APOSTOLOS KONSTANTINIDIS
CIVIL ENGINEER

EARTHQUAKE RESISTANT BUILDINGS
from reinforced concrete

VOLUME A
The art of construction and the detailing

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PANOPLIA© educational software included

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PREFACE

The civilization progress of a time-period and a country was always historically presented by the level of its constructions. This happens because the culture, the architecture, the mechanics and the technology either as a condition or as the result of people's cultural level are reflected upon the various constructions. In every region, the architectural forms were influenced by the environmental conditions present, sun or clouds, hot or cold, mountain or sea, rock or mud. At the same time, the intensity of the earthquakes played a catalytic role in the various civilizations which usually became extinct after a severe seismic event. People, due to the awe and their sense of weakness, always had and still have the tendency to forget such tragic events.

Nowadays, the dissemination of science and the advancements in the material science and technology as well as in the computing and software technology, enable us to face earthquakes with prudence but without fear. We have to modify our architecture in order to enhance the earthquake resistant capacity of the constructions the same way we have modified it in favour of the energy saving.

The new architectural form will predominate after it has proven that not only can it be materialized but also that it can sustain severe earthquakes. The antiseismic science and technology has made great steps during the last three decades. This has led to design and constructional rules which have been established as regulations, like the recent Eurocode 8. The engineers, mainly because of their scientific background, have accepted these design rules and they apply them with no hesitation. On the other hand, the new constructional rules as well as the new practices have not yet been adopted by the rest of the construction's materialization bodies.

This book refers to the constructional issue of the reinforced concrete, earthquake resistant buildings. The way of antiseismic construction, the materialization details, the required quantities of materials and labors are presented in the detailing of the structural frame. The detailing regards everyone involved in a building's erection, the architect, the civil engineer, the supervisor engineer, the contractor, the foreman and the technician.

In order to compose or to comprehend the detailing, the technician must have a thorough knowledge of the construction. The only way to learn such a complex subject as the reinforced concrete and such a critical subject like the antiseismic construction, first and foremost, one must learn to love them. In this book, the combination of knowledge and love is referred to as 'art'. This 'art' of the earthquake resistant construction is our intention to disseminate.

The realization of this book was possible thanks to the detailed knowledge and devotion of two good friends and colleagues, the civil engineer Giannis Lirakis and the Architect Engineer Costas Anastasiadis. The latter, with the use of various software programs, modeled and designed in numerous ways the examples included in this book.

I would like to thank all my collaborators engineers, technologists, contractors and technicians for their valuable help in the various issues and whom with particular gratitude I cite in the page of bibliography.

November 2008, **Apostolos K. Konstantinidis**
Civil Engineer

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INTRODUCTION

In a **building work**, the design of the **structural frame** is separated into three stages:

a) the 'preliminary design', where the forms of the structural frame for the various architectural solutions are proposed in order to decide the form of the work,

b) the 'final design', where the structural frame of the building is designed and dimensioned and its cost is estimated based upon the final architectural solution and

c) the 'detailing', where the 'load bearing system' (structural frame) of the building is designed in every detail. This stage also includes every constructional detail and technical guideline required for the construction.

The detailing is the most strenuous phase and requires a thorough knowledge of a large amount of complex issues regarding the construction.

In order to compose or/and comprehend the **detailing** the technician of the work, the architect, the civil engineer, the supervisor engineer, the contractor, the foreman or the technician must know the common communication 'language' of all his/her collaborators in combination with an -least good- knowledge of the constructional issues. The dissemination of the knowledge and the language is to the benefit of all materialization bodies since the inexperienced will learn and therefore communicate more effectively with the experienced ones while the latter will ensure the materialization of structures without problems and dangers. The collective work is the only way to increase the constructional level and this is the aim of the present book.

The constructional rules followed are almost in perfect compliance with all the antiseismic codes of the world e.g. Eurocodes(EC2 and EC8), ACI codes, New Zealand codes, Greek codes, as well as with all the relevant regulations of other seismic prone countries.

All the drawings and solutions in the examples of the book are clearly indicative and include only a fraction of the numerous existing solutions. Their possible high quality presentation should not mislead anyone to believe that they constitute the only solution.

Volume A' intends to present the entire general concept of the detailing without extended details and therefore the drawings that accompany this book are indicative and concise.

The book is accompanied by a **software CD** by which the reader may:

- download the detailing drawings regarding the sample project *<bkGR>* which is analysed in several chapters,
- watch, in a photographic sequence, the construction of a real structural frame, from the beginning to the end,
- install the **trial version** of PANOPLIA©, the detailing software.

The majority of the examples included in this book have been processed by the software PANOPLIA©. Its use will help in the familiarization of the trainee technicians with the advanced technology both for the detailing and for the electronic exchange of designs bids and orders via internet.

The **special edition** of the book includes:

- The sample drawings, printed,
- Special stereoscopic, paper glasses,
- A small volume with stereoscopic pictures.

The stereoscopic pictures serve a double cause:

a) to help in the more thorough comprehension of the details regarding the composite examples mentioned in this book and

b) to introduce the user to the new stereoscopic technologies included in the detailing software PANOPLIA©.

Athens, November 2008

Apostolos K. Konstantinidis
Civil Engineer

CONTENTS

CHAPTER 1

The structural frame

1. The structural frame

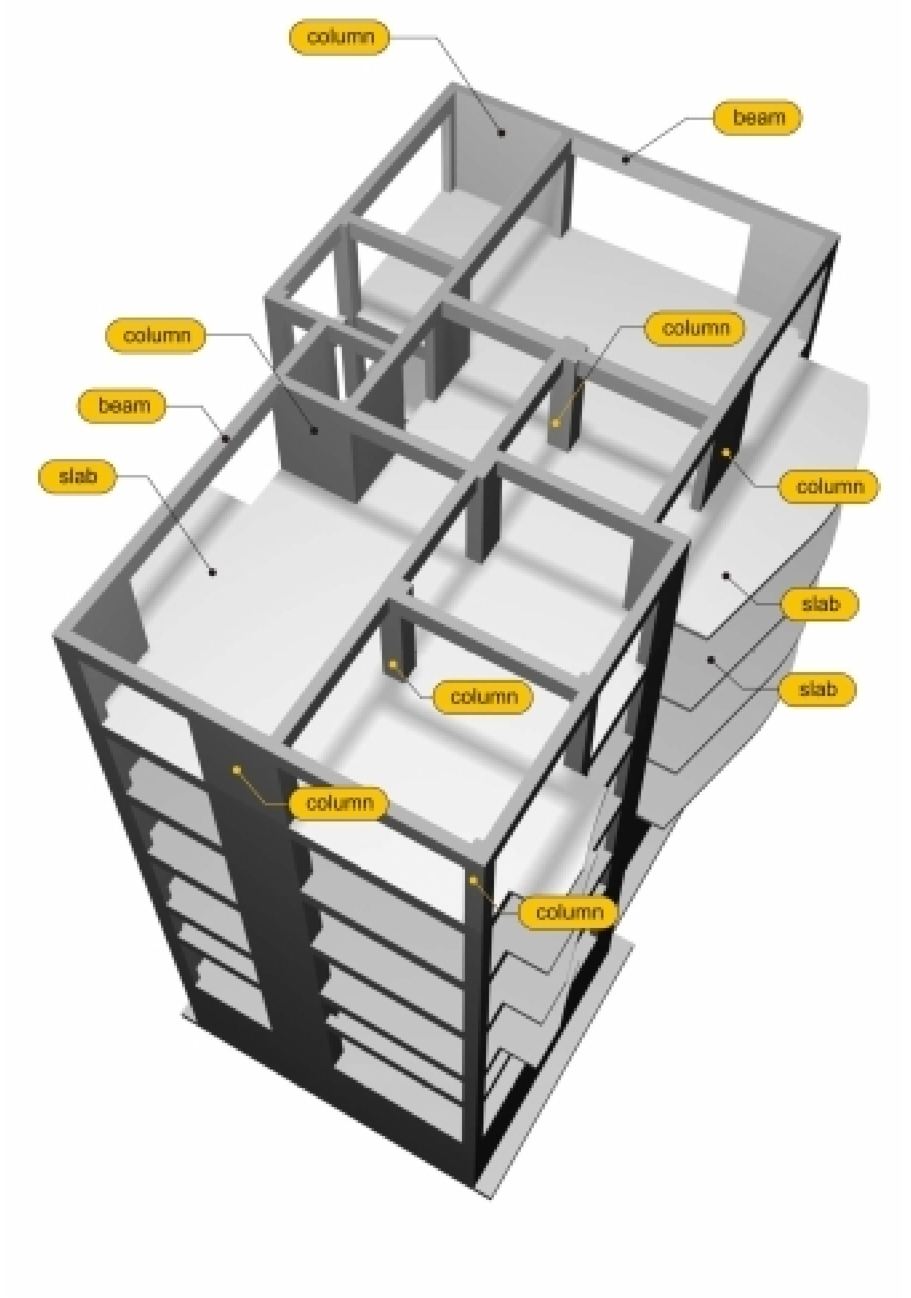
1.1. Introduction

Every structure consists of the load bearing system which is usually constructed by reinforced concrete, steel or by a combination of those two materials.

This book deals with building frames made out of reinforced concrete (RC). The structural frame might not be visible externally in the final stage of the construction but it exists internally and it constantly supports the structure.

The structural frame is composed of horizontal and vertical load bearing elements as well as of foundation elements.

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).

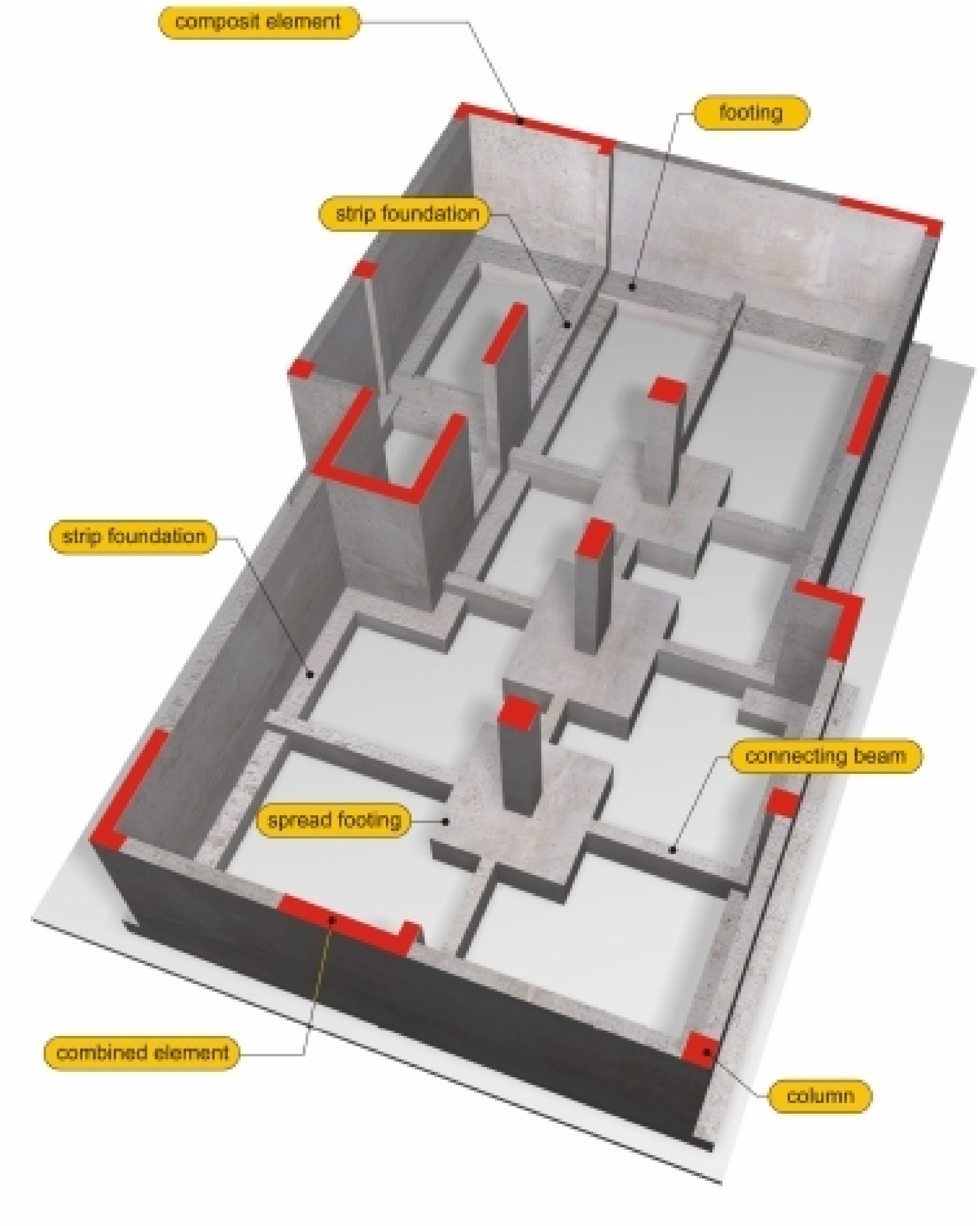


Structural frame <project bkGR> [1]

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

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

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



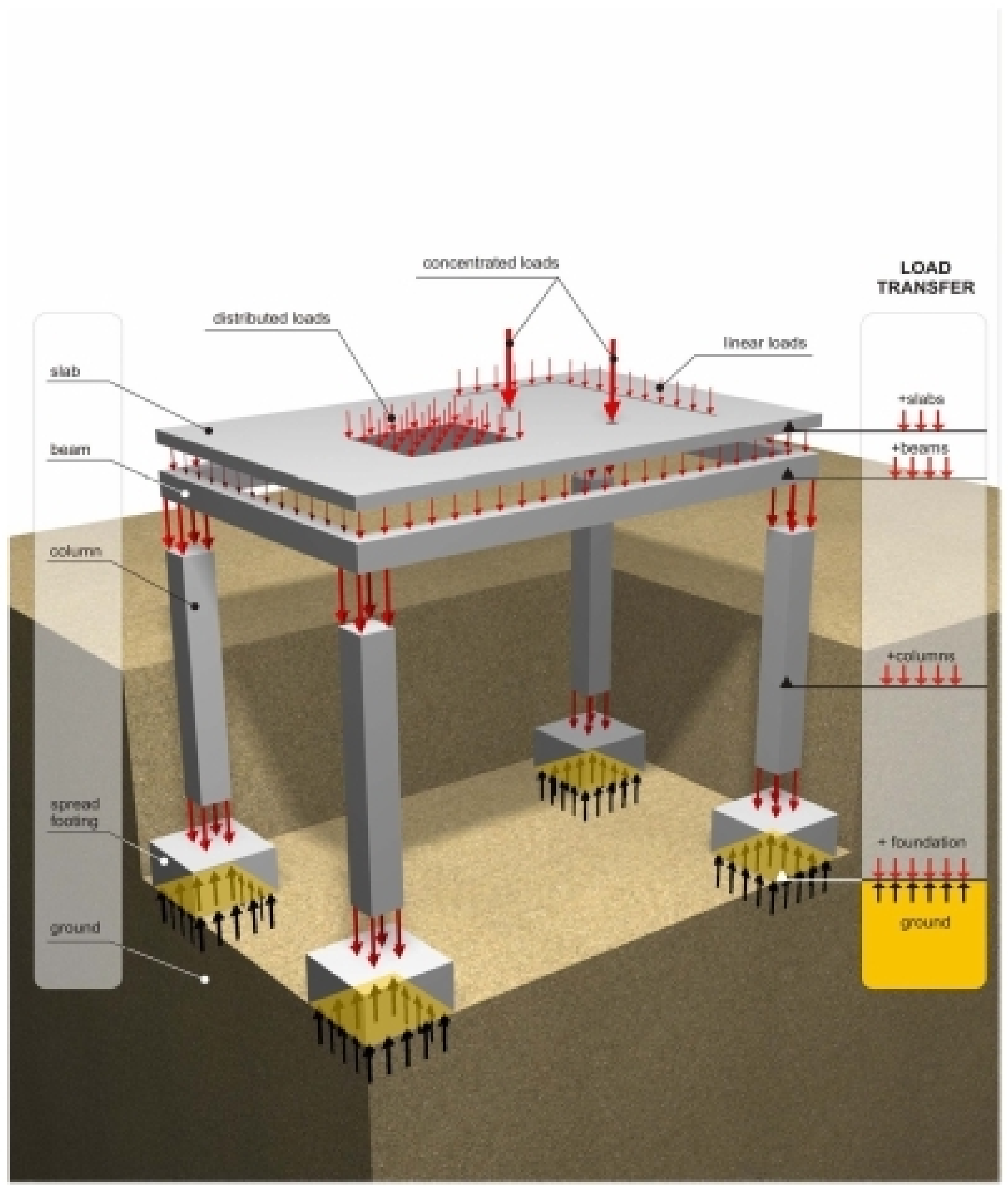
Structure's foundation

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 **piers**.

The structural frame must have enough strength to securely bear the gravity loads throughout the entire life span of the building.

An adequate load bearing system is based on a continuous load path throughout the structure. This means that the vertical loads must be carried by the slabs and transferred to the beams; the beams must transfer these loads to the columns which in their turn must transfer them to the foundation. Finally the foundation must carry the loads to the ground.



Load path from the structure's slab to the ground

The slabs carry the floor **loads** of each storey. These may be characterized as **permanent loads** (dead loads) i.e. marble floor covering and as **imposed loads** (live loads) i.e. loads applied by human activities.

The beams carry the loads transferred to them by the slabs as well as the weight of the walls seated on them.

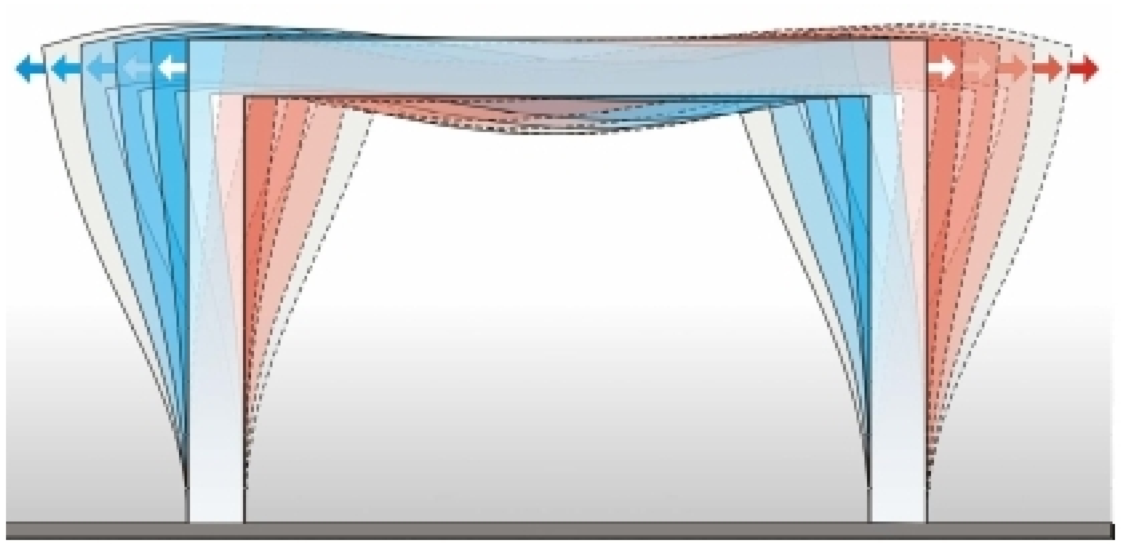
The columns carry the beam loads and they transmit them to the foundation.

The footings (foundation) carry the column loads and transfer them to the ground.

The foundation beams hold the footings in place when the structure is imposed to excess loading i.e. in the case of an earthquake or when differential settlements occur.

In the following chapters it will be shown that all these structural elements may be found in different forms than those mentioned above, however their behavior remains the same.

In countries with extensive seismic activity like Greece, the structural frame must be able to withstand not only the gravity loads but also the loads imposed in a few but vital cases during its life span such as the cases of earthquakes.



Frame deformation due to seismic action

In a structure, the seismic action causes deformations and stresses in various directions. These are the stresses that the structural frame must withstand.

Slabs are not designed to bear earthquake forces however they help in their even distribution by connecting the rest of the load bearing elements with their diaphragm action.

Not all elements are critical for the seismic performance of a structural frame. For example during an earthquake, the column's load-carrying capacity is much more crucial to the structural performance than the load-carrying capacity of a beam. This happens because the column's failure may lead to the failure of adjacent elements like beams and slabs which in turn may lead to the progressive failure of other columns thus resulting in the total building's collapse or in extensive failures. On the contrary the beam's load-carrying capacity loss leads to local area damages which in the case of a major earthquake may even turn out to be favourable for the structural stability. This is the reason why columns in earthquake prone areas are much stronger than the columns in countries with low seismic activity.

In order to have a better seismic performance of structures, we should use columns with large dimensions but this would limit the interior available space. For this reason the use of large columns is replaced with the use of shear walls in both directions of the structure. The shear walls contribute not only to the compressive strength of the building but also to the increase of its structural **stiffness** thus limiting the displacements and consequently the deformations caused by seismic actions.

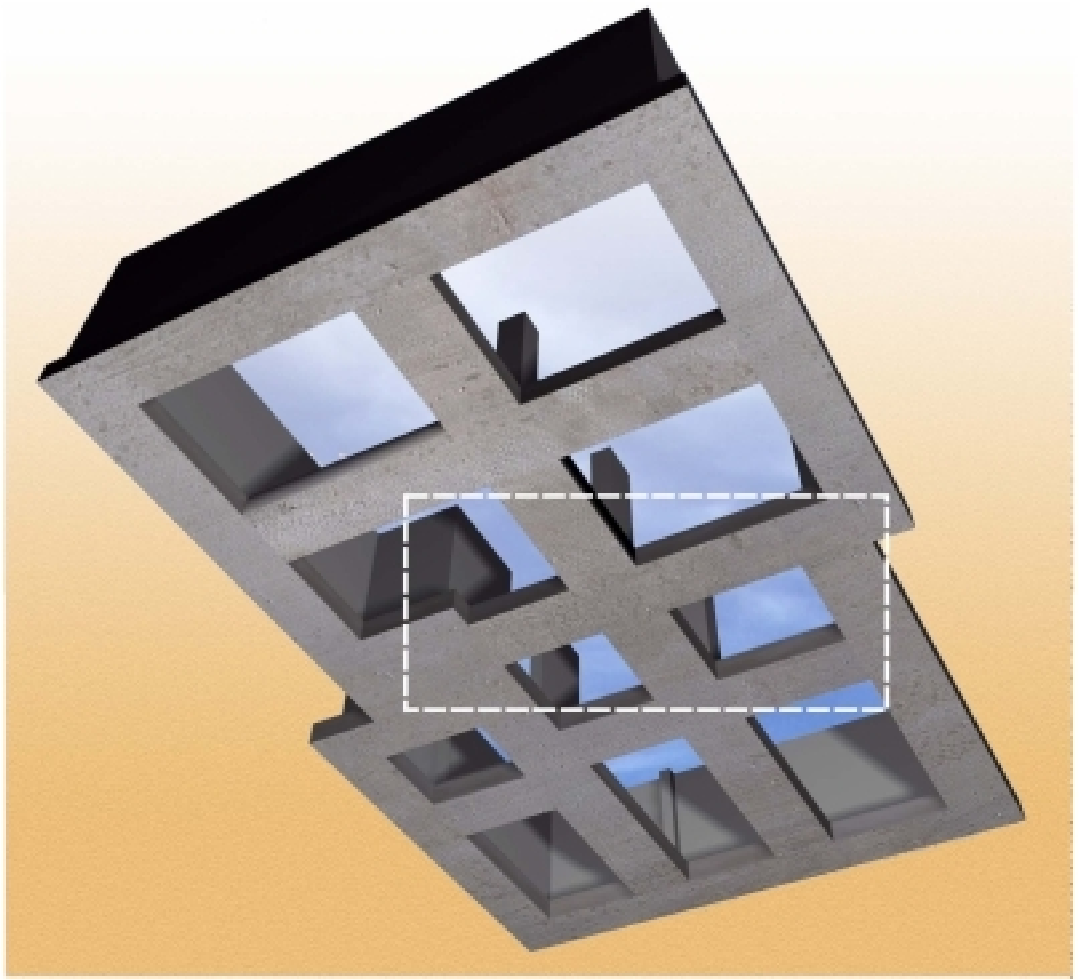
When seismic design is required, the use of beam supported slabs is mandatory. In cases where due to architectural or other reasons, the beam height is not allowed to be extended beyond the slab thickness, slabs must be thick enough to ensure the proper function of the beams with zones embedded to their thickness in the form of hidden beams.

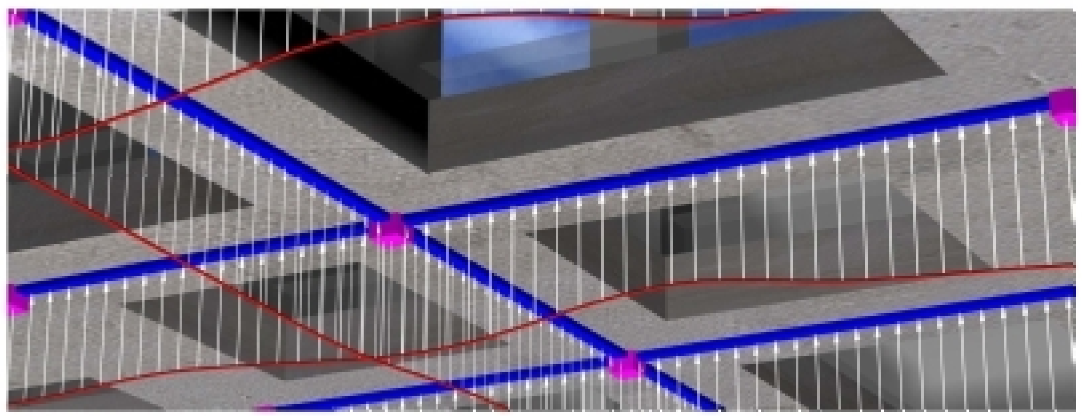
In multi-storey buildings, columns must not be discontinued in any storey; this means that a column starting from the ground (foundation) must extend all the way to the upper storey of the building. In Greece, such a column that terminates in an intermediate storey and not on the ground is **called "fitted column"**. Usually such a column must be supported by a beam (beam bearing column) since the Greek Code does not allow it to be supported by a slab. However, in order to maintain a good seismic behavior such columns must be avoided.

Possible failure of connecting beams or footings, results in direct failure of columns. This results in beam failures, and finally in slab failures. Such a mechanism will take place in all storeys leading to a complete building collapse.

The construction of a basement and the use of shear walls along the perimeter improve the structure's seismic performance.

The use of continuous footings or/and the use of connecting beams helps the smooth "bedding" of the structure upon the ground and the limitation of differential settlements whose occurrence would have caused cracking to the superstructure.





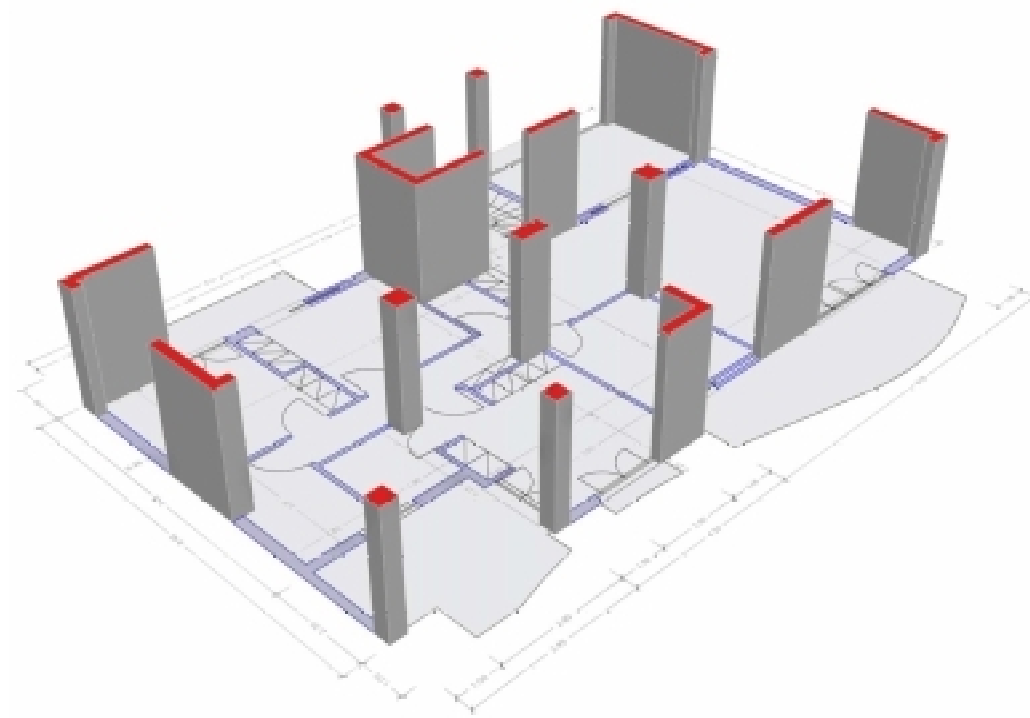
Underneath view of the structure's foundation and detail of the soil stresses diagram

After their construction, footings are covered with soil and rubbles the basement floors appear to be inactive. In reality they are active and they critically affect the structural behaviour especially during an earthquake.

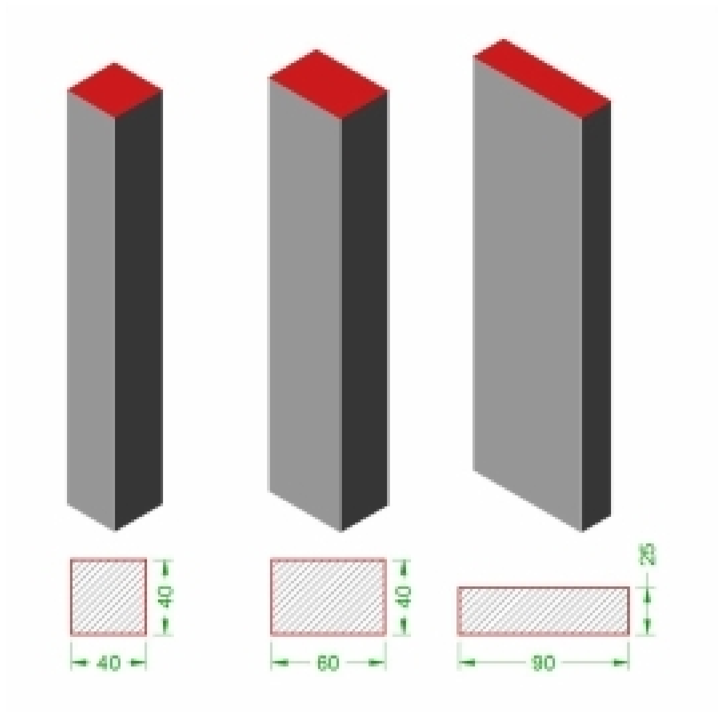
1.2. Structural frame elements

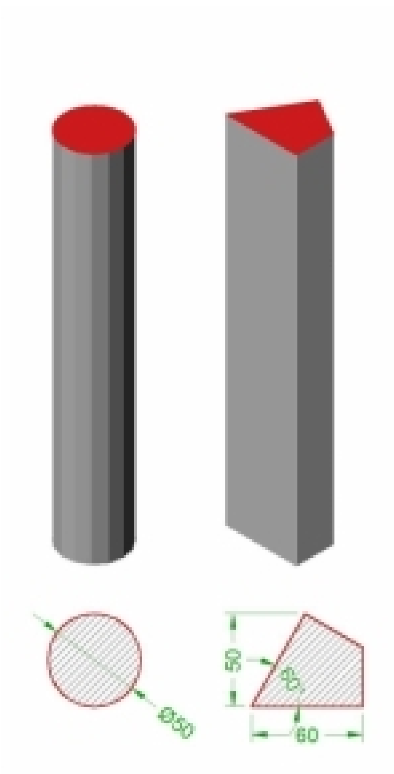
1.2.1. Columns

The vertical load bearing elements of the structural frame are usually called with their common name, **columns**. However due to their varied behavior, their different design rules and most of all, their differences in reinforcement and detailing, they are separated into three major categories: **columns**, **shear walls** and **composite elements**.



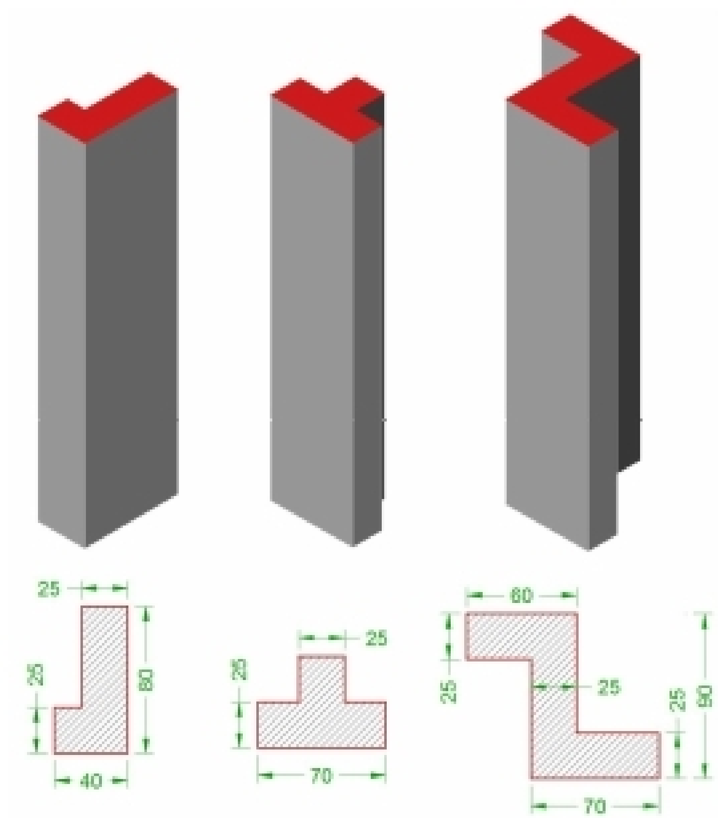
Columns are the rectangular elements in which the larger dimension is lesser than 4 times the smaller dimension e.g.40/40, 40/60, 25/90, etc.





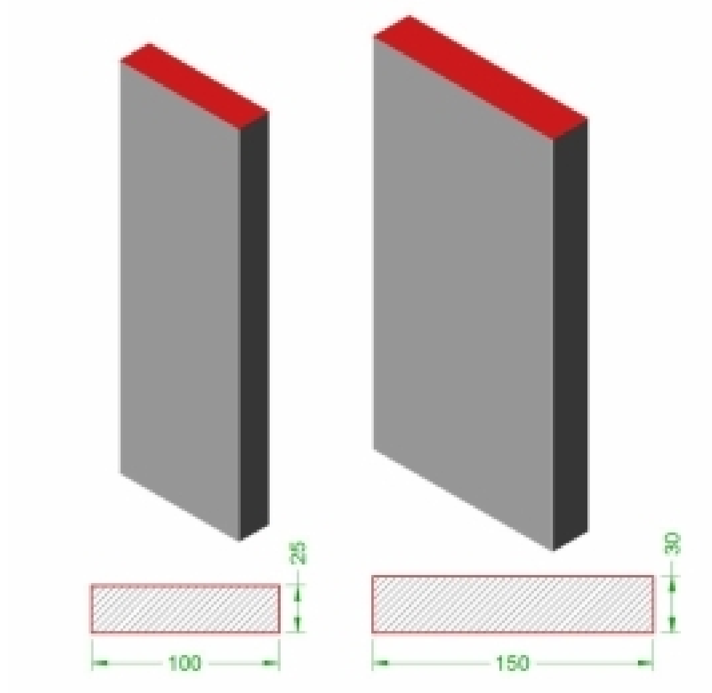
The columns category includes circular sections as well, for example D=50 and quadrilateral sections like 50/60 with an inside angle equal to 60˚.

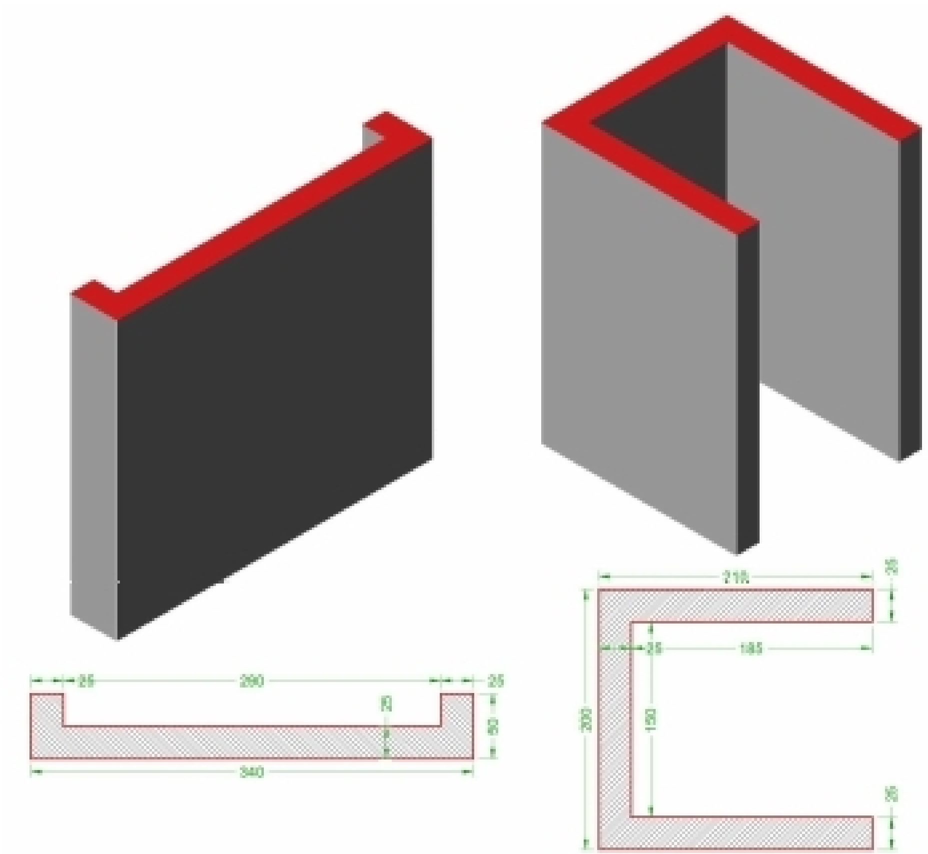
The columns category may also include elements with "Γ", "T" or "Z" cross-sections, in which the dimension ratio of their orthogonal parts is lesser than 4 e.g. "Γ" cross-section 40/80/25/25, "T" cross-section 70/50/25/25, "Z"cross-section 60/70/90/25, etc.



Shear walls are rectangular elements with a length to thickness ratio greater or equal to 4 e.g. cross-sections 100/25, 150/30.

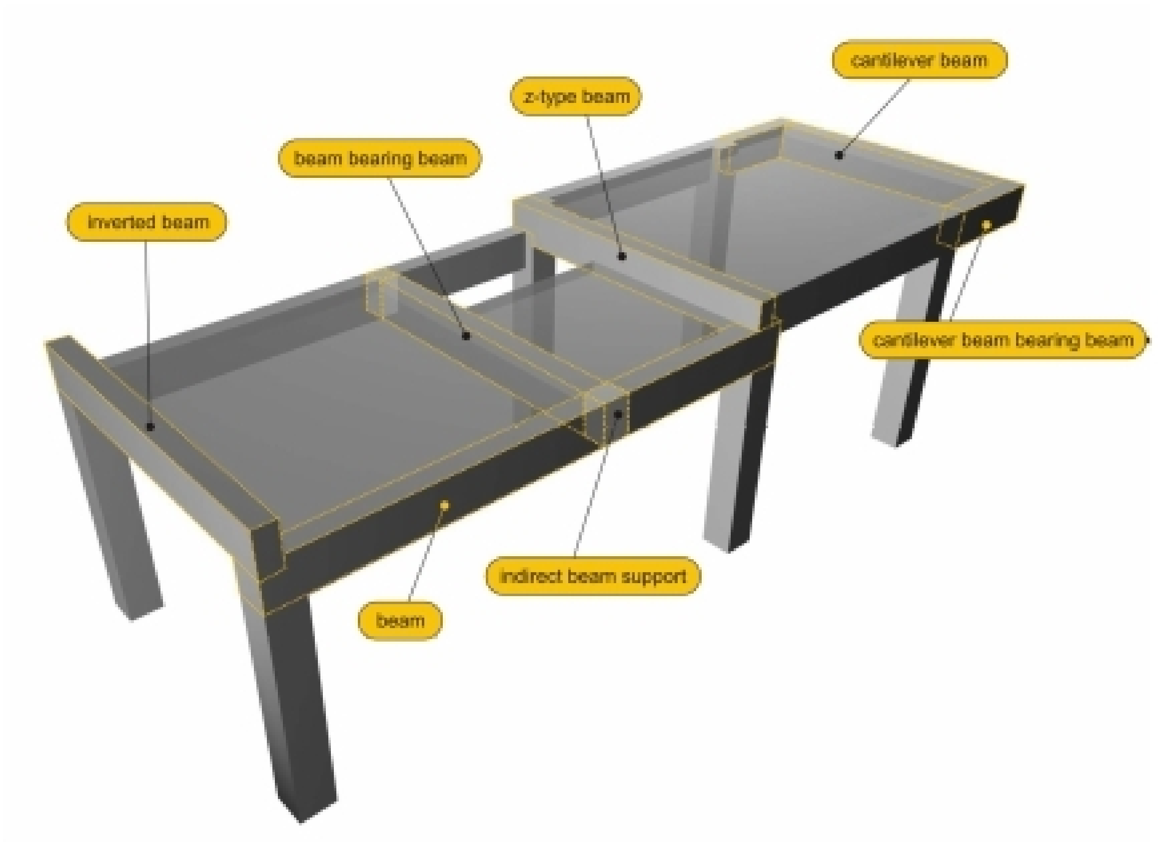
Composite elements are comprised by one or more rectangular elements, at least one of which must be a shear wall. Broadly speaking and due to the fact that at the two ends of each shear wall, columns are formed, a wall can be characterized as a composite element. For example a wall with " Γ" cross-section 120/100/25/25, "T" cross-section 120/70/25/25, elevator cores with or without flanges, double elevator core with gradient on side etc are composite elements.





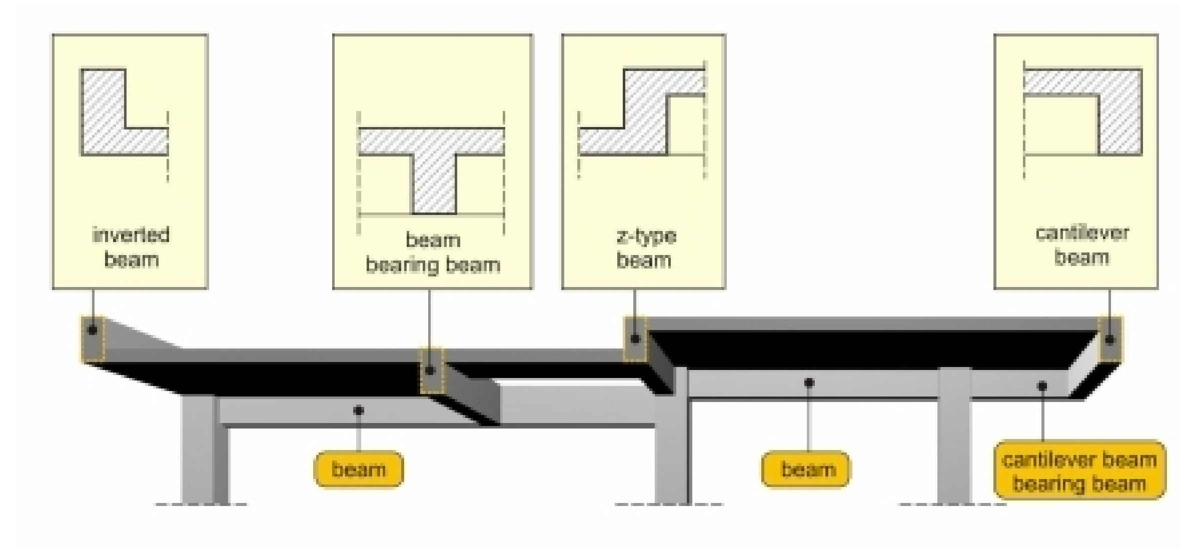
1.2.2. Beams

Beams are the vertical or sloping bearing elements of the structural system that connect columns and support slabs.



Various types of beams
<project: beams>

When beams support slabs, they work together thus forming a "T" section beam. The level of the slabs compared to the level of the beams results in the formation of **rectangular beams**, **inverted beams** or **"Z" beams**.



Generally, beams are supported by columns (beam to column connection). However, sometimes one or both beam ends are supported by another beam (beam to beam connection) and other times only one end is supported by a column or beam while the other end has no support at all. The beam supported only in one end is called **cantilever**.

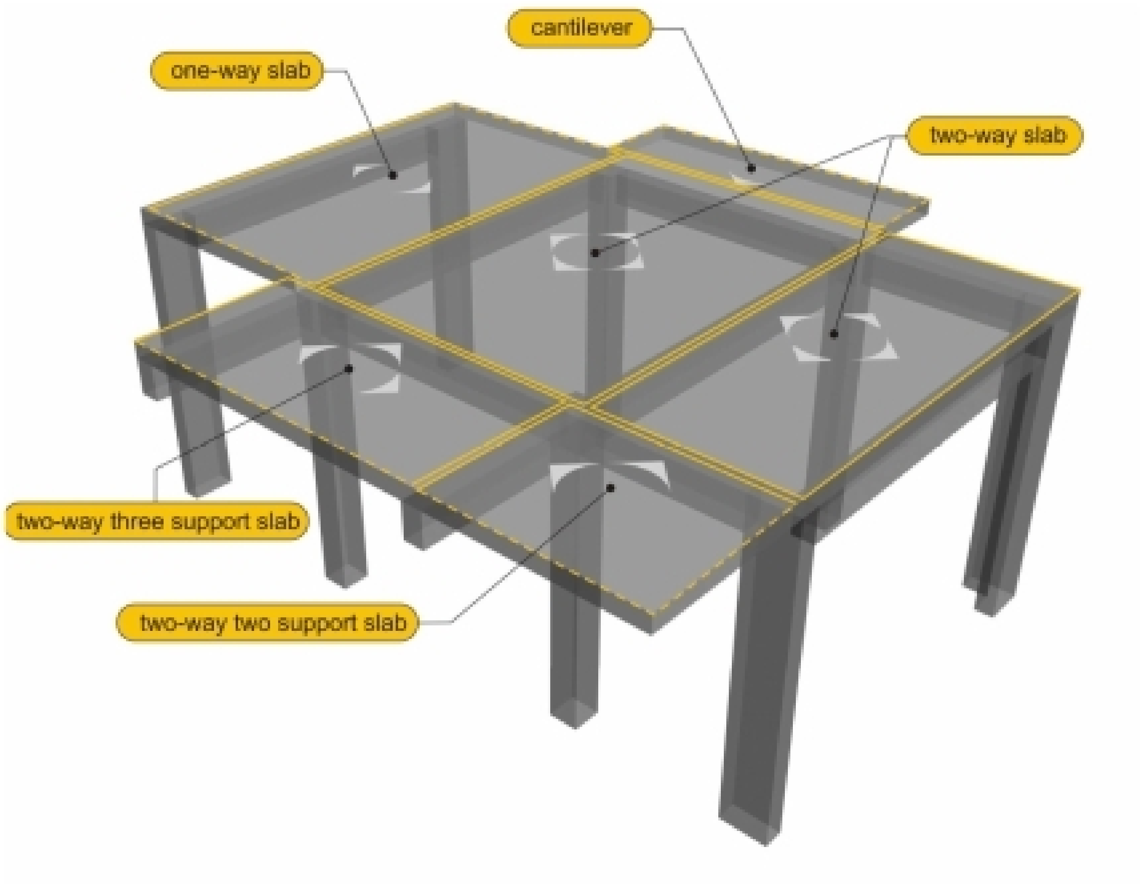
The beam to column connection is called **direct support** and the beam to beam connection is called **indirect support.**

The most commonly used beam is the one supported by two columns and the most scarcely used is the cantilever beam. Indirect supports should be rarely used and only when there really is no alternative solution.

In tilted roofs, both beams and slabs have cross sections and supports like the ones mentioned above but they are sloped.

1.2.3. Slabs

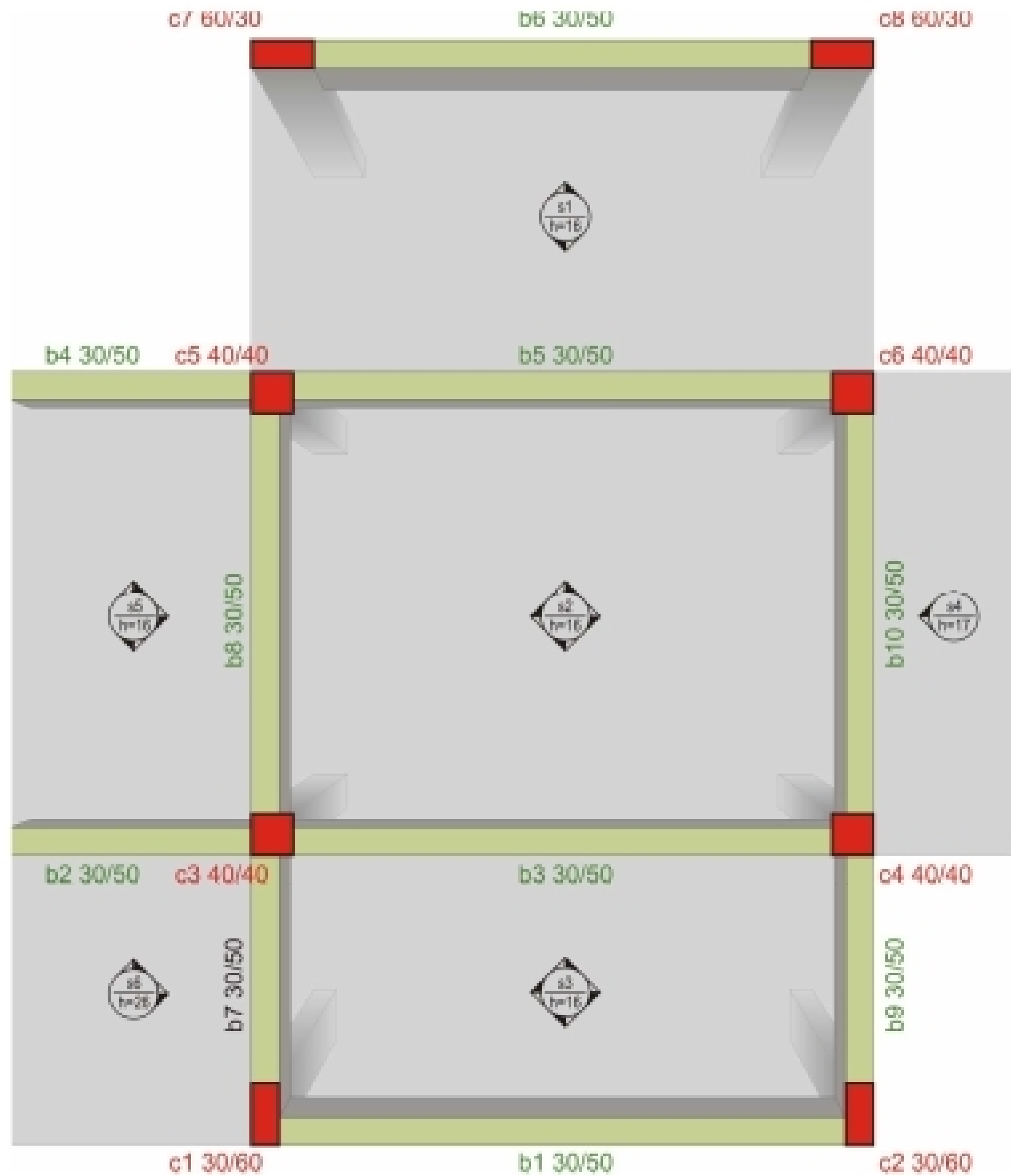
Slabs are surface plane elements that bear loads transverse to their plain.



Structure with various types of slabs met in construction
<project: slabs>

Most of the times, slabs are statically indeterminate elements that consequently redistribute the stresses applied to them. This ability makes them highly secure against bending and shear failure. Cantilevers are excluded since slabs which are statically determinate elements and therefore need special care in their construction.

Slabs are separated into categories dependent on their supports:



Hypothetical formwork plan, where the arrows show the supported sides of slabs

One-way slabs (Simply supported)
They are those supported on two out of four, opposite sides like Π1 of the above example.

Two-way slabs
They are those supported on all four sides like Π2, Π3 of the above example

Cantilever slabs
They are those with a fixed support on only one out of four sides, like Π4 of the above example.

Two-way three support slabs
They are those supported on three out of four sides, like Π5 of the above example.

Two-way two support slabs
They are those supported on two adjacent sides, like Π6 of the above example.

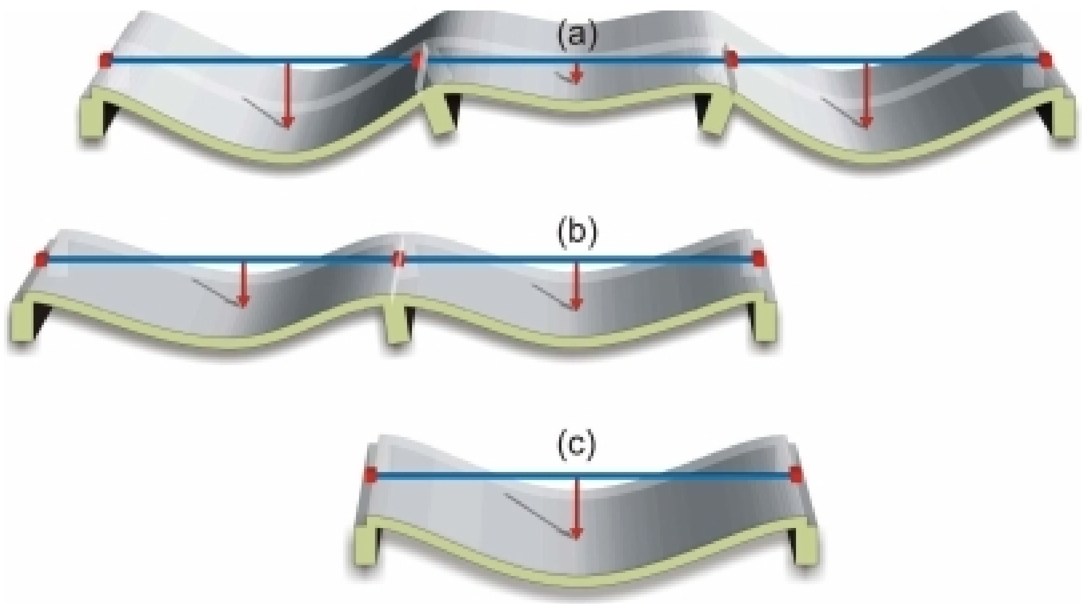
The above categorization regards rectangular slabs and is applicable only when the side supports are clearly defined in their full length. When a slab has a general polygonal shape it can be approximately simulated as a similar orthogonal shaped slab.

The slab's essential thickness is determined according to the required flexural and shear strength capacity as well as to the limitations of the allowable deflections. Usually the determinative factor is the second parameter because the slab's elastic stability (stiffness) is important throughout the entire service life of the structure. Its lack can even become apparent with human walking as it may initiate vibrational motion.

As regards to support, the safest slab is the two-way slab and the most vulnerable is the cantilever slab. This happens because in a two-way slab, potential loss of one support results in a two-way three support slab, while in the case of a cantilever slab potential support loss results in collapse.

Slabs behave better when having one adjacent slab and even better when having two adjacent slabs in both directions.

The following picture shows deformations, in a large scale but proportionate to one another, for three different types of slab continuity. It is obvious that continuous slabs suffer lighter deflections thus they have better elastic stability (stiffness).



The slab with the bilateral continuity (a) behaves in the best way. Next comes the slab with the unilateral continuity (b) while last comes the slab with no continuity (c).

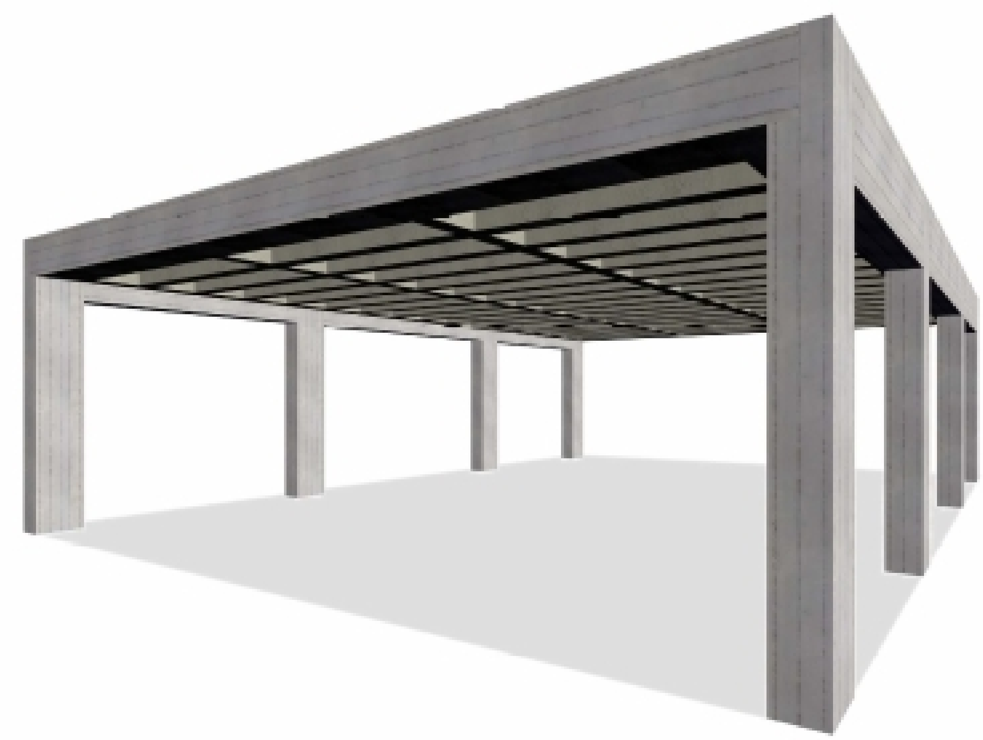
In common structures, for slab thickness equal to 15cm, the slab's span may vary between 3.60m and 6.00m and the cantilever spans may be up to 1.50m. For slab thickness equal to 20cm the slab's span may range from 4.80m to 8.0m and the cantilever spans may be up to 2.0m.

The 15cm thick slab has a self weight equal to 0.15m*25 kN/m³=3.75 kN/m² while the live load due to human use, furniture etc that it is called to bear, is equal to 2.0 kN/m² only. If the slab has a thickness equal to 20cm its self weight is 5.0 kN/m², and if it is equal to 30cm its self weight is 7.50 kN/m² whereas the live loads remain the same.

Therefore for large spans **ribbed slabs (waffle slabs)** (Zoellner, sandwich) can be used, like the one shown in the figure below. A ribbed slab with total thickness of 30cm may have a self weight equal to 3.75kN/m², which corresponds to the self weight of a 15cm thick solid slab.

Advantages of ribbed slabs:
- their large effective thickness provides them with a high level of elastic stability (stiffness),
- they have low dead weight consequently they apply relatively light stresses,
- they do not overload the structural frame and the foundation,
- because of their large effective thickness they comparably need lesser amount of reinforcement,

Disadvantage of ribbed slabs:
- Their construction is more challenging and therefore they require meticulous reinforcement detailing.

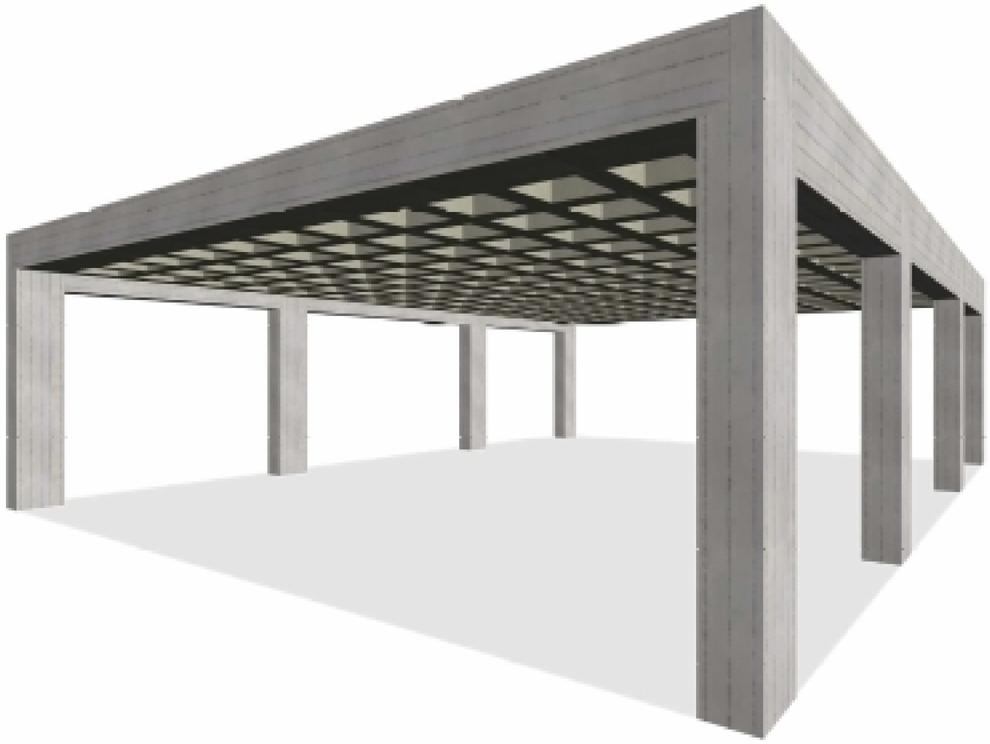


One–way ribbed slab
<project: zoellner10>

A one-way (simply supported) ribbed slab, in the primary direction is composed by usual **ribs** while in the secondary direction the ribs are vertical and sparsely placed thus ensuring the even load distribution.

The voids between the ribs are usually covered with extra light-weight polystyrene with a density of e.g. 25kg/m³ (compared to the density of the reinforced concrete that is equal to 2500kg/m³)

Usually two-way slabs have square **voids** between the ribs because the demand for adequate bending strength is equal in both directions. The square voids are being shaped either with the use of light-weight fillings like polystyrene or with the use of plastic moulds. The later have significant constructive advantages (qualitative, fast construction) thus providing proportional economical solutions.

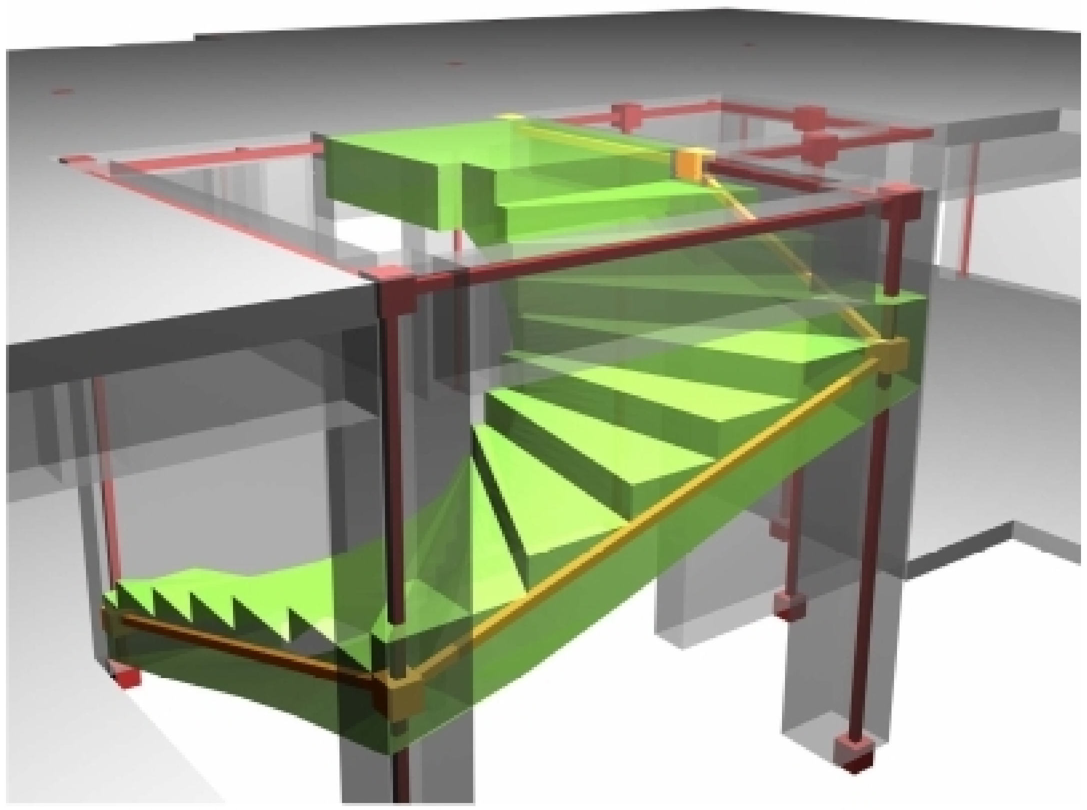


Two–way ribbed slab
<project: zoellner20>

1.2.4. Staircases

Although stairs are not part of the structural load bearing frame, they affect and they are affected by its behavior especially when horizontal loading is applied, mainly due to seismic actions.

If the staircases are both properly placed in the structure's plan and properly constructed they may even enhance the structure's antiseismic behavior



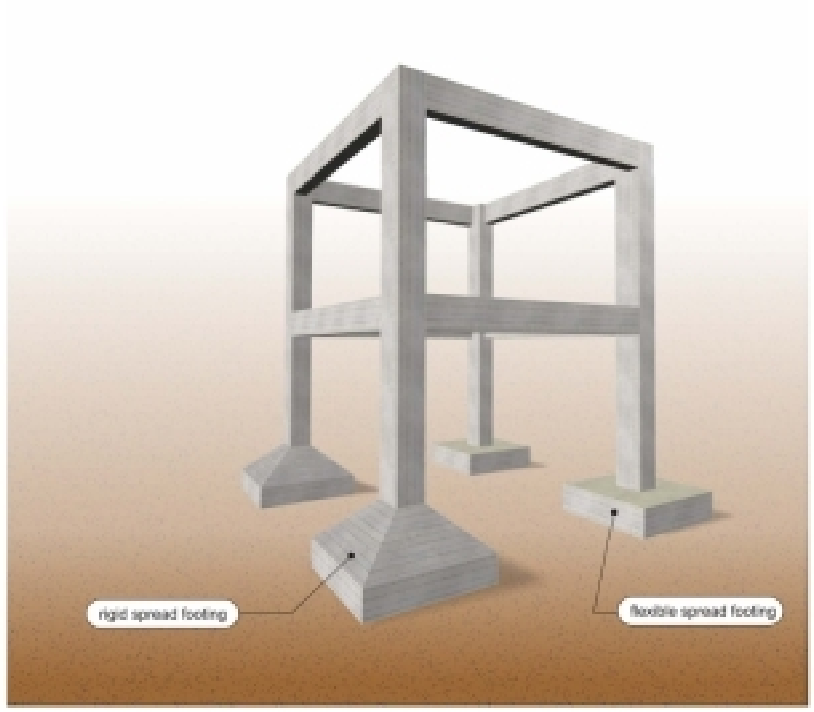
Staircases are architectural-service elements, they are cast together with the load bearing frame which they affect and they get affected by.

The main concern is to ensure that in the duration of a seismic event, stairs will not suffer serious damage. As a result, after a strong earthquake, their repair will be technically and economically possible but most important of all they will remain in service allowing the evacuation of the structure since the elevator use will be prohibited.

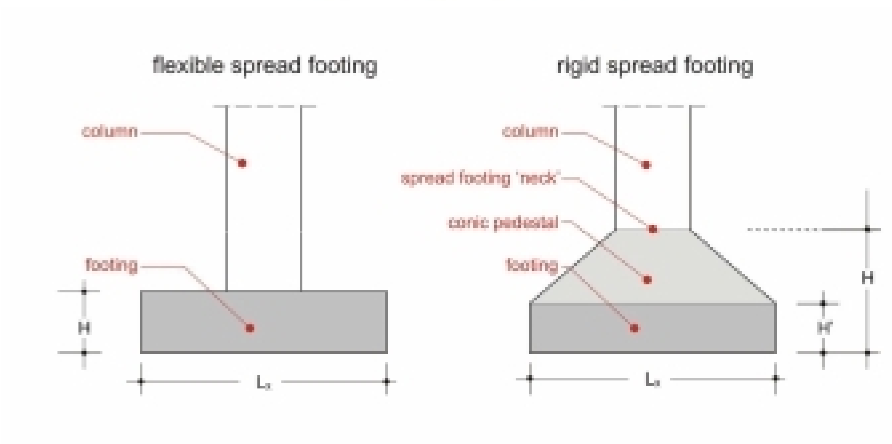
1.2.5 Foundation

The same way humans have their feet to transfer their self weight and other loads, softly to the ground, foundations carry with light pressures the structural frame loads to the underlying soil.

Foundation generally includes the **footings** and the **pedestals**. The simplest type of foundation is the spread foundation (pad foundation) i.e. isolated column footings.



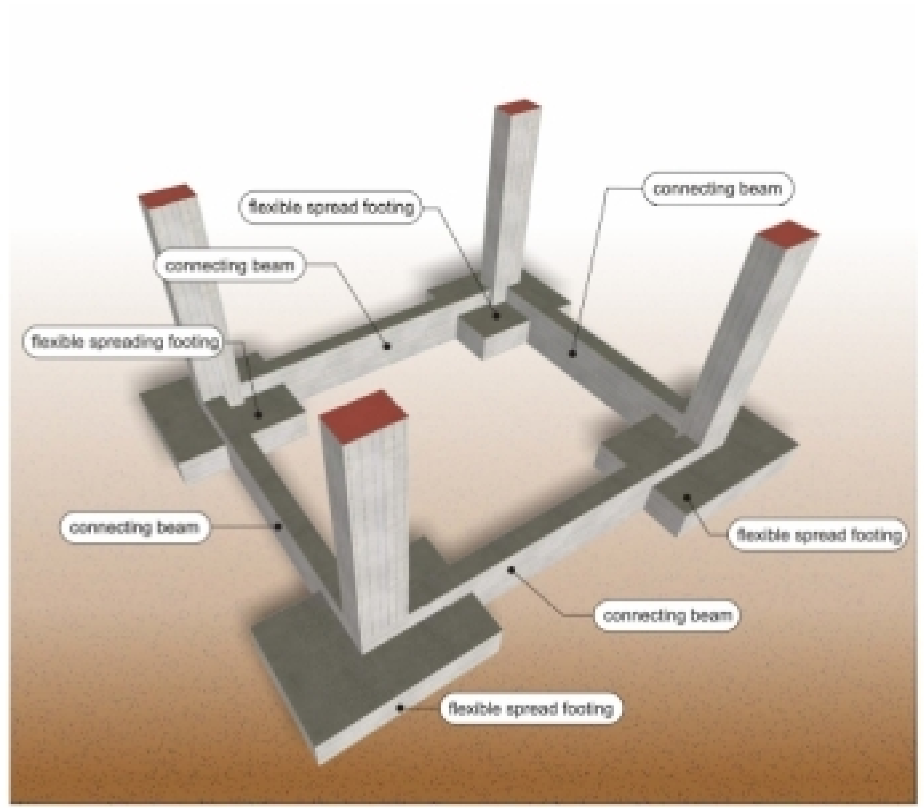
Foundation consisting of flexible and rigid spread footings (no connecting beams)
<project: Foundation10>



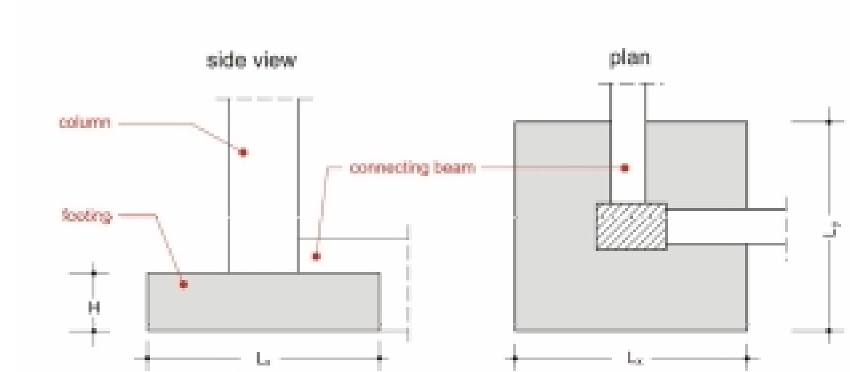
As a rule, spread footings consist only of a box and they are usually called flexible. Sometimes they may have a relatively large height and a sloped end, and they are called rigid.

Nowadays, flexible spread footings are used almost exclusively because of their easy construction and their low cost and labor. However in the past, when the material cost was higher than the labor cost, rigid spread footings were usually constructed.

The footings' dimensions depend on the soil's quality and the loads transferred by the columns (column loads are determined by the distance between the columns along with the number and loads of the structure's storeys). The usual footing dimensions range from 1.0x1.0m to 3.0x3.0m although sometimes they may be larger and their height varies between 0.50m and 1.00m for flexible spread footings and between 0.70 and 2 m for rigid spread footings.

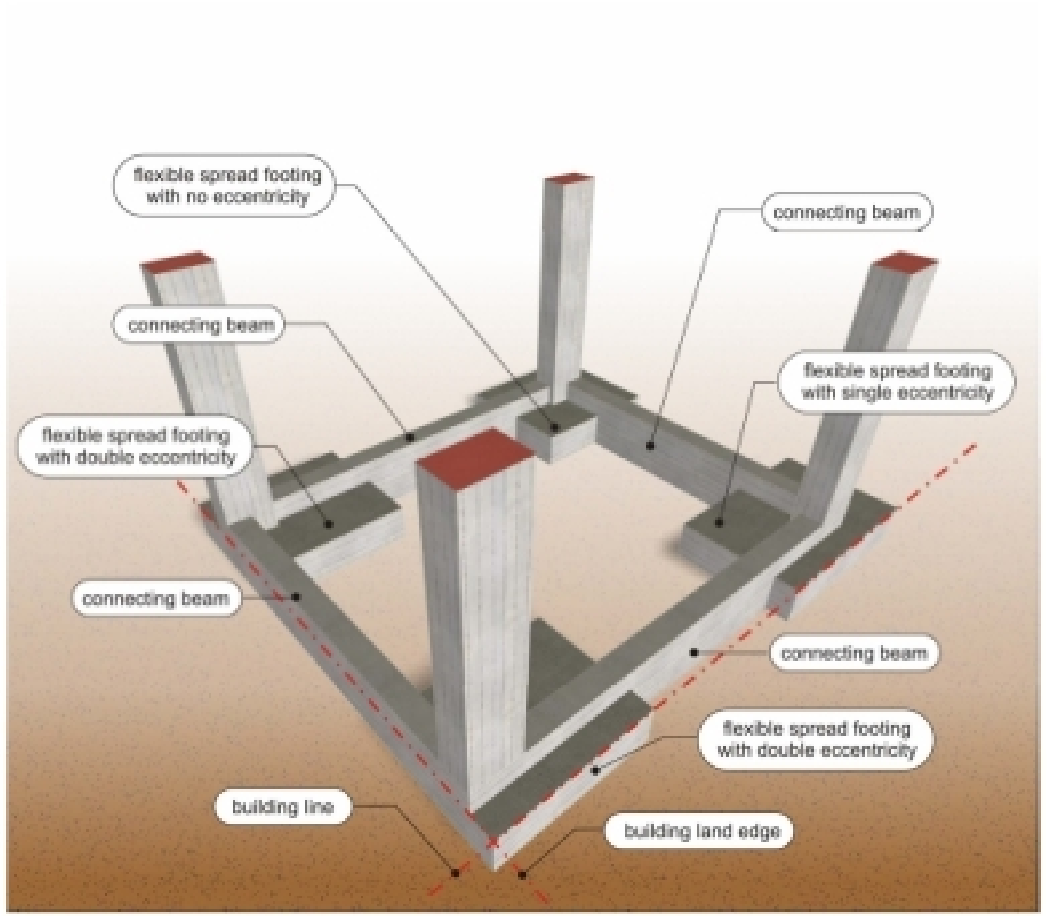


Foundation consisting of flexible spread footings and connecting beams
<project: Foundation20>



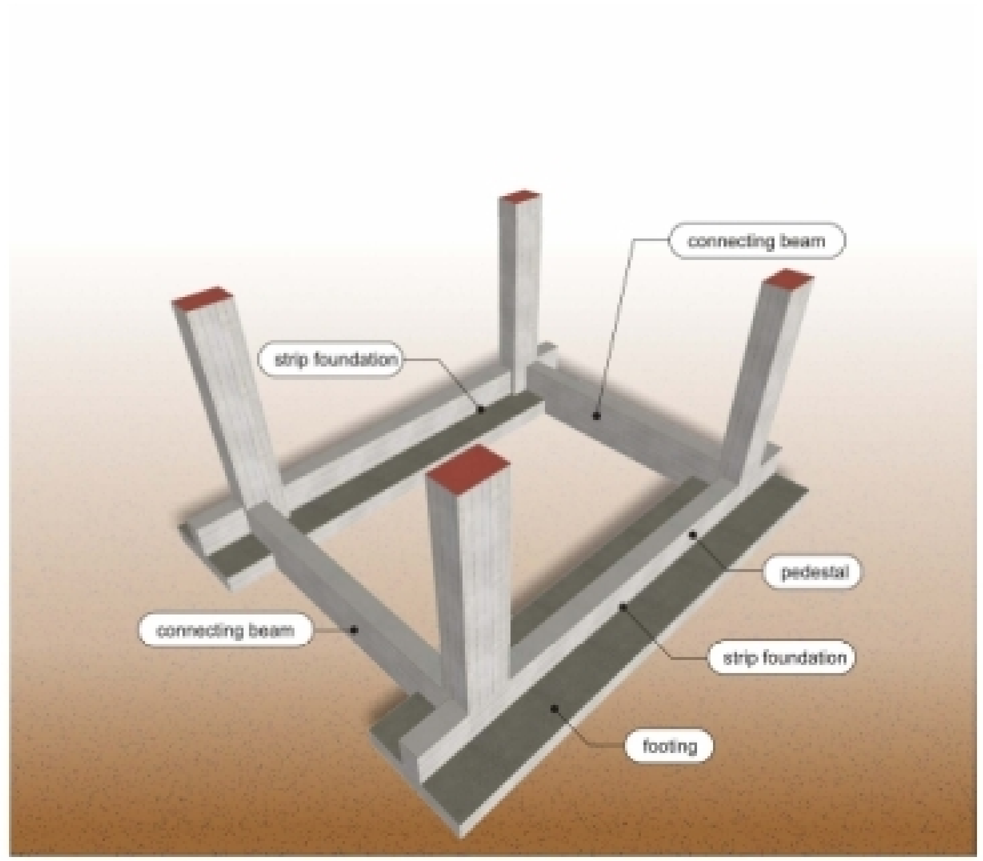
In order to ensure the proper behavior of the foundation, the use of foundation beams (connecting beams) is mandatory. These beams tie together the column's bases thus making the footings behave in a normal way especially during seismic incidents. Usually their cross section width ranges from 0.30 και 0.50m and their cross section height from 0.50 έως 1.50m.

Footings are constructed centrically to their mass centre, except in those cases when due to building restrictions they are **eccentrically constructed** e.g. like boundaries of the building line or edge of the building land as shown below.

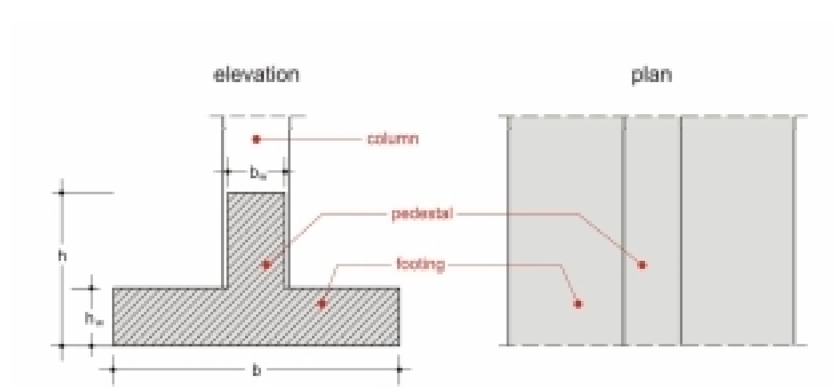


Foundation consisting of eccentrically constructed spread footings due to limitations of the building line and the edges of the building land
<project: Foundation30>

The bigger the footing's construction eccentricity is, the strongest must the connecting beam in that direction be.
Spread foundation (pad foundation) is used in a good quality soil. In case of low soil capacity strip foundation is used.

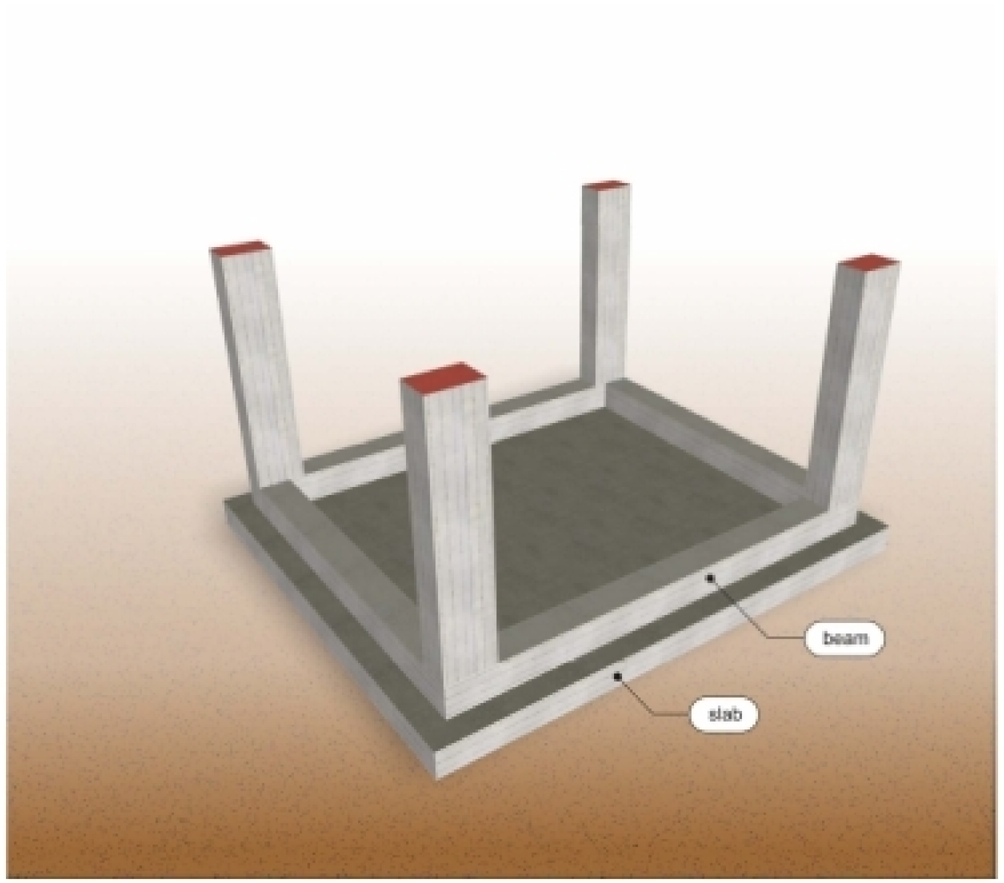


Strip foundation with connecting beams
<project: Foundation040>



Strip foundation consists of the pedestal and the footing. The usual dimensions of the footing vary between 0.40m to 0.60m for its thickness and between 1.00m to 2.50m for its width. The typical pedestal cross sections range from 0.30x0.80 to 0.50x1.50.
For a more effective behavior it is advisable to use grid foundation.

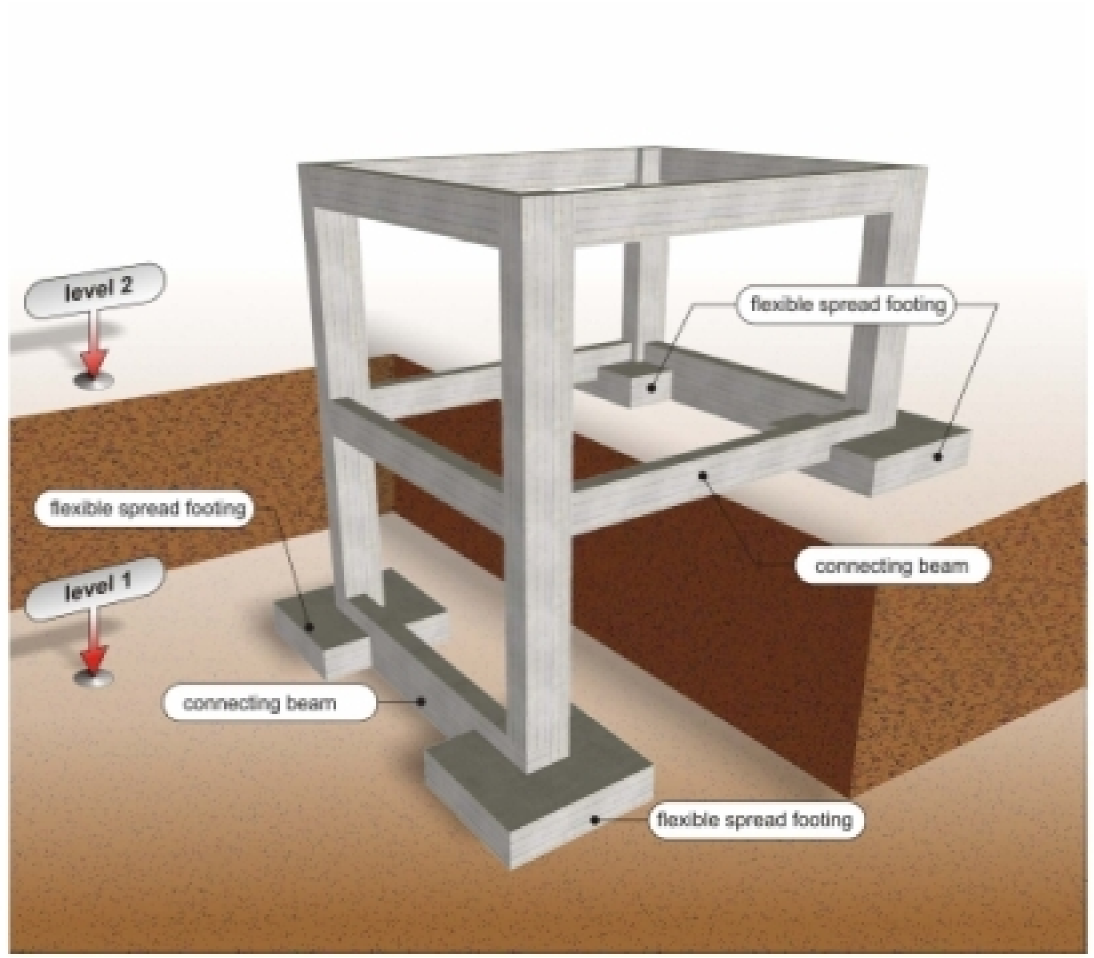
In poor soil conditions **raft foundation** is commonly constructed. It consists of a slab which extends over the entire loaded area. Frequently it is used in other soil conditions for practical reasons basically because of its fast and easy construction.



Raft Foundation with connecting beams
<project: Foundation50>

Raft foundation may have regular foundation beams for rib formation, as shown in the above figure, or beams incorporated into the foundation with the form of **hidden beams**.

The usual thickness of a raft foundation, ranges from 0.40m to 1.0m, while the dimension of the raft foundation beams vary from 0.30x0.80 to 0.50x2.00.

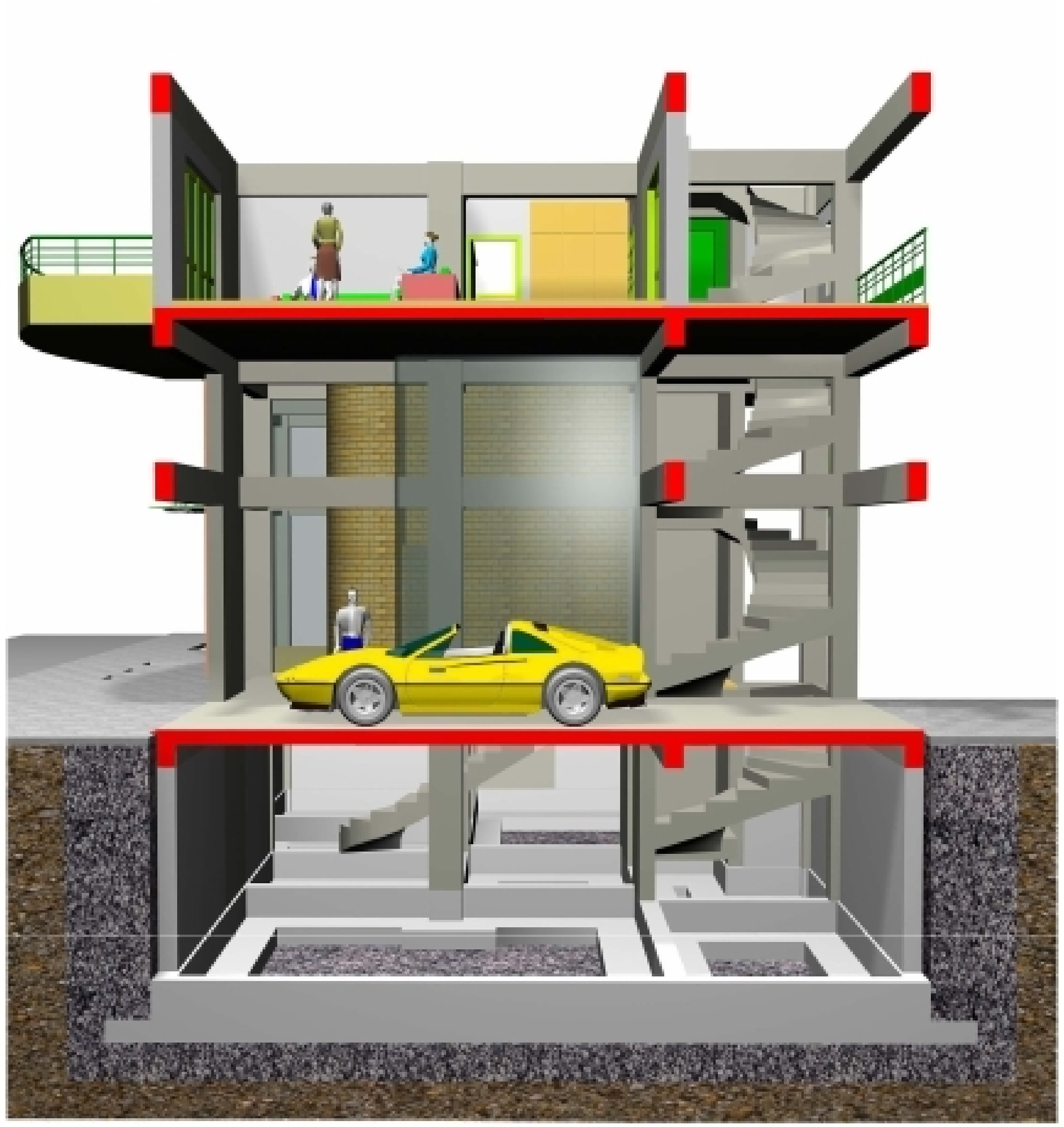


Two level foundation
<project: Foundation60>

Generally foundation should be placed in one even level however in certain cases like sloped building lands, foundation is placed on more than one levels.

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.



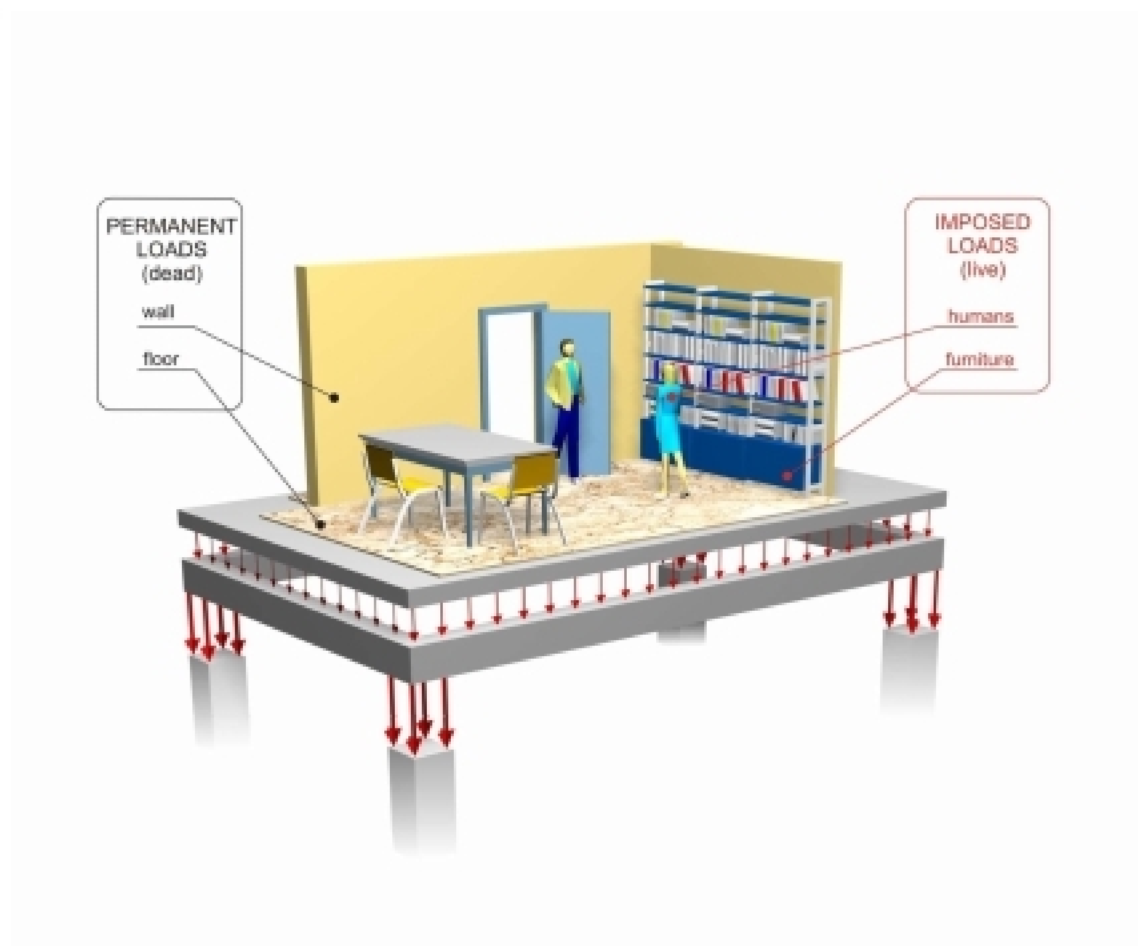
In every building like the one shown in the above figure, permanent (dead) and imposed (live) loads are applied. The latter are much lower than the former, for example 3 persons and the living-room furniture weight as much as a single m² of slab surface while a car weights as much as a sole beam.

Apart from the usual loads, in earthquake prone regions, the structural frame must have enough **strength surplus** distributed in such a way so that in the critical moment of an earthquake, to be able to respond successfully, retaining the structure intact.

Mass is the characteristic feature of a body. The force field surrounding each body defines the types of forces applied to it. The Earth's gravitational field applies the gravity force, otherwise referred as weight. During an earthquake, the appearance of additional horizontal accelerations causes the formation of horizontal seismic forces. These forces are applied to the structure and they constitute the structural frame loading. Structure loads can be classified into three categories gravity loads, seismic loads and wind loads.

1.3.1. Gravity Loads

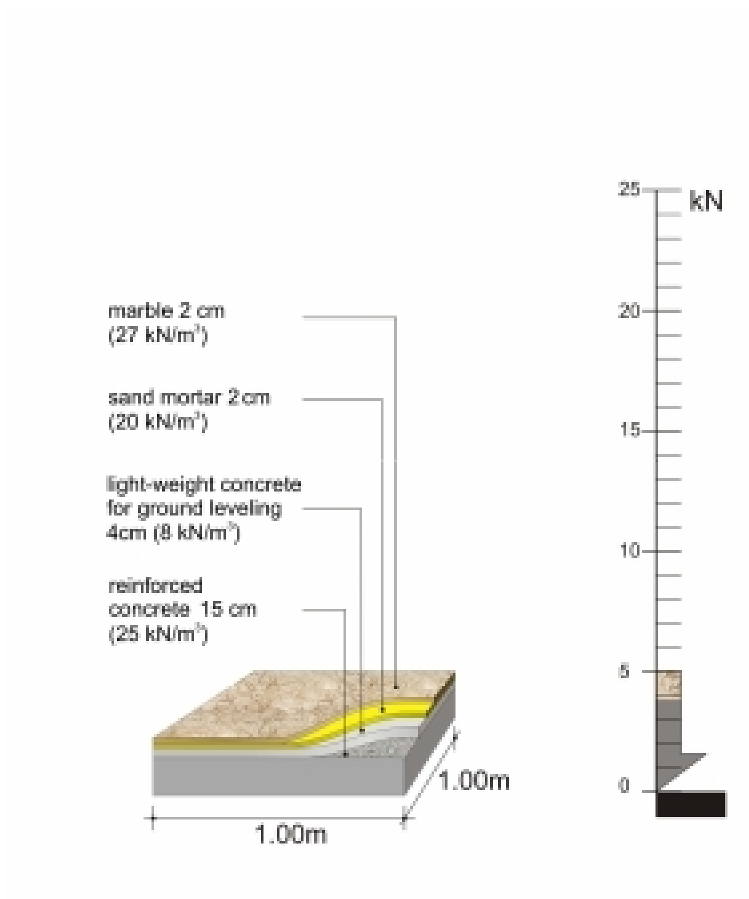
The loads applied to a structure are divided into permanent (dead loads) and imposed (live loads). The former include the self weight of reinforced-concrete structural members, of walls and coatings-coverings. The latter include loading caused by people, furniture, vehicles etc.



