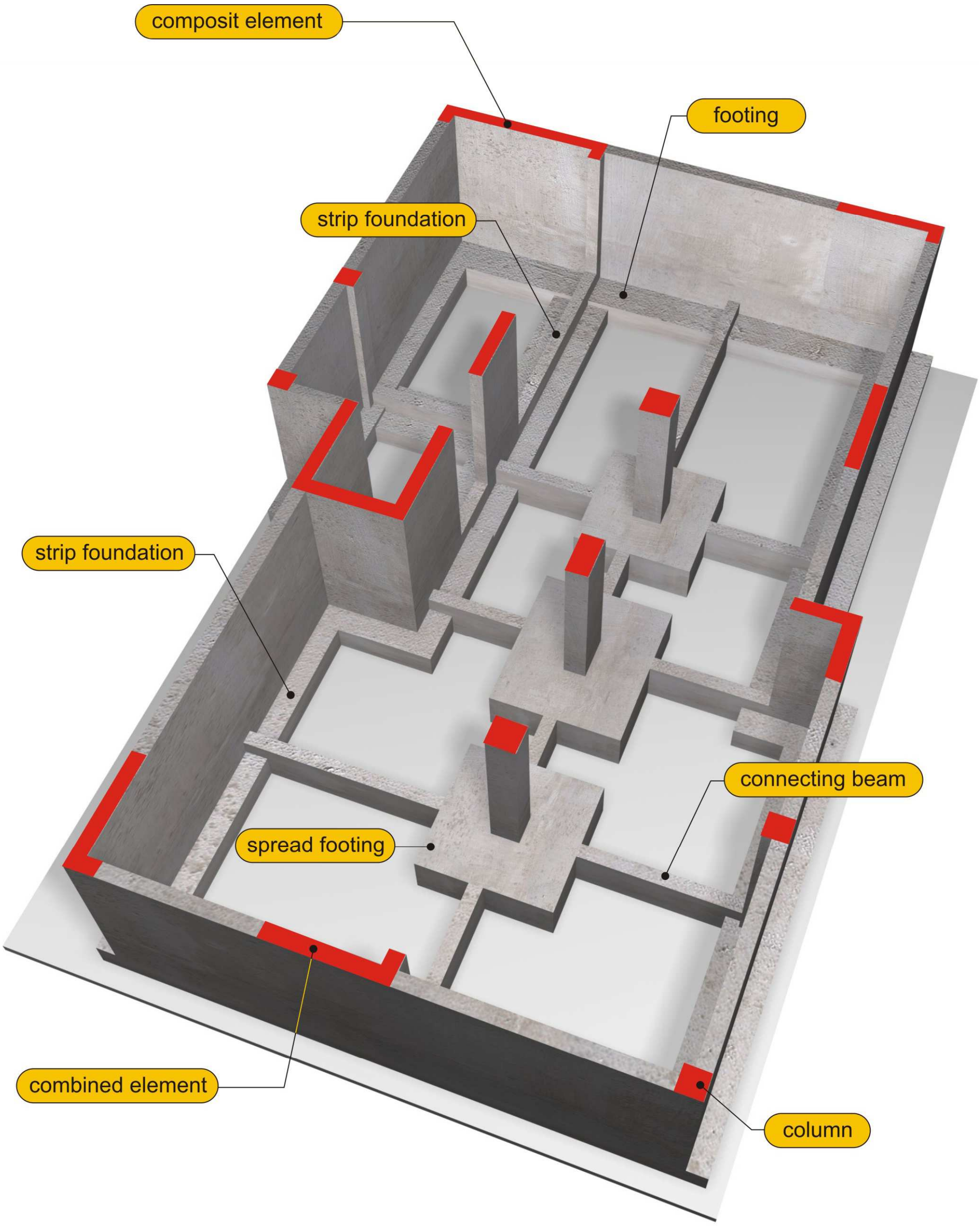


Structural frame <project bkENG> [1]

The horizontal load bearing elements include the **slabs** and the **beams**. The vertical load bearing elements consist of the **columns.**

[1] *The project <bkENG>, due to its size, runs only to the professional version of the included software.*

The following photorealistic figure shows the **foundation** of the building.



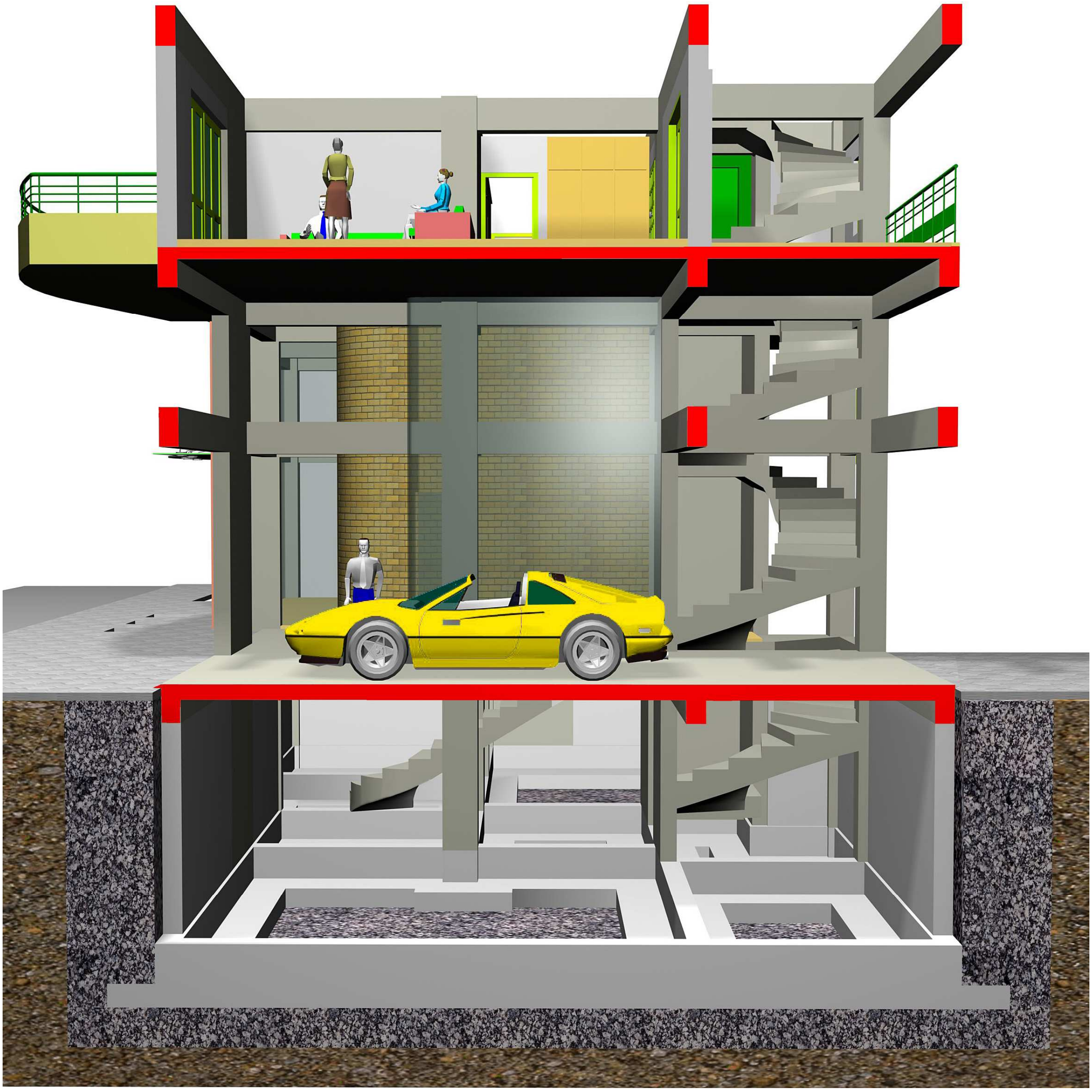
Structure's foundation

The foundation elements of this building are the **spread footings**, the **Foundation beams** and the **strip foundation**.

Other types of foundation may be the **raft foundation** (raft slab foundation) and the **piles**.

1.3 STRUCTURAL FRAME LOADING

The structural frame is designed to withstand, in a constant basis, the vertical gravitational loads (self weight, masonry walls, floor coverings, cars, furniture, people etc) and not in a continuous but in a periodical basis, the wind and snow actions. Moreover it must always bear the “self induced” loadings caused by temperature changes etc.



In every building like the one shown in the above figure, permanent (dead) and imposed (live) loads are applied. The latter are much lower than the former, for example 3 persons and the living-room furniture weight as much as a single m^2 of slab surface while a car weights as much as a sole beam.