Dead loads

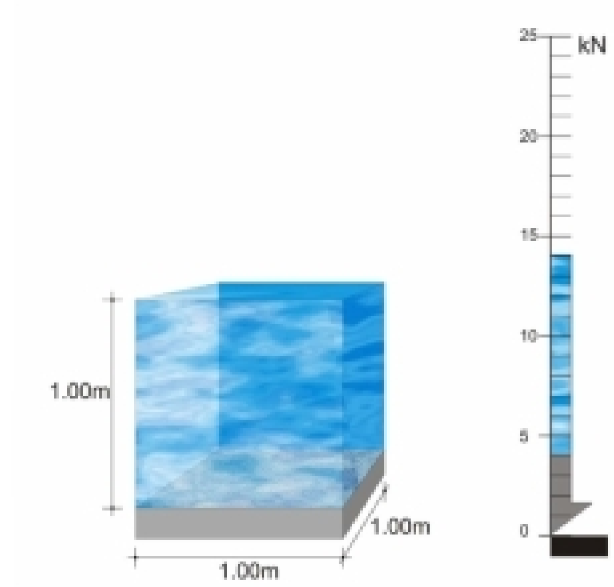
The density and the related unit weight of the materials used in construction are:

Reinforced concrete	ρ=2.50 t/m³ (ε=25.0 kN/m³)
Light- weight concrete for ground leveling	ρ=0.80 t/m³ (ε=8.0 kN/m³)
Sand mortar	ρ=2.00 t/m³ (ε=20.0 kN/m³)
Marble	ρ=2.70 t/m³ (ε=27.0 kN/m³)



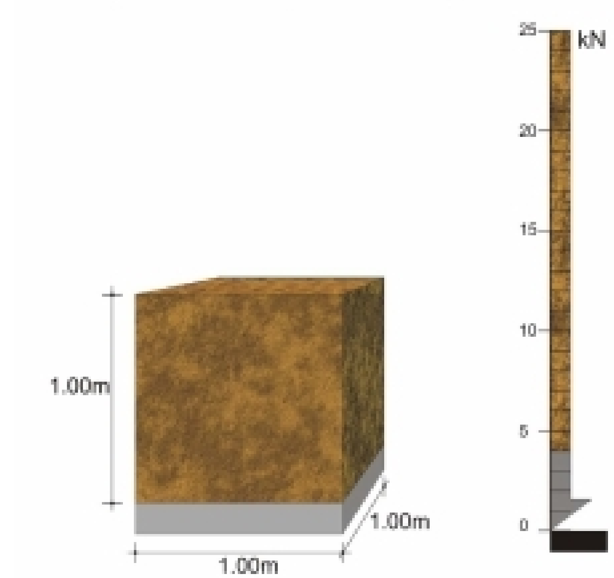
The dead mass of one m² of the above slab is,
*g = 0.15*2.50 + 0.04*0.8 + 0.02*2.0 + 0.02*2.7 = 0.5 t,*
i.e. the self mass of one square meter of a usual slab is
0.5 t (weight 5.0 kN)

Water ρ = 1.00 t/ m³ (ε = 10.0 kN/m³)



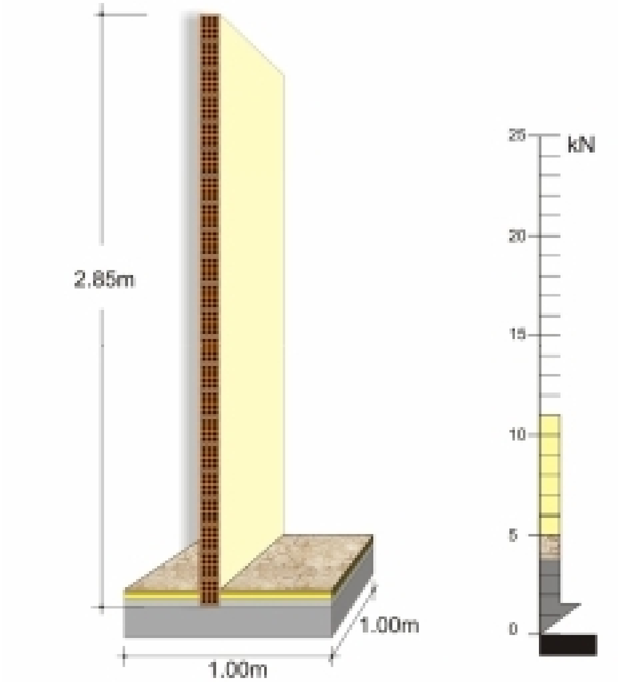
The dead mass of one m² of a pool slab,
when the pool is filled with just 1.0m of water is,
1.4 t (weight 14.0 kN)

Garden soil ρ = 2.50 t/m³ (ε = 25.0 kN/m³)



The dead mass of one m² of a slab, with 1.0m of soil on top is
2.5 t (weight 25.0 kN)

Masonry stretcher bond ρ = 0.21 t/m² (ε = 2.1 kN/m²)
Masonry Flemish bond ρ = 0.36 t/m² (ε = 3.6 kN/m²)

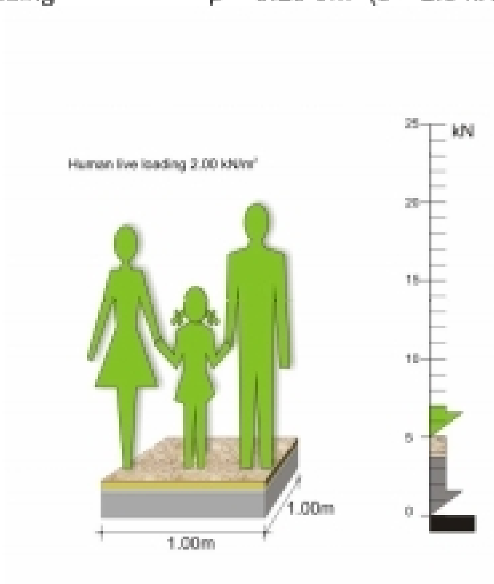


A wall of 1.0 m length, 2.85m height and 10cm thickness has a mass equal to 0.60t. (weight 6.0 kN)

Live loads

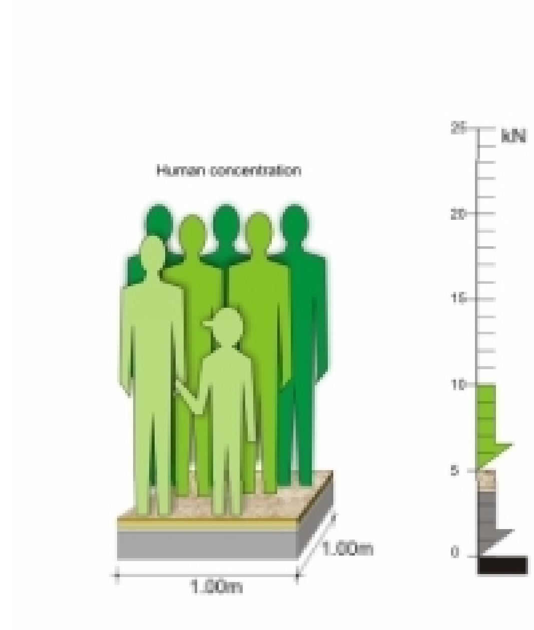
Human loading:

- Normal human loading ρ = 0.20 t/m² (ε = 2.0 kN/m²)



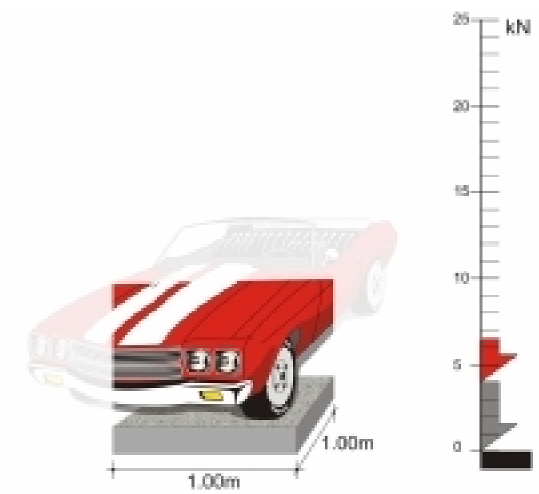
The live mass of one m² residential building is 0.2 t (weight 2.0 kN)

- Human concentration ρ = 0.50 t/m² (ε = 5.0 kN/m²)



The live mass of one m² commercial area is *0.5 t (weight 5.0 kN)*

Vehicle loading ρ = 0.25 t/m² (ε = 2.5 kN/m²)



The live distributed load of 1 m² of a parking space is 0.25 t (weight 2.5 kN)

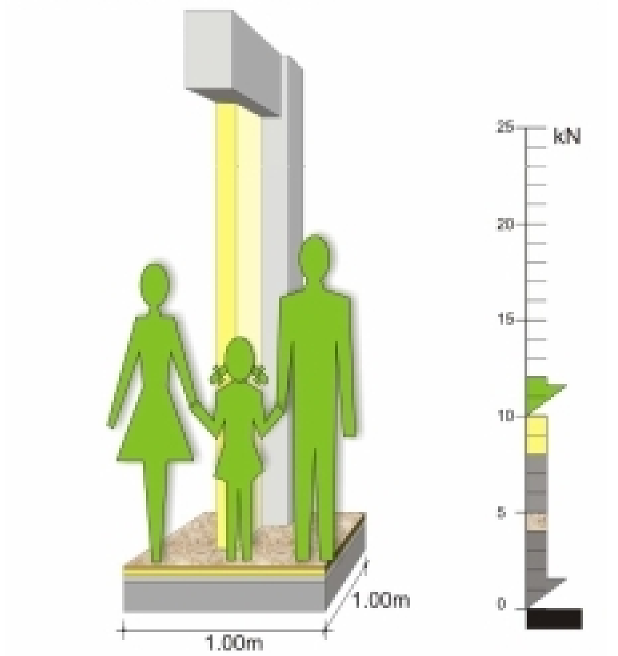
As a rule, snow loading is lower than the live load generated by the use of people and its value ranges between 0.60 and 1.50 kN/m².

Note :

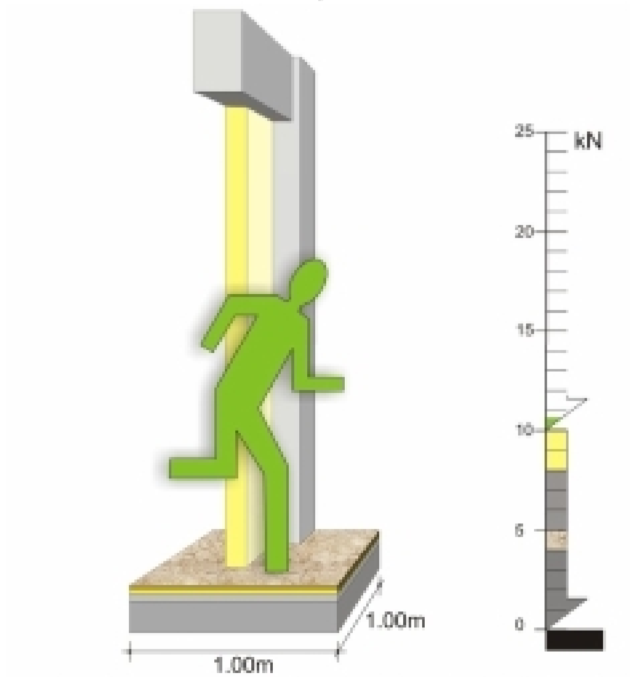
In order to calculate the amount of the total loading applied to a residential structure we assume 1m² of slab i.e. 1mx1m surface.

In every 1m² of floor surface, the permanent (dead) and the induced (live) masses, are in the order of 0.50t (weight 5.0KN) and 0.20t (weight 2.0KN) respectively. However when we consider the loads applied by beams, columns, walls and plasters, the total amount of the dead loads i.e.

the structure's self weights, is greater than 10 kN/m², as opposed to the live loads that remain equal to 2kN/m². Moreover in a specific time in the structure's life span, the possible extensive permanent loads may be around 100% in contrast to the possible extensive induced loads that may be around 30%. From all the above we realize how greater are the dead loads in comparison to the live ones and this is one of the most important problems of structures, they "use" to many dead loads in order to bear a few live loads.



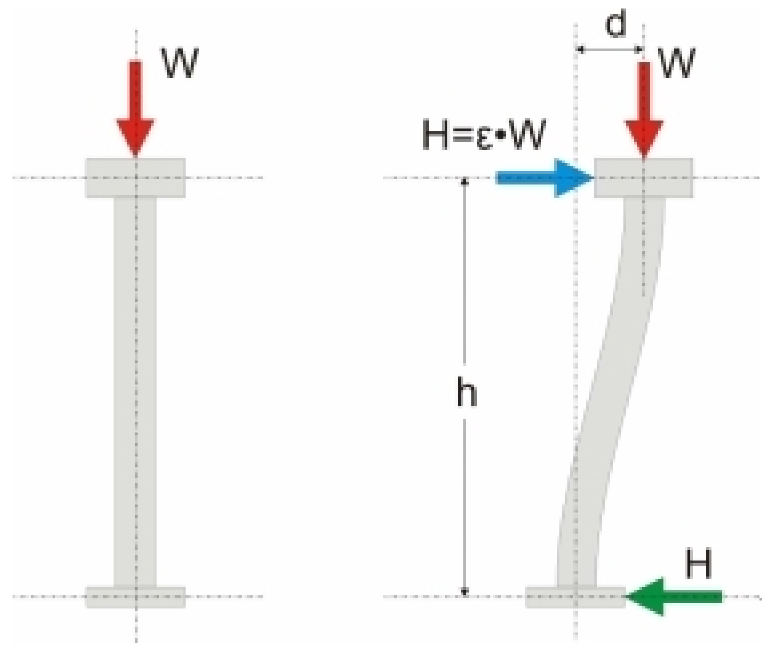
In a residential building, the maximum live loads are about 20% of the dead loads.



In random cases like earthquakes, the extensive live loads may reach 6% of the dead loads.

1.3.2. Seismic loads

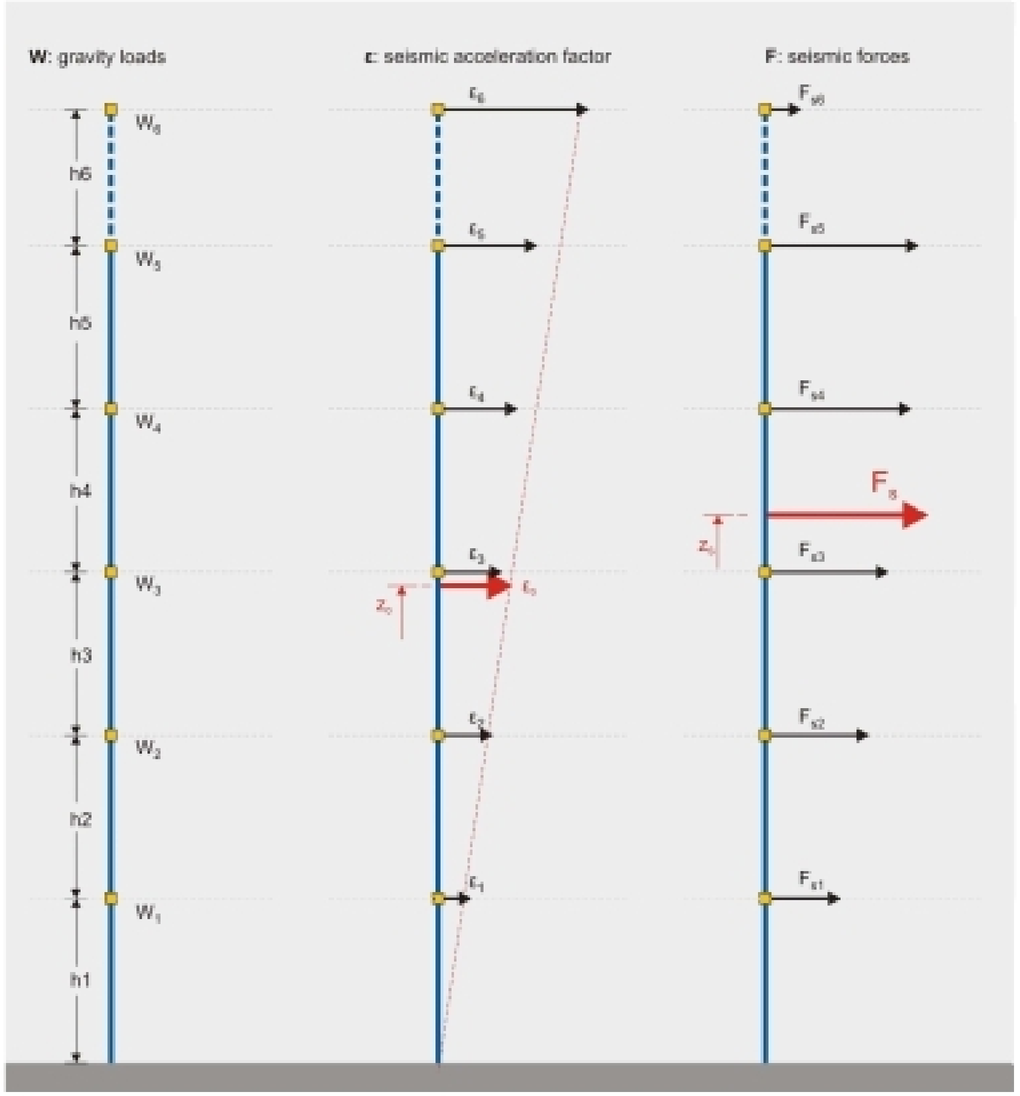
The effect that a seismic action will have in a structure is determined by regarding an earthquake with horizontal design **ground seismic acceleration** equal to **A=α*g**. Greece is divided into three **Seismic Zones I, II, III** and for each of these Seismic Zones the factor **α** takes the following values 0.16 for Zone I, 0.24 for Zone II και 0.36 for Zone III.



In the duration of an earthquake, a horizontal seismic force **H** is applied in every mass **M** that has gravity load **W**. The **H** force is equal to a percentage **ε** of the **W** force. **ε** value usually varies between 0.00 and 0.50 while in a very intense seismic action it may rise above 1.00.

The value of **ε** depends mainly upon the value of factor **α**, used for the calculation of the maximum horizontal ground seismic acceleration and upon other factors like soil classification, structural system's geometry, mass center.

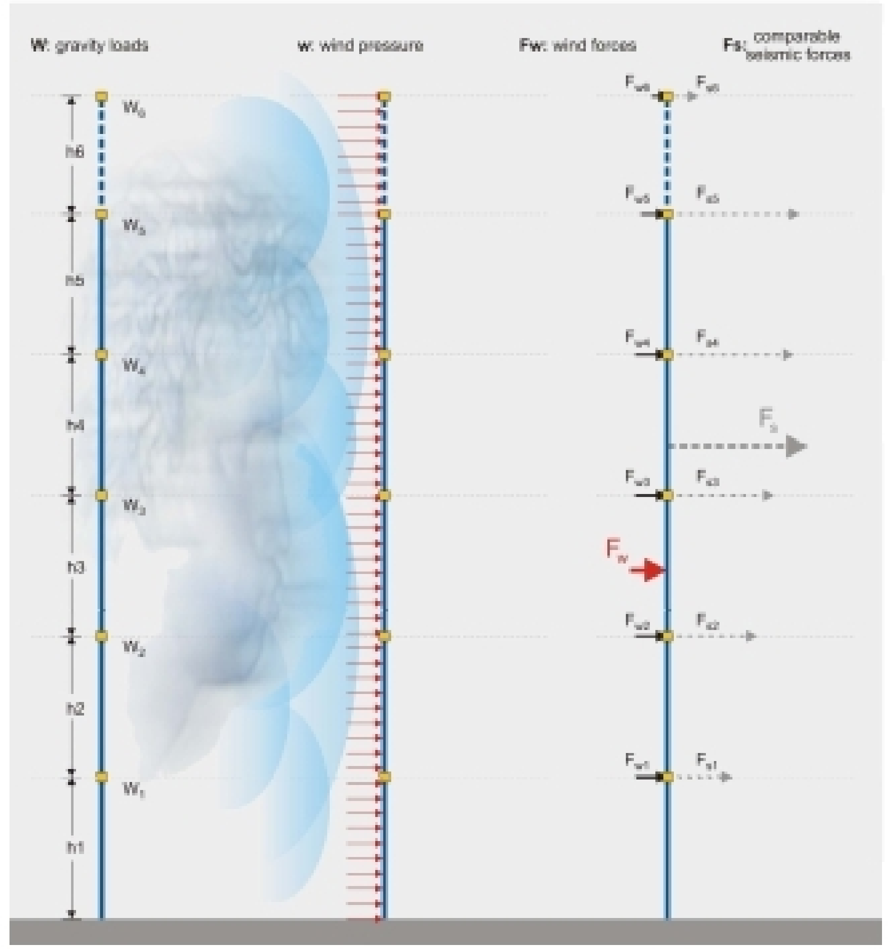
In general terms, the distribution of seismic accelerations has the form of a triangle.



The distribution of seismic acceleration has a form similar to a triangle

The structure shown above belongs to the Seismic Zone I (seismic ground acceleration equal to 0.16), the mean value of the design seismic acceleration is around 0.12g (ε_0=0.12) and the resultant seismic force Fs is around 1400KN. The theoretical height that this force is applied, is around the 2/3 of the structure's total height.

1.3.3. Wind loading



Comparison of wind forces Fw and seismic forces Fs

In the same structure, when placed in a geographical region with intense winds, the mean value of the wind pressure is around 1.50 kN/m^2 and the resultant force around 400 kN. The total service load applied is 12.000 kN. Therefore the wind force is equal to 0.03% of the vertical loads and its theoretical application area is in the middle of the structure's height. Comparing the wind and the seismic forces applied to that structure we realize that the wind effect upon the structure is at least four times smaller than the seismic effect.

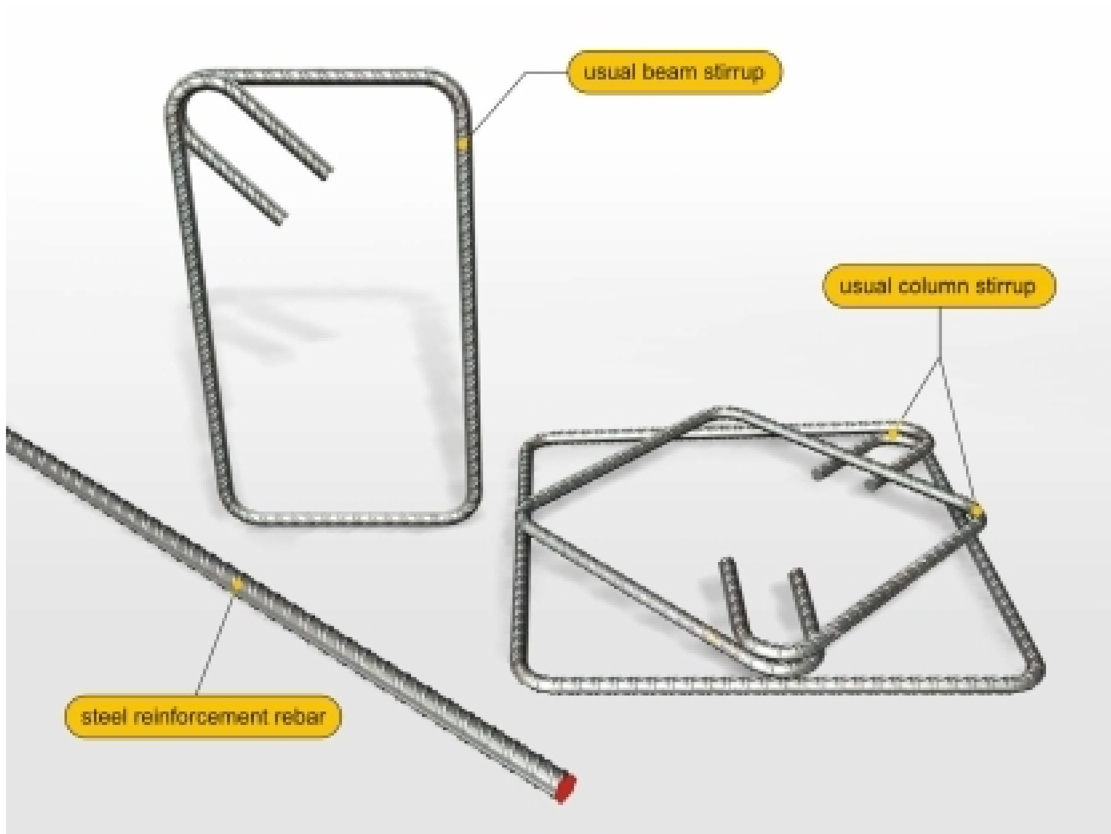
Reinforced concrete structures have large self weight both during the design and the service life, consequently wind loading does not affect their behavior to the same degree as it affects timber or steel structures.

In the dimensioning of earthquake resistant structures we consider either seismic or wind forces and not simultaneous loading. As a rule, the seismic action that applies a load analogous to the wind pressures has a greater value than the wind loading, consequently, in seismic design structures are not dimensioned for wind pressures. In Greece the effect of wind is significantly smaller compared to the effect of earthquake motions even in the Zone with the lowest seismic activity.

1.4 BEHAVIOR OF THE STRUCTURAL FRAME

Reinforced concrete is composed of two materials, **concrete** (beton) and **reinforcement**. The reinforcement is usually made out of steel and rarely, at least for the time being, is made out of composite materials, **composites**.

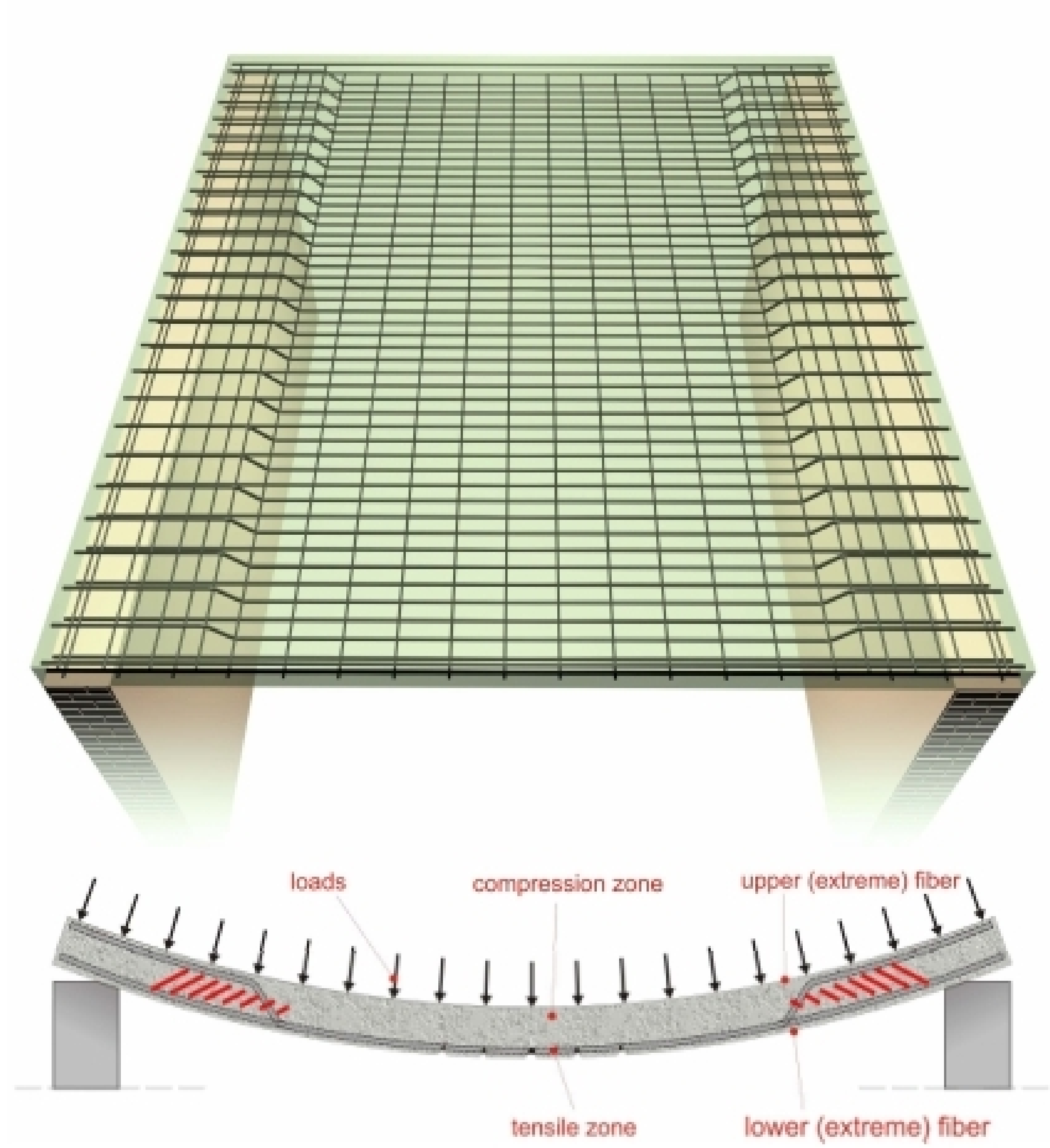
The reinforcement is divided in two basic categories: (a) the **longitudinal** reinforcement in the form of rebars and (b) the **transverse** reinforcement mainly in the form of stirrups.



In order to understand the behavior of a reinforced concrete structural frame, we will assume two simple examples, a simply supported slab and a frame composed of two columns and a beam.

1.4.1 The behavior and reinforcement of a slab

A slab, due to its loading (self weight, marble floor coverings, human activities etc) and also due to its elasticity, is deformed in the way shown at the following picture. The real deformation is in the order of millimeter and although it is not visible to the human eye it always has that same form.



Concrete has a high compressive strength; therefore in the compression zone where there are only compressive stresses, no longitudinal reinforcement is applied. On the contrary, concrete has a very low tensile strength therefore in the slab's tensile zone where there are only tensile stresses, longitudinal reinforcement is applied.

The introduction of reinforcement in concrete, results in a material with the ideal combination of compressive and tensile strength. In the tensile zone of the slab and especially in the middle of its span, hairline cracking occurs on the concrete's surface. These cracks may not be visible to the human eye but they exist, without though affecting the slab's behavior.

Diagonal stresses appear on the slab's support faces but as a rule they are dealt with by the concrete thus no transverse reinforcement is needed.

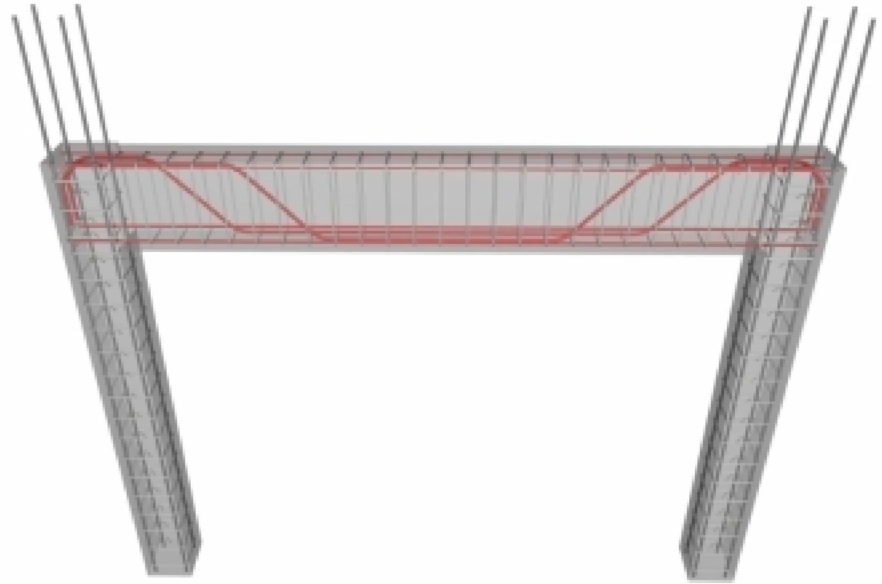
In the upper extreme fibers of the slab supports, it is possible for tensile stresses to appear; therefore a minimum amount of longitudinal reinforcement is placed in these areas. That reinforcement may be autonomous, may be slab-span reinforcement continued up to the supports or it may be a combination of those two. In this specific example the upper (negative reinforcement) comes from the slab's span reinforcement (bent up rebars).

Generally, slabs are not practically affected by seismic forces in their plane and that is the reason why they are not extra reinforced in order to withstand them.

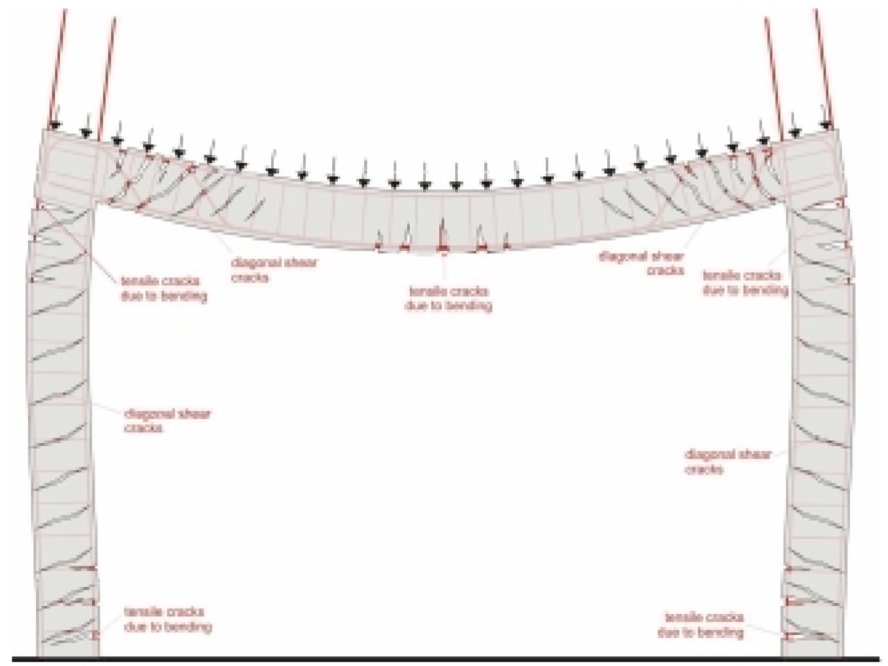
1.4.2 Behavior and reinforcement of beams and columns

FRAMES WHERE NO SEISMIC DESIGN IS REQUIRED

The following frame is composed by two columns and one beam and it bears only gravity loads i.e. no seismic loading is applied.



The following figure shows the concrete deformations and cracks. They are presented in a very large scale so as to thoroughly comprehend the way the members behave. In reality they are so small that they are not visible to the human eye.



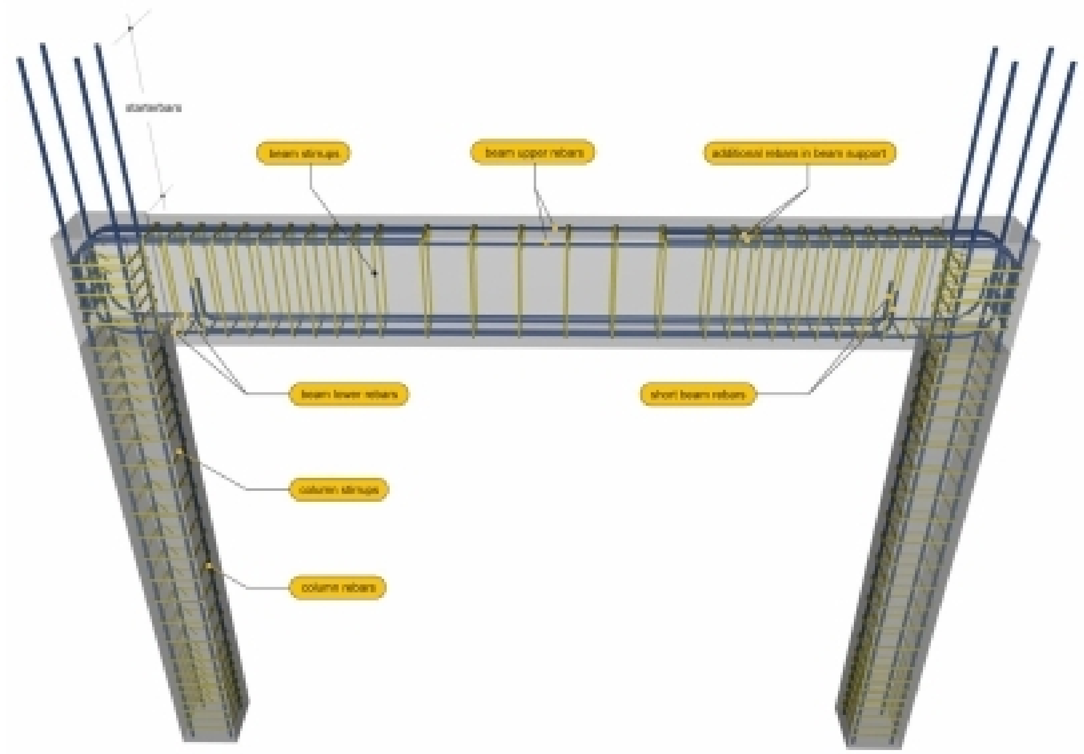
The tensile stresses applied to some areas of concrete cause the formation of cracks; therefore in those areas the necessary reinforcement is placed. When the cracks are perpendicular to the axis of the member, longitudinal reinforcement is placed i.e. rebars that prevent the expansion of the hairline cracking. When the cracks are diagonal, transverse reinforcement i.e. stirrups is placed to control them

In the case where the frame is subjected to gravity loads only and seismic forces are not supposed to be applied to it, the diagonal cracking could be controlled with the use of diagonal reinforcement.

FRAMES WHERE SEISMIC DESIGN IS REQUIRED

The following frame is exactly the same with the frame mentioned above. Both frames will behave in exactly the same way through their lifetime except in those few seconds during an earthquake.

An earthquake ground motion causes horizontal displacements that in their turn cause horizontal inertia forces, forces created by the sudden change in the kinetic state of the body.



Two- column earthquake resistant frame
<project: frame1>

During the seismic action the applied horizontal forces constantly shift direction. This results in a continuous change in the frame's behavior, consequently the tensile stresses and thus the inclined cracking appear in different positions and directions. This position- direction alteration is the reason why earthquake design and reinforcement detailing are so critical in areas with high seismic activity.

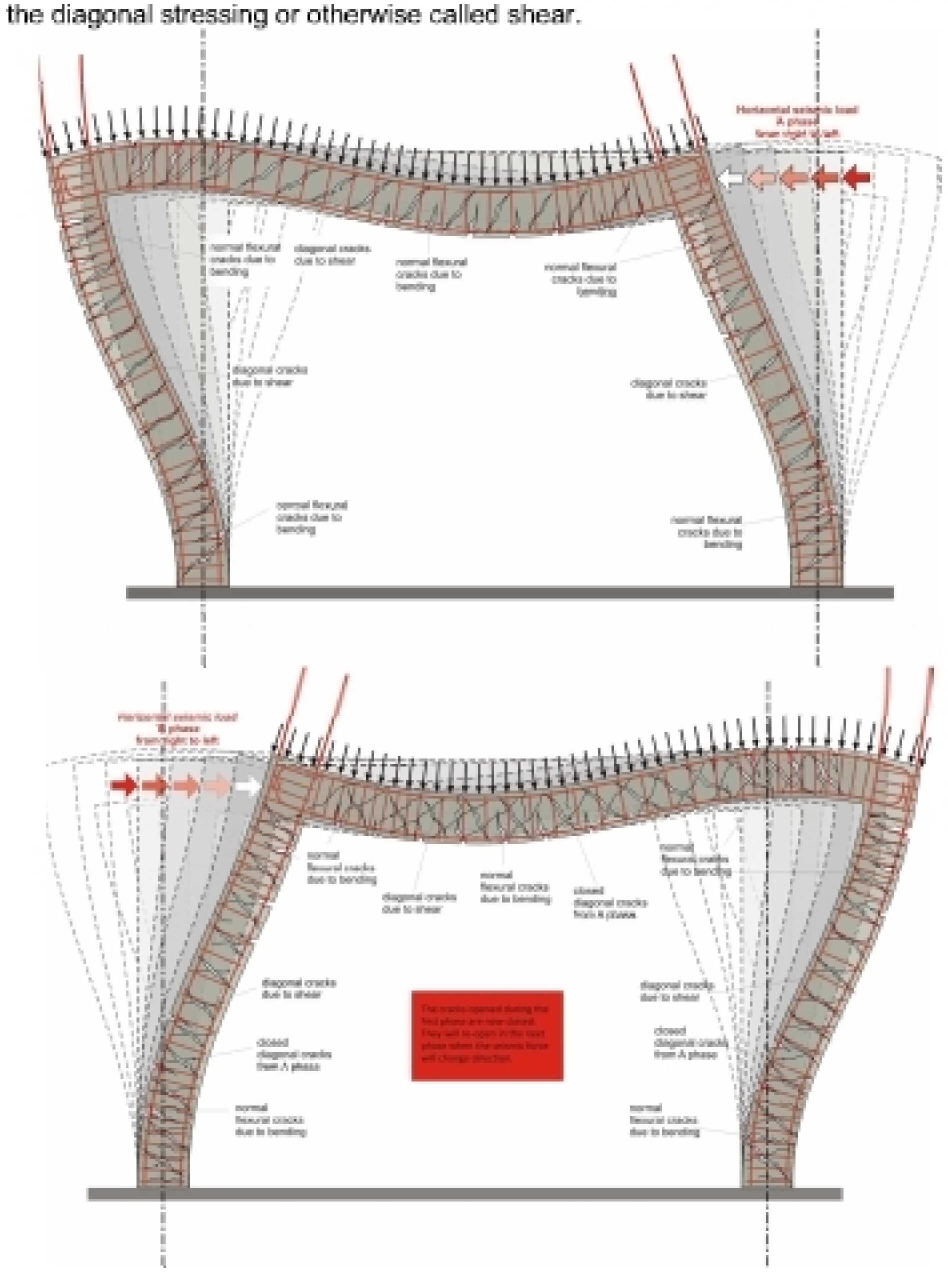
Fundamental rules in the reinforcement of antiseismic structural systems

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

Beams:

(α) Rebars placed in the beams lower part must be as well anchored as those placed in the upper part. This happens because tension and therefore the resulting transverse cracking, continuously change place during a seismic action and as a consequence in critical earthquakes, tensile stresses appear to the lower fibers of the supports.

(β) There must be enough, high strength and properly anchored stirrups because the high intensity of the diagonal stresses and thus the large inclined diagonal cracking, shift direction during an earthquake.

No matter how "well designed" a structure is, either because of exceeded design seismic forces or because of local conditions during the construction, one or possibly more structural members will exceed their design strength. In that case we desire to have two defense mechanisms:

<u>1st defense mechanism</u>: in case of an earthquake greater than the design earthquake we don't want failure (fracture) of any member even if it remains permanently deformed, this means that we need **ductile structural members.**

<u>2nd defense mechanism</u>: in the case of an extremely intense earthquake, where failure of some members is unavoidable, the elements that must not exceed their strength are columns; this means that the columns must have sufficient **capacity-overstrength**.
In the second defense mechanism all failures must be flexural because of their ductile nature as opposed to shear failures that have a brittle behavior (i.e. sudden fracture).

By designing the structure to withstand a major seismic incident, something achieved by the use of a high seismic factor, we avoid extensive failures. By providing ductility and capacity-overstrength to the elements we design against local failures. Local failing may happen for various reasons and if it occurs it may lead to the progressive failure of the structure.

The need for ductility in structural elements

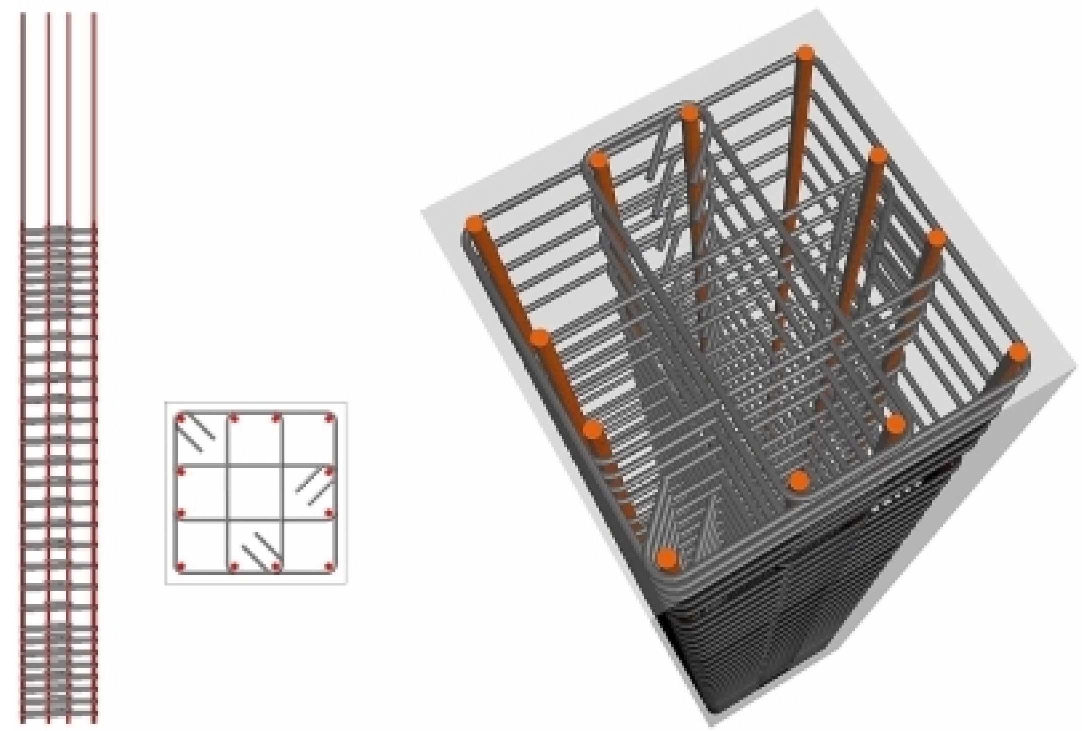
In both columns and beams supports , it is required to place a substantial amount of stirrups not only to bear the diagonal tension but also to ensure a high level of ductility which is crucial in the case of strong earthquakes.

Ductility is the ability of a reinforced concrete member to sustain deformation after the loss of its strength, without fracture.

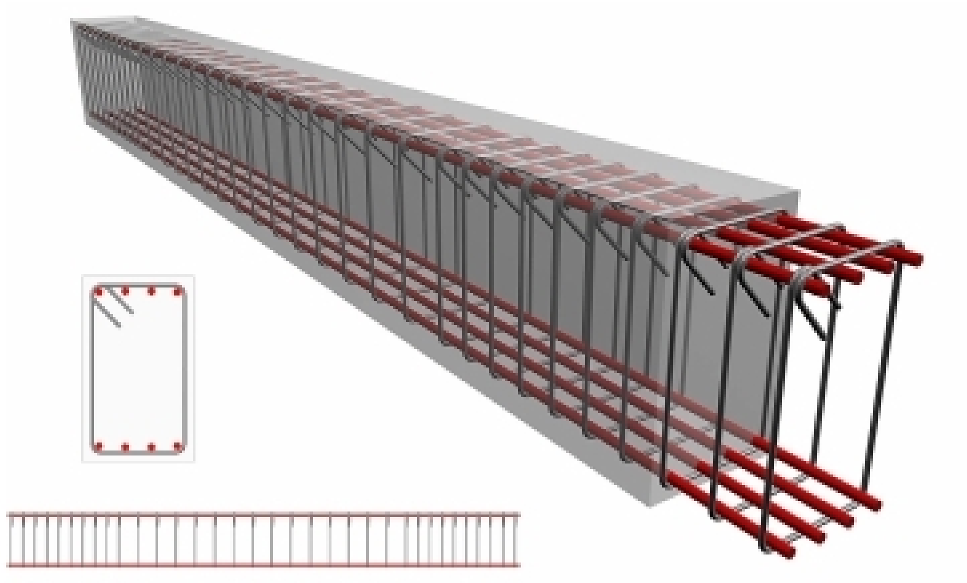
When design seismic actions are exceeded, only one element, the most vulnerable, will overcome its strength capacity. If that element is ductile, it will continue to bear its loading and will give the second most vulnerable element the possibility to contribute its strength. If that second element is ductile too, it will make the third most vulnerable element to contribute its strength and that way all the elements will successively supply their strength.

If all members of the structure system have enough ductility the structure's strength capacity will depend upon the strength capacity of all the structural members, otherwise it will be depended upon the strength capacity of the most vulnerable structural member.

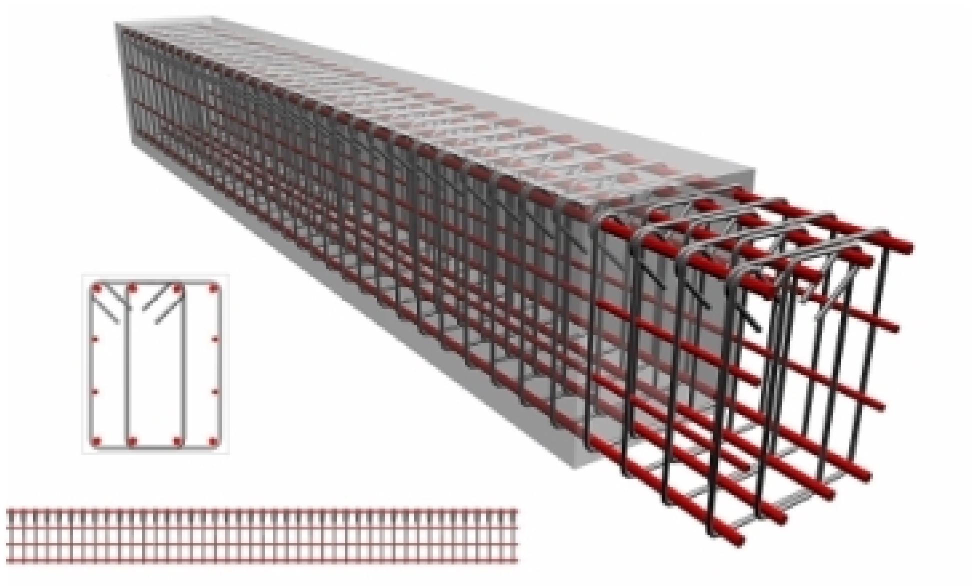
Ductility i.e. the element's deformation capability beyond its yielding point regards flexure and requires strength in shear. This is the reason why shear design is based on the elements capacity-overstrength so as to avoid potential shear failure.
Columns and beams basically fail in the joint area i.e. the area where the beam intersects with the column. Therefore columns and beams must be enough ductile in the joint area. If pounding 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 50x50 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.

CHAPTER 2

The construction methods of the structural elements of the building's frame

2. The construction methods of the structural elements of the building's frame

2.1 The materials

In earthquake prone regions, the most crucial factor of the reinforced concrete building's strength is the reinforcement placed inside its structural frame.

As a rule, in an already built structure the load bearing frame is not visible. Also, during its construction phase only the structural members are visible and the placed reinforcement, which is the strength's decisive factor in earthquake resistant structures, cannot be directly inspected. That factor, which is the most crucial of all, is thoroughly discussed in this chapter. Moreover the ancillary equipment and the materials needed for the combination of concrete and reinforcement in order to form the structural frame are also discussed.

The concrete is originally produced as a liquid mixture and can be casted into different shaped moulds. When these moulds are made out of timber, as they usually are, they are referred to as formworks.

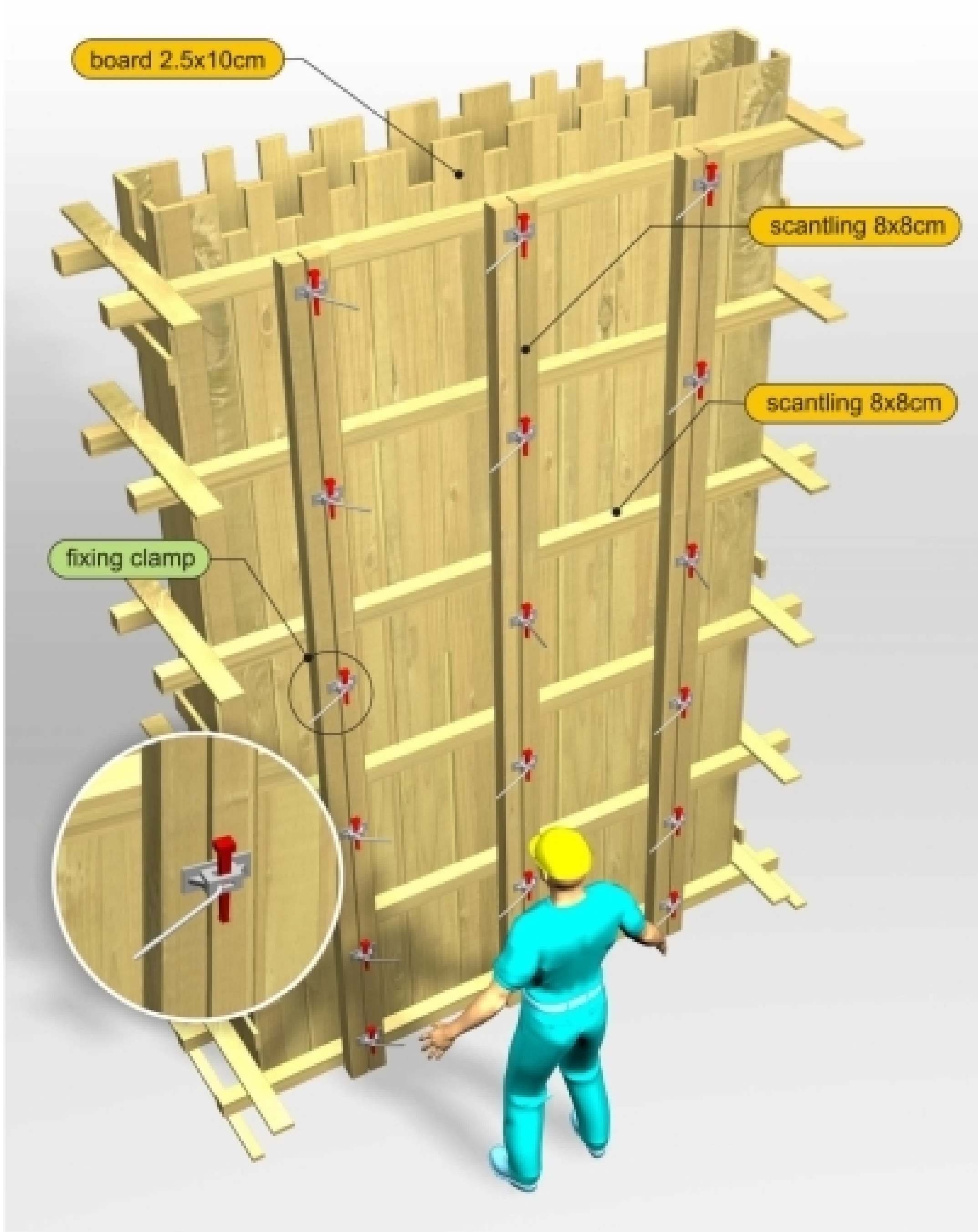
In order to secure the reinforcement bars' position inside the formwork, additional supports are needed. These are called spacers. They prevent the displacement of reinforcement during the casting process and they get incorporated inside the concrete's mass.

Reinforced concrete is a good heat conductor and since the structural frame has a large amount of mass, it critically affects the building's thermal-energy efficiency behavior; therefore the structural frame has to be insulated.

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:

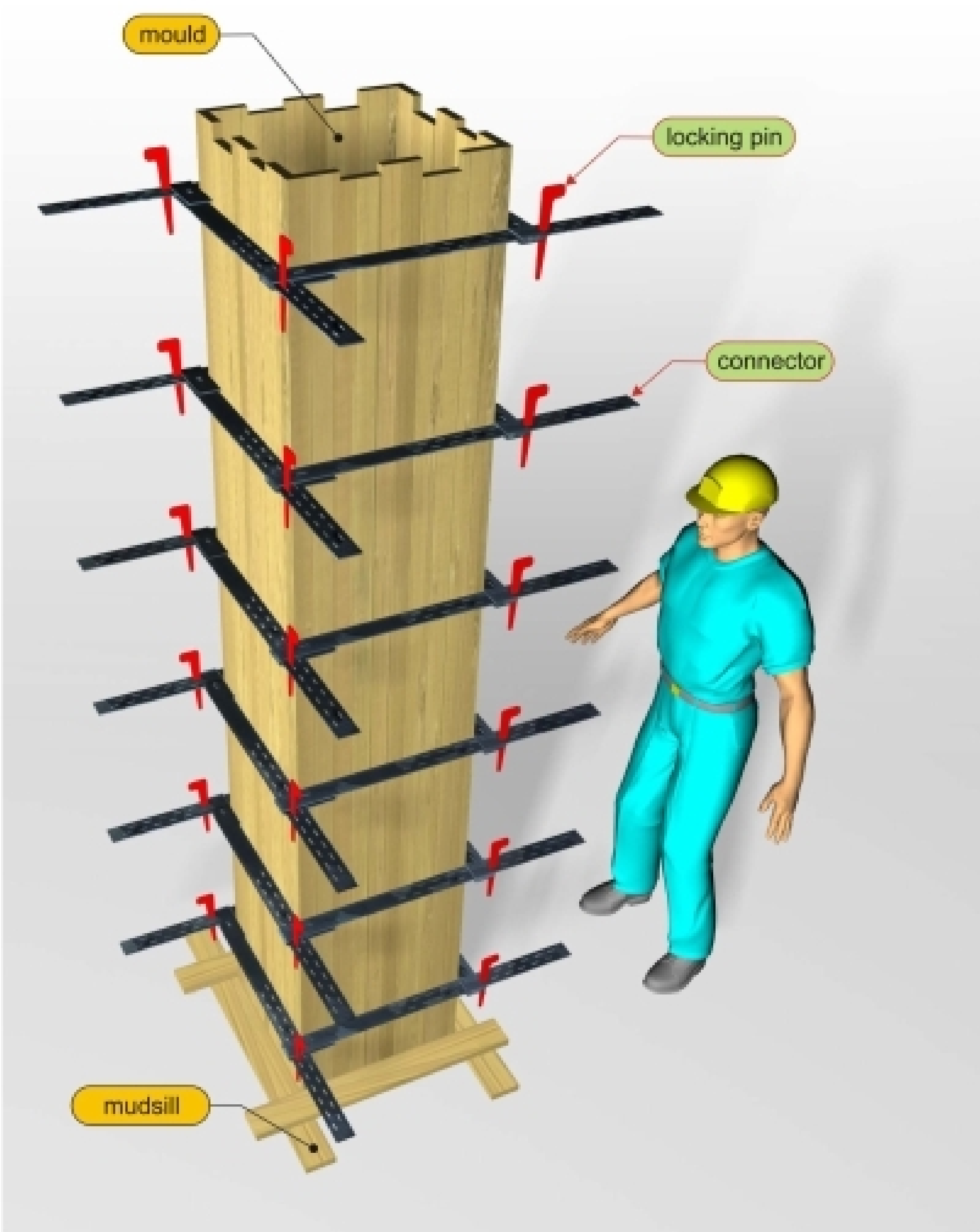
- **boards** with a usual thickness of 22mm, width ranging from 8 to 15cm, and length varying between 2.30 and 4.50m
- **scantling** (wooden joist) with a typical cross-section 8x8cm and lengths ranging from 2.40 up to 4.50m

- **beam** with a usual cross-section from 8 to 12cm x 12 to 20cm in different lengths from 2.50 up to 5.00m
- **shuttering plywood** with thickness ranging from 18 to 25mm, width 1.25m and length 2.50m
- **plank or balk** with 5.0 cm thickness, width varying from 20 to 30 cm and length 4.0m.

The elements of a conventional scaffold are made out of hollow steel sections with a usual diameter around Φ50. These sections are used for the formation of the **standards** and the **frames**.

Frames usually have a height ranging between 1.20 and 2.50m but when combined with the **base screw jack** and the upper **"Ψ-shaped" screw jack,** they may reach almost any height. Generally frames are vertically tied together with the use of **diagonal bracings** made out of hollow steel sections varying between Φ25 and Φ30 thus forming the **towers**.

The accessories of column moulds secure the position of the lateral elements against the "hydrostatic" pressures applied during casting. The most intense problem appears in columns and shear walls because of their large height and consequently because of the high lateral pressures that appear. The connectors are usually made out of steel, they have an adjustable length and they are placed every 20 to 50cm.



Industrial formworks are a combination of timber, steel, aluminum and plastic and their names vary according to their production industry.

The advantages of industrial formworks:

- high construction quality
- small amount of required personnel
- fast implementation

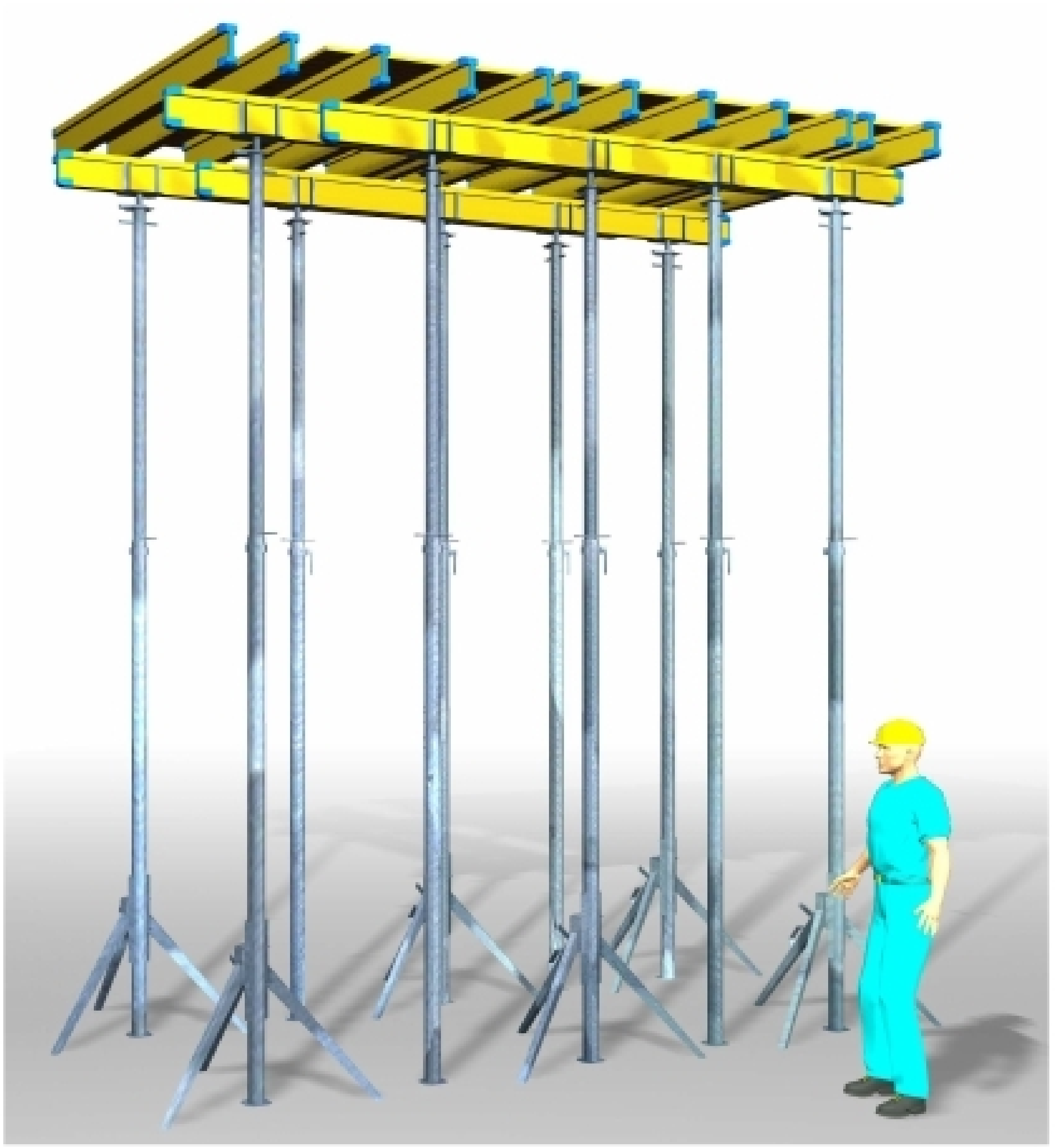
- civilized working conditions
- personnel security
- achievement of smooth surfaces that do not require finishing

The disadvantages of industrial formworks:

- high initial investment cost
- the need to have a detailed and accurate implementation design in every work
- the need for crane usage
- the created smooth surfaces lower the adhesion between the concrete substrate and the finishing
- low flexibility in small and complex constructions

By comparing the advantages and disadvantages and their corresponding importance, we finally conclude in the indisputable superiority of the industrial formworks against the conventional formworks. Taking into consideration that the use of self-compacting concrete (see § 2.4.9) will probably predominate in the construction of earthquake resistant structures, the industrial formworks are the ideal solution since it can adequately bear the large pressures applied to the inside of the mould.

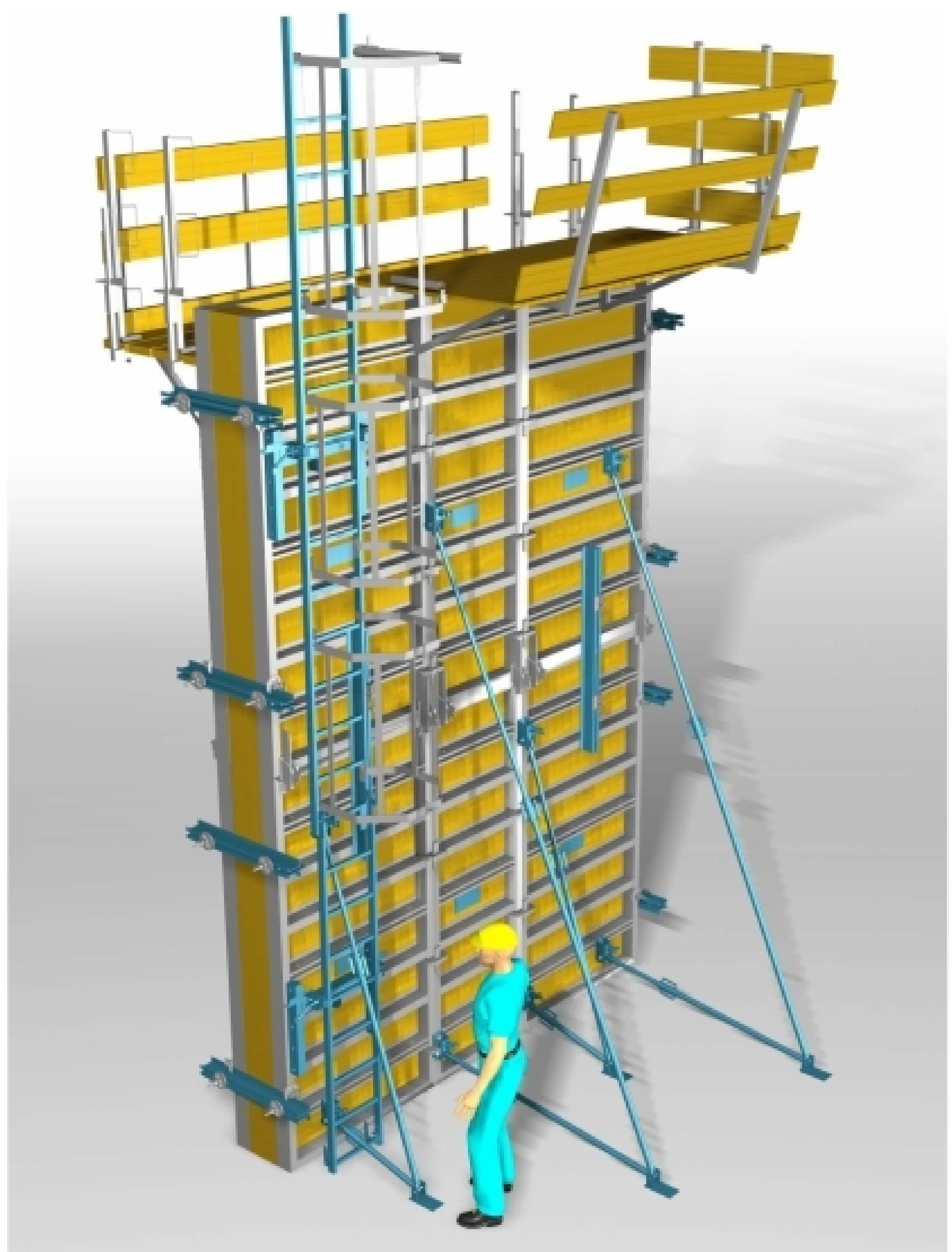
The following figures show three cases where industrial formworks are being used. In all three cases the common characteristic is the large height of the structural element.



Industrial scaffold for the formation of slab's formwork [1]

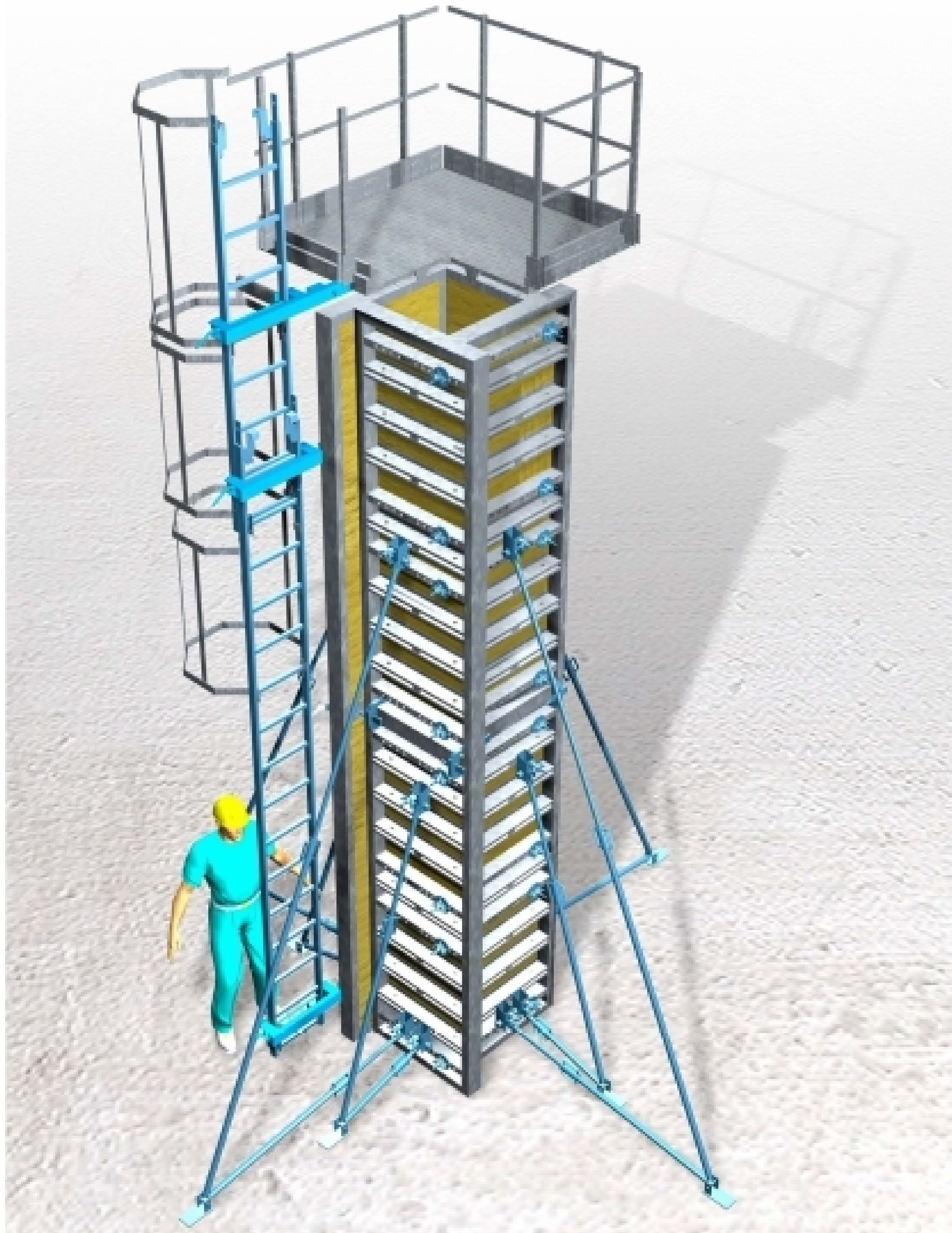
The construction of the beams' and slabs' formwork is performed with the use of composite, timber T-section beams and shuttering plywood without nailing. Scaffolds are made out of aluminum. Formwork dismantling is performed by releasing the special pins at the top of the scaffold, that way it controllably recedes around 5cm without damages and without danger of accident.

[1] In areas with low seismic activity the industrial formworks, based on their specifications, may reach up to 5.50m high without needing diagonal bracings. In earthquake prone regions, in order to face a possible seismic event either during the casting or during the curing process, it is suggested to use the same scaffolds according to their specifications, providing that all columns are constructed in order for the scaffolds to be tied upon them (see and § 2.4.5).



Shear wall moulding with the use of industrial metalwork

Assembling the formwork of a 5.50m 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 5cm. These pieces are tied together with butterfly valves, placed in predefined positions. The formwork is temporarily supported by light-weight diagonal struts. The working platform at the top as well as the ladder are being placed and removed within a few minutes.

If the surfaces of the shear walls, beams and slabs are going to be plastered it is mandatory to wash them well by means of pressure pumps in the order of 100 atmospheres followed by all the necessary practices in order to increase the adhesion between the substrate and the plaster.
In cases of particularly careful industrial formwork implementations, it is remarkable how the final plastering might be avoided due to the excellent and ready for coloration surface.

<u>Note:</u>
The use of moulds made out of water-resistant cupboard, metal sheet or plastic leads to the fineness and more economical construction of circular columns.

2.3 Thermal insulation of structural elements

When the thermal insulation is embedded inside the exterior or the interior shell of the building and it is independent of the structural frame's construction, the solution is clear and most of all effective. However, when the thermal insulation is placed upon the exterior or the interior surface of the structural frame as part of the total thermal insulation e.g. in buildings with masonry walls, various issues arise. These include **thermal bridges** and constructional matters regarding antiseismic behavior.

This paragraph deals with the cases where the concrete elements' thermal insulation is embedded in the structural frame. In masonry infills thermal insulation is usually placed inside the masonry walls.

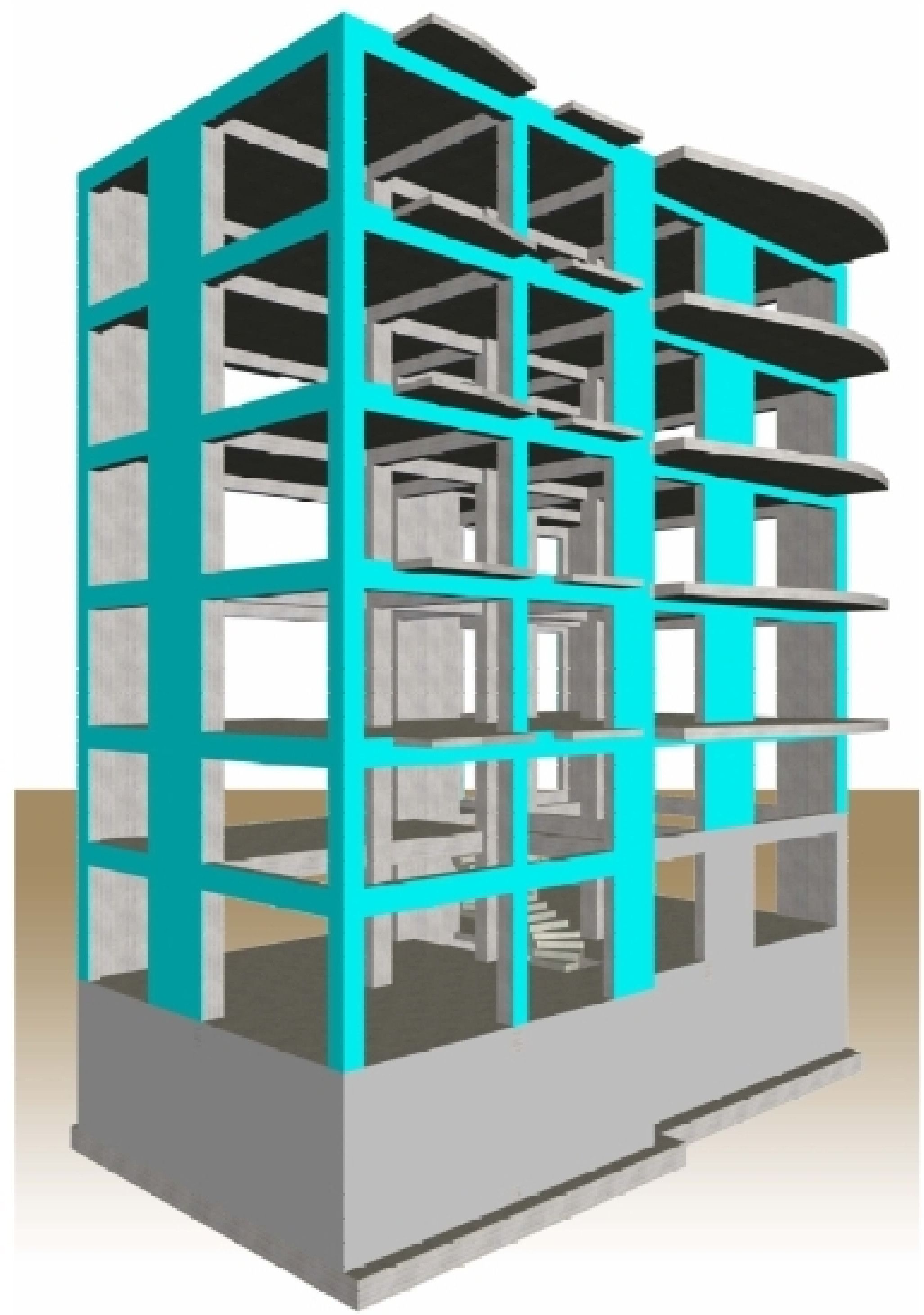
Generally, the structural elements of the frame are thermally insulated by the use of extruded polystyrene boards[2] with thickness ranging from 3 to 5 cm. These boards have ribbed surfaces for better adhesion both with the concrete substrate as well as with the plaster that will cover the final surface.

If the energy/bioclimatic design of the building requires the contribution of the structural frame's heat capacity (this is the common case in residential buildings) then the thermal insulation is placed upon the external surfaces of the structural elements.

In shear walls, columns and beams the thermal insulating boards are placed upon the element's surface that is on the outer face of the structure. On the other hand, in slabs, most of the times, it is preferable to place them on the bottom side. This is the best solution both from a practical and an energy point of view. However, it may not be ideal for the upper floor slabs.

If the thermal insulating boards are placed on the lower side of the slab and the surface is going to be plastered, it is recommended to place, prior to plastering, a light-weight flexible composite mesh e.g. glass mesh to prevent plaster cracking especially in the joint areas of the boards and the concrete or the walls.

[2] The minimum required thickness of the extruded polystyrene is based upon the coefficient of thermal conductivity λ and generally upon the thermal insulation design. When using environmental friendly materials, the minimum thickness of the thermal insulating board is around 4cm.

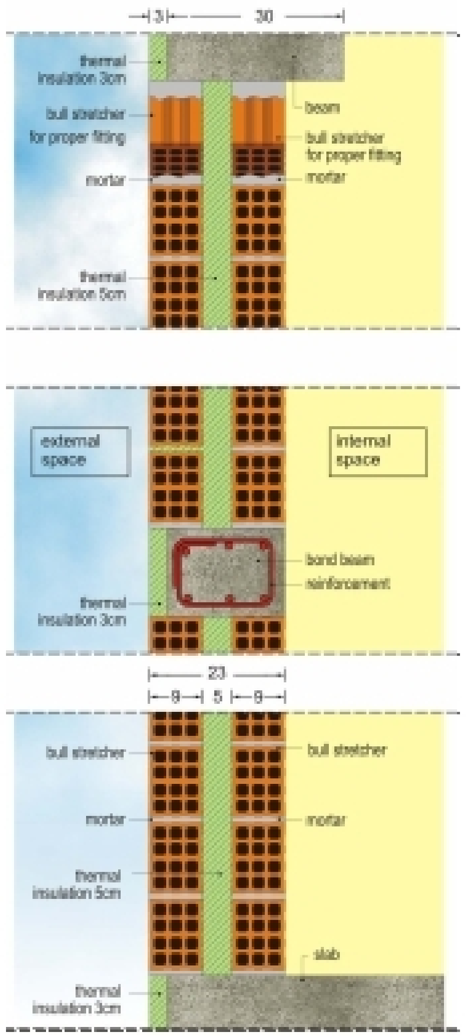


Representation of the thermal insulated frame of a building
<project: bkInsulationGR [3]>

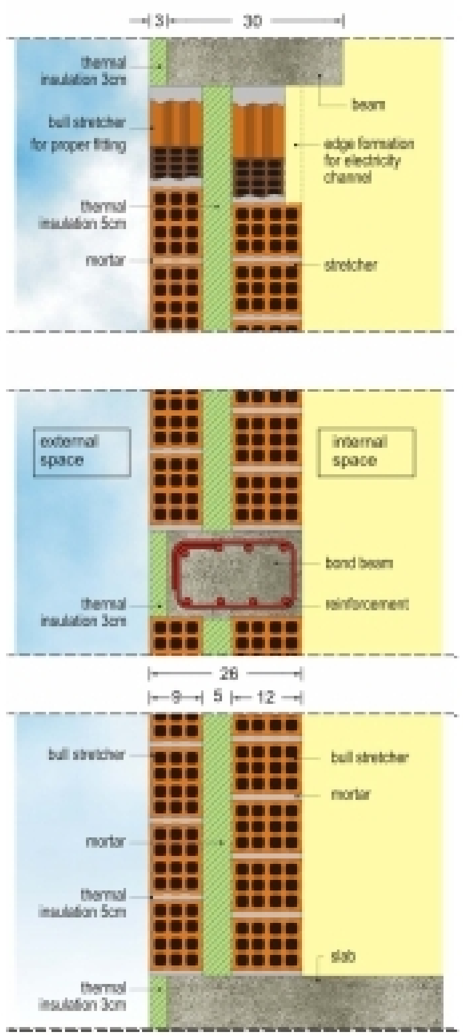
[3] The project<bkInsulationGR>, is an altered version of the project <bkGR>, due to its size, it runs only in the professional software.

Placing the thermal insulating boards to the exterior surface of the concrete elements creates one problem; it sets limitations to the proper fitting of bricks in the external masonry walls.
Some of the practices followed when building masonry infills are shown below.
The choice of the most suitable solution depends upon the importance of factors such as: the brick fitting near columns and beams, the formation or not of an edge between the beam and the wall, the weight of the wall, the space they take, the cost.

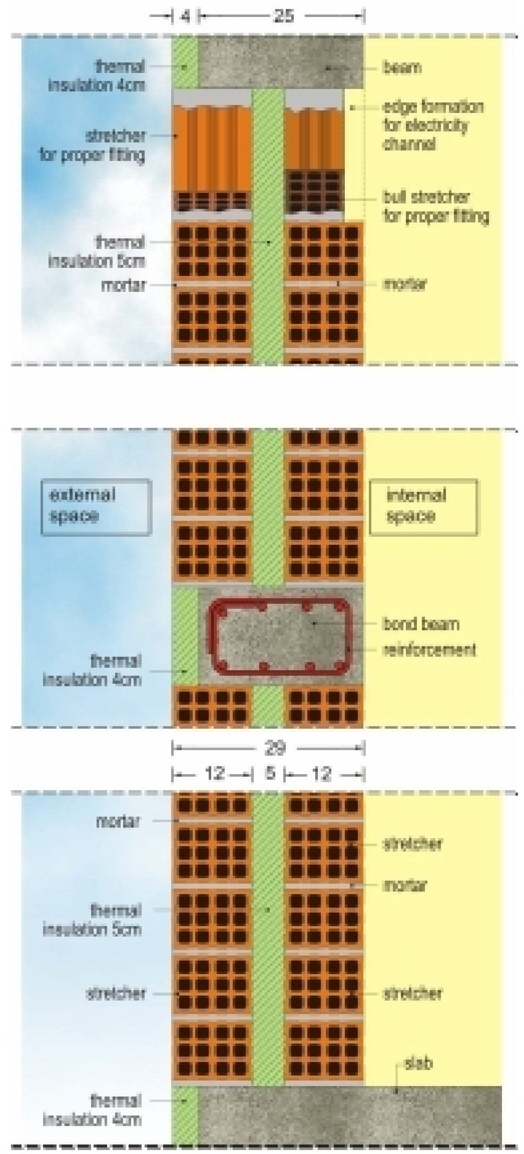
Typical solutions in exterior masonry walls
(by using 9x12x19 bricks)



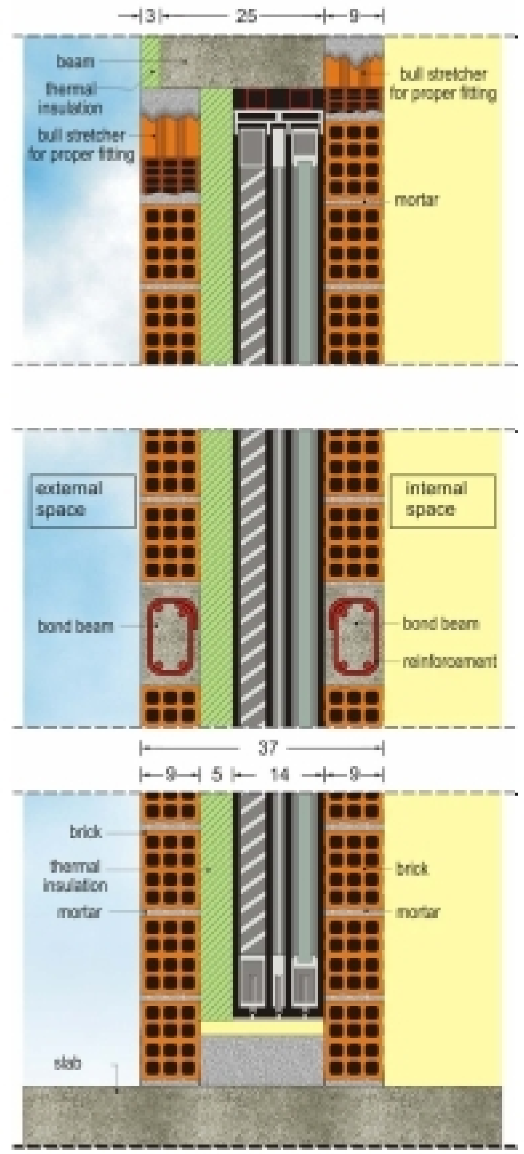
External blind wall with 2 bull stretchers



External blind wall with 1 bull stretcher and 1 stretcher



External blind wall with 2 stretchers



External wall with sliding frame

Notes:

- *In areas where the used bricks have different dimensions from the ones mentioned above, corresponding practices and rules apply.*
- *The 12cm thick wall when compared to the one with a thickness equal to 9cm, has disadvantages like a higher cost, a larger weight and a 12-9=3cm limitation of the interior space. On the other hand, it has advantages like the better brick fitting, the higher heat capacity (of the layer towards the inner face) and the possibility to embed electrical piping.*

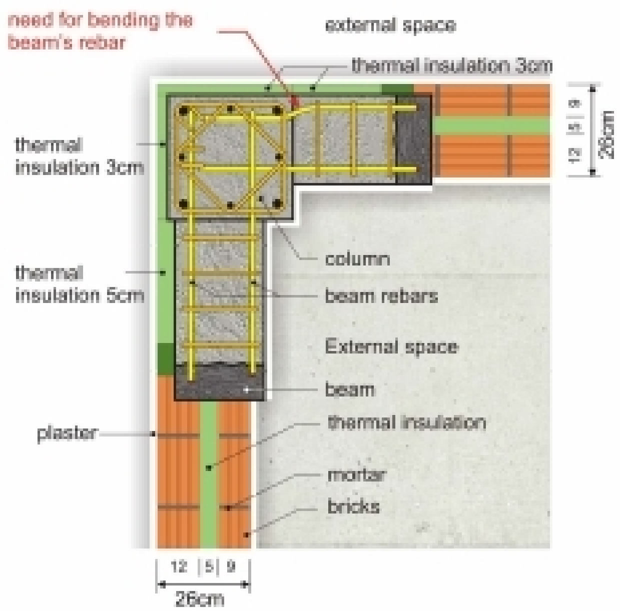
- *When it is important for the beam and the masonry to have exactly the same width (no edge formation), apart from the other solutions, a free space may be left between the thermal insulation board and the wall.*
- *When an edge is formed between the beam and the wall, it is preferred to have a large width rather than a small one.*
- *Based on the type of the electrical installation, we must allow space for the cable piping that will pass through the structural frame or/and the wall.*
- *A simple way to create channels in the support faces of beams and columns is the use of a board or an extruded polystyrene strip 2cm thick and 10 cm long.*
- *Frequently the real brick dimensions differ from those of standardization. For instance, nine times out of ten, the bricks with nominal dimensions 9x12x19 have real dimensions equal to 8.5x11.5x18.5.On the other hand, the beam's dimensions are usually correct.*
- *A typical bond beam reinforcement is: stirrups Φ5/10 or Φ6/15 and upper, lower longitudinal reinforcement 2 to 4 Φ10 rebars (depended upon the bond beam's width). The steel class may be $B500_A$.*
- *Bond beams' rebars might end before meeting the columns or they may get anchored inside them.*
- *The most practical way to anchor the bond beams' rebars inside the columns is by creating holes to the column sides and implanting starter bars by means of resin adhesives.*

Rules for choosing the correct thermal insulation thickness for the structural frame

As far as the thermal insulation efficiency is concerned, the necessary thickness is defined by the corresponding design, however constructional difficulties must be always taken into account.

As far as the proper masonry fitting is concerned, a good solution is to use thermal insulation 3 cm thick in both columns and beams.

As far as the reinforcement implementation is concerned, it is suggested to use thicker thermal insulation in columns than in beams. As a result, the corner bars of the beams will be anchored, unobstructed, inside the column's mass, as shown in the vertical beam of the figure, in contrast to the horizontal beam of the same figure, where the edge rebars of the beam have to be bent.

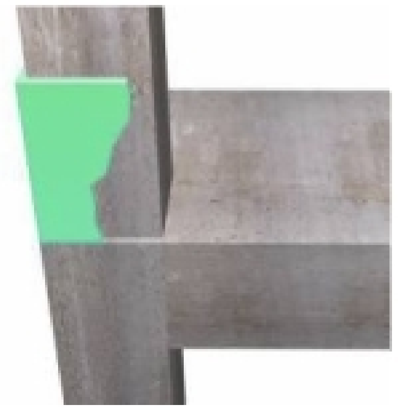


As far as the standardization of the columns' and beams' width is concerned, the use of 5cm thick thermal insulating boards helps both in the increase of the thermal insulation efficiency and in the standardization of the structural elements' dimensions in integer multiples of 5cm. However, this creates difficulties in the proper fitting of bricks in external walls. Usage of 9cm bricks instead of 12cm eliminates this problem.

Based upon all the above, an optimal technical solution is to use 3cm thick thermal insulating boards in the columns and 5cm thick boards in the beams. Moreover, the masonry should be built externally with thickness equal to 12cm.

Constructional problems

When a floor does not require thermal insulation e.g. pilotis or basement, extra attention must be paid to the vertical centering of columns so as to avoid having the columns of one floor placed outside the perimeter of the columns that belong to another floor. The next figure shows two columns that have a total cross-section 40/40, however, in the upper floor, the column has a 37/37 cross-section and a thermal insulation board with 3cm thickness.

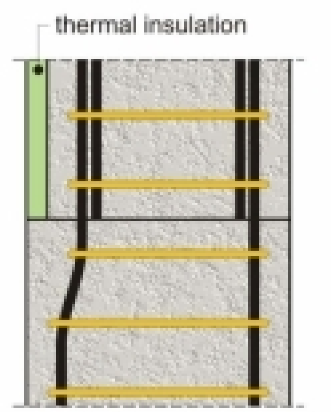


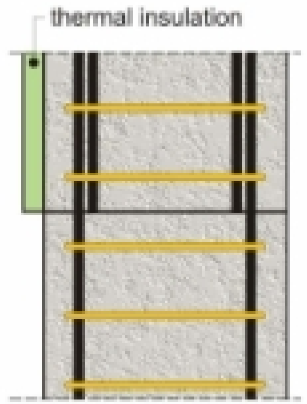
These cases are usually met around the perimeter of the building, in pilotis, in basements or in semi-open floors, when the thermal insulation is placed to the outer face of the structures (as it should in most cases). The created problem may be solved with various ways:

1^{st} Solution: Construct a column greater in size and with larger stirrups.

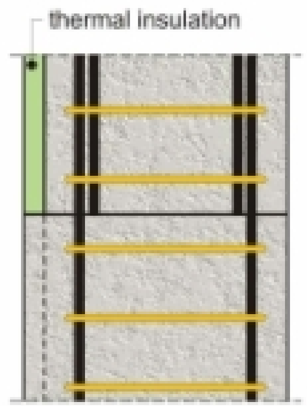
Drawbacks: The drawback in following this solution is the eccentricity of the column's rebars and the need for bending them up at a large angle, something that entails a high degree of constructional difficulty.

Application: This solution applies to all cases.





2nd Solution : Repositioning of the column's fixed spot to the edge of the thermal insulation thickness.
Drawbacks: It requires constructional attention and may have possible architectonical side-effects due to the formation of an edge.
Application: This solution applies only to superstructures.



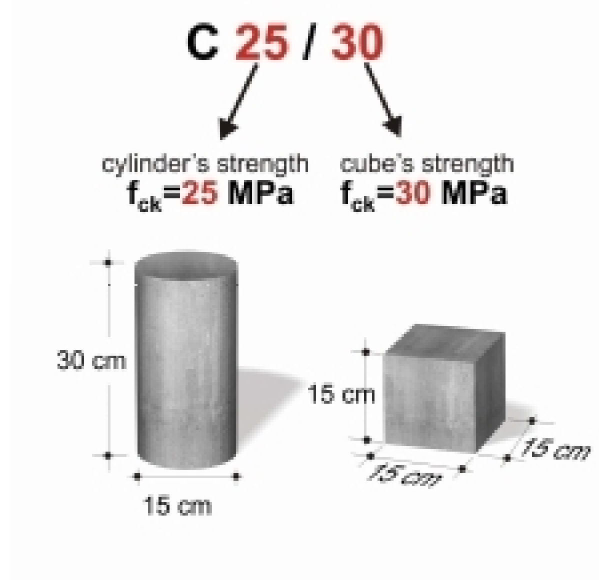
3rd Solution: Placement of unreinforced concrete (plain concrete) with thickness equal to the insulation thickness.
Drawbacks: A large concrete thickness with no reinforcement. This problem can be partially solved with the use of surface reinforcement and completely solved with the use of wire mesh when combined with the basement shear walls.
Application: In peripheral basement column.

Note:
An economical and constructional simple way to efficiently insulate a building and face fewer local problems in the structural frame, is to place the entire insulation at the external face of the building after the completion of the load bearing frame and the masonry walls. That way, a thermal insulating shell, e.g. 5cm thick is formed circumferentially in all exterior surfaces (concrete and masonry). The placement of this 'blanket' is being done after the construction of the structural frame and the masonry walls without thermal insulation. This specific solution, due to the formation of fewer thermal bridges, has the maximum energy efficiency and the advantage of that it can be replaced at any time. Like every other technological solution, the above mentioned method is contrary to traditional practices that regarded peripheral walls as monolithic elements, with plaster covering that determined the architectural character of the building. Of course times change and little by little energy changes become dominant, moreover the material science provides new ways of architectural expression that can be adapted to the local conditions of each region.

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. C25/30 is characterized by two equivalent strengths, which in this specific example are 25MPa and 30MPa. 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[5] 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	C95/105				

[4] This is the compressive strength used in the design
[5] In EKOS 2000 and CTR-97, the mentioned concrete grades are up to C50/60

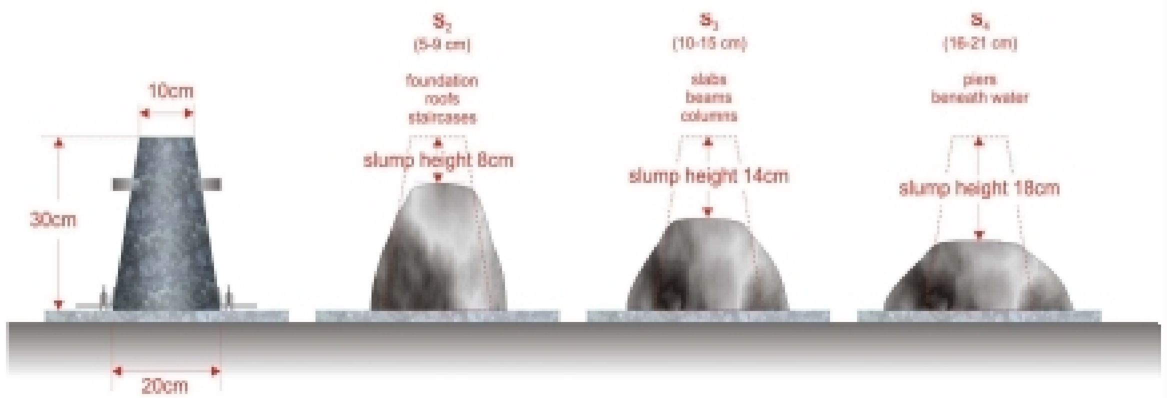
In Greece, old types of concrete (B) were being used, systematically until 1994 and periodically until 1997. The most commonly used was B160 (corresponding to today's C12/15), B225 (corresponding to an intermediate grade between today's C12/15 and C16/20) and B300 (almost corresponding to today's C20/25).

<u>*Note:*</u>
The regulations and practices mentioned below refer to the Greek CTR-97 (Concrete Technology Regulation, 1997). This Regulation is valid, in this transitional stage, along with the European Standard EN 206-1. The European Standard EN 206-1 is more advanced and has transferred a great amount of responsibility that had to do with building-site procedures, like concrete sampling, to the concrete supplier who of course must be properly certified.

The amount of cement used in the mixture, should be enough not only to ensure the required concrete strength but also, in relation to the concrete's use, to ensure its life span durability depended upon the surrounding present conditions:

use of concrete	usual	without finishing	Seaside location (<1km)	Inside water	Inside sea water	Other cases
Cement (kg/m3)	270	300	330	350	400	it depends

Adding water to the concrete mixture beyond a specified point, results in lowering its strength and increasing its porosity. The proper amount of water is depended not only upon the required strength but also upon the required workability of concrete, as a matter of fact, the later is the one that basically determines that amount. The workability of concrete is determined by the **slump height s**.
Depending upon its use, concrete must have a slump height ranging between specific target values. These target values are shown below:



2.4.2 Ordering concrete

When ordering a pre-mixed concrete we must give the supplier at least the following information:

a) Quantity in cubic meters: e.g. 60m³
b) Concrete grade e.g. C20/25
c) Minimum amount of cement[6]: e.g. 300kg/m³
d) Slump class S [7]: e.g. S_3
e) Super-plasticizer: e.g. YES (placed on order at the building site) [8]
f) Pump's size: e.g. 36 m
g) Time between truckloads: e.g. every 30 minutes

[6] If the concrete's grade e.g. C30/37, adequately covers the required amount of cement, there is no need to mention its minimum amount.
[7] In concrete containing 4th generation super-plasticizers, the desirable slump value is always exceeded.
[8] see paragraph 2.4.4

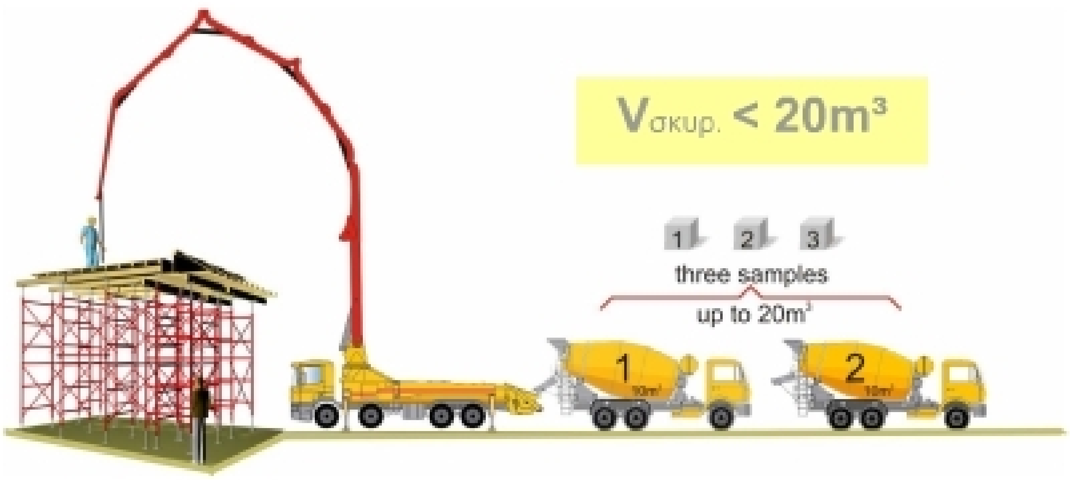
2.4.3 Concrete arriving on site

In every in-transit concrete mixer that arrives at the construction site one must always check that the dispatch note corresponds to the given order. Special attention must be paid to the exact time of the mixer's charging so as to ensure that between the completion of the casting and the charging, the elapsed time is lesser than two hours.

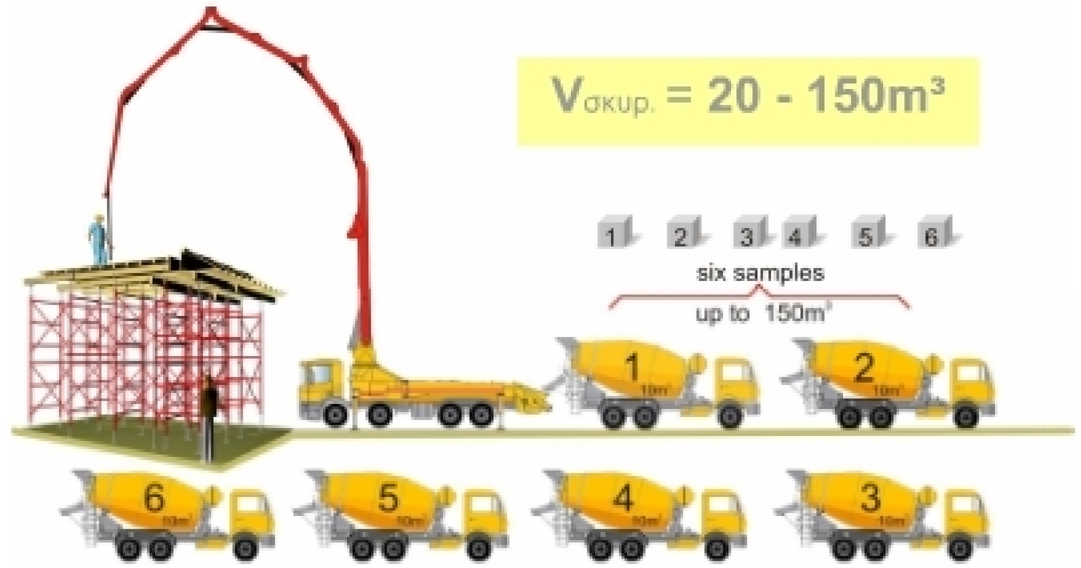
In case it is required to inspect the amount of concrete inside the mixing drum, one must always bear in mind that the concrete's unit weight usually ranges between 2360 and 2400 kg/m³. This means that a 10m³ mixing drum has a net weight varying from 23.6 to 24.0t.

The concrete's strength is confirmed by sample testing. According to the regulation the minimum number of test samples to be taken in the concreting process, depends upon the total amount of casted concrete:

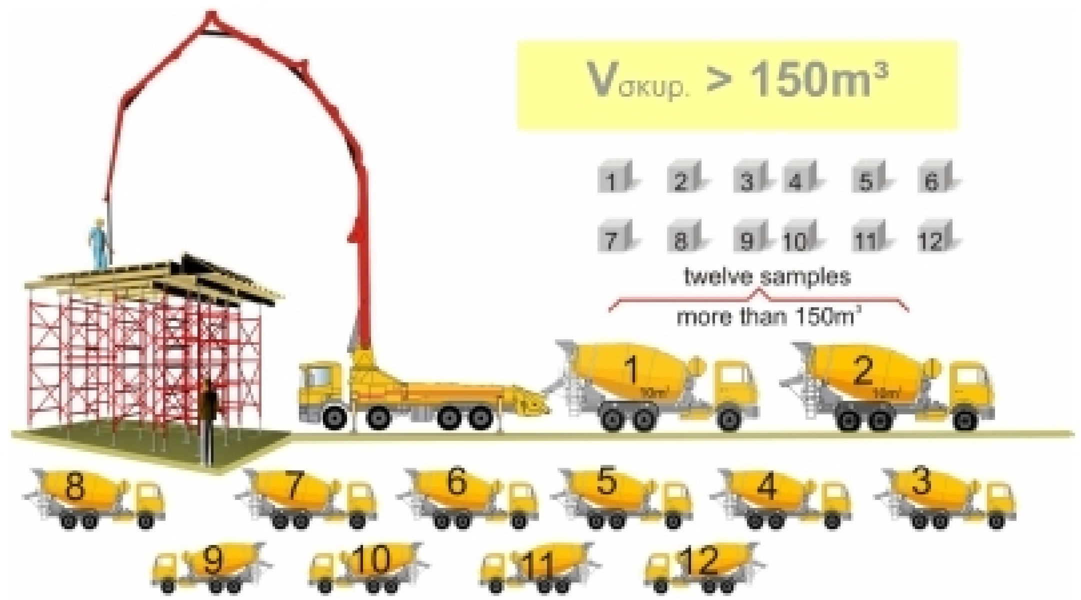
- For an amount of concrete lesser than 20m³, 3 test samples must be taken from different mixing drums.



- For an amount of concrete ranging from 20m³ to 150m³, 6 test samples must be taken from 6 different drum mixers.



- For an amount of concrete greater than 150m³, 12 samples must be taken from 12 different drum mixers.



Samples must be taken from different in-transit concrete mixers and must be transferred to a certified laboratory for special curing within 20 to 32 hours.

2.4.4 Concrete pumping

Adding water to an already made concrete mixture may increase its workability but at the same time it lowers its strength. However, concrete must be workable enough to efficiently pass between the narrow spaced steel reinforcement. This is achieved by use of a super-plasticizer added (1.5 to 2.0 kg/m³) inside the drum containing the wet concrete mixture before its discharge and mixed for 3 to 5 minutes in high rotating speed (8-12 R.P.M.).

Generally, the concrete used for the casting of foundation footings does not require a high level of workability and therefore adding a super-plasticizer is not necessary. On the other hand, in strip foundation, usage of super-plasticizer may be required when casting the pedestal, something always done after the completion of the footing's concreting. Finally when casting staircases (or sloped slabs) super-plasticizers should be avoided because the workable concrete flows towards only one side of the formwork.

2.4.5 Concrete casting

The first thing prior to casting is to thoroughly clear the formworks from dust, oil, etc. This should be done not only to ensure the building's strength but also to set a technical-social example, in other words to set an example of professional behavior for all people working in the building site.

Concrete's casting must be done directly from the pump's hose end. The concrete must be purred inside the slab's formwork in vertical and not horizontal layers. This happens because in case concreting has to be stopped for a long period of time, when it is resumed the new concrete will not bind with the old one and a horizontal joint will be created. On the other hand, when concrete fills the formwork parallel to the thickness axis, a potential stop in casting will lead to the creation of a vertical joint.

The boom's hose end should be around 0.50m above the formwork of the element to be casted. An exception can be made for usual columns and shear walls, where it can be up to 2.50m above the column's bottom side. In cases where columns or shear walls have a relatively large height e.g. 5.0 m, concreting must be done by one of the following ways:

a) The boom's hose end is positioned in an adequate depth inside the column's formwork,
b) Extra pipes are placed from the upper part of the column to an adequate depth and concrete is purred through them with the use of a special funnel.
c) Openings with adequate size are created e.g. around the middle of the formwork and the concrete is casted through them (technically challenging procedure).

The (a) and (b) procedures are more practical but they require a certain amount of space. For example when using the boom's hose end this space must have a diameter around 18cm and when using the extra pipes this diameter is decreased to 16cm. The required space can be provided only if columns' casting is performed separately from the rest of the elements. This means that concreting should not be done simultaneously in columns, beams and slabs with the use of one unified formwork. In earthquake prone regions simultaneous concreting should be avoided for one more reason: columns have a large amount of stiffness and therefore they are used for securing the position of formworks and scaffolds in cases of seismic events both during the casting and the curing process of the beams' and slabs' concrete.

2.4.6 Compacting concrete

Generally, concrete compaction should be carried out with the use of a vibrator. Two vibrating devices must be used regardless of the concrete to be casted. Based on the fact that one vibrator, serves around 5 to 10 m³ of concrete per hour, we calculate the required number of devices. For instance, when casting 100m³ of concrete in 6 hours time, we will need from 100/10/6=1.6 up to 100/5/6=3.2 vibrators, i.e. practically 3 vibrators are needed. When casting a small quantity of concrete e.g. 20m³, in 4 hours, theoretically one vibrator is enough, however having a backup device is mandatory for security reasons. Nowadays, the best solution is to use lightweight electric vibrators that ensure both high production rates due to their ease of operation and a high vibration quality which is very important especially in visible concrete surfaces (off-form concrete, architectural concrete)

2.4.7 Concrete curing

Concrete curing is mandatory. As a matter of fact, the higher the environmental temperature is, the more meticulously it has to be made. In every case, concrete's surface has to be moistened throughout the entire day for at least the first week after casting; however the curing process will last for 28 days.

Concrete curing in extremely <u>high temperatures</u> can be done in three ways:

a) Right after finishing the concrete's surface, we cover it with special sheets (burlaps). These sheets must be kept wet 24 hours a day for at least one week. Special attention must be paid to hold them down and prevent them from being blown away.
b) By ponding. We form a dam a few centimeters high (4 to 5 centimeters) around the perimeter of the slab right after concreting. We fill this dam with water thus creating a pond and we make sure to replace water loses due to vaporization. The circumferential dam may be constructed with bricks cut in half or simply with fast curing cementious mortar. This solution has two disadvantages: it is not economical and it stops all works on the top of the slab for at least 7 days.

c) We spray the concrete's wet surface with a special chemical fluid that becomes a membrane thus preventing concrete from drying out. This is the simplest procedure but in order to be effective, the concrete's surface must be free from grooves created by a manually operated screed board. This can be achieved only with the use of a mechanic screed board that compacts the concrete as it vibrates. Without doubt, concrete casting must be done with the best possible conditions i.e. very early in the morning or late at night, with concrete being the 'coolest' possible, aggregates stored in shadow etc.

Concrete curing in frost:
Normally concrete must not be casted in extremely low temperatures, however when this is unavoidable e.g. sudden drop of the temperature below zero, its free surface must be covered with concrete curing blankets. These are made out of thermo insulating materials like rolls or plates of rockwool, glasswool with aluminum covering, polystyrene boards later used in insulations. In that way, we can make use of the concrete's own heat. The blankets must be secured from wind up-turnings with e.g. rafters and balks. If the temperature drops too low, heaters like the ones used in out-door coffee shops may be used with their reflectors in an inverted position. In the past, barrels with fire were usually placed underneath the formwork; they contained sand wet with oil.
In areas exposed to extremely low temperatures, the use of air–entraining admixtures or additives is mandatory in order to protect the concrete from the catastrophic results of frost.

2.4.8 Removing the formwork

The following table presents the minimum time requirements before removing the formwork. It regards typical constructions for usual temperatures:

Constructional elements	*Cement strength*	
	32.5	42.5
Lateral sides of beams', slabs', columns', shear walls' formworks	3 days	2 days
Slabs' formworks and beam span formworks when the span is lesser than 5 m	8 days	5 days
Slabs' formworks and beam span formworks when span is greater than 5 m	16 days	10 days
Safety columns of frame beams and slabs with a span greater than 5 m	28 days	28 days

Nowadays, cement with 32.5 strength comes only in sacks. On the contrary, the cement used by most concrete production industries usually has strength equal to 42.5.
When removing the formwork of slab or a beam 5 days after concreting and intending to cast the next floor-which means doubling the loads applied to the floor without formwork - supporting scaffolds (falsework) must be placed beneath the formwork-free floor. This problem is much more critical in cantilever slabs.

General note:
It must be mentioned that there are a lot of exceptions to the above summarized rules where the suggested limits of most issues may be exceeded. However, in every case the supervisor engineer is responsible for satisfying the general or special specifications of the work.

2.4.9 Self-compacting (self consolidating) concrete

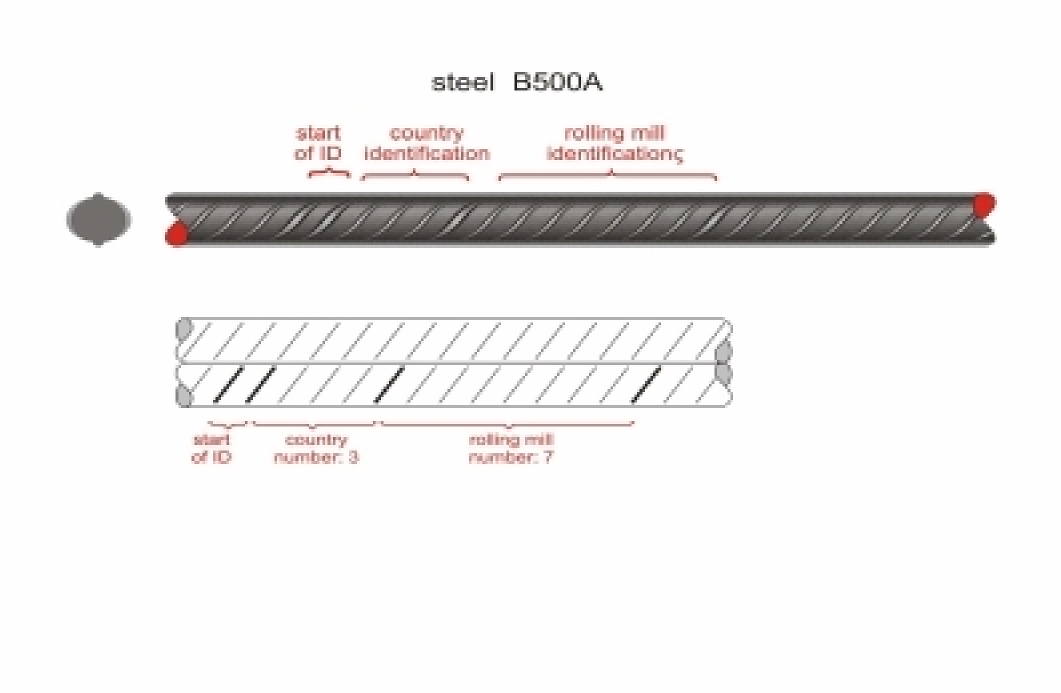
The science dealing with construction materials has created a new type of concrete, the self-compacting or self-consolidating concrete which is ideal for earthquake resistant structures that have narrow spaced reinforcement. It is a kind of 'gravel-concrete' (with aggregates ranging from 12 to 14mm). It contains 4th generation plasticizers and has a strength equal or greater than C25/30. Its slump height is far greater than the S_5 class (therefore its workability is determined by the spread test). It literally flows inside the formwork and it does not need vibration!

The steel

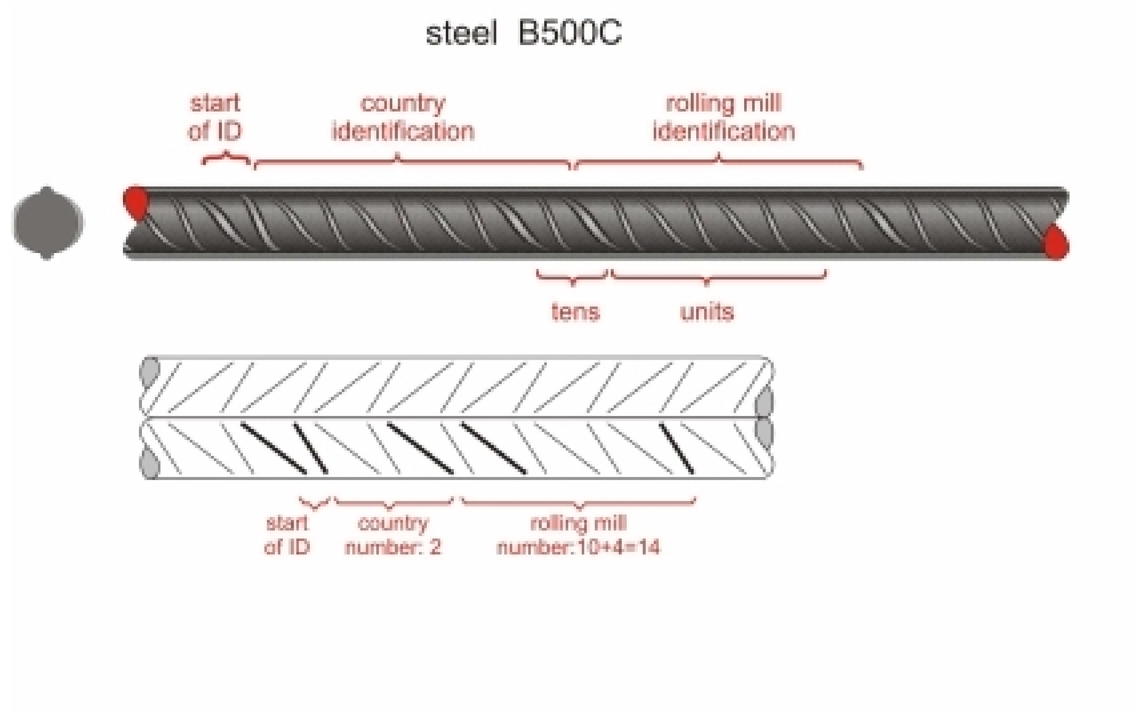
The steel implemented inside the reinforced concrete, is used in the form of circular rebars with a usual diameter ranging from Φ8 up to Φ25. In the market it is available in the form of straight bars 12 or 14m long and in the form of coils weighting around 1.5 to 3.0 tones.

Steel, either in the form of straight bars or coils, is a completely industrial product thus it has a standard level of high quality. This is the reason why its safety factor is 1.15 compared to the concrete's safety factor that is equal to 1.50. Although concrete is industrially manufactured, its production but mainly its transport and casting include a wide range of uncertainties.

In a practical level, the only class allowed to be used in reinforcement bars in Greek concrete structures is B500c and in wire meshes B500A. The class B500c is an advanced version of S500s. Its strength remains the same (500Mpa) but its ductility and weld ability are higher.



An example marking for the identification of the country and production site of a B500A steel rebar



An example marking for the identification of the country and production site of a B500C steel rebar

Numbers representing production countries

Country	Country's code number
Austria, Germany, Poland, Slovakia, Czech Republic	1
Belgium, Switzerland, Luxemburg, Holland	2
France, Hungary	3
Italy, Malta, Slovenia	4
United Kingdom, Ireland, Iceland	5
Denmark, Estonia, Belarus, Lithuania, Norway , Sweden, Finland	6
Portugal, Spain	7
Greece, Cyprus	8
Other countries	9

However, steel and reinforcement are two different things. The reinforcement is a sophisticated composition of steel pieces that has to be properly cut, formed and placed so as to behave in

the required way and support the structure not only in its entire service life but mainly in the few seconds of an intense earthquake.

Ordering concrete is a simple procedure; the only information required is the desirable amount, e.g. 52m³. On the other hand, ordering reinforcement requires the exact amount of a few hundred or a few thousand pieces of steel, for small and large buildings respectively. Reinforcement ordering requires a catalogue with the shape and exact dimensions of every piece of steel necessary for the structure's reinforcement.

As a rule, a formwork plan alone is not enough. The personnel responsible to place the reinforcement might not entirely comprehend the necessity of all reinforcement pieces as will the designer engineer or the supervisor engineer. Of course making an accurate list of all the required reinforcement is a complicated and strenuous task. According to the regulations it is mandatory only in public works and the person responsible is paid the same fee as the engineer that makes the final design (i.e. the design approved by the Town Planning Office). This legal obligation regards only public works because in the past private buildings were quite simple constructions. However, nowadays they can be as complex as public works therefore the implementation design is absolutely necessary, as it is in the advanced market of the rest of the world. The reinforcement implementation design is mandatory even in countries with low seismic activity because a good design ensures a feasible construction and a meticulous construction ensures the structural frame's strength.

Reinforcement is such a complex and critical issue that an excellent implementation study and a meticulous supervision alone are not enough. Steel must be produced according to all specifications mentioned in the **C**oncrete **T**echnology **R**egulation (CTR-08), the most important of which are: the company responsible for steel's production must have indoor facilities, must use certified materials, must have the proper machinery for cutting, bending and welding steel and most of all must employ at least one experienced technician with university or technological education.

Similarly to concrete which can be produced in the building site, steel can be cut, formed and assembled in the building site too. However, in both cases it is absolutely necessary to have a high level of technical organization, proper equipment and most of all experienced personnel.

Although steel has a standard industrial production quality, its cut, formation and basically its placement (inside the formwork moulds) quality are greatly affected by the human factor.
Especially in earthquake resistant structures, where a large amount of reinforcement is being placed, the design and construction are both equally important for the building's strength; therefore this series of books puts a lot of weight to the reinforcement factor.

2.6 Reinforcement specifications of antiseismic design

Reinforcement specifications of reinforced concrete earthquake resistant structures include the detailing specifications applied to conventional structures as well since earthquakes occur very rarely in the structures' life span.
For a structure to be earthquake resistant it must firstly abide by the regulations regarding usual structures. However, its construction demands greater attention because the critical moment of the seismic event will test the structure's strength capacity thus proving the need for meticulous application of all the regulations referring to reinforced concrete. Apart from the normal construction rules, other rules must be satisfied as well mainly regarding the vertical reinforcement like use of narrow spaced polymorphic stirrups.
The construction specifications regarding the formation and placement of reinforcement are compulsory for all structures since they are issued by the Greek Code for Reinforced Concrete (EKOS 2000) and the Greek Code for Seismic Resistant Structures (EAK 2000), as well as by the equivalent Eurocodes EC2 και EC8 which constitute laws of the country. A technician most of all must comprehend their necessity and based on that must always perform his/hers practices in compliance with them. The only capable force of reducing scrappiness and improvidence in construction is proper knowledge and not laws
In seismic resistant structures the requirement for a large amount of narrow spaced longitudinal and vertical reinforcement makes elements reinforcing a quite strenuous task. If in countries with low seismic activity the requirement for correct design implementation is taken as a fact, in earthquake prone countries, like Greece, this requirement is at least two times more important.
The basic specifications of antiseismic reinforcement are four:

(1) the reinforcement covering,
(2) the minimum distance between reinforcement bars,
(3) the light bending of rebars
(4) the antiseismic stirrups.

2.6.1 Reinforcement covering

The reasons why rebar covering is required, are:

a. Protection of reinforcement from **corrosion** (rusting).
b. The need for adequate **adhesion** between the steel and concrete.
c. **Fire protection**: the concrete that covers reinforcement protects it from deformations caused by the development of high temperatures due to fire in the building.
d. The need to **create cable and pipe channels** without harming the reinforcement[9].

Generally coverings secured by the use of plastic spacers have a considerable material procurement cost as opposed to their low implementation cost.

Of course it is possible to use other "common" materials as well, like pieces of marble. These although they have a low procurement cost their implementation is economically demanding. However, their largest problem is their correct application since they are placed after the positioning of reinforcement and prior to the concrete casting.

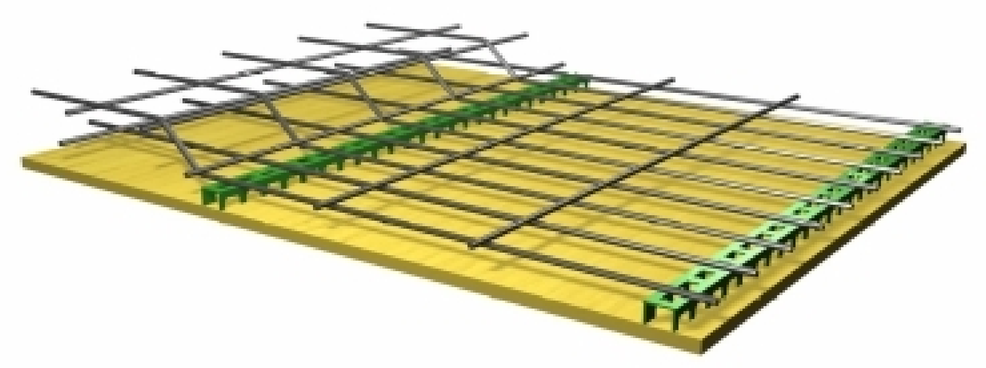
In cases where visible concrete surfaces (off-form concrete or architectural concrete) is required, one may use point or linear **spacers** made out of fiber reinforced concrete or even rebar chairs with fiber reinforced concrete tipped legs.

Covering of slabs lower reinforcement

The minimum required cover depth for slab reinforcement usually ranges between 2.0 and 3.0 cm depended on the environmental conditions present throughout the building's service life. The 2.0 cm would apply to a dry climate and the 3.0 cm to a seaside location.

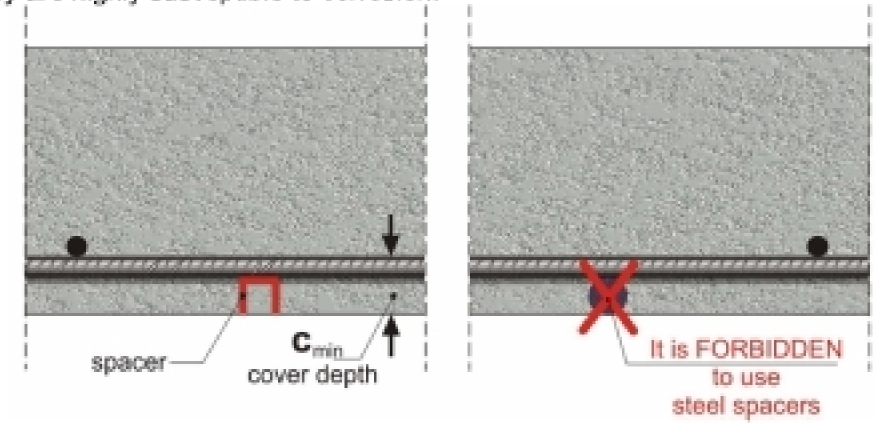
The required covering is achieved only with the use of special stands called spacers. These must not be affected by corrosion and should be placed approximately every 1.00 m.

[9] Normally, an electrician or a plumber during the construction stage usually engraves channels in the elements constituting the structural frame. Inside these channels he places electric cables or pipes. However, due to design modifications, he might have to open these channels by chipping the surface of the already constructed surfaces.



Cover depth of the slab's lower reinforcement is secured with the use of plastic spacers.

The simplest solution for providing the necessary cover depth of the reinforcement is special plastic spacers like the ones shown in the above figure. Usage of steel rebar spacers is forbidden as they are highly susceptible to corrosion.



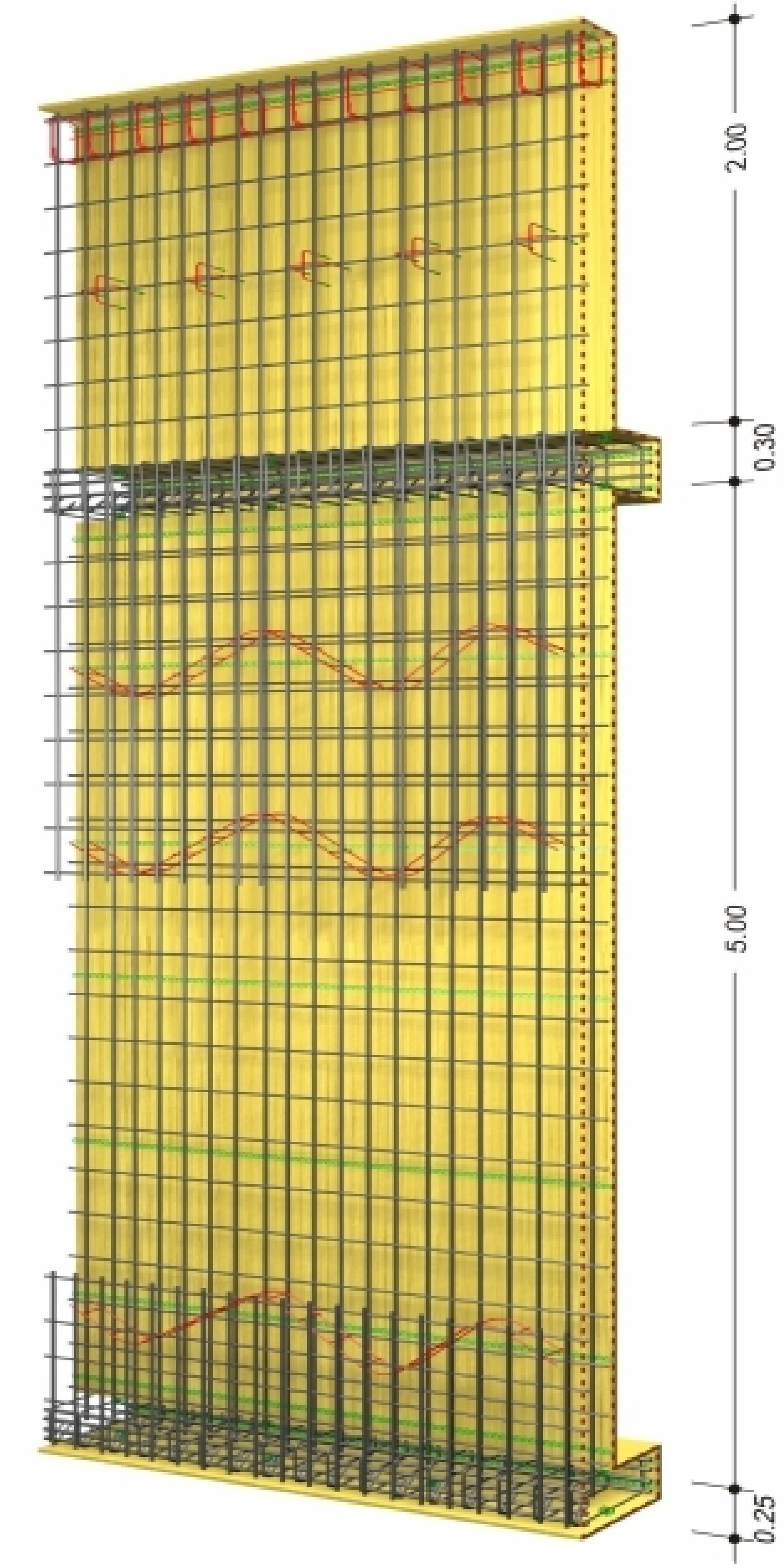
When rebars corrode the resulting volume expansion leads to concrete spalling and consequently to the cracking of the plaster. Extensive deterioration affects not only the residents' safety but also the structure's service life.

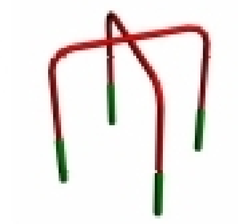
Ensuring the slab' upper reinforcement position

The position of the upper (negative) slab reinforcement, either placed in the support between two slabs or in the support between a slab and a balcony (cantilever slab), can be secured only with the use of special rebar chairs.

In the continuous slab with the cantilever, shown at the picture below, the upper reinforcement proper positioning is achieved by three ways:

(a) directly on the formwork with the use of rebar chairs
(b) indirectly with the use of folded mesh spacers
(c) indirectly with the use of S-shaped mesh spacers.





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.

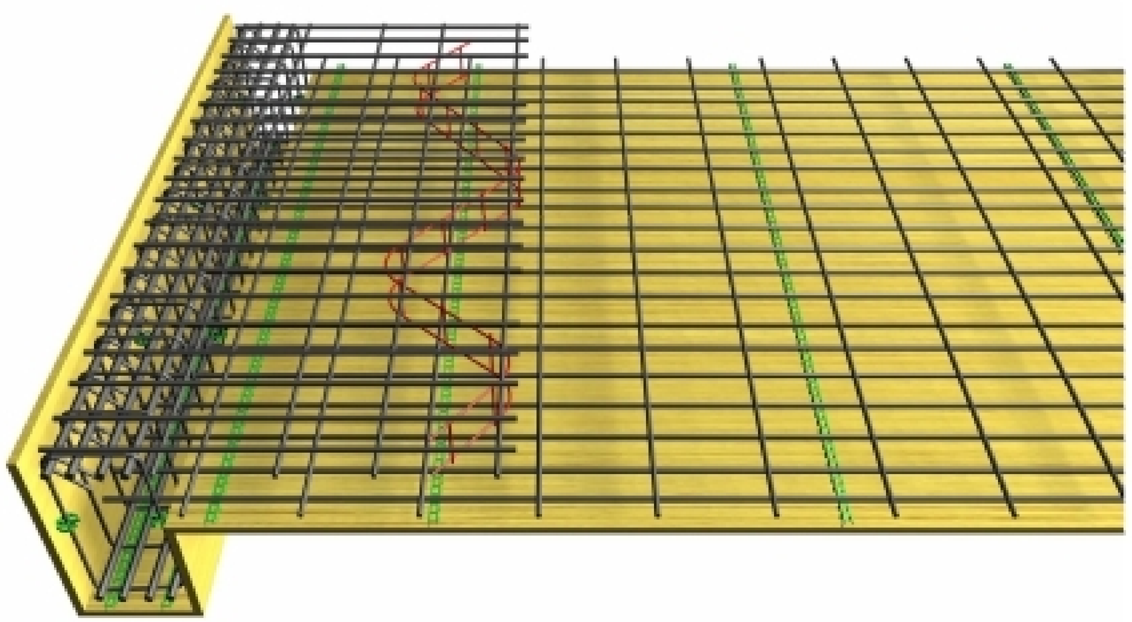
Prefabricated, comes in packages of straight lengths. It is formed in an S shape during the implementation.

Indirect, folded mesh spacer.

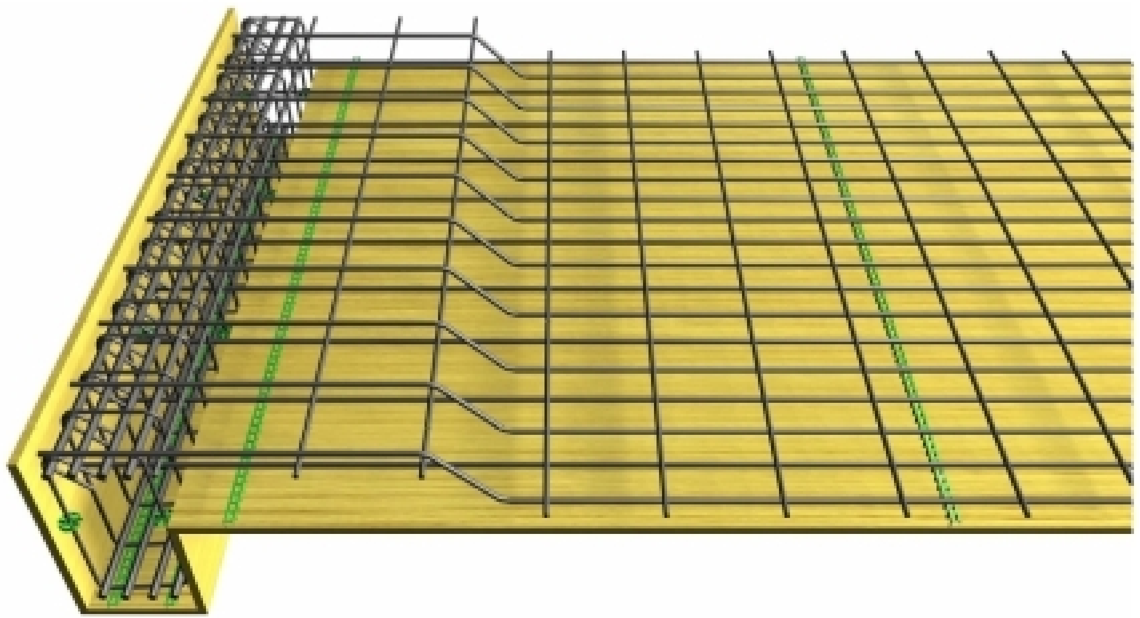
It is easily formed by folding wire of a standard density round Φ8/20, to the desirable height. In cases of cantilevers apart from spacer it can be used as "J-pin" reinforcement, necessary for the cohesion of the free edges.

Indirect "J-pin" rebar chair.

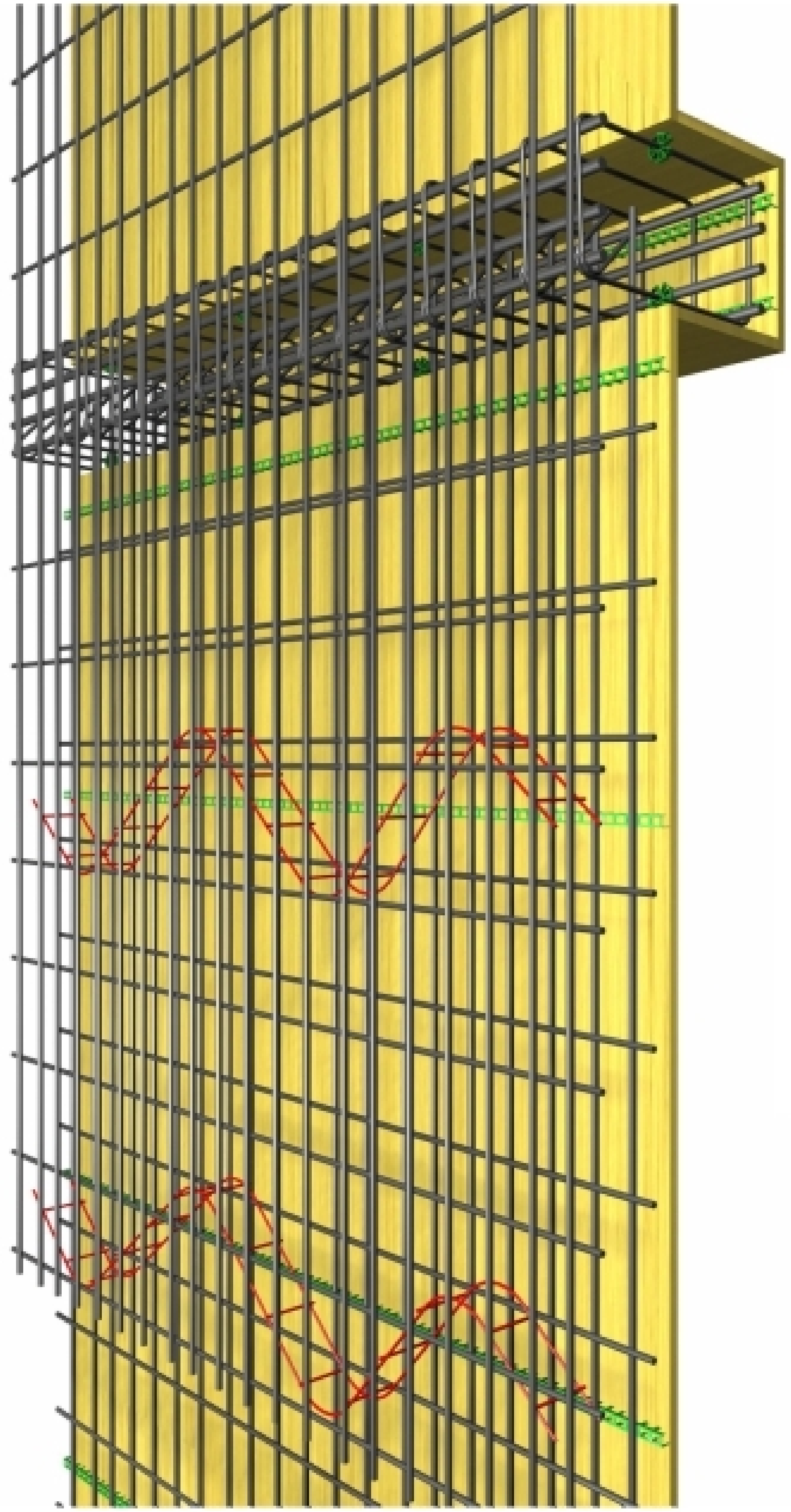
For sheer use in slabs' free edges.



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.

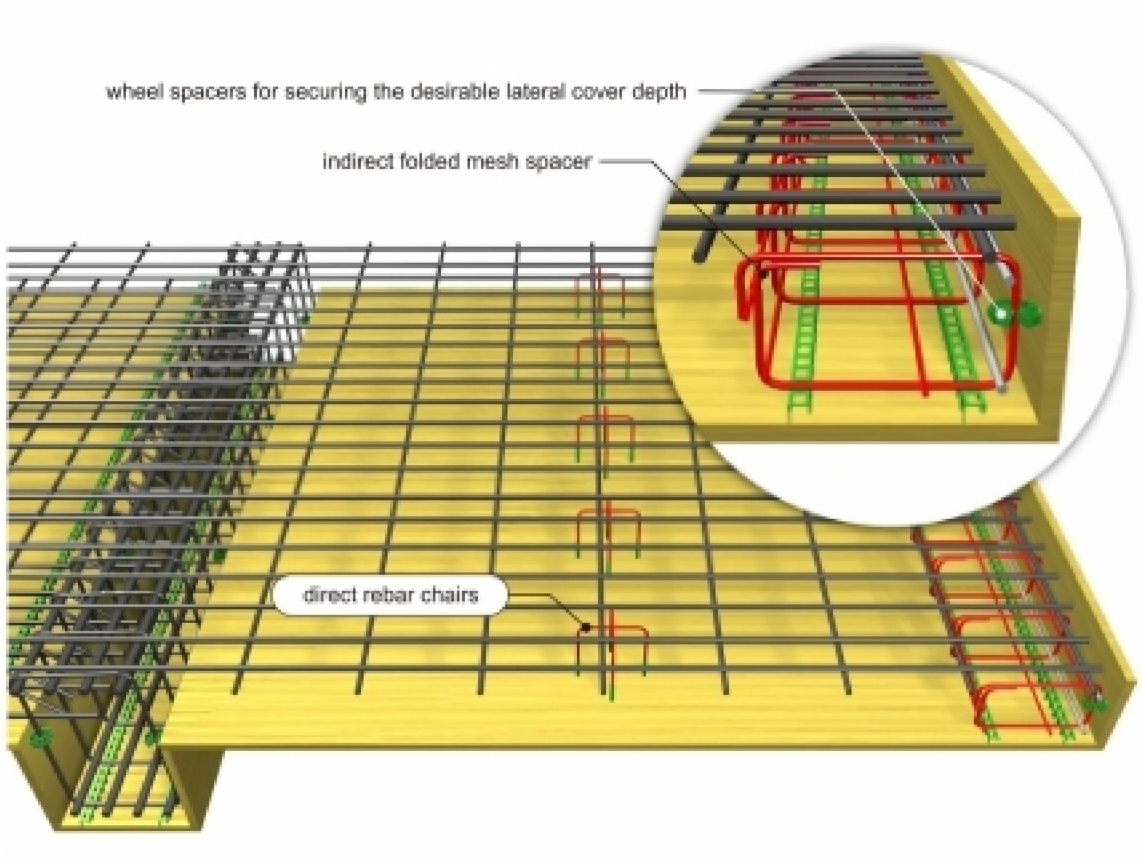


In cases where support upper reinforcement comes from bend up span rebars, its proper placement is achieved by the reinforcement bending and therefore bar chairs might not be necessary.



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

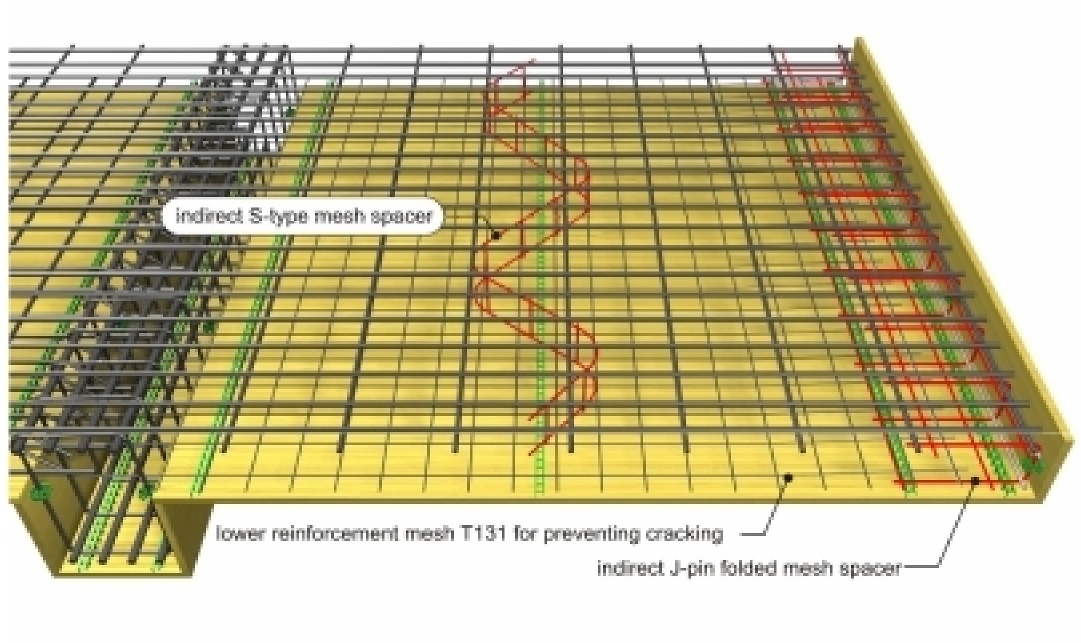
Two indirect S-shaped mesh spacers are placed to the left support of the continuous slab. These are fitted upon the lower reinforcement grate along the length of the linear plastic spacers.



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

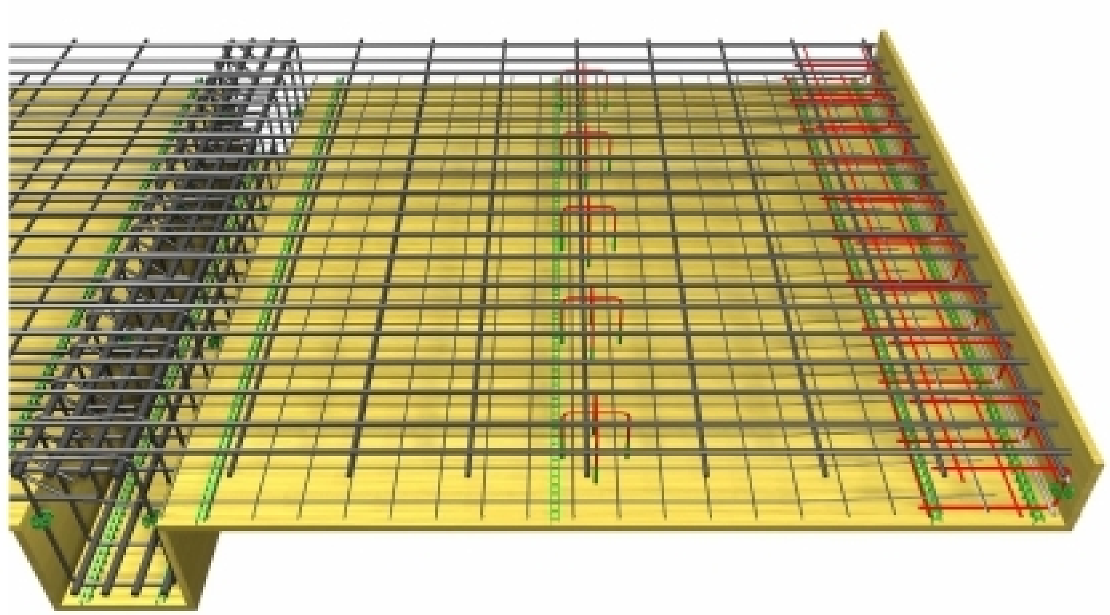
In the right support (cantilever balcony) of the above continuous slab, two rows of spacers are placed. The first row consists of indirect folded mesh spacers fitted upon two longitudinal plastic spacers and the second row consists of a number of direct rebar chairs.

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.

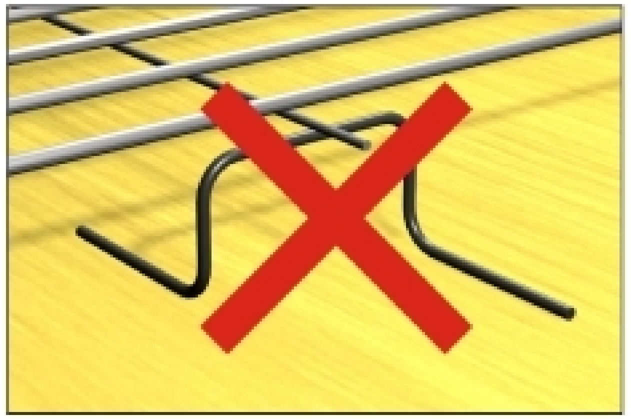


Support of the negative slab's reinforcement with indirect S-shaped mesh spacers and folded mesh spacers

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.



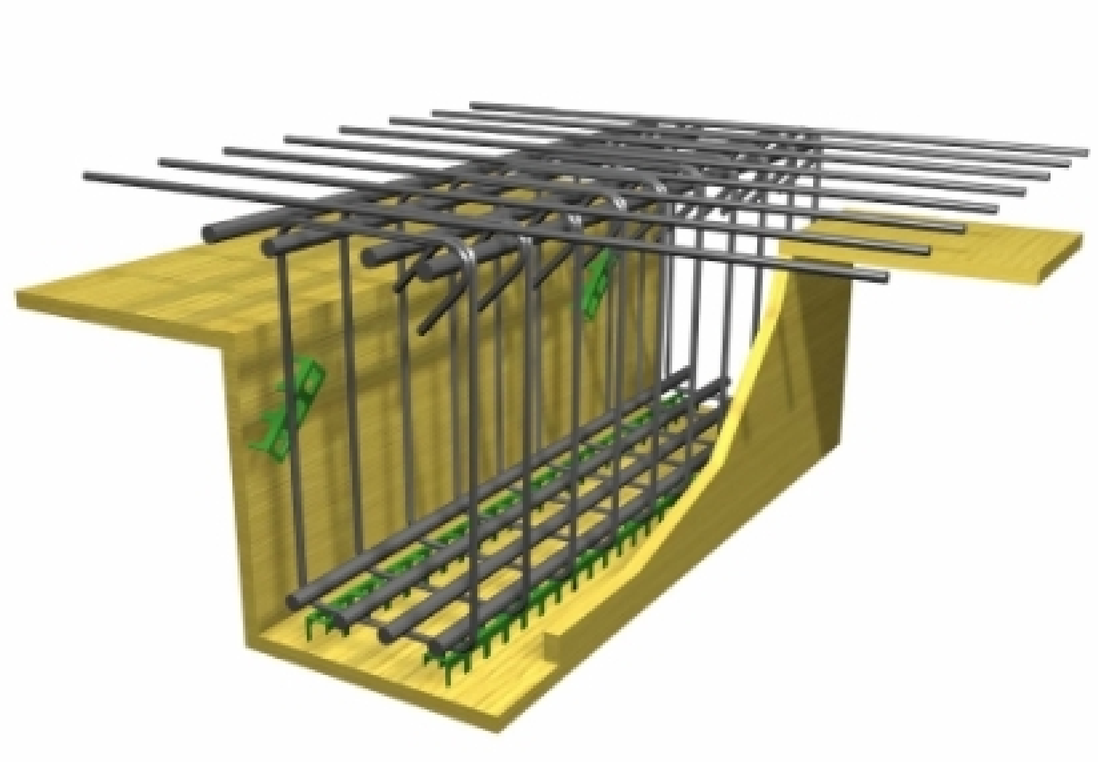
Another solution, even when there is reinforcement mesh on the lower side of the slab or the cantilever, is the use of direct rebar chairs rather than indirect S-shaped mesh spacers.



Use of steel rebar chairs directly placed upon the formwork is strictly forbidden and furthermore the use of old type impromptu spacers is more expensive.

Beam reinforcement covering

The minimum required cover depth for beam rebars usually ranges between 2.5 and 3.5 cm depended on the environmental conditions present throughout the building's service life. The 2.5 cm apply to a dry climate and the 3.5 cm to a seaside location.
Beam stirrups should be supported at the base of the beam, by a uniform inactive bar since all reinforcement loadings are transferred to these areas.
Lateral cover depths should be created with the use of special plastic spacers. When using stirrup cage it is wiser to place the wheel spacers upon the connecting rebars in order to secure their position during concrete casting.



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.

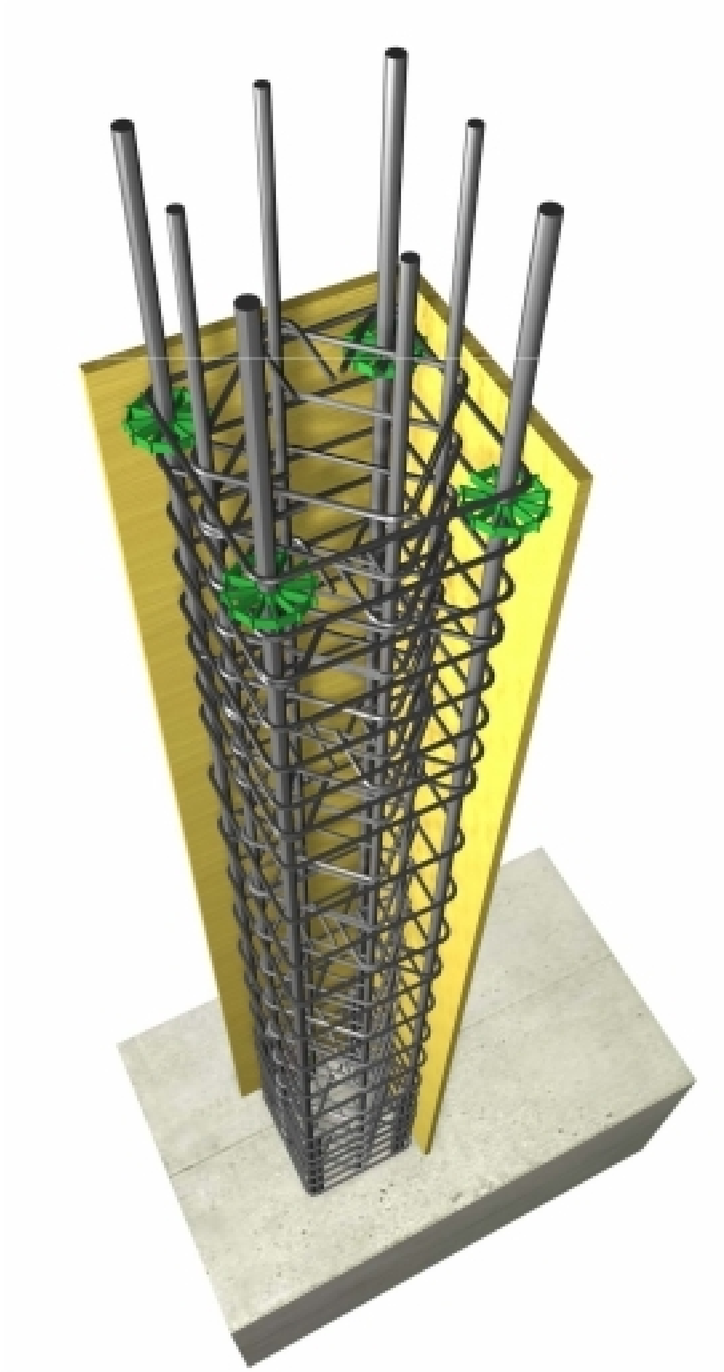
Column reinforcement covering

The minimum required cover depth for beam rebars usually ranges between 2.5 and 3.5 cm depended on the environmental conditions present throughout the building's service life. The 2.5 cm apply to a dry climate and the 3.5 cm 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.

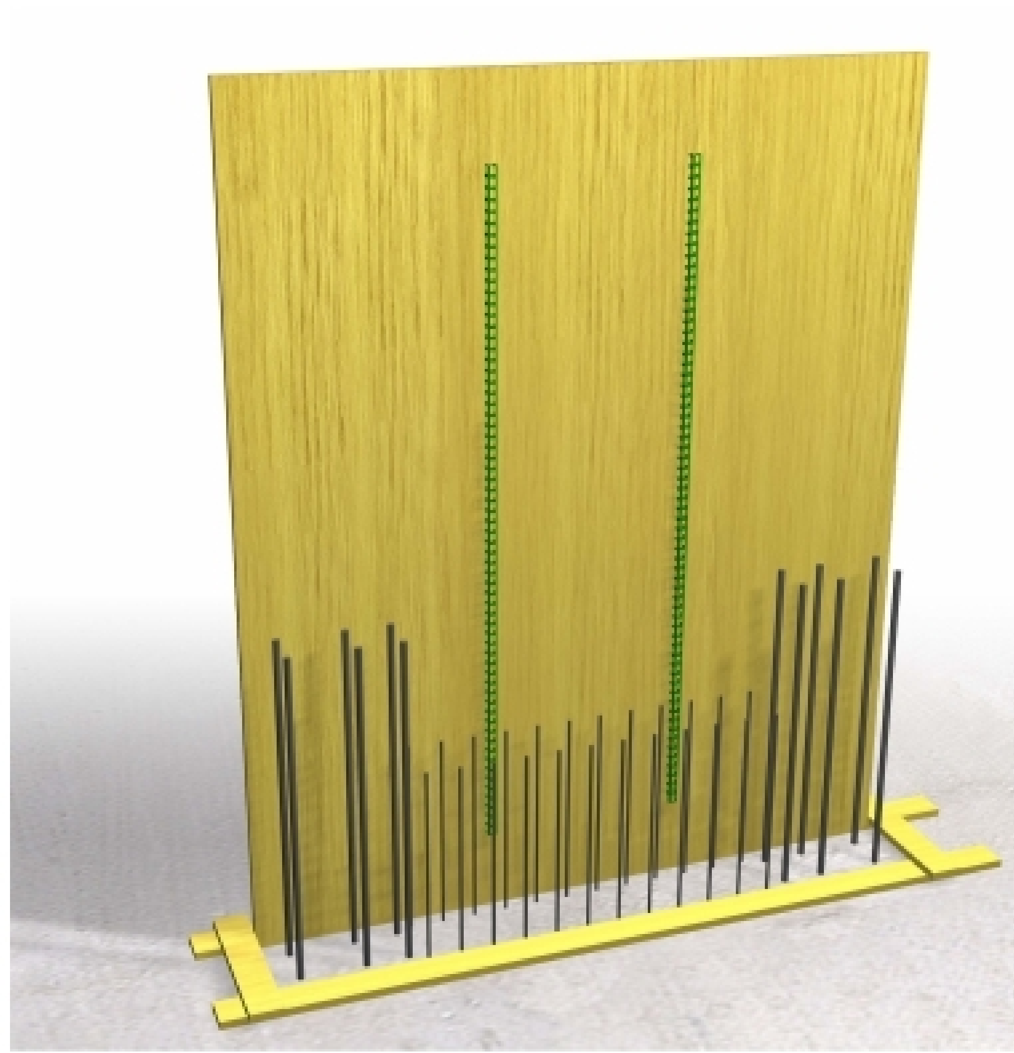
In every case though, spacers must be fitted after the positioning of the stirrup cage in order to facilitate the implementation of the cage and the proper centering of rebars.



Shear wall reinforcement covering

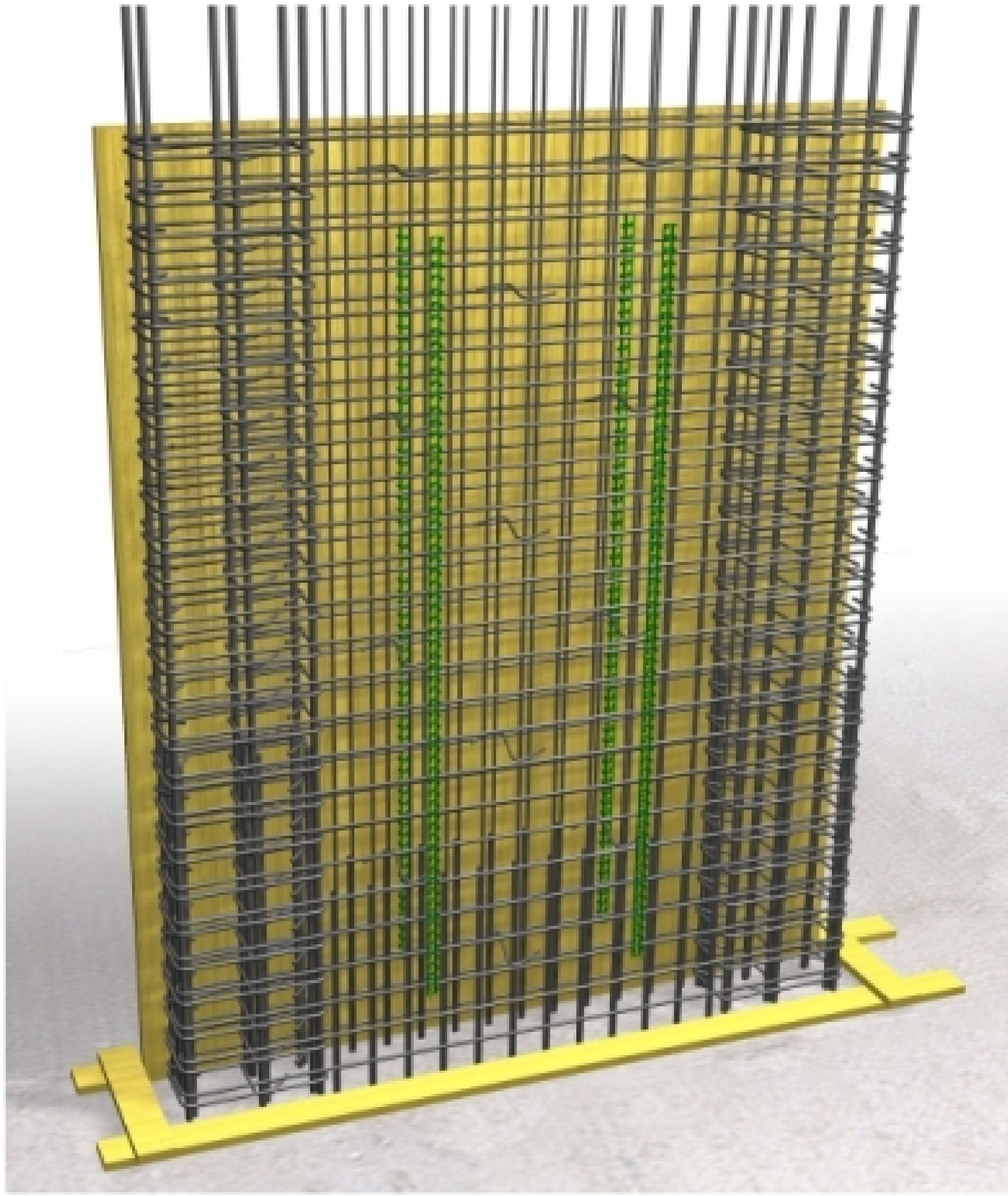
As far as the integrated columns at the wall edges are concerned, the required cover depth is created as mentioned in the paragraph referring to the columns' reinforcement covering. As far as the wall body reinforcement is concerned, its cover depth is created according to the following:

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.

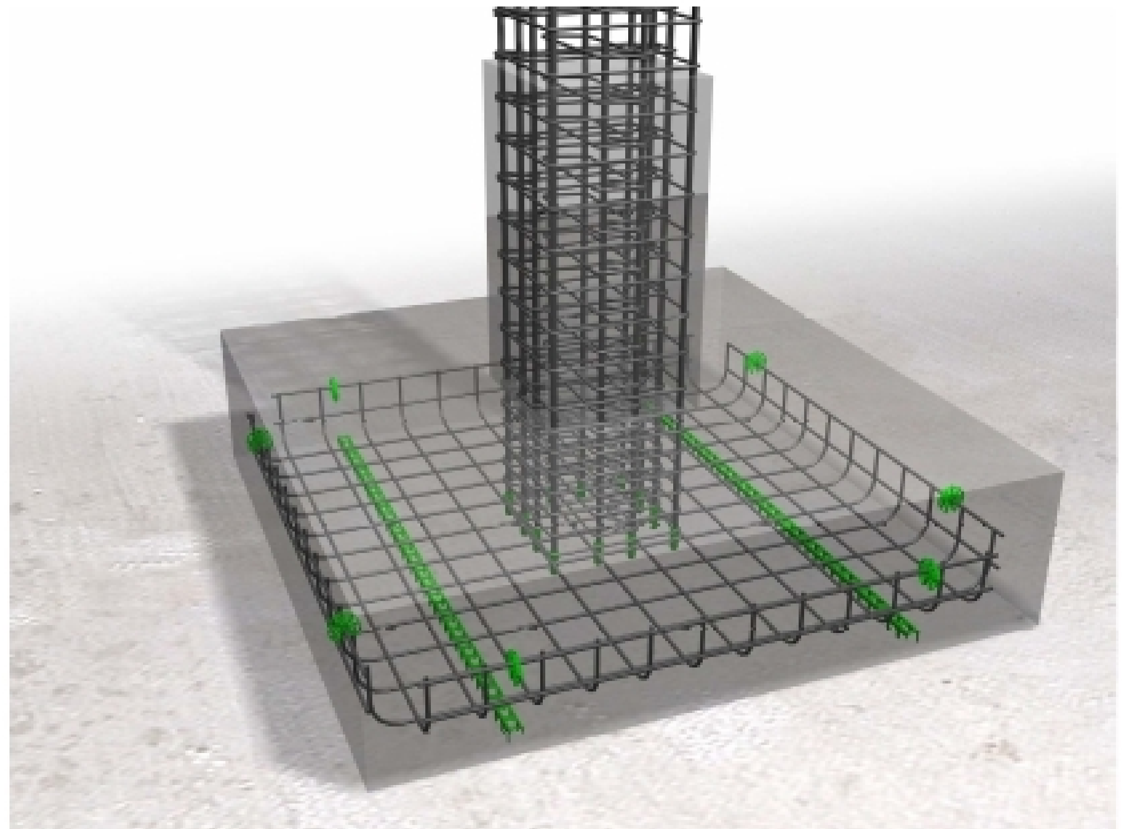
Foundation reinforcement covering

The minimum required cover depth of the foundation reinforcement is around 4.0 cm for foundation "sited" on ground leveling slab and around 7.0 cm 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

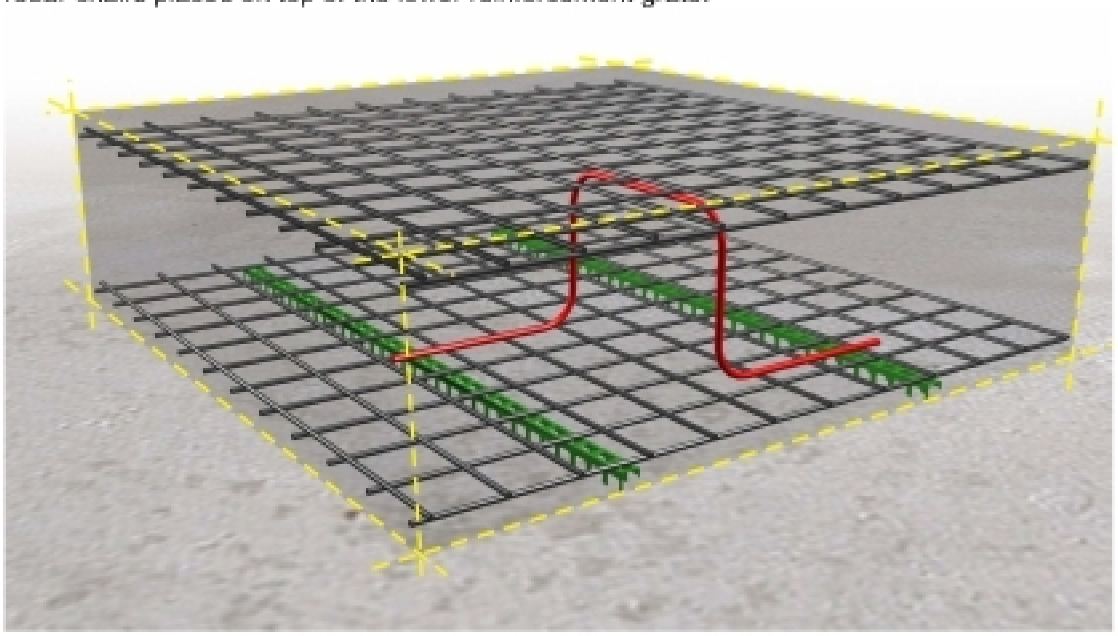
Use of spacers on the sides of the footings is obligatory in order to prevent rebars from slipping. Since they do not bear weight, they can be sparsely placed and they should be fitted vertically to avoid drifting during the concreting process.

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

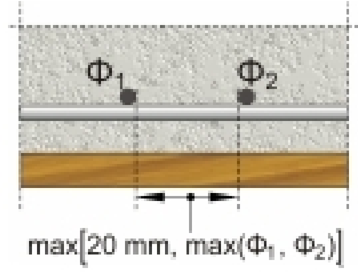
The distance among reinforcement bars must be such to allow the concrete's gravel to pass between them. In order to have properly anchored reinforcement, it is mandatory for rebars to be surrounded by concrete.

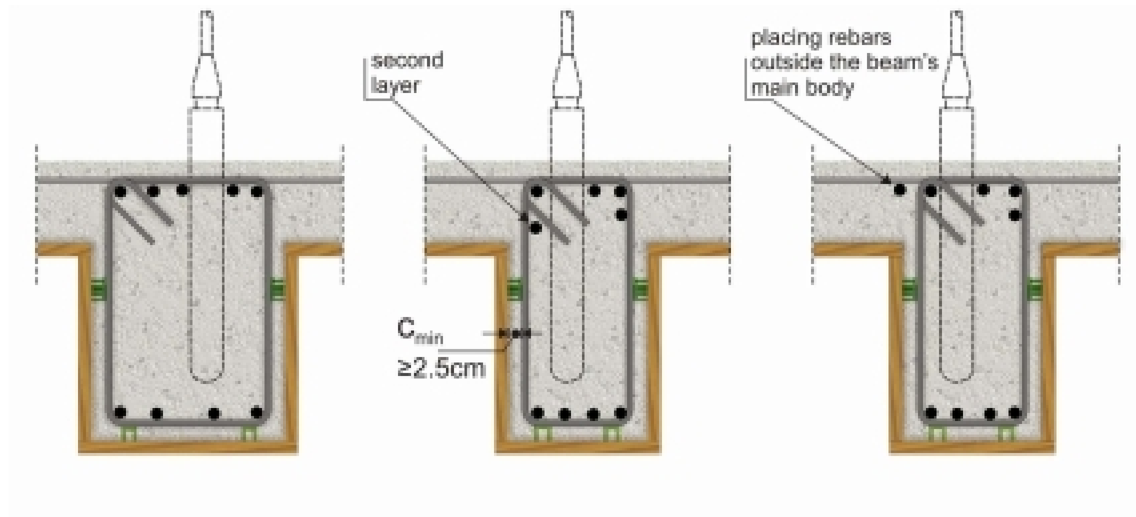
The minimum spacing between two reinforcement bars is the maximum of 25mm (or at least 20mm) and the diameter of the largest rebar. For instance, rebars with a diameter lesser or equal to Ø20 must have a minimum spacing of at least 20 mm and rebars larger than Ø20 must have a distance between them at least equal to their diameter.

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.





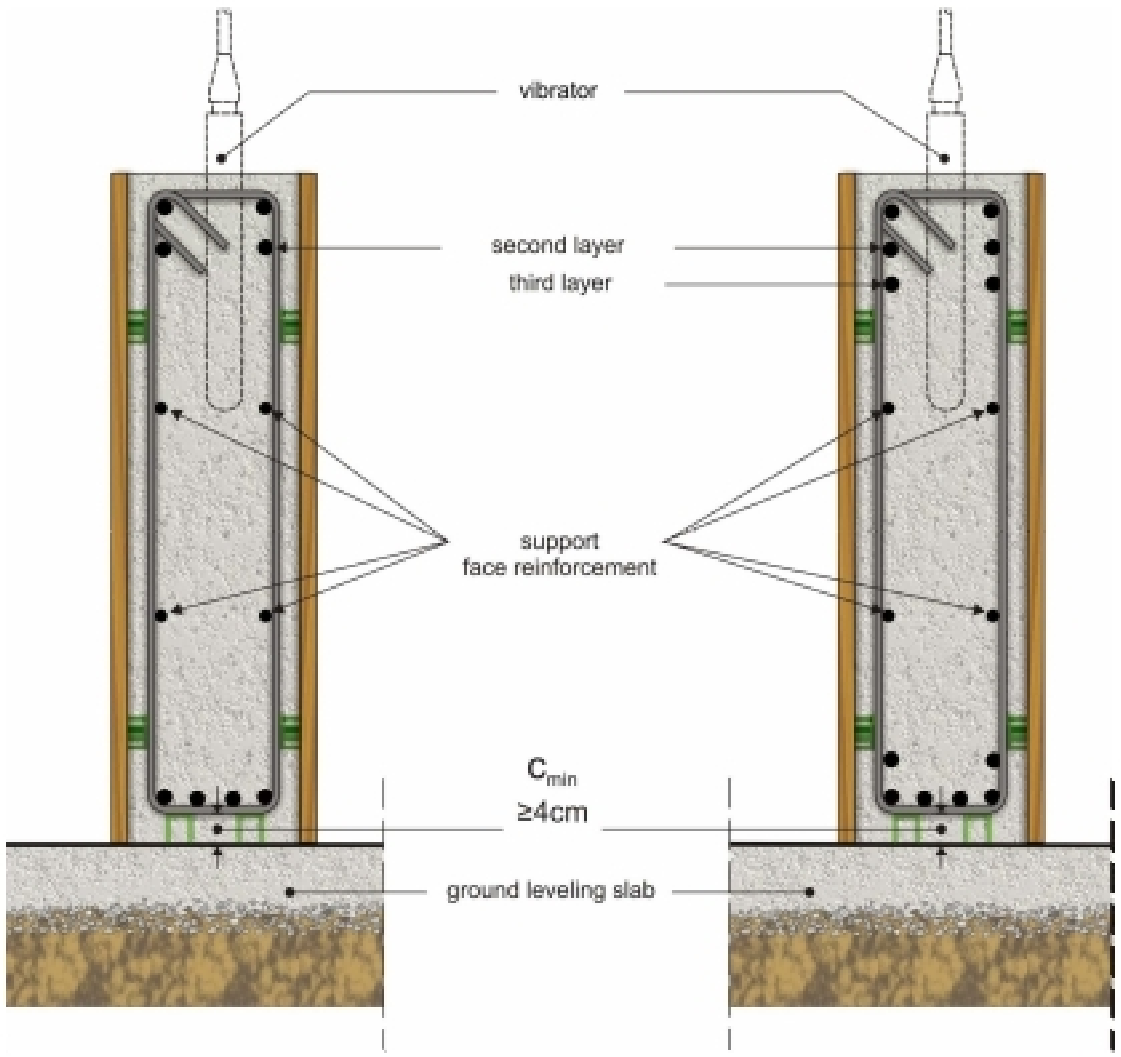
a) Large beam width

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.

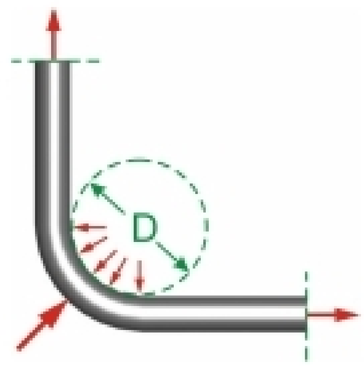
Connecting beams in foundation

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.



2.6.3 Rebar bending

Reinforcement bars are being bent either in order to follow the stresses developed in the member or to get properly anchored.



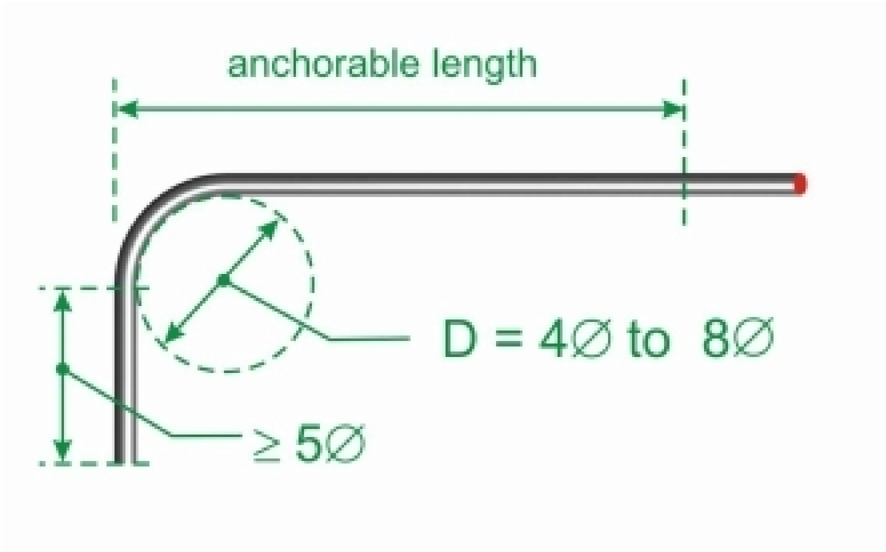
The minimum diameter D (mandrel diameter) to which a bar is bent shall be such to avoid bending cracks to the bar and ensure the integriy of concrete inside the bent of the bar where large forces appear. The smaller the mandrel diameter is, the larger these forces are and consequently the concrete may fail thus leading to the disintegration of the cross-section.

Anchorage with bends and hooks

Anchorage is the extended length of a rebar inside the concrete in order to provide adequate adhesion between those two materials. That way when the steel receives forces, it will be able to reach its maximum strength capacity. Anchorage may be achieved by a straight bar or by a hook at the end of the rebar.
If the mandrel diameter of a bent-up bar is not the one required, there is danger of cracking thus losing a large amount of strength capacity. This will happen even if the cracks are not visible to the human eye.
Forming the right mandrel diameter has no additional cost since bending machines have appropriate rings for changes in the rolls diameter.
Practically, the minimum bend diameters are:

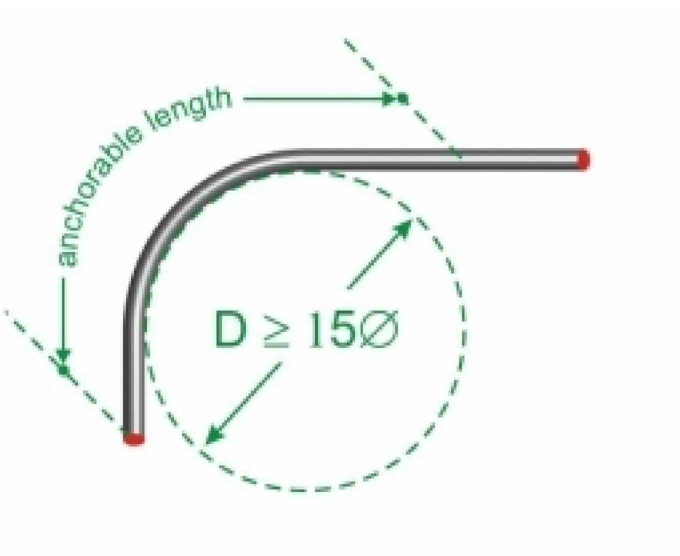
- for slab rebars 4Ø,
- for column or beam rebars anchored inside frame joints:

  (4 έως 5)Ø for rebars ≤ Ø 16,
  (7 έως 8)Ø for rebars > Ø 16.



The mandrel diameter may be equal to 80mm and 160mm for Φ16 rebars and Φ20 rebars respectively

Anchorage with bend in a well confined joint



A well confined structural member is an element that has enough and properly placed stirrups both around and inside its perimeter. This is thoroughly presented in the chapter reffering to columns.
The minimum mandrel diameter is defined by various factors but a typical value is around 15Ø. This method of anchorage is preferred when there is no possibility to use large sized columns (like a column with one side <70cm).

2.6.4 Antiseismic stirrups

In the case of an earthquake, the most critical factor regarding the strength capacity of a structure are the stirrups which should be produced and placed according to all antiseismic specifications. For example, in the 7.9.1999 earthquake, in Attiki, no buildings would have had collapsed if their vertical reinforcement was the one required by today's regulations and no serious damage would have been inflicted to 80% of the structures that presented severe problems in their structural frame.
Stirrups constitute one of the most crucial factors affecting the quality and the earthquake resistant strength of buildings.
Three are the major reliability parameters of stirrups:

a. The appropriate hooks at its free edges. Hooks are absolutely necessary for the proper behavior of stirrups especially during an intense seismic incident, when concrete spalling occurs, leaving hooks to be the only anchoring mechanism.
b. The mandrel diameter. Stirrups must be bend in rolls with a diameter at least equal to 4Ø, i.e. for Ø 10 they must have a diameter greater or equal to D = 40 mm.
c. The required distance between the legs of a closed stirrup. These must be placed at least 20 cm apart from one another (e.g. a column 50x50 must have three stirrups in each layer).

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.

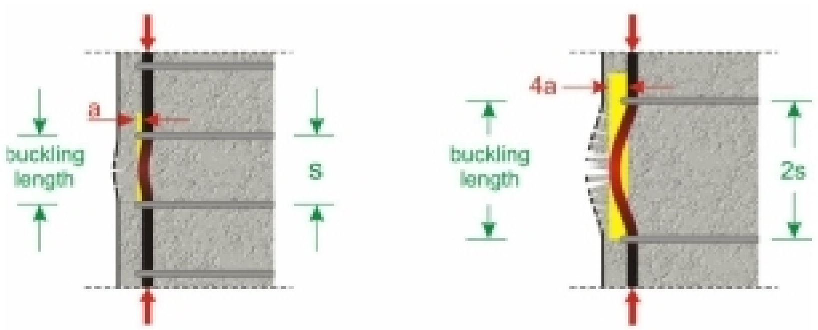
Throughout the world, structures collapse even when they have a large amount of reinforcement. The reason for this is always the same; lack of properly shaped and placed stirrups.

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.

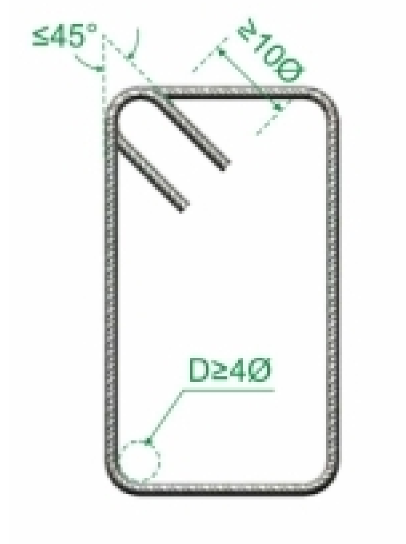
Typical failure of a column's upper part.

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.

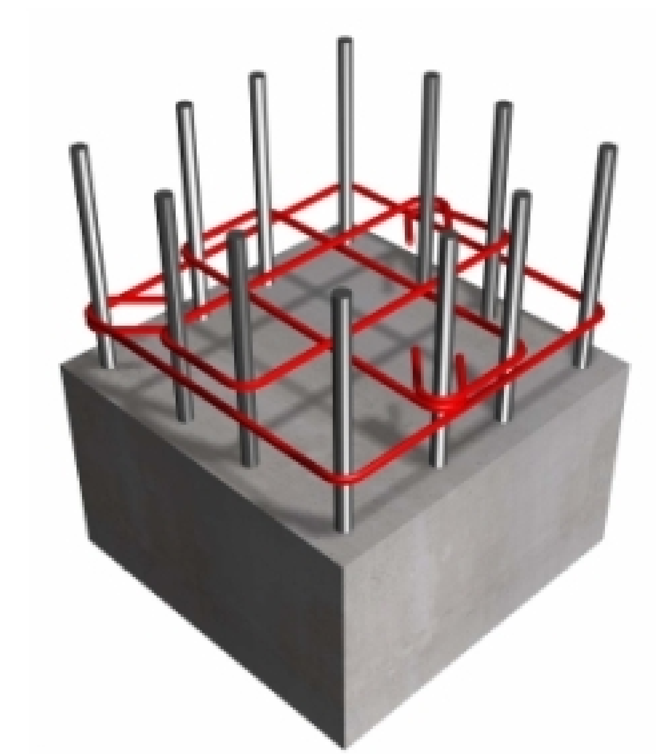
Failure of a column dimensioned according to old regulations that required a peripheral stirrup with its end bent in 90° instead of 135° (45°).



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.



Properly closed stirrup with a hook length equal to 100mm, bent in a 40 mm diameter roll (for stirrup bar Φ10)



Properly reinforced column 50x50 with 3 stirrups in each layer

2.7 Industrial stirrups - stirrup cages

The most complex, hard and time consuming part of the reinforcement implementation is the placement of stirrups. In the duration of this process a large amount of time is being spent and the biggest mistakes are being made.

The industrialization of such a complicated and diverse procedure that traditionally was made by hand was not an easy task. In the past decade this issue was dealt with the industrialized production of common stirrups at first and subsequently with the industrialized production of polymorphic stirrups.

In Greek market the breakthrough in stirrup industry was done with the production of polymorphic cellular stirrups from pi-SYSTEMS under the name Antiseismic Thoraces. This provided solution in the manufacture of even the most sophisticated stirrups mainly though it solved the problem of accuracy in the design implementation. Industrialization of the Greek market was continued by BITROS HOLDING S.A.

At the same time with Antiseismic Thoraces, the advancement of the traditional stirrup machinery, now referred to with the general term robot, led to the large scale production of composite polymorphic stirrups produced with a complete or a half circle.

The next stage in the vertical reinforcement industrialization was and still is the production of cages that consist of successive polymorphic stirrups. The development of welding machines made possible the formation of cages consisting of different types of stirrups in a number of spacings.

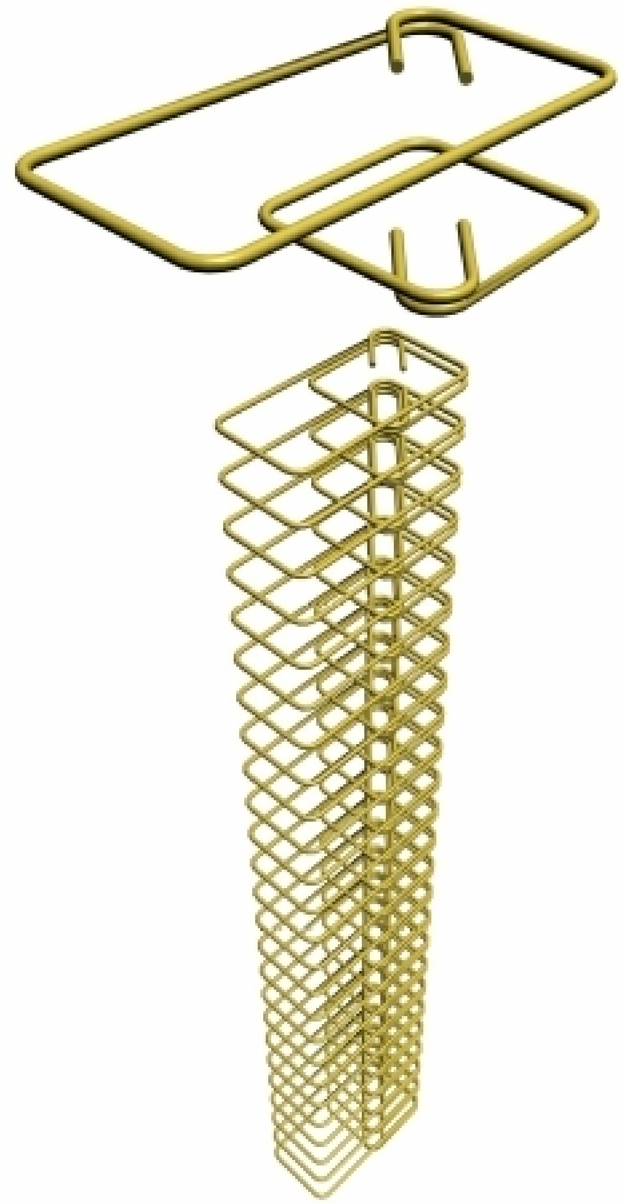
The massive industrial production of stirrup cages started from SIDENOR followed by Hellenic Halyvourgia. These companies produce, in a large industrialized scale, antiseismic stirrup cages in a small but practical variety of dimensions, shapes and spacings. Despite though the limitations, they have managed to cover a large percent of the market's stirrup needs.

Regarding the complete industrialization of antiseismic stirrup cages production in a world-wide level, the ideal solution is cellular stirrups. These were developed by pi-SYSTEMS and for the time being, they are in an experimental stage. Cellular stirrups were an extension of the ring idea. With today's industrial facts, rings are produced by the vertical cut in slices of steel pipes, in a first stage, and composite pipes, in a second stage.

TYPES OF VERTICAL REINFORCEMENT

Nowadays the types of stirrups met in the Greek market are:

- Common
- Spiral form/Thoraces
- SIDEFOR
- FORSTEEL
- Robot
- Cellular

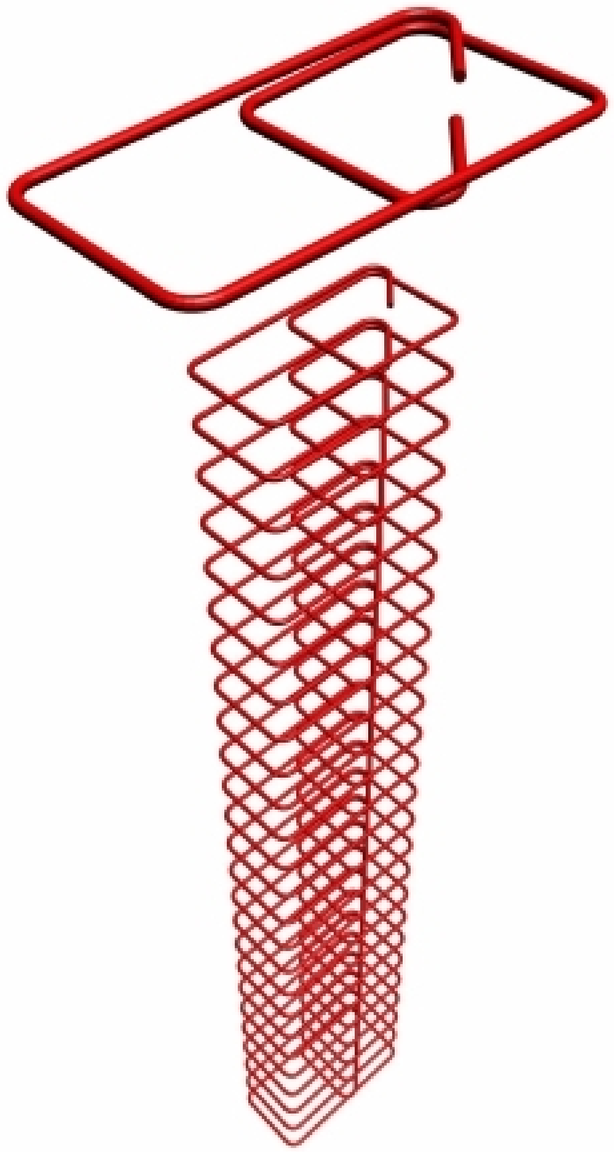


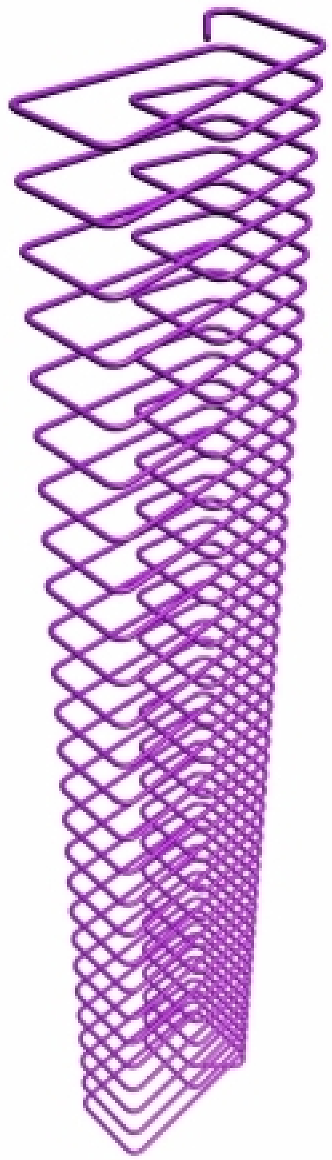
"Common" stirrups

Common stirrups are produced by hand; consequently their application has no limitations. Practically this means that they can be used in every type and size of columns.

"Spiral form/Thoraces" stirrups

Spiral form stirrups are produced by special CNC machines and they can be used in a wide range of column types and sizes. Practically the produced stirrups may be as large as the machine's largest dimension.



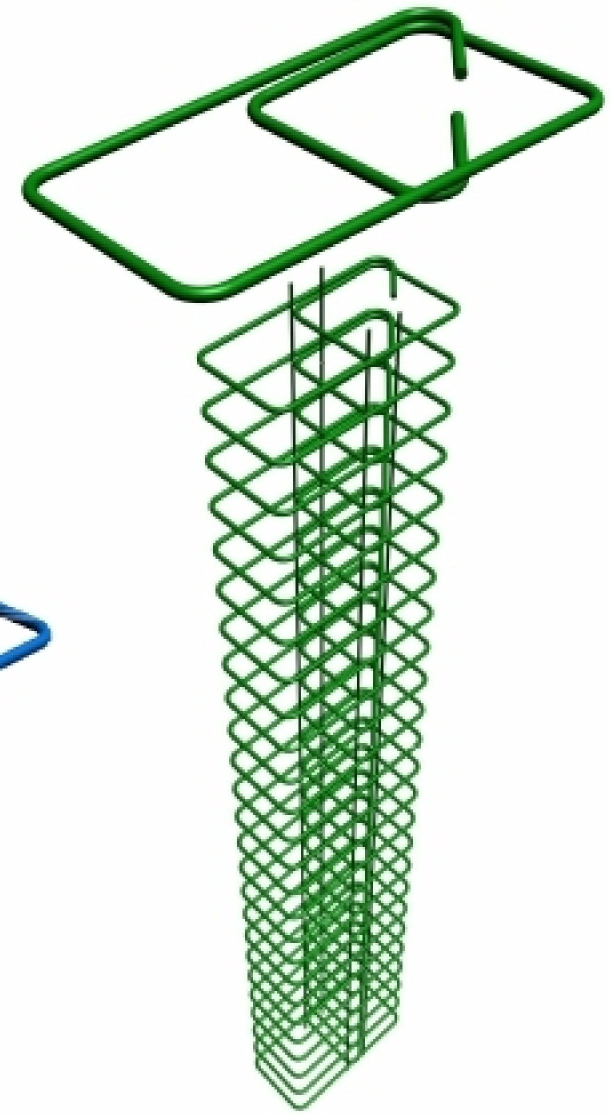


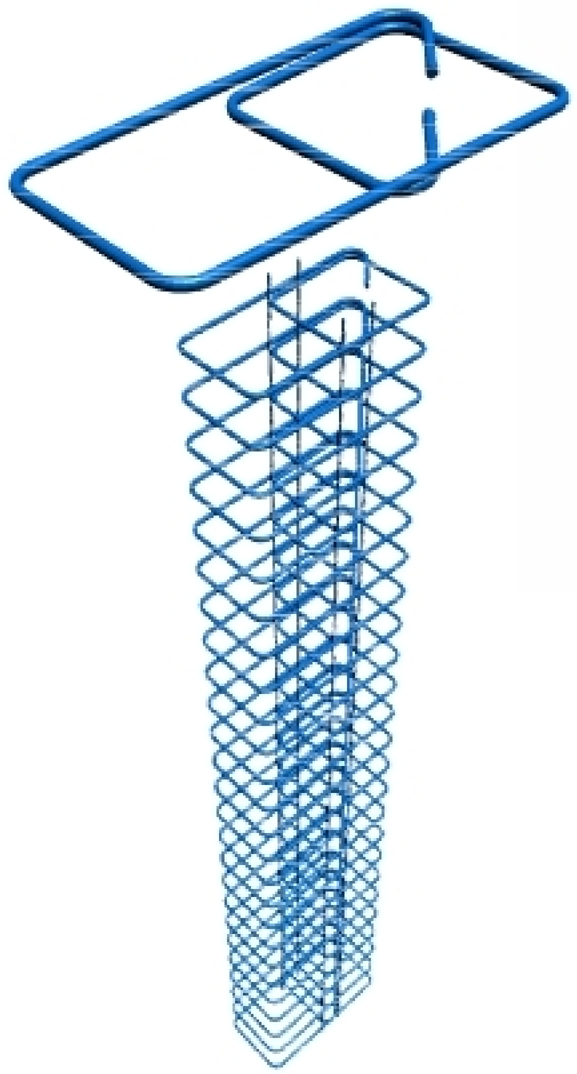
"Robot" stirrups

Robot stirrups are produced with the use of CNC machinery like the ones used for the production of spiral form stirrups. Their sole difference is that each stirrup is produced with only one complete circle.

"SIDEFOR" stirrups

SIDEFOR stirrups are produced as uniform stirrup cages ready for the implementation of the longitudinal reinforcement rebars. Like Robot stirrups, they are composed of complete circle stirrups connected with secondary rebars which have a diameter equal to Φ5.5. Their main characteristic is their industrialized production, they are ready-to-use but they are available in specific shapes and dimensions.



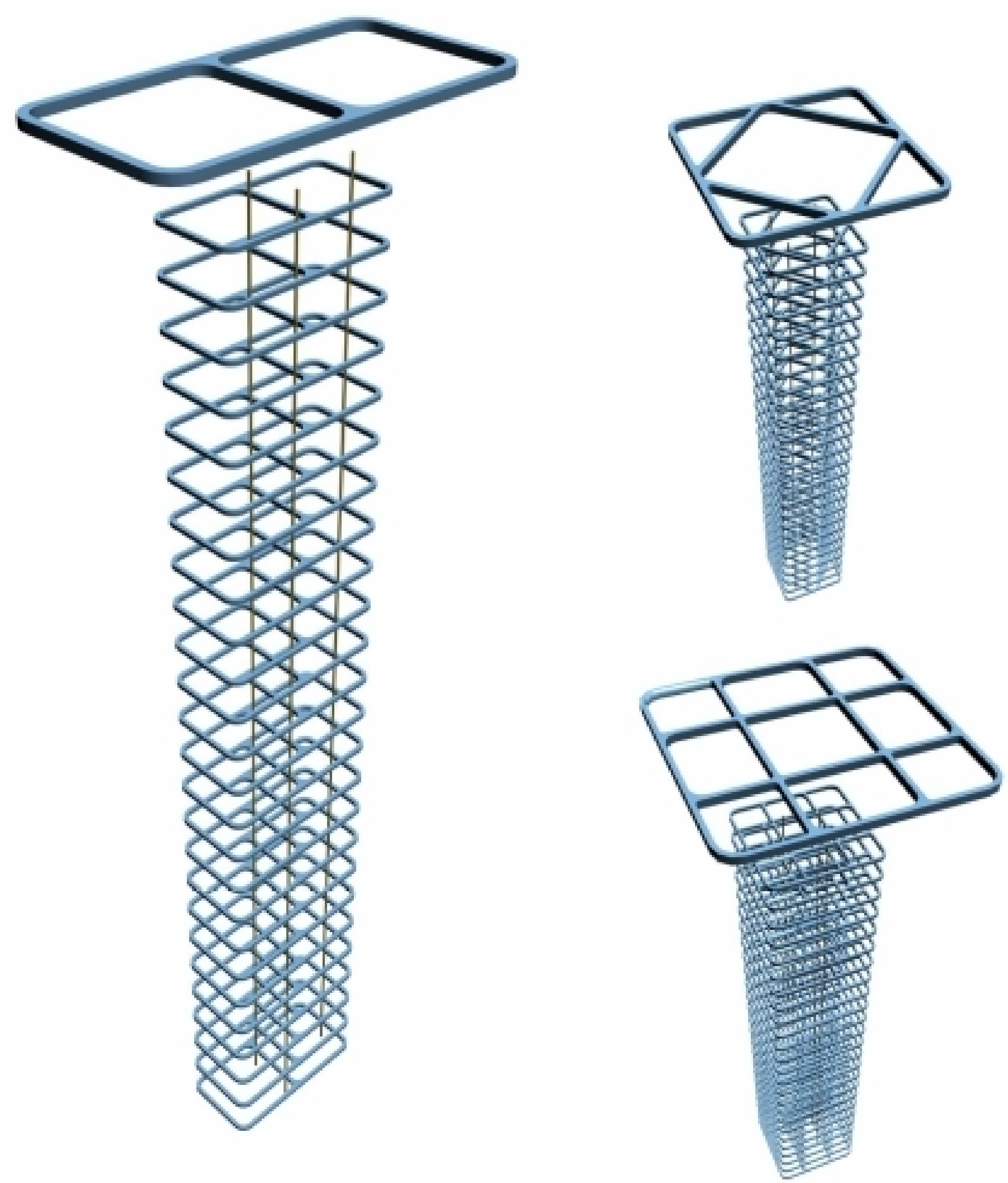


"ForSteel" stirrups

ForSteel stirrups are exactly like the SIDEFOR stirrups; their only difference is that the secondary bars used have a Φ6 diameter.

"Cellular" stirrups

Cellular stirrups are closed section (no loose ends) stirrups that are composed by many simple cells or one composite cell. They can be either industrialized assembled with the use of longitudinal connecting bars or manually assembled like the common stirrups. These stirrups are patented technology of pi-SYSTEMS in most countries around the world. At present, cellular stirrups are in an experimental stage for their further development.



2.8 Standardized cross-sections of reinforced concrete elements

Modern times require the use of standardized shapes and sizes of columns and beams composing the load bearing frame of structures. This means regular usage of elements with sections that belong to certain categories. Of course the use of elements with non-standardized sections is not prohibited but it should be made only in certain occasions. When building a structure, the largest the standardization is, the highest is the provided quality level and the lower is the resulting construction cost.

Standardization serves in:

- the reduction of construction cost since standard moulds and stirrups are more economical,
- the increase of construction quality as usage of standardized formworks and reinforcement helps in maintaining a standard high quality level,
- the familiarization of architects with typical static rules applied to structural members,
- the designers accumulating experience concerning the formation and behavior of construction,
- the faster and problem-free construction and supervision of the structural frame,
- the automatic optimization of the structural frame with the use of PC software.

It is highlighted that the shape and size standardization should not restrict the variety of sections available to the designer. However the latter should make use of it only when it is necessary.