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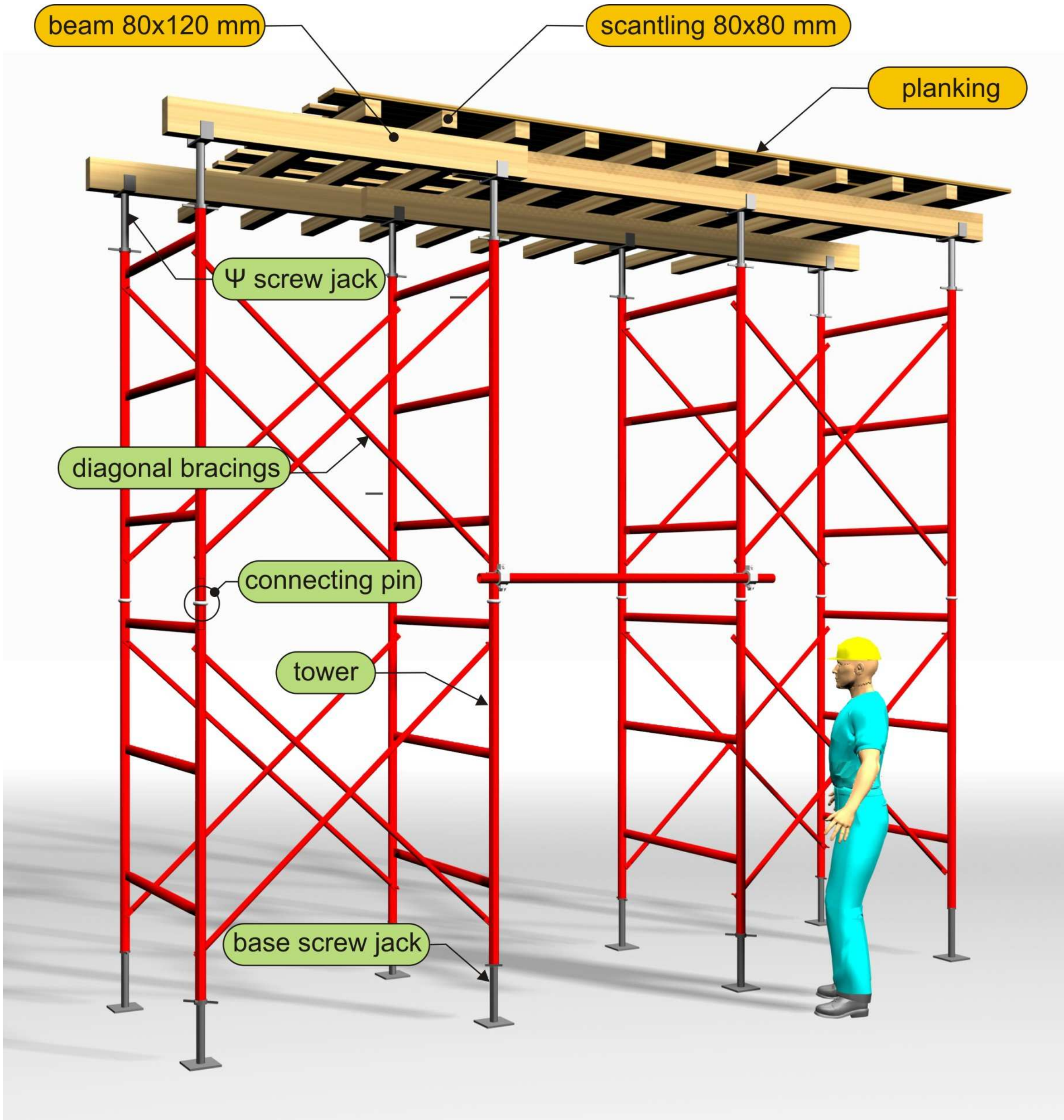
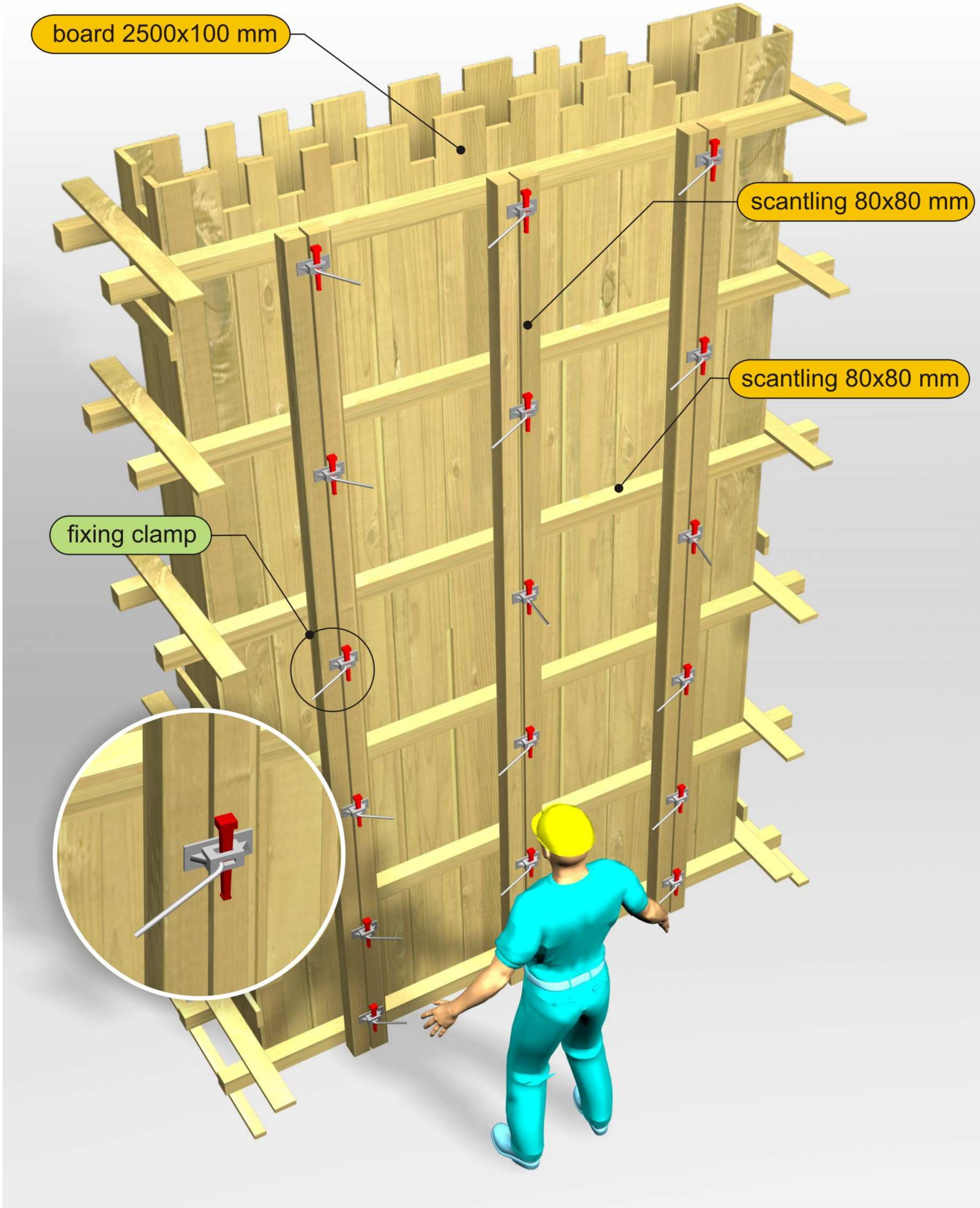
2.2 The moulds



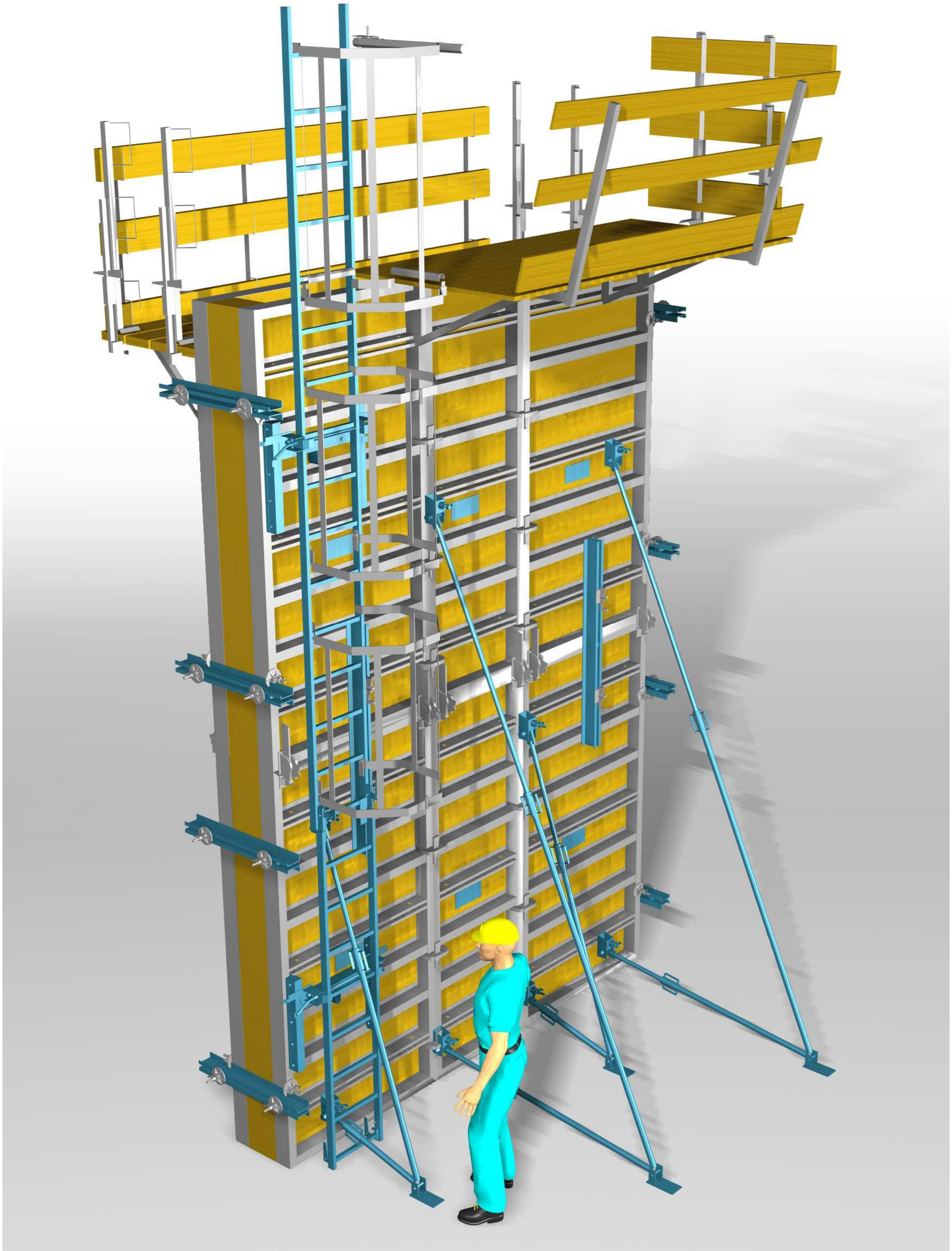
The elements of the moulds used for the formation of structural reinforced concrete members are separated in four categories:

1. Surface elements or **planking**
2. Horizontal bearing elements or **beams**
3. **Scaffolds** or staging
4. Accessories like connectors



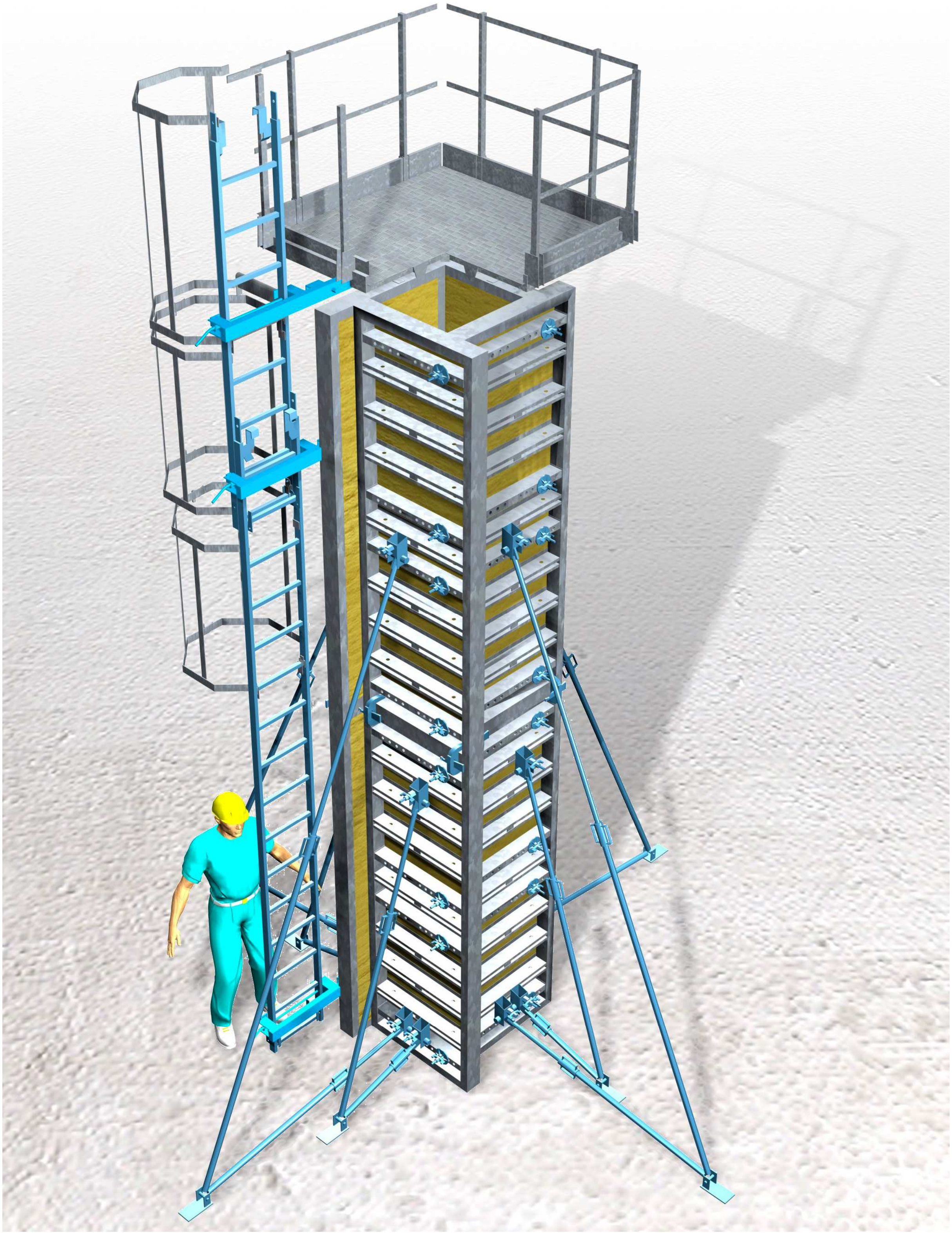
The mould elements might be conventional or industrialized. The former are mainly made out of natural timber and based on their section dimensions they are called:

- **boards** with a usual thickness of 22 mm, width ranging from 80 to 150 mm, and length varying between 2.30 and 4.50 m
- **scantling** (wooden joist) with a typical cross-section 80x80 mm and lengths ranging from 2.30 up to 4.50 m



Shear wall moulding with the use of industrial metalwork

Assembling the formwork of a 5.50 m high shear wall and positioning the working platform requires only a few minutes. Removing that formwork requires even less time and it is a fast and safe procedure.



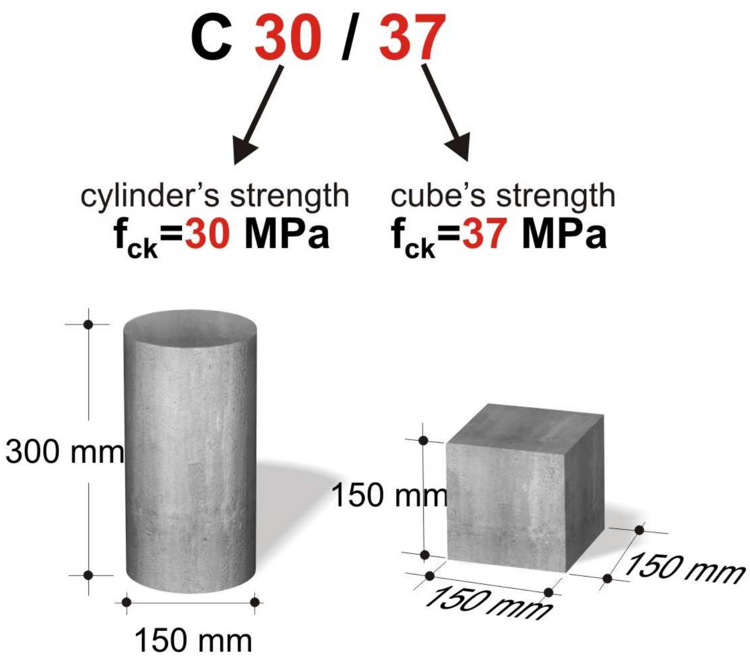
Column moulding with the use of industrial metalwork

This column is 5.50 m high and its formwork is quickly created by assembling formwork pieces with dimensions divided by 50 mm. These pieces are tied together with butterfly valves, placed in predefined positions. The formwork is temporarily supported by light-weight diagonal struts.

2.4 Concrete

2.4.1 General information

Concrete is composed by pitchers, gravels, sand, cement and water. It is created by blending these materials in measured amounts and stirring the mixture for a short period of time. The concrete’s main characteristic is the fact that it hardens within a few hours from its casting; moreover it gains a large amount of strength over the initial following days. Depending upon additional properties that the concrete is required to have, special admixtures may be added during the mixing process. These may be retarding admixtures or/and super-plasticizers for improving concrete’s **workability** or even steel or other composite fibers in order to increase the mixture’s compressive and tensile strength.



The classification of concrete grades is based on their compressive strength. Each concrete grade (Concrete) e.g. C30/37 is characterized by two equivalent strengths, which in this specific example are 30 MPa and 37 MPa. The first is the **characteristic strength f_{ck}** of a standard concrete cylinder[4] and the latter is the characteristic strength of a standard concrete cube.

The concrete grades mentioned in Eurocode 2 and EN 206-1, are:

C12/15	C16/20	C20/25	**C25/30**	**C30/37**	**C35/45**	**C40/50**	**C45/55**	**C50/60**	C55/67	C60/75	C70/85	C80/95	C90/105
Secondary Uses				Usual Uses					Special Uses				

According to Eurocodes, the minimum suggested concrete grade is that of C30/37.

[4] This is the compressive strength used in the design

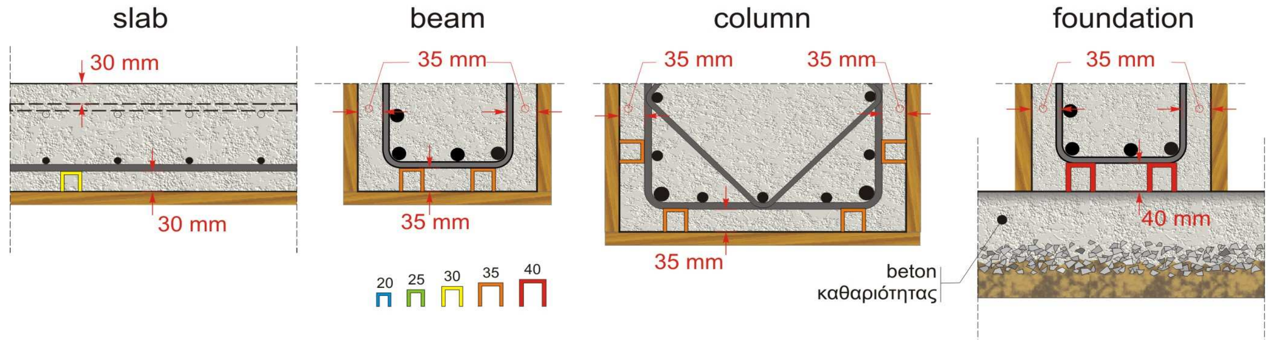
The protection of reinforcement steel against corrosion depends about its porosity and the quality and the thickness of the concrete coating. The density and quality of the concrete is achieved with the use of the suggested concrete grade. The following table demonstrates the combination of the suggested coating in conjunction to the concrete grade for the most usual environmental conditions.

	Environmental Conditions Category			
	Usual Conditions (XC2/XC3)	Extreme Conditions (XC4)	Sea side conditions (XD1/XS1)	**Pools** (XD2)
Suggested Concrete Grade	C30/37	C30/37	C30/37	C30/37
Minimum Coating	25 mm	30 mm	35 mm	40 mm
Suggested Favorable Concrete Grade	C35/45	C40/50	C40/50	C40/50
Minimum Coating	20 mm	25 mm	30 mm	35 mm

Minimum concrete coating of reinforcement steel and minimum suggested concrete grade

- In slabs 5 mm are subtracted
- In case of quality assured concrete production procedure 5 mm are subtracted m.
- In cases of a designed life span for the building of 100 years, 10 mm are added.
- In the surfaces of the footings - with cast concrete – that are in contact with the ground and there is an adequate ground formation or a footing mix layer, the minimum coatings must be ≥40 mm,. If there is no footing mix layer or ground formation, the minimum coatings must be ≥75 mm.

<u>Example:</u>



Construction in sea side area with a concrete grade of C30/37

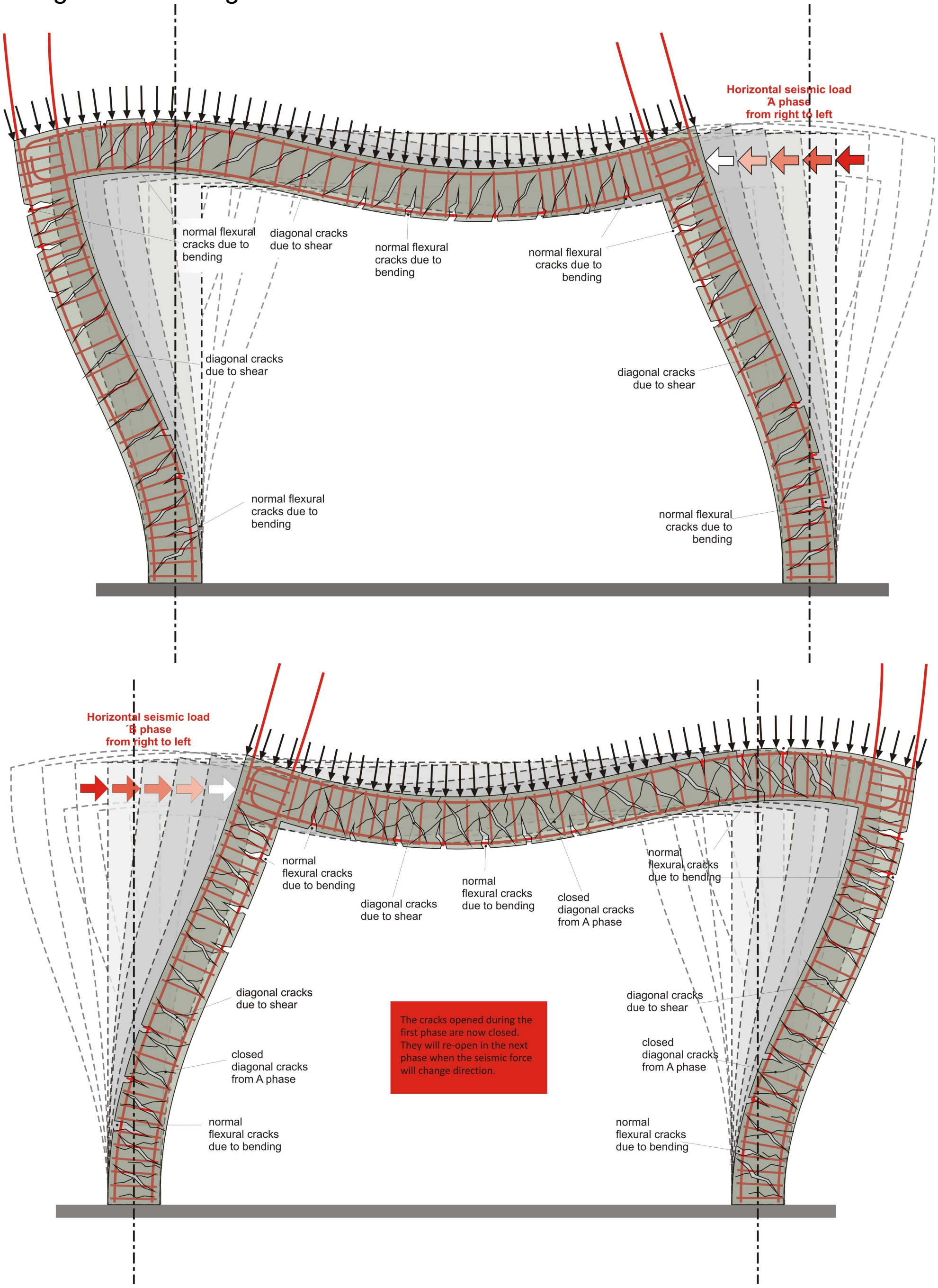
Fundamental rules in the reinforcement of antiseismic structural systems

The following needs – rules regarding the proper placement of reinforcement, derive from the behavior of structures:

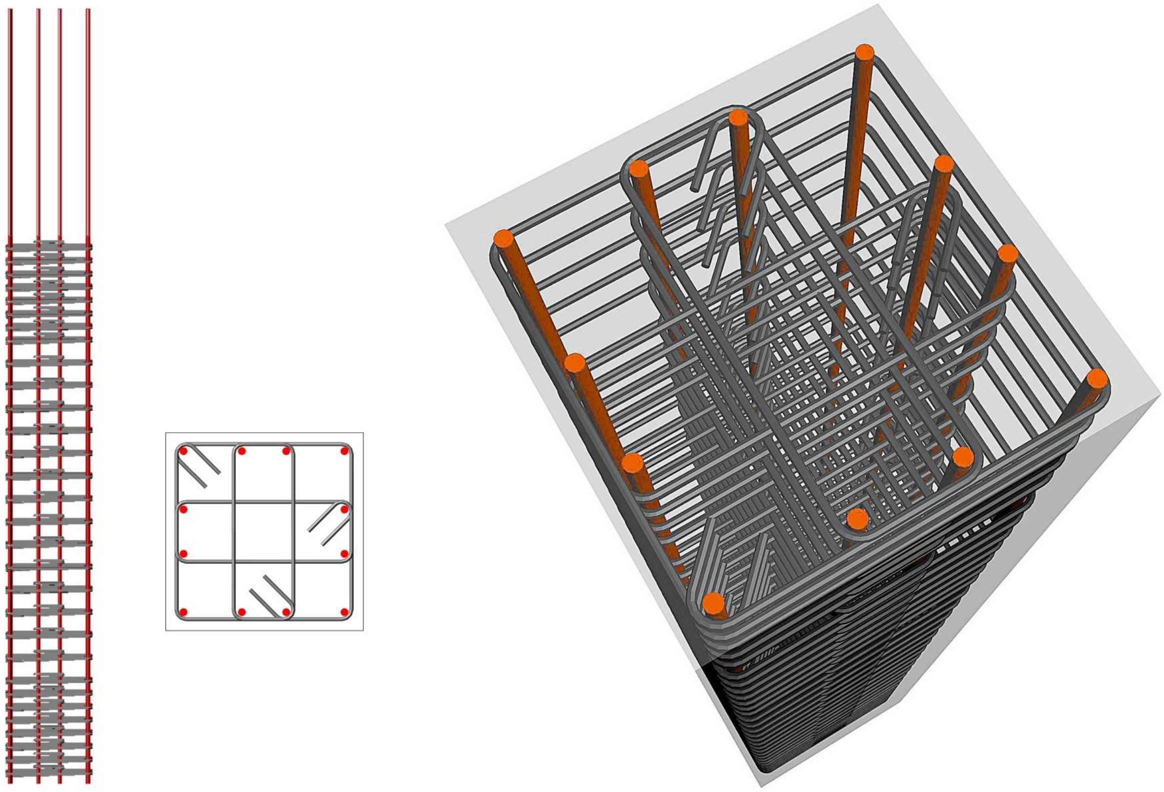
Columns:

(α) Rebars must be symmetrically placed around the perimeter of the cross section since the tensile forces and therefore the inclined cracking constantly change direction.

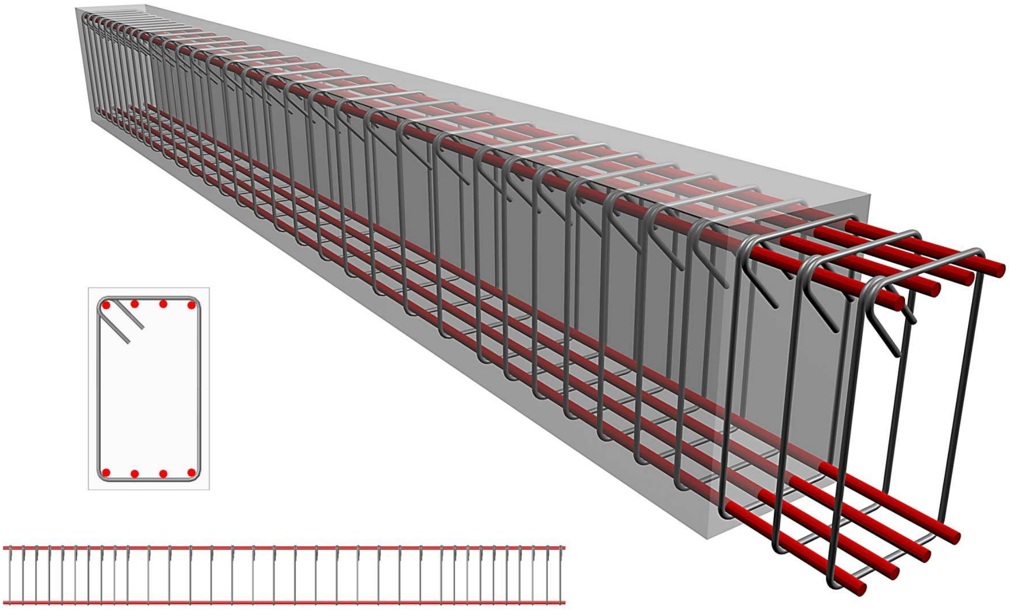
(β) There must be enough, high strength and properly anchored stirrups. This reinforcement protects the member from the large diagonal cracks of alternating direction, caused by the diagonal stressing or otherwise called shear.



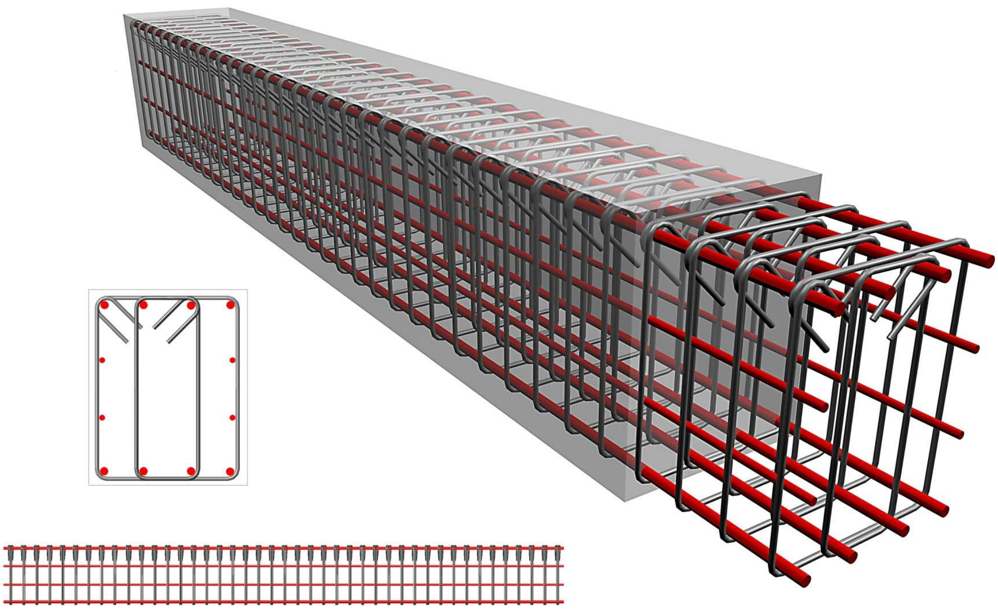
Behavior of a two–column frame during an earthquake between a column and a staircase or masonry infill is probable then the need for ductility extents to the whole length of the column.



Column with cross-section 500x500 and three stirrups on every layer, required by the Seismic Regulation for ductility



Beam with ductility requirements



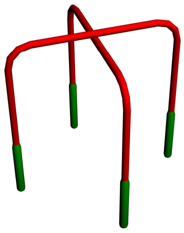
Beam with high ductility requirements

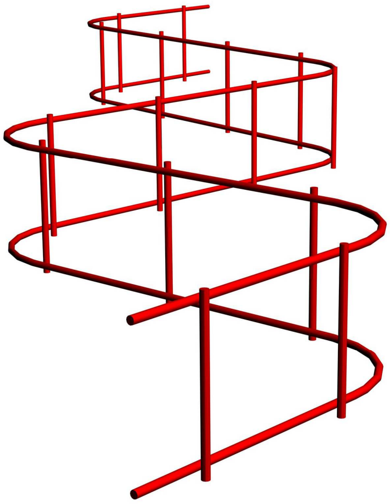
The need for column's capacity-overstrength

Capacity design ensures that the columns will have greater capacity than the adjacent beams therefore no matter how intense the seismic action will be, beam failure will precede the failure of columns. Failing beams will absorb part of the released seismic energy thus altering the structure's natural (fundamental) frequency and avoiding resonance. Generally, failure of one or more beams does not induce progressive failing, hence even in an extremely strong seismic event, the structure will not collapse and will retain a minimum serviceability level allowing its evacuation and most of the times its rehabilitation.

Direct, rebar chair.

Prefabricated element, made out of a thin steel rebar with plastic tipped legs in order to prevent corrosion of the support area between the rebar chair and the formwork.





Indirect, S-shaped mesh spacer.

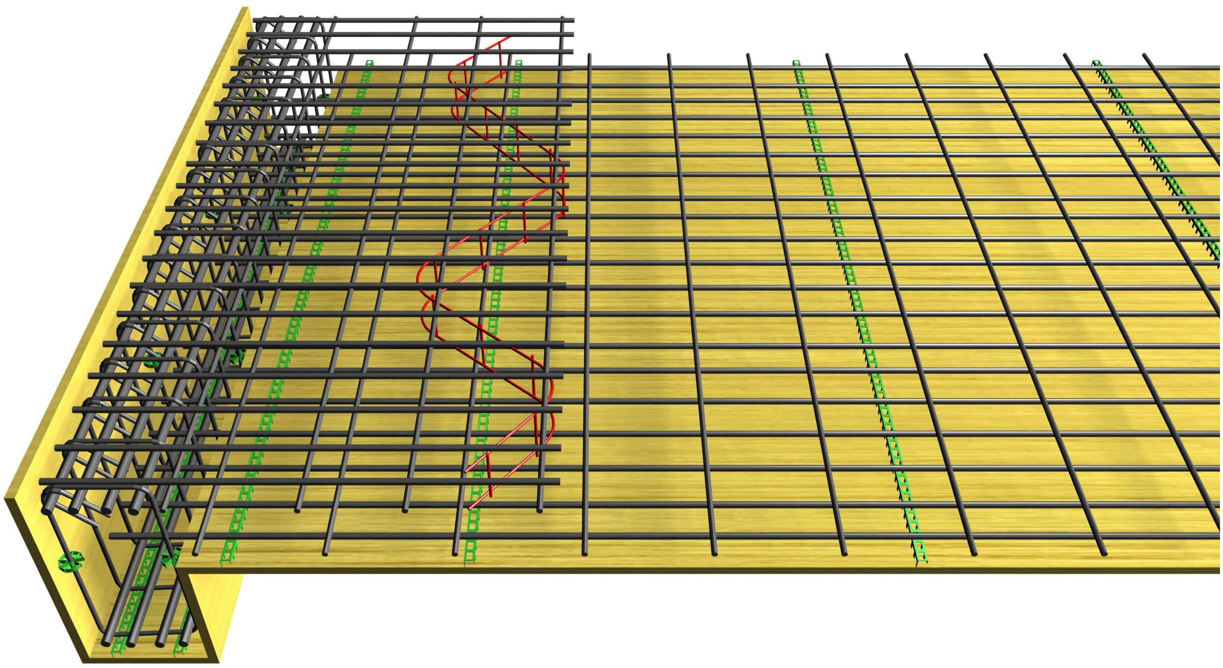
Prefabricated, comes in packages of straight lengths. It is formed in an S shape during the implementation.

Indirect, folded mesh spacer.