At present there is no official standardization, but based on the regular practices and the typical antiseismic requirements the following format is proposed:

COLUMNS

a) Rectangular

	25	30	35	40	45	50	60	75	100	150	200
25				25x40		25x50		25x75	25x100	25x150	25x200
30		30x30		30x40		30x50	30x60	30x75	30x100	30x150	30x200
35			35x35								
40				40x40			40x60	40x75			
45					45x45						
50						50x50		50x75			
60							60x60				
75								75x75			

Notes:

- *The 45x25 column is highly standardized only as far as the stirrups are concerned, because it is commonly used as integrated column to the ends of both shear walls and composite elements.*
- *When using industrial formworks, it is recommended to avoid usage of 40x40 columns. Moreover, it is preferred to use shear walls with length equal to 105cm instead of 100cm and 195cm or 210cm instead of 200cm.*

b) Circular

D	30	35	40	45	50	60	75	100

c) "Γ" isosceles

b/d	25	30	35	40	50	60	75	100	150	200
25				25x45			25x75	25x100	25x150	25x200
30				30x45			30x75	30x100	30x150	30x200

d) Elevator

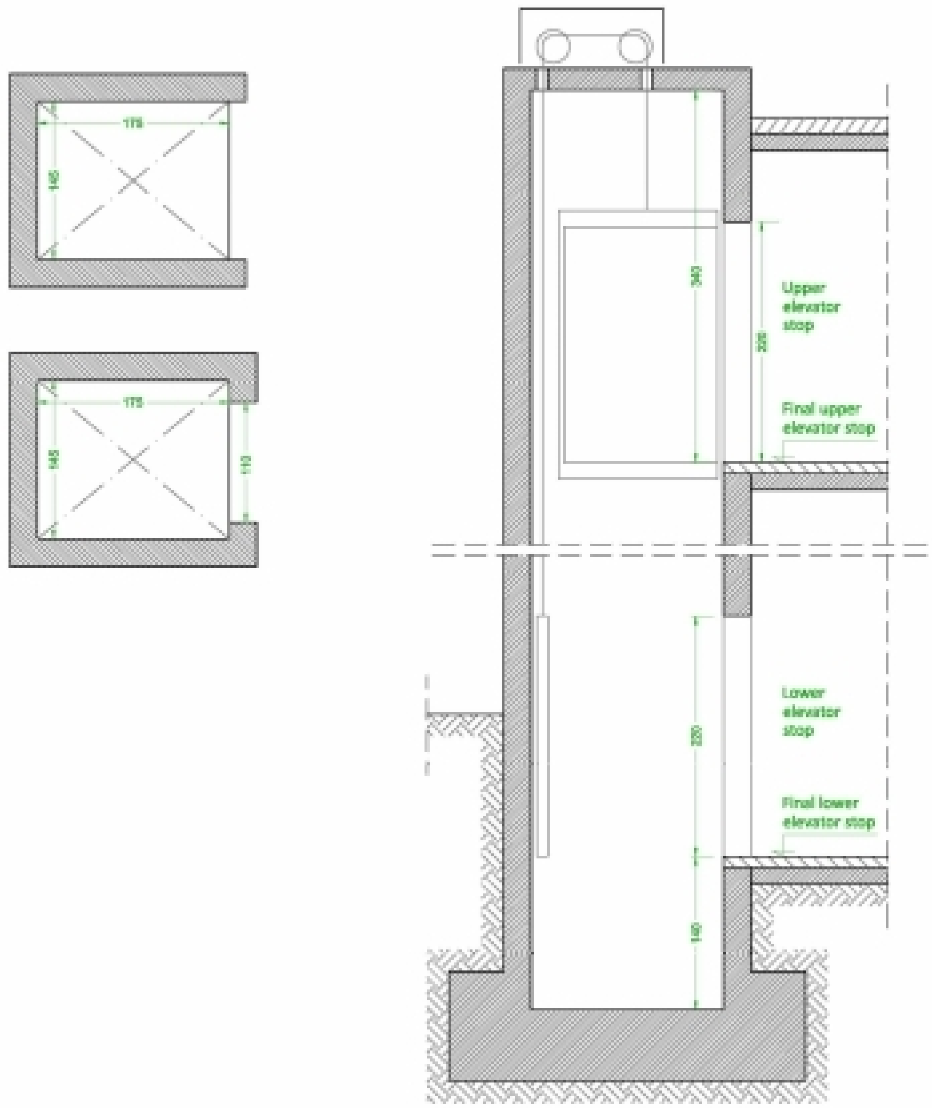
According to the specifications issued by the Ministry of Industry, the minimum clear openings in the elevator shaft are:

For common multi-storey residential buildings:
for mechanical movement 1.40 x 1.70 (m)
for hydraulic movement 1.35 x 1.85 ή 1.55 x 1.65 (m)

For buildings with height up to 9.0m:
for 3 persons 1.10 x 1.35 (m)
for 5 persons 1.20 x 1.50 (m)

The opening width of the elevator door must be equal to 1.05m (building width) and the lintel must be placed 2.20m above the final floor level. This specific width is necessary in order to provide sufficient space to enable a wheelchair user to pass unobstructed through the door even after the jamb has been placed. In multi-storey residential buildings, it is compulsory to construct elevator doors with that width however, its construction is recommended to every other building.
The clear height of the elevator shaft must be at least 3.40m, calculated from the final level of the upper storey.
The clear depth of the elevator shaft must be at least 1.40m, calculated from the final level of the first stop

In order to avoid fatal imperfections especially in the maintenance of the multi-storey structure's verticality, it is highly recommended to construct the internal space with dimensions at least 5cm larger than the minimum required. If there are concrete door posts, the elevator door must have a clear opening equal to 1.10 m. Usually elevators have a "Π" shape without door posts, either due to technical reasons or because a sliding elevator door is required. The typical width of the elevator elements (shear walls and door posts) is around 25 ή 30 cm.
In all cases, the required dimensions should be verified by the person responsible for the elevator installation.



Minimum clear dimensions of an elevator in a typical multi-storey residential building

BEAMS

b/d	25	30	35	40	45	50	60	75	100	125	150	200
20												
25				25x40		25x50	25x60					
30				30x40		30x50	30x60					
40						40x50	40x60	40x75				
50						50x50	50x60	50x75				

<u>*Notes:*</u>

- *Sections with width lesser or equal than 30cm, apply to relatively small structures with usual strength requirements.*
- *When thermal insulation is embedded inside the formwork, the only practical way to standardize this procedure is to use boards with 5cm thickness since industrial moulds and stirrups usually have dimensions divided by 5.*

FOUNDATION CONNECTING BEAMS

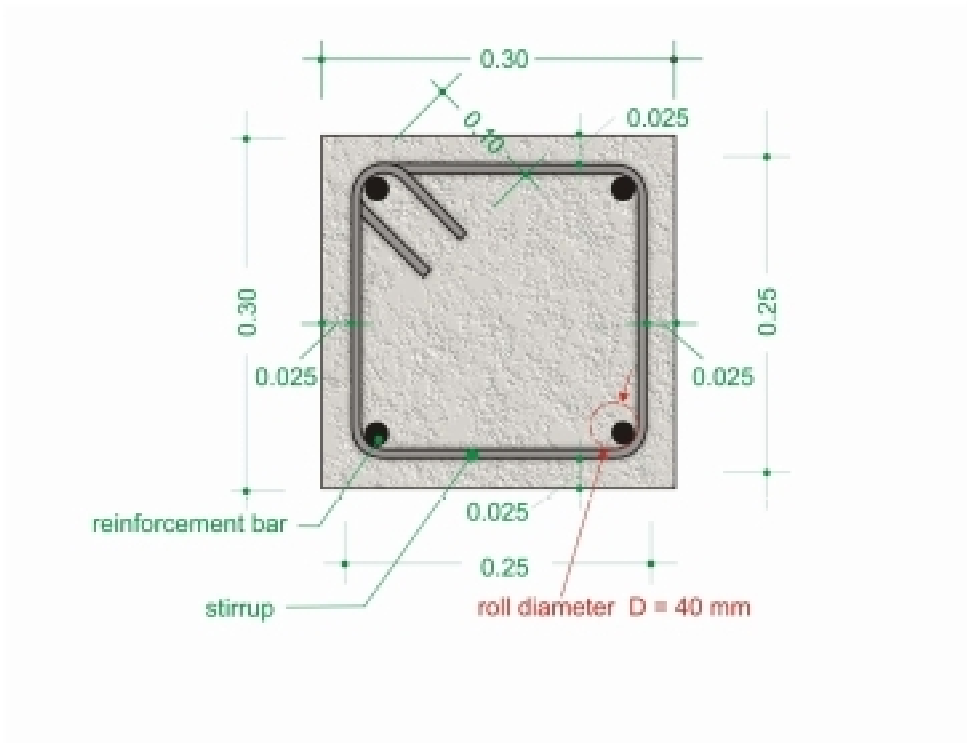
b/d	35	40	45	50	60	80	100	120	150
30						30x80			
40						40x80	40x100	40x125	
50							50x100	40x125	50x150

CHAPTER 3

Reinforcement in structural elements

3. Reinforcement in structural elements

3.1 Columns

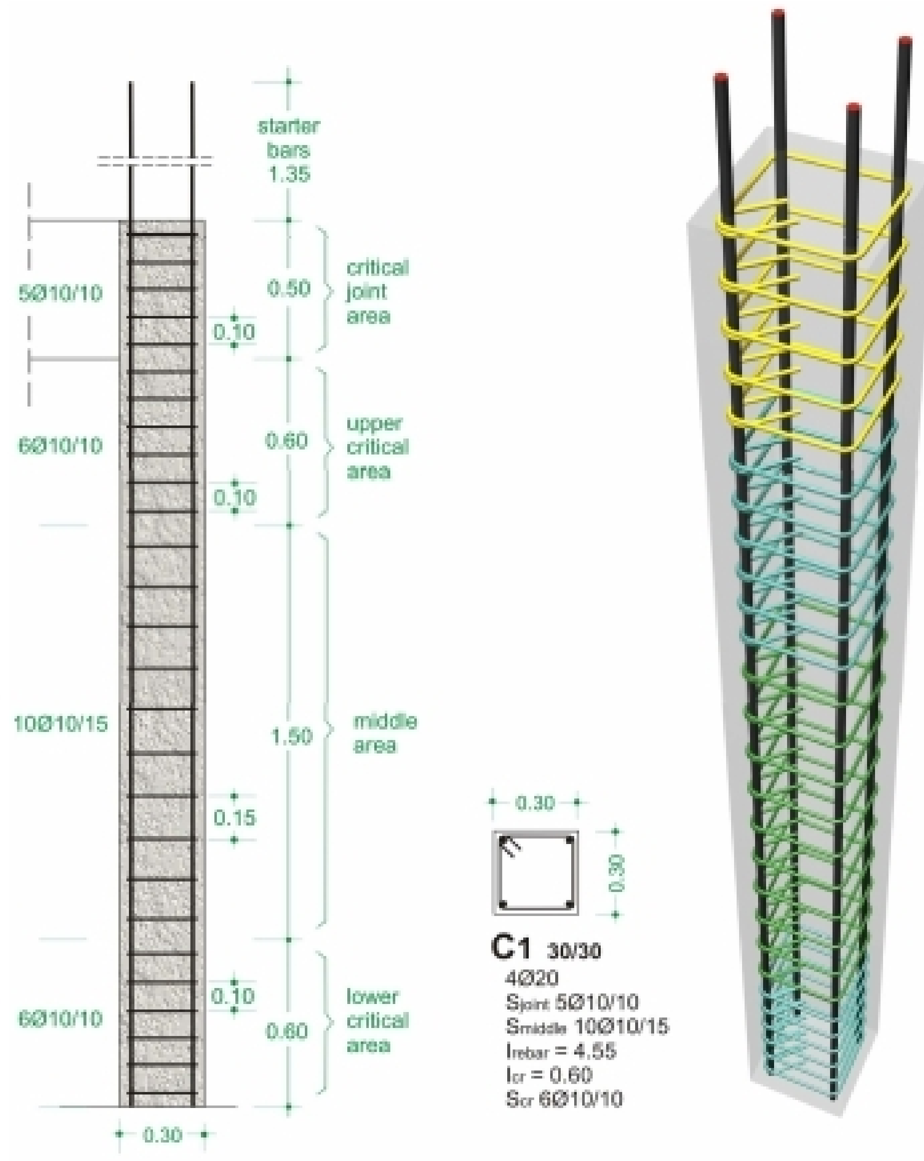


Consider a column with cross section 30x30cm. This is the smallest allowable column section when seismic behavior is required. It is reinforced with 4 longitudinal bars and one stirrup. The cross section described is not generally used but it was chosen in this introductory paragraph for training purposes.

The column has a length of 2.70m while the length of the above joint is 0.50m (equal to the height of the concurrent beam). The transverse reinforcement is a usual stirrup with a Φ10 diameter. The **longitudinal reinforcement** is comprised of 4 Φ20 bars. The stirrup's cover depth is 2.50cm. The **shear reinforcement** can be referred to with various names such as stirrups, ties, hoop reinforcement etc.

Columns are the most critical structural components to ensure the required seismic performance of the building and the shear reinforcement is the most critical component of the columns. In every column we define areas with high ductility demand (when earthquake loads are applied) which they are called critical, areas with lower ductility demand, called non-critical and the joint area (i.e. the common area between the column and the concurrent beam).

COLUMN 30 x 30cm (with critical and non-critical areas)



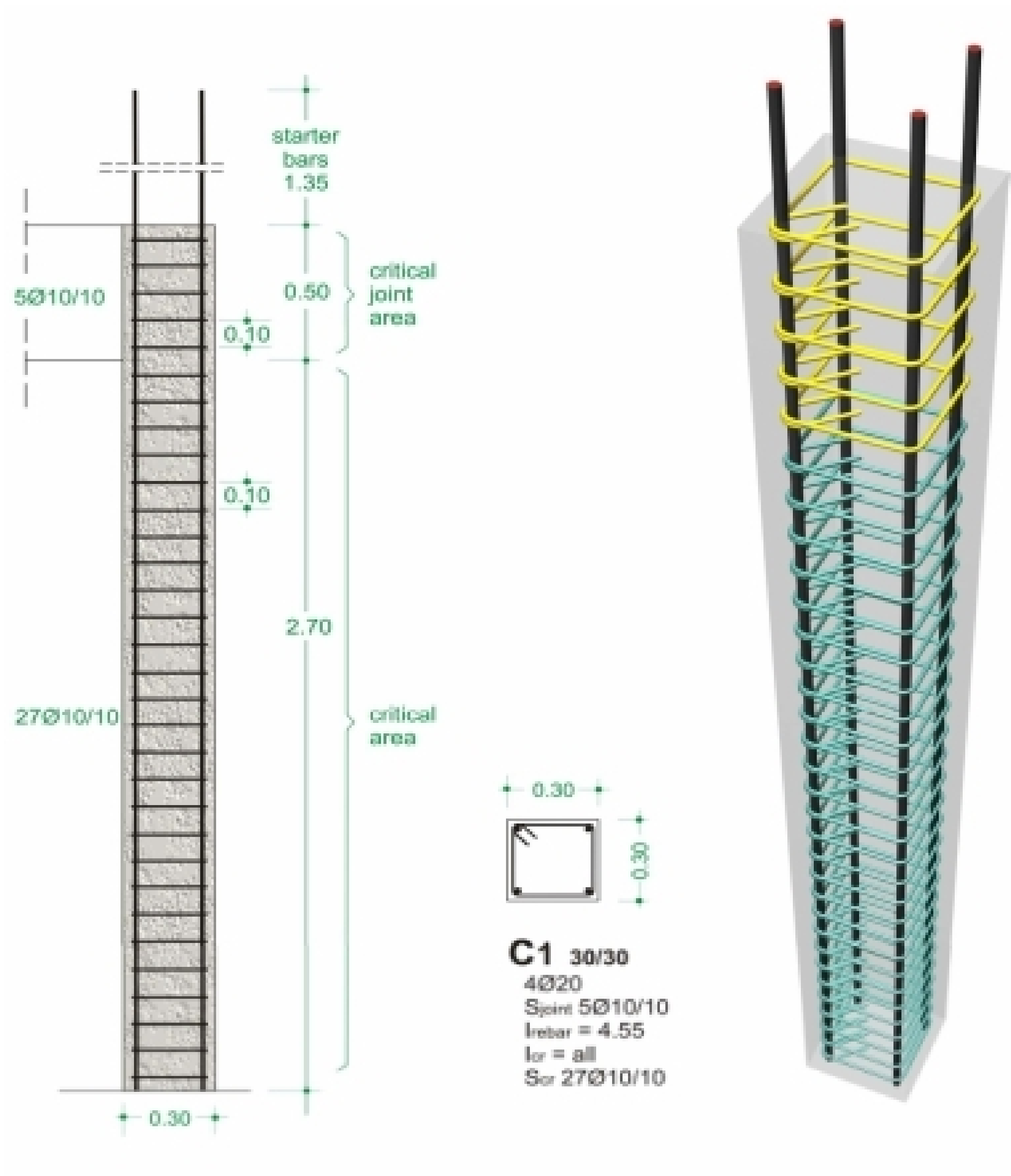
In the first case, Φ10 stirrups, at a spacing of 15cm, have been placed throughout the entire non critical area of the column. That area's length is 1.50m and therefore the number of the provided stirrups is 10. This is presented as 10Φ10/15.

The stirrups placed in each of the column's critical areas are Φ10/10, their total number is 6 and consequently they are presented as 6Φ10/10.

The stirrups placed in the joint area are Φ10/10, their total number is 5 and therefore they are presented as 5Φ10/10.

The label of the column's reinforcement detail provides guidance for the proper placement of the rebars.

COLUMN 30 x 30cm (with its entire length taken as a critical area)



In the second case the entire length of the column is regarded as a critical area and Φ10 stirrups have been placed at a spacing of 10cm. The column's length is 2.70m therefore, the provided stirrups are 27. This is presented as 27Φ10/10.

The stirrups placed in the joint area are Φ10/10, their total number is 5 and consequently, they are presented as 5Φ10/10.

<u>*Note*</u>

The hooks of the shear reinforcement should be formed in different positions along the perimeter of the stirrups in each layer but due to the frequent use of industrial stirrup cages this is not feasible.

3.1.1 Lap-splices in columns

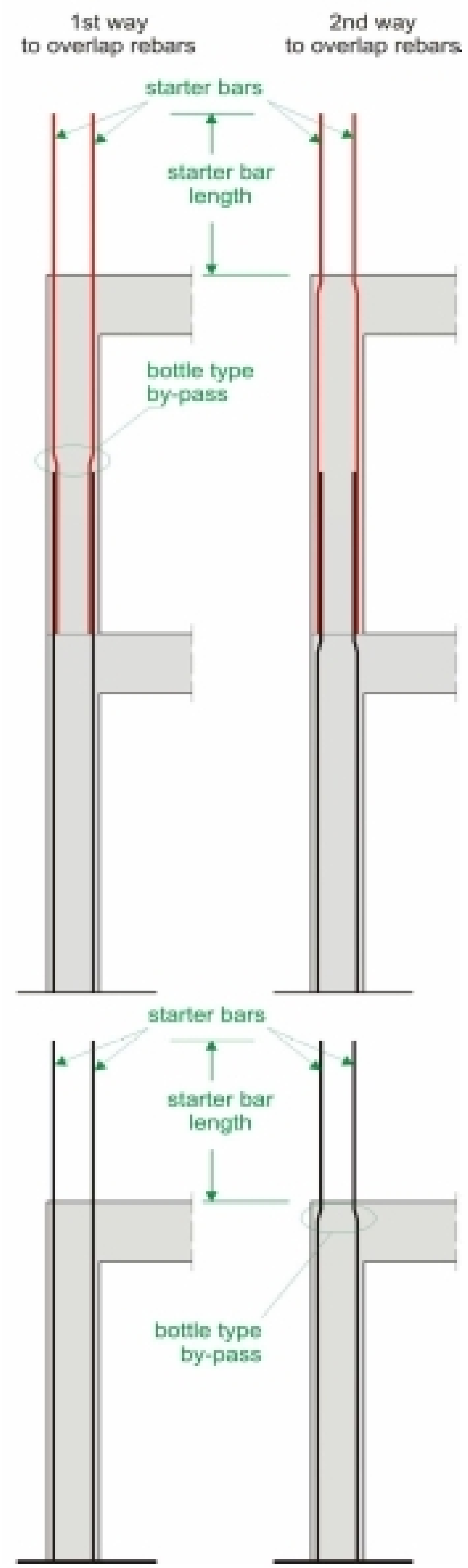
In multi-storey buildings it would be ideal if each of the column's longitudinal rebars could be placed as one single piece throughout the structure's entire height. This however cannot be accomplished for practical reasons therefore, the length of the longitudinal rebars is equal to the height of each storey.

When lapping steel bars from successive stories, it is important to ensure the correct transmission of forces from the rebars of the subjacent floor to the rebars of the superjacent floor. This can be achieved by welding, however this method has a number of technical difficulties and it is used only in special occasions. The practice usually followed is the rebar lap-splicing i.e. rebar lapping by means of contact.

The length of the placed bars must be extended by an additional length called **'lap length'**, which has to be equal or greater than the length required for the lapping of corresponding rebars between two successive storeys. This length is equal to the rebar's diameter multiplied by the 'contact coefficient' (its value varies from 40 to 70).

It is important to thoroughly understand how the lap-splices are being done in practice. One must always keep in mind that in order for the stirrups to provide confinement, every rebar must be placed inside one of their corners. This however is difficult to be done at the beginning and at the end of the lap-splice and it can be achieved only with special practices. In case the rebars are wired together on the site, the lap-splice is mandatory to be done according to the first way shown at the opposite figure.

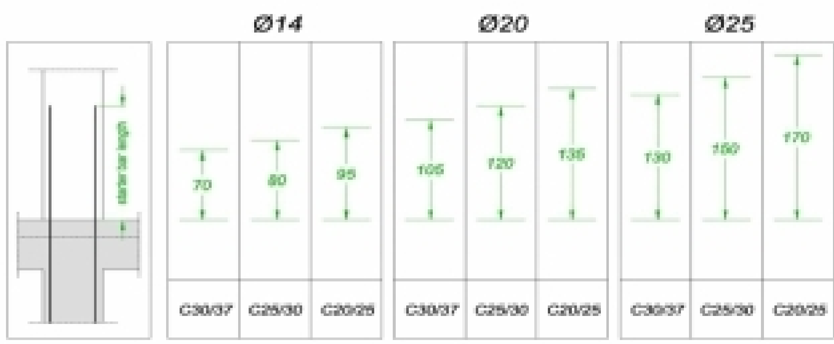
The starter bars of the subjacent storey must be kept straight while the rebars of the above floor must be bent at their joint point. The bent part must extend to one or two stirrups. The use of rebars with diameters greater than Φ20 or Φ25 makes bending in situ extremely difficult if not practically impossible, that is why the rebars have to be bent prior to their placement with the use of a bending machine.



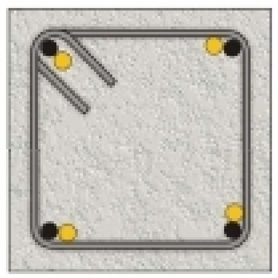
Note:

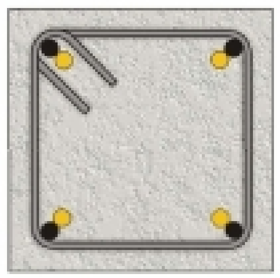
The 'contact coefficient' is proportional to the steel's yielding strength and reverse proportional to the concrete's compressive strength [1].

The following table shows the necessary lap lengths in cm, for three different rebar diameters in combination with three different concrete grades



The bent rebars can be placed in contact with the straight ones in any direction as shown at the following figures.

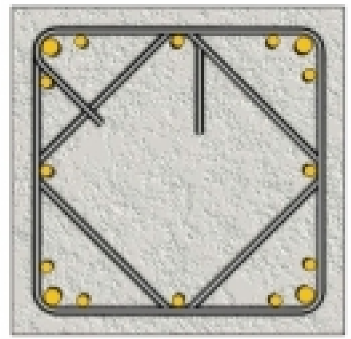




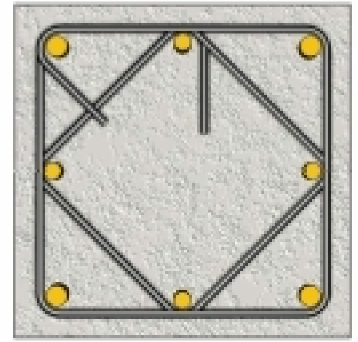
In case there are no seismic design requirements and for serviceability reasons, it is preferred to place more bars with smaller diameter around the perimeter instead of fewer bars with larger diameter. When seismic design is required, as it is for the columns referred in this book, it is preferred to place rebars only inside the corners of the stirrups thus ensuring that no buckling will occur. Therefore, it is better to use fewer bars with larger diameter. Moreover, structures designed to withstand the seismic hazard, have a considerable amount of steel reinforcement in their joint areas so the small number of column rebars enables the proper reinforcement.

[1] For steel class B500 and concrete grade C20/25, the contact coefficient is in the order of 67, for concrete grade C25/30 the contact coefficient is in the order of 58, and for concrete grade C30/37 the contact coefficient is in the order of 51.

In a square 40x40cm section with the stirrups placed in a rhombic layout (having 4+4 corners), 30cm^2 total area of required reinforcing steel and use of longitudinal rebars up to Φ20, the usual reinforcement is 4Φ20+12Φ14[2]. If using longitudinal rebars up to Φ25 the ideal choice is 4Φ25+4Φ20[3].



*reinforcement comprised by **16** bars, 4Φ20+12Φ14*



*equivalent reinforcement comprised by **8** bars, 4Φ25+4Φ20*

The use of longitudinal rebars with diameter greater than Φ20 is allowed only if the following conditions are met:

(a) Use of high-strength concrete mixture, so as to lessen the required lap lengths.

(b) Mandatory use of **bending machine** for the bending of the longitudinal rebars (in the lap-splice areas) and of course, an accurate detailing with the exact rebar dimensions.

(c) Use of crane as a single Φ25 rebar with 4.65m length weights around 18 Kg.

The first condition regards the concrete industry while the second and third regard the formation and placement of the reinforcing steel. The latter two conditions are discussed further below.

High-strength concrete mixtures like C25/30 or C30/37 should be given no consideration as:

(a) they are produced by most cement industries.

(b) although they have a relatively higher cost compared to the regular concrete mixtures, their use allows for a smaller amount of reinforcing steel.

(c) they have a high cementius content thus ensuring a longer structural frame's service life. This is crucial in cases where the buildings are in adverse environment such as being at a distance<1 Km from the sea.

[2] From table 1 derives that 4Φ20+12Φ14 correspond to 4*3.14+12*1.54=12.56+18.48=31.04cm².

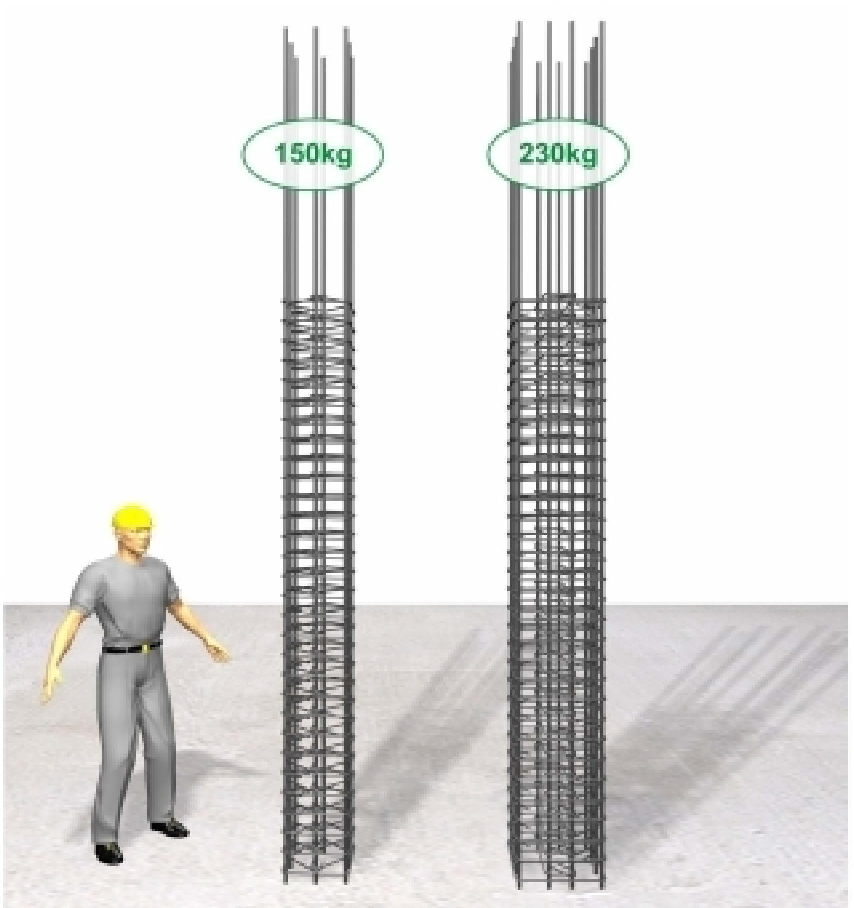
[3] From the same table derives that 4Φ25+4Φ20 correspond to 4*4,91+4*3.14=19.64+12.56=32.20cm²

In most countries of the world with an advanced construction industry, concrete grades higher than C25/30 and C30/37 are being used even in the common structures.

The construction industrialization together with the development of the reinforcement implementation, lead growingly not only to the use of prefabricated stirrup cages but also to the use of prefabricated columns that are positioned with the use of a crane.

The prefabricated reinforcement and its mechanical implementation are two simultaneously developing techniques.

The earthquake resistant columns have a large mass. For instance, the smallest allowable column mentioned before (stirrups and longitudinal reinforcement), has a mass equal to 60kg as opposed to the usual antisesimic columns whose mass is much greater. A common 40/40 column with Φ10/10 stirrups placed in a rhombic layout and 8Φ20 longitudinal reinforcement, weights 150kg and the also usual 50/50 column, with stirrups placed in a cross layout and 12Φ20 longitudinal reinforcement, weights 230kg.



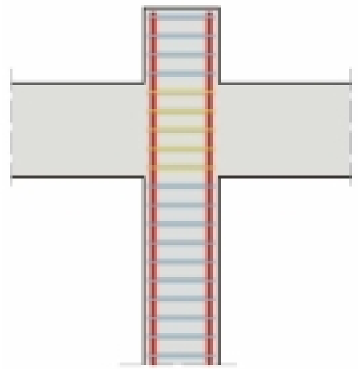
the reinforcement of the 40/40 column weights 150kg

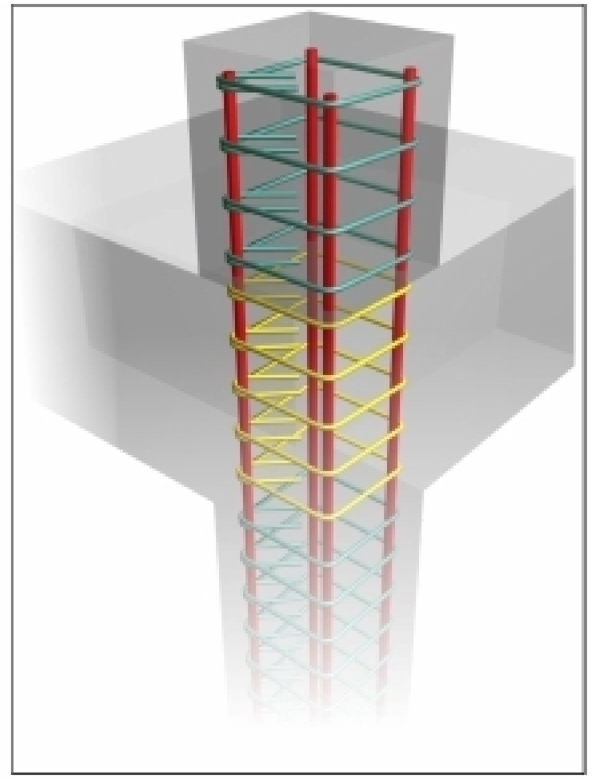
the reinforcement of the 50/50 column weights 230kg

3.1.2 Anchoring the reinforcement of the upper floor level

Column rebars must be properly anchored to the upper floor level in order to behave in the required way.

The most effective way to anchor the upper floor column rebars is by creating a "concrete hat" on the top of the column thus allowing the rebars to be anchored without being bent.

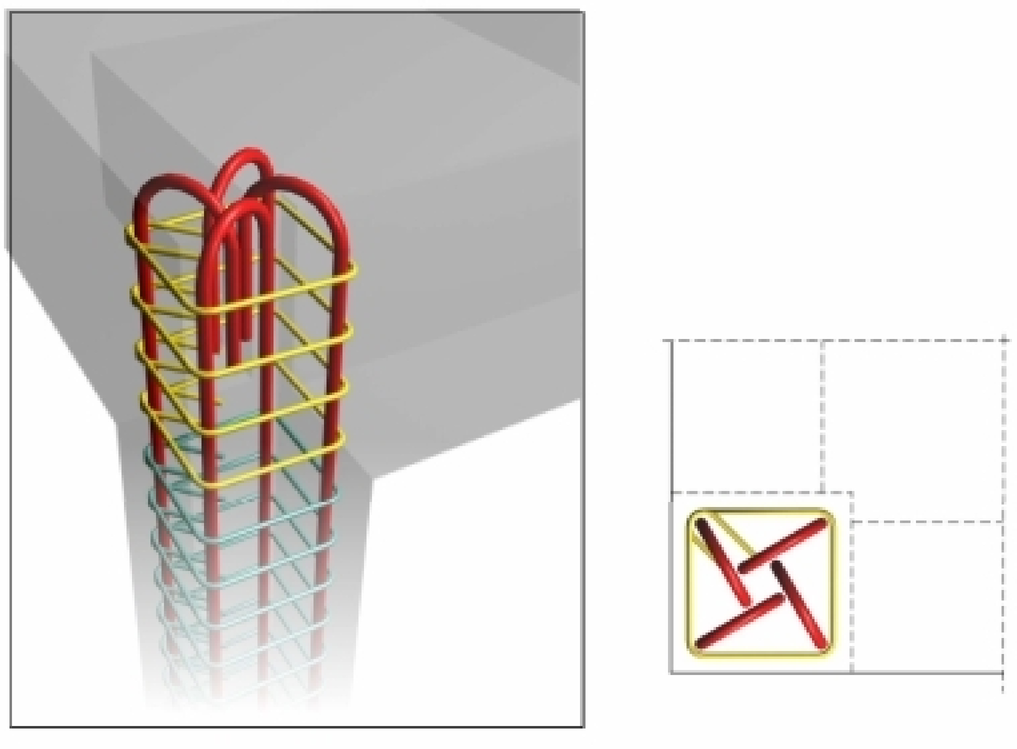




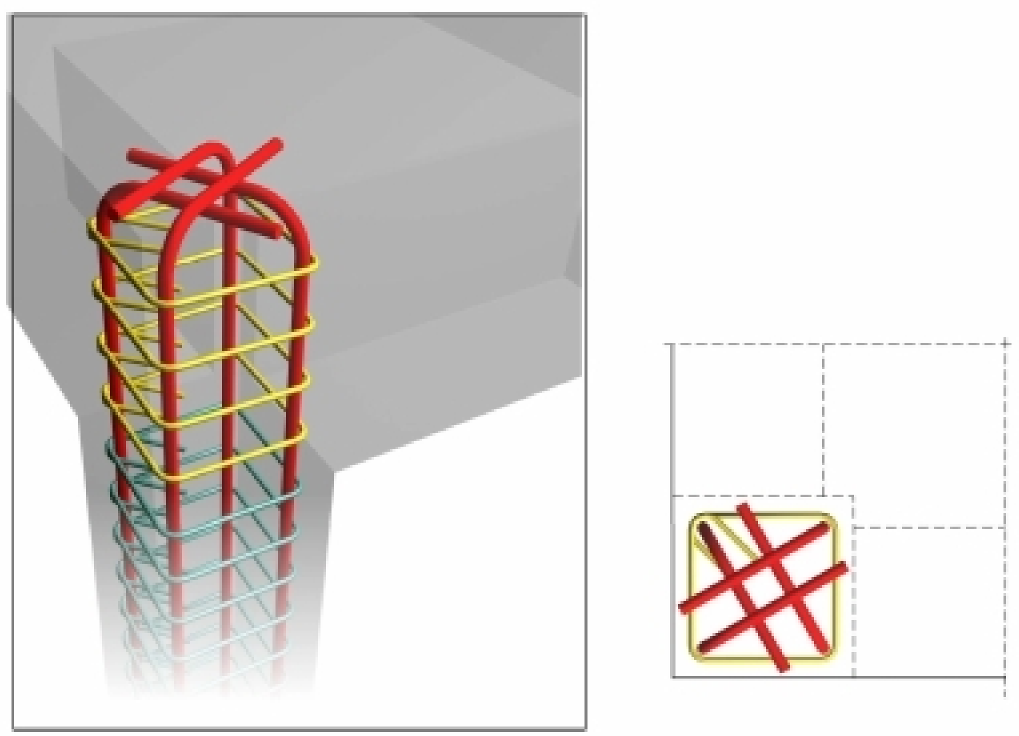
Anchoring the upper column rebars with the use of an additional 'concrete hat' upon the flat roof is a simple and neat solution.

If the construction of a 'column hat' is not a desirable solution due to reasons like e.g. the need for a flat roof, then the column rebars of the upper floor can be anchored according to one of the following ways:

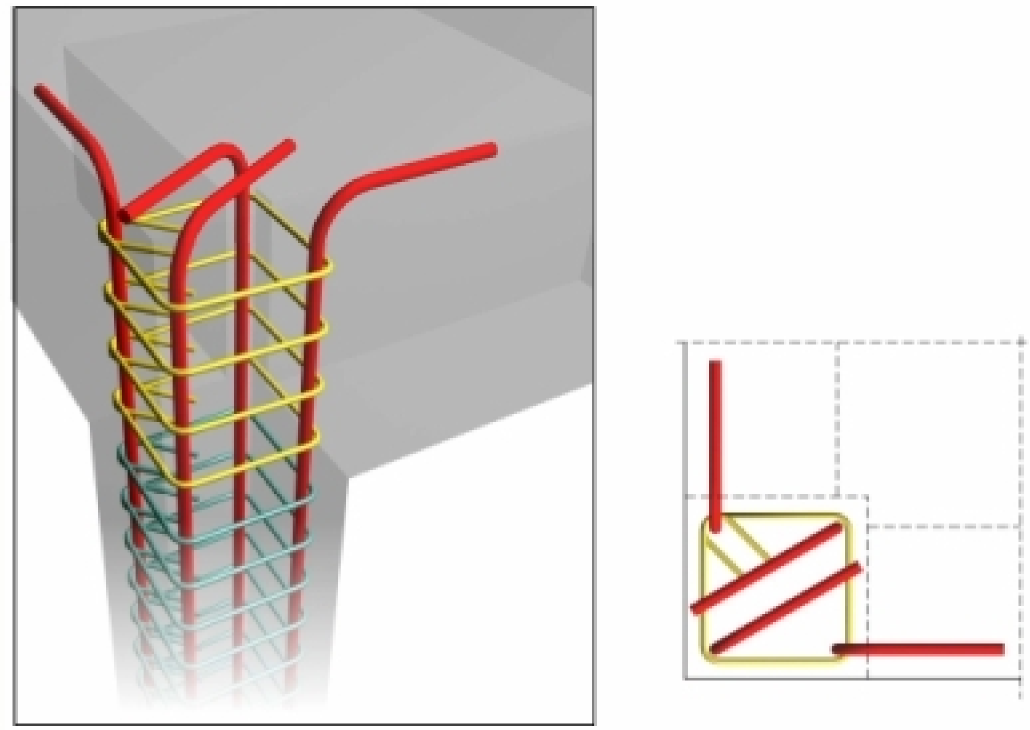
(a) hooks bent at 180°



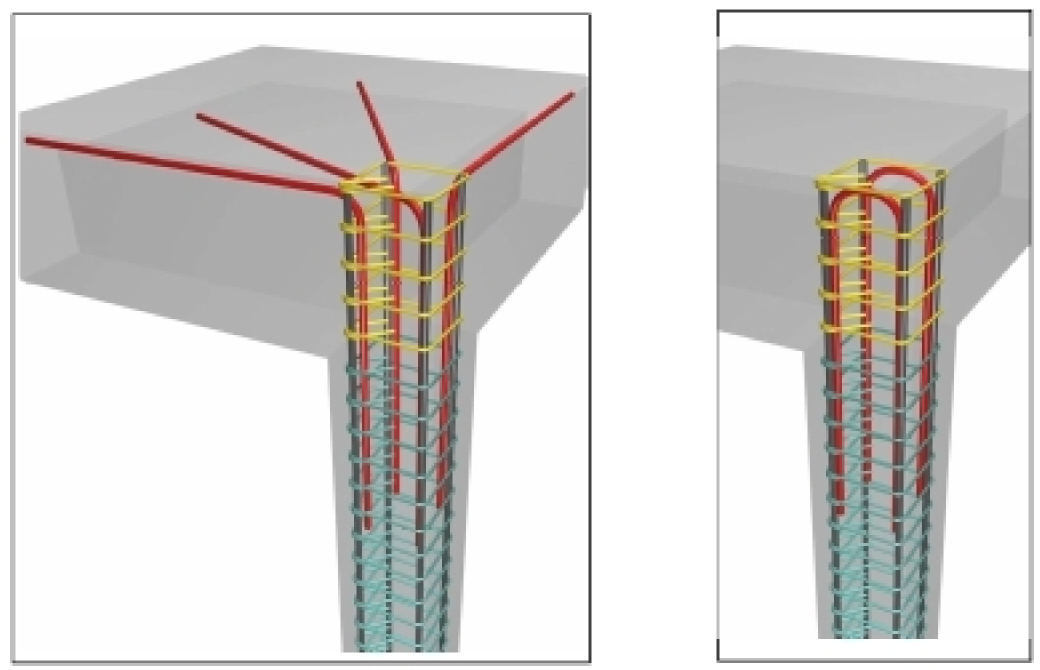
(b) hooks bend at 90° (A case)



(c) hooks bend at 90°(B case)



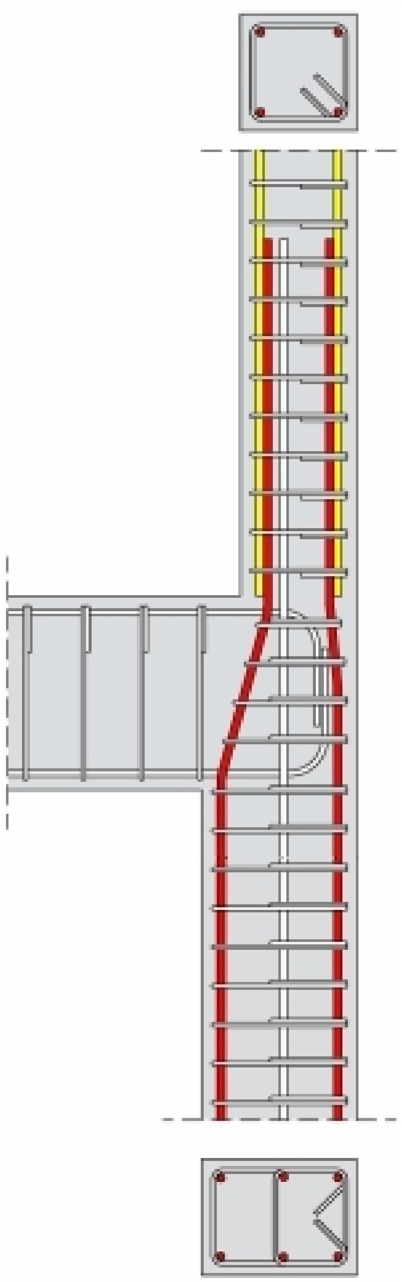
(d) use of extra hairpin reinforcement bent at 90° or 180°



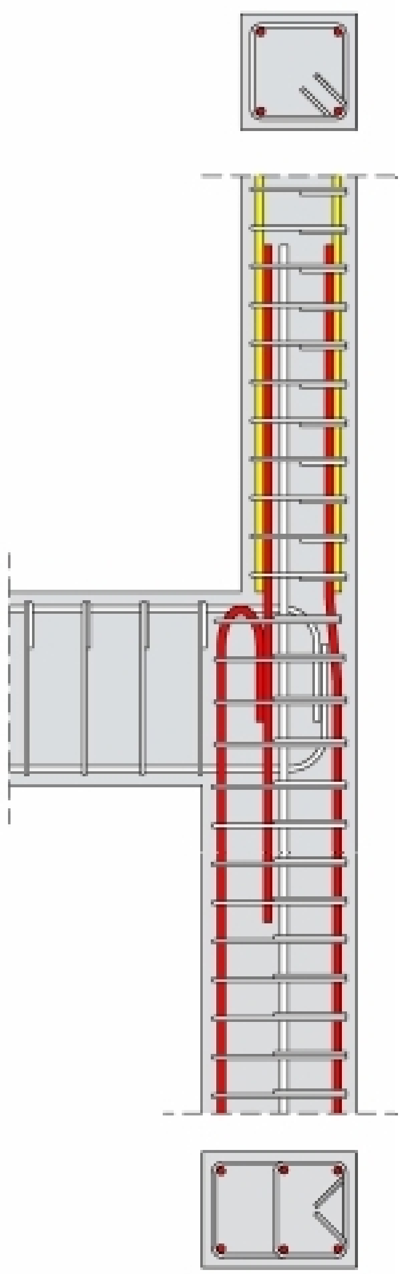
(e) When placing small bar diameters inside high-strength concrete mixtures, the straight anchorage length might be short enough to fit inside the joint area.

3.1.3. Reduction of the column's section size along its length

The reduction of the column's size from one storey to the other is not favorable either from a theoretical or from a practical point of view. Especially in columns where earthquake resistant behavior is required it must be avoided. However, there are cases where the subjacent column is larger than is the superjacent column.



Reduction of the section's size along the height by bending rebars into the shape of a bottle



Reduction of the section's size along the height by terminating some of the old rebars and implanting new ones

The reduction of the column's size between two successive storeys creates two basic problems. The first regards the reinforcement layout that differs between the upper and the lower column and the second regards the difficulty in the anchorage of the lower column rebars that are placed outside the peripheral stirrups of the upper column.

The first problem is faced by fitting starter bars to the proper places at the upper part of the lower column.

The second problem is faced with two different ways:

(a) By ending the rebars that are placed outside the peripheral stirrups of the upper column and

(b) By bending the lower column rebars, into the shape of a bottle, and anchoring them inside the upper column.

This work, either done by the first or by the second way, must be done with extreme care because the earthquake resistant column must have transverse reinforcement (stirrups) that will provide adequate confinement in the joint area. It is advised to form the stirrup hooks in different places between successive layers. It is reminded that this practice is necessary for the column's strength even if the adjacent beams fail.

In order for the bent up rebars to be adequately confined in the interior part of the joint area, they have to be placed inside the corners of stirrups. This can be achieved by forming the stirrups (by hand, on by one) with a decreasing section size.

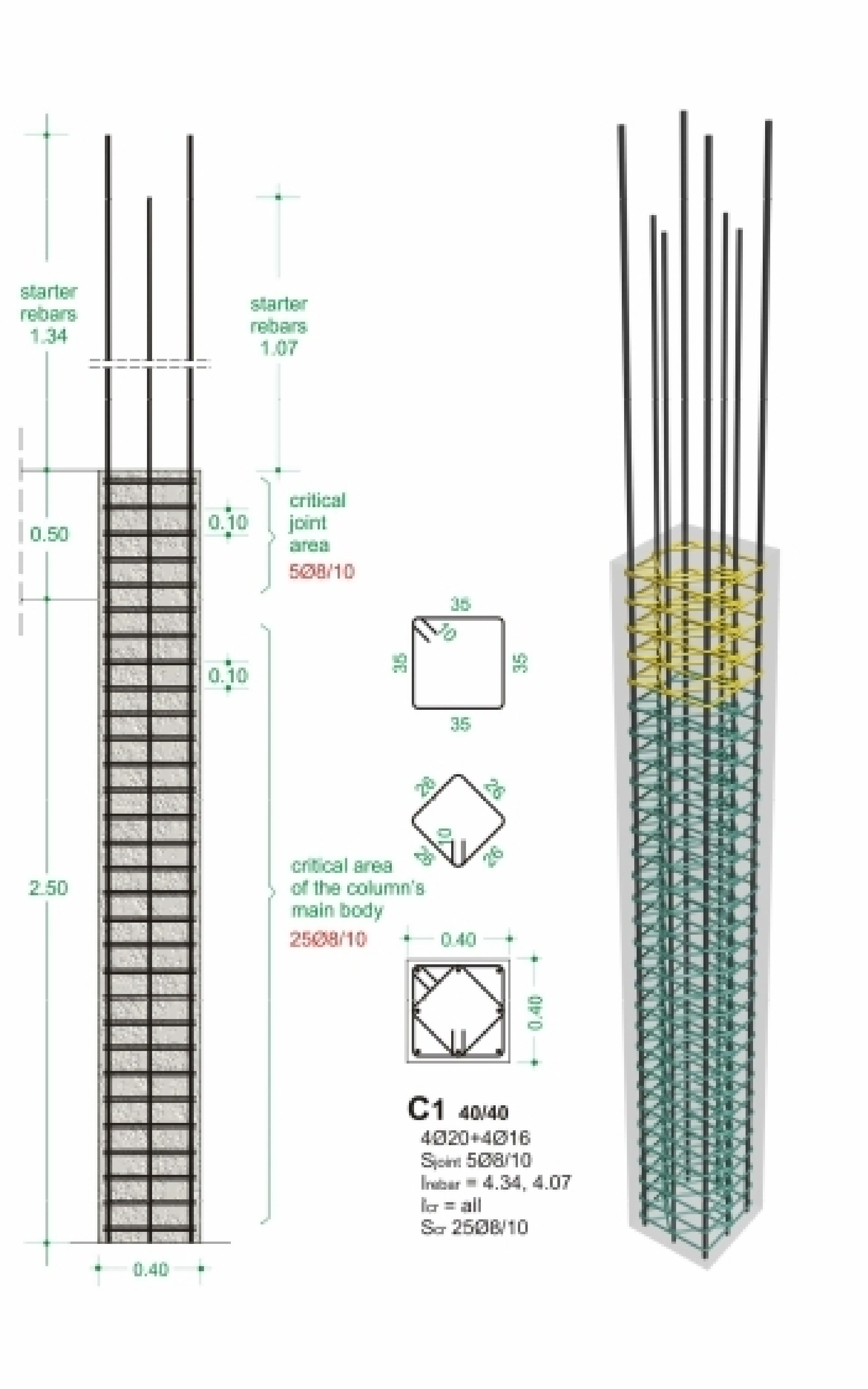
The rebars of the lower column that continue to the upper column, is advised to be bend inside the joint area.

When ending the rebars placed outside the peripheral stirrups of the upper column, their anchorage must be secured by one of the ways described in the previous paragraph.

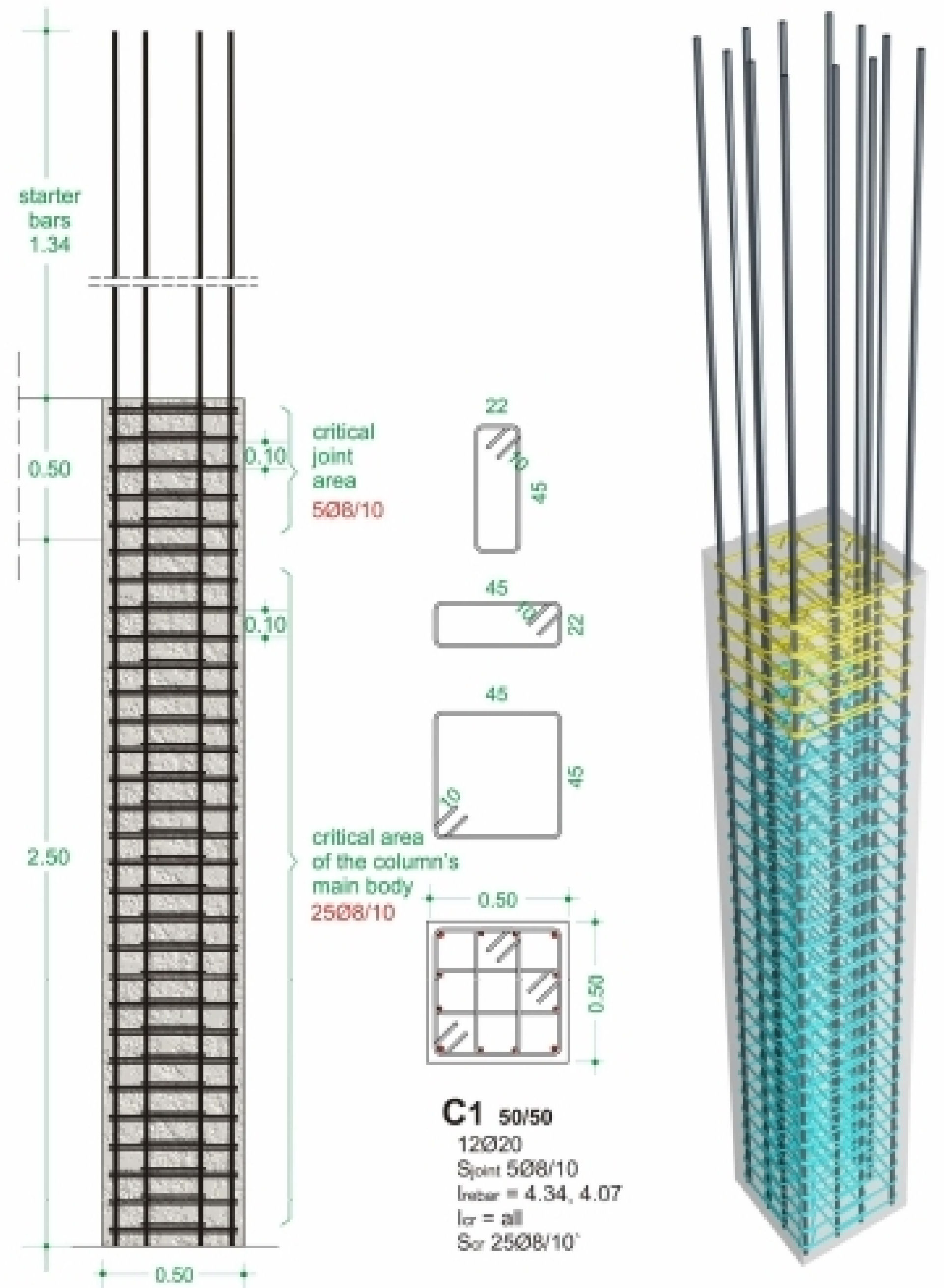
The same rules apply to any case of reduced column size, e.g. in case of bilateral reduction of the column's section size.

3.1.4 Reinforcement in typical columns

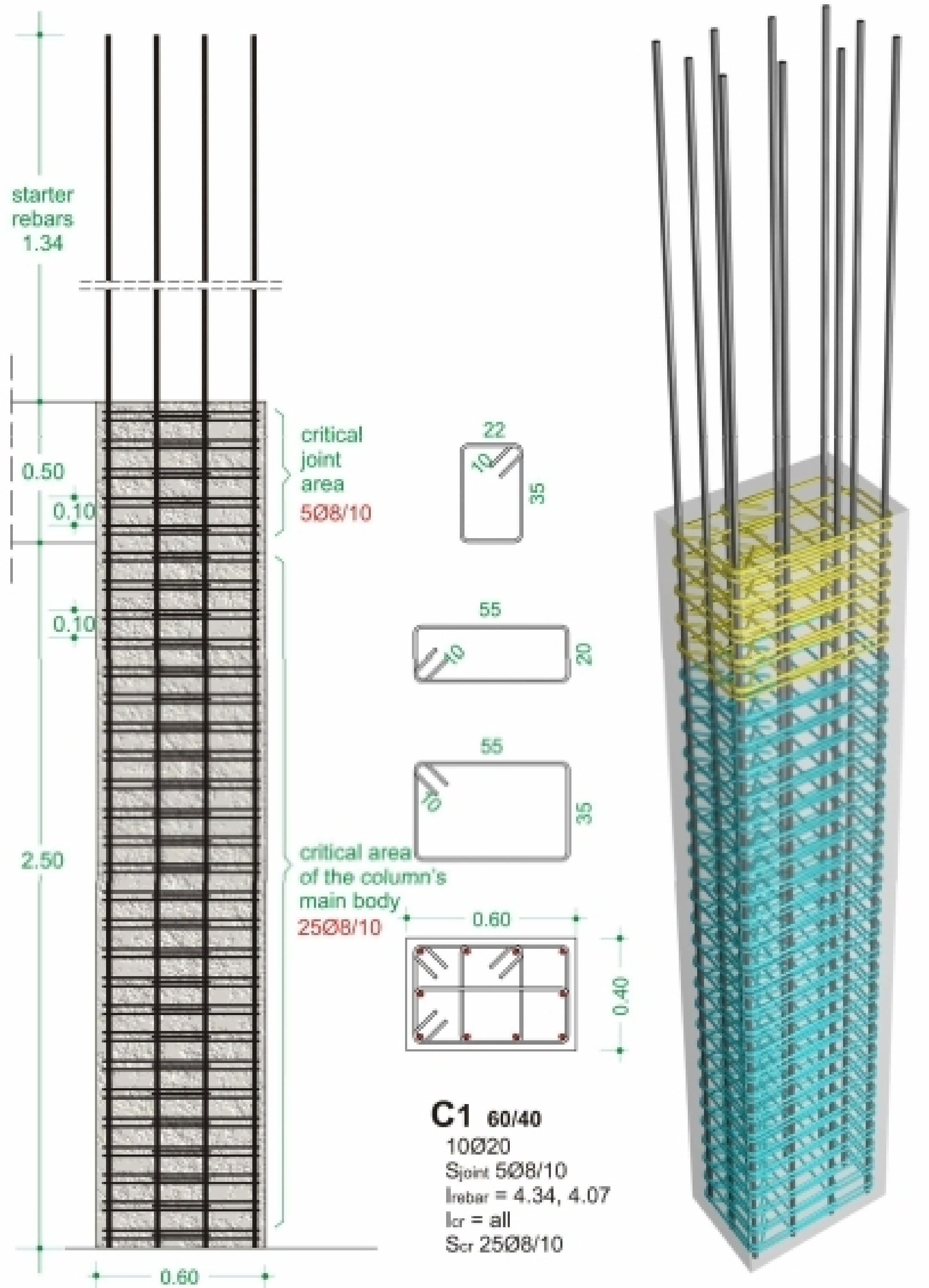
Column with section 40x40cm



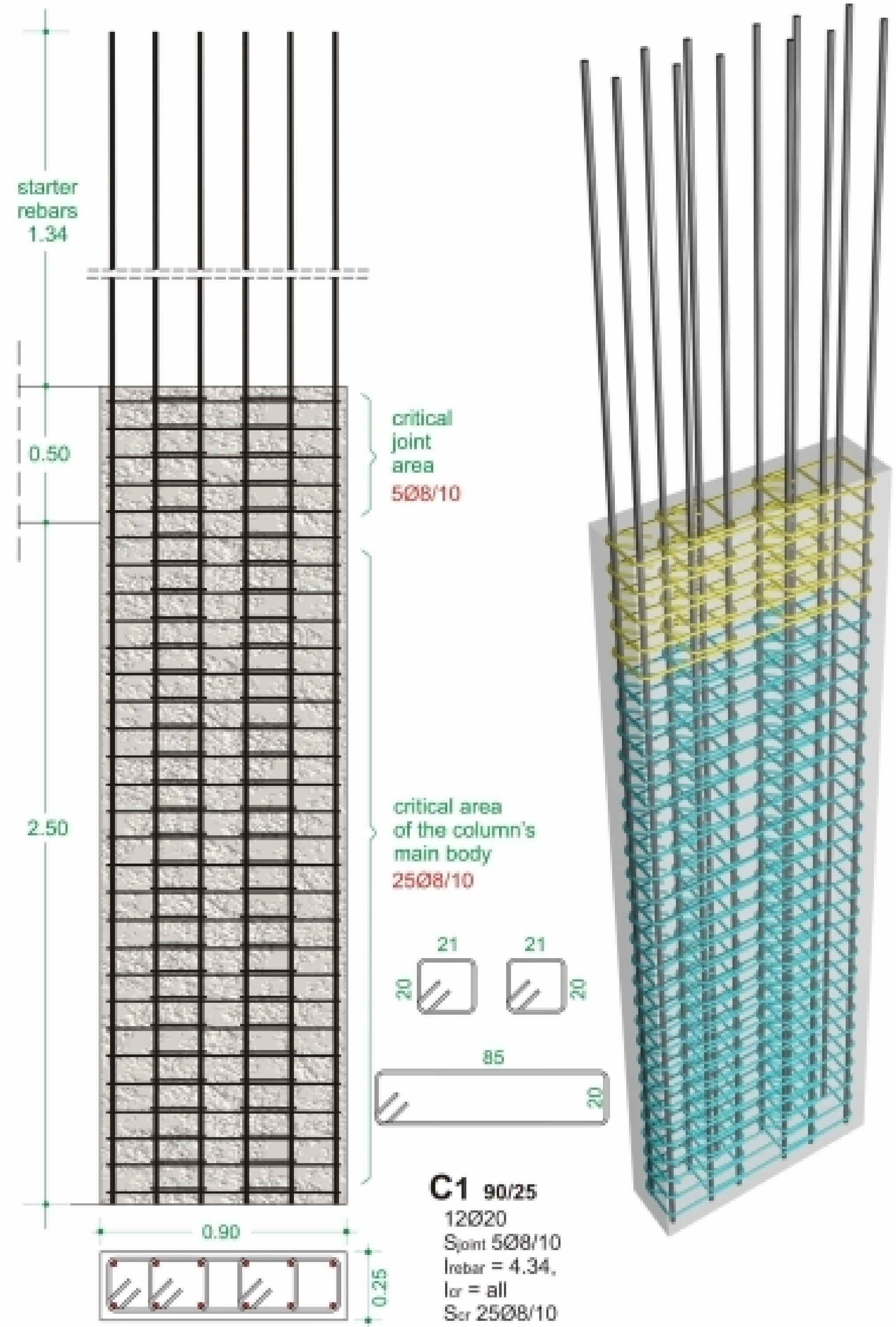
Column with section 50x50cm



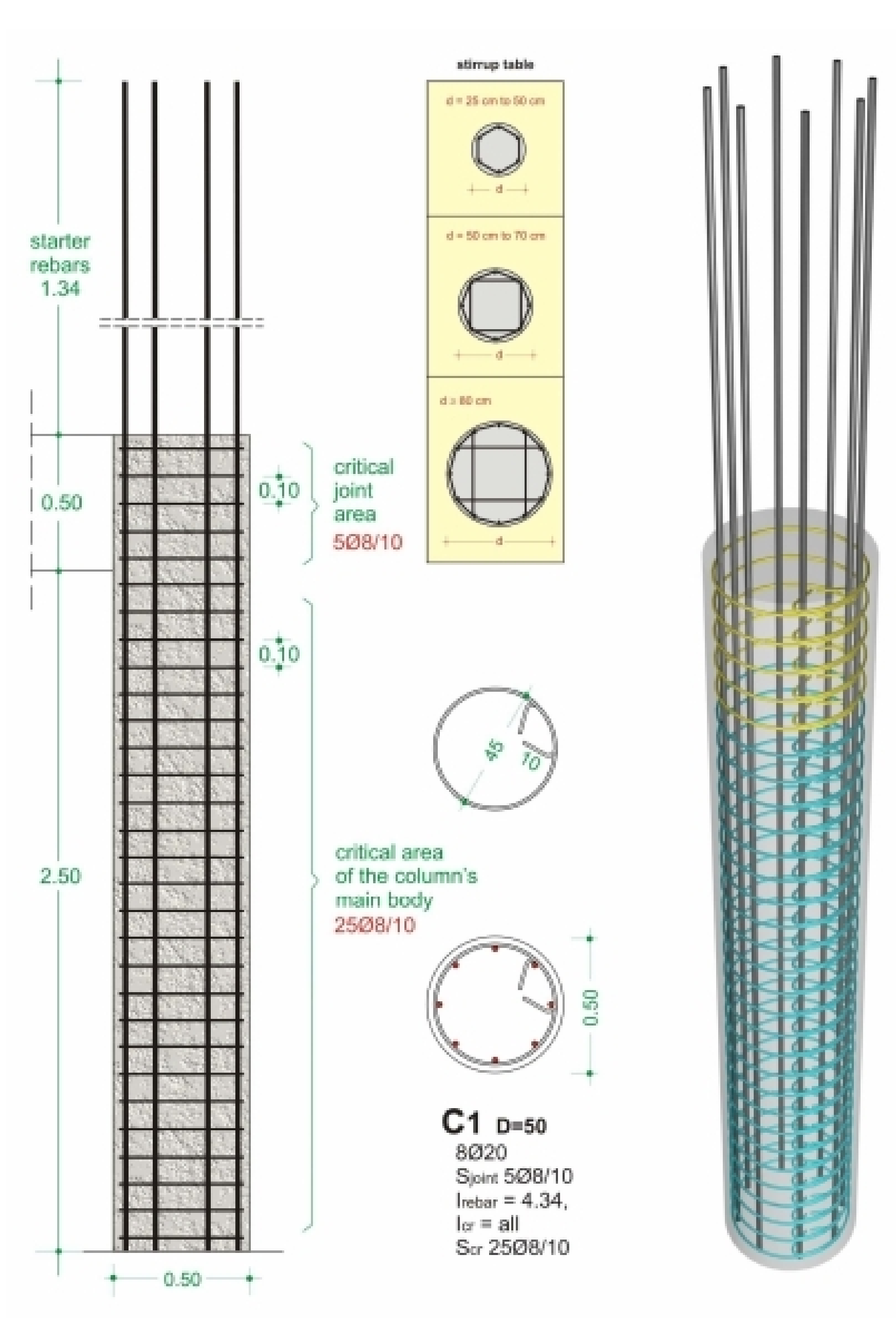
Column with section 60x40cm



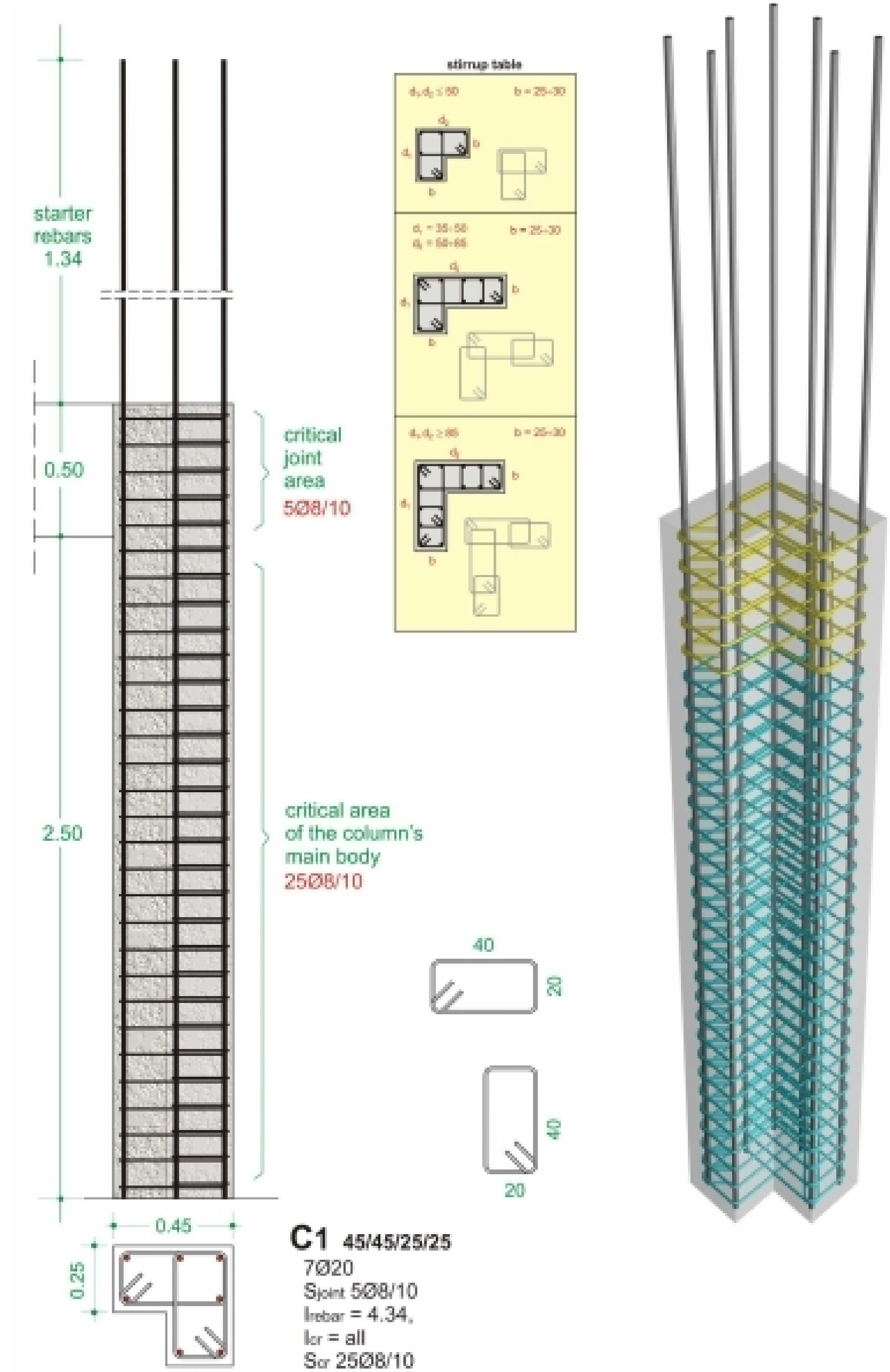
Column with section 90x25cm



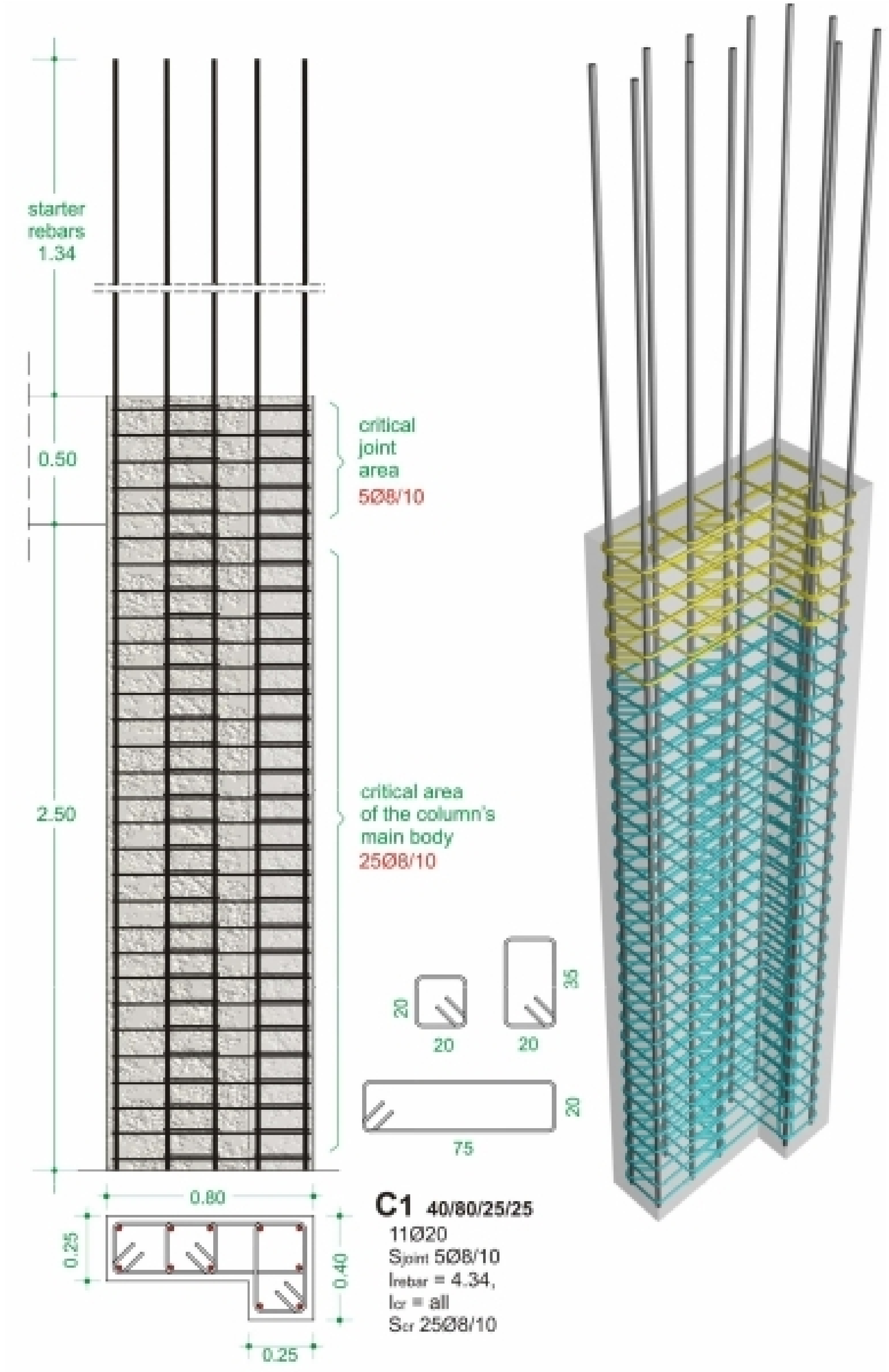
Column with a circular section D=50cm



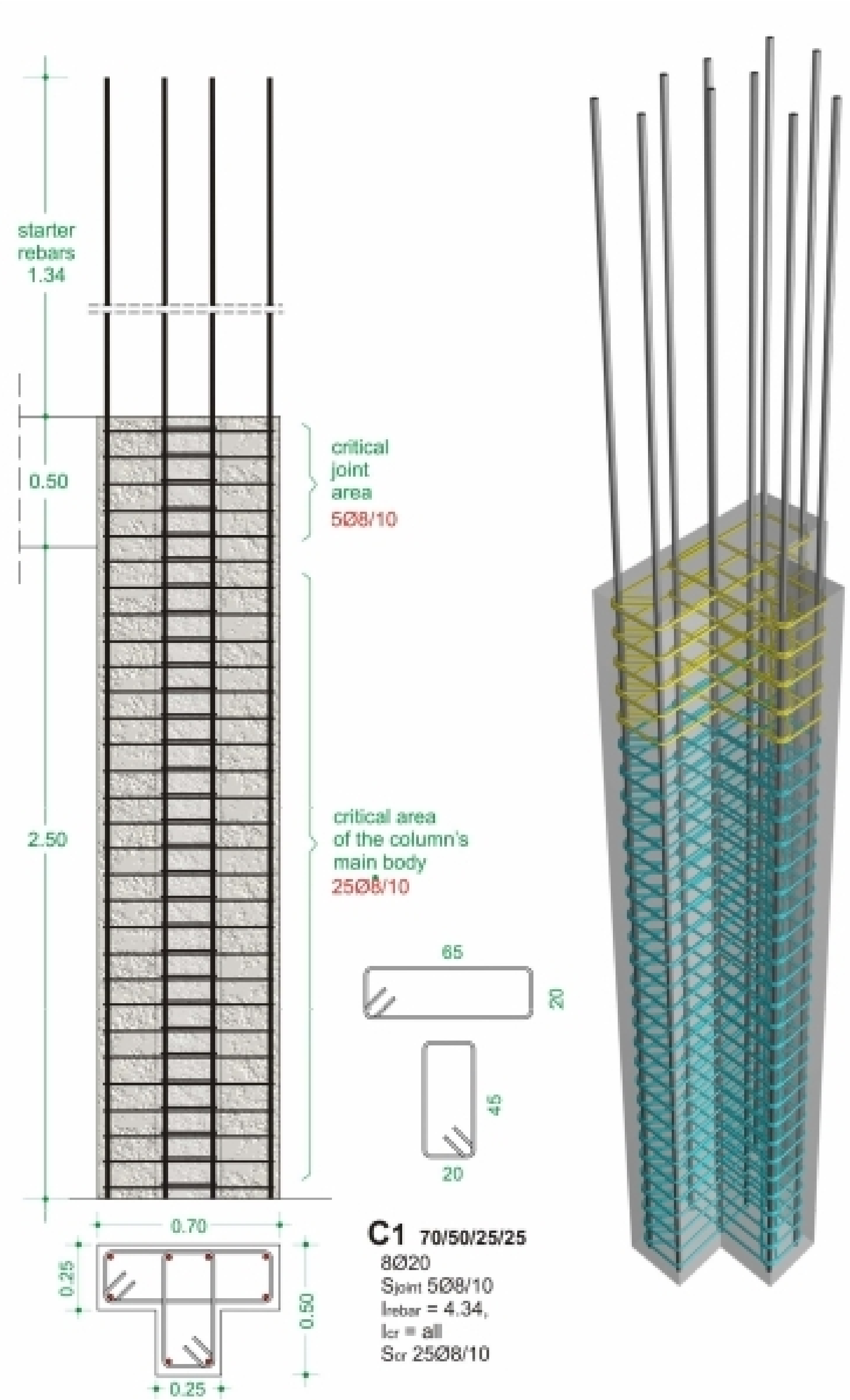
Column with 'Γ' section 45x45x25x25cm



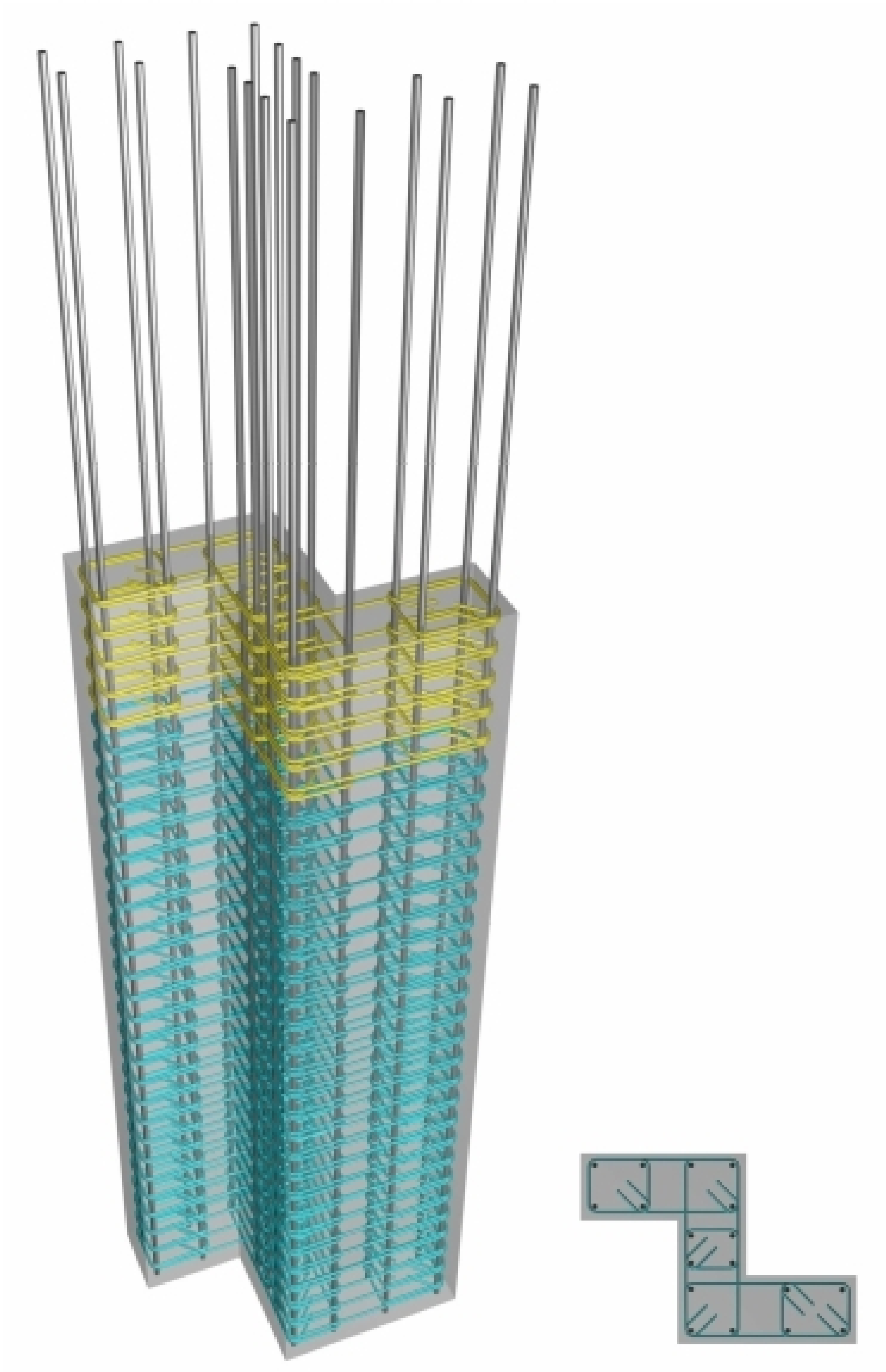
Column with 'Γ' section 40x80x25x25cm

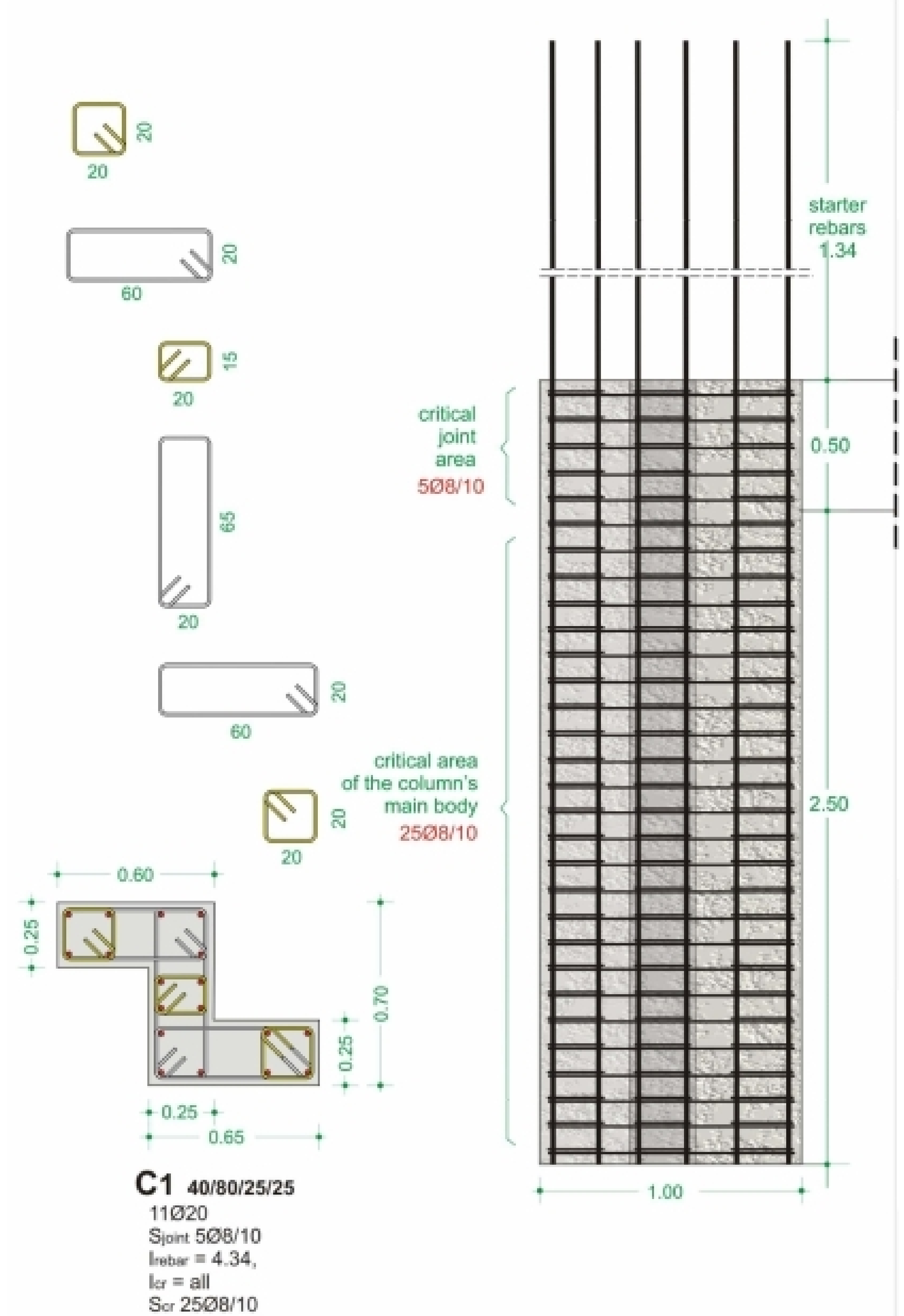


Column with 'T' section 70x50x25x25cm

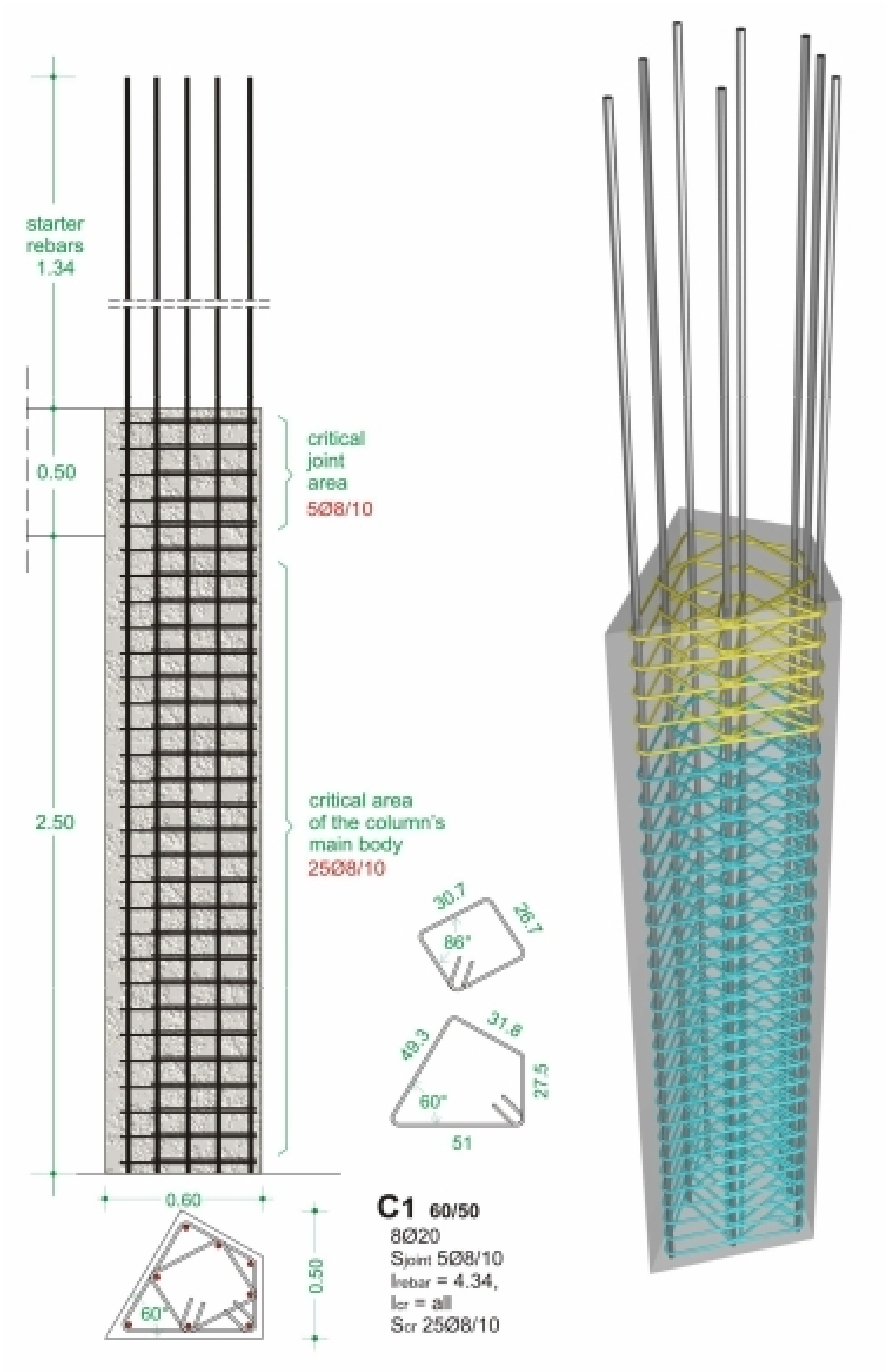


Column with 'Z' section 70x65x60x25x25x25cm





Column with quadrilateral section 60x50



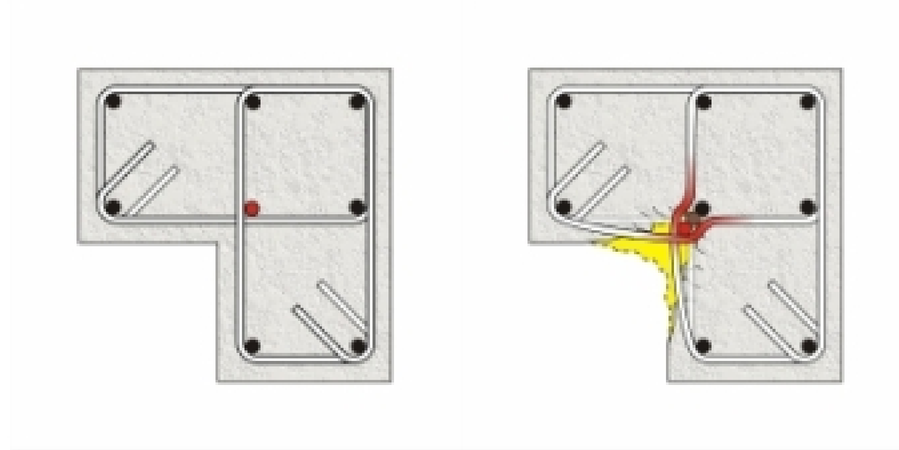
<u>Note:</u>

Placing a rebar in the internal corner of composite sections ('Γ', 'Z' section etc) is optional because:

a) it does not significantly enhance the flexural strength since it is not placed in a section's corner (based on the fact that tensile stresses appear to the external corners of the elements' sections)

b) it does not increase the confinement because in case of an intense earthquake, where concrete spalling will occur, that rebar might buckle since it is not completely restrained.

c) however, in all cases this corner rebar may be constructional used without though calculating its contribution to the section's confinement.



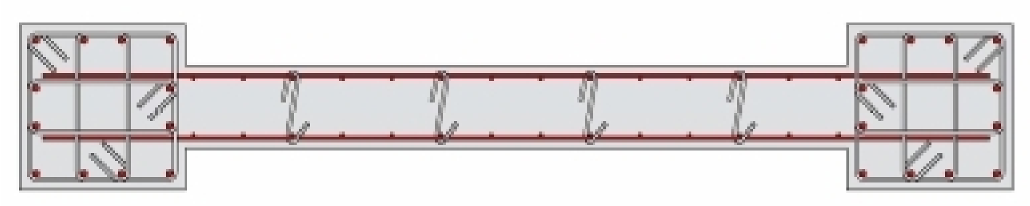
The internal rebar (in red), in a severe seismic event, might buckle (due to the bulking of stirrups) and therefore it will not contribute to the confinement.

3.2 Shear walls

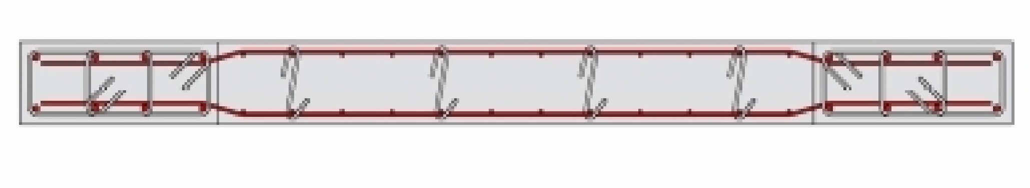
3.2.1. General

Shear walls are vertically oriented elements that apart from their ability to bear vertical loads, they also limit the horizontal deformations of the structural frame. Since as a rule, they carry gravity loads, their large size is not entirely required. On the other hand, that large size is absolutely necessary in order for them to resist the horizontal seismic forces. Ground earthquake motions cause severe flexural and shear stresses to the shear walls. These stresses can only be carried by a strong and properly placed, inside their entire mass, reinforcement.

Shear wall refers to any vertical element with a length to thickness ratio of 4 or more. The classification of an element as shear wall determines the way that the reinforcement will be placed inside its concrete mass. In order for a shear wall to behave in the required way, it must have two columns embedded inside its ends or otherwise called two boundary elements.



In case the shear wall does not have clearly defined boundary elements, two hidden columns are formed at the edges of the wall's mass. Their width is equal to the shear wall's thickness and their length must be at least equal to one and a half times the wall's thickness (≥ 1.5b).



The boundary columns apart from assisting in the assembling of the shear wall also ensure a minimum strength capacity. During a severe seismic event, it is possible for wall consistency degradation to happen. In such a case, at the lower critical level of the building, the two embedded columns, with the high ductility that they have, will continue to bear the largest amount of the applied vertical gravity loads and seismic forces.

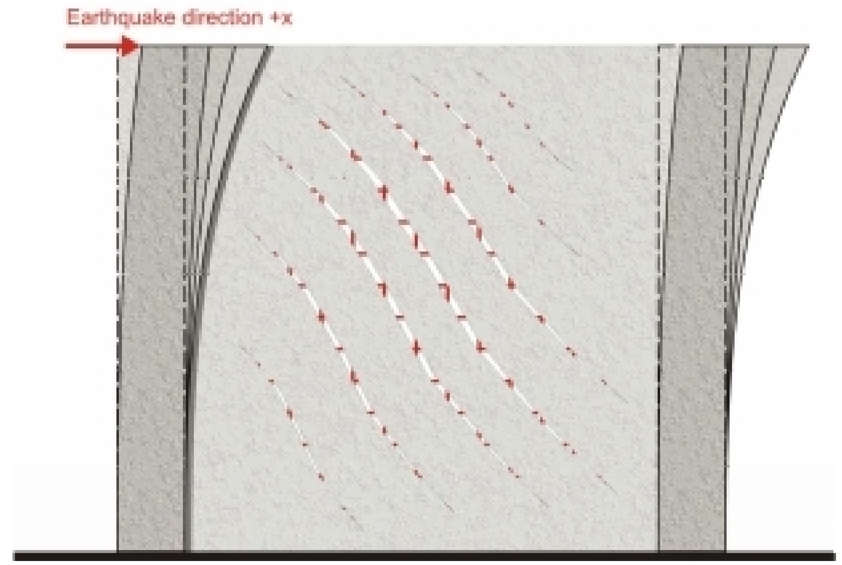
Notes:

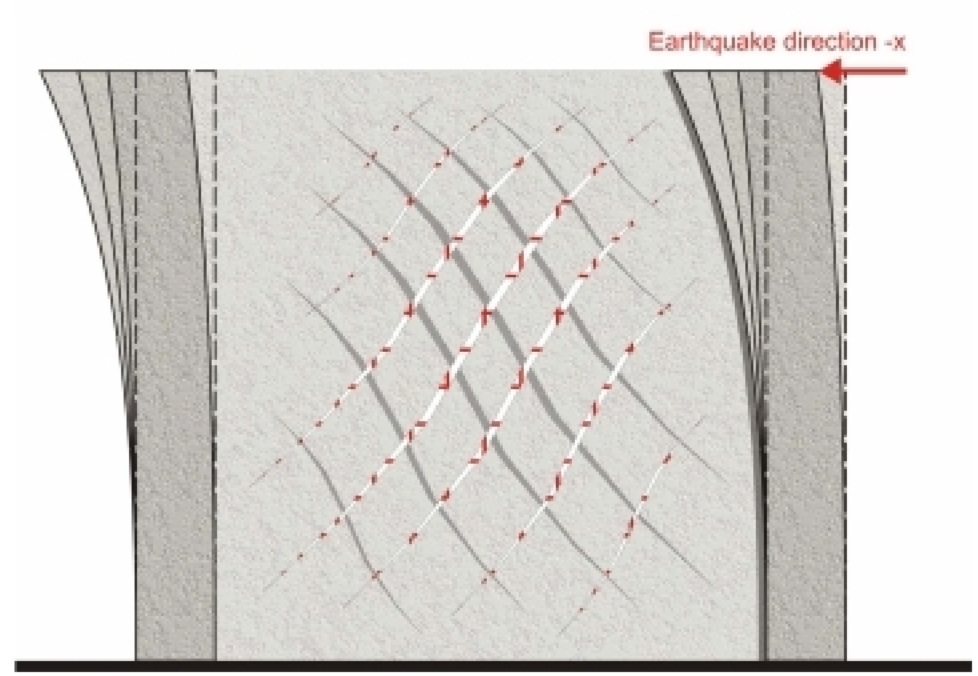
a) Forming a 45cm column (regular or hidden), has the advantage that it is the maximum length to place a three-legged stirrup and the distance between the stirrup legs to be around 20cm as required by the regulation.

b) Forming a 40 cm column usually does not provide adequate anchorage length. On the other hand, the use of a 50cm column requires a four-legged stirrup.

3.2.2 Shear wall's behavior

In the duration of a seismic event, flexural and mainly shear loads are applied to the wall. As a result, in the entire element's surface, stresses appear along the diagonal axis. The diagonal shear stresses shift direction with the change in the earthquake shaking. These stresses are efficiently carried by the well-confined boundary columns, while in the main body of the shear wall they are carried by the double reinforcement mesh (horizontal and vertical rebars).



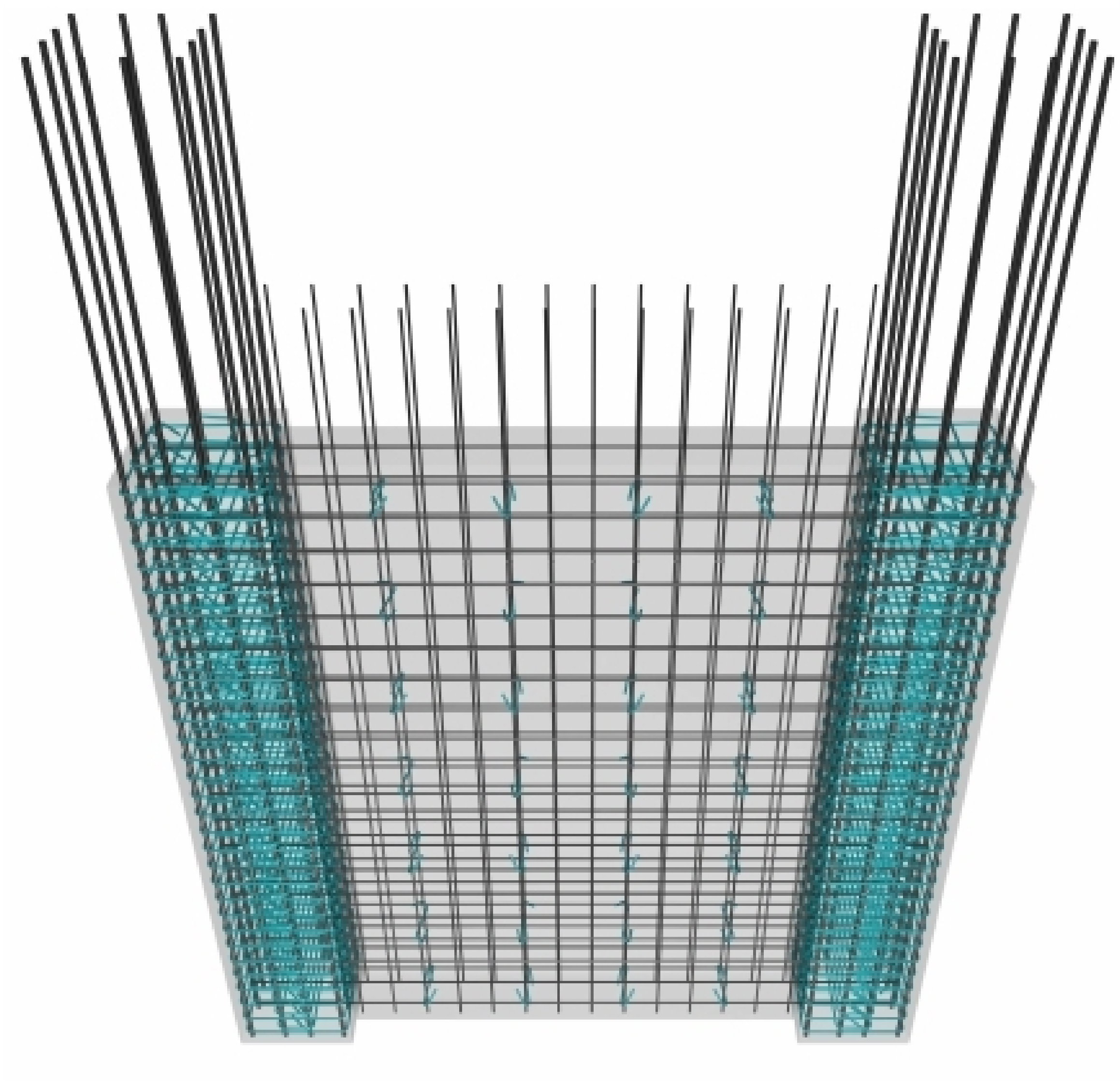


The cracks that open due to the applied seismic forces in one direction, will close when the direction changes. This will continue to happen in the entire duration of the earthquake.

3.2.3. Shear wall's reinforcement

The boundary elements, either regular or hidden, are reinforced according to the rules that apply to columns.

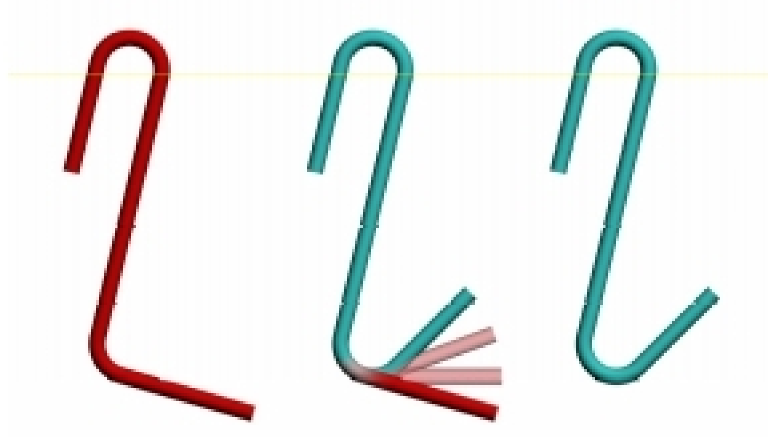
The wall body is reinforced by two parallel grates one at each face. These are called curtains and they are held together with the use of an 'S'-shaped vertical bar. The vertical grate rebars must have a diameter at least equal to Φ10, while the horizontal rebars may even be Φ8 however, as a rule, both horizontal and vertical rebars are calculated and implemented with the same diameter. The 'S' shaped reinforcement must be greater or equal to $4\Phi8/m^2$ and it might even be made out of soft steel (old class S220).



When we do not want cracked surfaces e.g. in pool sides, we use narrow spaced grates with the lower possible rebar diameter.

The 'S'- shaped reinforcement

The 'S'-shaped bar provides antibuckling restraint to the longitudinal reinforcement. Moreover, it ensures the vertical and the horizontal rebars will continue to work together even after possible concrete spalling in case of an intense earthquake event.

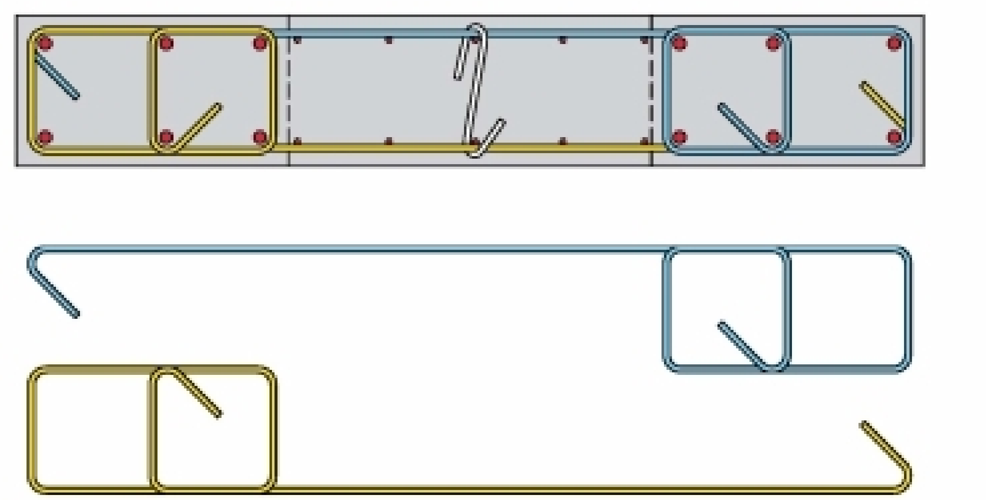


The 'S'-shaped link is formed with one closed corner at an angle equal to 180°, or 135° and the other corner bent at an angle equal to 90°. This is necessary for its trouble-free placement. However, after its implementation the second corner must be also bent at an angle at least equal to 135°.

It is allowed to use soft steel in order to be able to bent the 'S'-shaped reinforcement by hand.

When the vertical rebars are placed in an interior layer, then the 'S'-shaped link must restrain the horizontal rebars to the area that they intersect with the vertical ones or even better to go around both horizontal and vertical rebars at the same time.

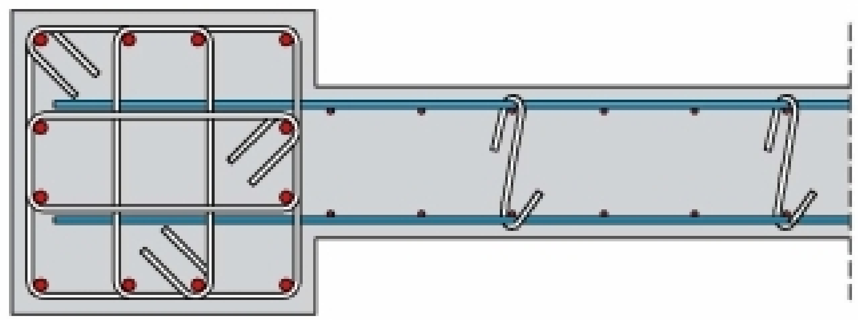
Alternatively, in an orthogonal shear wall, the reinforcement of the boundary column and the distribution rebars of the wall's body can be implemented as two 'Γ' shaped parts, as shown at the following figure. The 'Γ' shaped parts may be formed with the use of folded mesh.



3.2.4 Anchoring the horizontal rebars of the shear wall's body

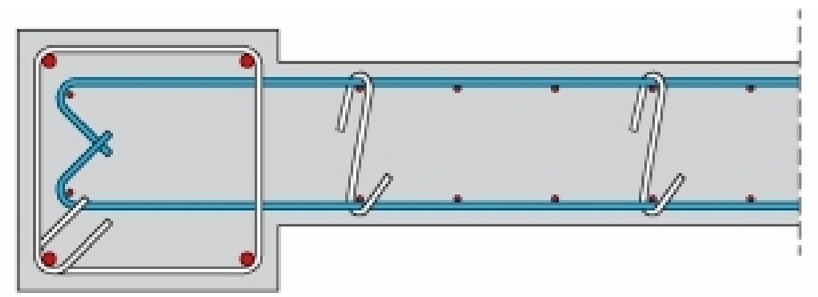
(a) Anchorage inside a strong boundary column

When the boundary column is strong enough and the horizontal rebars (distribution bars) get anchored inside the column's core, a straight anchorage length can be used.



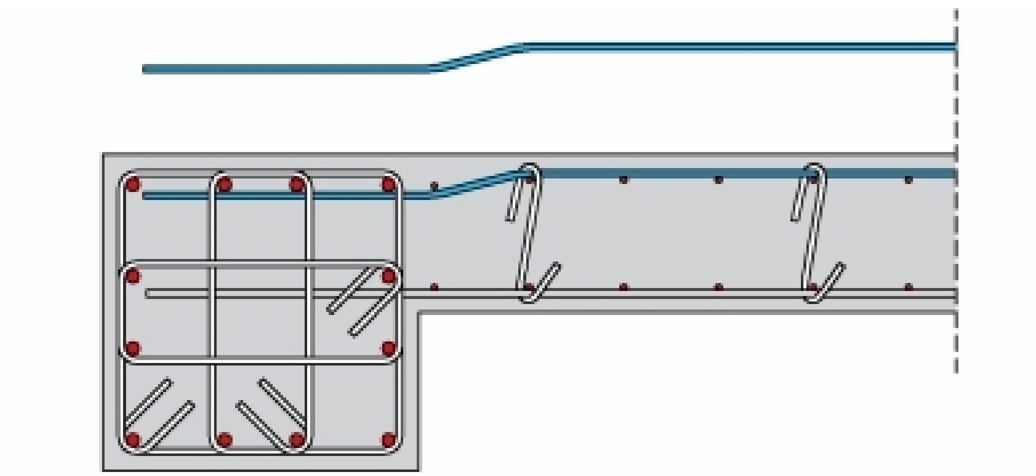
(b) Anchorage inside a weak boundary column

When the boundary column is weak and its width is not long enough to allow for a straight anchorage, it is mandatory to anchor the horizontal rebars by forming a hook at their ends.



(c) Straight anchorage inside the core, when the boundary column is strong enough and its one face colinear with one side of the shear wall:

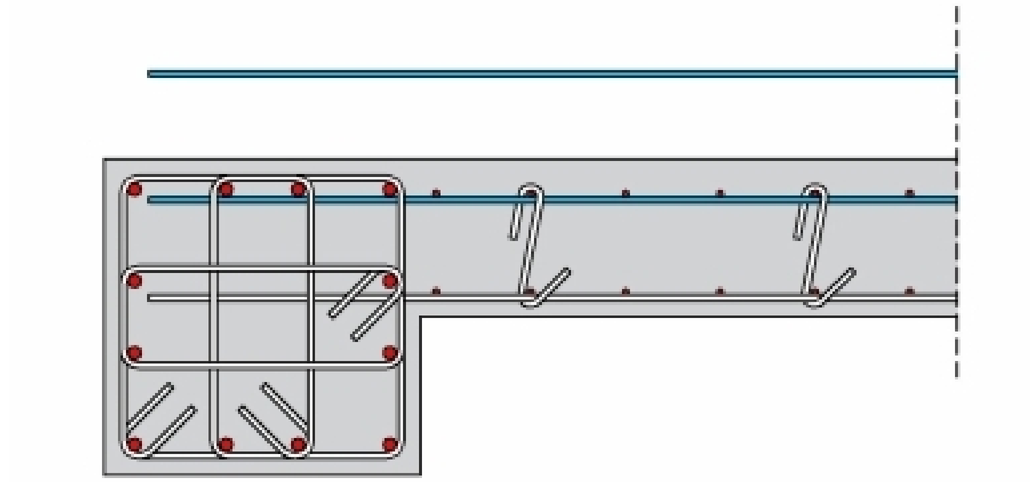
(i) case:



In this case, the disadvantage lays in the need for bending up the horizontal rebars in certain areas. For Φ8 and Φ10 bars, this can be easily done during the implementation, with the use of a bending tool; however, for larger diameters it has to be done with a bending machine.

In this case, the S'-shaped reinforcement must restraint the horizontal rebars to the point where they intersect with the vertical ones.

(ii) case:



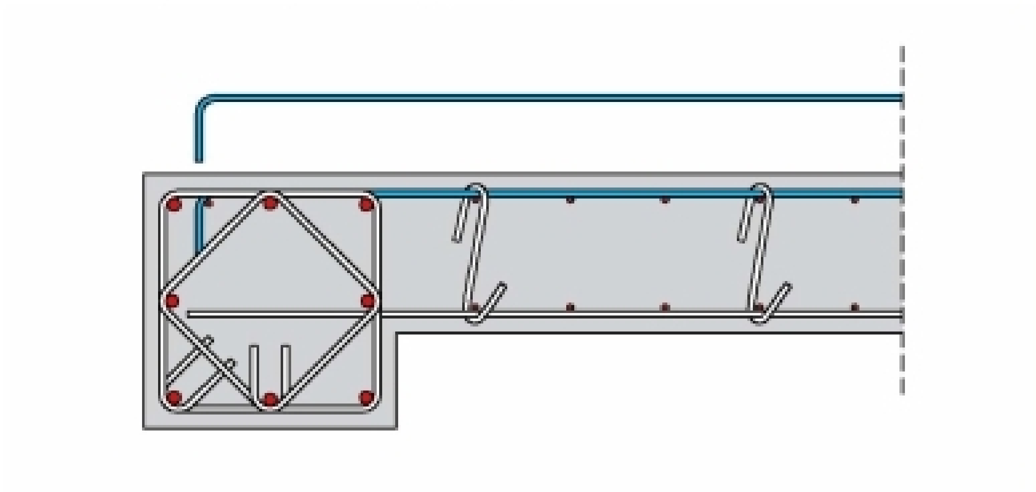
In this case, a straight anchorage is used and the horizontal rebars do not have to be bent. This increases their cover depth but since they mainly carry shear forces no serious problem arises. Moreover, the internal lever arm of the vertical rebars is diminished but only around 1cm so practically again, no problem appears.

As a conclusion, it is recommended to use a straight bar anchored inside the boundary column because apart from the other advantages, it provides the required cover depth for the 'S' shaped bars when they go around both the horizontal and the vertical distribution rebars at the same time.

(d) Anchorage by encircling the boundary column and ending in a hook.

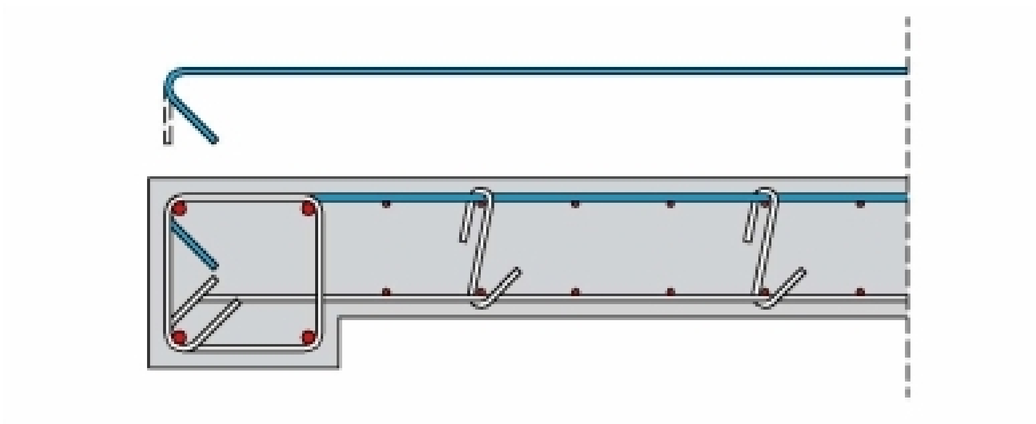
No matter if the column is strong or weak, the horizontal rebars must end in a hook which will be placed in the inside of the confined column.

1st case: adequate straight anchorage length:



The anchorage might be achieved with a 90° hook placed inside the body of the boundary column

2nd case: inadequate straight anchorage length:



When the column's width is not large enough to provide an adequate straight length of anchorage, hooks bend at 45° (135°) are being used. These are either completely prefabricated so as to have 45° bend in both edges, or they are assembled on the site with horizontal rebars with ends bend in 45° and 90°. These will be alternately placed along the height.

(e) Anchorage of continuous peripheral basement shear walls

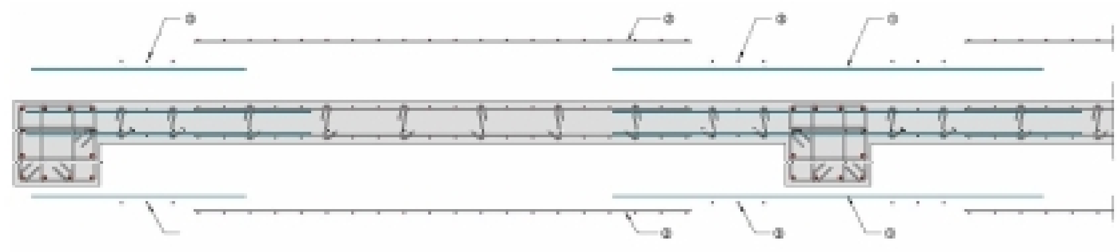
In continuous basement shear walls the difficulty in the reinforcement implementation lays in the column area. In order to overcome this difficulty straight distribution rebars may be placed there. These bars have a relatively small length. They will be lapped with the larger intermediate distribution rebars and they will be wired together with the vertical ones.

It is very practical to use horizontal and vertical distribution bars in the form of a ready-to-use wire mesh. In such a case, the practices described below are being followed:

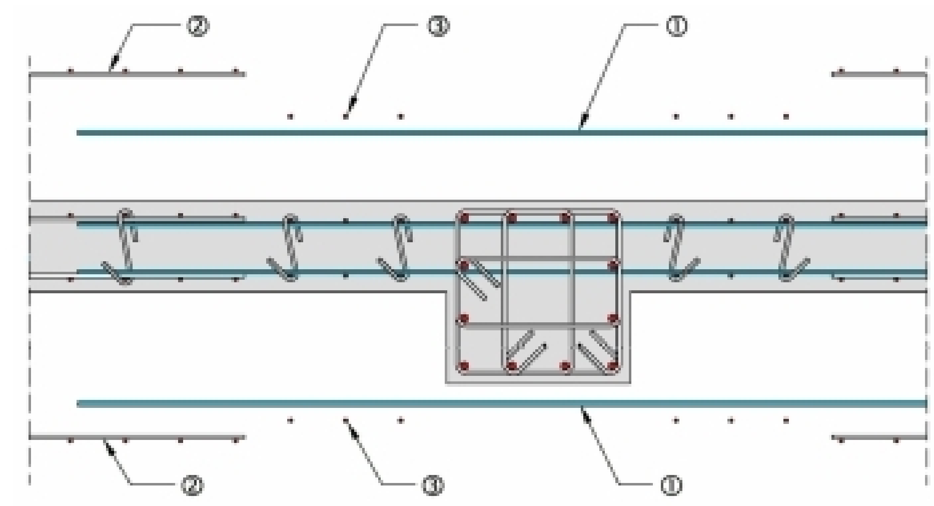
Firstly, the 'short' horizontal rebars (starter bars) are placed on either side of the column, followed by the implementation of the wire meshes as shown at the next page.

Notes:

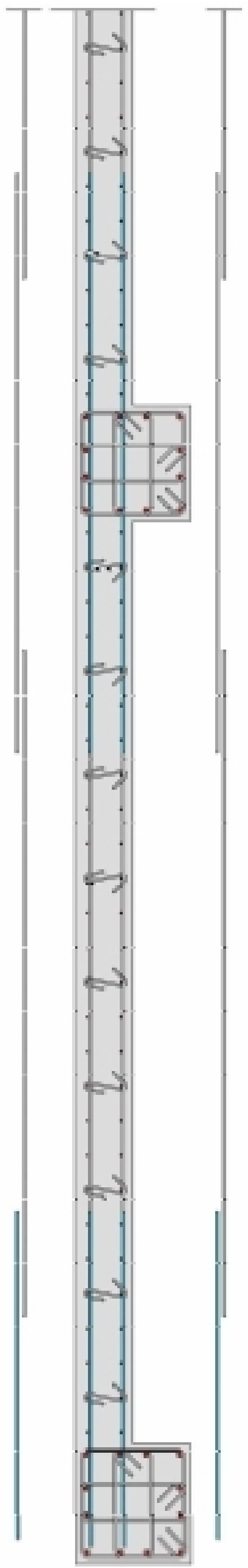
If the industrial wire mesh does not fit to the shear wall's span length then the short starter bars placed in the columns' area might have a larger length. In such a case, the vertical distribution rebars between the end of the wire mesh and the column, are placed by hand after the implementation of the mesh.



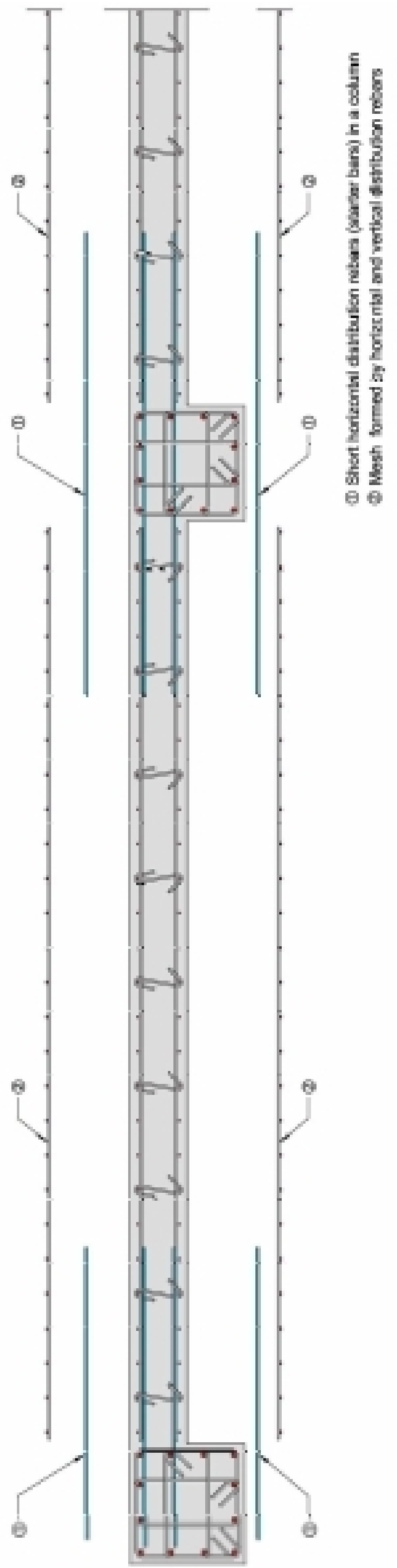
In case the column longitudinal rebar layout creates a difficulty in the implementation of the short distribution rebars, the latter can be bend at their end.



① Short distribution column bars
② Industrial mesh
③ Additional vertical distribution bars

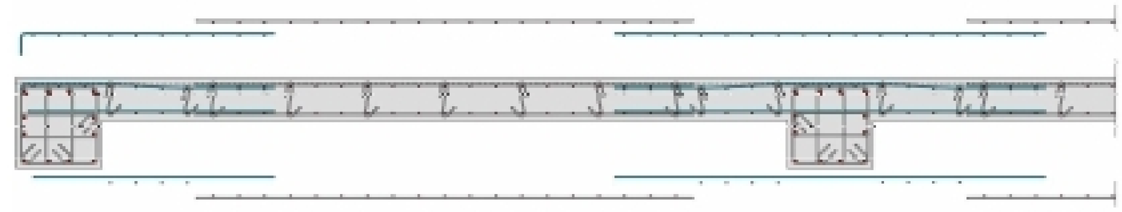


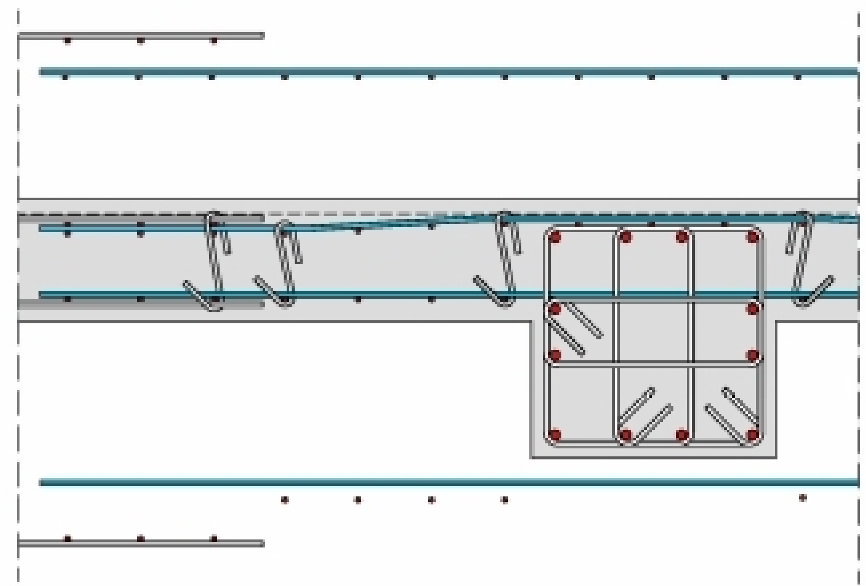
Reinforcement of 'continuous' basement shear walls with bars



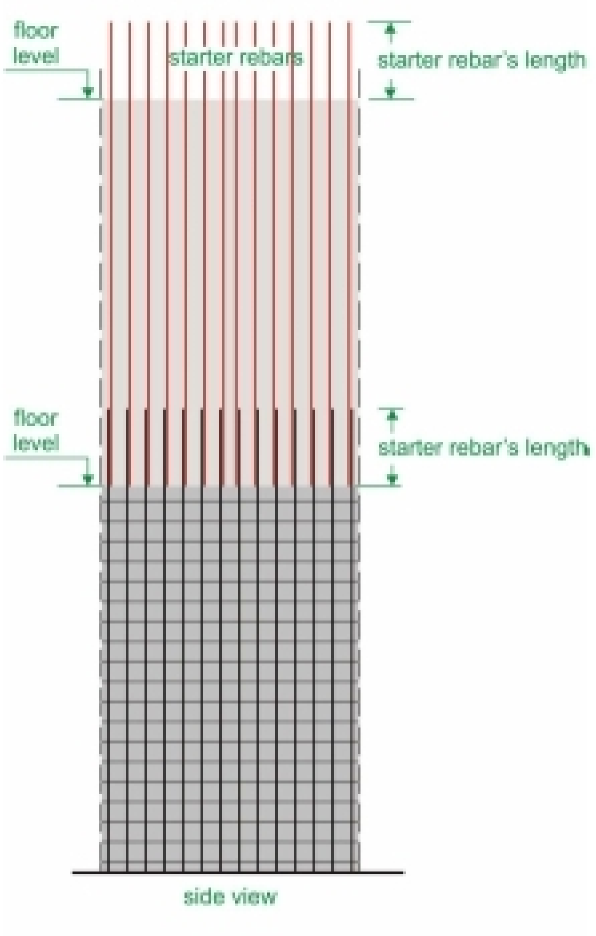
Reinforcement of 'continuous' basement shear walls with industrial wire meshes

Usually, in the perimeter of the building, in the storeys above the ground, there is a seismic joint (3 to 5cm), or thermal insulation (3 to 5cm) which are not required in the basement. However, their thickness can be used in the basement shear walls to secure the cover depth and to enable the implementation of the distribution meshes outside the column reinforcement, as shown at the following figure.

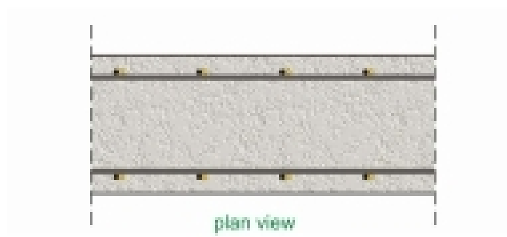




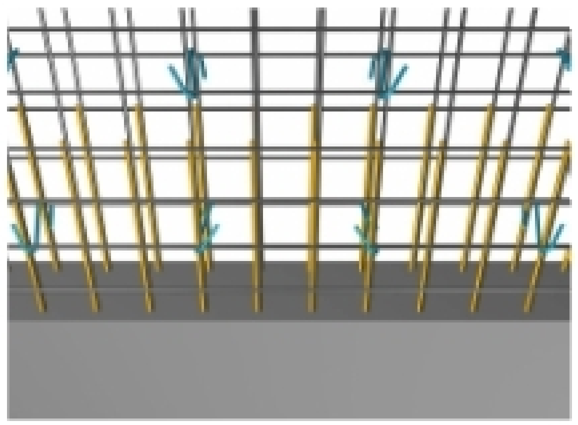
3.2.5. Lap-splices of vertical bars



The rules that apply are the same with those mentioned in chapter 3.1.1 that deals with lap-splices in column rebars. However, there is one critical difference that simplifies the lapping of the vertical reinforcement placed to the shear walls' body: there are no stirrups thus the vertical co-linearity of the rebars is not necessary. In walls' bodies lapping is being done with the use of a simple contact lap-splice parallel to the longitudinal axis of the element.



Generally, the lap length is not extremely large because the vertical rebars' diameter is usually small. For a typical diameter Φ10/B500c, the required lap length is equal to 67cm, 58cm and 51cm, for concrete grades C20/25, C25/30 and C30/37 respectively.



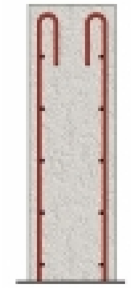
Note:

Theoretically, the finest solution is to lap 50% of the rebars at a time in different heights.

3.2.6. Anchorage of vertical rebars

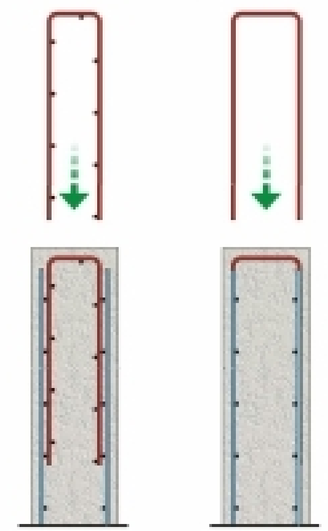
Bars must be anchored at the upper part of shear walls. This anchorage must be done according to the same rules that apply to the anchorage of column rebars. However, as a rule, it is a more simple procedure, due to the smaller diameter of the vertical reinforcement placed inside the wall's body and also due to the possibility of rebar lapping with a contact lap-splice. Two basic cases are defined, anchorage inside the shear wall's mass and anchorage inside the adjacent slabs' body.

(a) Anchorage of rebars in the shear wall's mass



i) with hooks

The hooks must be formed by a bending machine with the use of the appropriate rolls (see §2.6.3). The angle of the hook might be 135 ° however, it is preferred to be 180°.

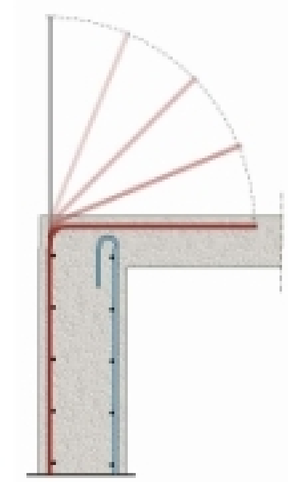


ii) with an additional Π rebar

A 'Π' shaped bar (figure a) provides, apart from the anchoring, the proper finishing of the shear wall reinforcement. The use of a wire mesh (figure b) has a lot of advantages regarding its implementation however, due to the welded distribution reinforcement, the 'Π' shaped bar, must be formed to fit between the two parallel vertical meshes.

This type of anchorage is preferred in most cases and especially when the accurate implementation of the wall's body rebars along the height cannot be easily done e.g. in the case of a basement where the body rebars are implemented together with the foundation reinforcement.

(b) Anchorage of rebars inside an adjacent slab



i) Having a slab on one side

In case the upper part of the shear wall has only one side connected to a slab, the outer vertical rebars, may assist in securing the fixed support of the slab.

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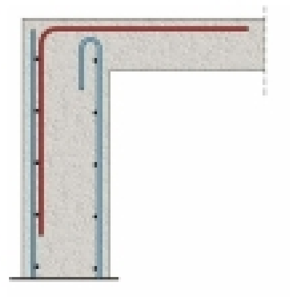
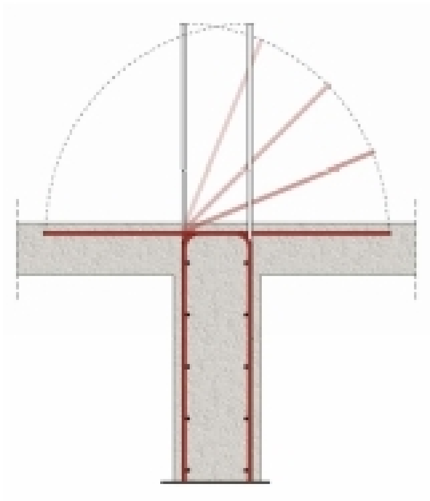
An alternative solution is to place a 'Γ' shaped wire mesh.



ii) Having a slab on both sides

In case the shear wall has slabs on either side, its rebars can be anchored inside the slabs' mass and at the same time they can be a part of the required slab support reinforcement.

Finally, it is highlighted that apart from the above mentioned solutions there is a wide range of other combinations.



3.2.7 Starter bars in shear walls

The need to construct co-linear or vertical shear walls in different phases arises quite often. Most of the times the starter bars are placed in the traditional way i.e. by extending the horizontal rebars of the first shear wall towards the direction of the shear wall that will be constructed in a following phase.

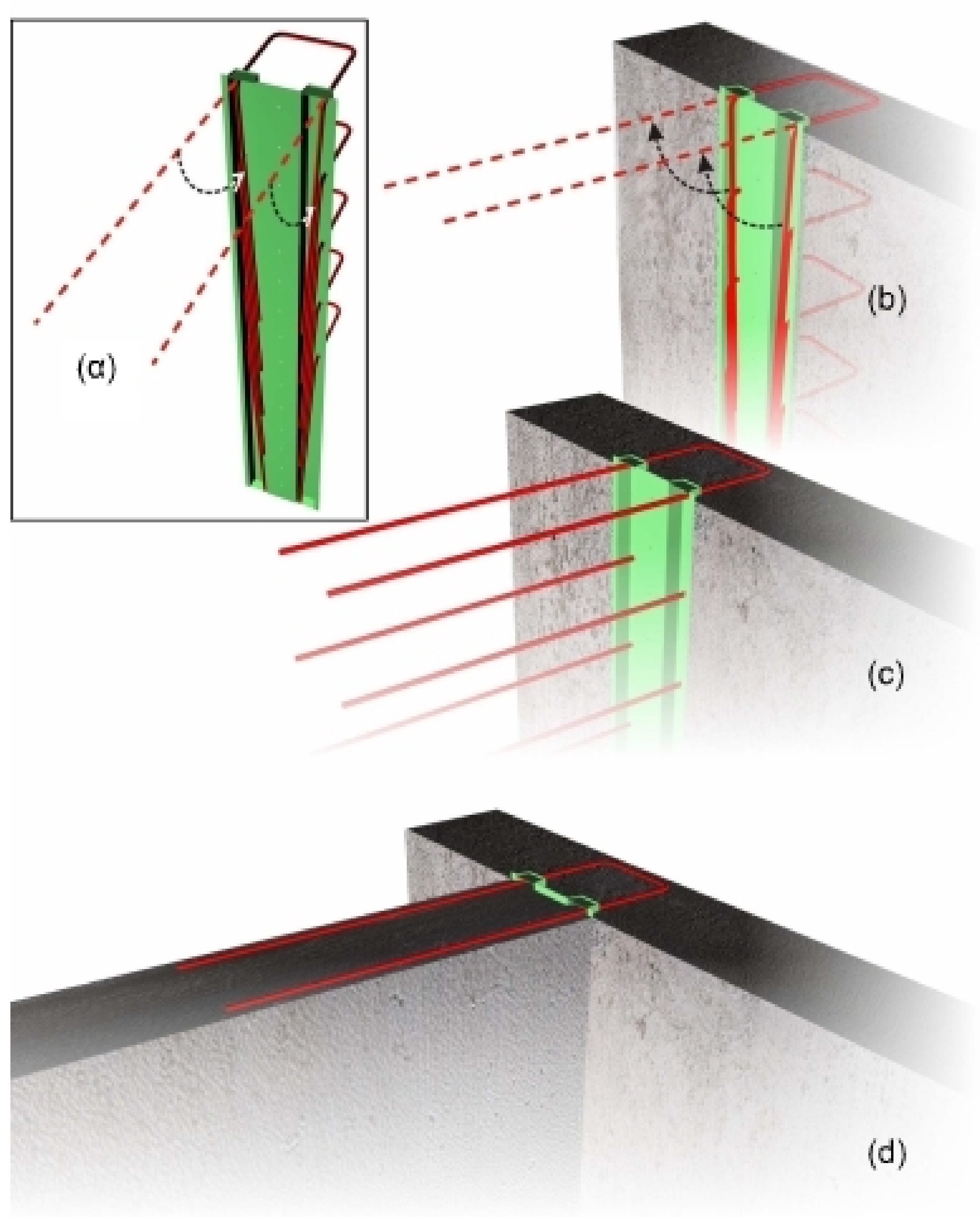
In the cases where the new shear wall will be perpendicular or co-linear with the old one and the starter bars will cause problems in further excavations or they will be damaged by handling machines, the special technique described below is being used:

(a) the starter bars are shaped like a hair pin, their legs are temporarily bent and they are encased in a standardized steel or in an impromptu (e.g. made out of polystyrene) thin box,

(b) the thin box is nailed upon the formwork. Then follows the implementation of the first shear wall reinforcement and finally comes the concrete casting,

(c) after the formworks removal, the starter bars are once again centerlined. If the encase box is an impromptu construction, it is removed.

(d) the second shear wall is constructed



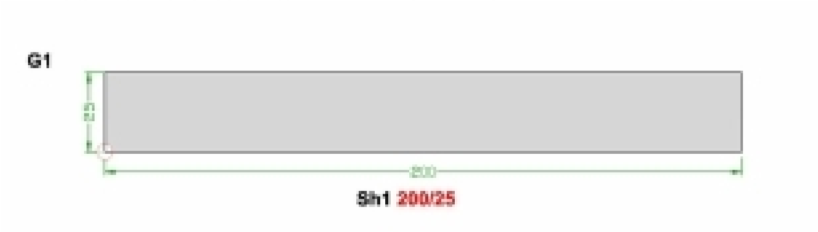
The four phases when adding a vertical element

This technique is used either for vertical or colinear shear walls. It is ideal when constructing a partial foundation by an excavating and concrete pouring sequence. This is used when there is danger for the adjacent building. We excavate a part of the common edge and we concrete the shear wall and its foundation. Then we excavate the next part and so on.

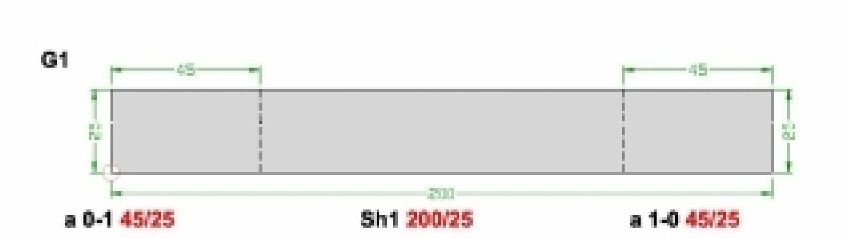
3.3. Composite elements

A composite column is every vertical element composed by a number of rectangular members, one of which is considered to be a shear wall i.e. has a length to thickness ratio ≥ 4.

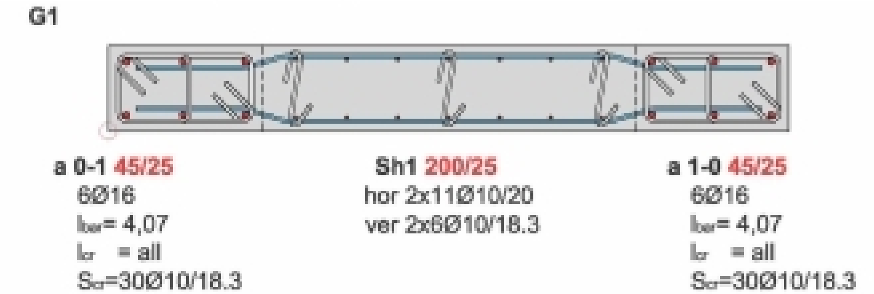
The simplest composite column is the one-member shear wall, like S1.



From a static point of view, S1 is composed by the shear wall T1 which has a section equal to 200/25.

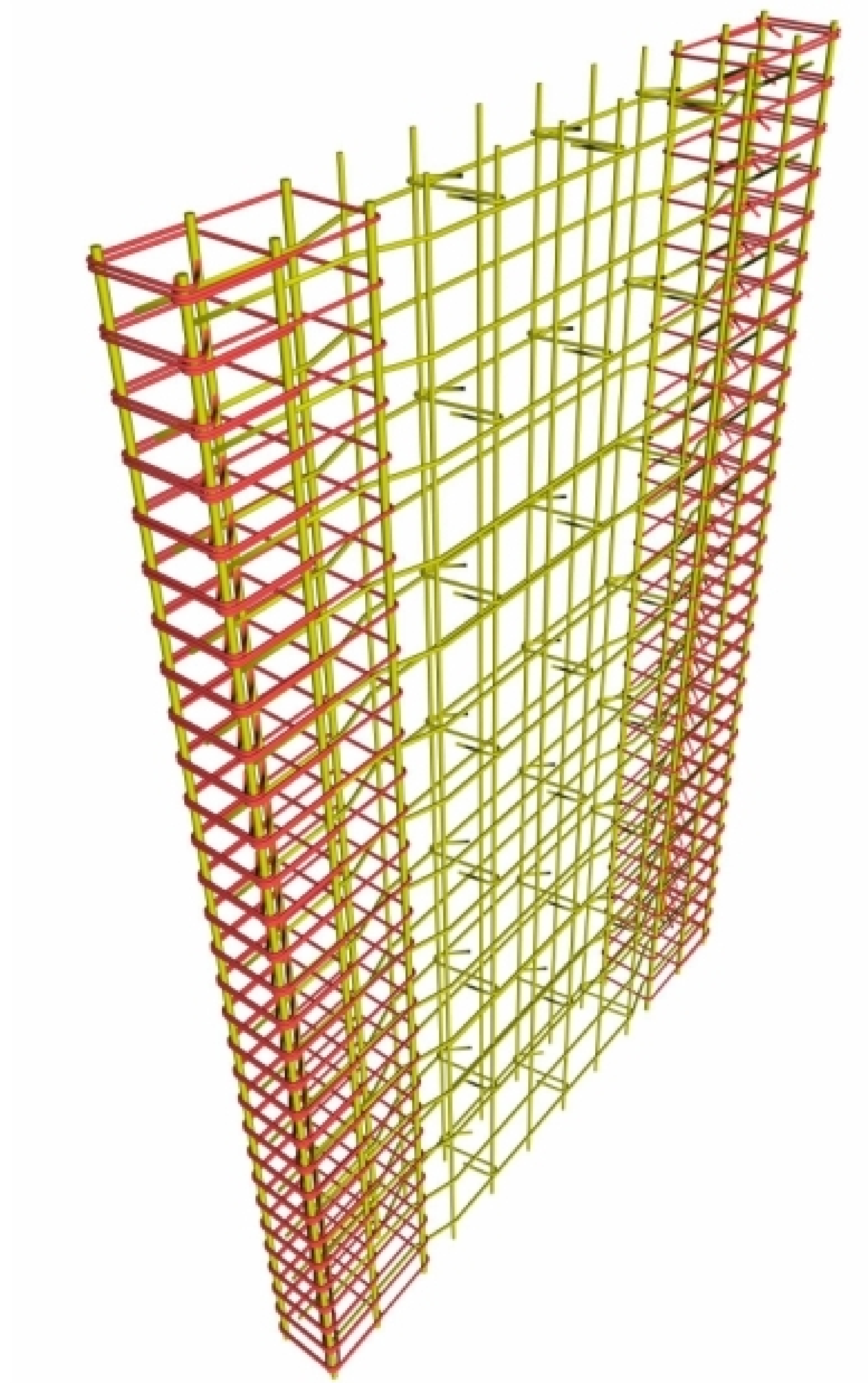


From a reinforcement point of view, S1 is composed of the hidden (boundary) columns a0-1 and a1-0 with 25/45 section and the shear wall's main body T1 with a section of 200/25 (including the length of the two boundary columns).

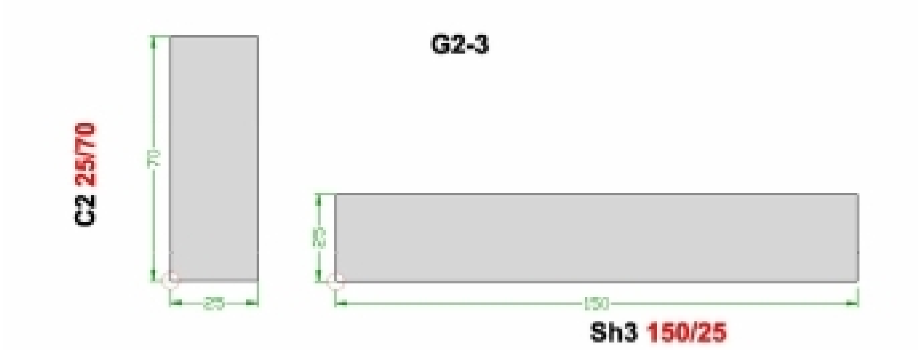


The S1 reinforcement consists of the clearly defined reinforcement of the three members that comprise the composite element, the two orthogonal columns and the shear wall's main body.

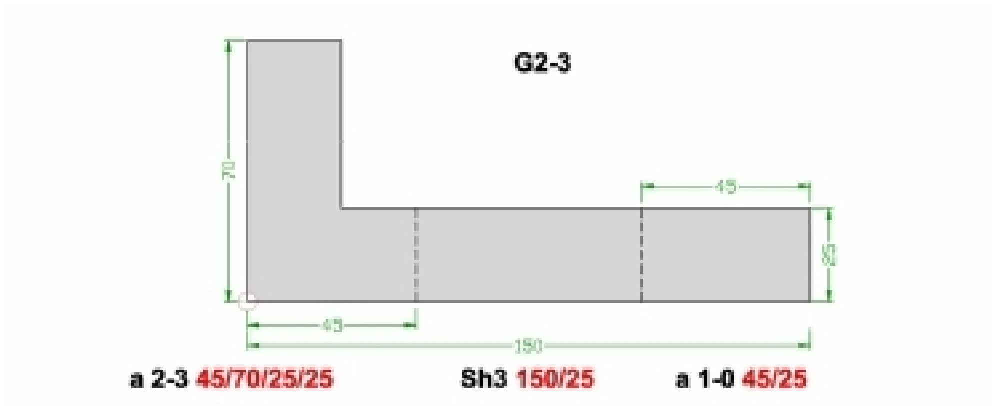
In this specific example as well as in the others that follow, the horizontal rebars have been anchored by bending. It is obvious that any ther type of anchorage from those mentioned in the previous chapter could have been chosen.



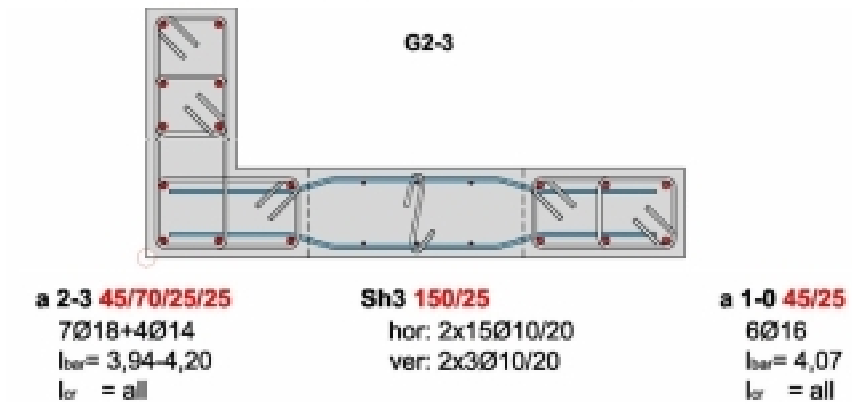
The ‘Γ’ section element G2-3 is a composite element comprised of two members.



From a static point of view, the G2-3 is composed of the column C2 which has a 25/70 section and the shear wall Sh3 with length and thickness equal to 150cm and 25cm respectively.

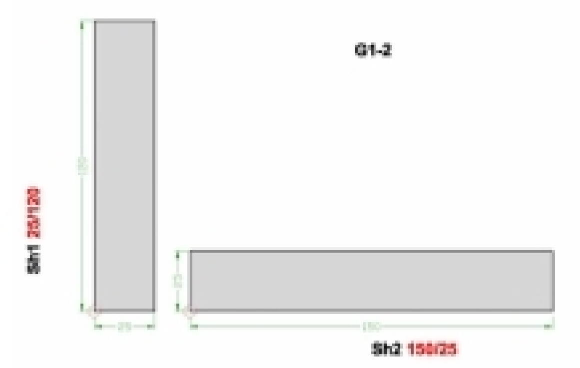


From a reinforcement point of view, the G2-3 consists of two boundary (hidden) columns: the 45/70/25/25 ‘Γ’ section column, the rectangular column a3-0 with a cross section of 25/45 and the shear wall’s main body Sh3 with a section equal to 150/25.

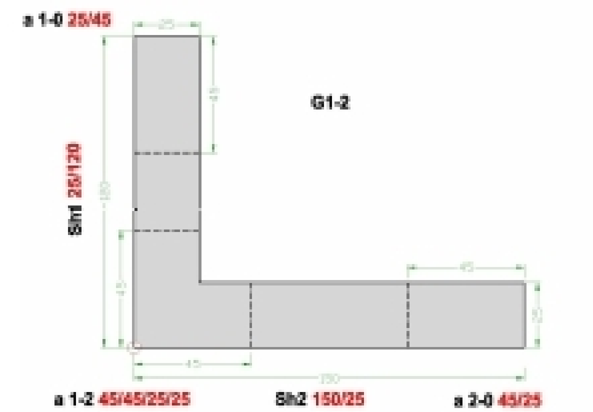


The reinforcement of G2-3 is composed of the clearly defined reinforcement of the three members that comprise the composite element, the two columns and the shear wall’s main body.

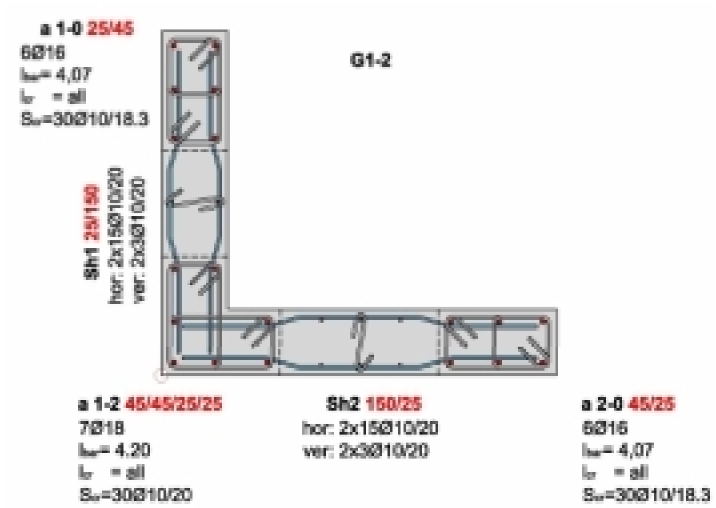
The ‘Γ’ section element G1-2 is a composite element that consists of two members.



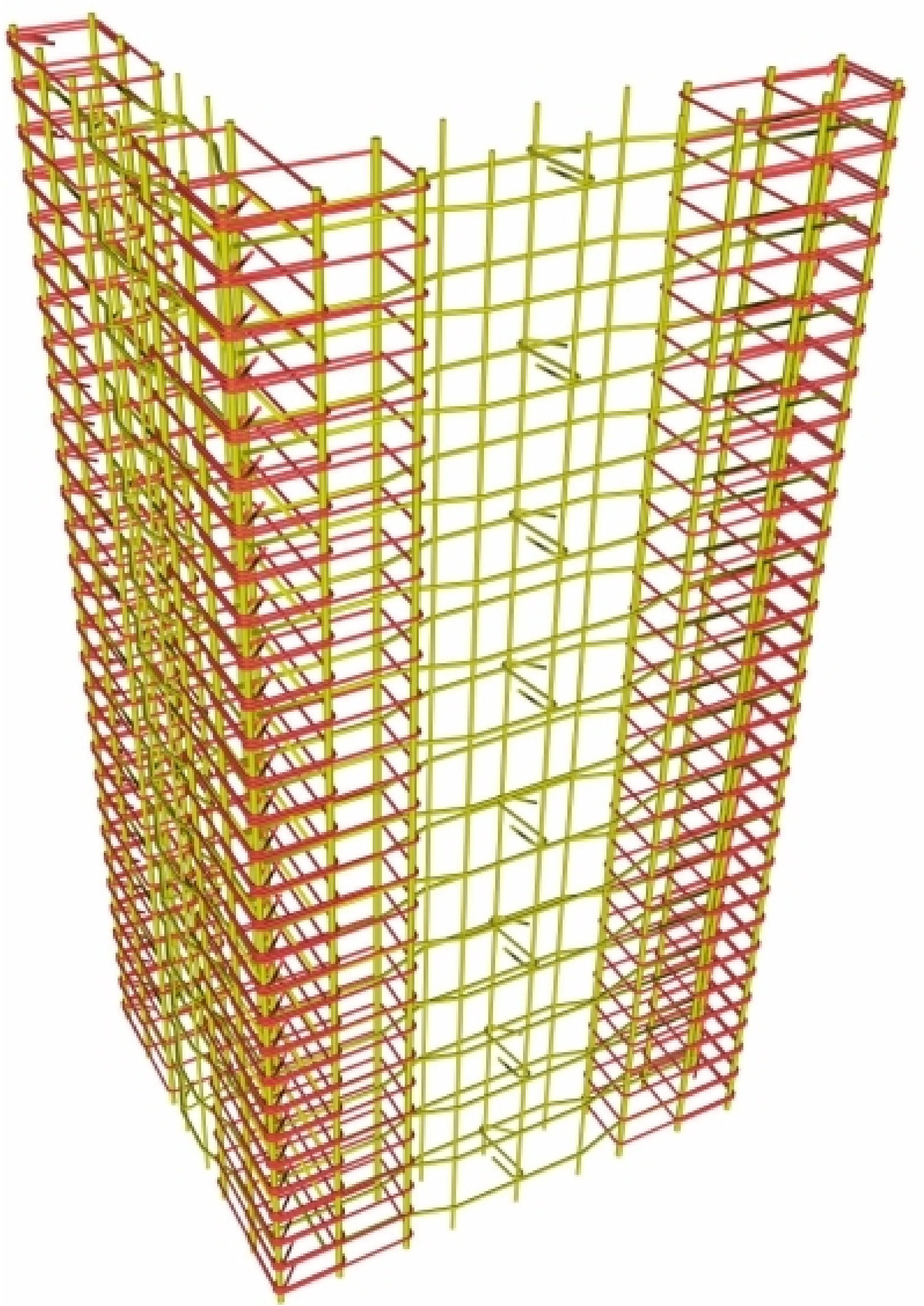
From a static point of view, the G1-2 is composed of the shear wall Sh1 which has a 25/120 section and the shear wall Sh2 with length and thickness equal to 150cm and 25cm respectively.

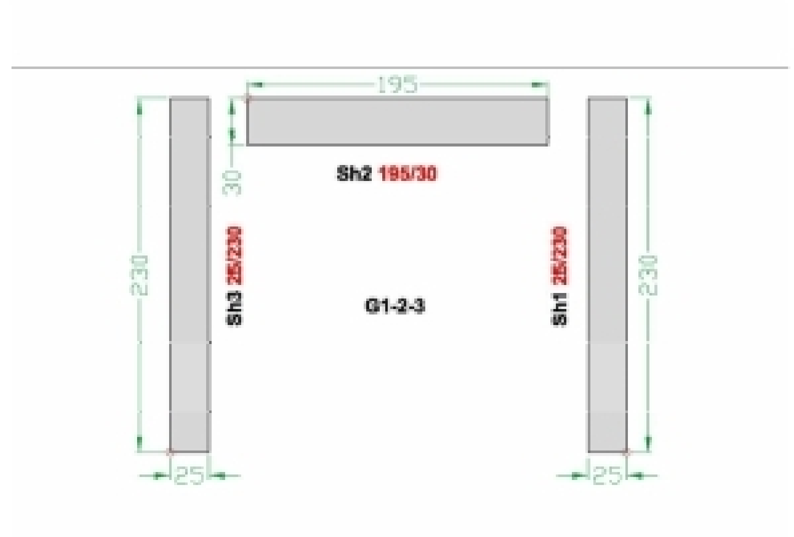


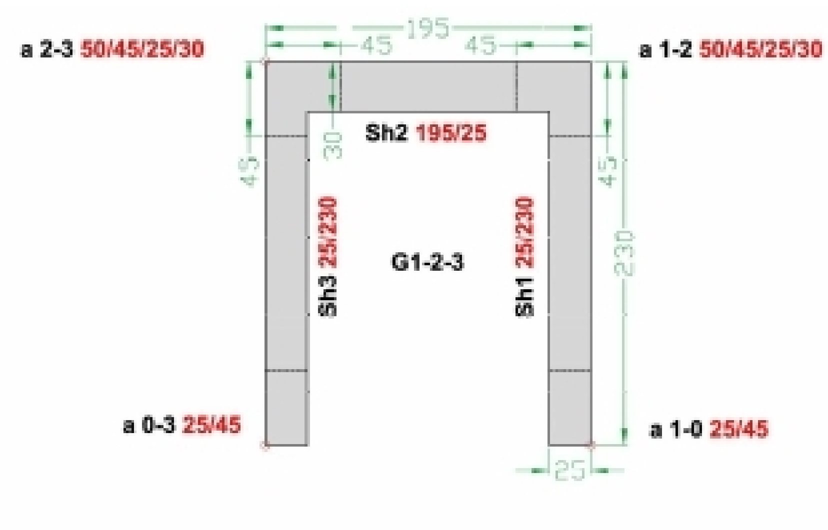
From a reinforcement point of view, the G1-2 consists of three boundary (hidden) columns: the 45/45/25/25 ‘Γ’ section column a1-2, the rectangular column a1-0 with a cross section of 25/45, the 45/25 rectangular column a2-0 and the shear walls’ main bodies Sh1 and Sh2 with sections equal to 25/120 and 150/25 respectively.

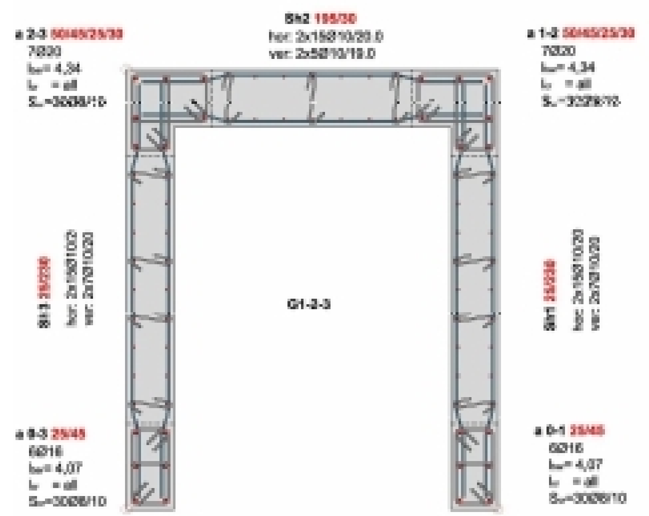


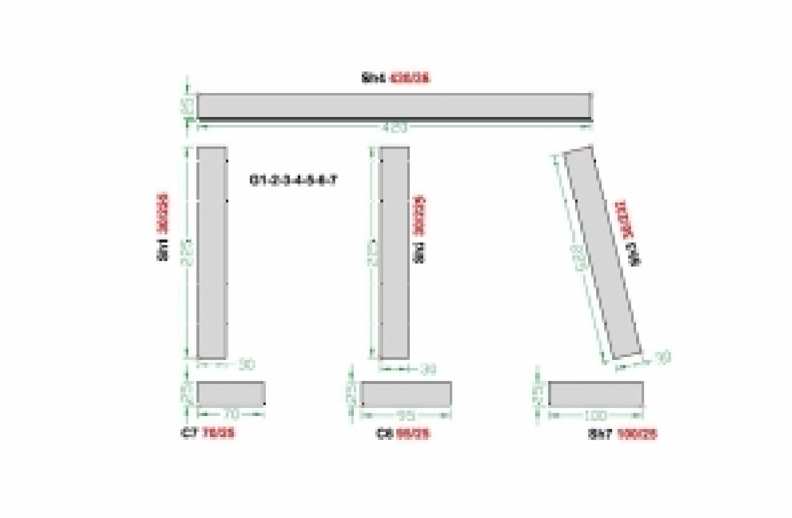
The reinforcement of G1-2 consists of the clearly defined reinforcement of the five members that comprise the composite element, the three columns and the two shear wall main bodies.

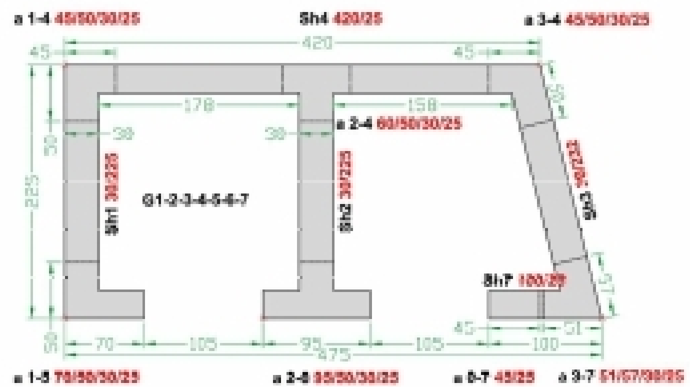


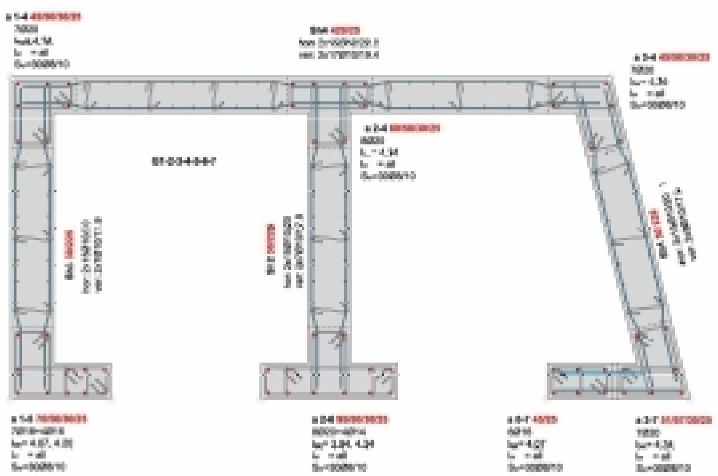


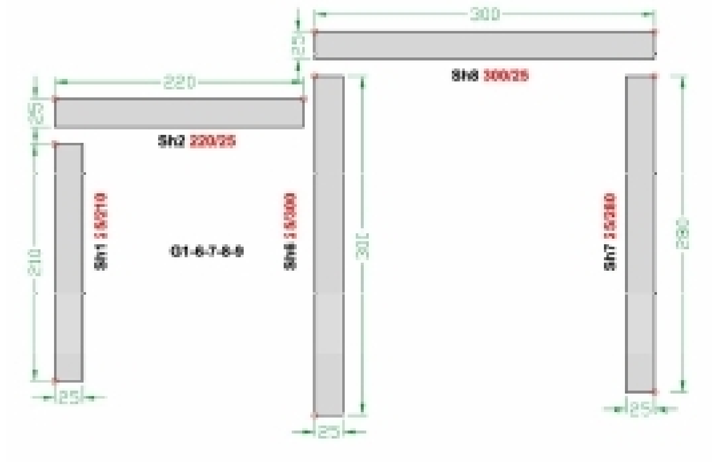


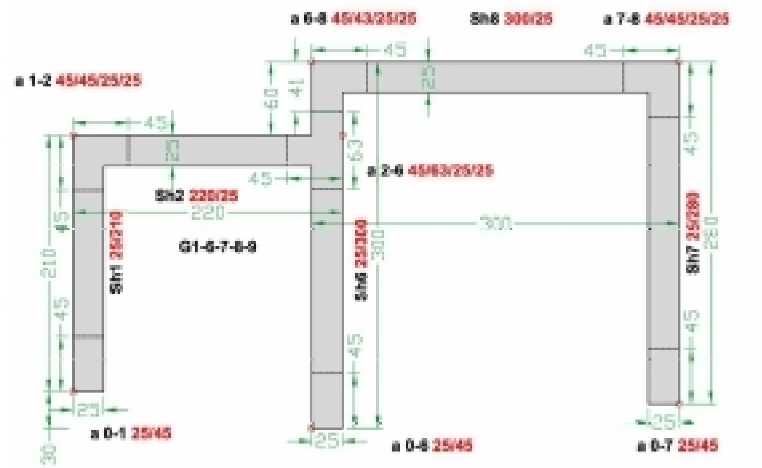


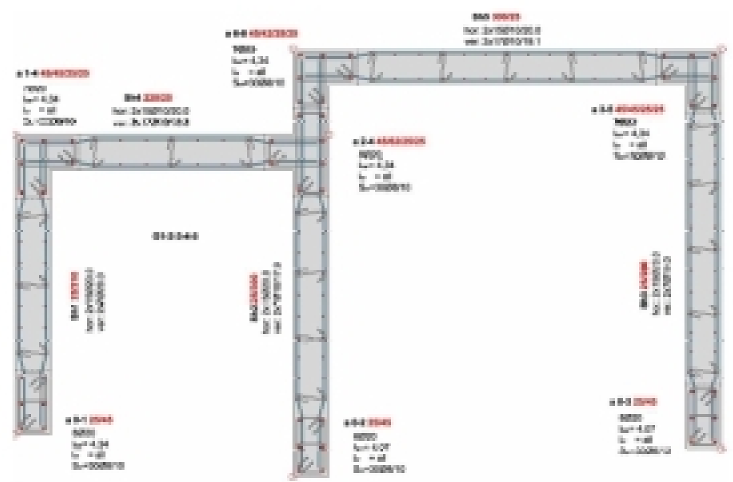






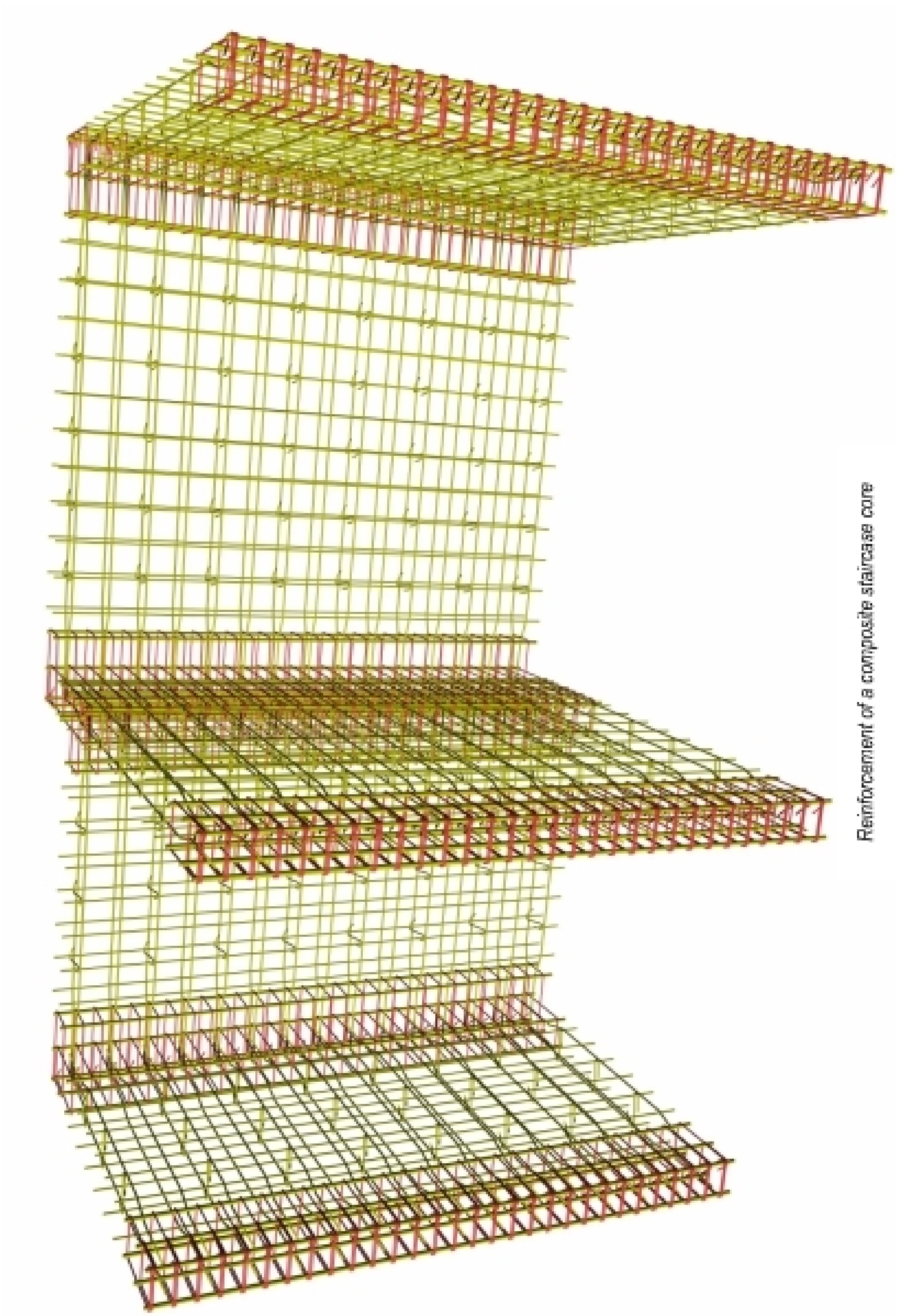






Note:

The columns a 2-4 and a 2-5 could have been constructed as a single 'Z' section column.



Reinforcement of a composite staircase core

3.4 Beams

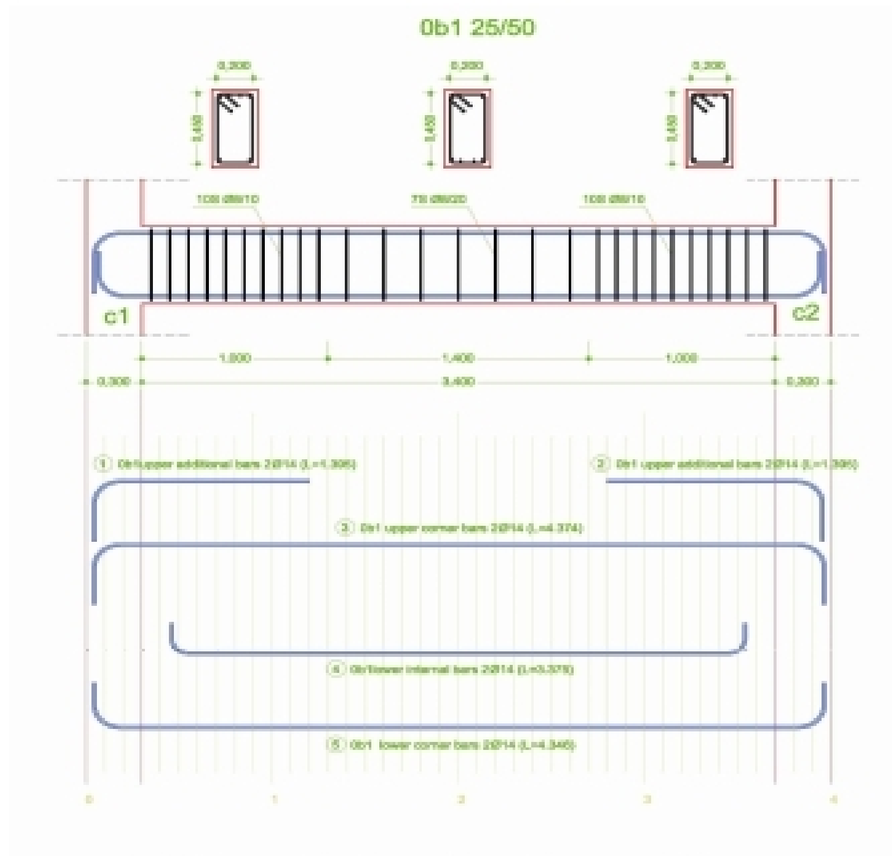
3.4.1. General

The following figure shows one beam supported by two columns.

This beam, due to its elasticity (stiffness) and the loads that it bears (self weight, supported slab, walls, etc), is deformed by the way mentioned in chapter 1.4.2 The reinforcement placed inside beams is comprised of the longitudinal bars and the transverse reinforcement in the form of stirrups (ties).

The longitudinal rebars are placed in order to resist the flexural tensile stresses that appear along the beam axis while stirrups are used to carry the diagonal tensile stresses caused by shear.

Moreover, stirrups help in the critical areas' confinement.



Details of longitudinal rebars in characteristic areas of the beam.

The number placed in front of the beam b1 indicates the floor that this beam belongs to. In this case, it is the number 0 which corresponds to the ground floor[4]. 1 represents the 1st floor, 2 the 2nd floor, -1 the first basement and so on. This means that the beams' number prefix is …,-2,-1,0,1,2,…

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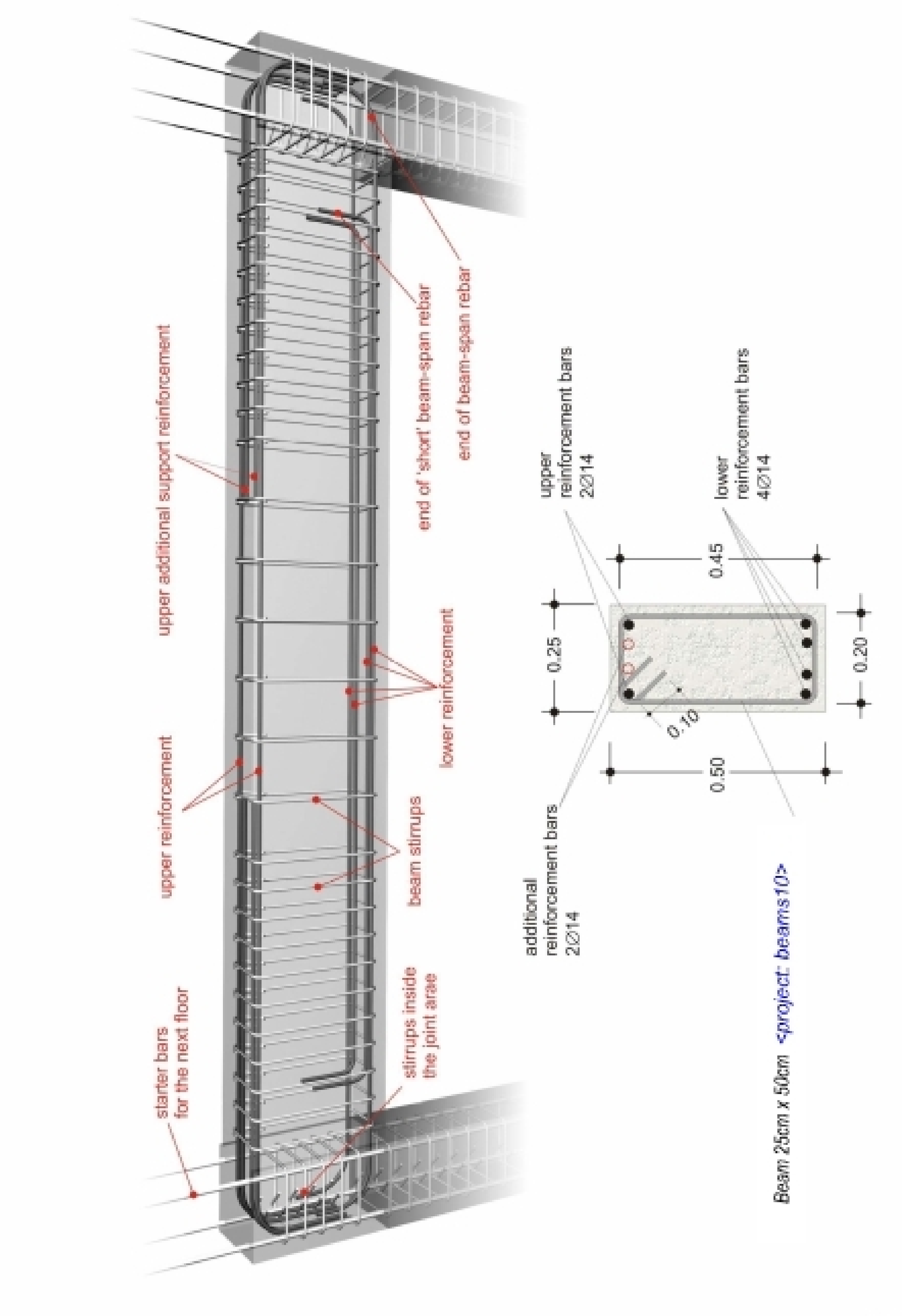
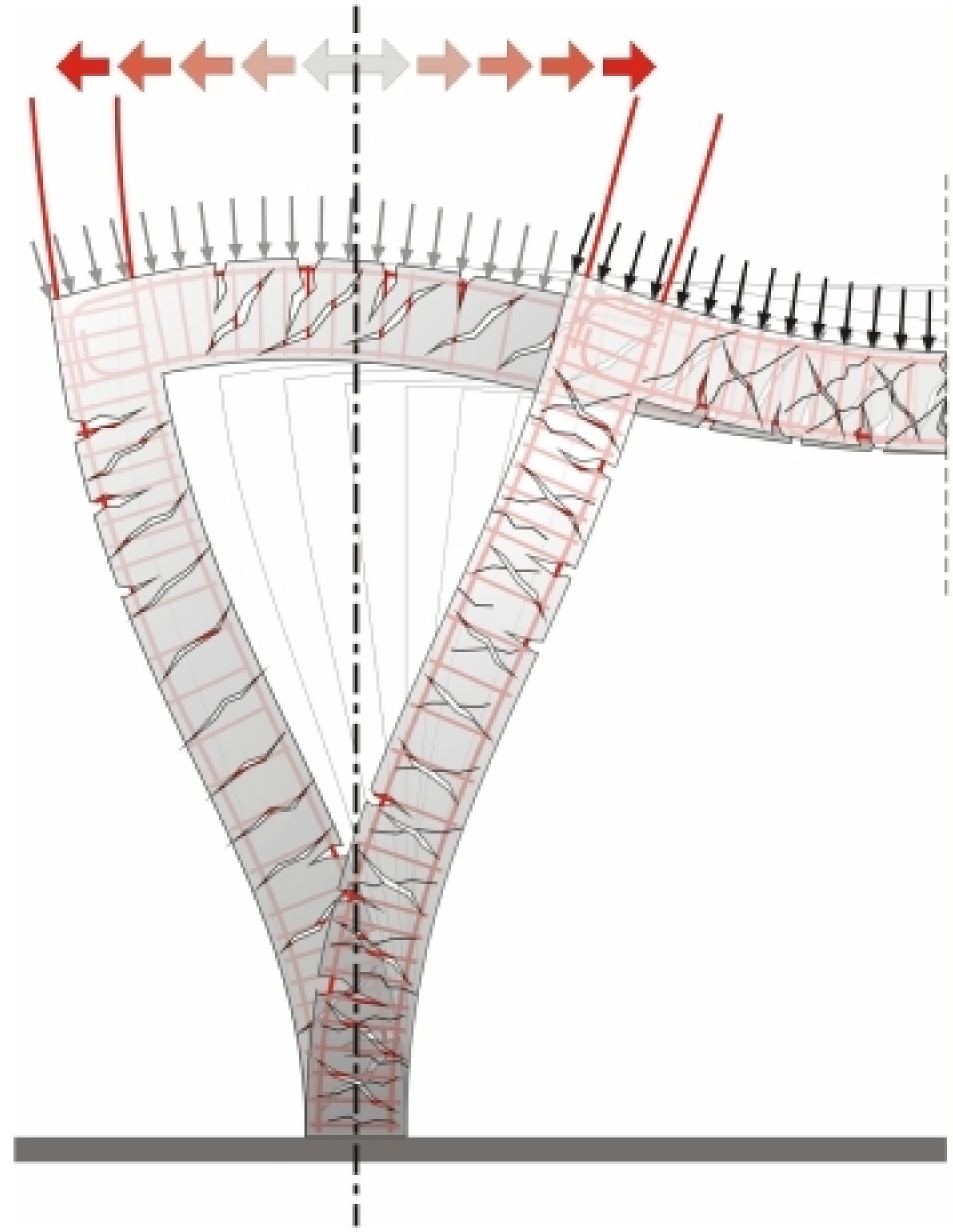
[4] in places where the first floor above ground is not referred to as ground floor but as 1st floor, number 1 represents the ground floor and the beams' number prefix is …,-2,-1,1,2,3,…

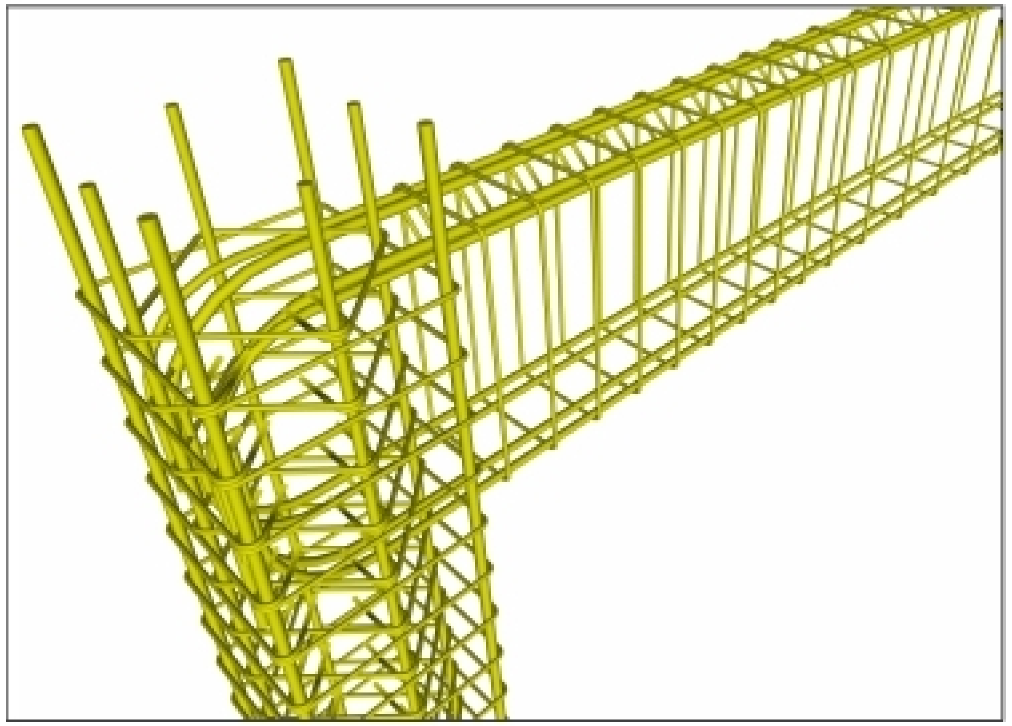


Since most of the times beams with names b1, b2 etc appear in all floors, it is compulsory to use the prefix both in the constructional drawings and in the beams' labels so as to avoid confusion with the drawings and the various materials used (these are specified in the beam's labels).

The label 10SΦ10/10.0 means that 10 stirrups, with a Φ10 diameter and 10cm spacing, will be provided at the critical length of the beam, which in this case is equal to 1m. In the detail drawing of the following continuous slab, the label 12SΦ8/17 that refers to the beam's span, which has a length equal to 2m, indicates that 12 stirrups with a Φ8 diameter will be placed around every 17cm (the exact distance between them is 200/12=16.7cm).



A seismic ground motion causes reverse bending moments to the beam.



In the joint area of an earthquake resistant frame both the upper and the lower reinforcement are fully anchored.

The stirrups hold the rebars in place and they carry the diagonal tensile forces that usually shift direction.

The beam's area next to the face of the column is characterized as 'critical' because it carries the largest stresses. Its length is equal to twice the depth of the beam (in our example 2*0,50=1,00 m). The stirrups placed at the critical areas must be narrow spaced and properly closed.

The beams' width must be greater or equal to 20cm and at least 2Φ14 must go through the full length of the beam both at the top as well as at the bottom.

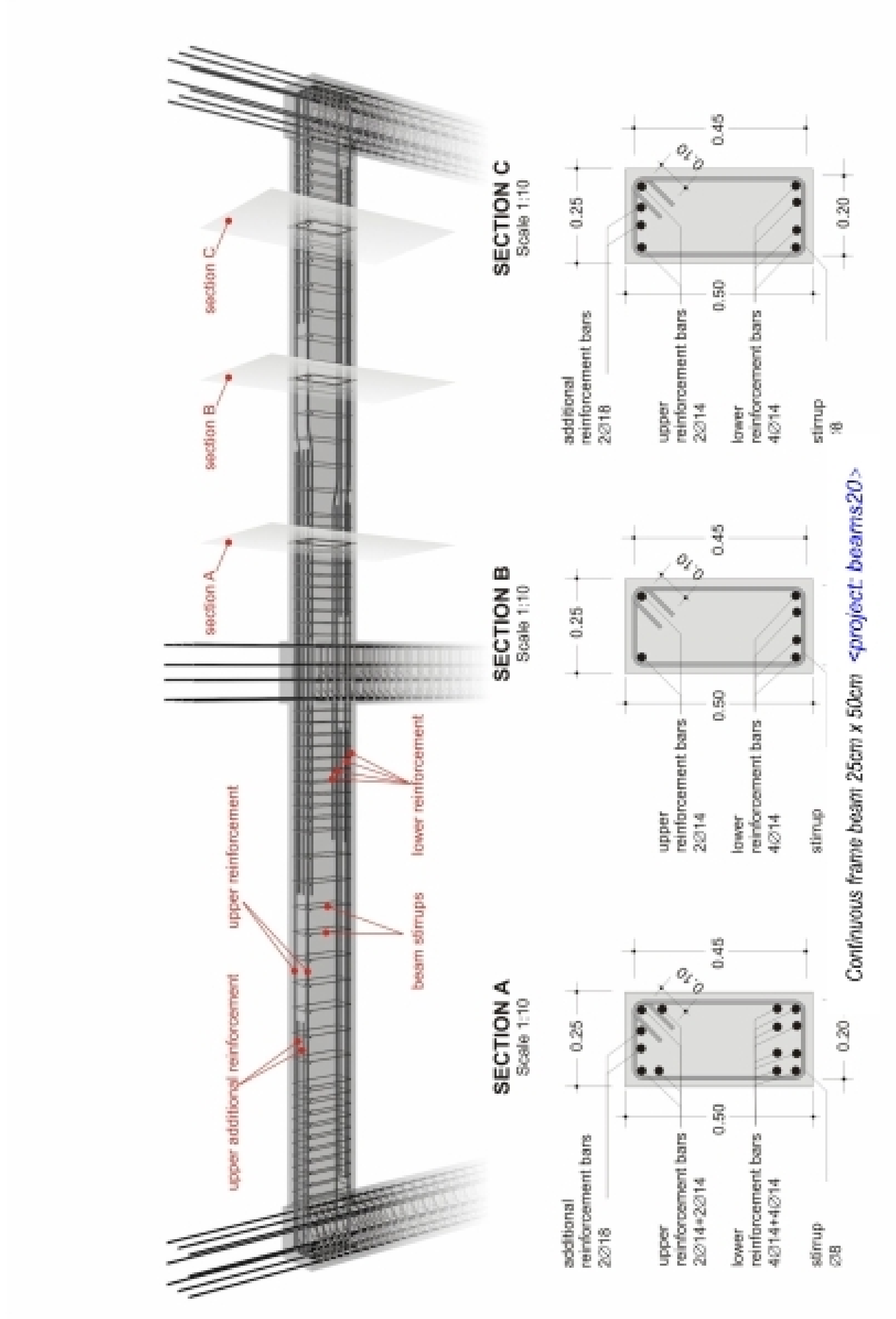
3.4.2. Continuous beam

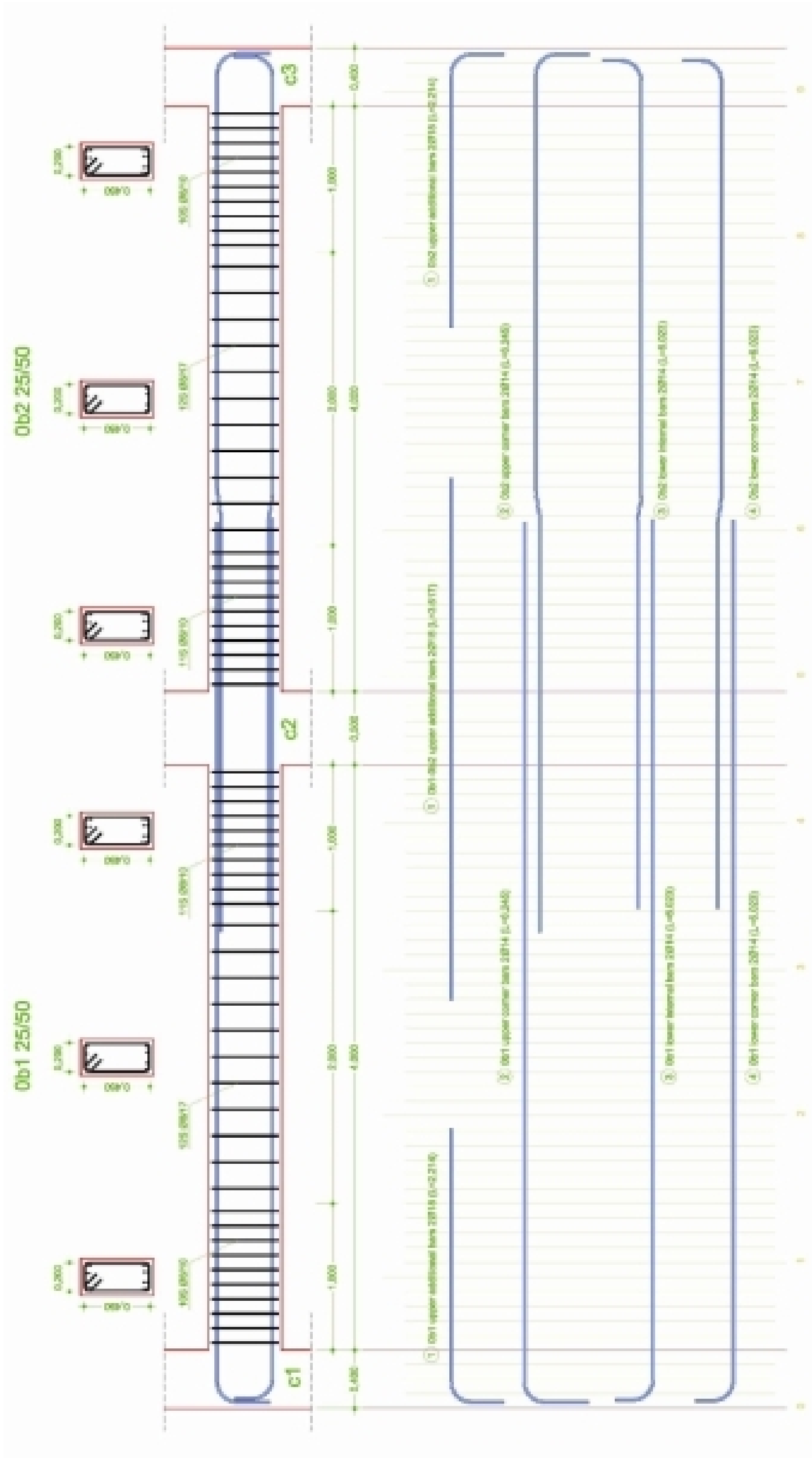
The continuous beam is a commonly accepted term for a succession of two or more colinear beams which are supported by columns or by other beams with no antiseismic behavior requirements. It is not frequently constructed in earthquake prone countries like Greece. On the other hand, it is used in a large scale in areas with low seismic activity.

As far as the reinforcement is concerned, the construction of a continuous beam with no seismic behavior requirements is much more simple compared to the earthquake resistant beams.

The following figure shows, in a photorealistic view, two continuous frame beams with antiseismic requirements.

The detail sections show the proper placement of the beams' reinforcement.



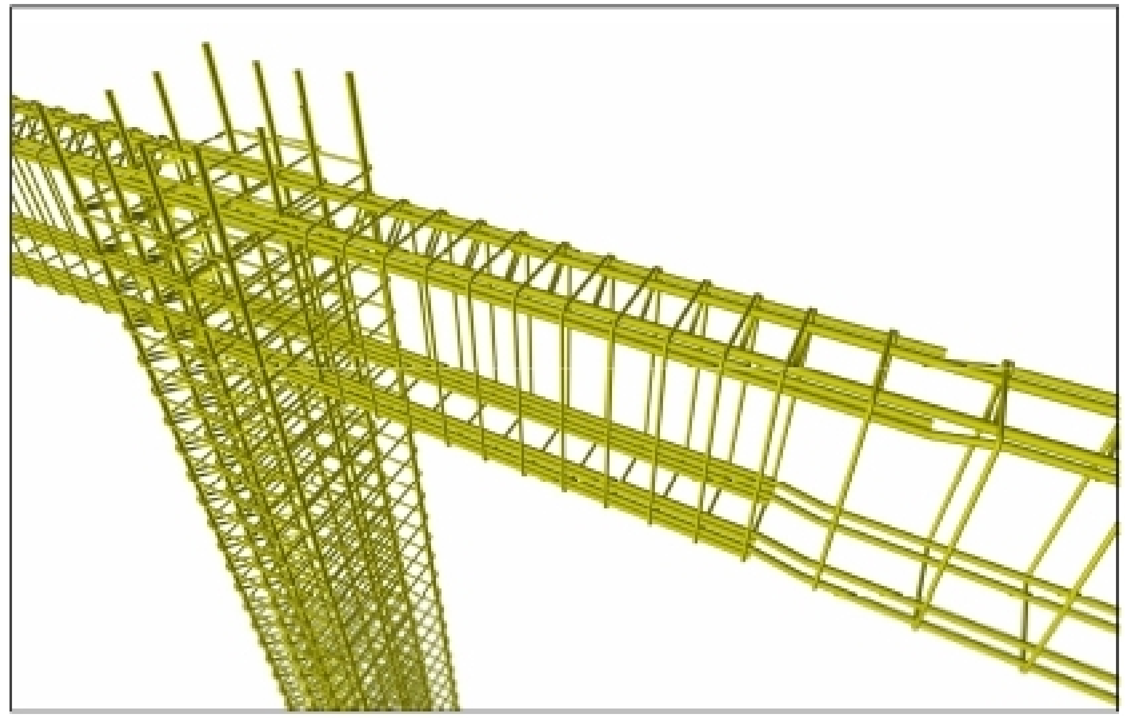


The reinforcement details of the two continuous beams of the frame

3.4.3. Reinforcement placement

Placing rebars along the length of the beams (longitudinal reinforcement):

In two successive beams that have the same section, the longitudinal rebar pairs placed both inside the upper and lower stirrup corners are colinear therefore, it is compulsory for the one to be bent so as to bypass the other. This bending must be vertically done in order to have adequate space for the proper concreting.



When using large diameter rebars (greater than Φ14), the bending cannot be manually done during the implementation therefore, it has to be done prior to placement by means of a double bending machine.

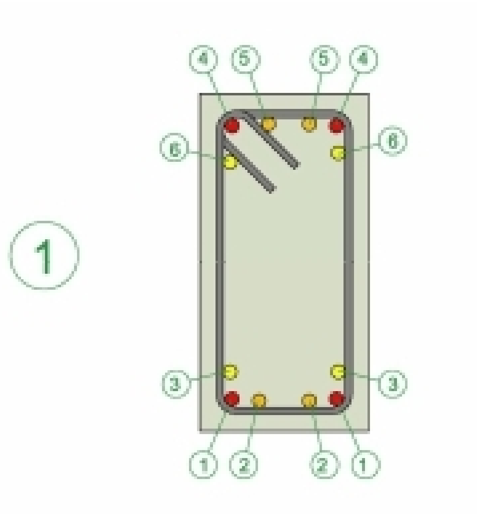
An effective rule to follow in cases like this is: (a) the bars placed in beams with odd numbers 1,3,5,... to be straight and (b) the corner bars placed in beams with even numbers 2,4,6,... to be appropriately bent.

Placing rebars in a beam's cross section

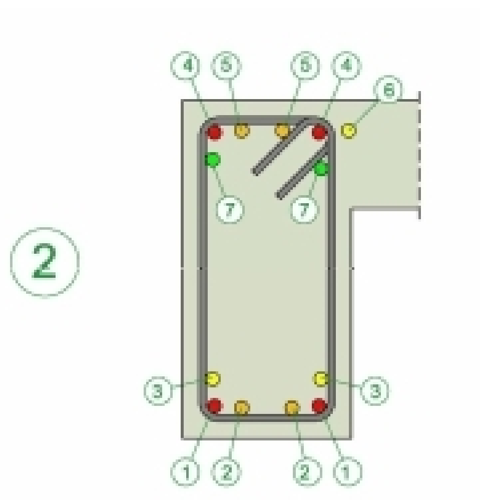
The case (1) shows, in priority order, the possible rebar positions in a rectangular 25/50 beam (with no slab on top).

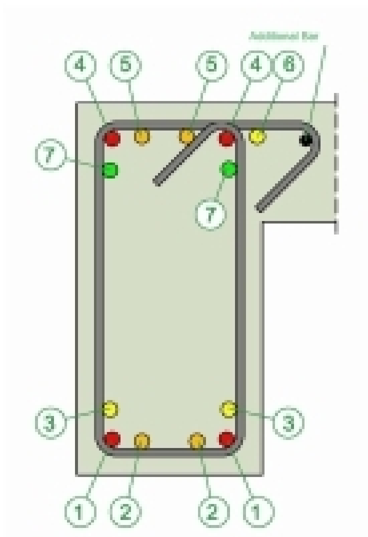
At the lower part of the beam, the first rebars to place are the corner bars 1, then the internal bars 2 followed by one bar 3 or if it is necessary by a second bar 3.

At the upper part of the beam the same things apply as well.



The case (2) shows a "Γ" section beam where at the upper part, the priority 6 is given to the rebar placed outside the perimeter of the stirrup. The bar 6 must be positioned at a distance around 2cm away from the stirrup so as to avoid damage during additional operations by plumbers, electricians etc. This bar should be fitted upon the slab support rebars or upon the upper leg of the stirrup which might close outside the beam's body.

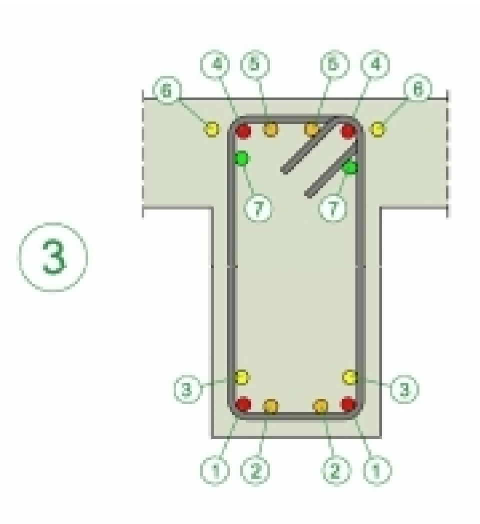




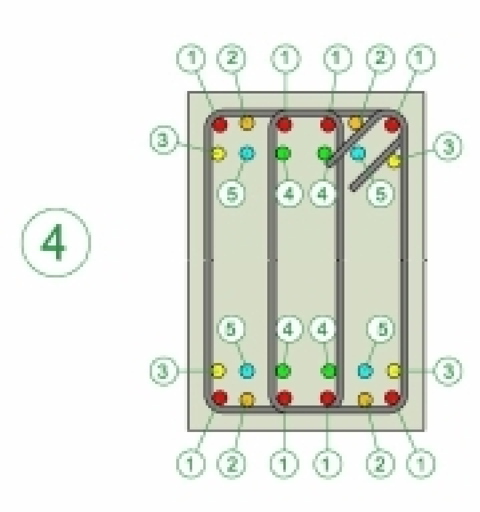
Notes:

- *Rebars in place 6 may be used only when they cross the adjacent column or when they are anchored inside it.*
- *In many cases, the stirrup cage is constructed and fitted inside the beam half closed so as to facilitate the implementation of the longitudinal rebars. Moreover its upper leg has a larger length which allows, after the placement and the wiring of the longitudinal rebars, its trouble free closing with the use of the proper machinery.*

The case (3) shows a "T" section beam, where at the upper part the priority 6 is given to the rebars outside the perimeter of the stirrup.

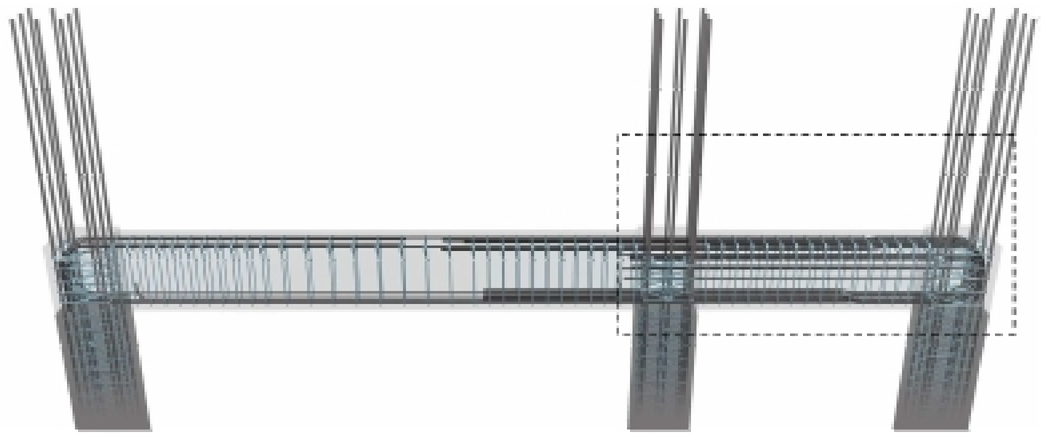


The case (4) shows in priority order, the possible rebar positions in a rectangular 35/50 beam with a four legged stirrup. It is mandatory to place firstly the corner bars 1, then one rebar 2 and the second rebar 2 followed by the rebars 3. If the reinforcement requirements are so large that cannot be met by an increase in the rebar diameter, bars 4 and 5 of the second layer are placed one by one.

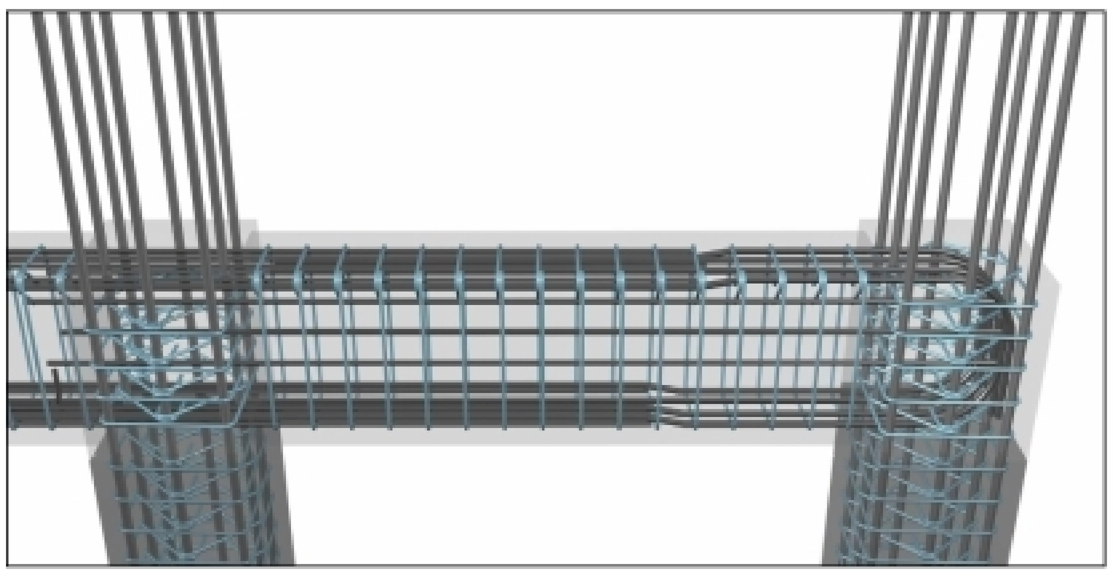


3.4.4. Short beam

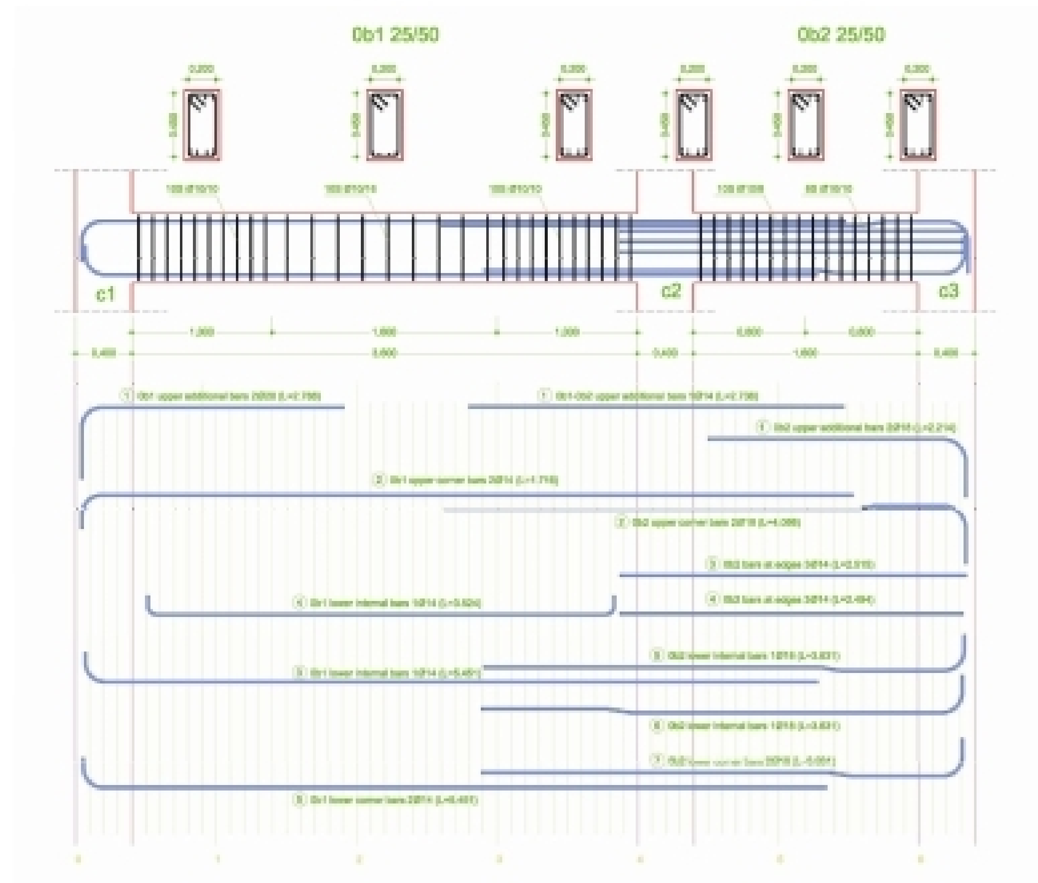
A beam which has a short span length compared to the span length of the other beams that belong to the same floor, might not have a serious bending problem but as a rule, its behavior is greatly affected by intense shear stresses. A part of the applied shear forces comes from the gravity loads however, the largest part is caused by the earthquake ground motion. Apart from the intensity of the shear forces, the short beams must counteract the effects of these forces direction shifting in the duration of the seismic event. This means that we have cyclic shear loading that tends to disintegrate the element. In short beams, the diagonal tensile stresses are carried by placing a strong transverse reinforcement towards all directions i.e. by placing narrow spaced, properly closed stirrups and lateral rebars. Theoretically, the best solution is to use special "X" shaped stirrups, however most of the times, this is a technically challenging procedure.