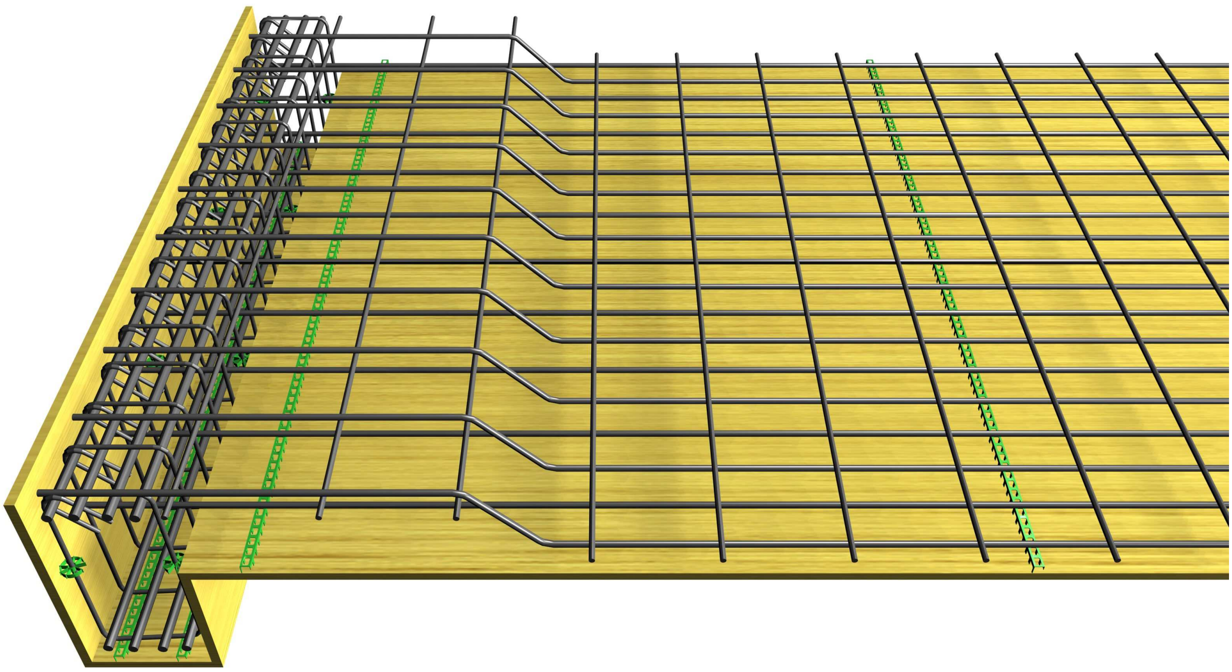
It is easily formed by folding wire of a standard density wire mesh e.g. Ø/200, to the desirable height. In cases of cantilevers apart from spacer it can be used as “J-pin” reinforcement, necessary for the cohesion of the free edges.

Indirect “J-pin” rebar chair.

For sheer use in slabs’ free edges.

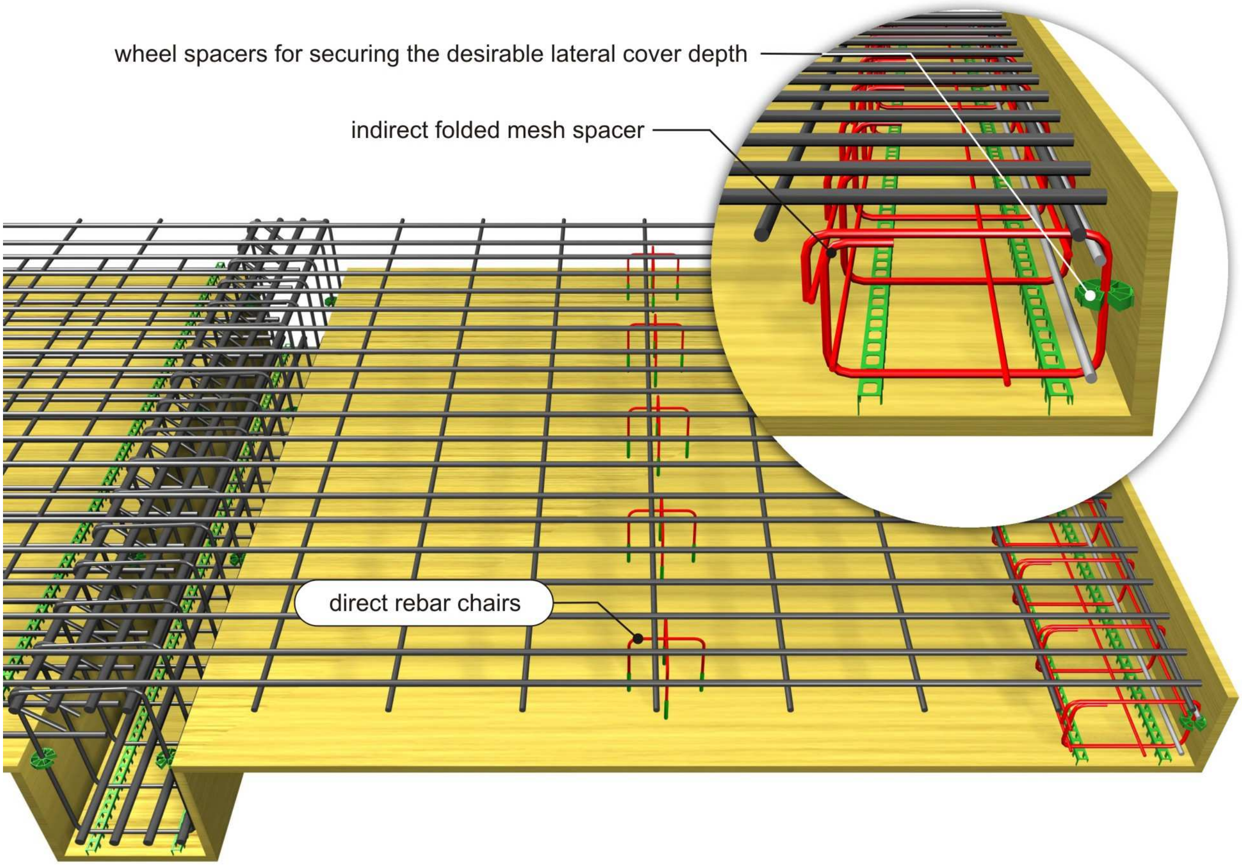


In cases where mesh is used as upper reinforcement in a slab support, its position can be secured with the use of an S-shaped mesh spacer placed on the lower reinforcement grate along the length of the plastic spacer.



In cases where support upper reinforcement comes from bend up span rebars, its proper placement is achieved by the reinforcement bending and therefore bar chairs might not be necessary.

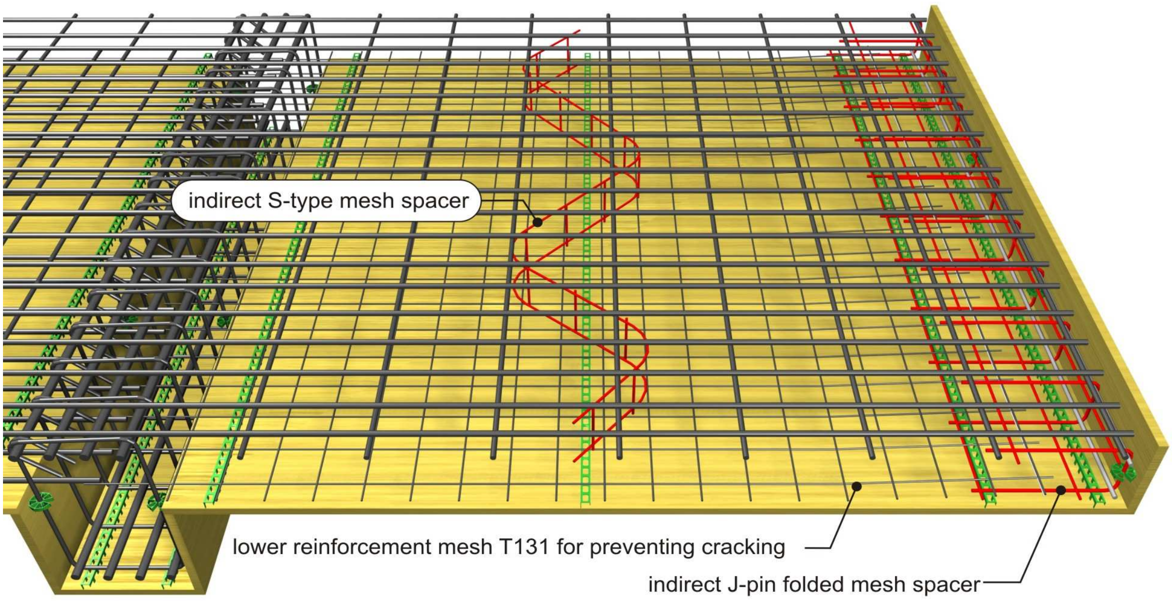
Two indirect S-shaped mesh spacers are placed to the left support of the continuous slab. These are fitted upon the lower reinforcement grate along the length of the linear plastic spacers.



Support of the negative slab’s reinforcement with rebar chairs and folded mesh spacersς

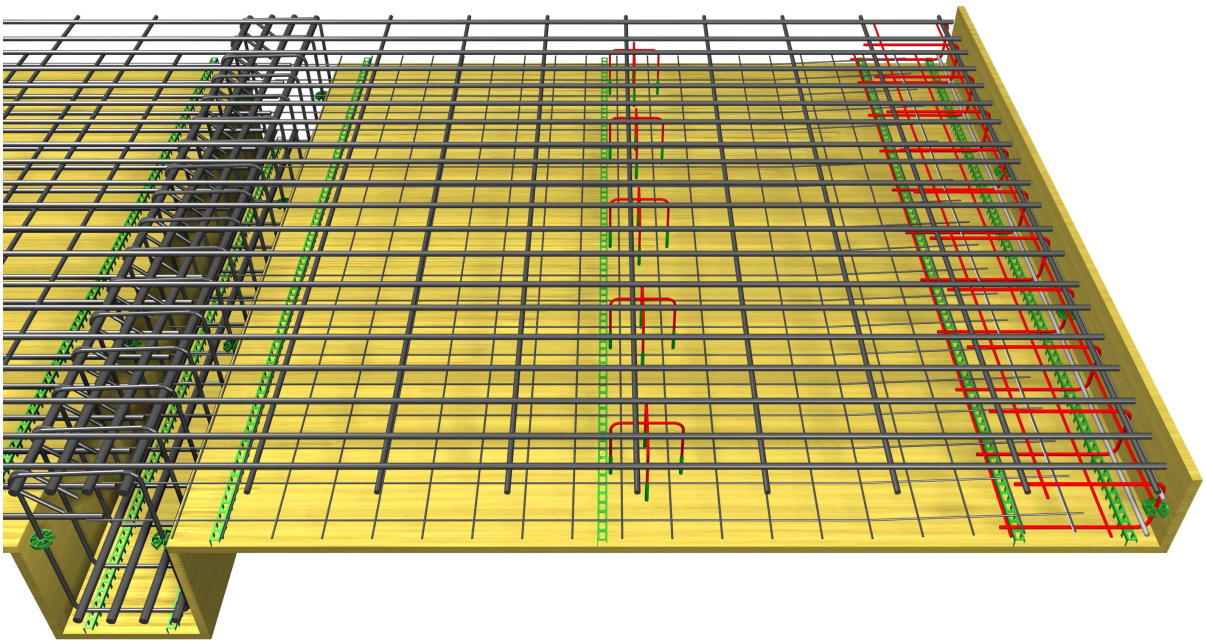
In the right support (cantilever balcony) of the above continuous slab, two rows of spacers are placed. The first row consists of indirect folded mesh spacers fitted upon two longitudinal plastic spacers and the second row consists of a number of direct rebar chairs.

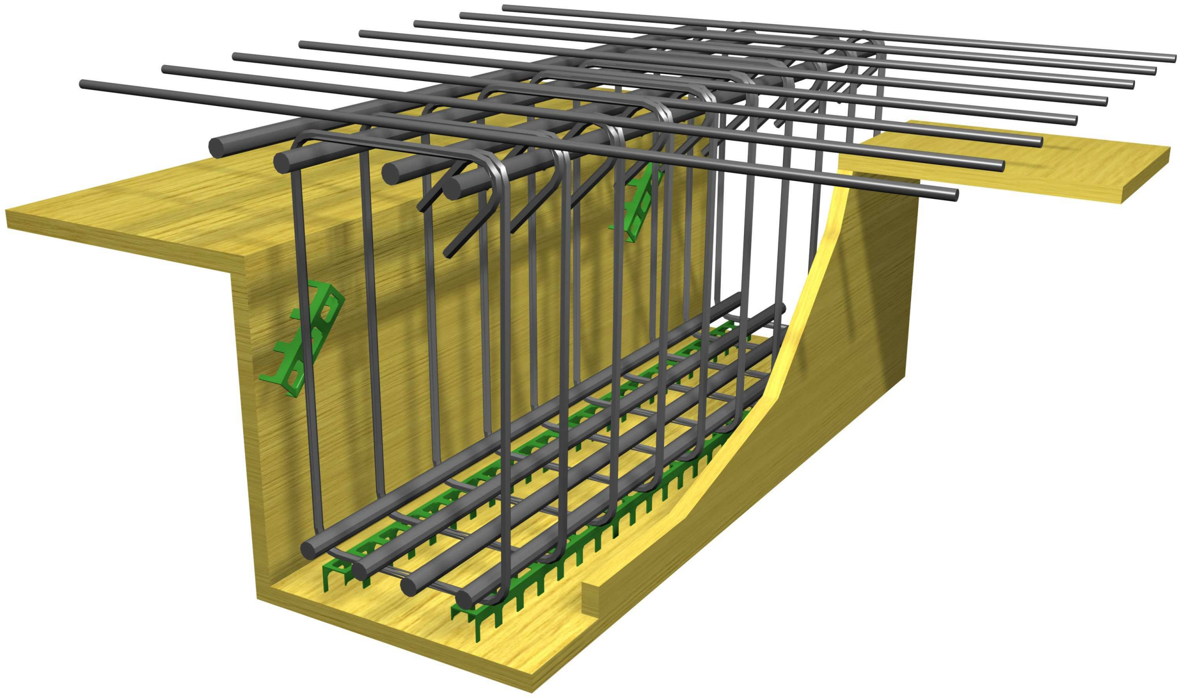
It is mandatory to prevent the folded mesh spacer from lateral slipping and this can be achieved with the use of local spacers. They must be placed right after the implementation of the folded mesh spacer and prior to its wiring with the slabs’ reinforcement. When using wheel spacers extra attention should be paid to their vertical placement so as to avoid drifting during concreting. However when they are used in slab “foreheads” (as shown in the above figure) they can be horizontally placed since concrete does not fall directly upon these areas.



Support of the negative slab's reinforcement with indirect S-shaped mesh spacers and folded mesh spacers

Alternatively, when having a light-weight steel mesh as the lower reinforcement of a cantilever it is recommended to use indirect S-shaped mesh spacers instead of direct rebar chairs. In that case it is more practical to place a “J-pin” mesh spacer inside which the mesh will be properly sited.





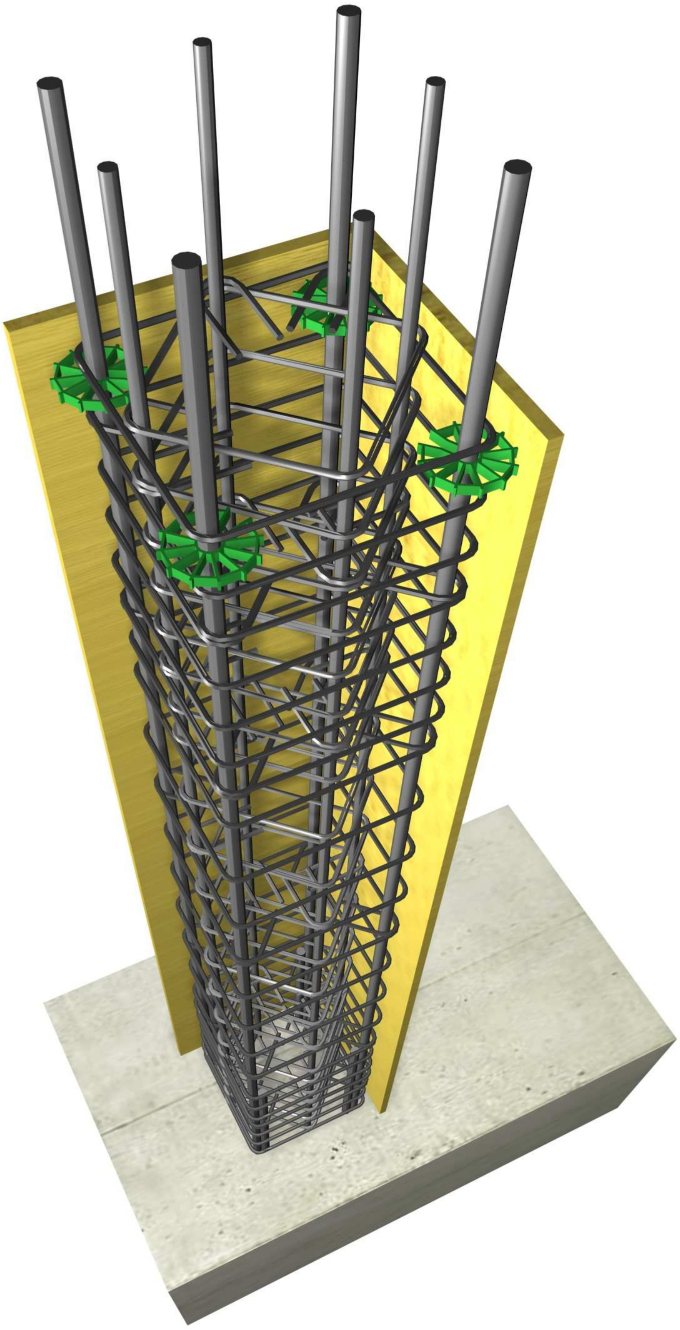
Lateral spacers do not bear any loads, therefore it not necessary for them to be heavy duty. Moreover they should be placed after the implementation of the stirrup cage inside the beam's formwork and prior to the wiring of the beam's rebars to the slabs reinforcement.

The use of lateral longitudinal plastic bars (like the ones placed at the bottom part of the beam) creates two problems: a) it does not enable the implementation of the stirrup cage inside the beam's formwork and b) it obstructs the proper concrete casting of the beam. If the stirrup cage has been industrially producted, it will have secondary longitudinal connecting bars. In such a case, pieces of vertically fitted plastic bars may be used.

Column reinforcement covering

The minimum required cover depth for beam rebars usually ranges between 25 and 35 mm depended on the environmental conditions present throughout the building's service life. The 25 mm apply to a dry climate and the 35 mm to a seaside location.

Forming the desirable covering of column reinforcement is quite a simple task. For example, four (4) individual spacers placed at the column's upper part, are enough since the column's base rebars are wired together in the lap-splice areas.



Especially for columns, the use of spacers for creating the required cover depth helps in the proper centering of the vertical rebars. Therefore when the reinforcement of the next storey is being placed no extra time (with a corresponding additional cost) will be spent in bringing the rebars to their proper position.

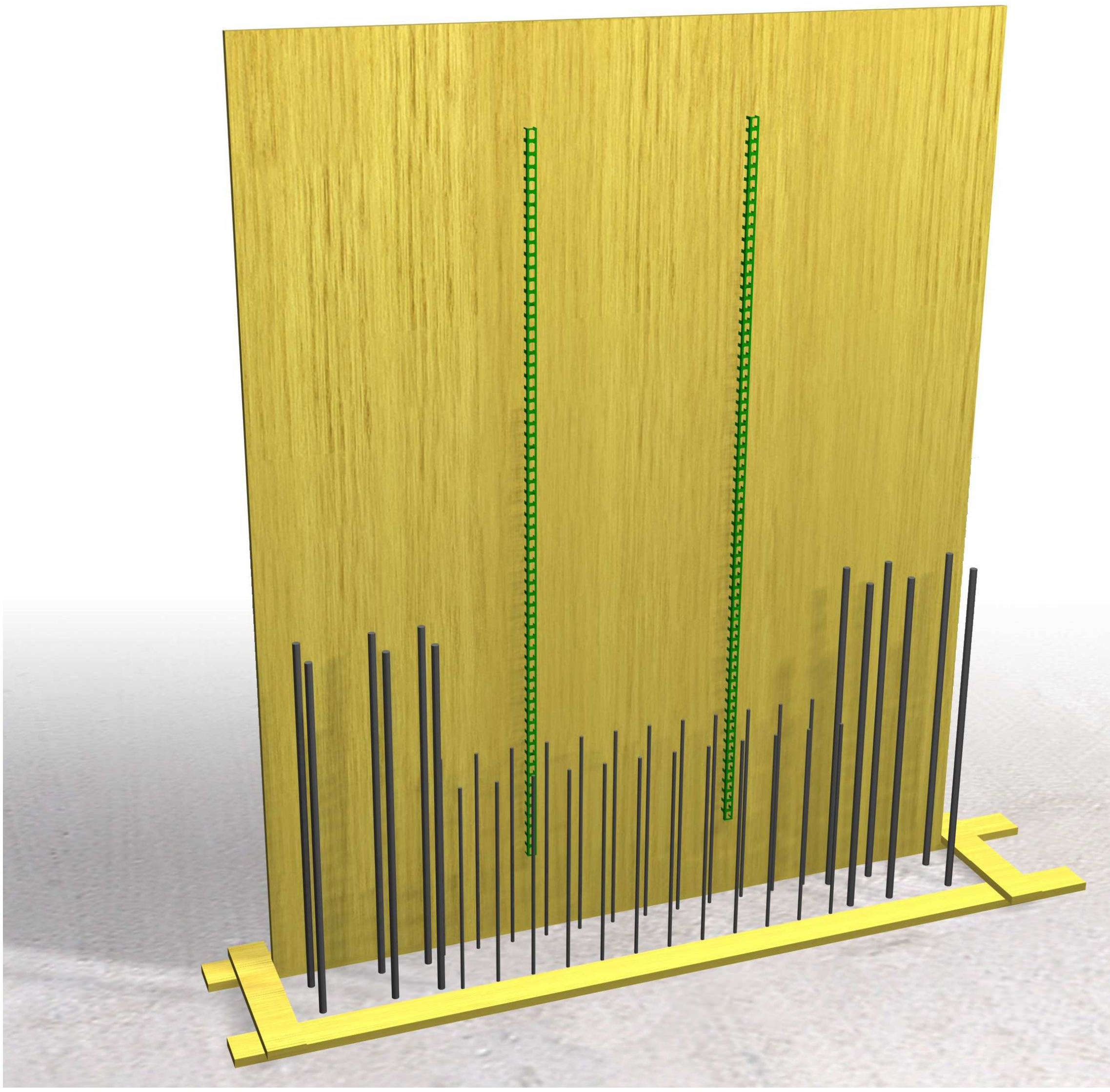
Covering can be secured either with wheel spacers placed on the upper part of rebars (in that area there is no danger to be drifted during the concreting) or with the use of vertical wheel spacers fitted upon the stirrups or finally with the use of plastic pieces vertically positioned upon the formwork.

In every case though, spacers must be fitted after the positioning of the stirrup cage in order to facilitate the implementation of the cage and the proper centering of rebars.