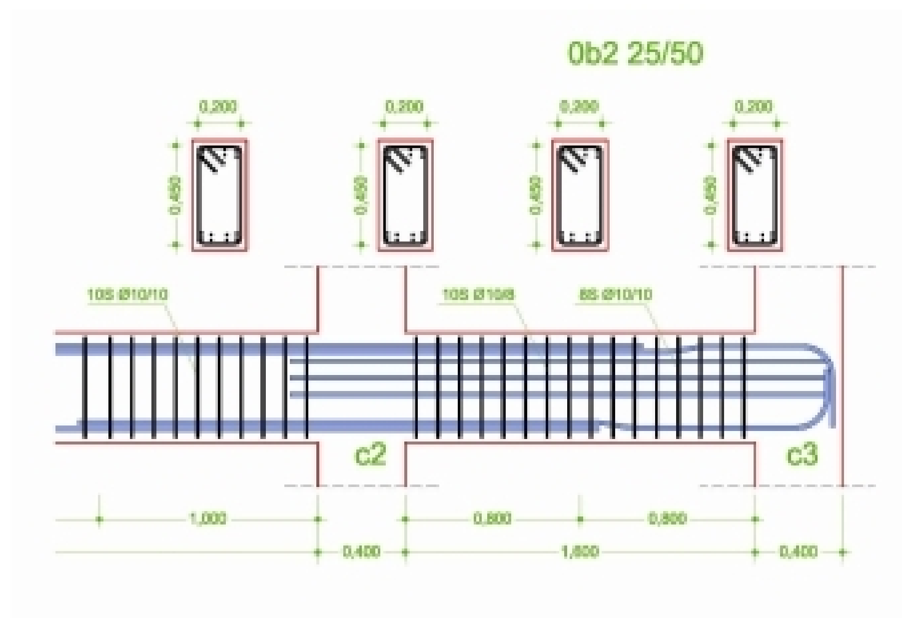
The right beam might be short compared to the left one but it has a larger amount of reinforcement (both longitudinal and vertical). <project: beams30>



The short beam is reinforced with (a) narrow spaced strong stirrups and (b) with lateral rebars.



Continuous beam's reinforcement details



Detail drawing of the short beam rebars

3.4.5. Beam under torsion

When a beam supports a slab (or when it carries another beam only on its one side), it is subjected to direct torsion.

Beam under direct torsion <project: beams40>

For common buildings in areas with high seismic activity, torsion is a quite dangerous stress condition, because:

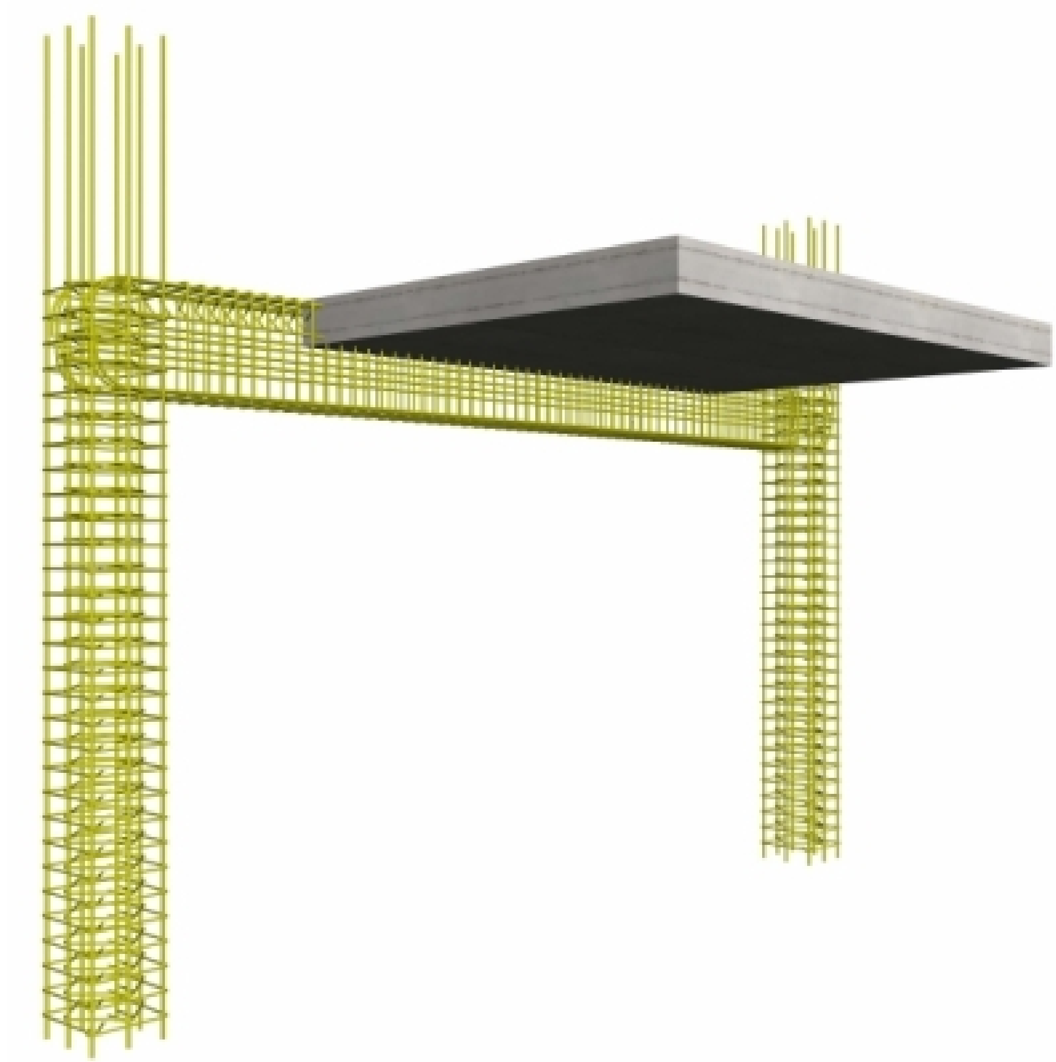
a) It is a statically determined stress. This means that if a failure occurs there is no possibility for transition to another static state.

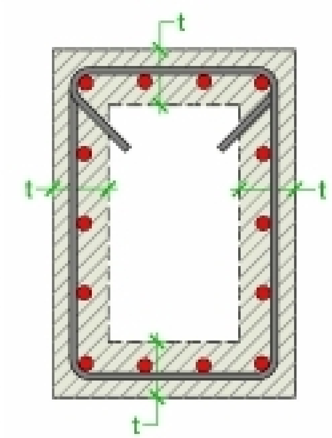
b) The rotations caused to the beam due to creep are relatively large thus leading to large slab deformations.

c) Failure is caused by shear stresses therefore, it is of a brittle nature and consequently there are no signs for the impending failure.

d) It is not easy for the technicians to understand that the formwork of the elements under torsion must not be removed in the usual time. On the contrary, the formwork must remain in place until the following-phase-casted-concrete that affects these elements is adequately hardened.

e) Reinforcing beams subjected to torsion follows special rules. In order to apply these rules, one does not only require thorough knowledge but also extreme care during the implementation.





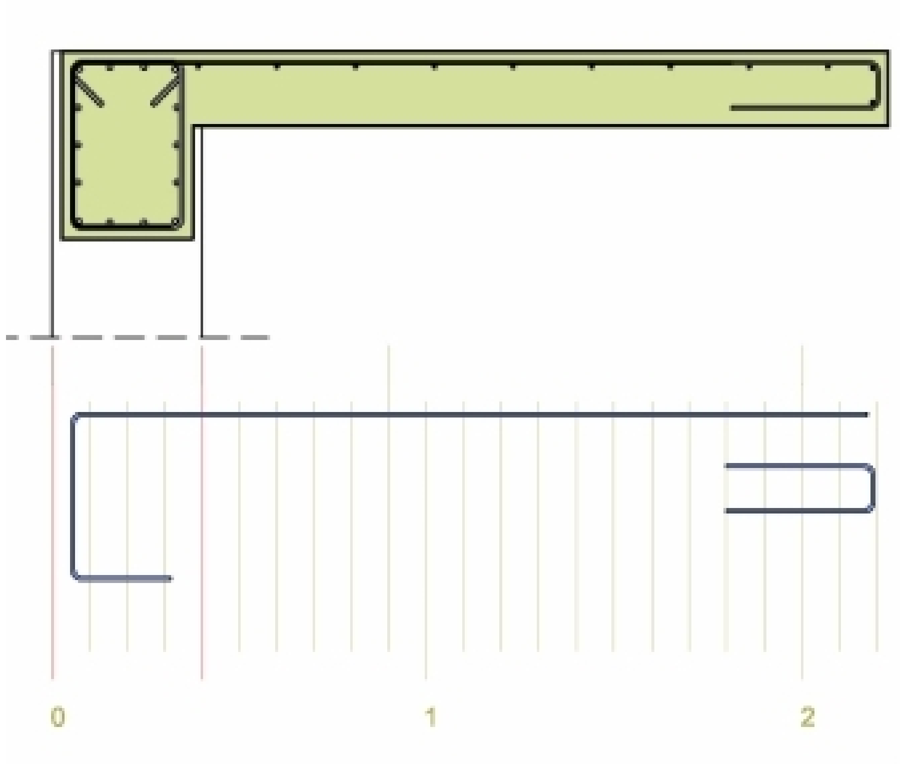
Either the beam section is hollow or solid it counteracts with the torsional moment and maintains a state of equilibrium with a closed flow of torsional shear stresses, in a peripheral zone.

Due to the high shear strength requirements, beams under torsion, are usually constructed with a large width. That way the beam's section approximates the square shape.

Torsion causes diagonal tensile stresses along the entire perimeter of the beam and in order these stresses to be carried both longitudinal and vertical reinforcement is required. The longitudinal reinforcement at the upper and lower side of the beam is provided by the upper and lower rebars, while the longitudinal reinforcement of the side-faces is provided by the rebars placed along the stirrups' legs depth.

The longitudinal rebars of the support areas are called to withstand the highest torsional stresses. Therefore, in order to behave in the required way, all rebars placed at the upper, lower and side parts of the beam must be properly anchored inside the column.

In order for the vertical reinforcement i.e. the stirrups to carry the required stresses; they must be properly closed therefore, it is mandatory to be formed with a double hook.



In order to be able to place the slab reinforcement, the beam's formwork must have its back side-face open.

The rebars of the slab supported by a beam, must be anchored at least with a double bend, as shown at the above detail. The rest of the reinforcement has to abide by the rules regarding cantilevers as explained in the following chapter.

In order to be able to place the slab's rebars, the formwork must have its back side-face open. Alternatively, the vertical slab bar could be constructed 5cm shorter so as to be placed unobstructed above the longitudinal reinforcement at the bottom part of the beam.

There is also another more complex but old and well-tried practice: in the slab area where torsion appears, the stirrup and the slab rebar are formed with one single bar, as shown at the figure bellow.

The reinforcement solution with unified stirrups – rebars in the slab area

3.4.6. The feasibility of concrete casting in beams

In the construction of a building, the proper reinforcement implementation will be proved only during the concreting process. The steel fixer must always bear in mind that the concrete and vibrator have to pass unobstructed between rebars. In case the columns, the beams and the slabs of one storey are simultaneously casted, the reinforcement implementation requires even more attention and care.

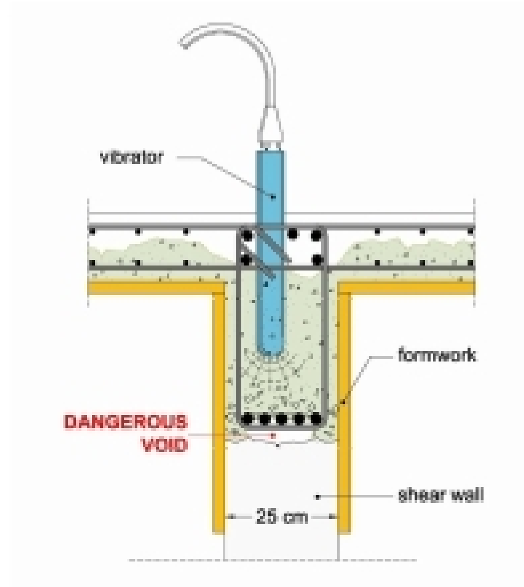
Since the proper concreting correlates with the proper construction, it is recommended to complete the concrete casting of a floor in two phases. The first phase should include the mould and the concreting of the columns and the second phase should include the mould and the concreting of the beams and the slabs.

The key to a feasible concrete casting is the use of a second rebar layer, as described in paragraph 3.4.2. Placing the bars at the two edges of that second layer is not a strenuous procedure since they are wired together with the stirrup legs. That way, enough space is provided for the concrete and even for the vibrator to pass vertically between the rebars.

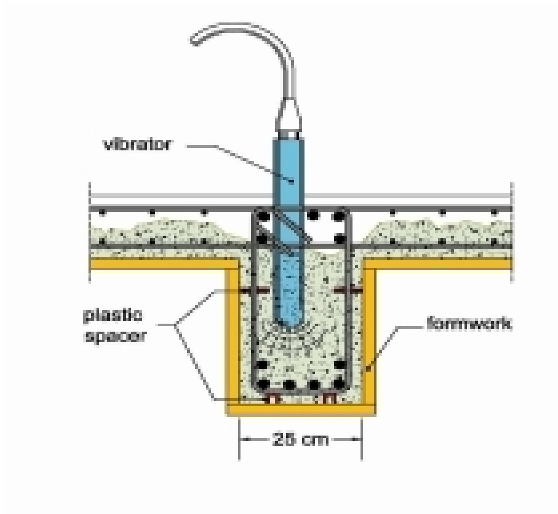
As a rule, in earthquake resistant structures there is a large amount of reinforcement and if its implementation is not done with the proper way, most of the times, the following serious constructional faults appear in the joint areas:

(a) In case the columns, the beams and the slabs of one storey are simultaneously casted, small or large voids appear inside the columns' concrete mass which are extremely difficult to fill.

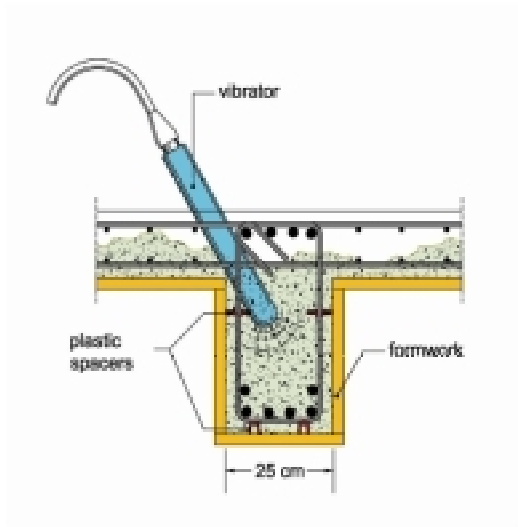
(b) In case the columns are casted separately from the other elements, the concrete does not pass under the rebars so as to bond with the already casted column. The worst part is that this fault cannot be seen by the eye as the concrete passes normally through the cover depth. Unfortunately, it is only until after the formwork's removal that one may realize if this is properly constructed.



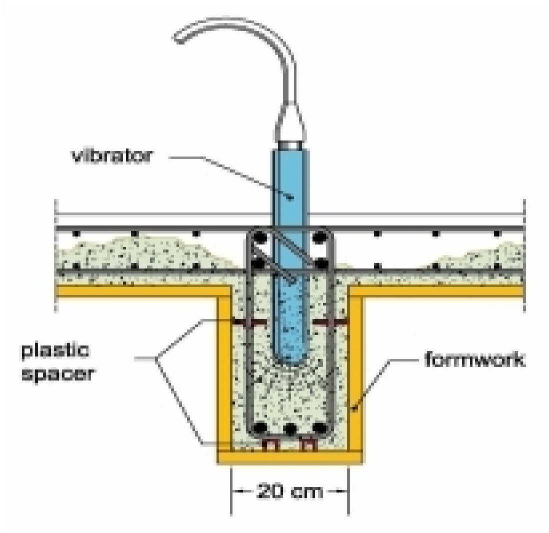
The following figures present 5 rules for the proper reinforcement implementation and the proper concrete casting:



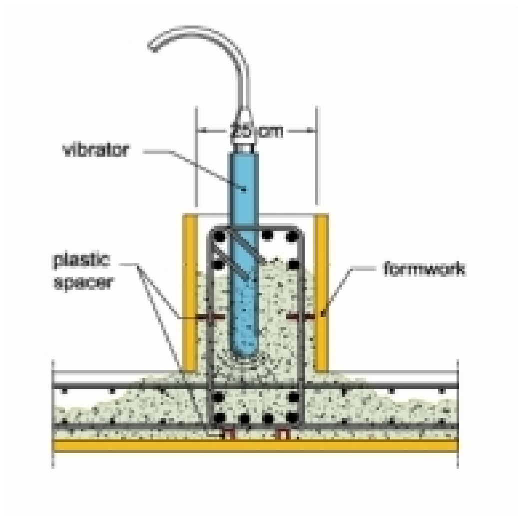
The vertical vibration is the most desirable one. (1)



In the presence of a slab, an alternative vibration possibility is the lateral placement of the device. (2)

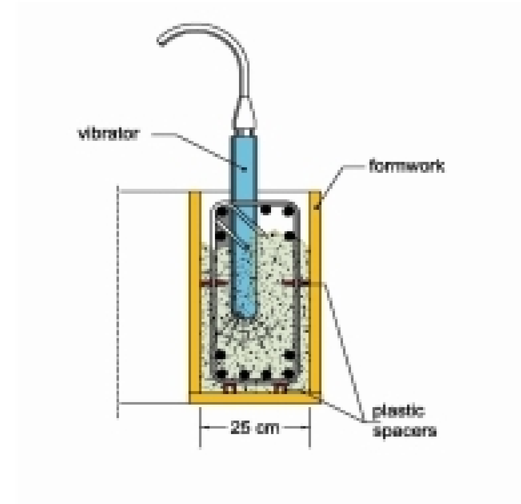


The 20cm wide beam should be avoided. However, when it is constructed it requires great care. (3)



The only way to vibrate an inverted beam is by vertically positioning the device. (4)

In the case where the beam is not connected on either side with a slab (foundation beams), the only way to vibrate the concrete is by the vertical placement of the device. (5)



3.5 Slabs

The general concepts regarding slabs were explained in paragraph 1.2.3 while the concepts regarding their behavior were explained in paragraph 1.4.1. This paragraph refers to the rules concerning the slab reinforcement.

3.5.1 One-way slab (simply supported slab)

The following describe the way to reinforce a one-way (simply supported) slab.

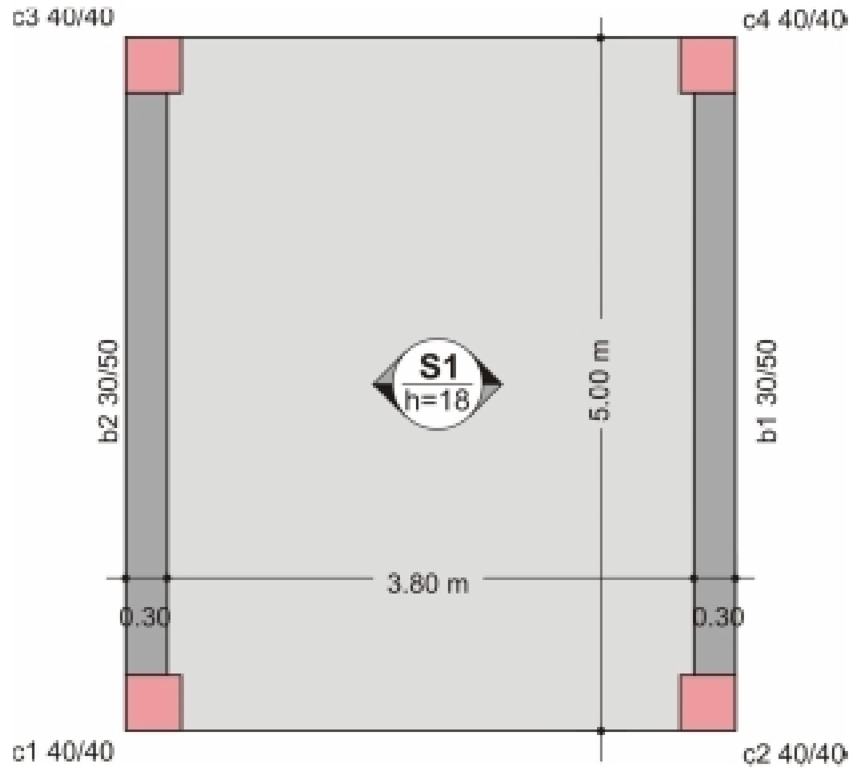
The structural frame consists of four columns, two beams and one slab
<project: slabs10 >

The one-way slab is supported by two beams.

The example regards slab S1 which is 18cm thick, its primary dimension is equal to 0.30+3.80+0.30=4.40m and its secondary dimension to 5.0m. The slab sits upon beams b1 and b2 which are supported by column pairs K2, K4 and K1, K3 respectively.

Usually, when a slab sits upon a beam the support is considered to be pinned[5].

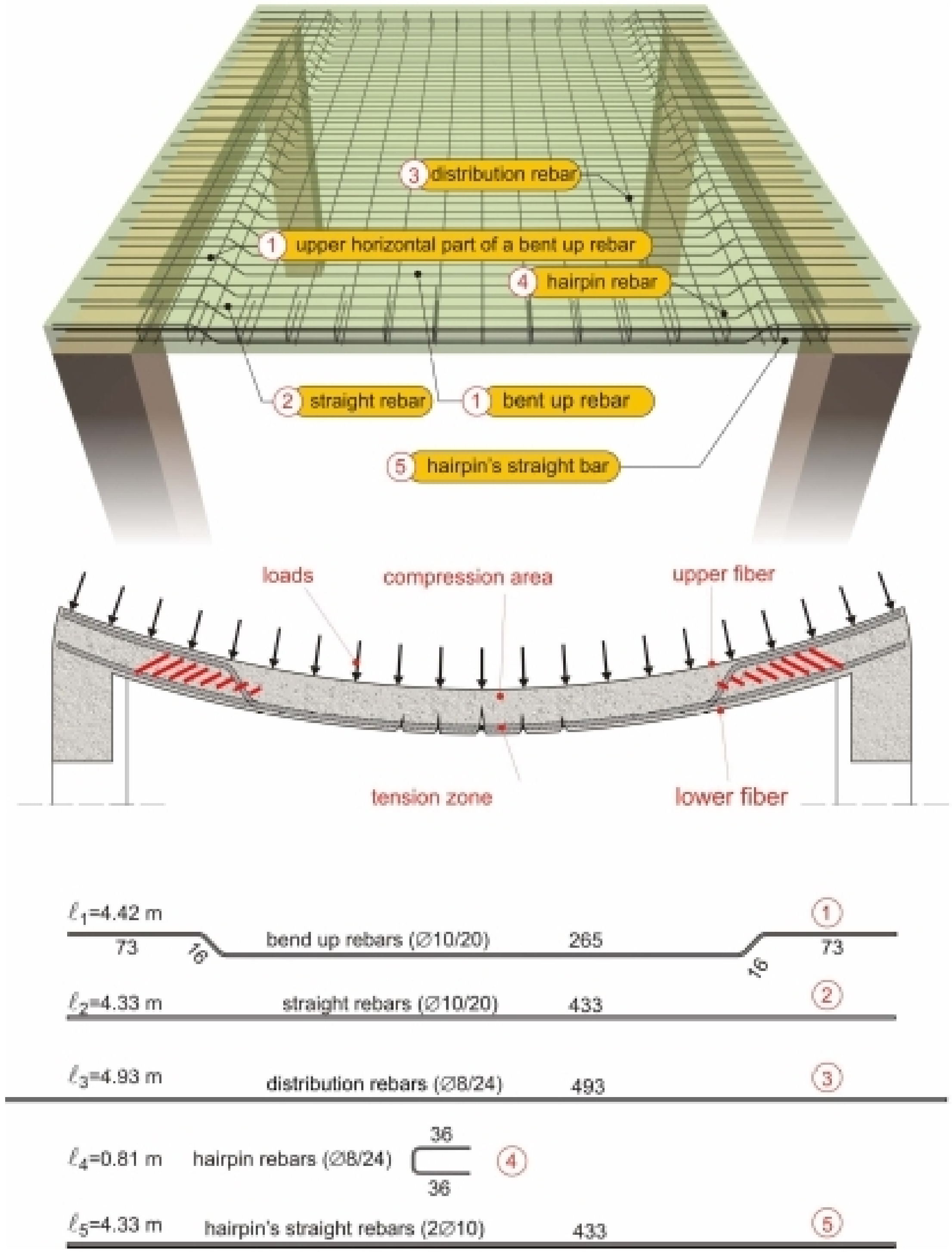
The following figure is called **carpenter's formwork drawing[6].** It symbolically illustrates the structural frame of reinforced concrete.



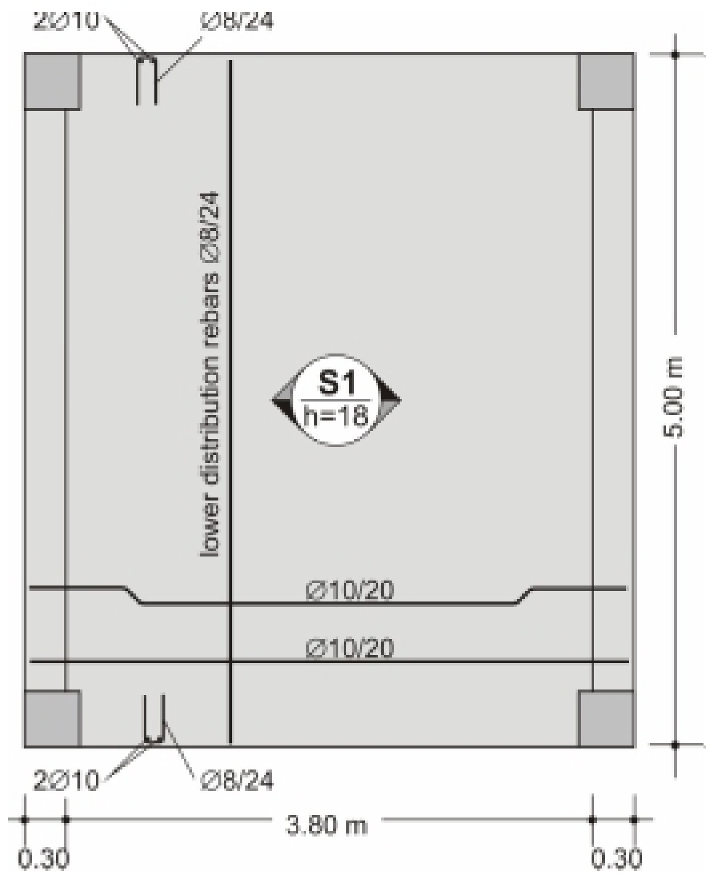
The carpenter's formwork drawing regards the formation of the slab's moulds

[5] The simultaneous concreting of a slab and a beam results to a monolithic support between them. This causes the appearance of torsional moments to the beam and negative bending moment to the support area of the slab. The magnitude of these moments depends upon the beam's elastic stiffness which is relatively large. However, after the formwork's removal it is dramatically decreased due to creep i.e. the deformation caused with time. According to the regulation, the effect of the beam's rigidity may be neglected but when it is not neglected it must be taken equal to 1/10 of the elastic stiffness. The effect of the torsional stiffness is practically zero except in cases of a static system's equilibrium as it happens in the example of § 3.4.5 (beam under torsion).

[6] Formwork is the term given to moulds into which concrete is poured. The wooden formwork is built on site out of timber. The formwork drawings are allocated for two specific uses one for the creation of the formwork by the carpenter and thus it is called carpenter's formwork drawing and one for the steel reinforcement implementation by the steel fixer which is called steel fixer's formwork drawing.



Behavior and reinforcement of one-way slab



*The **steel fixer's formwork drawing** regards the slab's reinforcement*

The slab of the above example has four types of reinforcement:

1st) primary reinforcement

In a one-way slab the need for reinforcement appears mainly in the span and towards the bending direction. The necessary bars are placed based on the amount of the calculated required reinforcement. In this specific case the provided bars are Φ10/10. This means that Φ10 rebars have been placed every[7] 10cm.

2nd) secondary reinforcement or distribution reinforcement

Apart from the primary reinforcement that is placed parallel to the deformation direction, there is also need for reinforcement in the other, the secondary direction. In that direction, the placed rebars are Φ8/24 which means that bars with a Φ8 diameter have been placed every[8] 24cm.

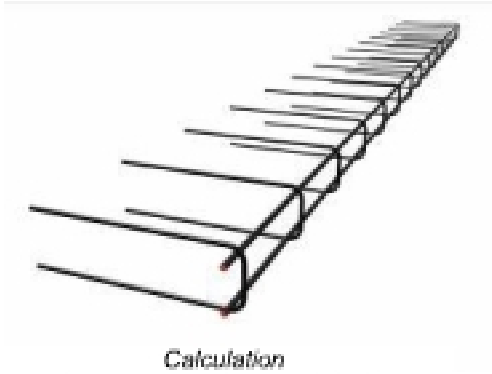
[7] The reinforcement in slabs is calculated per 1m of width. In this specific example, in every 1 m (100 cm) of slab width there are 100/10=10 rebars. The Φ10 rebar has a cross-section area of $\pi * d^2/4 = \pi * 1.0^2/4 = 0.785 cm^2$ and therefore, the total amount of reinforcement placed in 1m is 10bars*0.785=7.85cm^2. This value can be taken directly from table 3.

[8] The Φ8 rebar has a cross-section area equal to $\pi * 0.8^2/4 = 0.50 cm^2$. The rebars placed in 1m are 100/24=4.17 consequently, the total amount of secondary reinforcement is 4.17*0.50=2.09cm^2/m. This value can also be taken directly from table 3 in ½*Φ8/12

3rd) free edge reinforcement

The free edges of slabs are more susceptible to stresses and therefore, in these areas hairpin reinforcement is placed. Its proper position is secured by means of two bars placed inside its corners.

Hairpin reinforcement is easily formed by a folded wire mesh (see and paragraph 2.6.1).



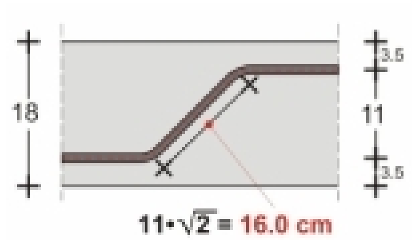
4th) support reinforcement

The minimum required reinforcement in the support areas is provided by two ways:

1st way: Half the span rebars i.e. Φ10/20 are shaped with bends at their ends (in every two bars one is straight and one is bend-up). The other half span rebars are formed with a straight length. That way has been followed in this specific example.

2nd way: All span rebars i.e. Φ10/10 are manufactured and implemented with a straight length while in the upper part of the support areas additional straight rebars are placed.

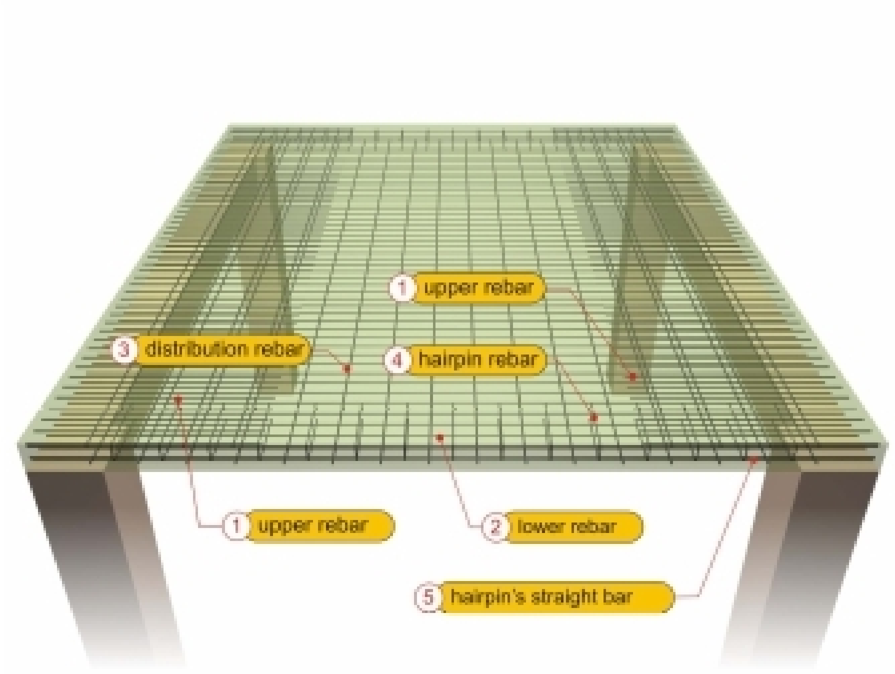
Calculation
of the bent-up part of a rebar

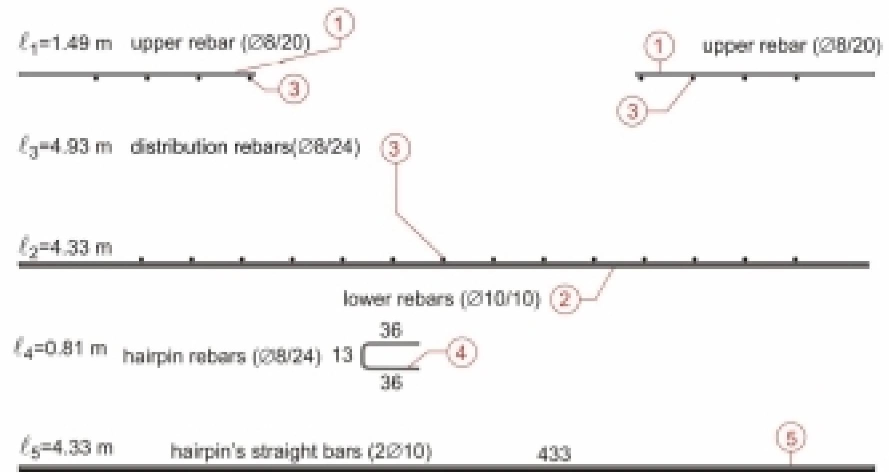


If the slab's thickness is 18cm, then the bent-up part will have a length equal to:

(18-3.5-3.5)√2= 11*1.4=16.0cm*

For an effortless and economical implementation, when using straight-length rebars it is obligatory to use industrial wire meshes as shown at the following figure.

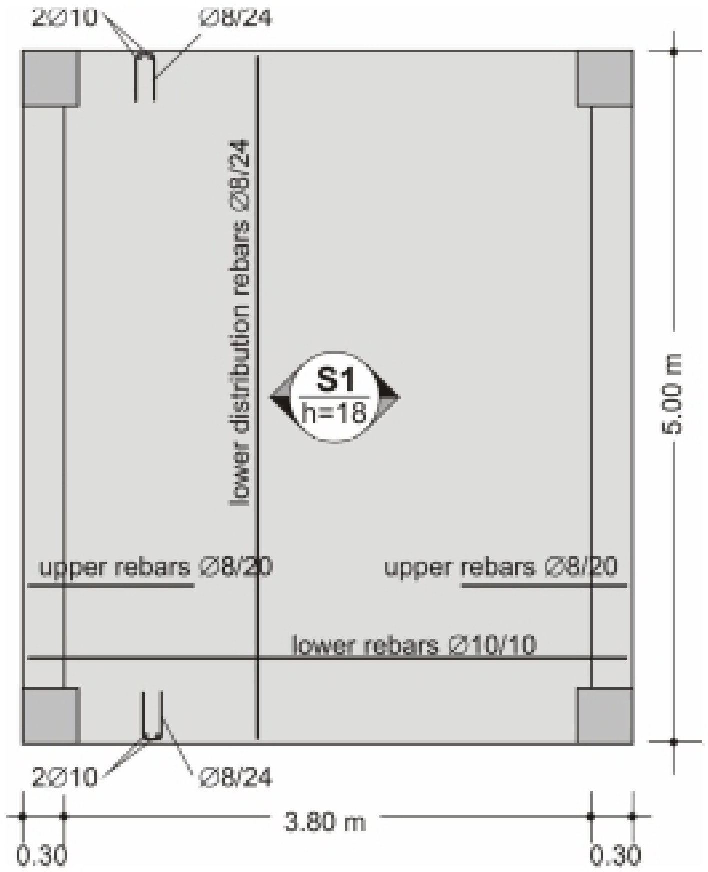




Reinforcing the one-way slab of the above example by means of straight-length bars

<project: slabs15>

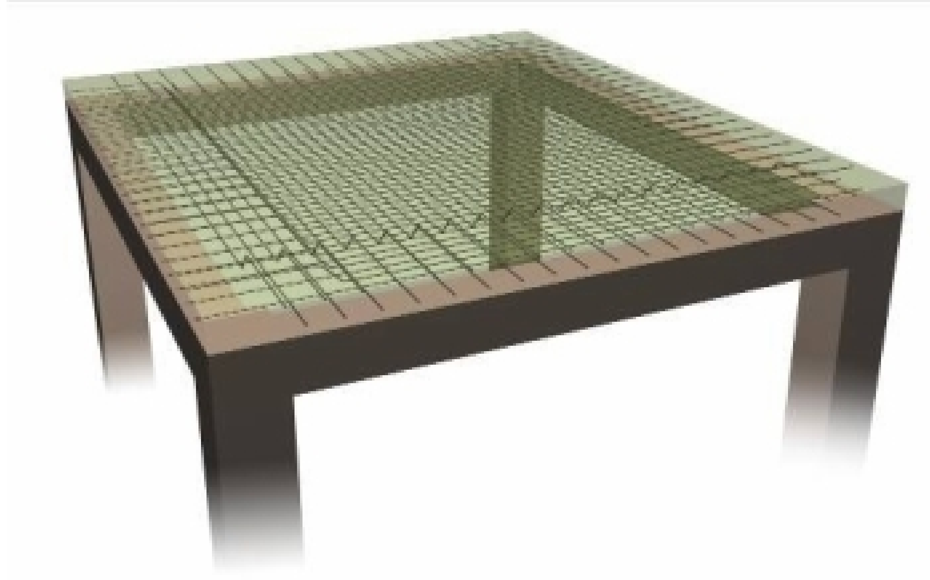
In case a slab is reinforced only with straight-length bars which, as a rule, means reinforcement with wire meshes, the steel fixer's formwork drawing is shown at the figure below.



The steel fixer's formwork drawing of a one-way slab, reinforced with straight-length bars

3.5.2 Two-way slab

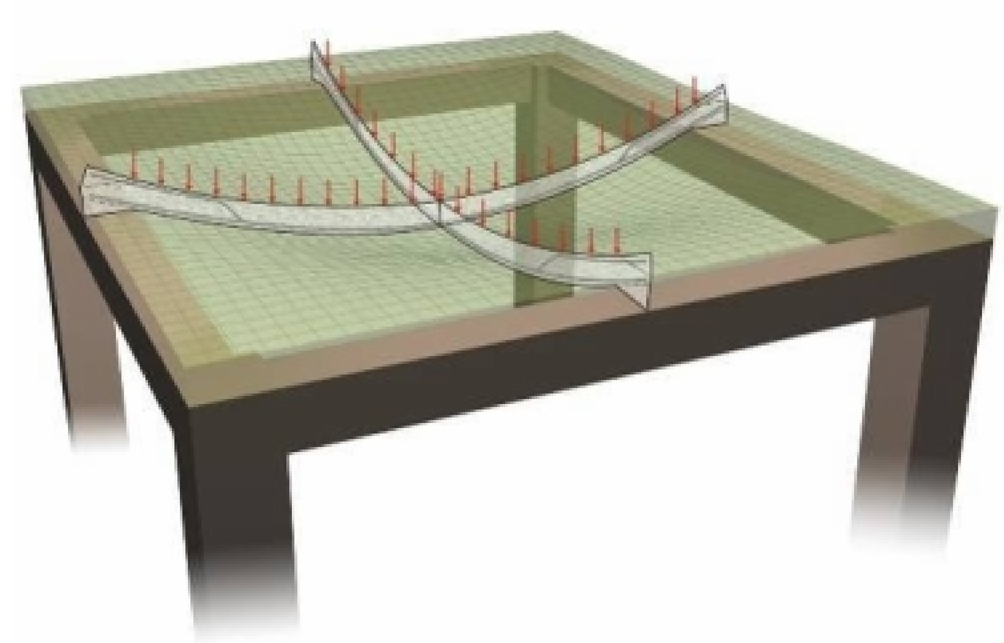
If two beams are added under the free edges of the slab in the previous example, then the slab S1 becomes a two-way slab.



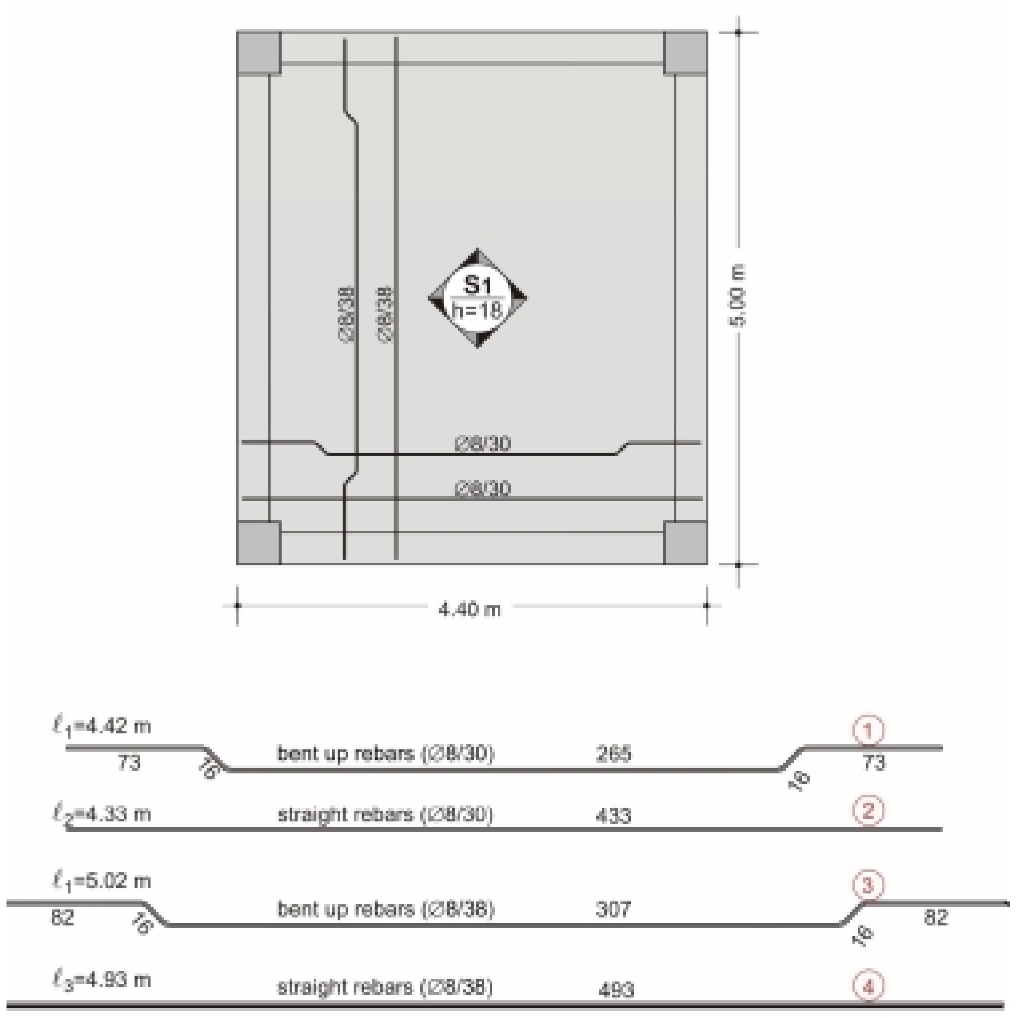
The two-way slab S1 is supported by four beams
<project: slabs20>

The behavior of a two-way slab is similar to that of a one-way slab the only difference is that the former works in both directions.

The reinforcement rules are also similar in both directions.



Behavior of a two-way slab



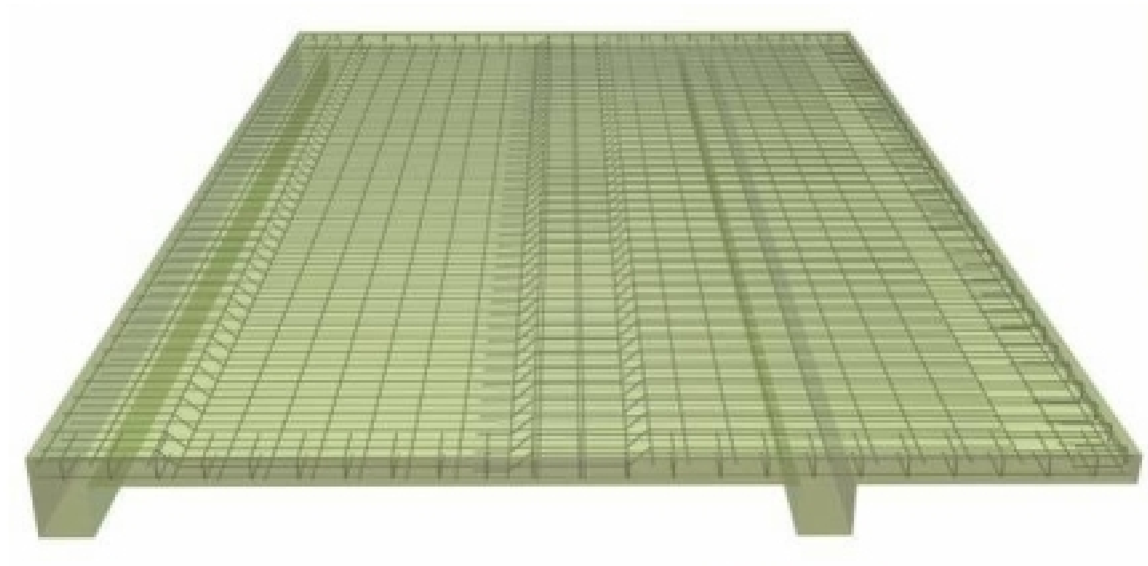
The steel fixer's formwork drawing of a two-way slab

For reasons regarding behavior, safety and economical design, the two-way slab is far more efficient than the equivalent one-way slab[8].

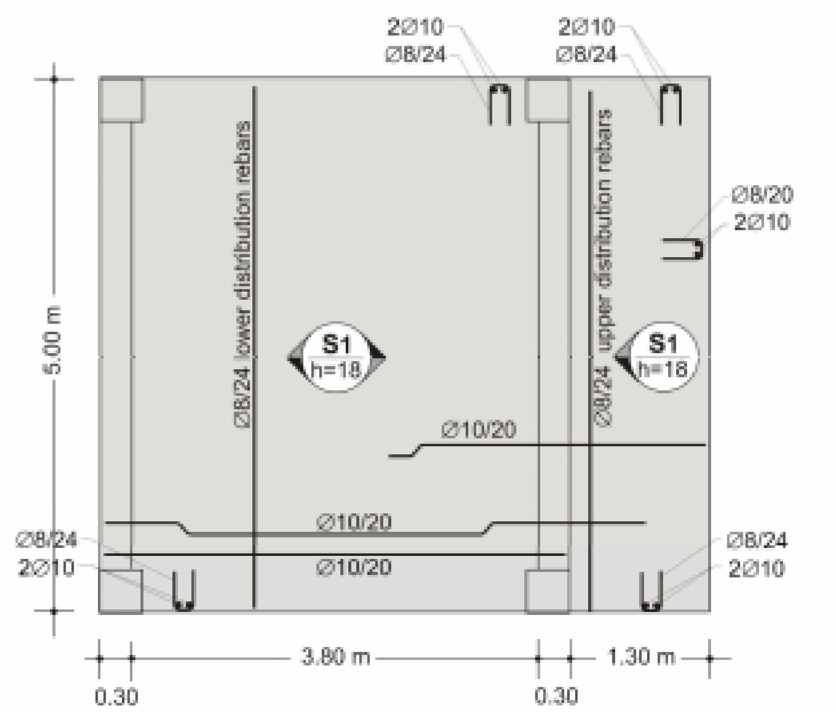
[8] The two-way slab of the example, with the same dimensions and the same applied loads as those in the one-way slab, requires reinforcement equal to Φ8/15 in the primary (most heavily loaded) direction and Φ8/19 in the secondary direction. The primary direction reinforcement Φ8/15, is equal to 3.35cm²/m (from table 3) which corresponds only to 43% of the reinforcement required in the equivalent one-way slab which is equal to 7.85 cm²/m.

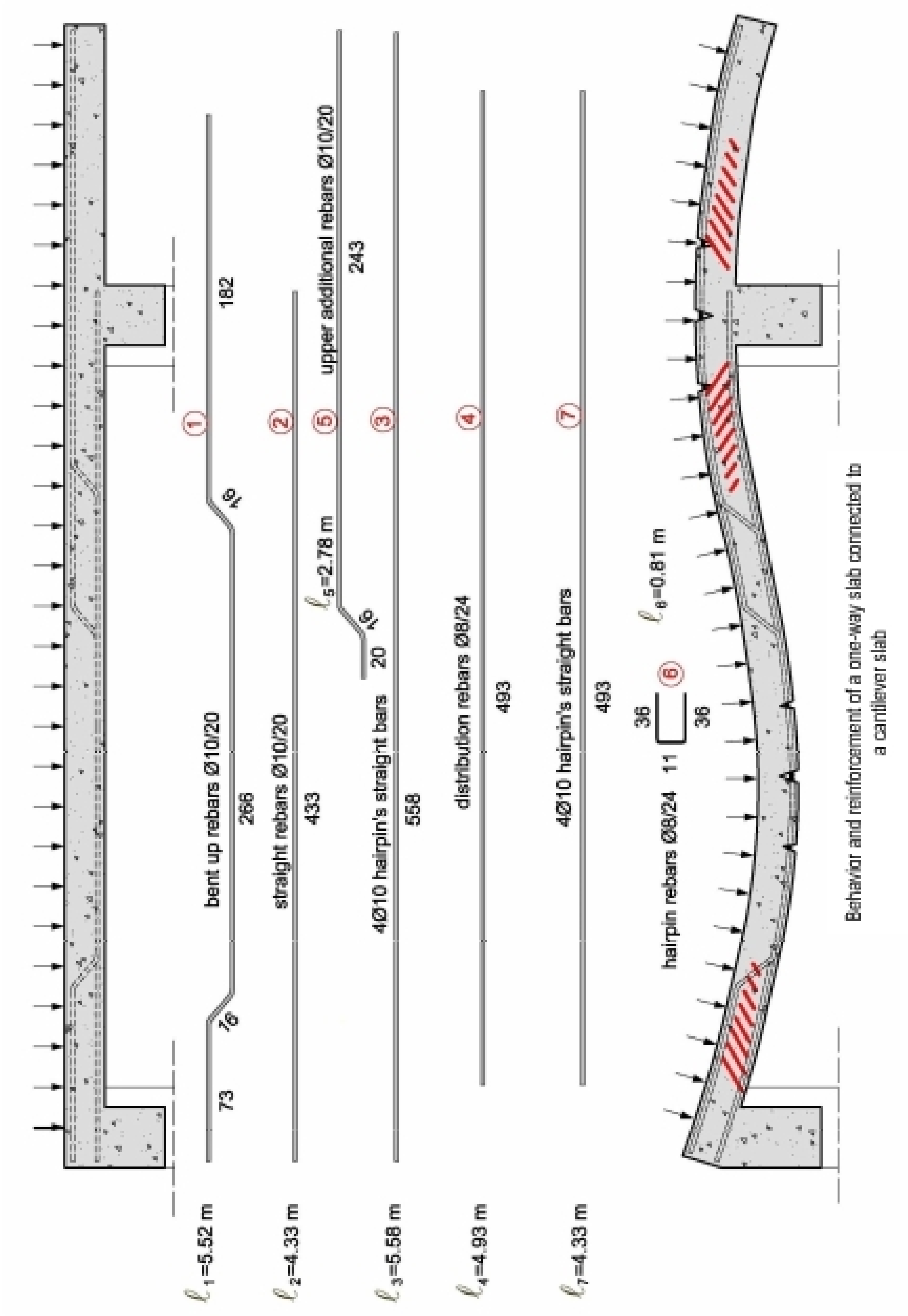
3.5.3 One-way slab connected to a cantilever

The behavior and the reinforcement of a one-way slab connected to a cantilever are described below. If the first slab is a two-way slab both the behavior and the reinforcement rules are analogous.



One-way slab connected to a cantilever <project: slabs30>



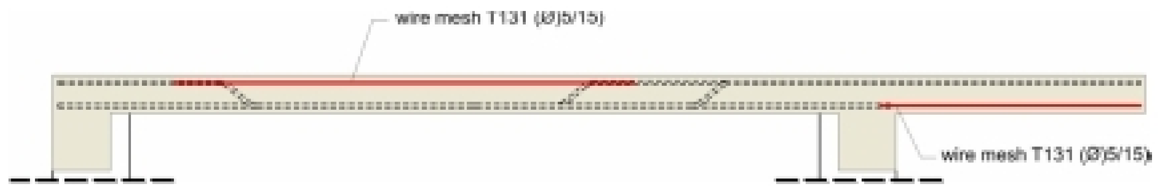


Behavior and reinforcement of a one-way slab connected to a cantilever slab

Note:

The bars shown at this example constitute the primary and the secondary reinforcement required by the static calculations. They are placed in parts of the lower and upper slab surfaces and they secure the structure's strength against the primary loads defined by the regulations. However, apart from the primary loads there are other most of the times incalculable loads that cause less intense, secondary stresses. These are successfully carried in areas with reinforcement while in all other areas they incline the formation of cracks. These type of stresses, except from concrete's drying shrinkage, are differential deformations caused by sudden differential stressing, e.g. the placement of building materials upon a part of a slab, mainly though they are deformations caused by earthquake forces. The cracking does not affect the structure's strength but it arises serviceability and aesthetic issues. The cracking's control can be achieved by an additional light ***coherence reinforcement*** [10] *placed at the lower and upper slabs' surfaces in the areas that remain unreinforced.*

In the upper floor slabs and generally, during the construction stage, in all weather-exposed slabs it is almost mandatory to place a light wire mesh so as to avoid the cracking caused mainly due to the weather conditions present throughout the building's construction.



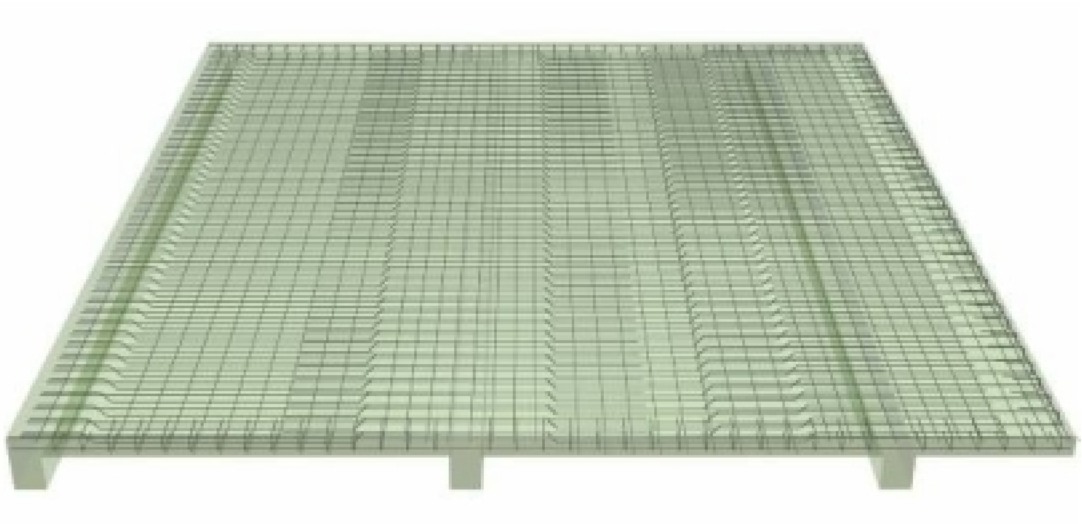
The coherence reinforcement is provided by a light wire mesh e.g. T131, placed at the lower surface of the cantilever slabs and at the upper part of the slabs' span which does not have primary reinforcement, as shown at the above figure.

The coherence reinforcement's cover depth is secured as shown also in § 2.6.1.

[10] The coherence reinforcement is analogous to the surface reinforcement which is required by all regulations only for cracking prevention, when due to adverse environmental conditions present throughout the structure's service life, there is a large reinforcement cover depth.

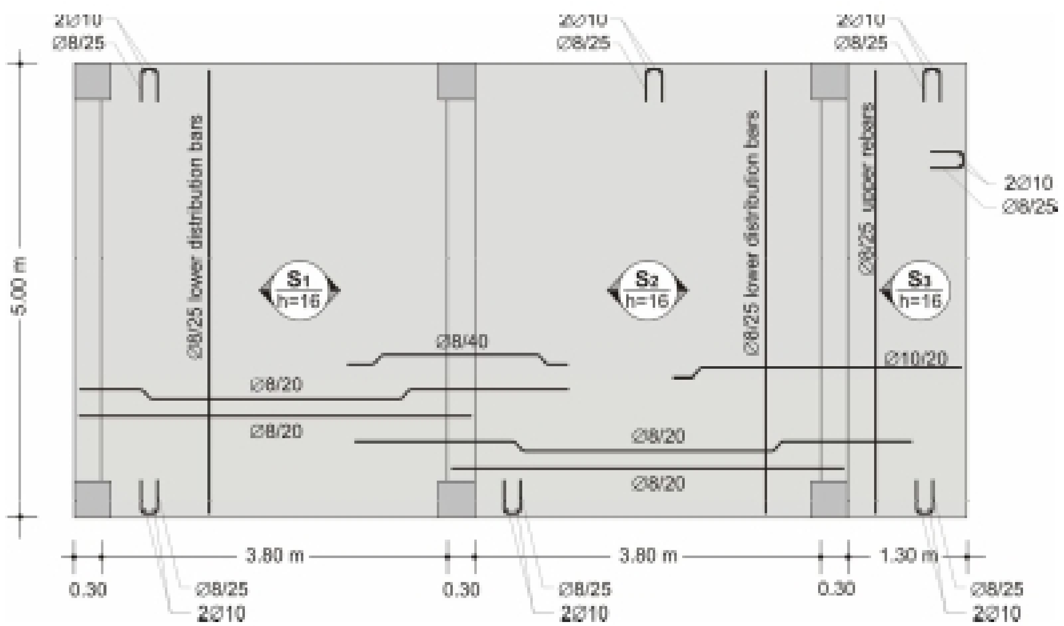
3.5.4 Continuous slab connected to a cantilever

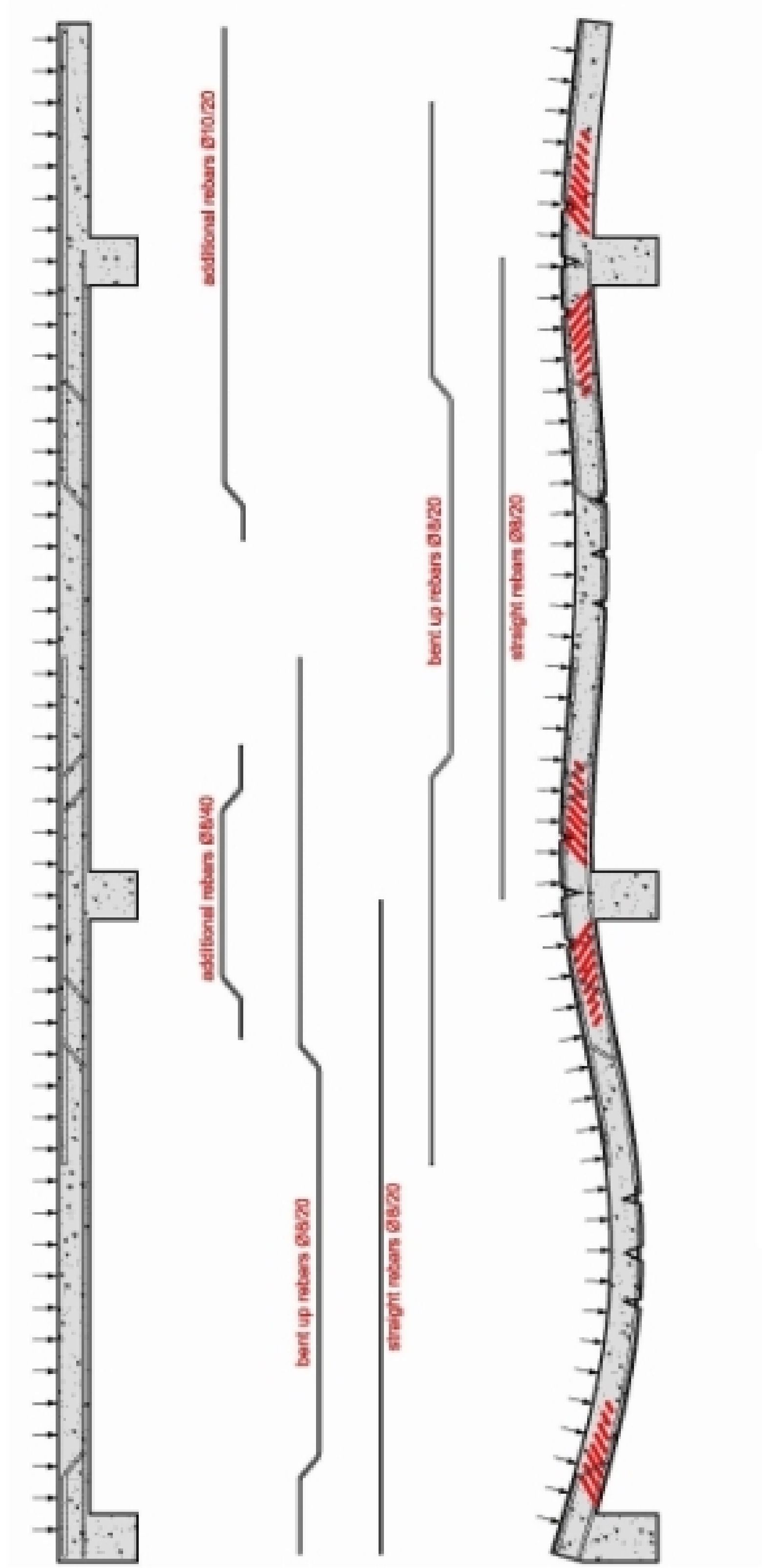
In the case of three continuous slabs the third of which is a cantilever, the behavior and the reinforcement have the following form.



Two continuous one-way slabs connected to a cantilever

<project: slabs40>

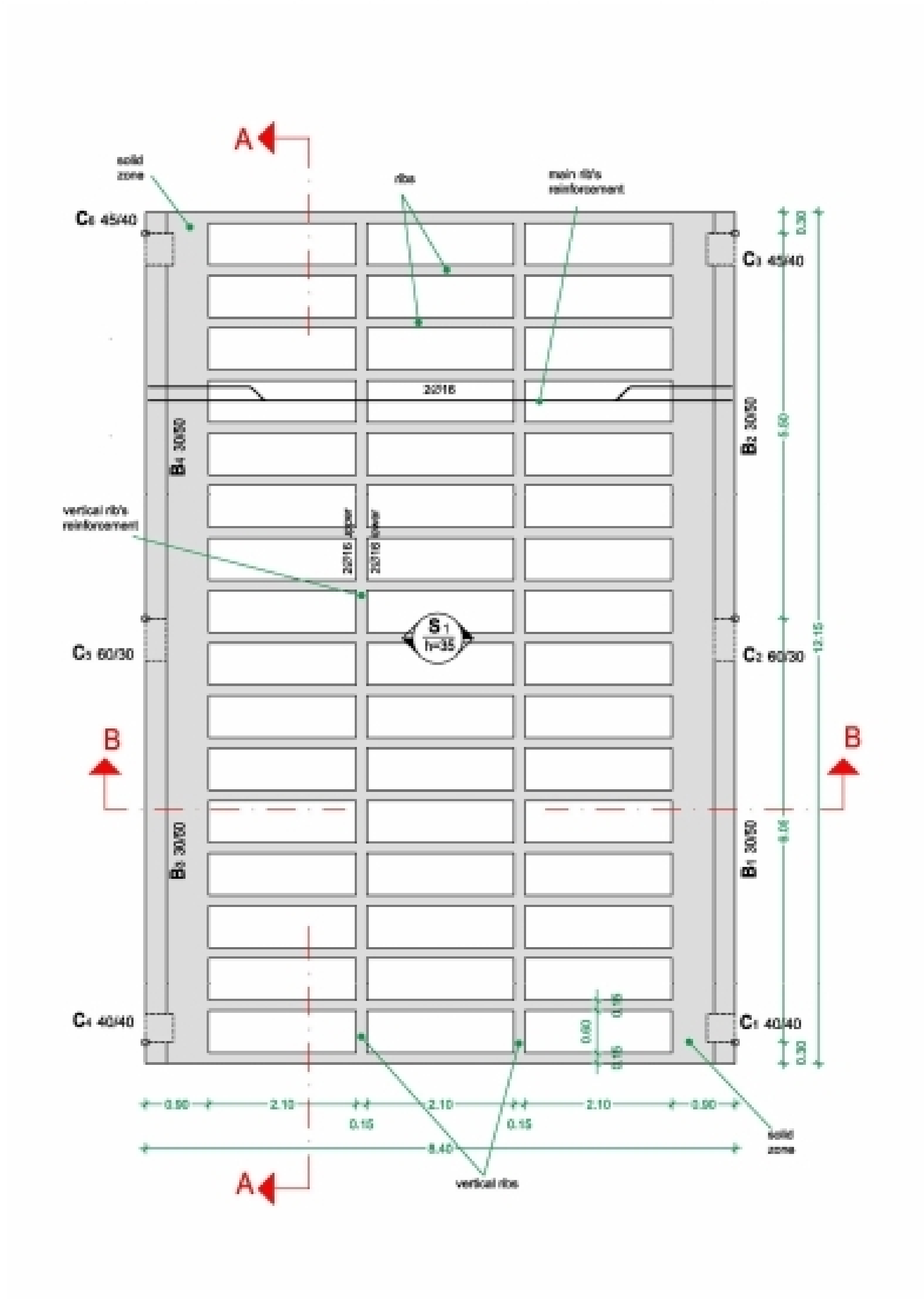




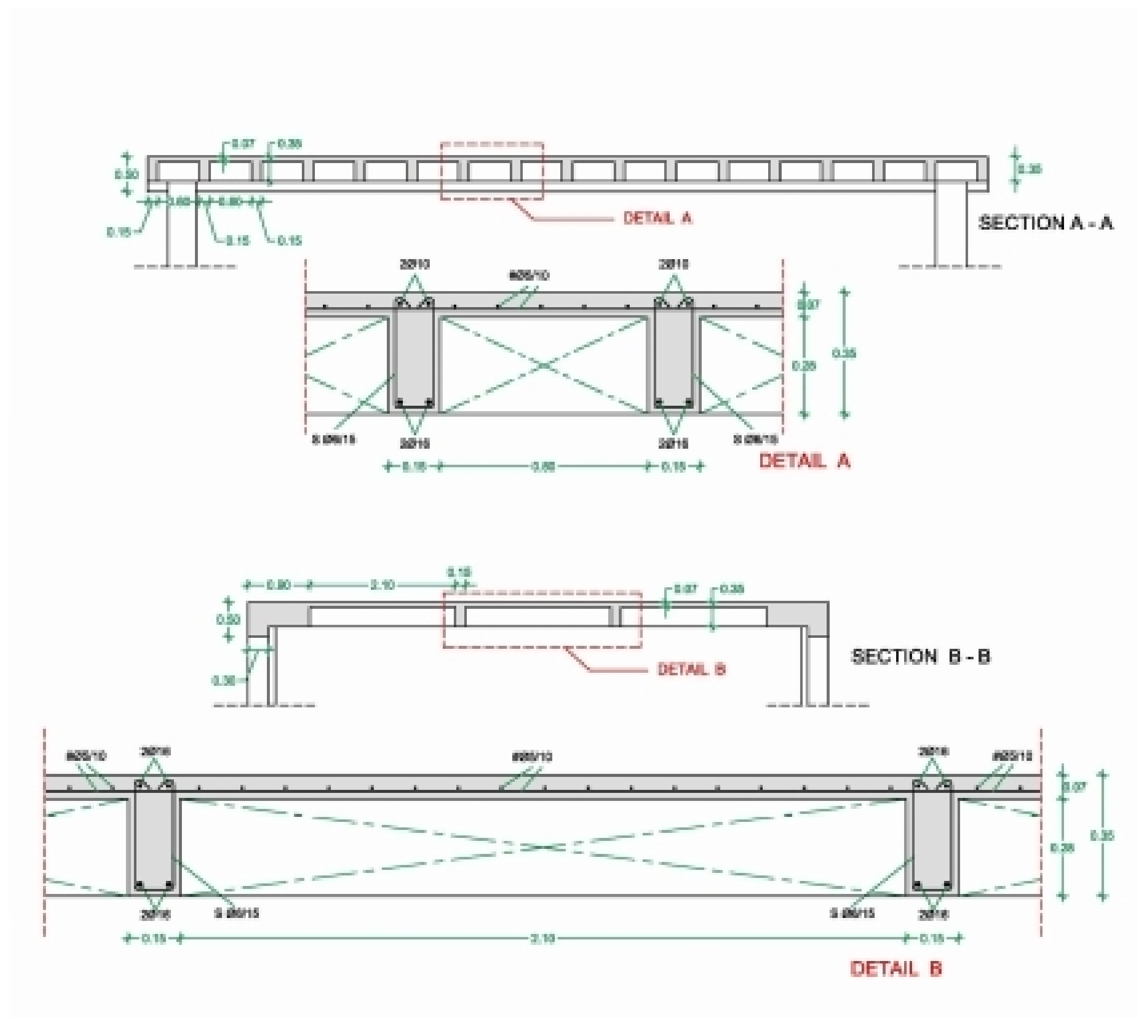
Continuous slabs connected to a cantilever slab
(the deformations are shown at a large scale)

3.5.5 Ribbed slabs

The ribbed slab (or zoellner slab) is something between a slab and sum of beams. Generally, during a seismic event ribbed slabs, like rigid ones, are not stressed along the vertical direction therefore, their reinforcement is practically independent of the earthquake forces.



The rib reinforcement follows the same rules with the beam reinforcement. However, mainly as far as the stirrups are concerned, the amount of placed rebars is not as large as it is in beams. Between the ribs, the slab is usually reinforced with a common wire mesh[11].



Reinforcement details of a ribbed slab

When the ribbed slab is continued by other slabs (as it commonly is), the support areas are called to withstand severe moments and shear forces, therefore the ribs' width is preferred be greater than e.g. 20cm.

[11] Since slabs are not considered to carry earthquake loads, standardized wire meshes B500A (according to table 2) can be used in order to provide both the slab reinforcement and the ribs' stirrups. In this specific example, a T196 (Φ6/10) wire mesh could be used for the slab reinforcement and a T188 (Φ6/15) wire mesh could be used for the formation of the ribs' stirrups.

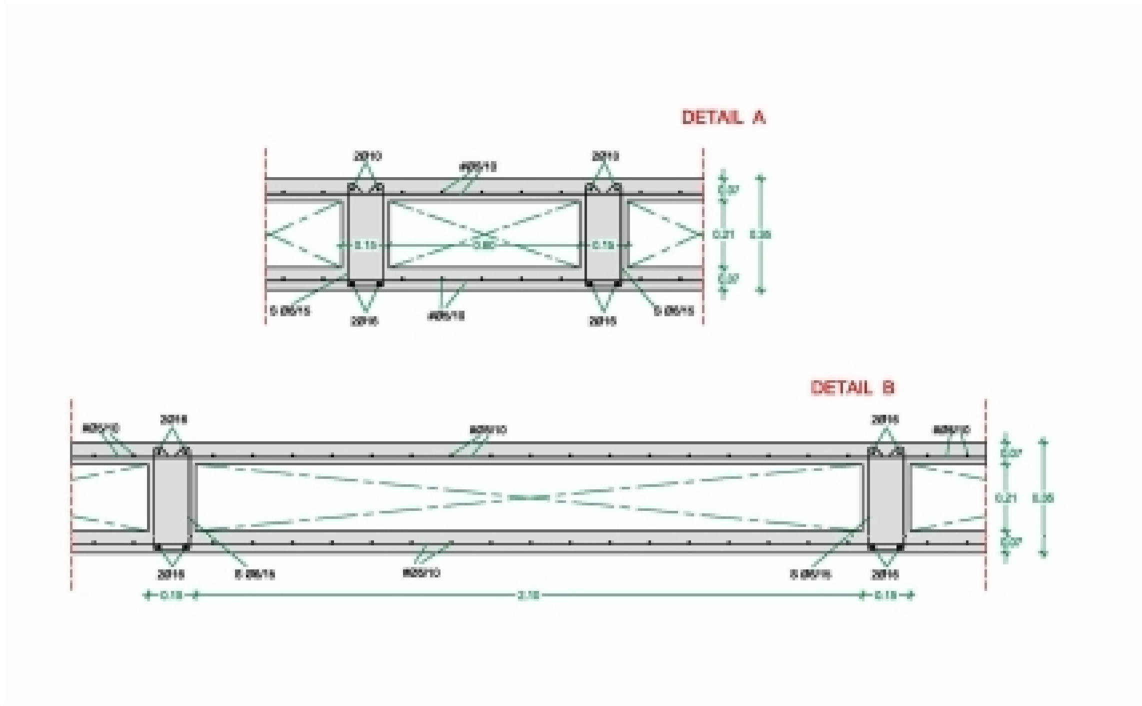
3.5.6 Sandwich slabs

In reality, sandwich slabs are ribbed slabs with a slab placed both to their upper and lower surface.

Sandwich slabs may have the disadvantage of a larger weight compared to the ribbed ones but on the other hand, they have the advantage that their spans and supports behave in the same proper way. Their construction is more demanding than that of the common ribbed slabs but at the same time, they have the advantage of a uniform, solid lower surface.

As shown bellow, the only difference between the prior mentioned ribbed slab left as it is and the prior mentioned ribbed slab but calculated and constructed as a sandwich slab, is the different sections.

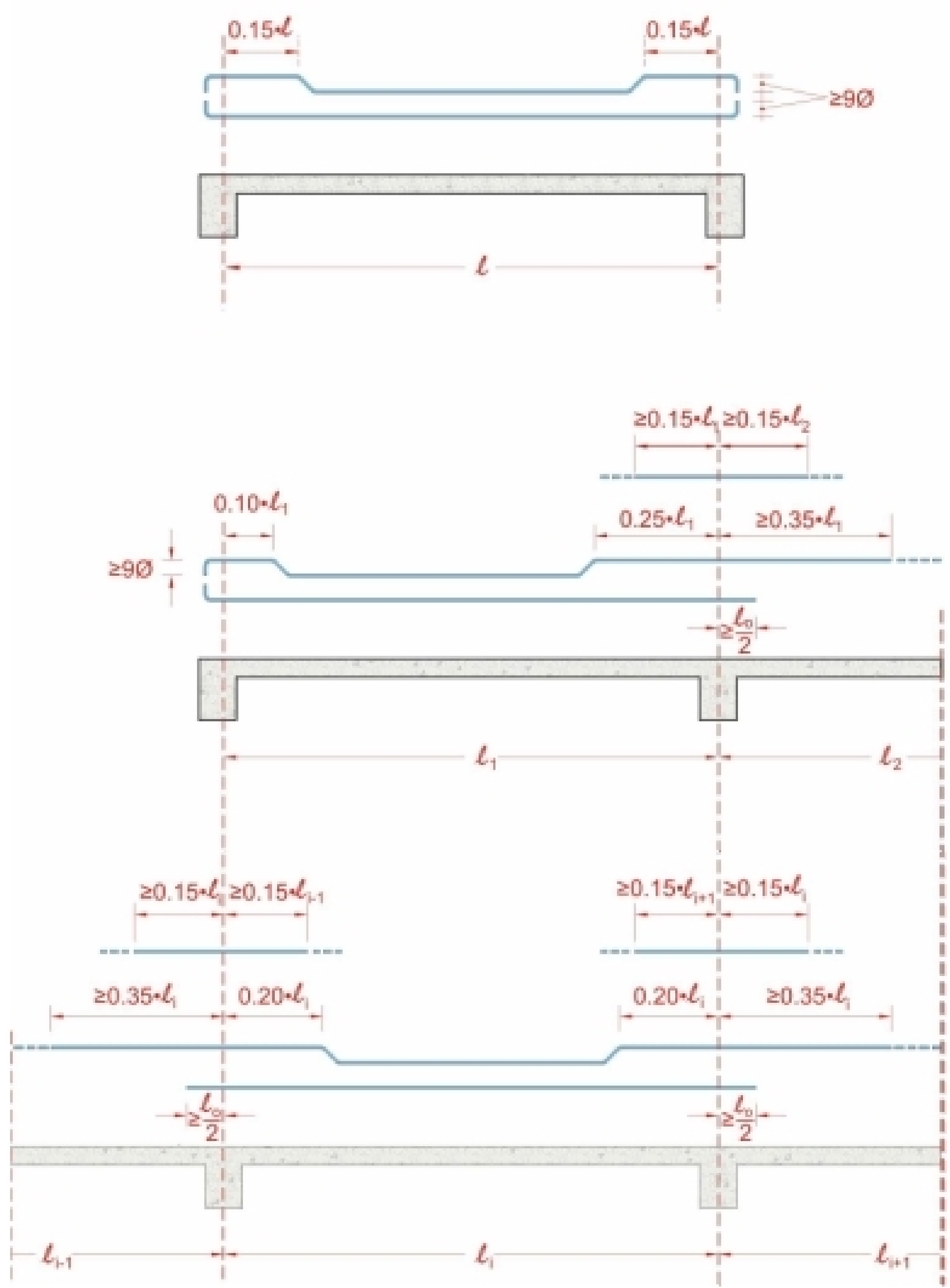
Generally, it is advised to use sandwich slabs only in cases of large slab thickness.

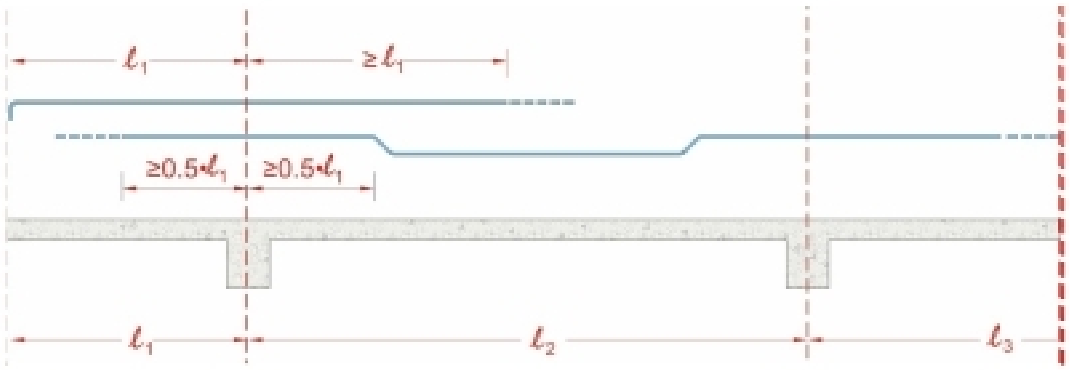


Reinforcement details of a sandwich slab

3.5.7 RULES FOR THE DETAILING OF SLAB REBARS

This paragraph refers to some of the rules that one should follow when bending up slab rebars. These rules apply to both one-way and two-way slabs, with usual lengths and commonly applied loads and only when the reinforcement detailing is not provided by another more accurate way.





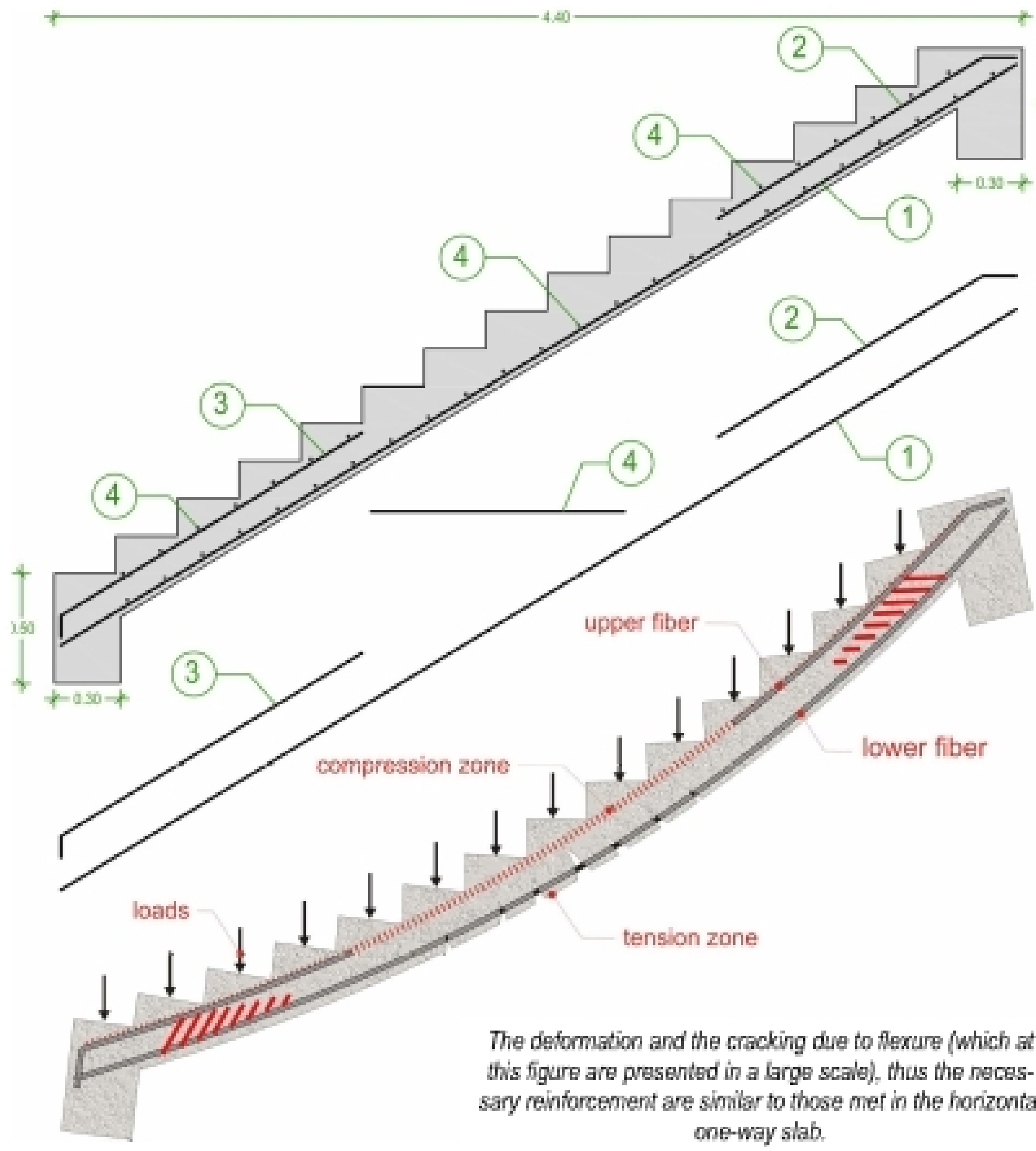
- In one-way slabs, the length l is equal to the distance between the two edges upon which the slabs are supported.
- In two-way slabs, the length l is regarded equal to the smaller dimension of the slab.
- In cantilever slabs, the length l equals the distance between the support and the opposite free edge of the slab.
- When a slab's support is considered fixed, the previous corresponding rules apply.
- When the lower rebars are being bent in order to provide support reinforcement, the straight created upper horizontal part must be extended by the anchorage length.
- The anchorage length of the rebar (dashed line) is directly proportional to the diameter Φ and the concrete grade and reversely proportional to the steel class (in the Greek code the standard steel class is B500). In usual cases the anchorage length is in the order of 50cm. The use of industrial wire mesh is favorable for the anchorage length.
- Bending the rebar at 90° or 135° in the edges of pin supports is positive for the proper behavior of slabs. However, as a rule, it is not necessary especially in high concrete grades.
- If the formwork drawings contain specific dimensions of the reinforcement bars detailing then these predominate over the above mentioned empirical rules.

3.6 Staircases

Staircases appear in a number of forms and behave in different ways, as shown at the following figures: simply supported (pinned on both sides, fixed on one side, fixed on both sides), cantilever, winder, helical, etc. The following paragraphs examine the reinforcement of the most commonly met staircases which are the orthogonal and the winder stairs.

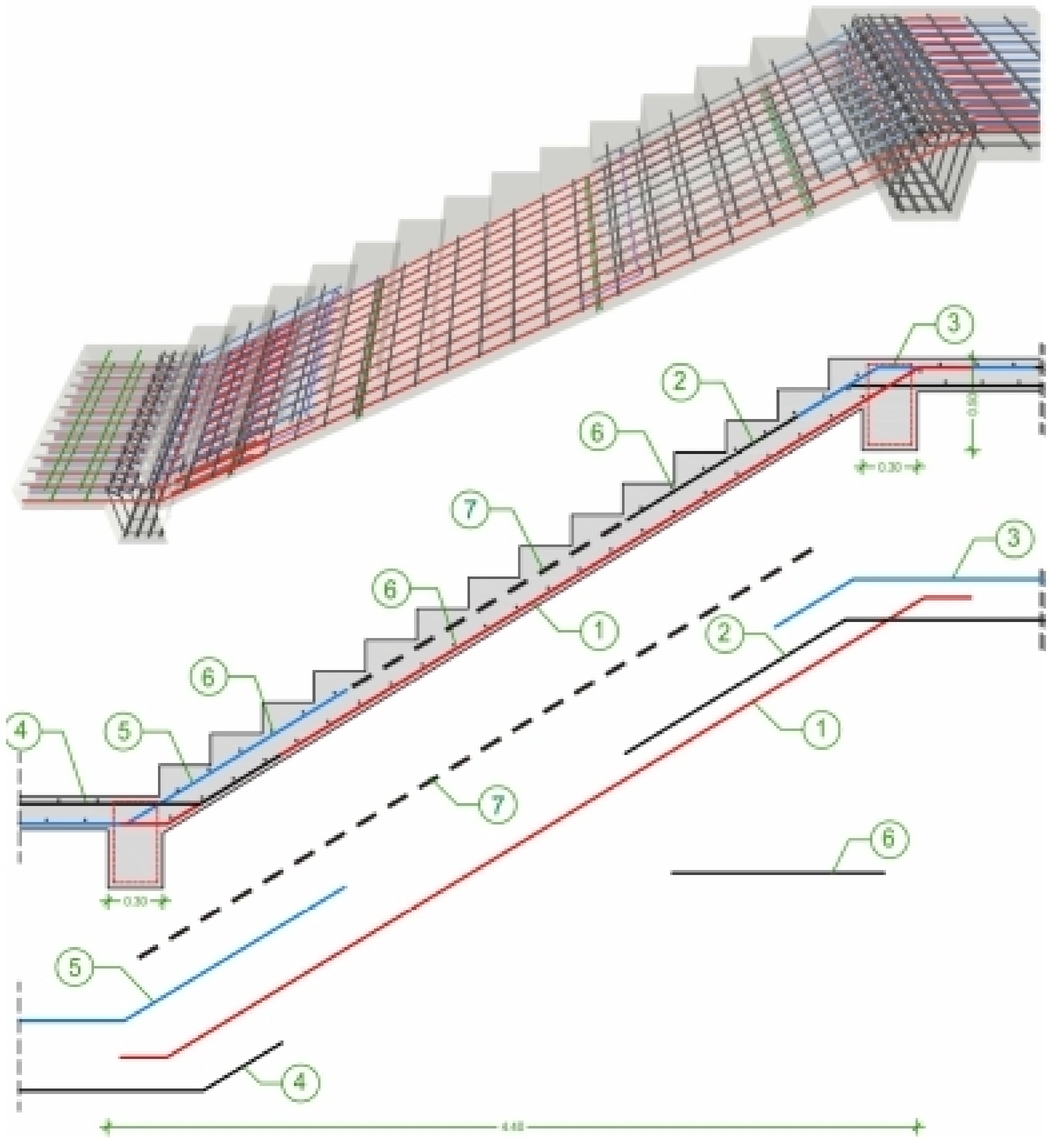
3.6.1 Simply supported staircase

A simply supported staircase behaves similarly to the simply supported slab mentioned in paragraph 3.5.1



The deformation and the cracking due to flexure (which at this figure are presented in a large scale), thus the necessary reinforcement are similar to those met in the horizontal one-way slab.

3.6.2 Simply supported staircase continued by slabs



Due to the continuation of the staircase by slabs at its base and top, bending moment is formed in the supports (upper fibers) and therefore, rebars are required both at their upper fibers.

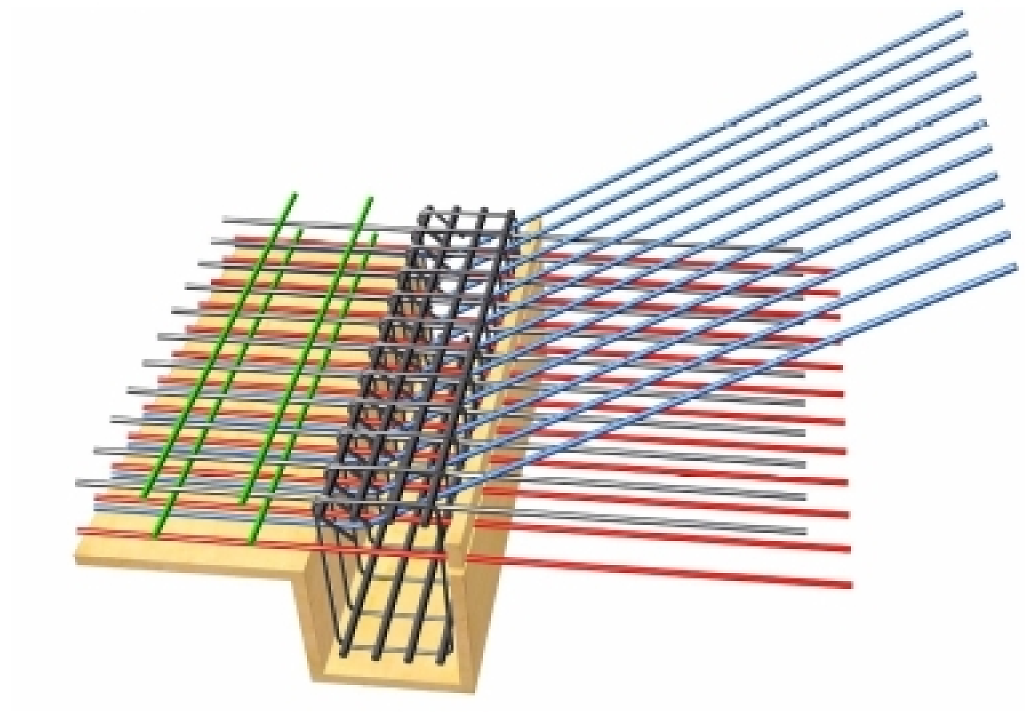
<u>Note:</u>

In most occasions, staircases are continued by the floors' slabs, as in the previous example; therefore, they contribute to the seismic diaphragmatic behavior of the floors' slabs. During an earthquake, slabs sway only along their horizontal plane and consequently they are not stressed by additional flexure. On the other hand, the staircases, due to their slope, transfer the diaphragms' seismic forces to the columns. This subjects them to deformation transverse to their plane which causes the formation of seismic flexural moments. All the above show that staircases behave like slabs when vertical loads are applied upon them and like beams when they are stressed by earthquake forces. Since the seismic loads continuously shift direction, the applied earthquake stresses constantly appear reversely therefore, staircases require reinforcement both at their upper and lower fibers. Most of the times, due to the fact that the accurate estimation of the staircase's exact behaviour includes a large number of uncertainties, it is preferred to place reinforcement along the entire length of both its upper and lower surface (rebars 7).

3.6.3 Starter bars in staircases

A staircase connects two subsequent floors therefore, it cannot be monolithically casted with them since the formwork and the reinforcement implementation as well as the concreting are done firstly at the subjacent floor and after a few days at the superjacent floor. The most usual way to construct a staircase[12] is together with the superjacent floor. However, in order to achieve a connection with the subjacent floor there must be properly placed starter bars. Moreover, starter bars must be positioned and at the superjacent floor for the staircase of the next level.

The following describe the practice followed for the positioning of starter rebars in the subjacent and the superjacent floor.



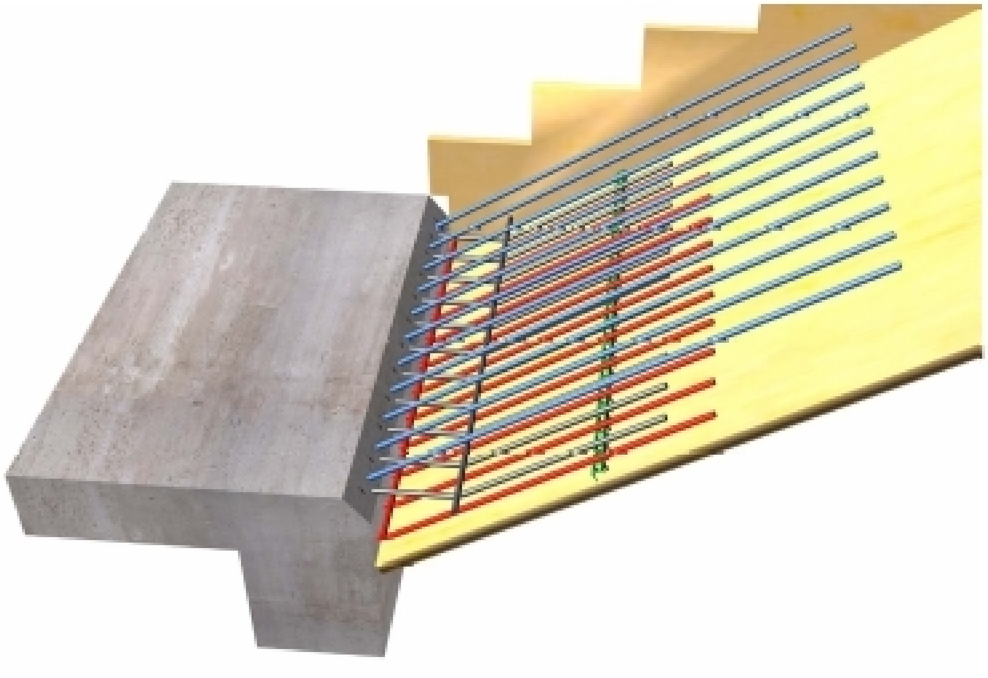
Starter bars at the base of a staircase

The landing reinforcement is extended towards the direction of the staircase for the next floor whose formwork and reinforcement implementation as well as its concrete casting will be carried out in a following phase of the construction.

The proper position of the starter bars is secured between thin formwork strips.

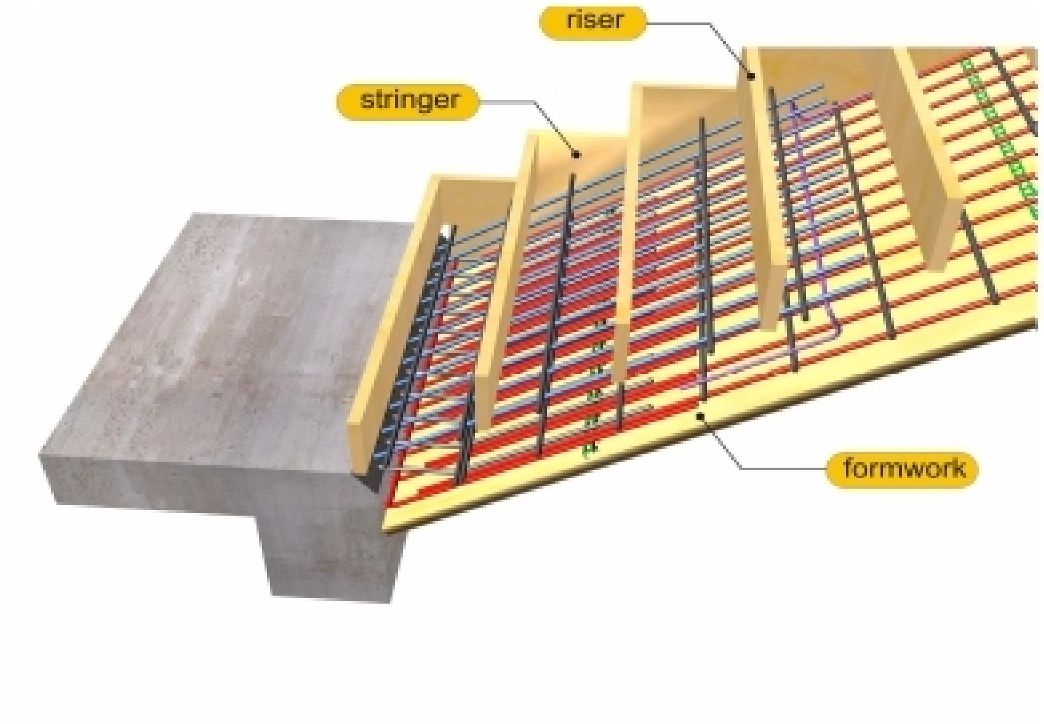
---

[12] *The most practical and economical method is the use of a completely prefabricated reinforced concrete staircase fitted inside the structural frame. In earthquake resistant structures, the staircase is an element strongly affected by the seismic forces therefore, the installation of a pricast staircase in an already constructed structural frame is a sensitive task. It requires special attention in order to provide an adequate support and accurately predict the effect that its installation will have to the structure. The precast staircase can be installed upon the load bearing system either after the frame construction of both two floors, supported by special starter bars, or during the construction of the superjacent floor, supported by starter bars fitted only to the subjacent floor.*



The starter bars are bent at the proper angle prior the staircase's planking

Before the positioning of the staircase's formwork (planking), the starter bars are properly bent at the necessary height (of course they could be implemented as already bend-up bars however, this entails accuracy difficulties).



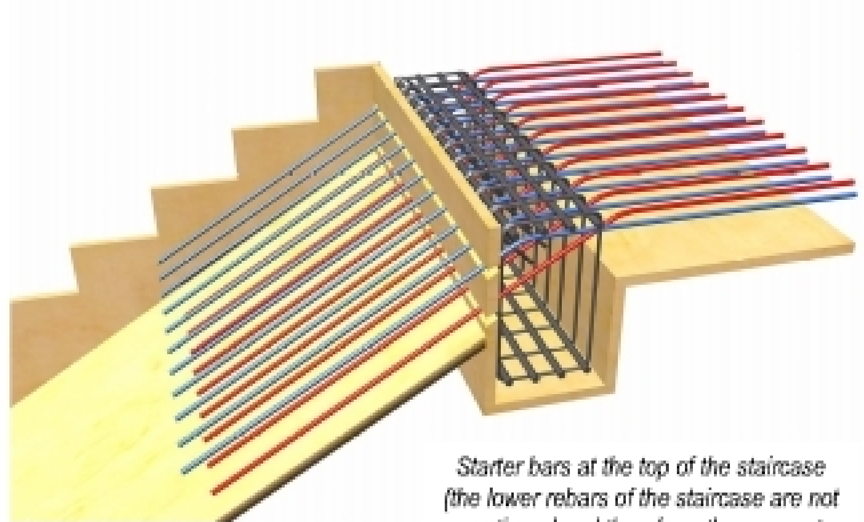
The formwork and reinforcement of a staircase around the area of the starter bars

During the final phase of the staircase's reinforcement implementation, the lower rebars (in red color) are wired to their proper position with the distribution bars. The next phase includes the positioning of any necessary additional upper rebars followed by the placement of their distribution bars. The stringers and the risers are placed last.

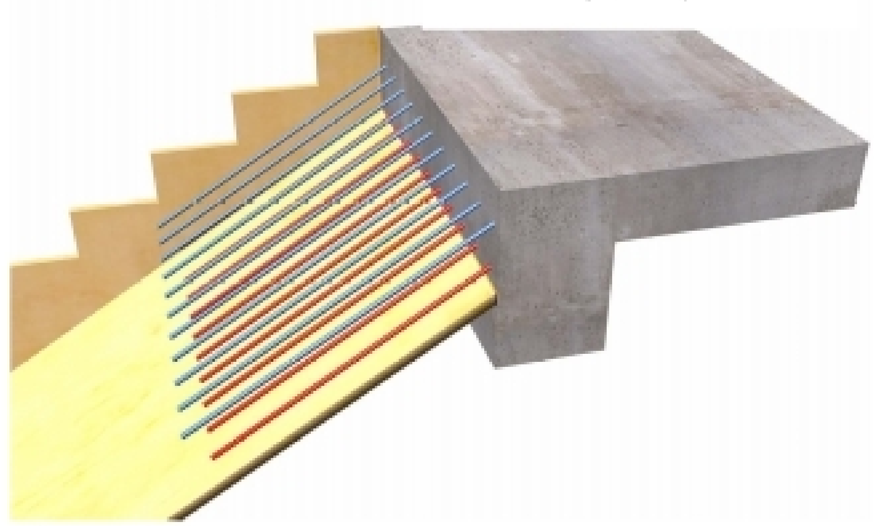
At the top part of the staircase, the reinforcement is normally implemented based on the fact that the staircase will be monolithically casted with the slabs-beams of the floor. Generally though, it is necessary to place starter bars for the next staircase.

Note:

In the special occasions where the staircase will be constructed in a following phase, starter bars are left at the top part of the staircase according to the following details[13]:



Starter bars at the top of the staircase (the lower rebars of the staircase are not continued and therefore, they are not presented)

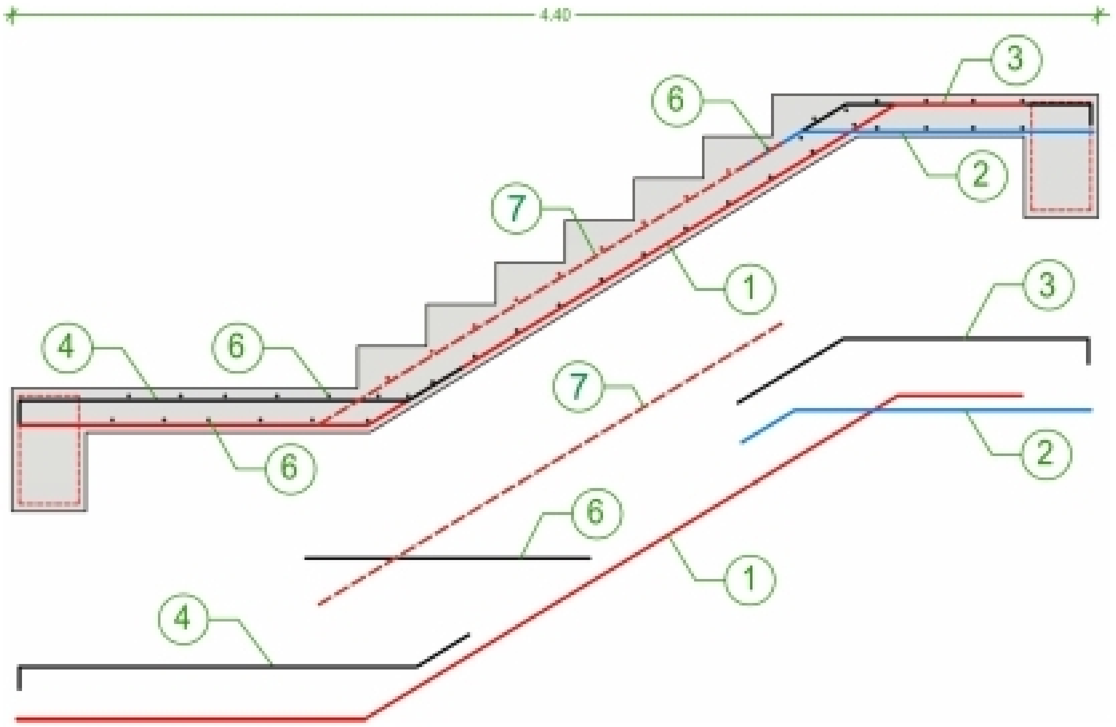


The staircase that will be constructed in a following phase will be supported upon those starter bars and the starter bars of the lower floor.

[13] In the case where the stair ends to a slab instead of a beam, it is recommended to construct a reinforced zone in that area. The starter bars will remain the same and the slab's lower rebars will be extended "waiting" to be anchored

3.6.4 Staircase with landings

The flights of the orthogonal staircases are not always straight. On the contrary, most of the times they are polylines with successive sloped and horizontal segments. The following example shows a typical staircase with landings into which most cases are reduced.



When the staircase contributes to the seismic diaphragmatic behavior of the floors (as is the rule), it is recommended to use negative rebars as well [dashed bar (7)]

<u>*Notes:*</u>

The negative rebars, apart from everything else, help in the proper concreting of the staircase's sloped flights because they retain the wet concrete in a satisfactory degree.

A good solution in order to cover the needs for (a) distribution rebars of the lower reinforcement, (b) free edges' hairpin bars and (c) rebar chairs, is to use the unified bars shown at the next figure.

Another solution for the combination of these three requirements is the use of the upper reinforcement's distribution bars. This solution provides stronger rebar chairs.

Lower distribution rebars – free edges hairpin bars and rebar chairs, with a single bar

Upper distribution rebars – free edges hairpin bars and rebar chairs, with a single bar

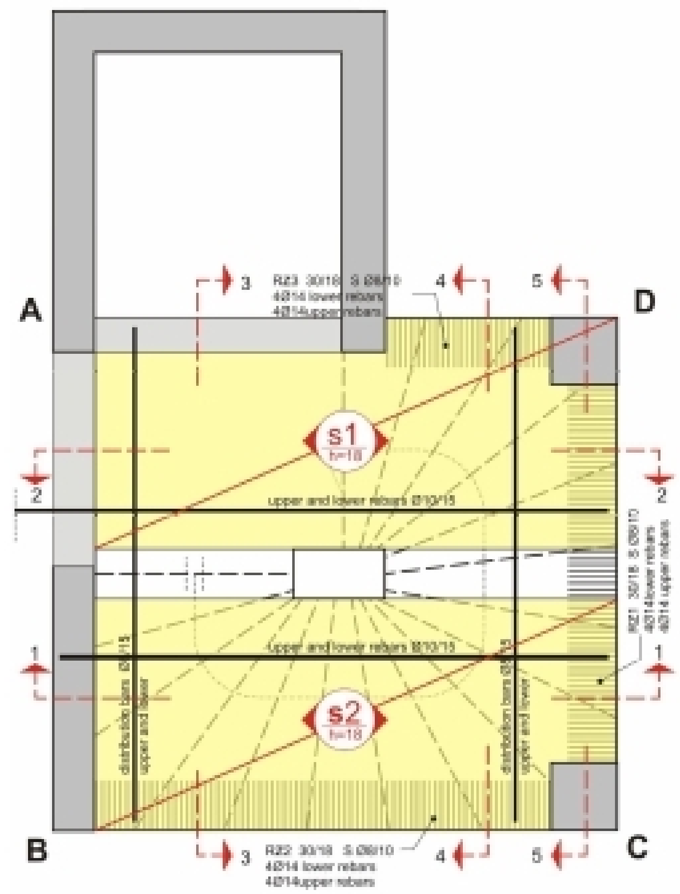
3.6.5 Winder staircase

As a rule, in small buildings for space economy, the staircase is constructed with winder steps therefore; practically it does not have level but crooked flights.

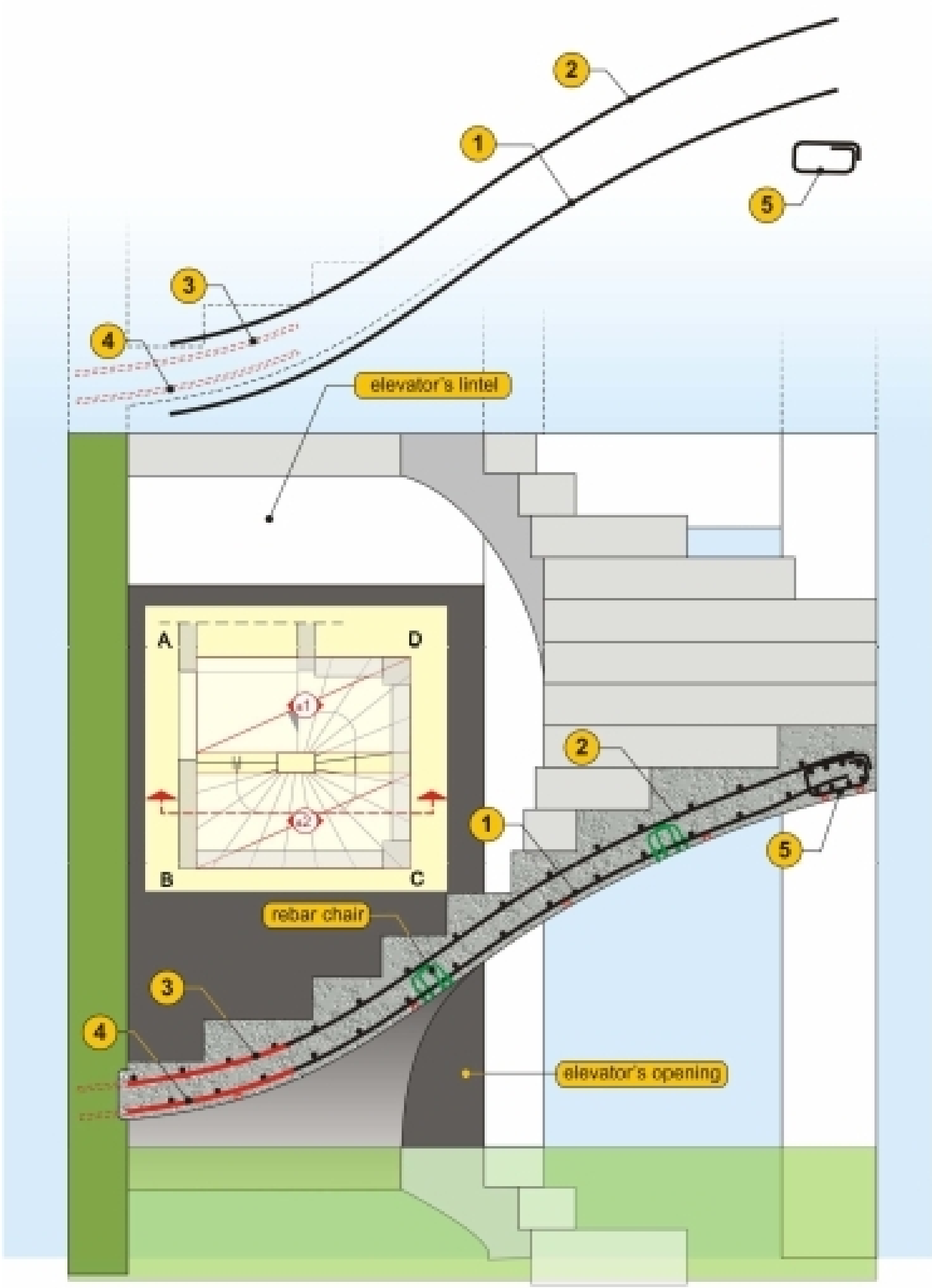
These flights, for a less strenuous reinforcement implementation, are considered to be level and are reinforced by following rules similar to those regarding straight staircases.

Every flight is reinforced separately from the other however, constructional they intersect. The two primary flights which are sited upon two opposite beams (sections 1-1 and 2-2) are firstly reinforced then follows the reinforcement of the secondary vertical flights.

In space-economical winder staircases, the supports' distances between the columns are relatively short therefore; there is no need to construct beams as well. This happens because, apart from the technical difficulties that it involves, it leads to the formation of extremely strong **short columns** which are particularly dangerous during an earthquake. An efficient simulation of the static behavior can be achieved by using reinforced zones between the supports from column to column or from beam to column and then to reinforcing the primary and secondary staircase flights, as shown at the following example.



PLAN VIEW



SECTION 1-1

The support of the staircase upon the shear wall can be achieved by various ways based on the designer's simulation and the dominate practices. Some of the support options are presented below:

(a) Simultaneous reinforcement implementation and concrete casting of both the staircase and the shear wall. Theoretically, this is the most effective solution however, it involves large constructional difficulties and therefore it is not usually chosen.

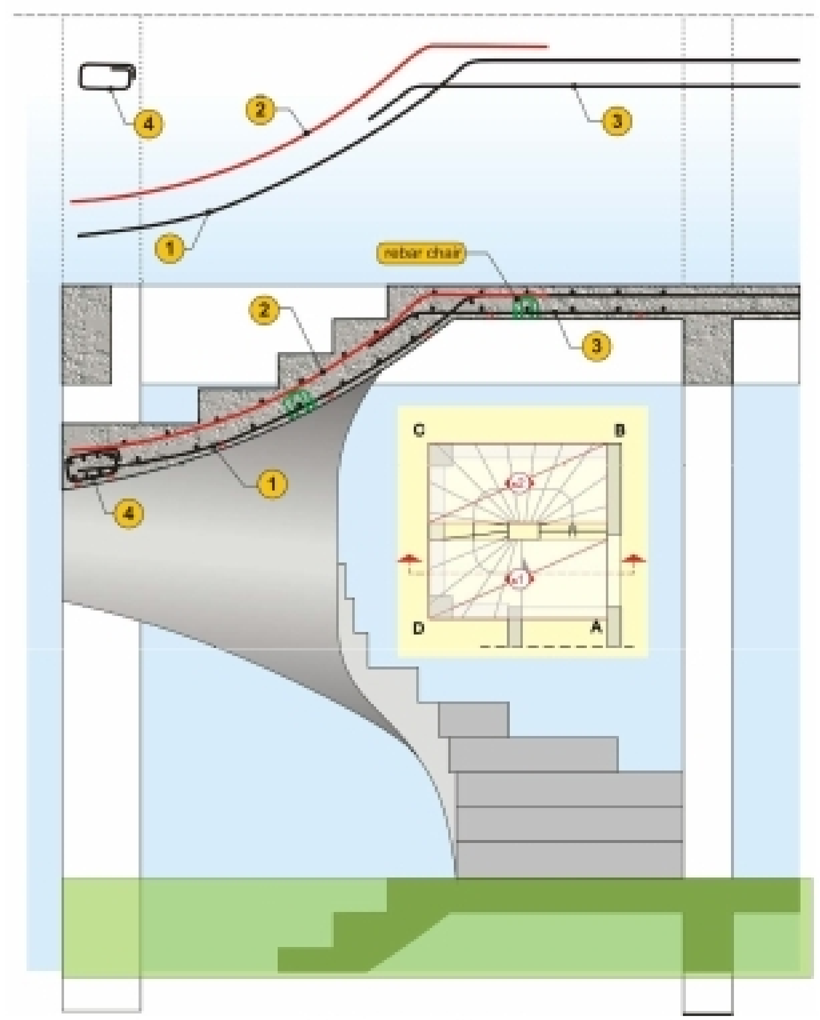
(b) Positioning of starter bars (3) and (4) during the shear wall's construction. This practice is being followed in the above example. It is recommended to place the starter bars by the way explained in §3.2.7, in short height though.

(c) Positioning of starter bars (3) and (4) during the shear wall's construction, without the formation of a 'nest'.

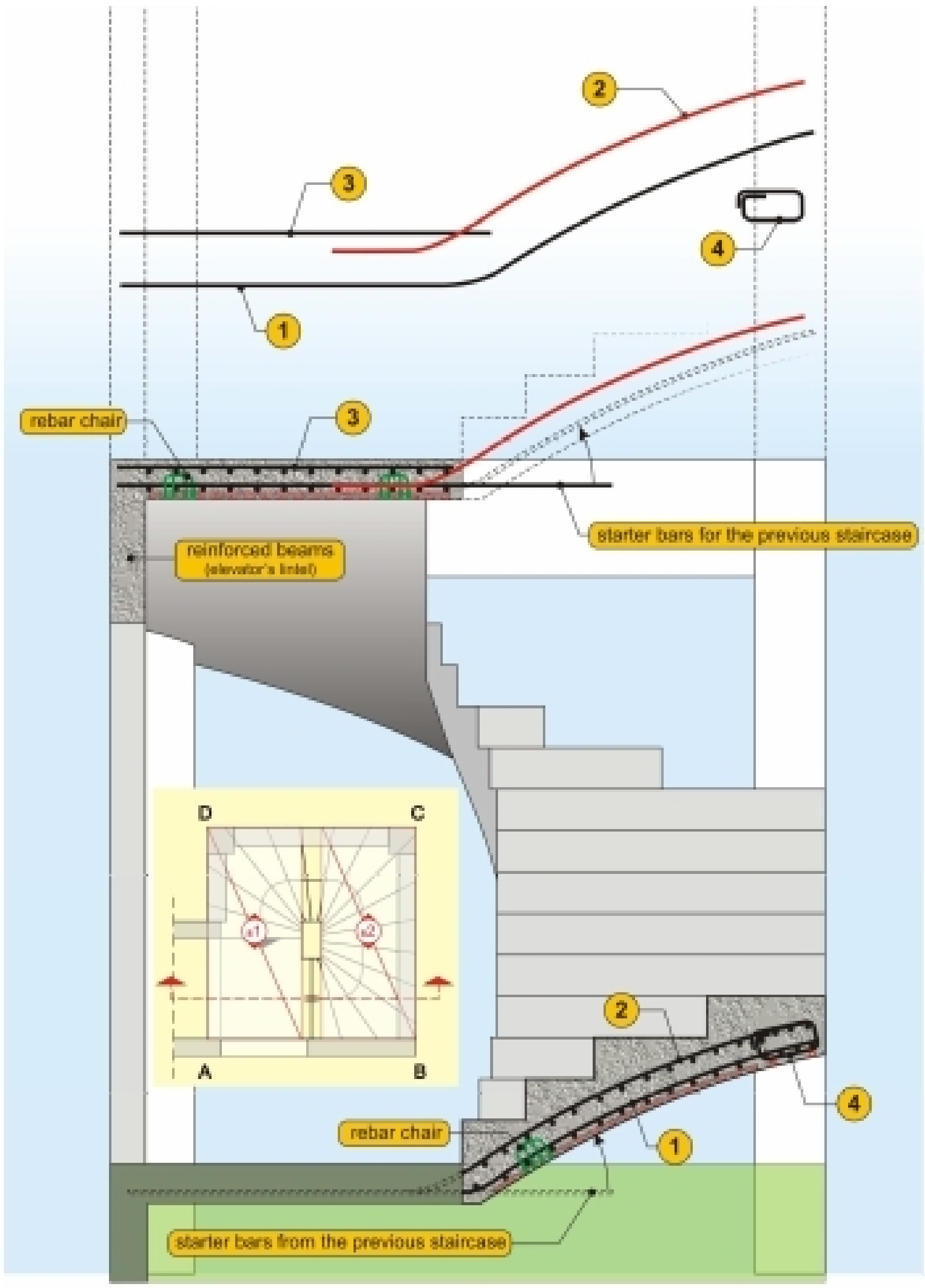
(d) Positioning of starter bars (3) and (4) after the shear wall's construction, by drilling holes and resins usage.

(e) Fitting of special supports upon the shear wall, for the formation of specific support conditions e.g. pin support.

(f) Avoidance of anchorage into the shear wall by forming a reinforced zone parallel to it (this zone is, either way formed by the distribution reinforcement). Of course, in any case, the longitudinal reinforced zone RZ2 must be properly anchored upon the shear wall.



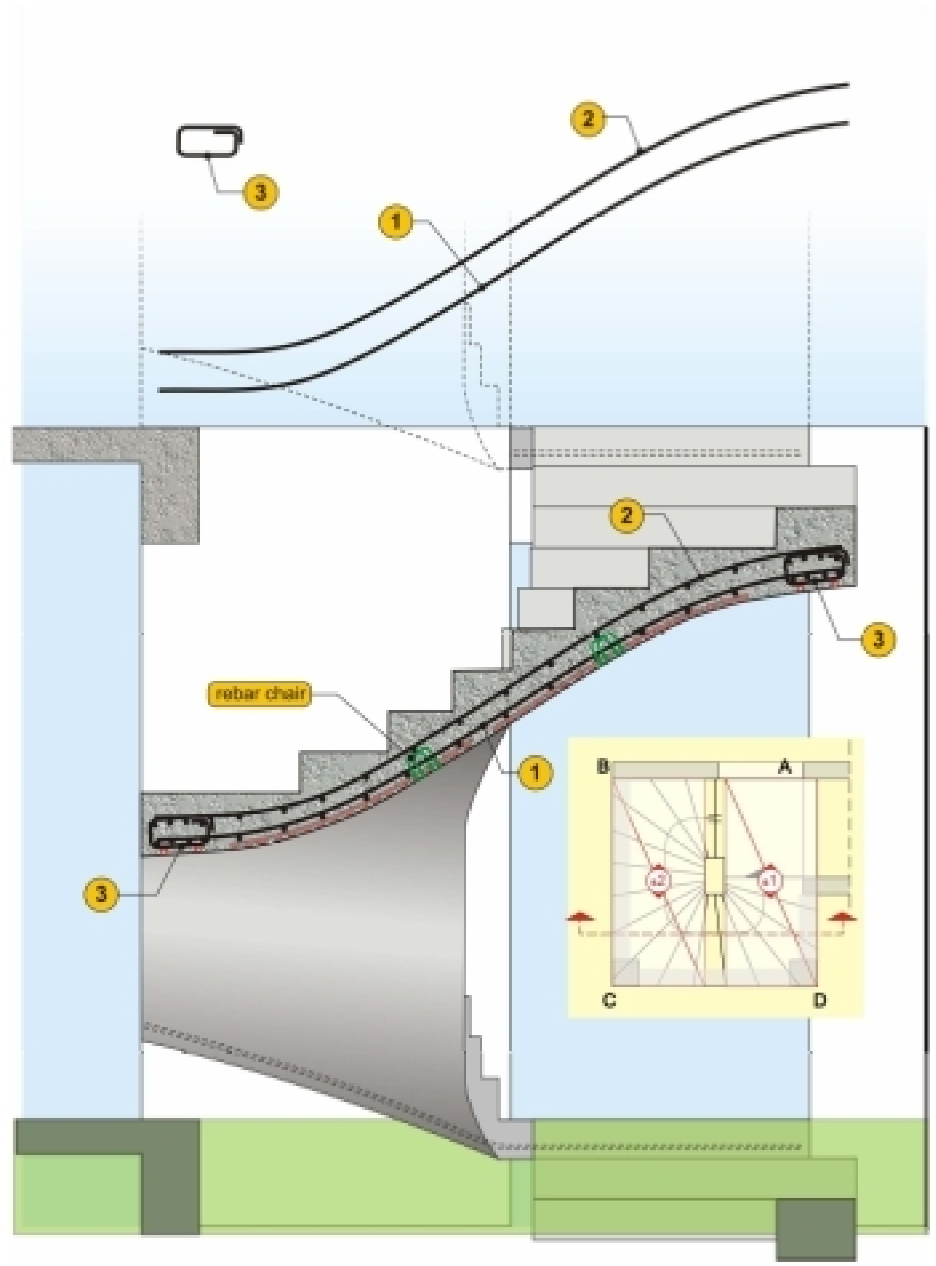
SECTION 2 - 2



SECTION 3 – 3

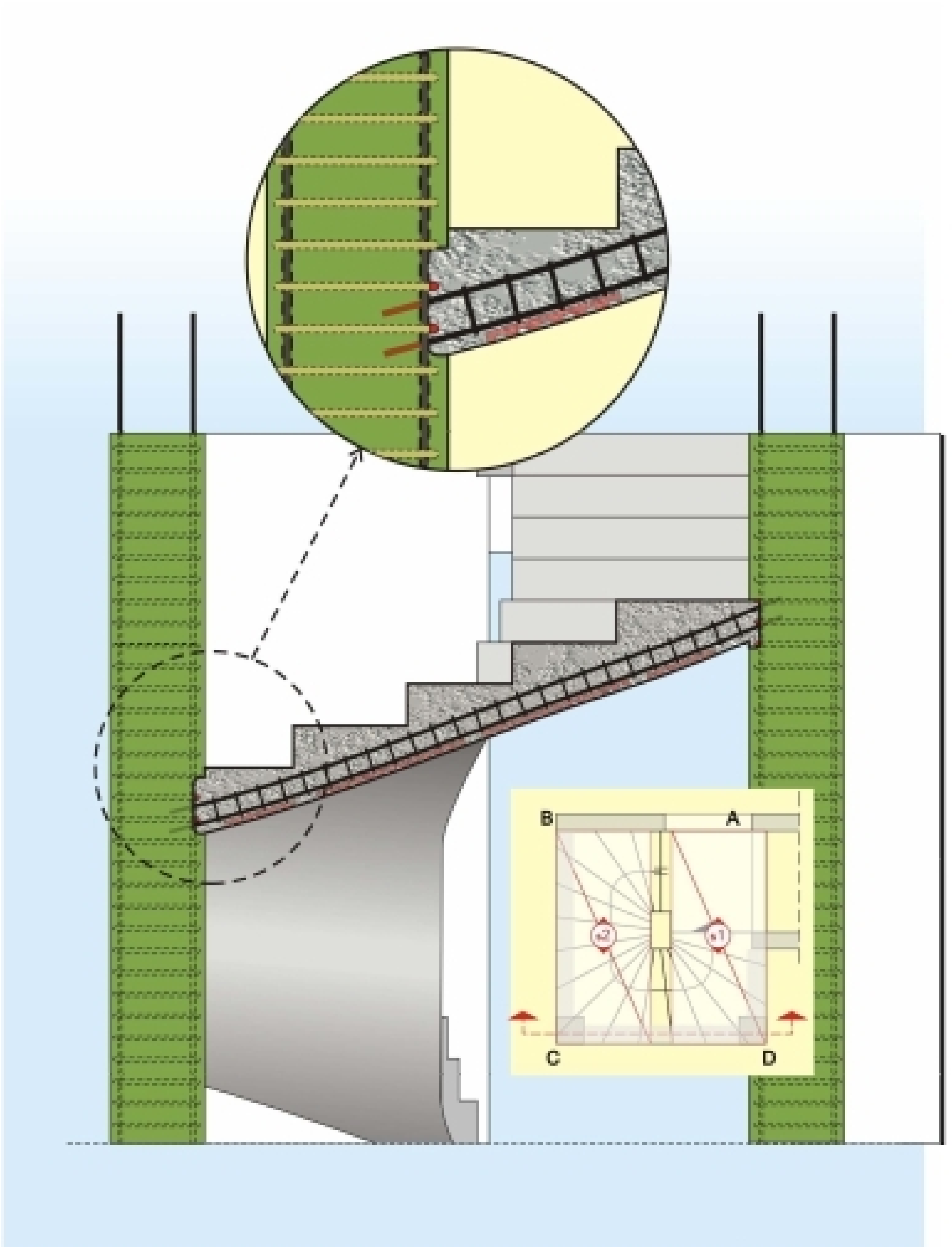
The reinforcement zone along the secondary direction of the staircase's support, could be neglected however, as a slab's free edge, it would require hairpin reinforcement (see § 2.6.1). The difference in labor cost and used materials between those two options is not significant. The use a reinforced zone with the upper and lower reinforcement enhances the ductile behavior of the staircase.

Due to the large section width of the staircase, the shear strength is usually satisfactorily high therefore, usage of open-form stirrups-rebar chairs is acceptable. Of course, it is more effective for the stirrups to be properly closed with hooks bent at 135°.



SECTION 4 - 4

In winder staircases, extra attention must be paid to the horizontal area between the flights both during the design and the planking of the staircase so as to ensure that the staircase's thickness (vertical to the planking) is equal to the thickness of its outer flight. Then it will be feasible to secure the proper positioning of the upper reinforcement grate with rebar chairs of equal height. These rebar chairs can be four-legged industrial produced, wiggly impromptu created or handmade hairpin bars placed at the distribution rebars ends.



SECTION 5 - 5

When the staircase is supported upon a column, the applied rules are the same with those mentioned above regarding the staircase's support upon a shear wall.

Either there are starter bars or they are fitted afterwards with resins, the bars of the reinforced zone are placed as unified pieces. Since, as a rule, the outer flight is smooth, it can be reinforced with bars of a larger diameter compared to those used in the staircase.

Generally, the smaller the diameter of the staircase rebars is, the less strenuous is the shaping of the bars' various parts.

Notes:

1) *If the masonry filling at the area surrounding the staircase is considered to be rigid, the construction of reinforced zones, in the secondary flights of the staircase, enhances the ductility of the surrounding area. This, in the case of an earthquake, helps to the cracking avoidance in both the staircase and the filling walls (behavior analogous to a **bonding beam**).*

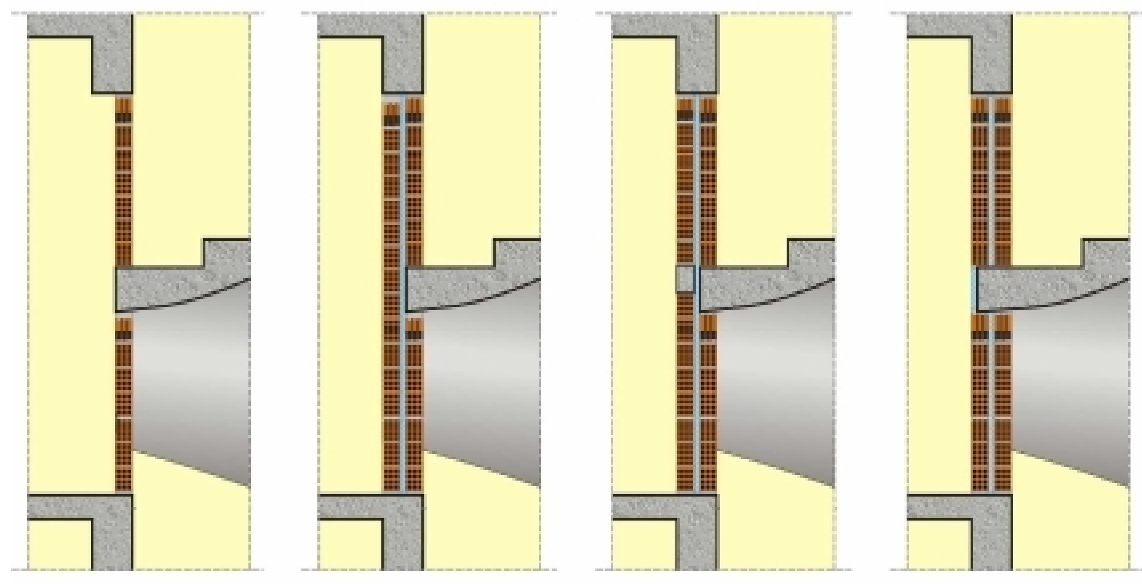
2) *Extending the staircase under the floors' beams is not mandatory however, when it is done is ensures a more effective staircase reinforcement and a better brick fitting. The following figures show 4 cases where the stair is extended under the beams:*

   (a) Masonry stretcher bond without thermal insulation

   (b) Double stretcher bond with thermal insulation

   (c) The same as (b), with an additional bonding beam at the free wall

   (d) Extension of the staircase to the entire wall thickness and a thermal insulation strip placed to the staircase's end



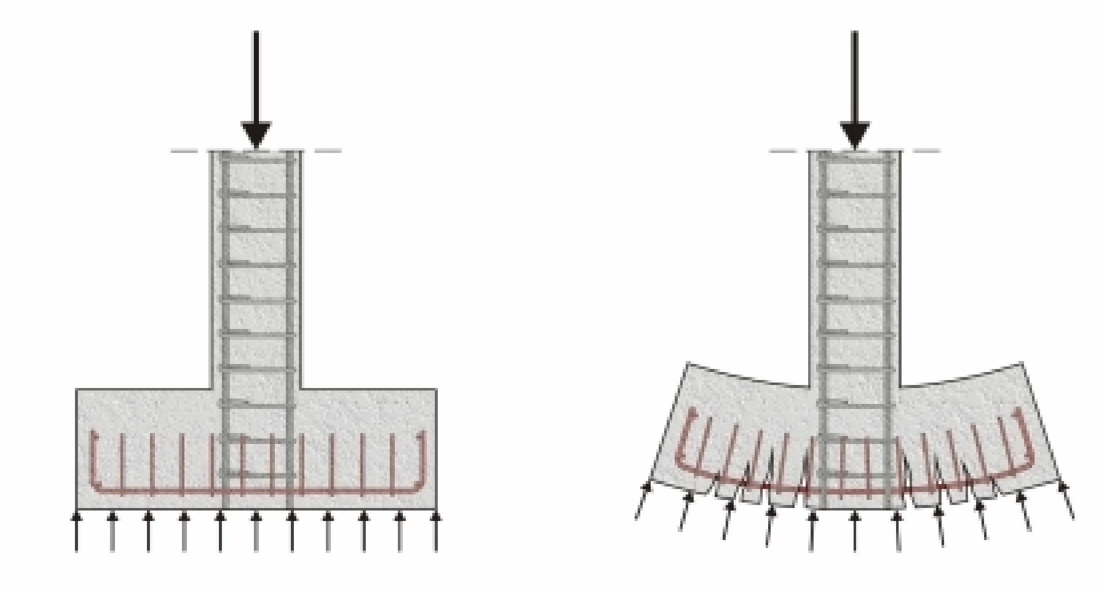
(a) (b) (c) (d)

3.7 Foundation

3.7.1 Spread footings

Paragraph 1.2.5 provides all information regarding spread footings. The following example concerns a simple spread footing with its footing shaped like a box.

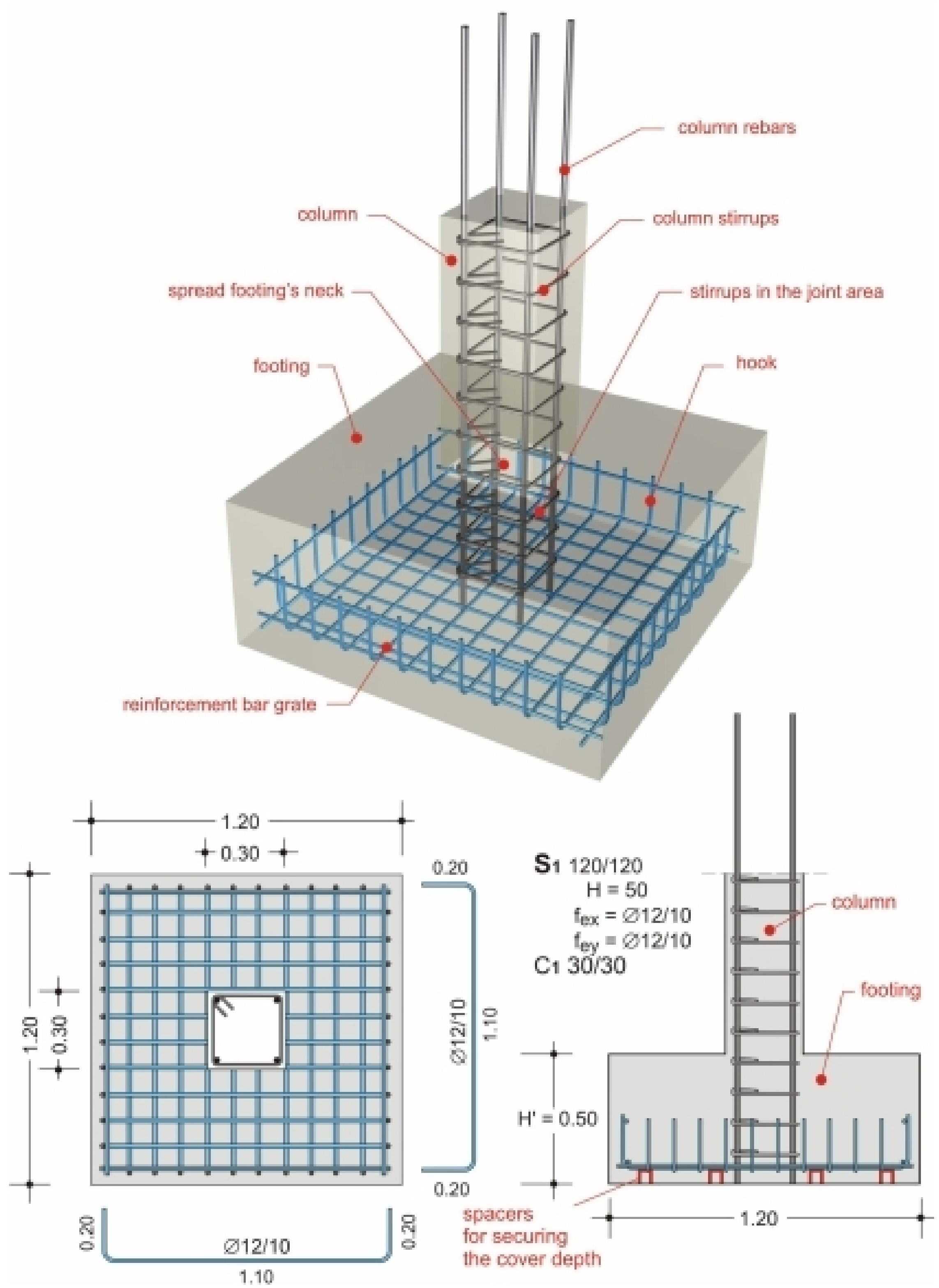
The spread footing behaves like an inverted cantilever with loads applied in the upward direction. As a rule, a spread footing is a quite rigid element therefore, the applied soil stresses are almost linear and in case of a symmetric (with respect to the pedestal) footing, they are orthogonal. These soil pressures consist the loads carried by the footing which behaves like a slab and is deformed by the way shown at the following figure.



Soil pressures and deformation of an isolated spread footing

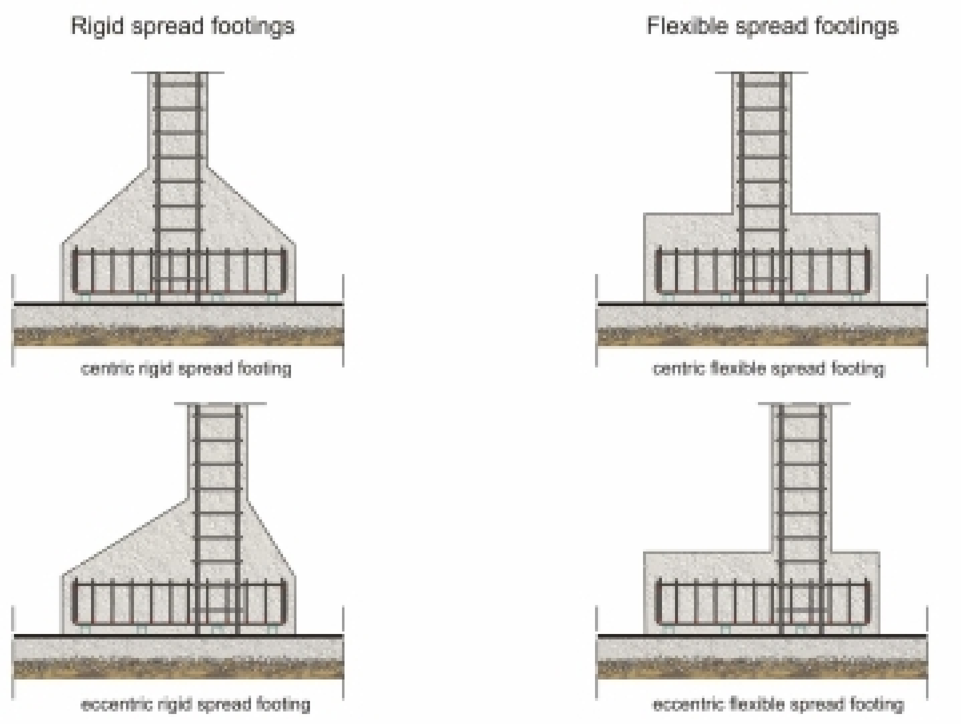
The real deformation is in the order of a millimeter and although it is not visible to the human eye, it always has that same form. The reinforcement is placed at the lower surface of the footing both along the x and y axis.

The column rebars can be anchored inside the footing either with a straight anchorage length or with a 90° hook at their end (resembling a 'shoe'). The chosen type of anchorage depends upon the footing's total depth and the level on which the column is considered fixed which is usually the upper part of the adjacent connecting beams. Most of the times, that level is high enough to allow for a straight anchorage length. Practically, the need for hooks at the base of columns arises mainly in the case of a solid raft foundation with a relatively small slab thickness.



Reinforcement of an isolated spread footing

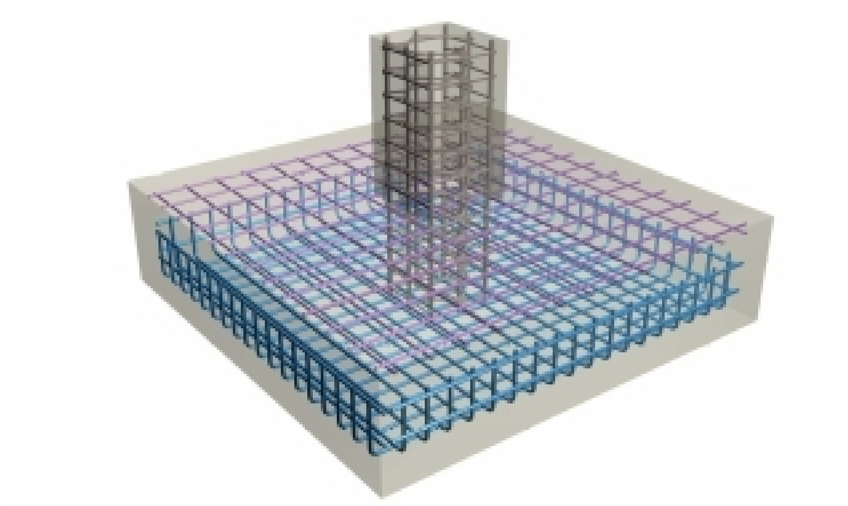
The reinforcement is the same both for flexible and rigid spread footings either being centrically or eccentrically constructed.



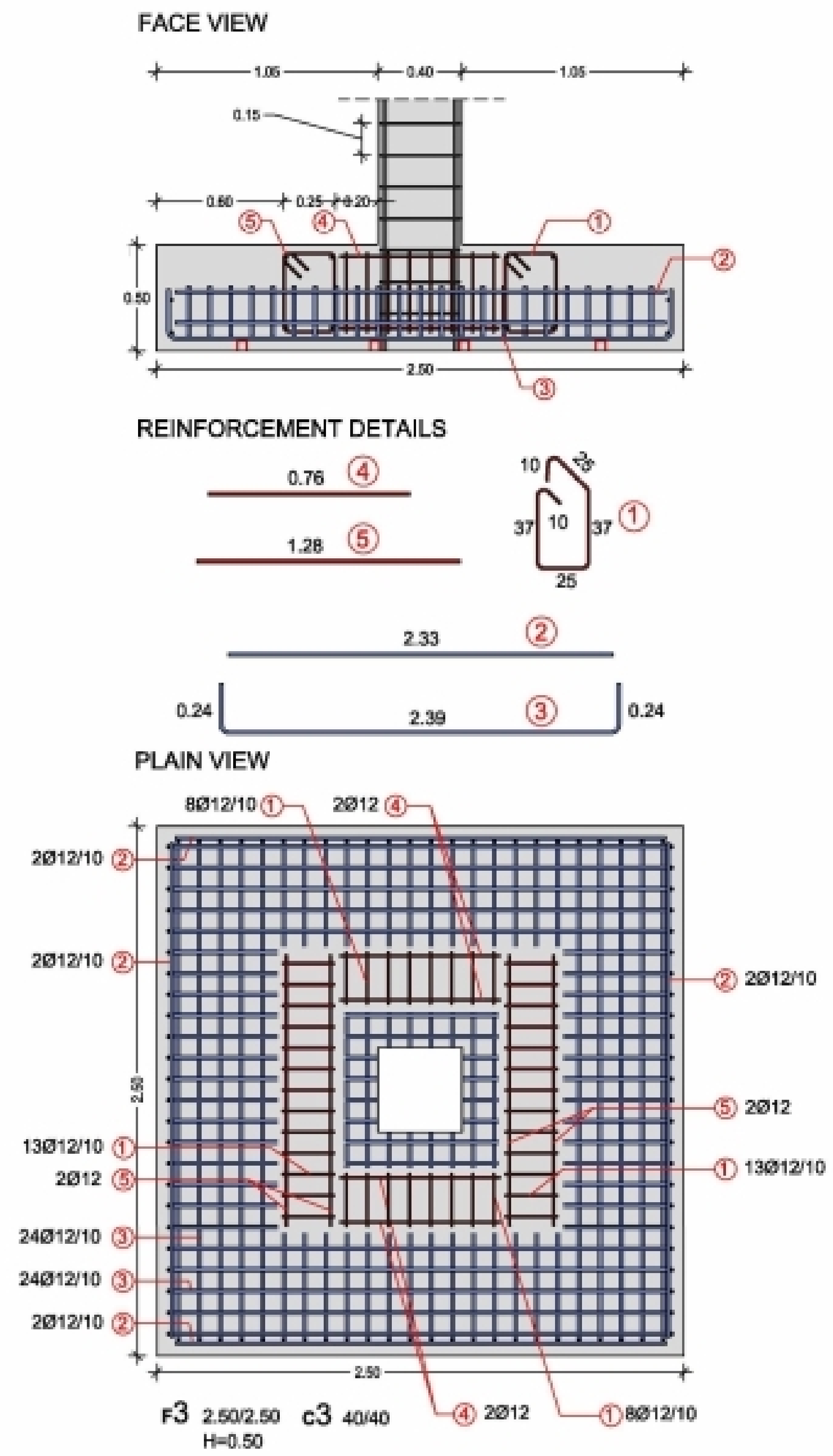
The footing is reinforced with an orthogonal wire mesh that may have horizontal and vertical bars of different diameter and spacing. Bending the rebars ends helps in the proper anchorage of the reinforcement.

According to the Greek regulation, the minimum allowable rebar diameter in a footing is Φ12 and the maximum acceptable spacing between the reinforcement bars is 15cm.

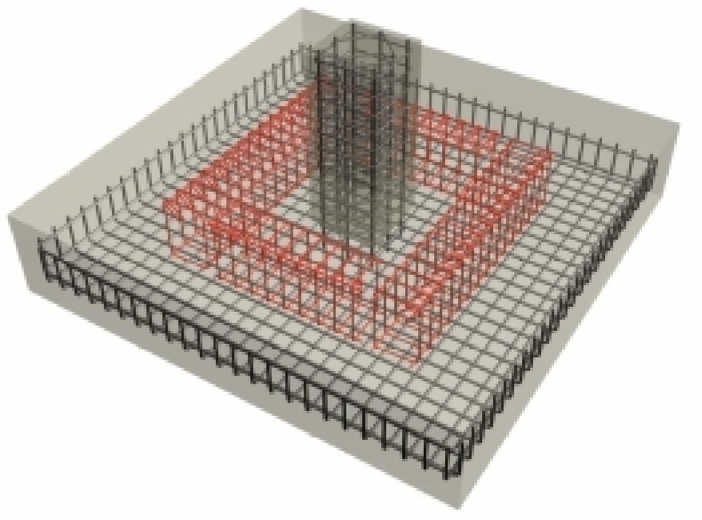
In certain occasions, the footing may have a reinforcement wire mesh both at its upper surface (see following figures).



Spread footing reinforced at the upper and lower surface

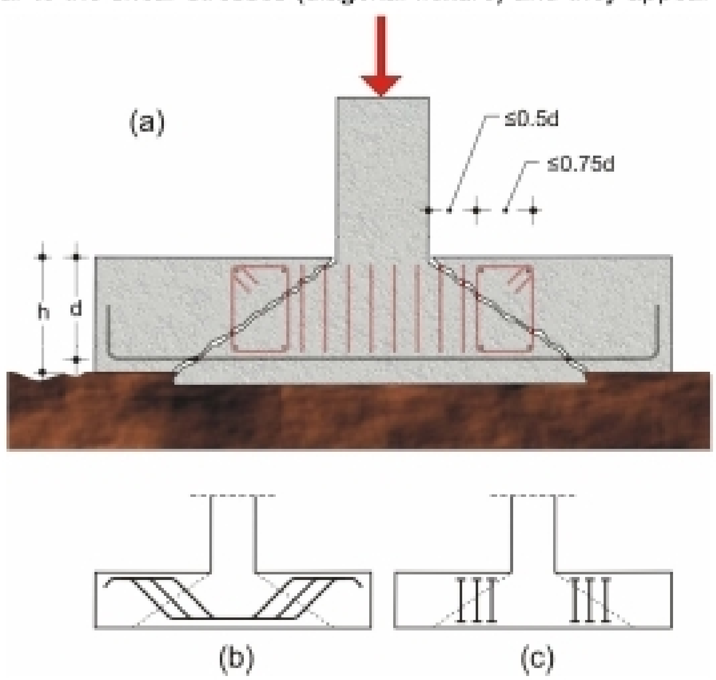


In some other cases, the spread footing may have punching shear reinforcement as well. This reinforcement is usually provided in the form of a peripheral stirrup cage.



Controlling punching shear, with the use of stirrup cages.

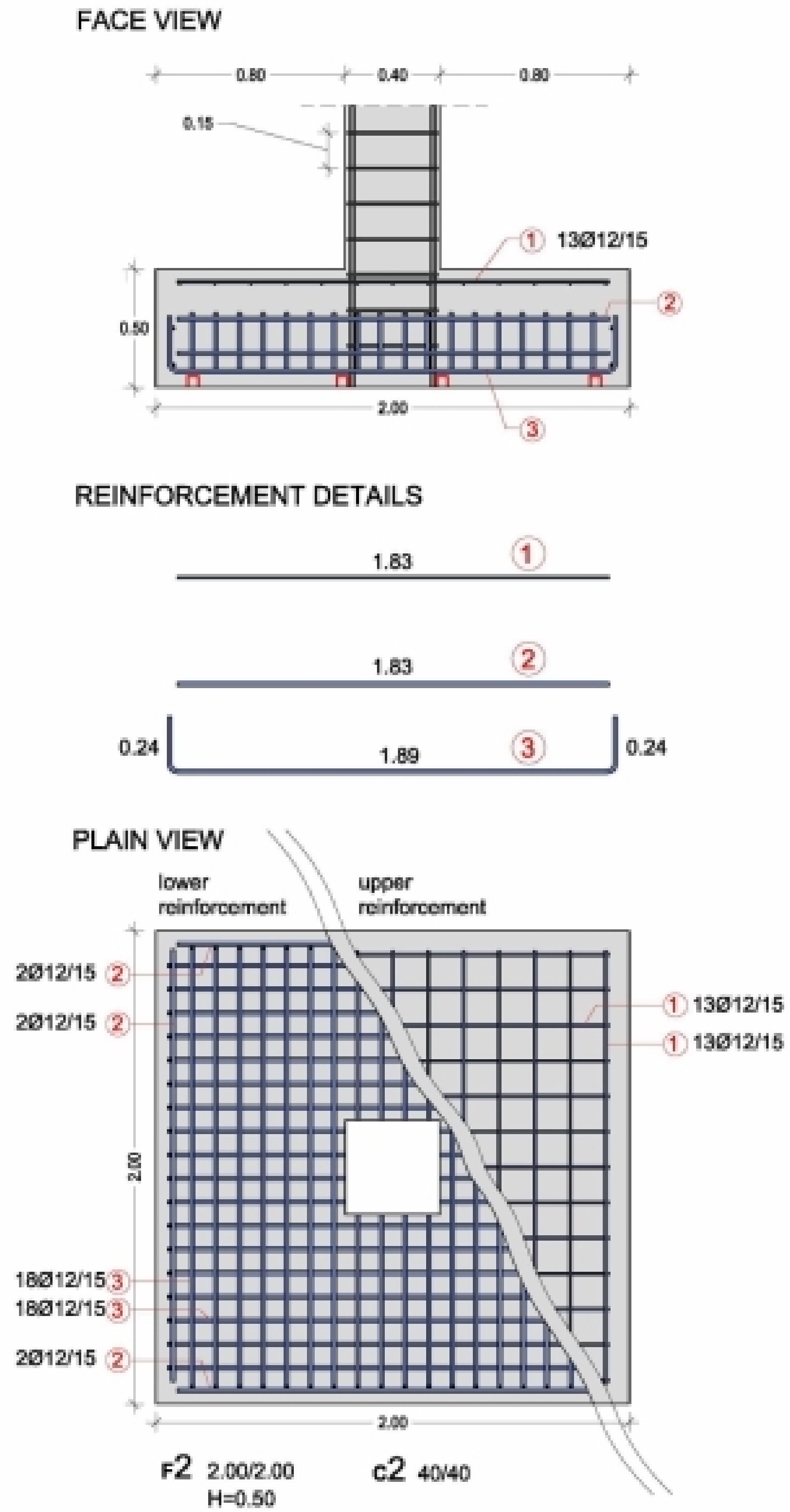
Punching shear stresses are similar to the shear stresses (diagonal flexure) and they appear along the perimeter of the column. Punching shear is a type of column **sliding** along the side of a cone that forms a 35° angle with the horizontal axis, as shown at the opposite figure. The first stirrup leg must be placed at a maximum distance of 0.5d away from the face of the pedestal and the last stirrup leg at a maximum distance of 1.25d.



<u>Note</u>:

In this specific spread footing, punching shear is controlled by stirrup cages (figure a) however, it could be also controlled with bundles of properly bent-up rebars (figure b), or with special industrial elements (figure c).

The density and rebar diameters of the reinforcement (punching shear reinforcement included) for the 2.50/2.50 footing with a 40/40 column are given bellow:



Spread footing with punching shear reinforcement

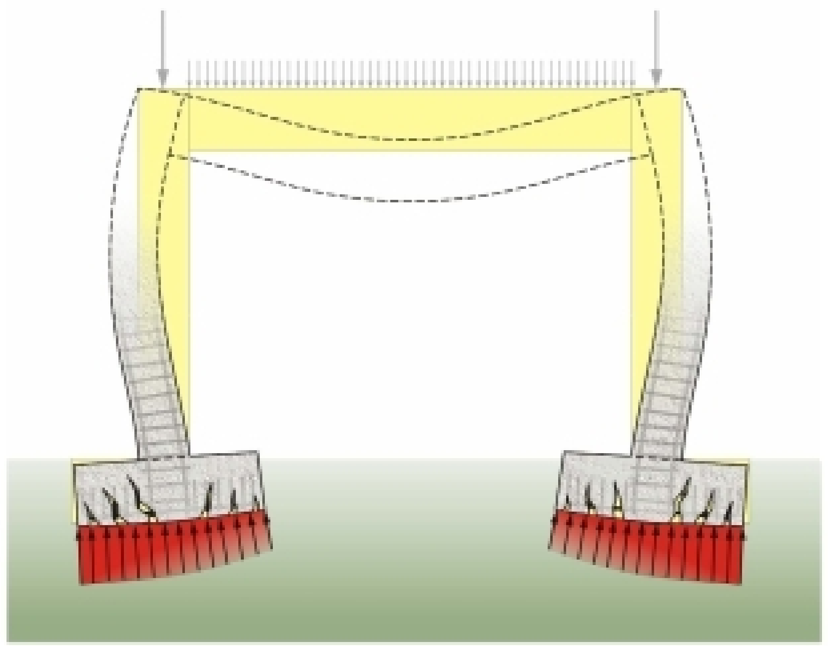
3.7.2 Frame foundation

(a) Spread footings without connecting beams (semelles)

Columns belong to frames i.e. clusters of columns and beams and the behavior of their foundation depends upon the interaction between the frames and the soil. It is important to examine the frames' behavior in relation to the foundation and soil.

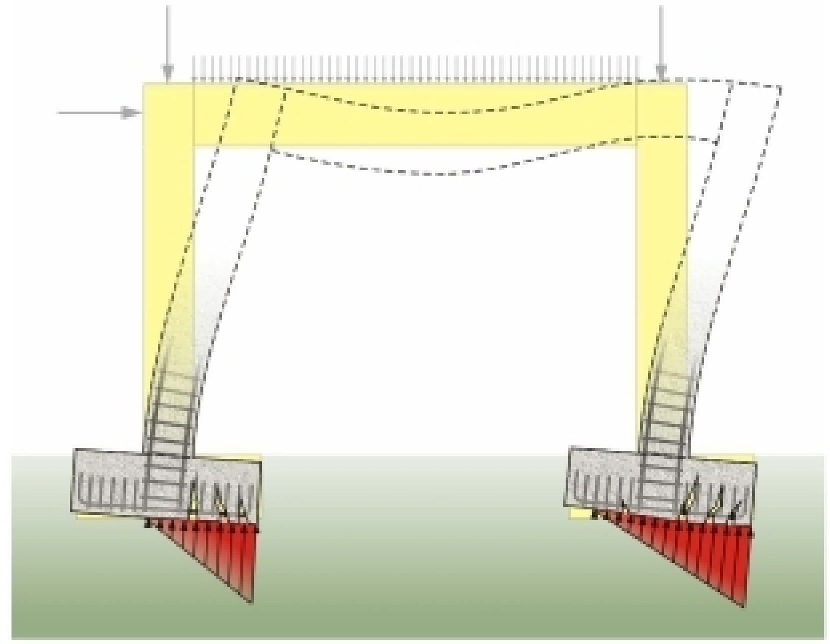
The simplest frame consists of two columns, as shown at the following figures:

Two-column frame with centric spread footings
<project: foundation110>



Behavior of a two-column frame with centric spread footings (no seismic loads applied)

When no seismic forces are applied, the soil pressures have a slight trapezoidal form and the spread footing is subjected to severe rotation.

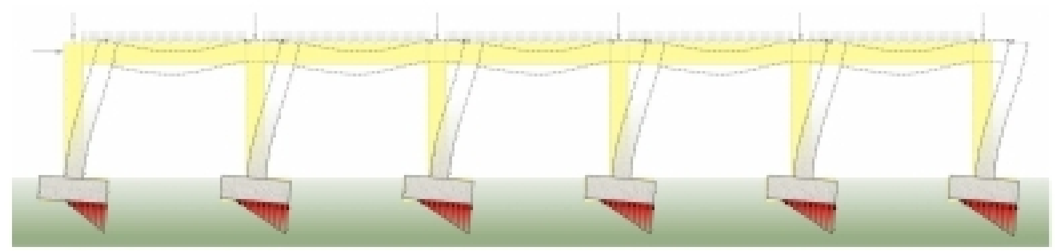


Behavior of a two-column frame with centric spread footings (under seismic loads)

When seismic loads are applied, the two spread footings are heavily over-stressed and they are forced to 'work' partially thus leading to large soil pressures. When the earthquake forces shift direction, there is a symmetrical change in the spread footings' over-stressing.

Notes:

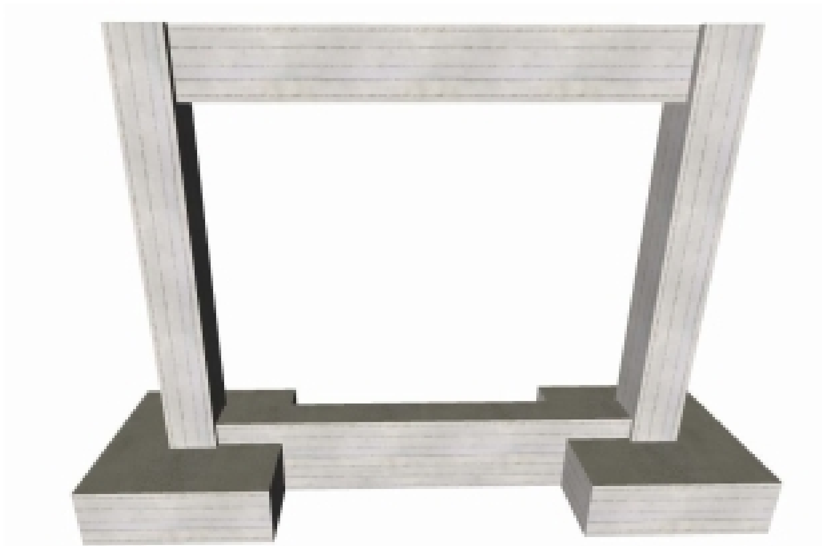
1. *In case of an earthquake, a large part of the footing cannot work in the required way. All spread footings have almost the same behavior (boundary spread footings are slightly over-stressed), as shown at the following figure. <project: foundation115>*



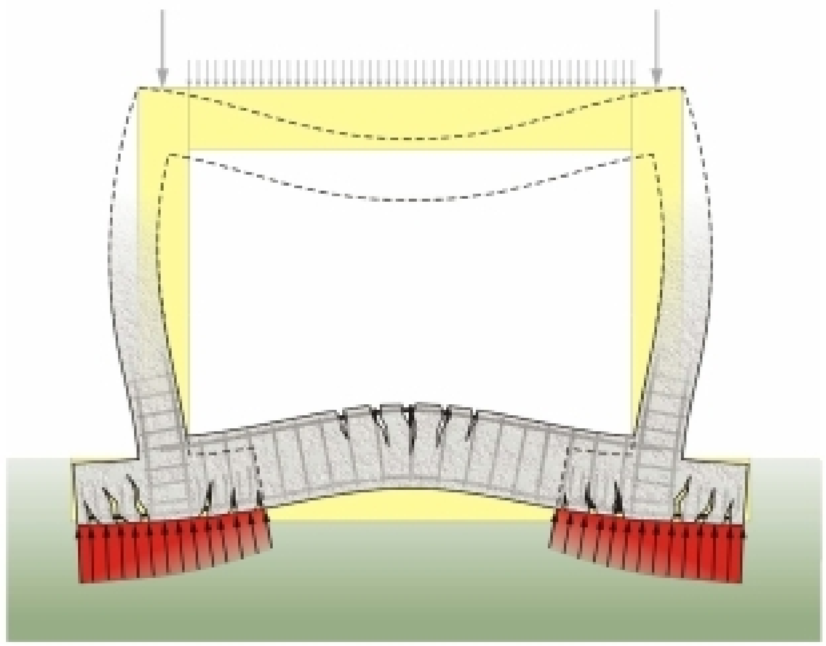
2. *According to the present regulation, the use of spread footing untied by connecting beams is not allowed. However it is useful to know the way they behave, because, in Greece, most buildings constructed prior to 1978 have no connecting beams and therefore, their possible rehabilitation requires special attention.*

(b) Spread footings with connecting beams (semelles)

Generally, it is useful to place connecting beams at the foundation because they carry the horizontal shear forces and prevent damage from differential settlements. However, in earthquake resistant structures, they are not just simply useful but absolutely necessary because apart from everything else, they centerline the spread footings and secure the fixed support of columns to a high degree. The following figures shown the behavior of spread footings tied together with connecting beams.

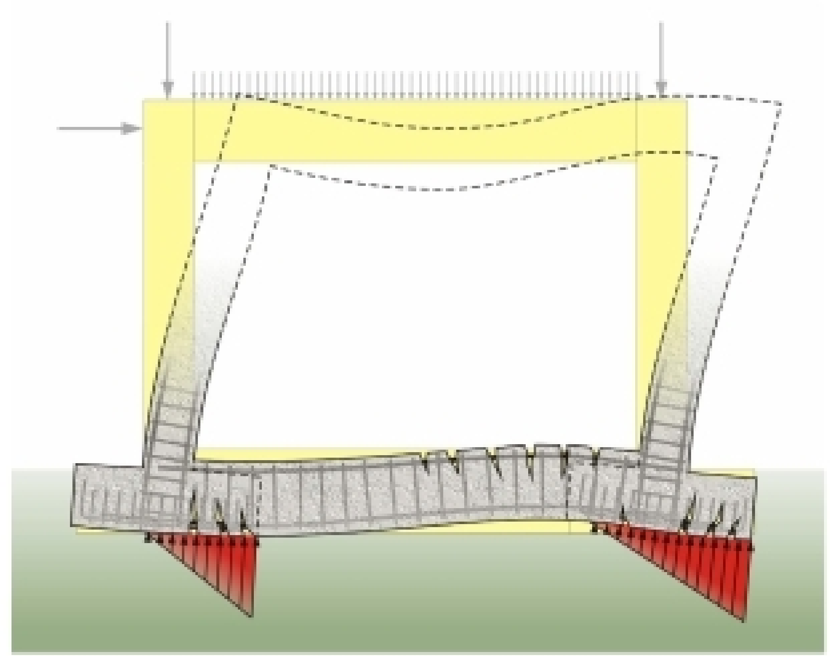


Two-column frame with spread footings and connecting beam
<project: foundation120>



Frame's behavior (no seismic loads applied)

When no seismic forces are applied, the soil stresses have an almost orthogonal form and the spread footings together with the connecting beam are roughly deformed.

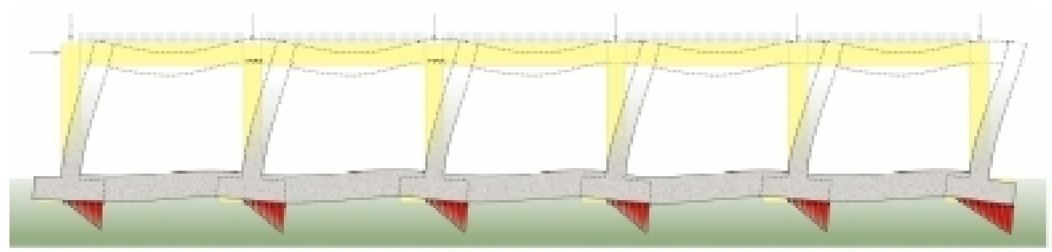


Frame's behavior when the earthquake forces are applied to the +x direction

In the duration of an earthquake, both spread footings work in a satisfactory level. The one is over-stressed thus creating larger soil pressures while at the same time, the other one is relieved. When the earthquake shifts direction, the stress conditions reverse. The connecting beam is subjected to large and continuously changing deformation and stresses.

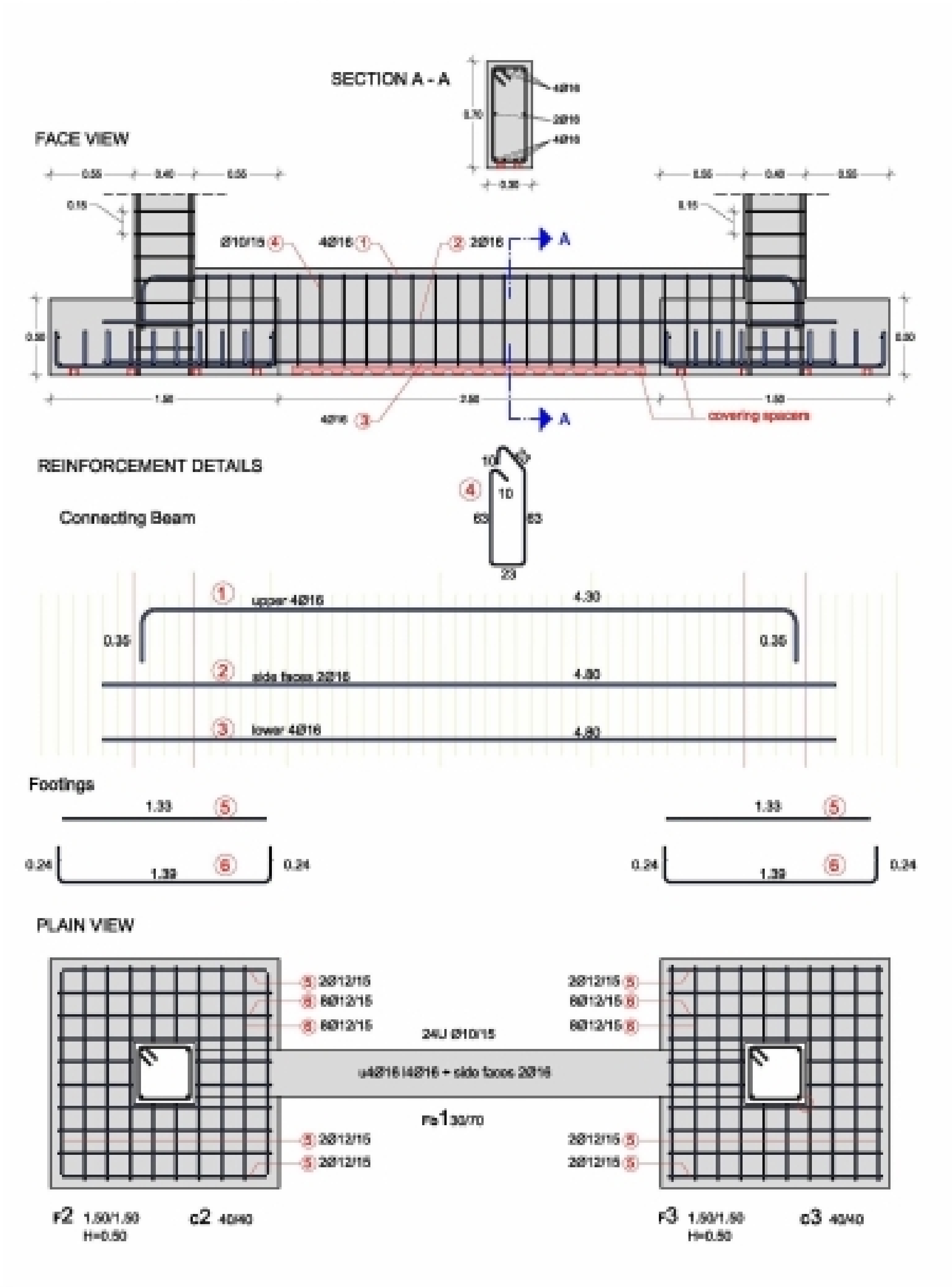
<u>*Notes:*</u>

1. *In a multi-column frame with spread footings and connecting beams, the behavior of the former, in a seismic event, is satisfactory. The boundary spread footings are over-stressed (or slightly under-stressed depended upon the earthquake's direction).*
   <project: foundation125>

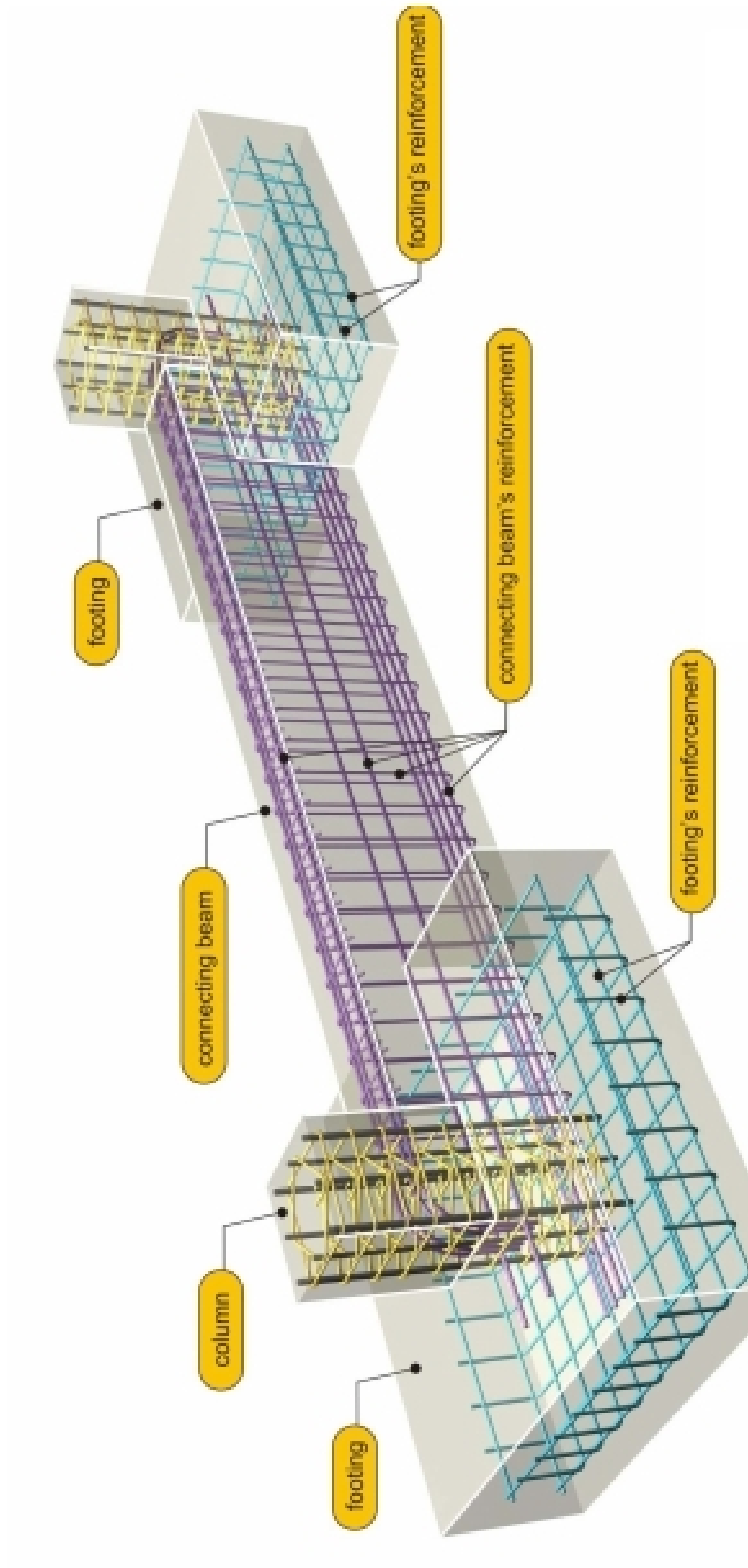


2. *The earthquake causes reverse stresses in every part of a connecting beam thus applying almost the same flexure at the upper and the lower fiber.*

The following figures show the plain view, the elevations and the detailing of the two-column frame foundation reinforcement of the example:



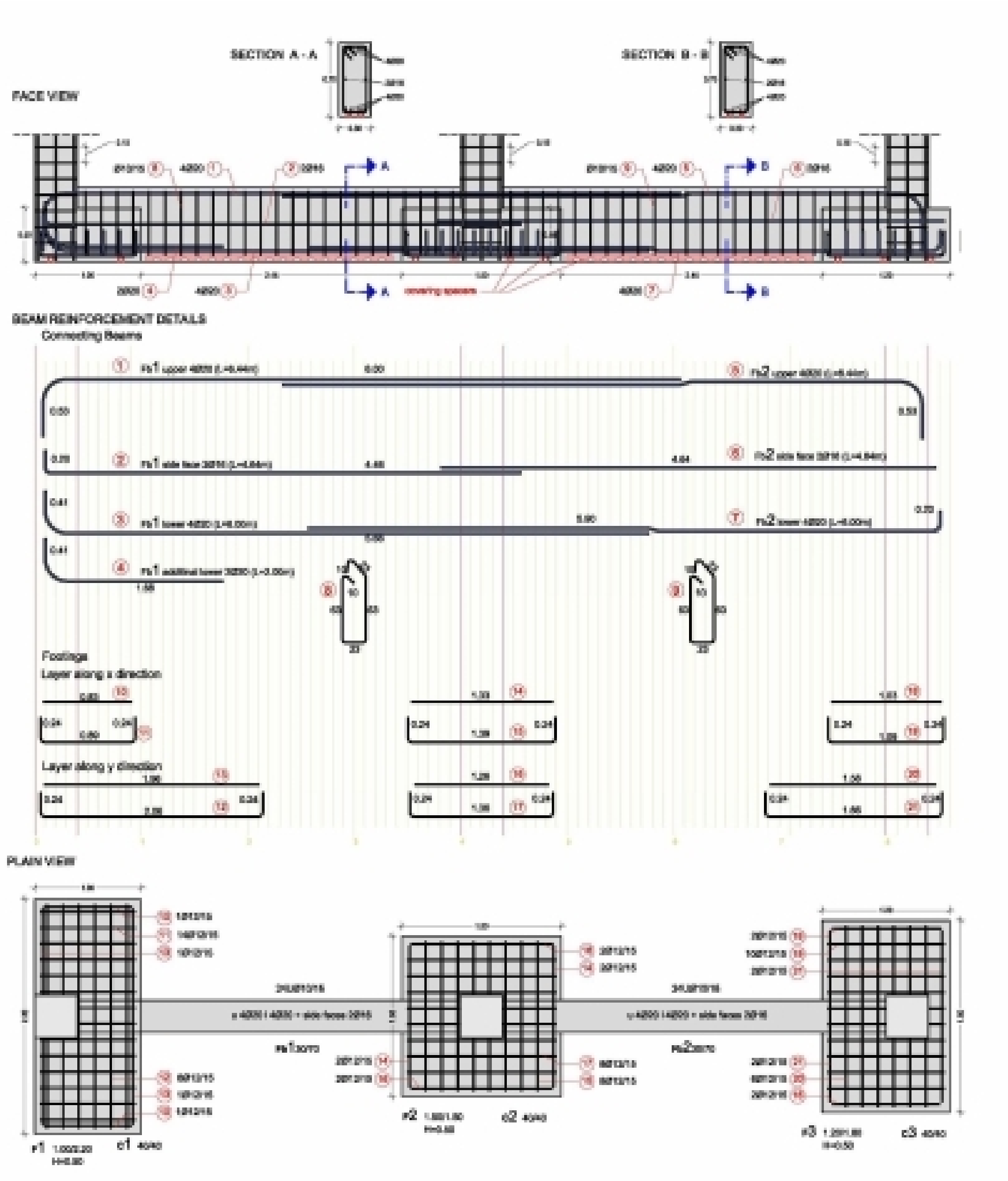
Foundation reinforcement of a two-column frame <project: foundation121>



3-D figure of the foundation reinforcement in a two-column frame with spread footings and connecting beam

(c) Continuous connecting beam

In case of more than two continuous spread footings and consequently more than one connecting beams, the reinforcement follows the same rules mentioned above.



Reinforcement of a continuous connecting beam <project: foundation130>

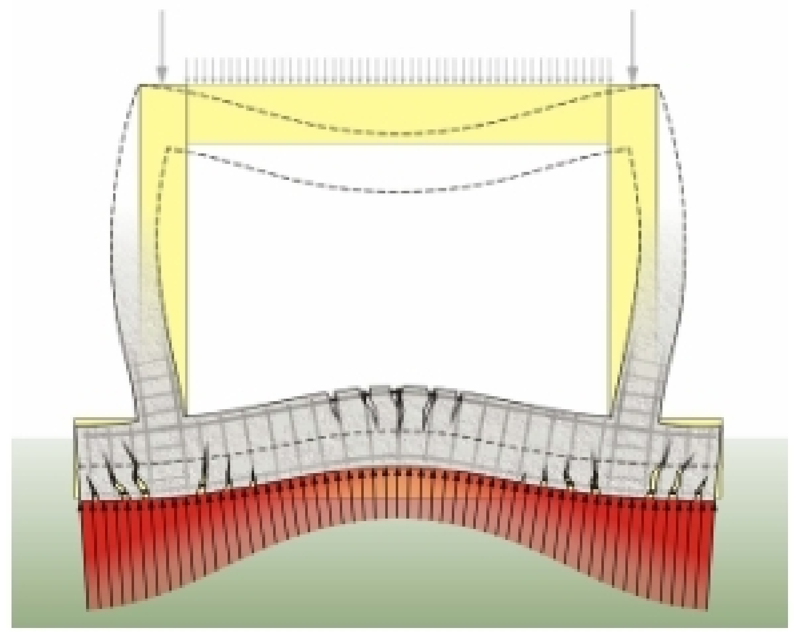
Extending the footing away from the edge column is extremely useful for the proper behavior of the spread footing (it levels the stress distribution) and therefore, must be aimed when it is constructional feasible.

3.7.3 Strip foundation

The strip foundation is the foundation element that behaves, simultaneously, like a spread footing and a beam. Strip foundations combine the properties of spread footings and connecting beams.

Two-column frame with a strip foundation that extends (beyond the columns) on both sides
<project:foundation140>

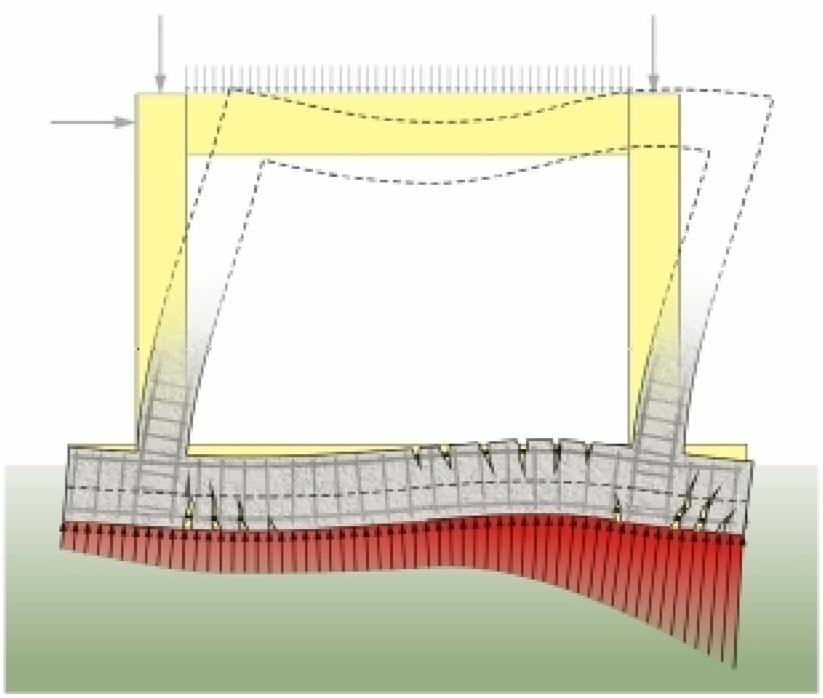
The strip foundation behaves in a way similar to that of spread footings tied together by a connecting beam. However, due to the fact that the footing and the foundation wall consist a unified body along the entire length of the structure, the systems inertia is larger therefore, its behaviour is more satisfactory.



Behavior of a two-column frame with strip foundation (no seismic loads applied)

When no earthquake forces are applied, the soil pressures are symmetrically distributed in the entire length of the strip foundation.

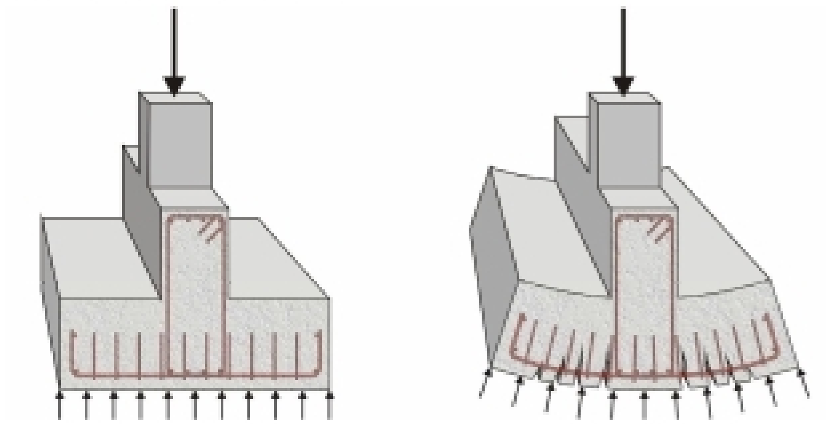
The stresses created to the soil are larger in the area of columns.



Behavior of a two-column frame with strip foundation (under seismic loads)

In the duration of an earthquake, one edge is over-stressed thus creating larger soil pressures while at the same time, the other edge is relieved. When the seismic forces shift direction the footings' over-stressing symmetrically changes. The deformation and stress applied upon the strip foundation are large and continuously reversing.

The footing behaves like a bilateral cantilever (fixed upon the strip foundation's wall). Its behavior is similar to the behavior of the spread footings therefore, it requires reinforcement to its lower fiber, as shown at the figure below.

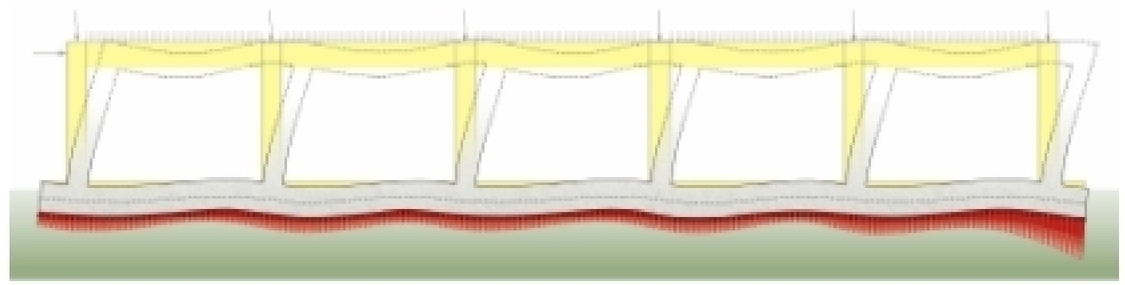


Behavior of the a strip foundation's footing

The soil's reaction, stresses the footing slab in an upward direction. This causes deformations at the lower surface of the footing which are carried by the reinforcement.

<u>Notes:</u>

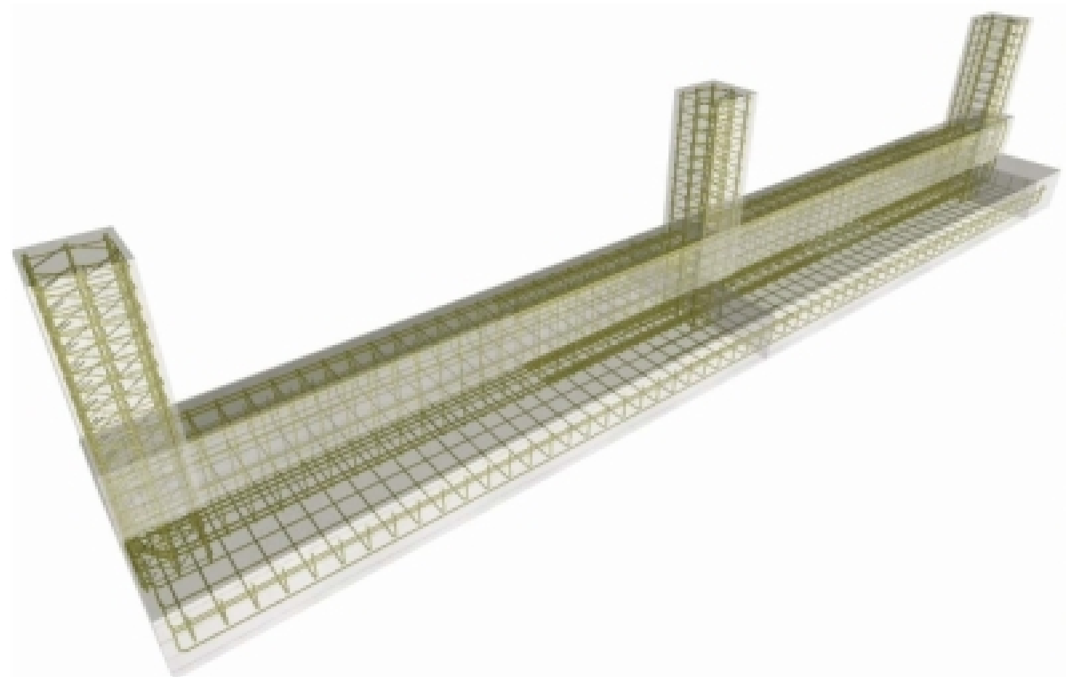
1. *Strip foundations behave extremely well during an earthquake. Depended upon the seismic forces' direction one edge is heavily over-stressed. In large parts of the strip foundation, the deformation continuously reverses and therefore, it requires strong reinforcement both at the upper and lower fibre, especially at the first and last opening of a continuous strip foundation.* <project:foundation145>



2. *In order to have a more efficient behavior of the strip foundation's boundary parts, it is useful to extend the strip foundation beyond the edge columns to an appropriate length.*

(a) Strip foundation with wall and footing

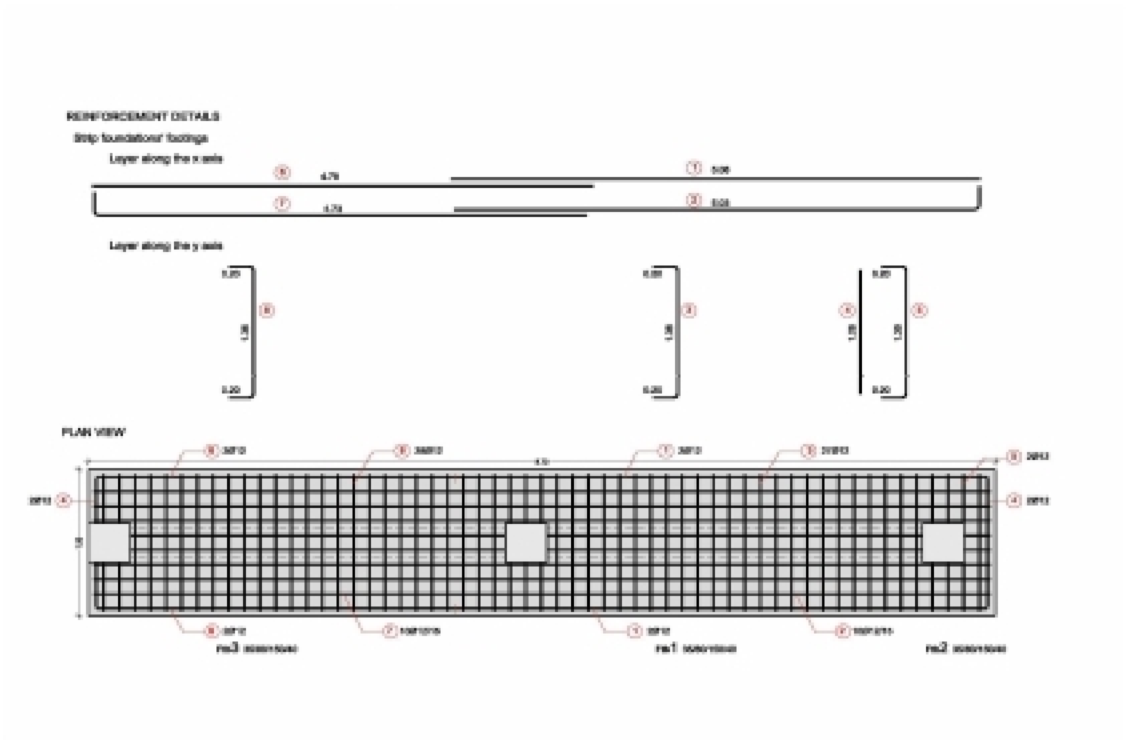
The behavior of this element is quite obvious since the footing distributes the applied loads to the soil, it is stressed by the soil's reaction and behaves like a cantilever slab while the foundation wall behaves in a way similar to a beam.



3-D figure of the a strip foundation's reinforcement
<project:foundation150>

The footing's reinforcement follows the same rules that apply to isolated spread footings however, its one dimension is of a large length.

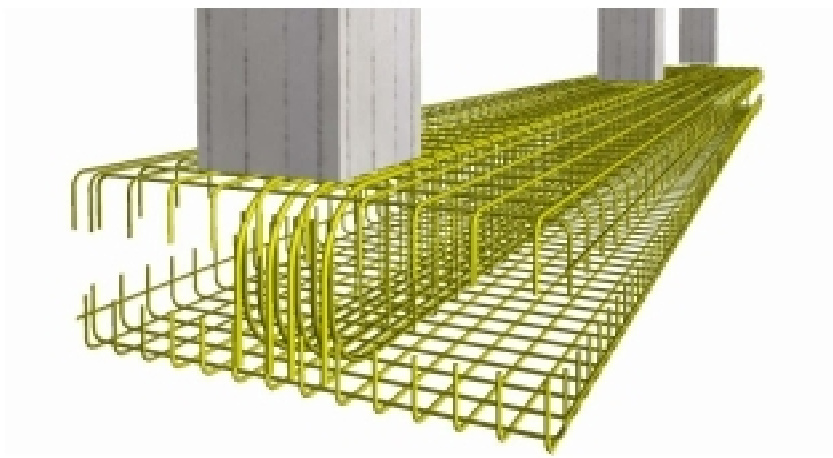
The foundation wall reinforcement follows the same rules that apply to connecting beams. Its reinforcement details are analogous to the corresponding reinforcement details of the previously mentioned continuous connecting beam.



(b) Strip foundation with a unified wall and footing

In a strip foundation with a unified wall and footing (orthogonal section), the footing's total depth is equal to the wall's height.

The only difference between the regular strip foundation and the strip foundation with a unified wall and footing is the fact that the latter requires reinforcement at the footing's lower surface.

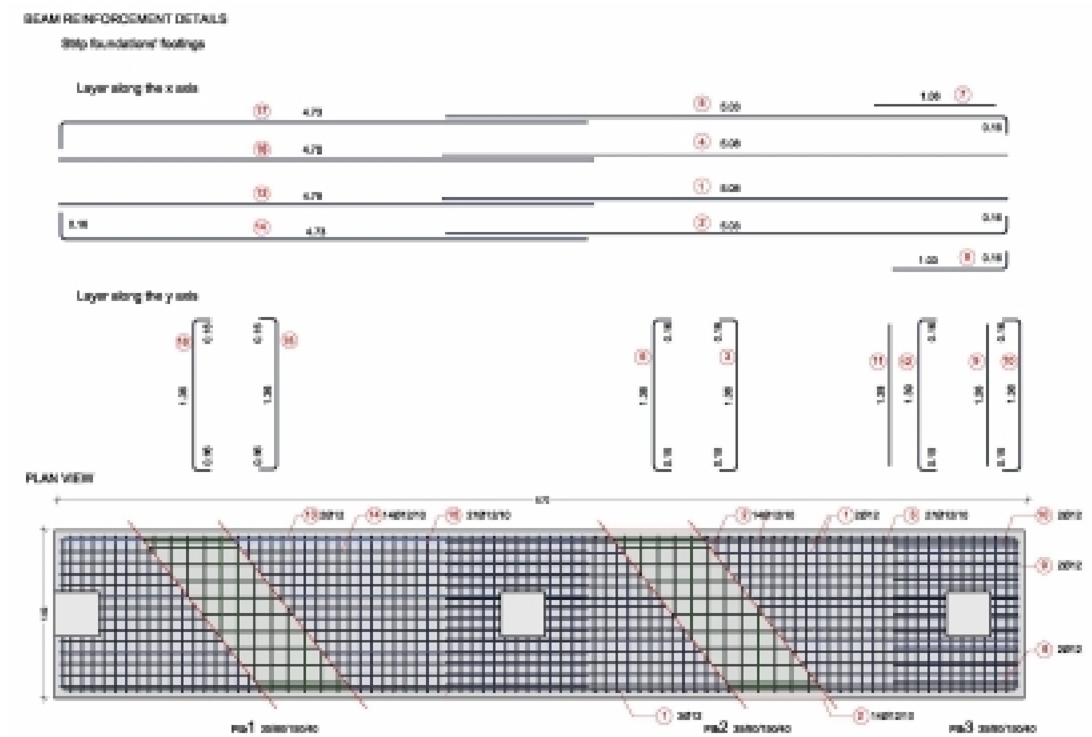


Reinforcement of an orthogonal strip foundation
<project:foundation160>

In the strip foundation where the footing and the wall have the same dimensions a hidden beam is formed. In this specific case, it has a four-legged stirrup while the footing is reinforced with a wire mesh placed both at its upper and lower part.

The footing's reinforcement follows the rules that apply to isolated spread footings but rebars are placed both at the upper surface.

The wall reinforcement (in the case where the hidden beam is formed), follows the same rules that apply to connecting beams.

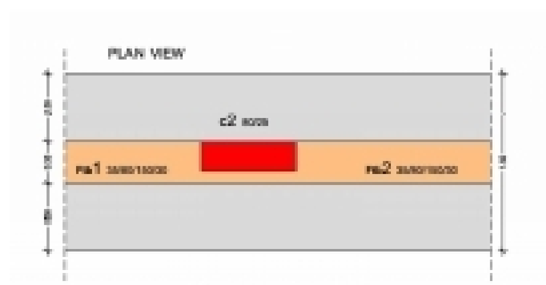


The foundation wall reinforcement details of this specific strip foundation are similar to the reinforcement details of the previously mentioned continuous connecting beam.

(c) Strip foundation in which the wall extends beyond the column's face

Generally, it is useful to place stirrups inside the column and the beam of a joint area that belongs either to the superstructure or the foundation. However practically, this is a strenuous procedure and therefore, it is preferred, in priority order, to place stirrups inside the columns.

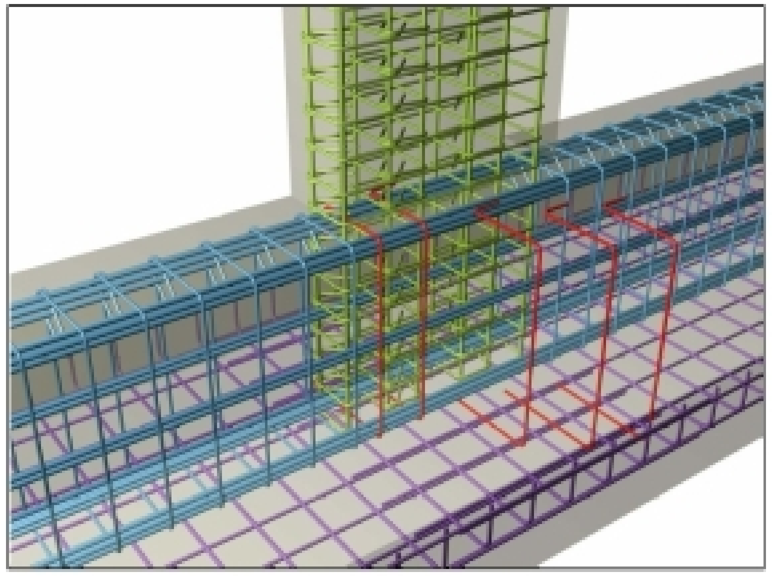
When the foundation wall extends beyond the face of the column, additional vertical reinforcement is required. This reinforcement may be provided in the form of regular stirrups or additionally fitted stirrups in the shape of a hairpin, as shown at the following figures.



The column with 80/25 section, in the common wall of the building, is partially sited upon the strip foundation that has a wall of 35/80.

1st example: one-sided extension of the foundation wall

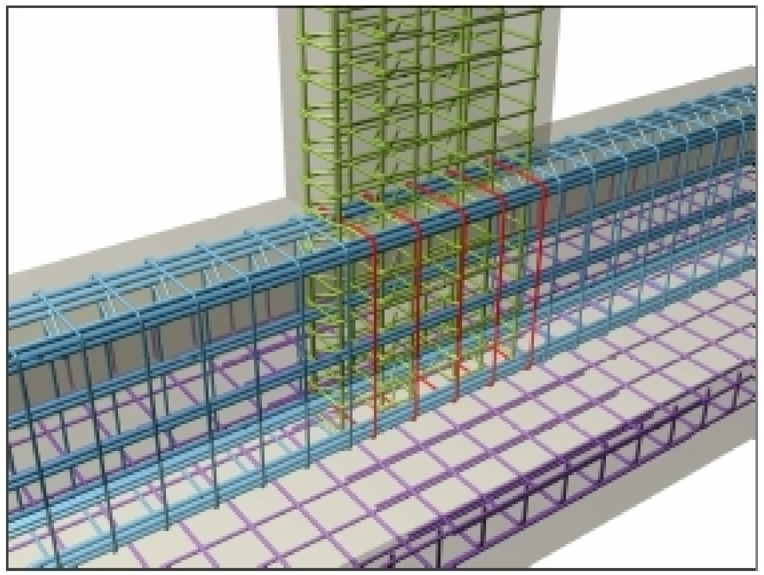
After the implementation of the stirrup cages inside the strip foundation walls, the wall's part that extends beyond the column remains un-reinforced along the vertical axis. The hairpin bars (in red colour) that will be placed in that area are shaped and placed in a separate phase.



Strip foundation that extends beyond the column

The vertical reinforcement positioned at the common area between the foundation wall and the column, is comprised of hairpin bars placed afterwards one by one.

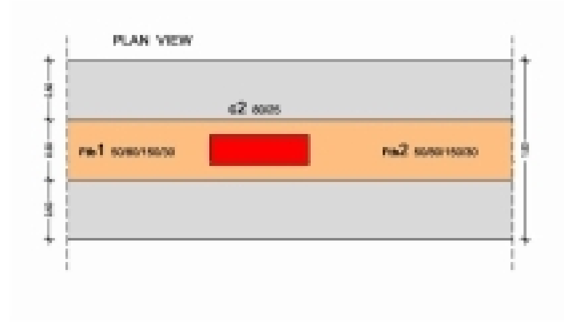
In that area, the vertical reinforcement at the back side of the strip foundation is provided by the column's longitudinal reinforcement (i.e. from the column rebars).