Shear wall reinforcement covering

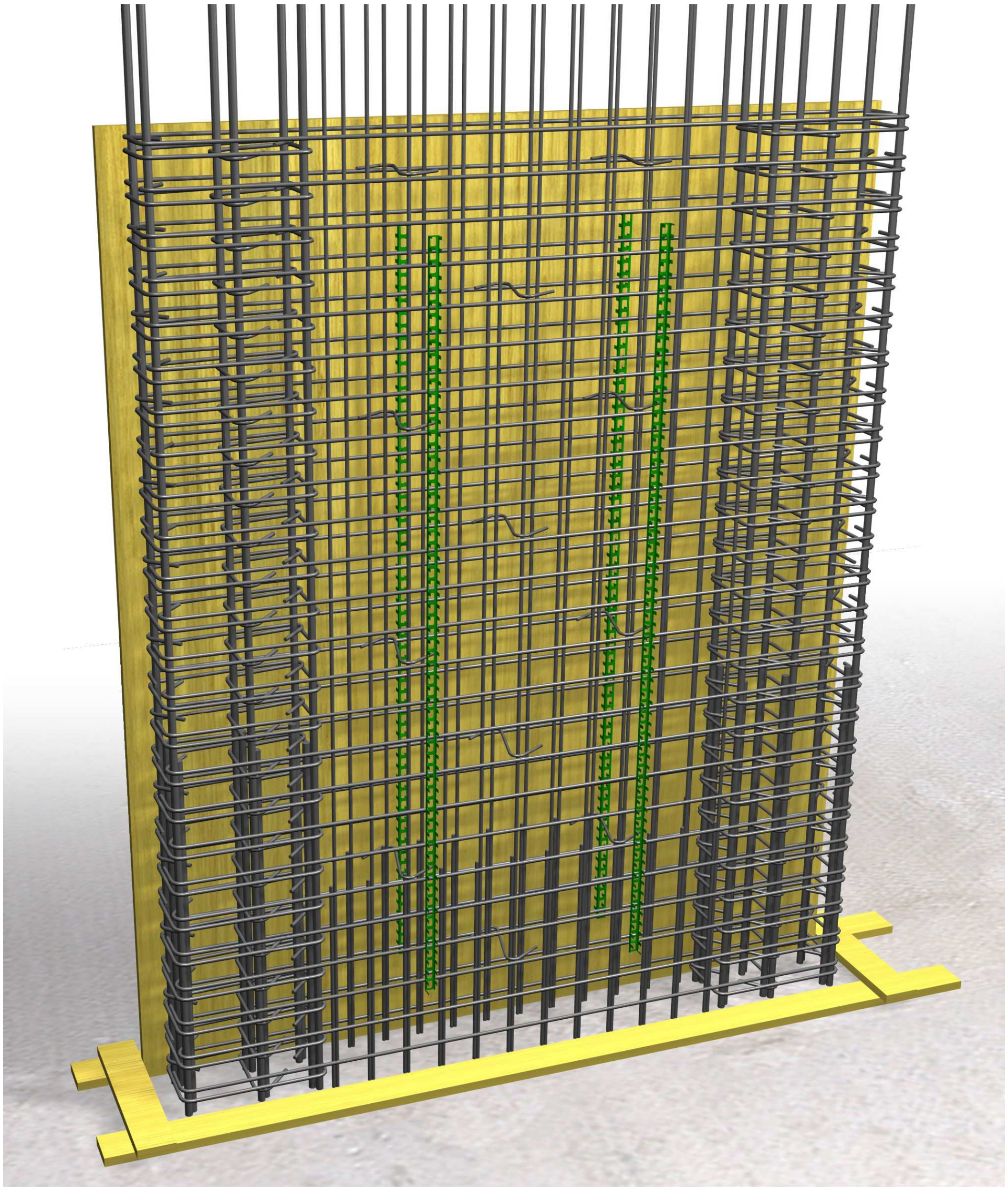
As far as the integrated columns at the wall edges are concerned, the required cover depth is created as mentioned in the paragraph referring to the columns' reinforcement covering. As far as the wall body reinforcement is concerned, its cover depth is created according to the following:

After forming the back of the wall, plastic rods are nailed upon the formwork. These rods have a usual length around 2.0 m and they can be used as one single piece or separate smaller pieces.



The two longitudinal spacers are nailed upon the formwork

After this, follows the implementation of the edge columns, of the body reinforcement and of the spacers that are fitted upon the internal reinforcement grate. That way after the placement of the formwork’s last piece the required cover depth and the proper centering of the reinforcement will be secured.



After the reinforcement implementation and prior to ‘closing’ the shear wall’s formwork, the two plastic bars are tied upon the inner reinforcement grate.

In shear walls the most effective way of the reinforcement implementation is to place the reinforcement before the assembling of the formwork. In that case, spacers are fitted upon the rebars.

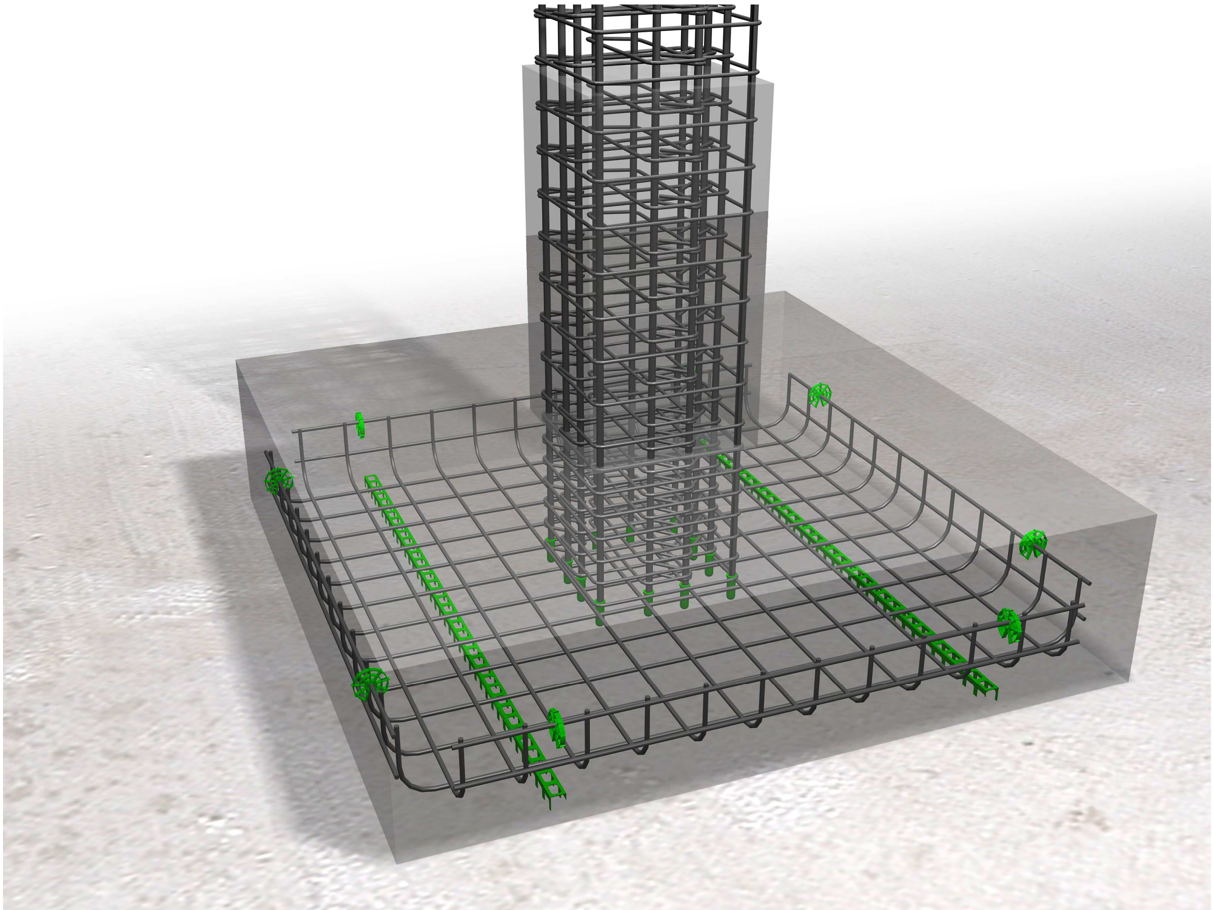
Foundation reinforcement covering

The minimum required cover depth of the foundation reinforcement is around 40 mm for foundation "sited" on ground leveling slab and around 70 mm for foundation "sited" directly upon the ground.

The construction of foundation directly upon the ground's surface is allowed only in special cases. The ground leveling slab ensures many things like:

1) comfortable area to work on
2) capability of accurate marking of the areas of footings and columns
3) a stable substrate on top of which spacers will be placed
4) avoidance of a muddy foundation ground due to water usage or possible rain

The required covering may be created by point or even better by linear spacers. Because of the weight they bear and due to their required height, it is recommended to use heavy duty spacers.



Securing the cover depth of the spread footing's reinforcement with plastic spacers

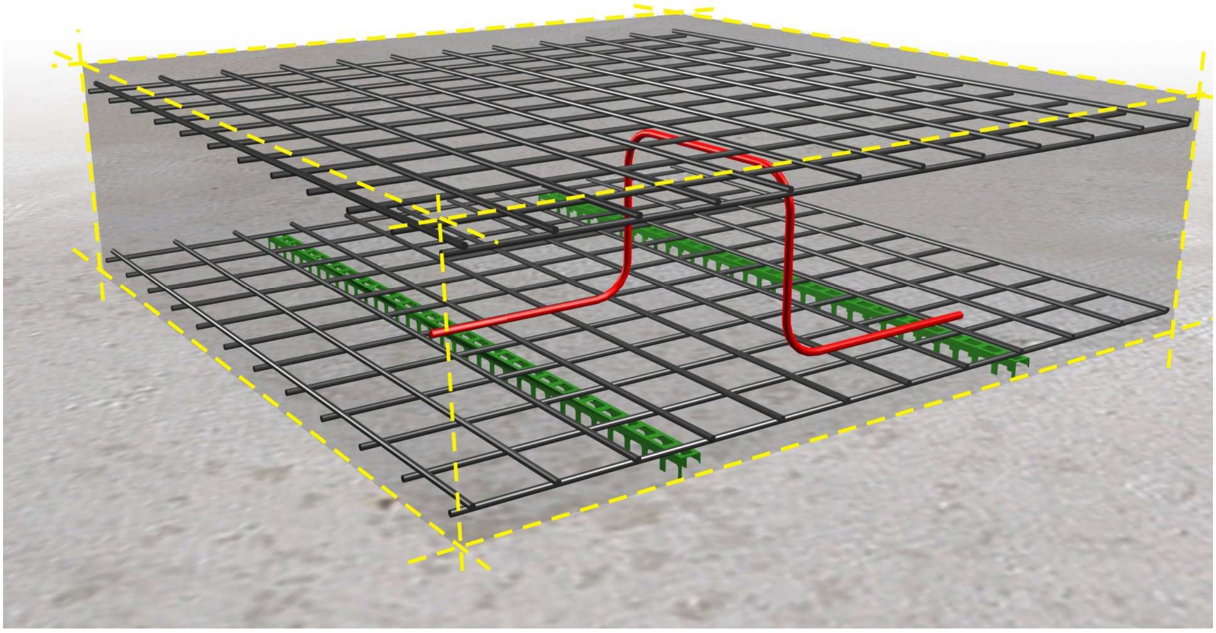
Use of spacers on the sides of the footings is obligatory in order to prevent rebars from slipping. Since they do not bear weight, they can be sparsely placed and they should be fitted vertically to avoid drifting during the concreting process.

Ensuring the proper position of upper reinforcement in foundation slabs

In cases of total or partial raft foundation or when constructing the bottom slab of a pool, the use of rebar mesh as upper reinforcement is necessary.

Just like in superstructure slabs, in the areas around the slab edges, “J-pin” rebars may be combined with open or closed reinforcement mesh.

In the intermediate area, the required cover depth can be created with the use of special steel rebar chairs placed on top of the lower reinforcement grate.

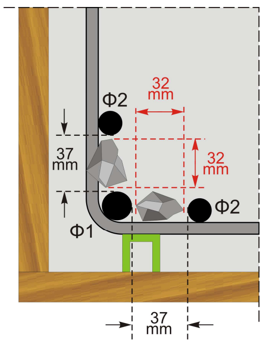


The upper foundation grate is supported by steel spacers, which are sited upon the lower grate

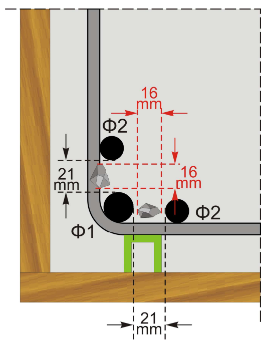
2.6.2 Minimum spacing between reinforcement bars

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.

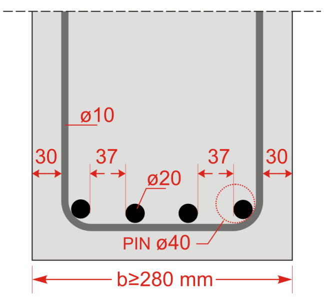


Usual Concrete



Self Compacting Concrete

<u>Example:</u>

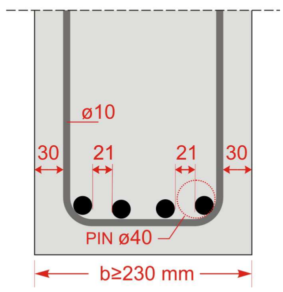


Usual Concrete

Beam **4Ø20**

Stirrups Ø10

Coating =30 mm



Self Compacting Concrete

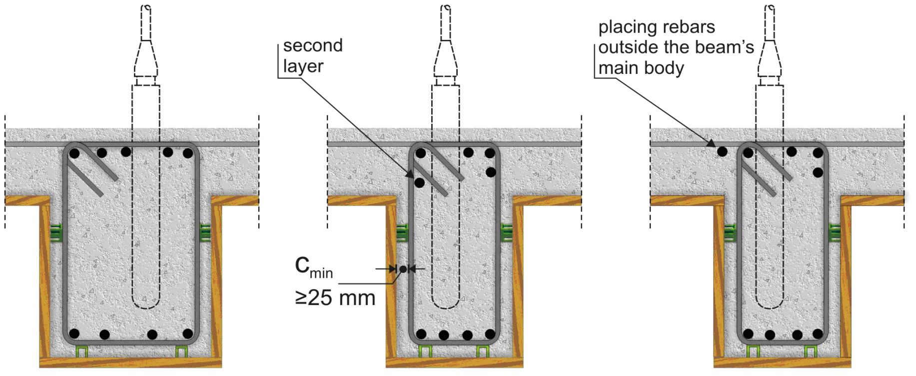
Beam **4Ø20**

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.*

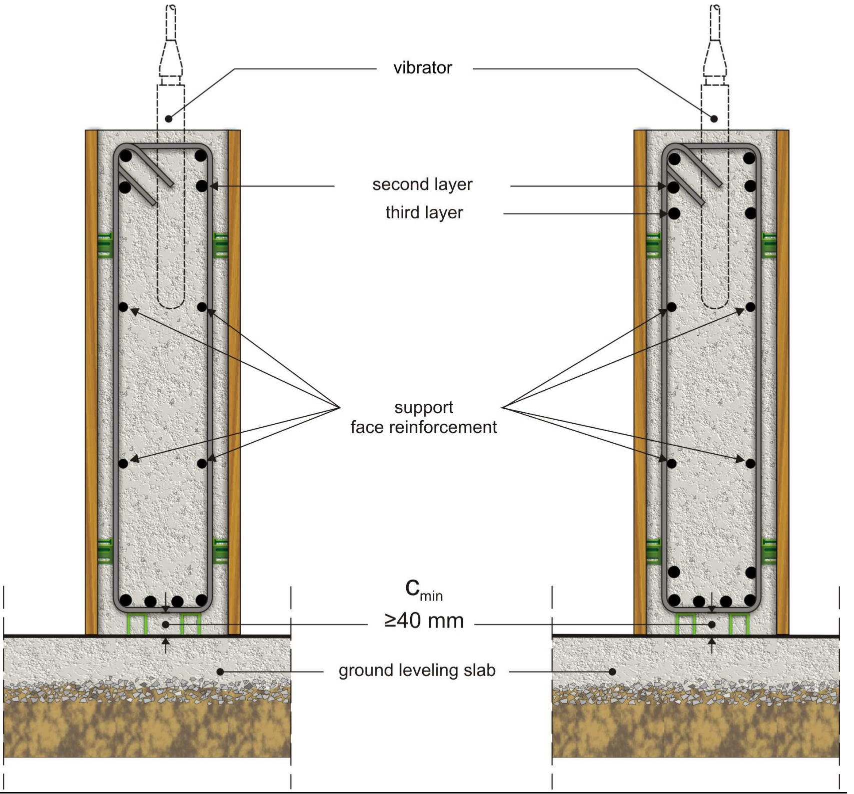
c) By placing rebars on both outer sides of the beam's main body.

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

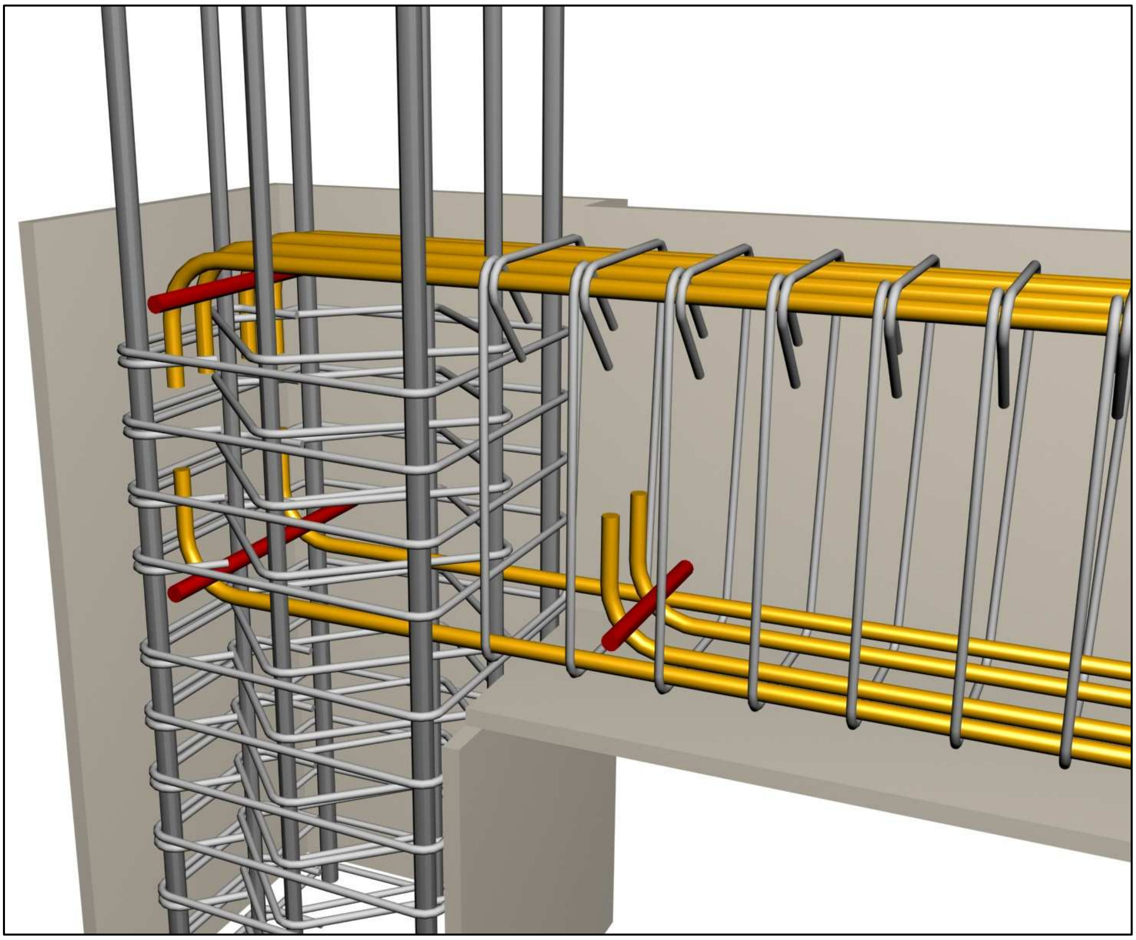
Connecting beams in foundation

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.

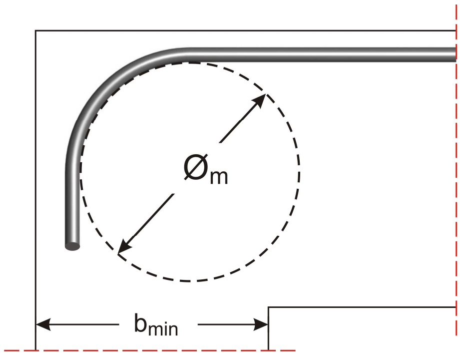


Simple hook anchorage



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

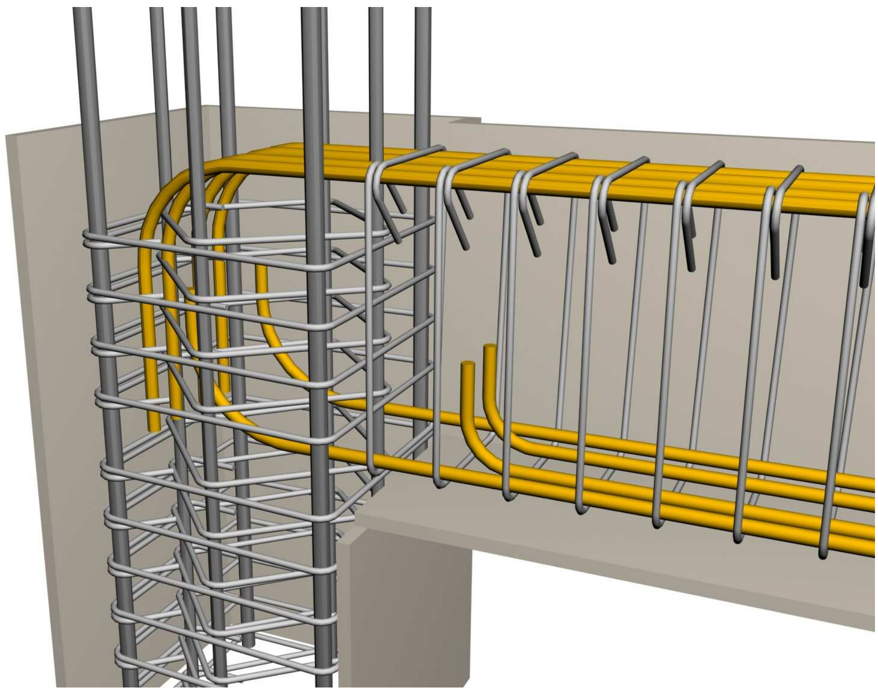


In columns that have a small dimension in the anchorage direction, (see the table below) the bending is implemented with the use of a large diameter drum.

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

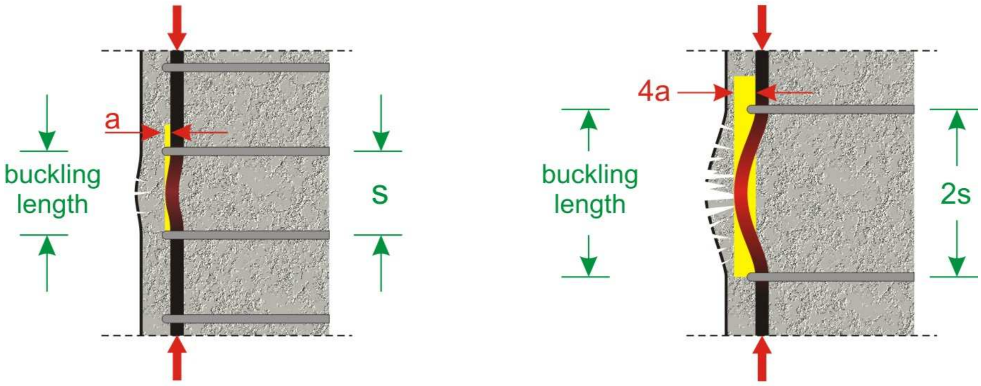
For grade C30/37 concrete and B500 steel, for various bar diameters, the minimum bending drum diameter and the minimum column dimension are displayed in the following table.

	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 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.