Wall reinforcement of a strip foundation, that extends beyond the column, with additional hairpin bars

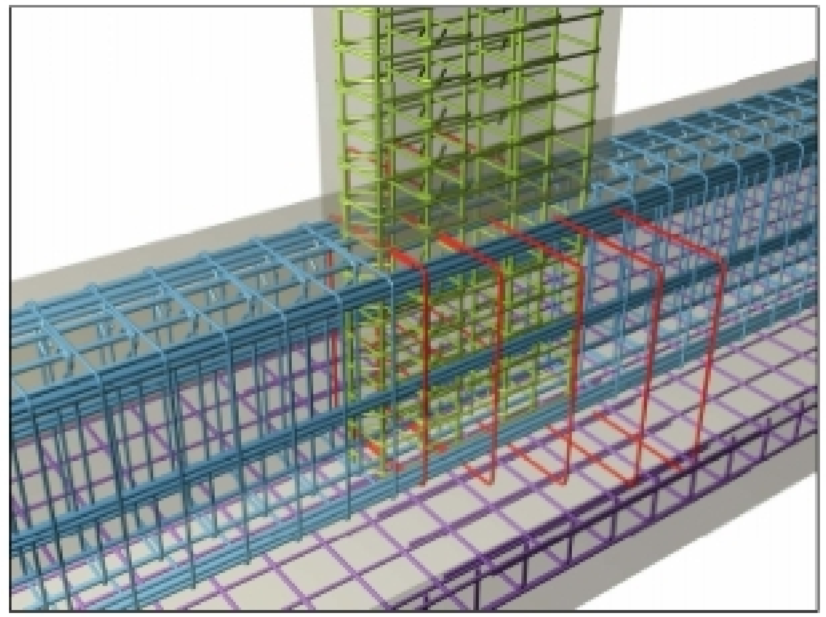
The ends of the hairpin bars may have a straight length or they may be bent in the form of a hook, depended upon which of the two is more feasible (see relevant note).

2nd example: two-sided extension of the foundation wall



The 80/25 column is sited upon the center of the strip foundation wall. The strip foundation and the foundation wall have sections of 50/80 and 35/80 respectively.

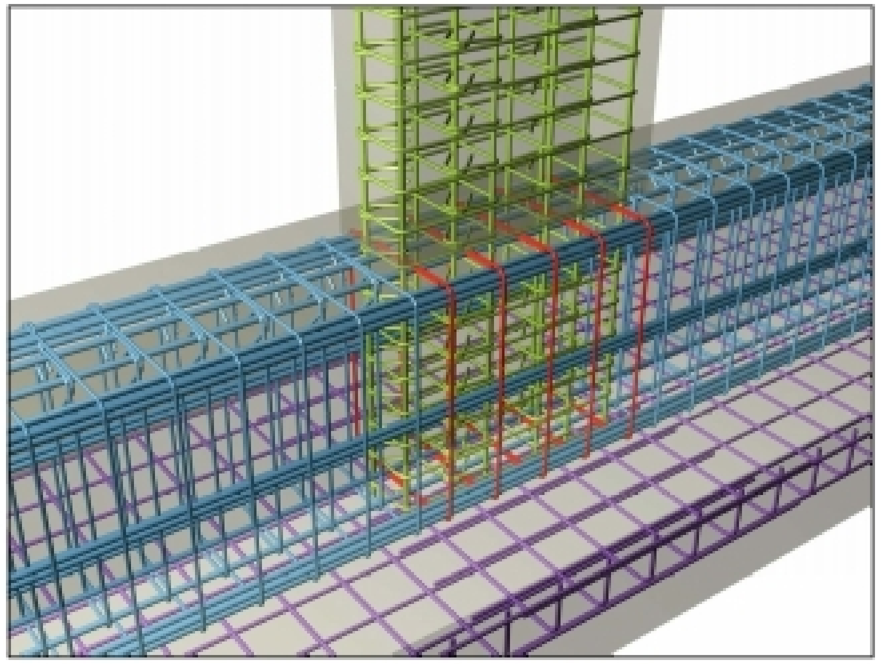
After the implementation of the stirrup cages inside the strip foundations' walls, the wall parts that extend beyond the column remains un-reinforced along the vertical axis. The double hair-pin rebars (in red colour) that will be placed in that area are shaped and positioned in a separate phase.



The ends of the hairpin bars are formed with a straight length

The vertical reinforcement positioned at the common area between the foundation wall and the column, is comprised of bilateral hairpin bars positioned one by one on both sides of the beam.

In this specific example, the stirrups placed inside the strip foundations' wall are four legged and after the cages' implementation the outer part of the wall, in the column area, remains without vertical reinforcement. The inner transverse reinforcement (the 2 middle legs of the 4 legged stirrups) in that specific area of the foundation wall is provided by the column rebars.



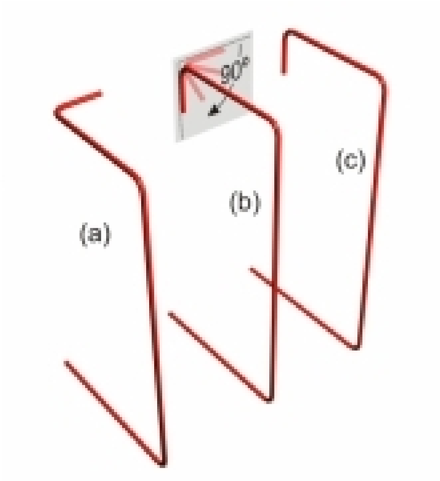
Vertical reinforcement placed inside the wall of a strip foundation that extends, beyond the column, on both sides

Notes:

1. There is no need to mention that in order to assemble any of the previously mentioned reinforcements, the formwork must not be constructed until after the completion of the reinforcing.

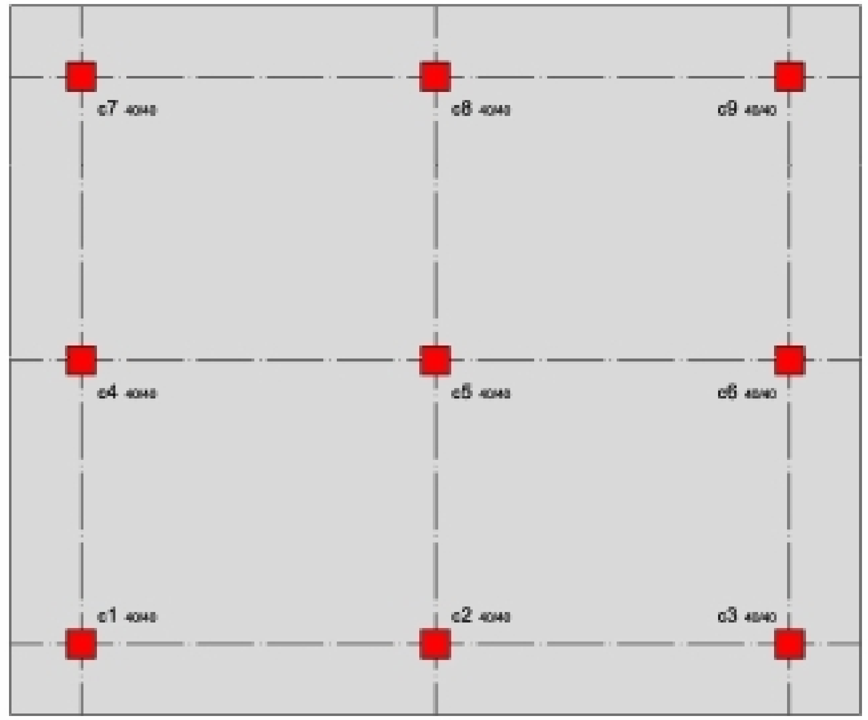
2. If there is access to those specific parts of the strip foundation, it is useful to form the hooks at the ends of the hairpin bars either during their shaping or after their implementation.

3. The next figure shows a combination of prefabricated hooks and proper fitting after the rebars' implementation. The 90° bend can be achieved by means of a special bending tool by the steel fixer.



3.7.4 Raft foundation

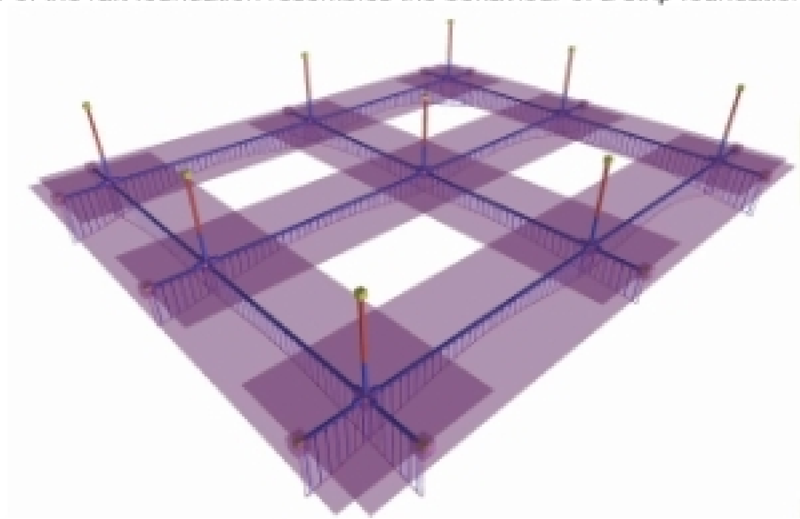
The extensive foundation (which is usually called raft foundation), is a unified foundation that extends throughout the entire area of the columns.



Raft foundation

As a rule, raft foundation is used as a building's foundation when the soil has a low bearing capacity.

The behaviour of the raft foundation resembles the behaviour of a strip foundation grate.



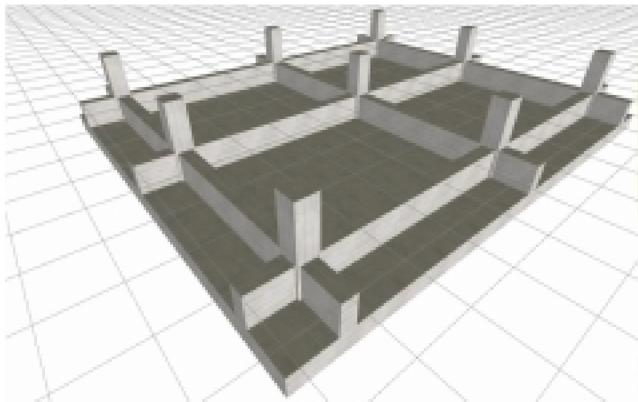
Form of soil pressures in a raft foundation

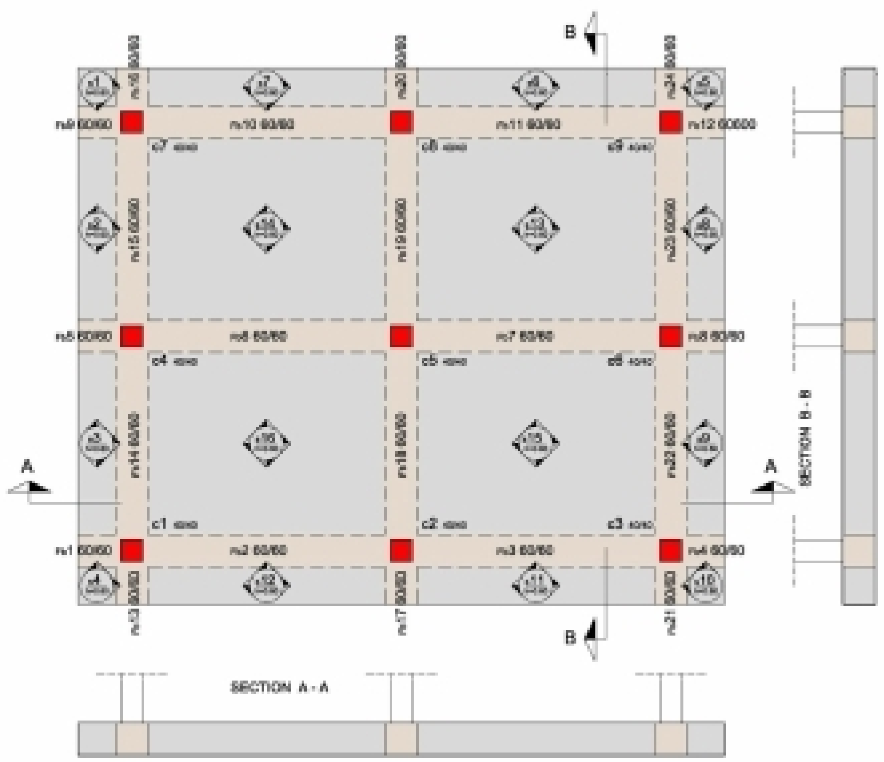
The stresses applied upon the soil are larger in the columns' area and lighter in the intermediate areas. The presence of beams acting as stiffeners helps in a more even distribution of the soil pressures between the columns' areas and the intermediate areas of the raft foundation.

The raft foundation may belong in one of the following four general categories, (1) ribbed raft foundation, (2) solid raft foundation, (3) raft foundation with hidden beams, (4) mixed raft foundation.

(1) Ribbed raft foundation

In a ribbed raft foundation apart from the unified foundation slab there are also beams which behave as stiffeners. The beams add stiffness to the foundation and apart from everything else, they level the soil stresses.





Unified foundation slab (raft foundation) with stiffeners (beams)
<project: FoundationRough10>

The formwork's assembling and the reinforcement implementation of a raft foundation stiffened by beams are two relatively strenuous procedures.

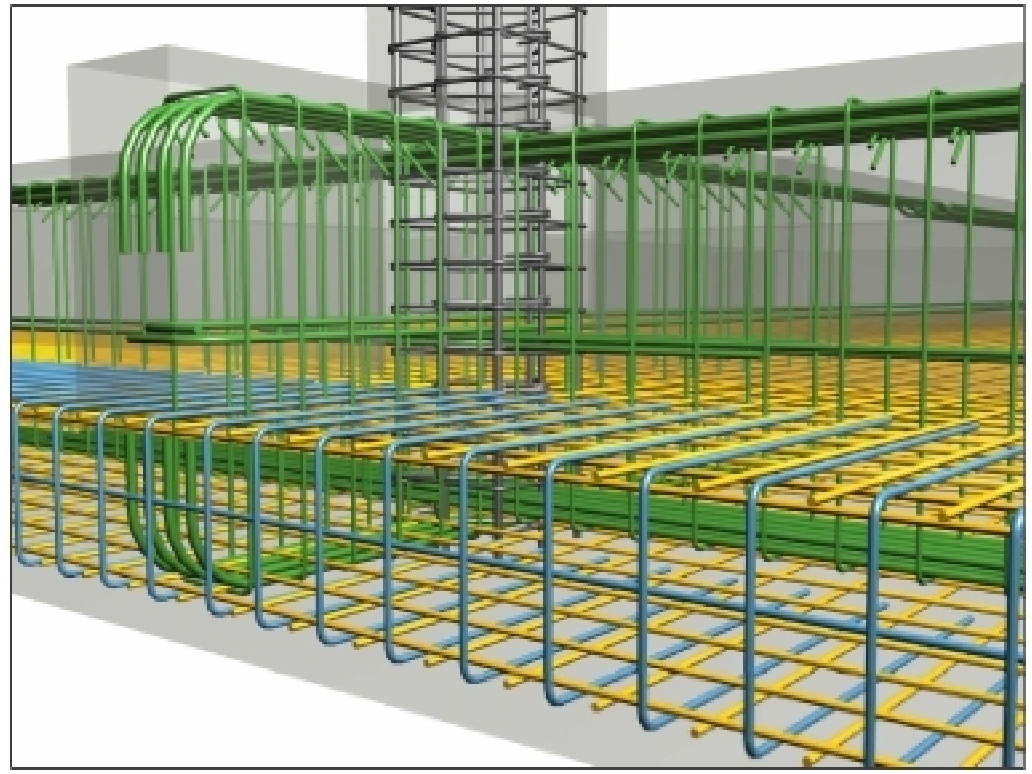
As shown at the following figure, the ribbed raft foundation reinforcement can be separated into three categories:

(a) slabs' reinforcement (in yellow color)

(b) slabs' free edges reinforcement (in blue color)

(c) beams' reinforcement (in green color)

The column rebars are in grey color.



Reinforcement of a ribbed raft foundation

The foundation slabs are reinforced with two wire meshes, one placed at the lower fibers and one at the upper fibers, by following the reinforcement rules that apply to slabs.

The beams are reinforced with strong stirrups and bars placed both at the upper and lower fibers, by following the reinforcement rules that apply to beams.

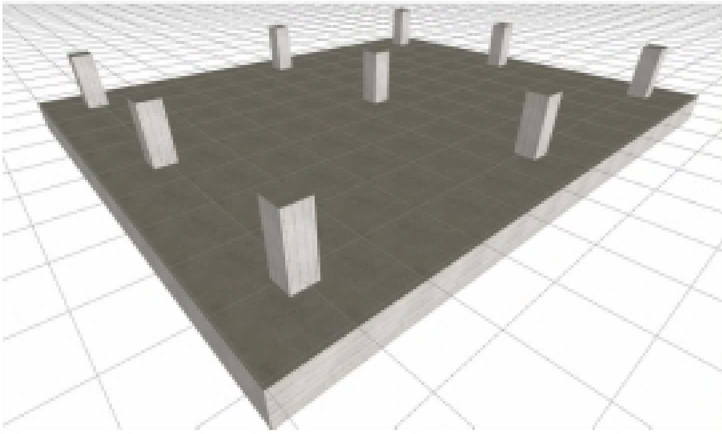
The slabs' free edges are reinforced with common hairpin bars or with a wire mesh folded like a hairpin, by following the reinforcement rules that apply to slabs.

Note:

A foundation grate can be stiffened either by beams or by walls. In the latter case, the reinforcement of the foundation slab does not depend upon the wall's reinforcement.

(2) Solid raft foundation

The unified solid raft foundation is the most simple foundation form and its formwork assembling as well as its reinforcement implementation do not require hard labor.



Solid raft foundation

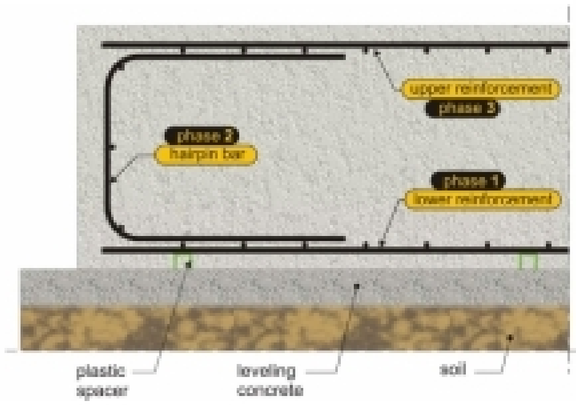
In the solid raft foundation, there is only one unified foundation slab.

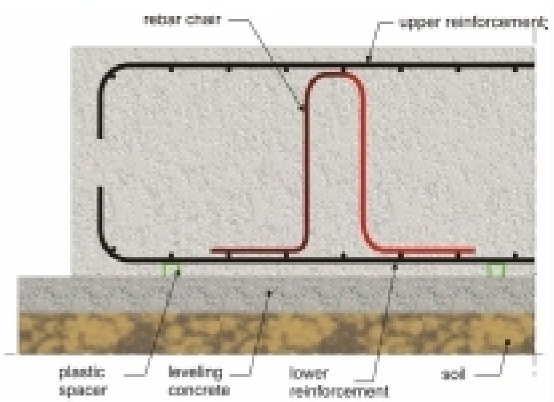
The foundation slabs are reinforced with two wire meshes, one placed at the lower fibers and one at the upper fibers. Since the most intense stresses appear along the columns' axis, their surrounding areas are usually reinforced with stronger or double grates.

The slabs' free edges are reinforced with common hairpin bars or with a wire mesh shaped like a hairpin.

<u>*Notes:*</u>

1. *On a practical level and mainly when using a folded wire mesh as a free edge's reinforcement, the hairpin rebars are positioned in the 2nd phase, as shown at the first figure.*
2. *The alternative solution for providing the free edges' reinforcement includes the formation of hooks at the ends of the upper and lower rebars as shown at the second figure. This solution compared to the hairpin solution, apart from everything else, has a higher shaping-cost but mainly it lacks a natural peripheral rebar chair.*





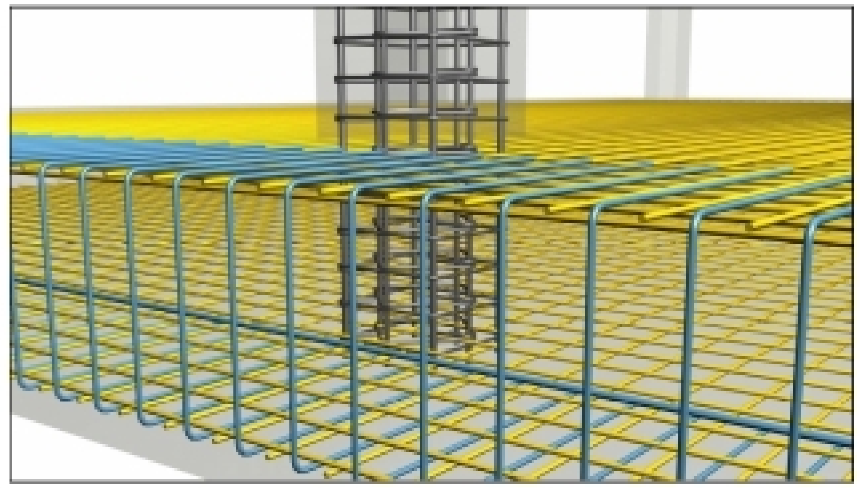
The reinforcement of a solid raft foundation can be separated into three categories, as shown at the following figure:

(a) slabs' reinforcement

(b) slabs' free edges reinforcement

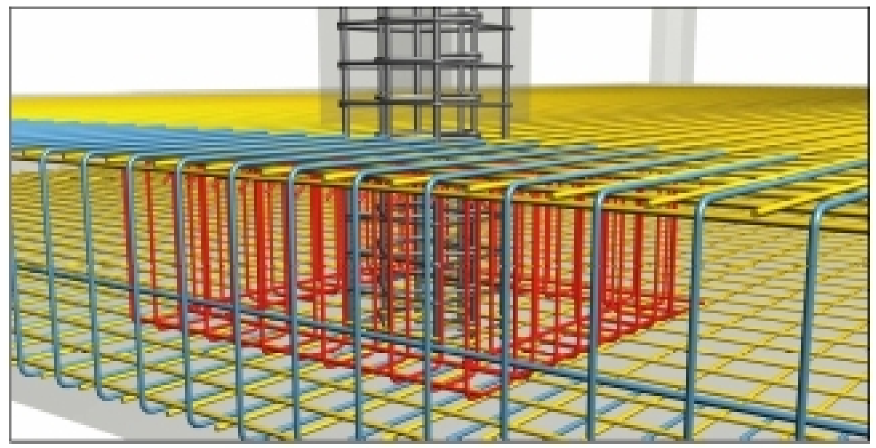
(c) punching shear reinforcement (when necessary) in the area surrounding certain columns (in red color)

The column rebars are in grey color.



Reinforcement of a solid raft foundation

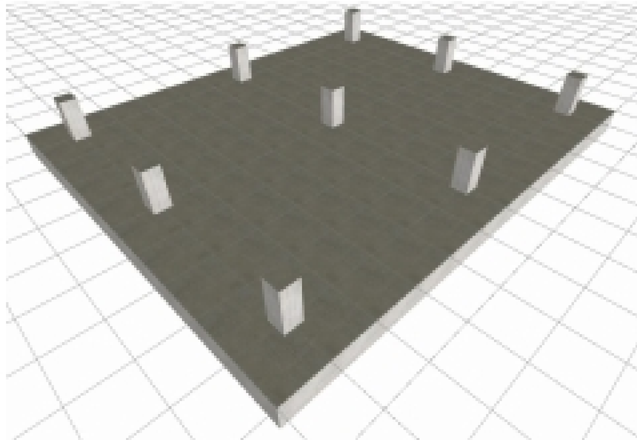
The punching shear reinforcement, when it is required, is similar to the one used in the isolated spread footings of paragraph 3.7.1, as shown at the following figure.



Raft foundation with punching shear reinforcement

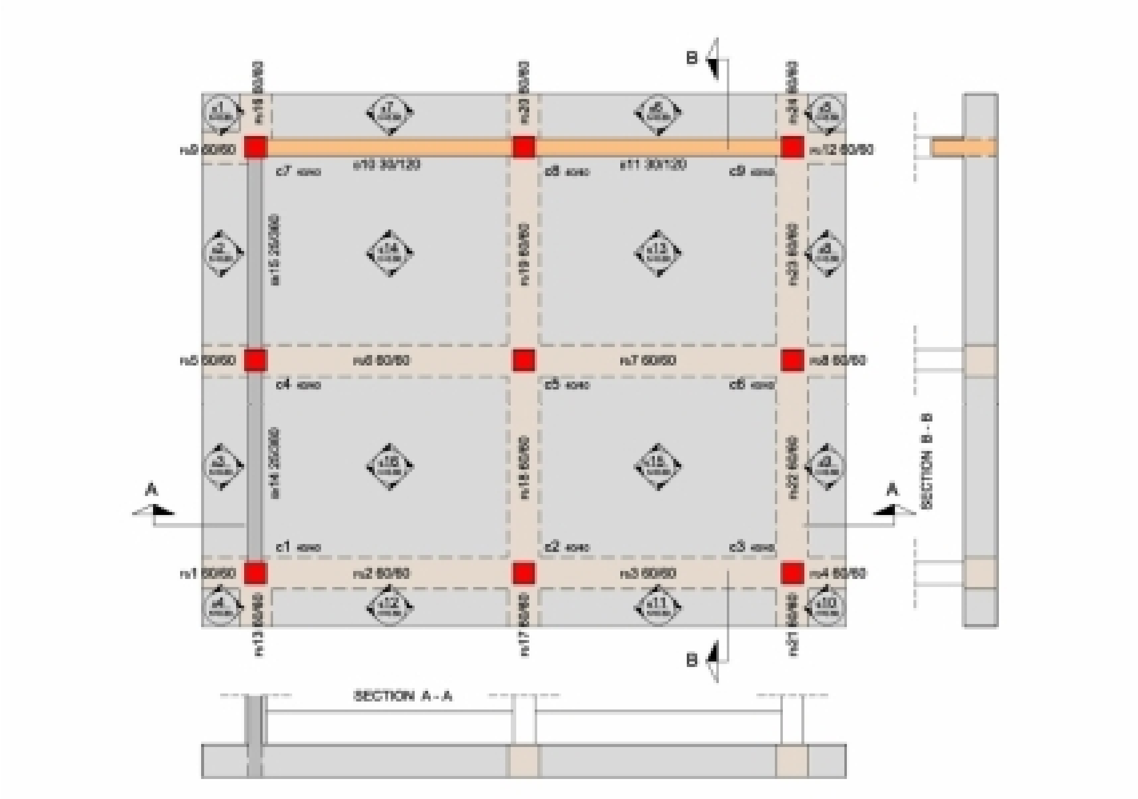
When the columns are subjected to large loads and the foundation slab's thickness is analogically small, it is obligatory to use punching shear reinforcement. That reinforcement can be provided by stirrup cages, as it is in this example, by bundles of properly bent rebars or by special industrial elements.

(3) Raft foundation with hidden beams



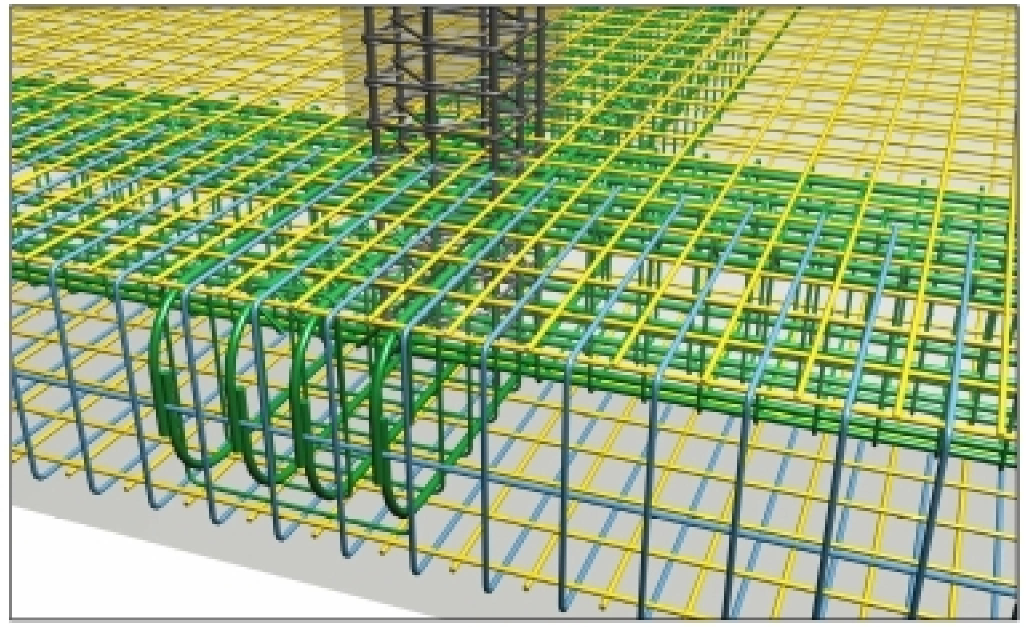
In a raft foundation with hidden beams, the foundation slab is unified and has no additional stiffeners. This means that geometrically, it is as simple as the previous case.

Its formwork assembling does not require a lot of effort as opposed to its reinforcement implementation.



Raft foundation with hidden beams <project: FoundationRough20>

The reinforcement of the raft foundation with hidden beams is the same with the reinforcement placed inside the ribbed slab foundation. The only difference lays in the fact that the total depth of the beam-stiffener is equal to the slab's thickness.

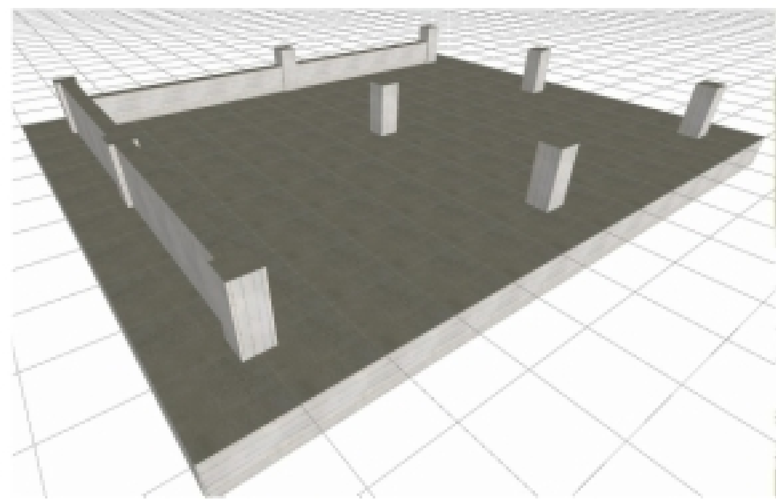


Reinforcement of a raft foundation with hidden beams

The stirrups placed inside the hidden beams may be two-legged or four-legged (as they are in this example). On other occasions, stirrups with more than four legs can be used.

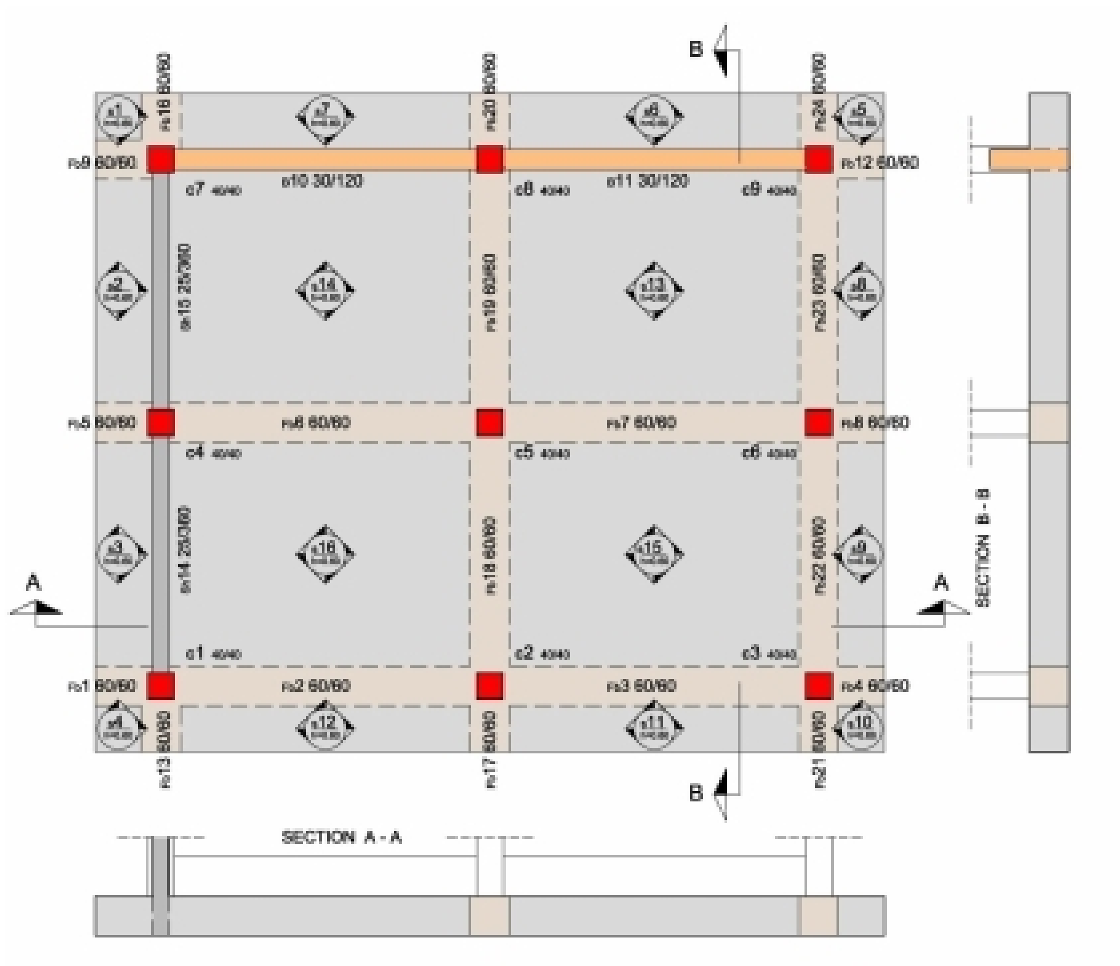
(4) Mixed raft foundation

The mixed raft foundation is an extensive foundation which is partially stiffened by beams or by walls.



Mixed raft foundation

<project: FoundationRough40>



This specific raft foundation includes solid parts, parts stiffened by beams and parts stiffened by walls.

The formwork assembling and the reinforcement implementation of a mixed raft foundation involve a lot of difficulties however, sometimes, it is an unavoidable solution e.g. in basements where it is obligatory to have shear walls.

3.7.5. Foundation cases

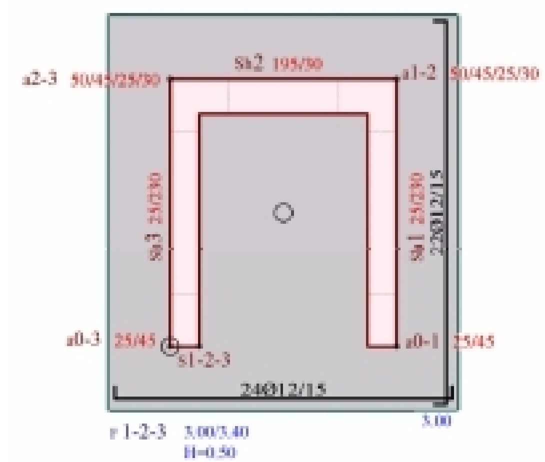
(a) Foundation of composite elements

The composite elements, in the case of spread footing foundation, require one unified spread footing.

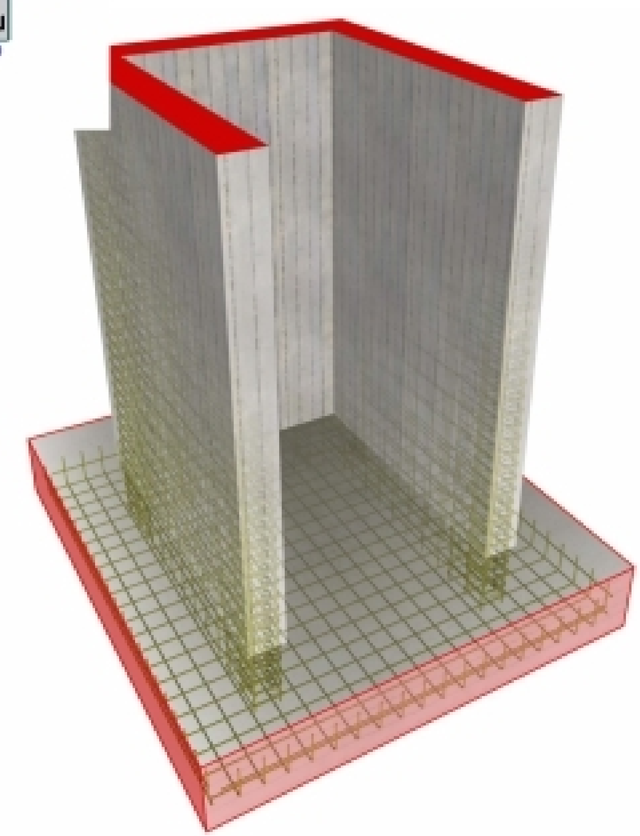
In order to comprehend the reinforcement of composite elements, the following sections regard the reinforcement of the unified footings used in the two characteristic examples of paragraph 3.3

Elevator

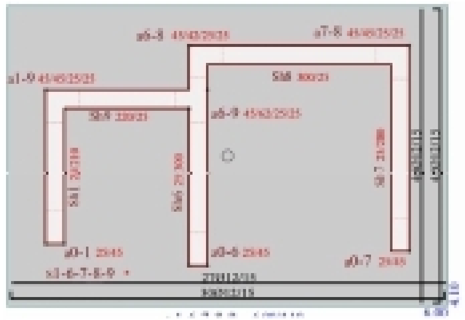
The three shear walls of the elevator constitute one element (elevator core) whose foundation is composed of a spread footing reinforced by a grate of rebars placed at its lower surface.



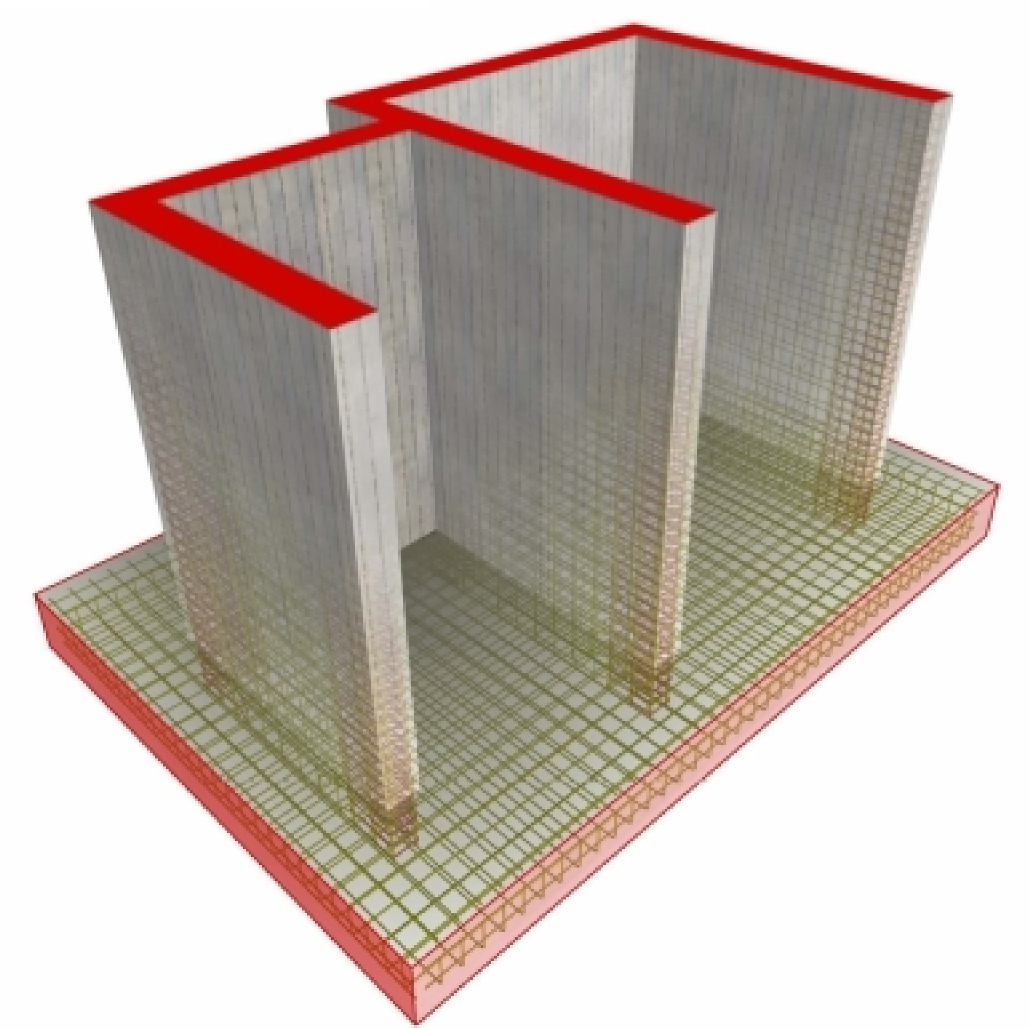
Unified spread footing of an elevator core



Staircase



Unified spread footing of a staircase

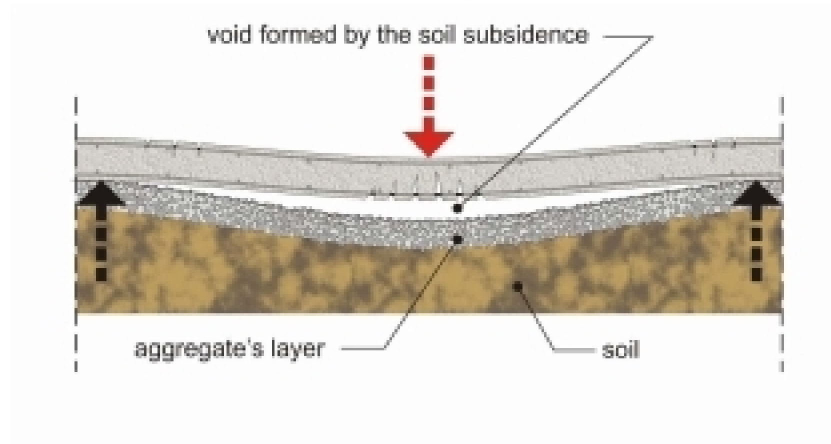


In the case where the foundation of the staircase is composed of a unified spread footing, due to its extremely extensive surface, it is required to place a double reinforcement grate (at the upper and lower surface).

Vehicle ramps on ground

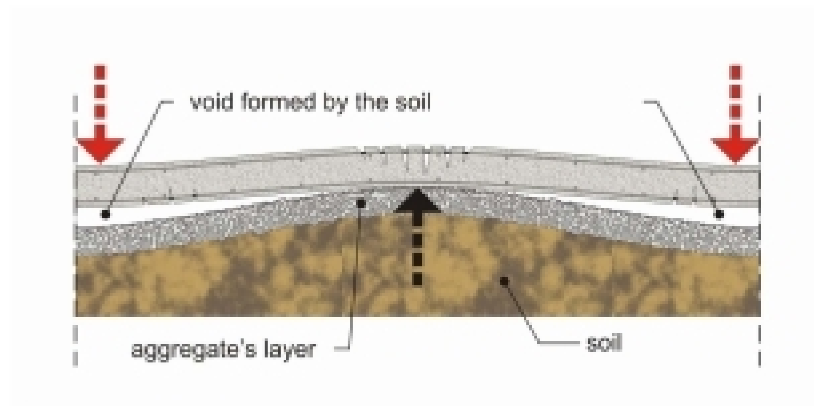
The vehicle ramp on ground is an extensive load bearing element which at the same time constitutes its self-foundation. As in every other foundation, the soil condition has a fundamental importance and most of the times in ramps' case, it is formed at least partially with embankment (polder).

Most of the times, no matter how much effort has been put to the proper compaction of the embankment, there is uncertainty about its homogenous future behavior, as shown at the following figures.



The first case of a floor's unfavorable behavior is the subsidence (recess) of the soil under the middle of the ramp's width and the formation of tensile stresses in the lower fibers

[the deformations shown at the above and the following figure are presented in a large scale].



The second case of a floor's unfavorable behavior is the subsidence of the soil under the one or the two ramp ends and the formation of tensile stresses in the upper fibers.

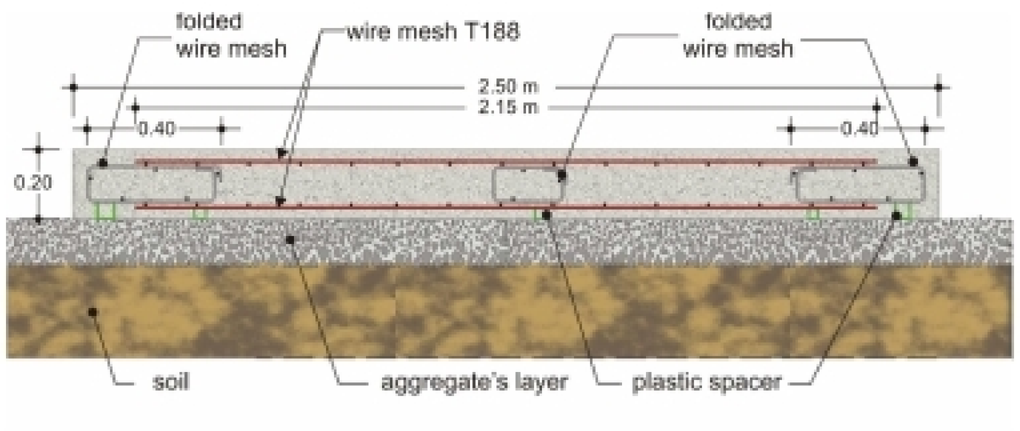
In these cases, the ramp must be reinforced with a double wire mesh, one placed at its lower surface and at its upper surface.

Prior to the ramp's reinforcement implementation one should ensure a level and properly compacted surface. This can be achieved either with the use of a thin concrete layer (3 to 5 cm), or with the use of gravel or with 3A and proper compaction.

Usage of aggregates for the formation of the ramp's substrate allows the application of plastic spacers however, these must be positioned upside down so as to avoid sinking inside the substrate.

In order to provide the reinforcement with two wire meshes, it is mandatory to use rebar chairs.

For ramp widths reaching up to 2.5m and since there it is possible to cast and vibrate concrete from both sides of the ramp, rebar chairs can be replaced by open-form folded wire meshes (hairpins) or by closed form folded wire meshes which at the same time will provide efficient cohesion of the ramp's edges.



A combination of reinforcement, support and lap-splicing of a standardized wire mesh T188 (Φ6/15 with dimensions 2.15x5.0 m)

<u>Notes:</u>

- *In case of an extremely well-formed substrate, it is allowed to use only a single wire mesh which will be placed for example at the 2/3 of the ramp's thickness.*
- *In a ramp, stresses can be created in both directions; therefore, always assuming the same behaviour, the placed wire mesh is usually of a square shape. The wire meshes used for the ramp's reinforcement must be normally lap-spliced (in usual cases a length of 2 up to 3 openings is enough).*
- *Heavy-duty ramps require edge reinforcement as well. That reinforcement can be also used as rebar chairs.*
- *The edge behavior does not appear only to the ramps' edges but also to the areas around joints. The joint edges are treated by the same way as the side edges. It is useful to place the joints in the shortest possible distances e.g. every 15 meters.*

Extended slab on ground

Extended building slabs on ground, are mainly floors constructed upon the upper basement after the foundation's embankment (polder).

The slab on ground is an element analogous to the ramp on ground and their behavior is almost alike. The reinforcement is implemented with the same way however, it involves an additional difficulty that arises due to the extended slab's surface which in the case of a double wire mesh creates problems in both the reinforcement implementation and the concrete casting.

<u>Notes:</u>

1. *The problem of securing the double wire mesh's proper position at the upper and lower parts of the slabs is not that intense in the superstructure because: firstly, there are the beams that separate and support the slabs' reinforcement and secondly, the reinforcement of the slabs is strong and therefore, carries effectively not only its self weight but also the loads applied by the movement of the personnel responsible for the steel fixing and the concrete casting.*
2. *The solution to this problem is (a) a well-formed surface with fine aggregates properly compacted, or an additionally casted thin layer of concrete (3 to 5 cm) and (b) usage of narrow spaced rebar chairs (with practices similar to those mentioned in paragraph 2.6.1)*
3. *A larger live load, applied upon the slab, requires the use of a stronger wire mesh.*
4. *Generally, the standardized wire mesh with square openings like T196(#Φ5/10) and T188(#Φ6/15) of steel class B500A [table 2], presents a satisfactory behavior under the common loads applied upon basements' slabs.*

CHAPTER 4

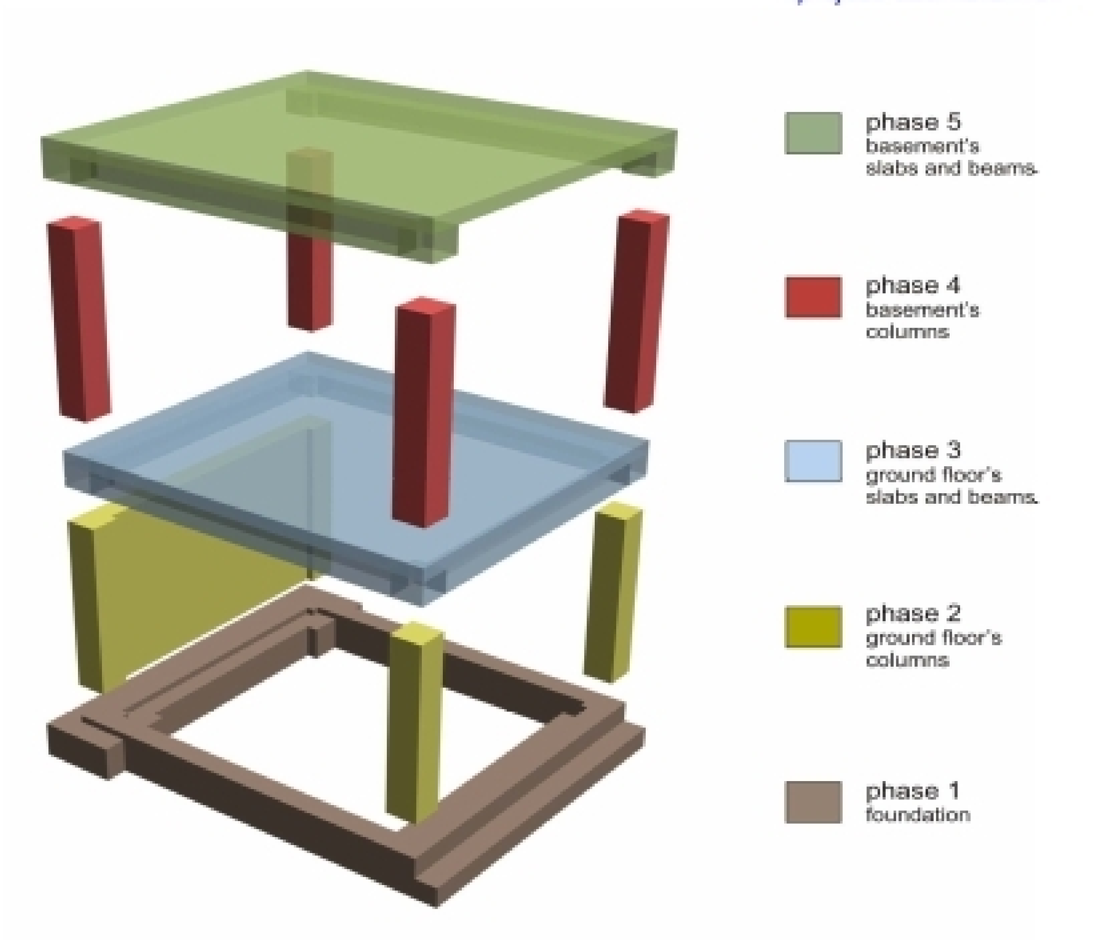
Quantities surveying and Cost estimation

4. Quantities surveying-Cost estimation

The following paragraphs refer to the quantities and cost estimation of the building shown at the next figure.

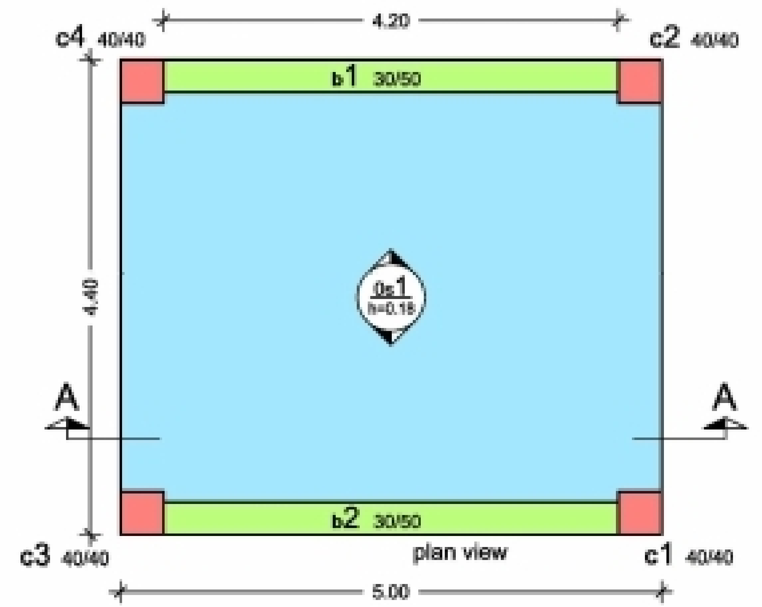
It is comprised of a ground floor and a basement (with one shear wall) while its strip foundation is combined with spread footings tied together by connecting beams. The following paragraphs present the detailed quantities estimates of materials like concrete, formworks, spacers, reinforcements, the reinforcement schedules' optimization as well as the total quantity and cost estimation of the structural frame.

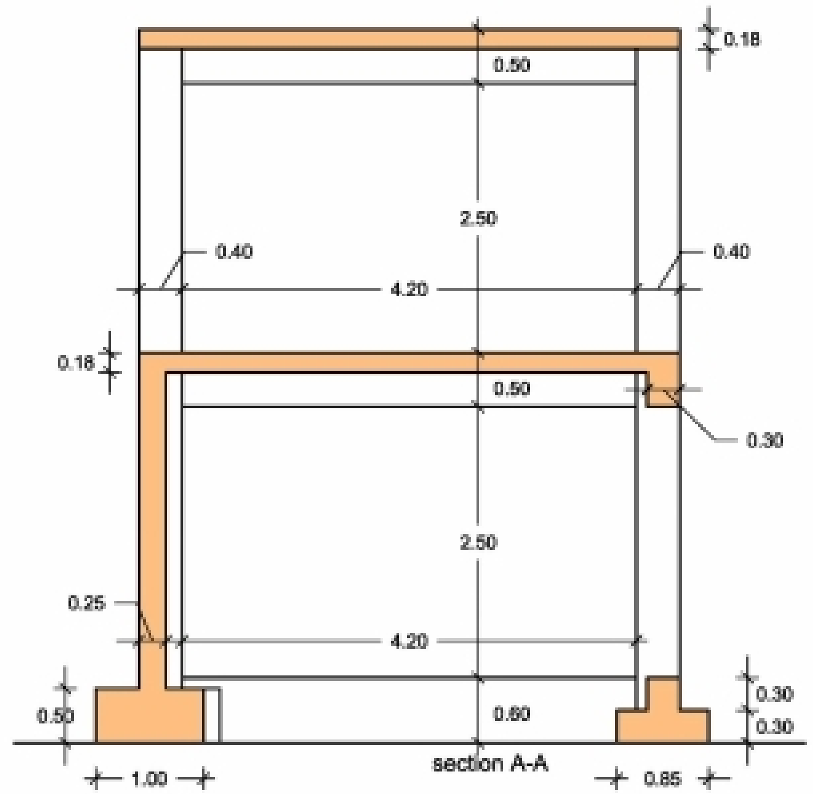
A simple building with a ground floor and a basement
<project: Estimation10>

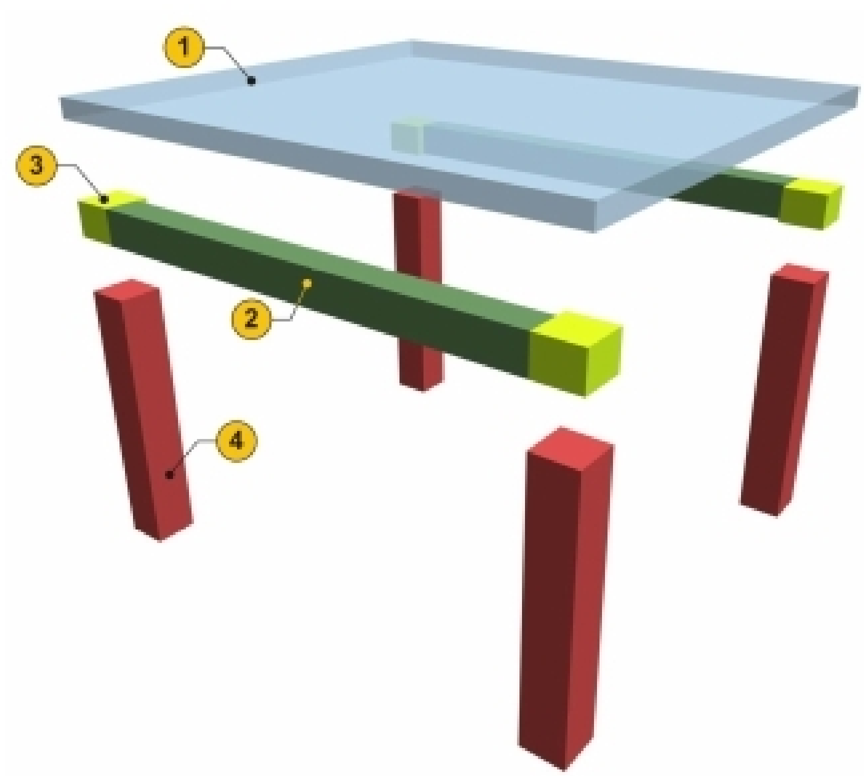


4.1. Estimation of the concrete's quantity

Ground floor







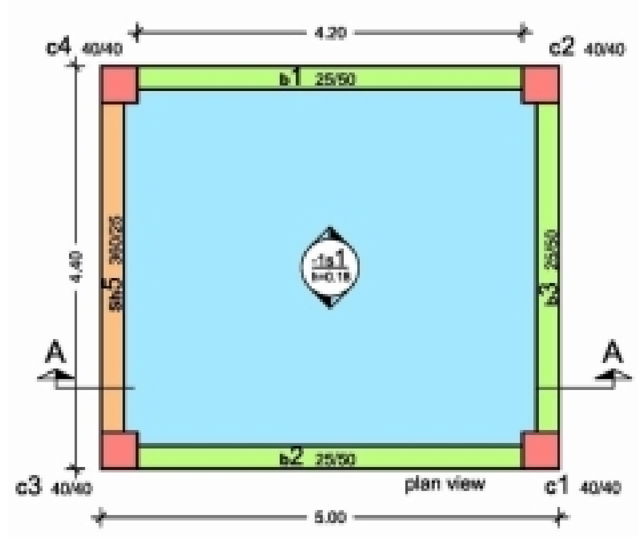
Beams – Slabs

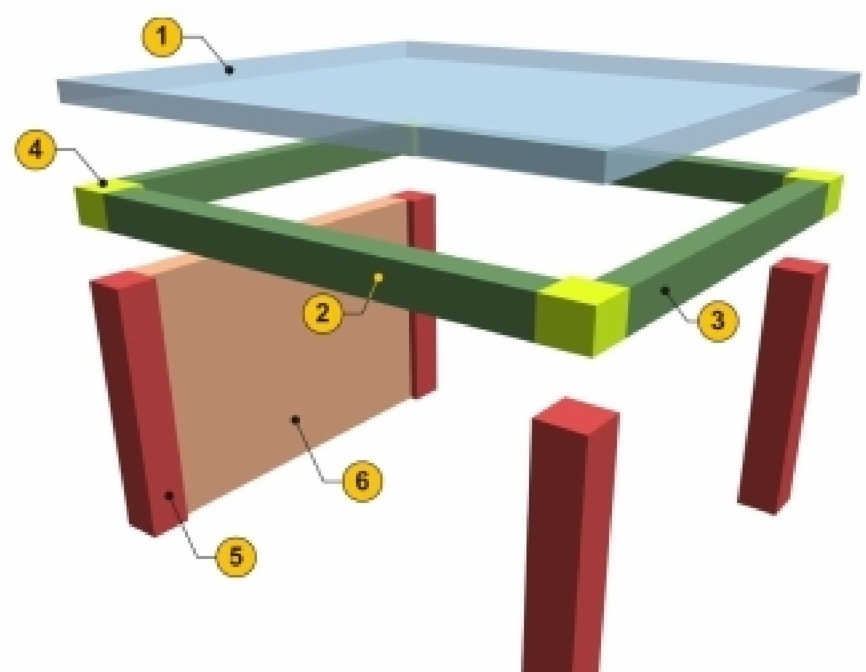
①	S1: 4,40 x 5,00 x 0,18	= 3,96
②	b1,b2: 2 x [(5,00-2 x 0,40) x 0,30 x 0,32]	= 0,81
③	C1,2,3,4 (part of the joint area): 4 x (0,40 x 0,40 x 0,32)	= 0,20
	Sum	**= 4,97 m³**

Columns

④	C1,2,3,4: 4 x (0,40 x 0,40 x 2,50)	**= 1,60 m³**

Basement





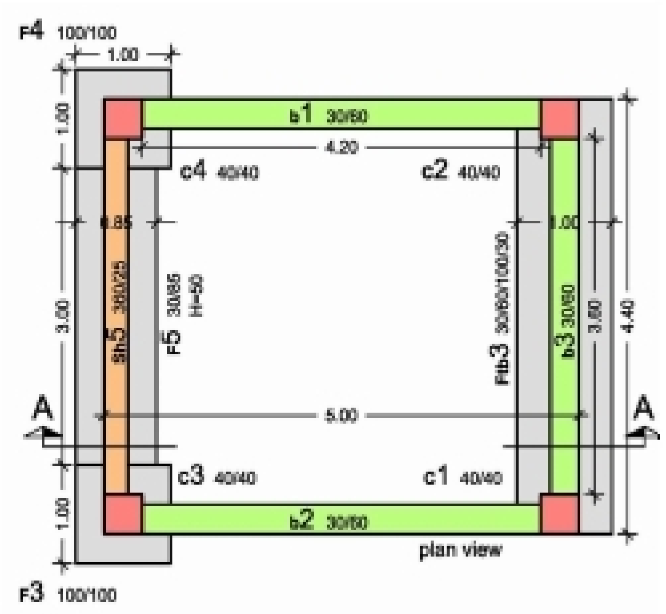
Beams – Slabs

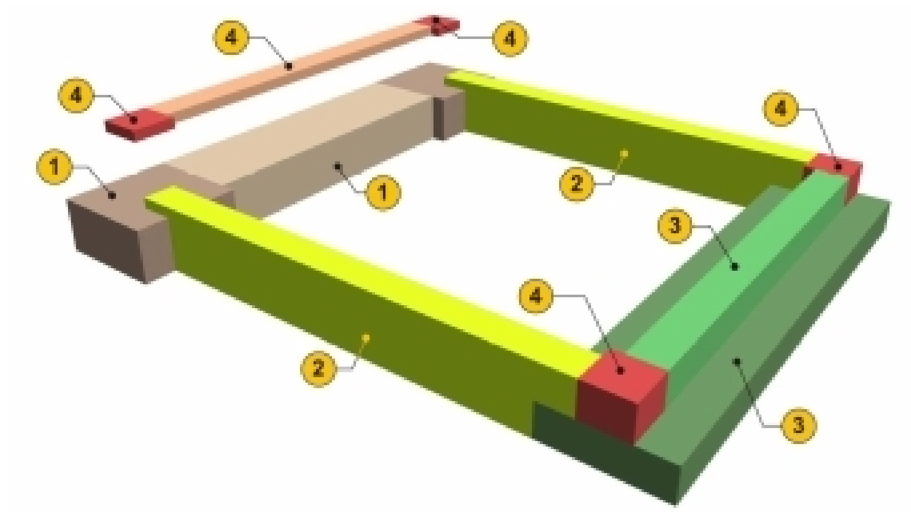
①	S1: 4,40 x 5,00 x 0,18	= 3,96
②	b1,b2: 2 x [(5,00-2 x 0,40) x 0,25 x 0,32]	= 0,67
③	b3,sw5: 2 x [(4,40-2 x 0,40) x 0,25 x 0,32]	= 0,58
④	C1,2,3,4 (part of the joint area): 4 x (0,40 x 0,32)	= 0,20
	Sum	**= 5,41 m³**

Columns

⑤	C1,2,3,4: 4 x (0,40 x 0,40 x 2,50)	= 1,60 m³
⑥	SW5: 3,60 x 0,25 x 2,50	= 2,25
	Sum	**= 3,85 m³**

Foundation





① Footings f3,4,5:
2 x (1,00 x 1,00 x 0,50) +3,00 x 0,85 x 0,50 = 2,275

② CB1,2:
2 x (3,60 x 0,30 x 0,60) + (2 x 0,30 x 0,10 x 0,30) +
+ 2 x (0,30 x 0,30 x 0,30) = 1,368

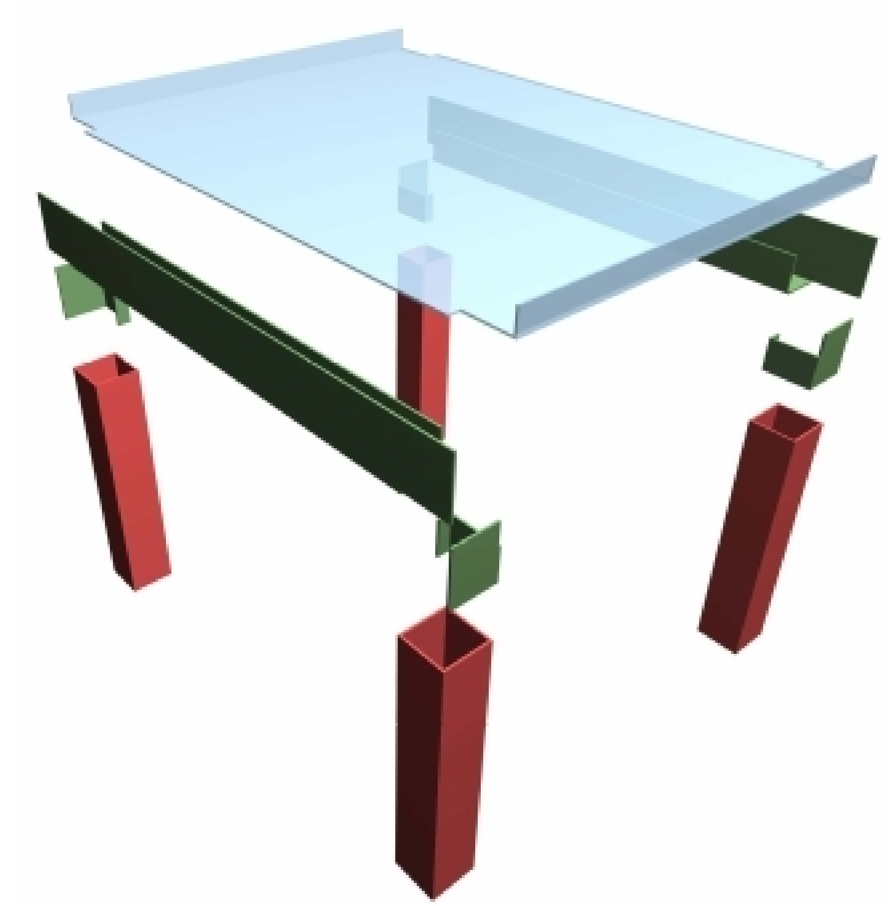
③ SF: 4,40 x 1,00 x 0,30 + 4,40 x 0,30 x 0,30 = 1,716

④ Columns (additional volume due to foundation depth equal to 0,60 m, compared to the footings' depth which is 0,50m):
4 x (0,40 x 0,40 x 0,10) + 3,60 x 0,25 x 0,10 = 0,154
(2 x 0,10 x 0,10 x 0,20 = 0,004)
Sum = **5,51 m³**

4.2. Estimation of the formworks' quantity

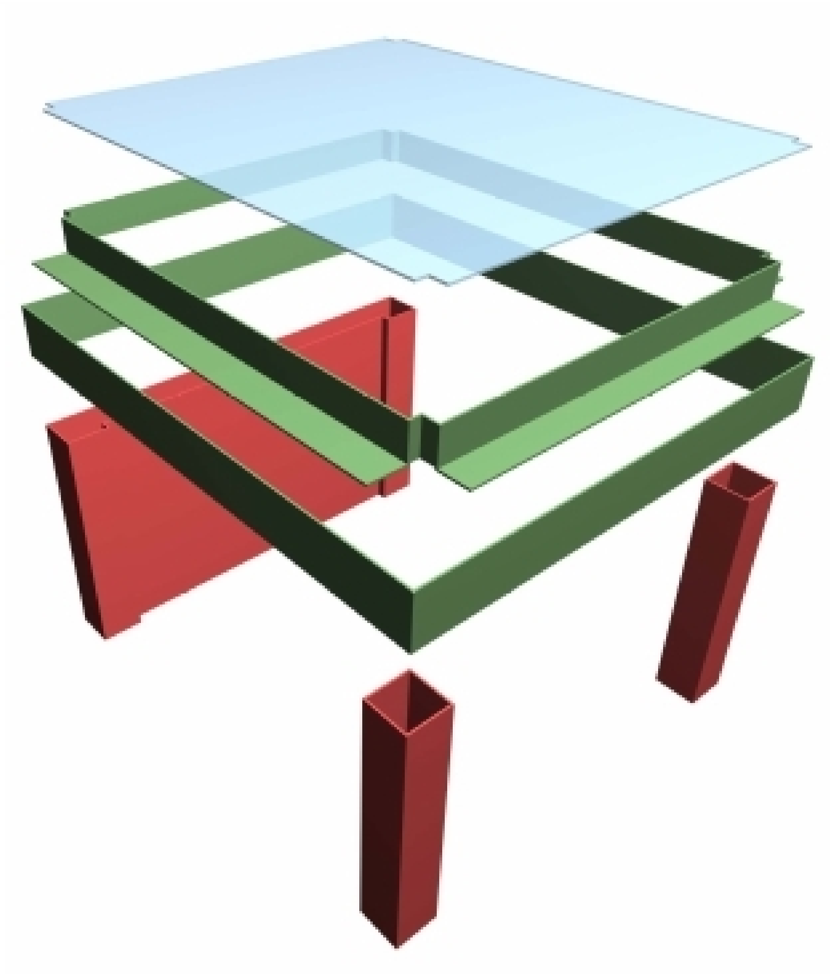
In constructional works, it is common practice to pay the technicians responsible for the form-work implementation, based upon the quantity (in m^3) of casted concrete. However, the most proper way is to separate those two things therefore, the following pages regard the estimation of the required moulds.

Ground floor



Beams – Slabs			m^2
S1:	3,80 x 5,00 – 4 x 0,40 x 0,10 + 2 x 3,60 x 0,18	=	20,136
b1,b2:	2 x 5,00 x 0,50 + 2 x (5,00-2 x 0,40) x 0,32 + + 2 x 4,20 x 0.30	=	10,208
columns (joints):	4 x 0,40 x 0,50 + 4 x 0,40 x 0,32 + 4 x 0,10 x 0,32	=	1,440
	Sum	=	**31,784**
Columns:			
	4 x (0,40 x 0,40 x 2,50)	=	**16,000**

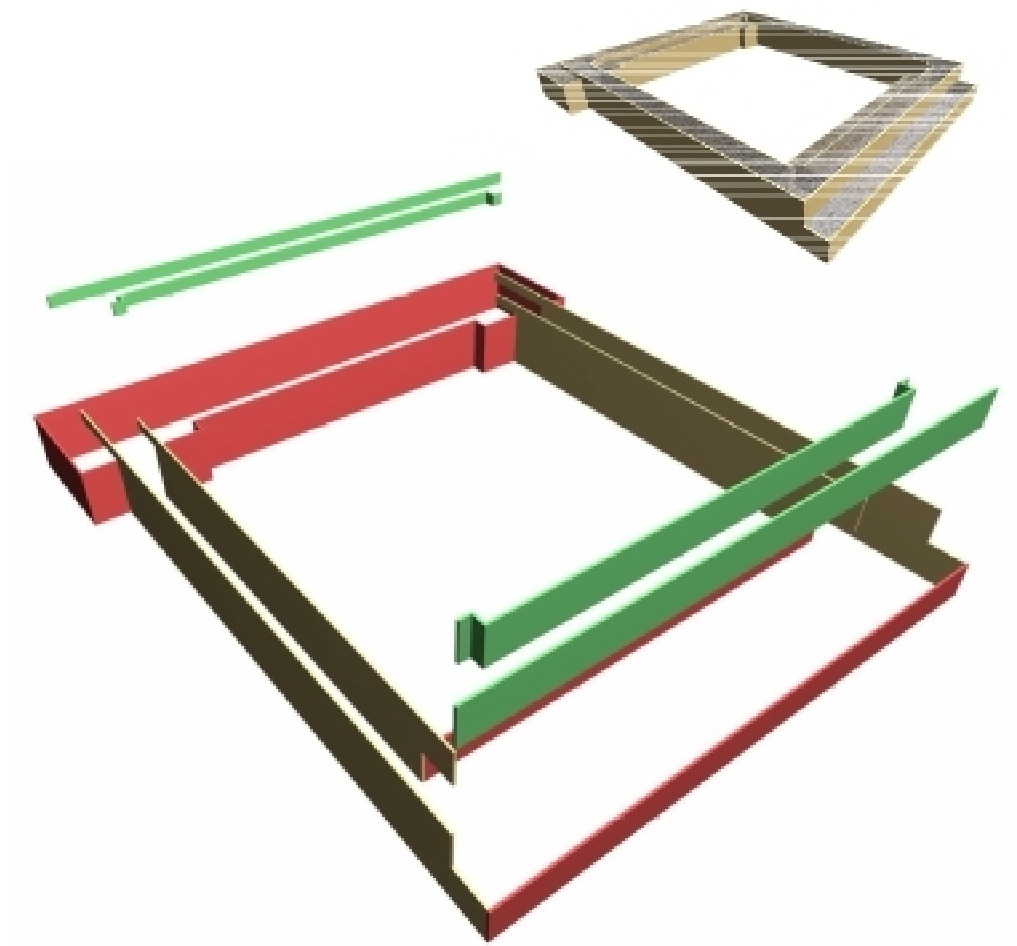
Basement



Beams – Slabs			m^2
S1:	4,50 x 3,90 - 4 x (0,15 x 0,15)	=	17,460
b1,b2:	2 x [5,00 x 0,50 +4,20 x 0,32] + 4,20 x 0,25	=	9,788
b3:	4,40 x 0,50 + 3,60 x 0,32 + 3,60 x 0,25	=	4,252
sw5:	4,40 x 0,50 + 3,60 x 0,32	=	3,352
internal column sides	4 x 2 x 0,15 x 0,32)	=	0,384
	Sum	=	**35,236**

Columns:	4 x (0,40 x 0,40 x 2,50) – 2 x (0,25 x 2,50)	=	14,750
Shear wall sw5:	2 x (3,60 x 2,50)	=	18,000
	Sum	=	**32,750**

Foundation



			m^2
Footings F3,4,5:	0,50 x [5,00 + 2 x 1,00 + 0,30 x 2]	=	5,85
Cb1,2:	2 x [0,70 x0,10 + 4,30 x 0,60 + 0,30 x 0,30] 2 x [0,30 x0,10 + 3,60 x 0,60 + 0,30 x 0,30]	=	10,04
Sf4:	(3,80 + 4,40) x 0,30 + (3,60 + 4,40) x 0,30	=	4,86
Columns:	2 x 2 [0,10 x 0,30 +0,10 x 0,10] + +(4,40+3,60) x 0,10	=	0,96
	Sum	=	**21,71**

4.3 Estimation of the spacers' quantity

If there is no other rule to follow when calculating the spacers of the formwork, one could use the empirical rule presented below:

RULES FOR ESTIMATING THE QUANTITTIES OF SPACERS AND REBAR CHAIRS

Superstructure and foundation beams:	(2m of 'linear spacers + 2 'pieces of point support') in every meter of 'clear beam length'
Columns:	(8 'pieces of point support') per column
Shear walls:	2m of 'linear spacers' in every meter of the shear wall's length
Foundation slabs and footings:	(1.25m of 'linear spacers') in every square meter of 'clear slab area'
Slabs' free edges:	(1m of 'linear spacers' + 1m of 'rebar chairs' + 1 'piece of point support') in every edge meter
Slabs' supports:	1m of 'rebar chairs' per meter of 'every slab support'

- *1 m of 'linear spacers' might be 1 m of a plastic spacer, or 5 special formed spacers, or any other number of local spacers, etc.*
- *1m of 'rebar chairs' might be 3 four-legged point spacers, or 1m of a folded wire mesh, or 2 pieces of impromptu steel rebar chairs, etc.*
- *1 'piece of point support' might be a properly formed plastic or concrete point support, or a peg, etc.*

Foundation

Footings of the strip and the spread footing foundation:

linear spacers with thickness equal to 4.0cm:

[4,40 x 1,00 +5,00 x 0,85 +2 x 0,15 x 1,00] x 1,25 = 11,20 m

Connecting beams:

linear spacers of 4,00 cm: 2 x 4,20 x 2,00 = 16,80 m

point spacers of 4,00 cm: 2 x 4,20 x 2,00 =16 pieces

Basement

Columns:	8 x 4 = 32 pcs. of point support
Shear wall:	3,60 x 2,50 x 2 = 18,00 m of linear spacers with thickness equal to 2,50
Beams:	(2 x 4,20 +3,60) x 2,0 = 24,00 m of linear spacers equal to 2,50 cm
	(2 x 4,20 +3,60) x 2,0 = 24 pieces of point spacers equal to 2,50 cm
Slab:	3,90 x 4,50 x 1,25 ≈ 22,00 m of linear spacers with thickness equal to 2,50

Ground floor

Columns:	8 x 4 = 32 pcs. of point support
Beams:	2 x 4,20 x 2,0 = 16,80 m of linear spacers equal to 2,50 cm
	2 x 4,20 x 2 ≈ 16 pieces of point spacers equal to 2,50 cm
Slab:	3,80 x 5,00 x 1,25 = 23,80 m of linear spacers with thickness equal to 2,50 cm

Slab's free edges:

3,60 x 1,00 x 2 = 7,20 m of linear spacers with thickness equal to 2,50 cm

3,60 x 1,00 x 2 = 7,20 m rebar chairs with height equal to 11,0 cm

3,60 x 1,00 x 2 ≈ 8 pieces of point spacers equal to 2,50 cm

Quantities sum: **m**

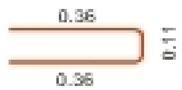
Linear spacers of 4.00 cm:	11,20 +16,80	=	28,00
Linear spacers of 2,50 cm:	18,00 + 24,00 + 22,00 + 7,20 +16,80 + 23,80	≈	112,00
Rebar chairs of 11,00 cm:		=	7,20

pieces

Point spacers of 4,00 cm:		=	16
Point spacers of 2,50 cm:	32 + 24 + 8 + 32 + 24	=	120

4.4 Estimation of the reinforcements' quantity

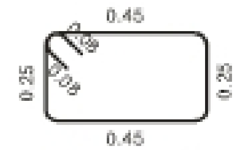
4.4.1 Ground floor - Slabs

Elem.	Description	Sketch	L (m)	Quant. (v)	Length (L*v)	D. Ø
S1	upper x		4.42	24	105.98	10
	lower x		4.33	25	108.25	10
	lower y		4.93	16	78.88	8
	addi-tional		0.81	15	12.14	8
	addi-tional		0.81	15	12.14	8

ESTIMATION OF REBARS

Diam. Ø	Weight/m (Kg)	Quantity n	Total length L*n (m)	Additional weight b (Kg)	Total weight L*n*sw + b (Kg)
8	0.395	46	103.16	0.0	40.7
10	0.617	49	214.23	0.0	132.1
Sum	-	95	-	0.0	172.8

4.4.2 Ground floor – Beams

Element	Description	Sketch	L (m)	Quant. (v)	Length (L*v)	Diam. Ø
Ob1	lower		4.28	1	4.28	14
	lower		5.33	3	16.00	14
	upper		5.37	2	10.75	14
	additional upper		1.75	1	1.75	14
	additional upper		1.75	1	1.75	14
	stirrups		1.61	31	49.85	8
Ob2	Same as Ob1					

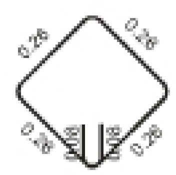
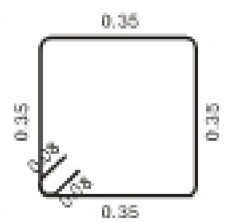
ESTIMATION OF REBARS

Diam. Ø	Weight/m (Kg)	Quantity n	Total length L*n (m)	Additional weight b (Kg)	Total weight L*n*sw + b (Kg)
14	1.210	16	69.07	0.0	83.6
Sum	-	16	-	0.0	83.6

ESTIMATION OF STIRRUPS

Diam. Ø	Weight/m (Kg)	Quantity n	Total length L*n (m)	Additional weight b (Kg)	Total weight L*n*sw + b (Kg)
8	0.395	62	99.70	0.0	39.3
Sum	-	62	-	0.0	39.3

4.4.3 Ground floor - Columns

Element	Description	Sketch	L (m)	Quantity (v)	Length (L*v)	Diam. Ø
0C1	Corner		3.15	4	12.62	16
	Top		3.13	4	12.53	16
	Stirrups		1.24	30	37.06	8
	Stirrups		1.61	30	48.24	8
0C2 , 0C3, 0C4 : The same as 0C1						

ESTIMATION OF REBARS

Diam. Ø	Weight/m (Kg)	Quantity n	Total length L*n (m)	Additional weight b (Kg)	Total weight L*n*sw + b (Kg)
16	1.580	32	100.60	0.0	159.0
Sum	-	32	-	0.0	159.0

ESTIMATION OF STIRRUPS

Diam. Ø	Weight/m (Kg)	Quantity n	Total length L*n (m)	Additional weight b (Kg)	Total weight L*n*sw + b (Kg)
8	0.395	240	341.21	0.0	134.6
Sum	-	240	-	0.0	134.6

4.5 Total estimation of the materials' quantities

ESTIMATION OF CONCRETE (m^3)

Level	Superstructure		Foundation	Sum (m3)
	Slabs - Beams	Columns	Foundation	
Ground floor	4.97	1.60		6.6
Basement	5.41	3.85	5.51	14.8
SUM (m3)	10.38	5.45	5.51	21.3

ESTIMATION OF FORMWORK (m^2)

Level	Superstructure		Foundation	Sum (m2)
	Slabs - Beams	Columns		
Ground floor	31.78	16.00		47.8
Basement	35.24	32.75	21.72	89.8
SUM (m2)	67.02	48.75	21.72	137.6

REINFORCEMENT ESTIMATION (m)(kgr)

	Superstructure			Foundation			Sum	
Rebars	Slabs	Beams	Columns	Slabs	Footings	Beams	(m)	(Kgr)
Ø8	129.98	-	-	-	-	-	329.42	129.98
Ø10	132.08	-	187.11	-	-	-	517.72	319.19
Ø12	-	-	-	-	76.17	61.14	154.65	137.30
Ø14	-	192.65	-	-	-	-	159.22	192.65
Ø16	-	-	395.05	-	-	197.17	374.83	592.23
Sum of rebars	262.07	192.65	582.16	-	76.17	258.31	1535.83	1371.36
Stirrups	Slabs	Beams	Columns	Slabs	Footings	Beams	(m)	(Kgr)
Ø8	-	92.89	309.72	-	-	-	1020.34	402.61
Ø10	-	-	-	-	-	86.32	140.00	86.32
Sum of stirrups	-	92.89	309.72	-	-	86.32	1160.34	488.92
SUM	**262.07**	**285.54**	**891.88**	**-**	**76.17**	**344.63**	**2696.17**	**1860.28**

4.6 Optimization of the reinforcement schedule

The quantities estimates of the previous chapter are based upon the theoretical rebar lengths as provided by the software. Since the reinforcement bars have specific lengths, usually 12 ή 14 m, ordering them with their exact lengths will lead to the formation of oddments i.e. short rebars of length e.g. 0.80m, which cannot be used. Every reinforcement supplier has his own method to manage these oddments in order to minimize their cost and at the same time offer constructional accuracy. The methods followed in order to manage the issues of oddments and constructional accuracy are generally referred to as optimization. The persons responsible for the reinforcement's optimization can be either the designer engineer in charge of the detailing or the quantity surveyors of the reinforcement supplier. The following paragraphs present generally the issue of optimization together with a proposition.

In every case, no matter which optimization method is being followed, the estimates[1] of the bars number used in the reinforcement implementation must mention the percentage of rebar losses[2]. This happens because the reinforcement cost estimation[3] must include these losses as well.

The Engineer makes the reinforcement schedules based upon two basic assumptions:

1[st]) by presuming that the formworks will be constructed exactly as shown in the drawings and

2[nd]) Based upon the dimensions of the drawings and the theoretical anchorage and lap-splice lengths, he/she defines the theoretical rebar lengths.

However, in the construction, the dimensions of the real formworks present an unintended 'constructional deviation'; as a result, cutting rebars to their theoretical lengths is economically challenging and creates a large amount of oddments.

The unavoidable constructional deviation depends upon the tools, the experience and the diligence of the contractor responsible for the formworks' implementation. This deviation is considered to be in the order of 1 up to 3cm.

Moreover, the rebars' cut to random lengths is productive only in the case of coil-cutting machines but even in these cases the coil usually covers rebars with a diameter up to Φ12, or Φ14. In all other cases, the rebar must be cut to supplementary amounts of industrial bars with usual lengths equal to 12 or 14m. In order for this to be feasible, and always to a certain degree, the available rebar oddments must be separated according to their diameter and length which from a practical point of view, is a complex and space/labor demanding procedure.

Finally, there will always be rebar losses. A large amount of losses includes an increased material cost and a lower labor cost while a small amount of losses corresponds to a larger labor cost. The targeted goal is the optimum combination that leads to an economical solution where the minimum rebars length requirements are obligatorily met.

An effective optimization method which provides an effective combination of cost-losses is the method of the 'standardized cut and storage' in which the rebars have length of a specific step equal to e.g. 25cm [4].

[1] The theoretical mass of the rebars mentioned in table 1 (e.g. for Φ20, 2.47 kg/m) usually in practice, has a deviation that ranges from +1 to +2%.

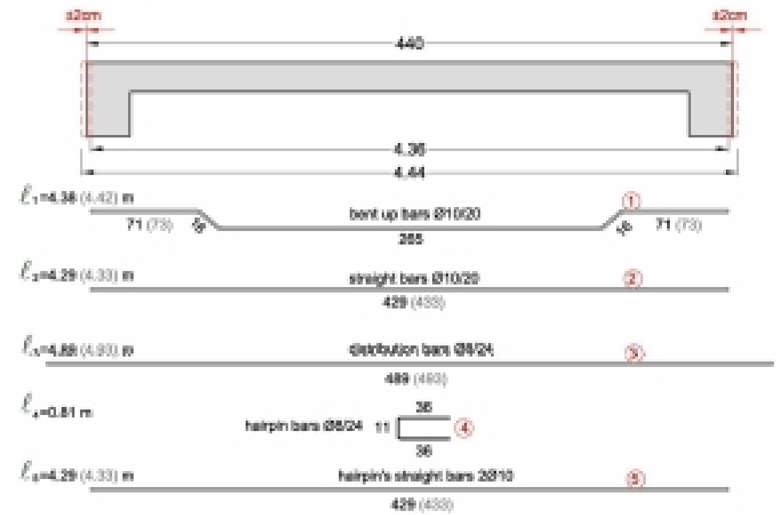
[2] The loss percentage is a relative quantity and is completely independent of the actual mass. It varies from +1% to +6%, according to the optimization method followed by each reinforcement supplier.

[3] The most simple and practical way to include the reinforcement in a bid and to estimate its cost, is by setting the price based upon the actual mass of the properly shaped and ready-to-implement reinforcement, having calculated the losses as well. Each total amount will be defined by measuring the reinforcement's weight.

[4] The standardized cut and storage offers many advantages to the organized reinforcement suppliers. The two major advantages are:

The following paragraphs examine 3 optimization examples regarding the rebars of specific structural elements, based upon the following assumptions: (a) constructional deviation= 2cm and (b) standardized cut with a step equal to = 0.25m.

<u>1[st] example (the slab of §3.5.1)</u>



In the example of the one-way slab in §3.5.1 the total slab length was 4.40m and the length of the lower rebars was 4.33m.

In both ends of the slab, the side formwork might slip to the left or to the right around 2cm therefore, in the two worst cases, the slab's span length may take a value between 4.40-0.02-0.02=4.36m and 4.40+0.02+0.02=4.44m. Rebars are critically affected when the slipping of the slab's ends happens towards the inside. In order to avoid such a case and have the proper cover depth, the lower rebars must be formed with a length equal to 4.33-0.02-0.02=4.29m.

The standardized cut length is 4.25m or 4.50m. In this case, it is not possible to cut the rebar to a length either shorter (than 4.25m) or longer (than 4.50m) and therefore the optimization regards only the constructional deviation. Consequently, the rebars (2) must be cut to a length of l2=4.29m instead of 4.33m. The same thing applies and to rebars (5) which will be cut to a length equal to l5=4.29m rather than 4.33m.

By an analogous way of thinking, we concluded that the rebars (1) will have a cut-length of l1=4.38m instead of 4.42m. The length difference is divided in the upper horizontal parts of the bent-up rebars which will be formed with a length equal to 71cm rather than 73cm.

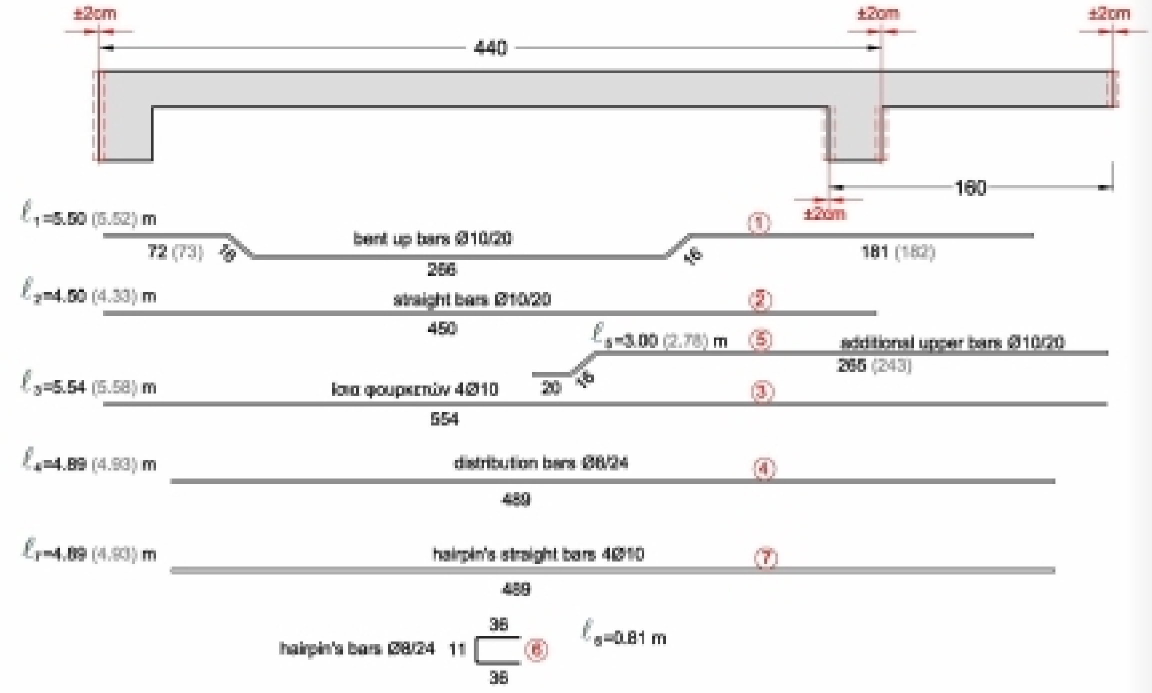
The hairpin rebars (4) have a short length and there is no reason for cut optimization.

The rebars (3) will have a cut-length of l3=4.89m rather than 4.93m.

a) The rebars' cut and storage as well as the gathering of the rebars requested by an order, are separate tasks performed by different personnel.

b) at all times, the supplier may know the exact number of every specific length-rebar requested by e.g. the daily orders, and therefore he can manage his stock. The 'standardized cut and storage' entails losses in the order of +2%.

2nd example (the two slabs of §3.5.3)



In the example of the simply supported slab connected with a cantilever slab mentioned in §3.5.3, the total length of the first slab was 4.40m and of the second slab was 1.60m. According to the previous example the total lengths of those two slabs may range between 4.36 and 4.44 for the first slab and between 1.56 and 1.64 for the second slab.

The effect of 'constructional deviation' upon the optimization:

The constructional deviation of the two slabs does not affect the majority of the rebars' lengths because it is possible for the latter to move to the adjacent slabs. Rebars (3) are the only ones that have limitation and since they do not have a margin either to the left or to the right, they must be formed with a length equal of 5.54m instead of 5.58m. For the same reason the vertical bars (4) and (7) must be formed with a length equal to 4.89m rather than 4.93m.

The effect of 'standardized cut' upon the optimization:

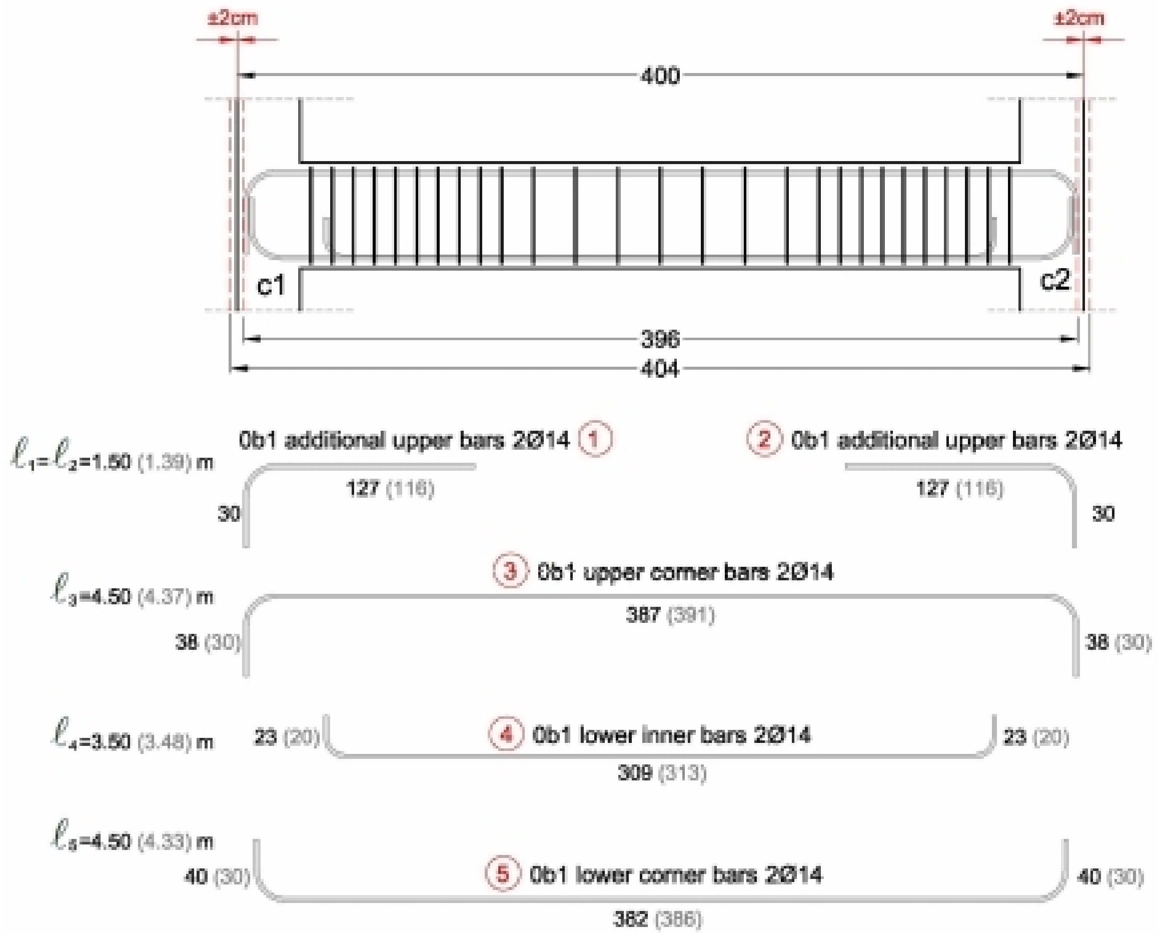
The rebars(1) must have a length of 5.50m instead of 5.52m due to a minor difference (where the left upper horizontal part of the bent-up rebar becomes 72cm instead of 73cm and the right upper horizontal part becomes 181cm instead of 182cm).

The rebars (2) will be formed with a length equal to 4.50 rather than 4.33.

The rebars (5) will be 3.00m long instead of 2.78 (where the last length will become 2.65 instead of 2.43)

The rest of the rebars have a limitation and cannot be standardized therefore, the bars (4) and (7) will be formed with a length equal to 4.89 rather than 4.93.

3rd example (the beam of § 3.4.1)



In the example of the simply supported beam in § 3.4.1 the beams is 4.00m long and therefore, the total length may vary between 3.96m and 4.04m. The constructional deviation does not affect the support rebars (1) and (2), which will be formed with a total length equal to 1.50m instead of 1.39 (where the last length will become 1.27 rather than 1.16).

The lower and upper rebars of the beam are affected by the constructional deviation. This is the reason why the bars length must be shortened by 4cm, however, the hooks may become larger so as to achieve the required final length (hooks must not extend outside the concrete's mass and inside the beam's cover depth).

The rebars (3) will have a total length of 4.50m instead of 4.37l, with a span length equal to 3.87 rather than 3.91 and their hooks will be 0.38 long instead of 0.30.

Consequently the reinforcement bars (4) will have a total length equal to 3.50m rather than 3.48, with span length 3.09 instead of 3.13 and their hooks will be 0.23 long rather than 0.20.

The rebars (5) will have a total length of 4.50m instead of 4.33, with span length equal to 3.82 rather than 3.86 and their hooks will be 0.40 long instead of 0.30.

4.7 Estimation of the structural frame's cost

By the quantities estimates, we calculate the amount of materials and labor required for the building's erection prior to the construction. Based upon these estimates and by taking into account the prices offered in the market, we estimate the cost.

After the completion of every constructional phase, as built data must be collected (quantity survey) so as to calculate the exact amount of materials used. The final work cost will be defined based upon these measured quantities and the initial bids. When there is an accurate detailing and a meticulous supervision, the quantities estimates prior to the construction and the quantities measurement after the construction's completion approximate one another.

The estimates of the various quantities prior to the construction must never be neglected because apart from calculating the initial work cost, these quantities are used for ordering the various materials.

The final work cost depends upon a range of factors like the size and location of the construction, the number of columns and beams, the seismic risk zone, the type of foundation etc.

In November 2008, the mean value of the reinforced concrete's price was ranging between 250 and 320 €/m3 of concrete. This price includes all cost factors like materials, labor, material's VAT and every other material and labor indirectly required. On the other hand it does not include the cost of the thermal insulation boards, the additional formwork cost when visible concrete surfaces are required (off-form concrete, architectural concrete), the additional cost due to the possible use of self compacting concrete, the personnel's social insurance, the VAT regarding the labor on site, etc.

The cost of the individual work procedures is analytically presented below:

Concrete supply

It includes the material's purchase, transportation and pumping as well as the use of super-plasticizers. At the present time, the price ranges from 74 up to 85€/m^3.

Formwork's assembling[5]

It includes the use of appropriate timber and moulds, all the necessary steel support elements, the transportations, the required labor for the formwork's assembling and removal, the use of every necessary machinery or tool as well as the casting, compaction and curing of concrete.

Normally, the price should be referred in €/m², but in the market it is usually found per m^3 of concrete. There is no need to mention that the offered price in m^3 is set based on the corresponding m^2 of formwork. Nowadays, the current price varies between 55 €/m^{3}and 75 €/m^3.

Supply or reinforcement bars properly cut and shaped (VAT included)

It includes the steel's purchase, cut, shaping, transportation and up-lifting.

[5] The most crucial factor that determines the cost for the formwork implementation is the m² of moulds, in combination with the m³ of concrete. Therefore, the bids and the billing of the formwork's implementation are provided per m³ of concrete, or per m² of formwork.

The current price ranges from 0.6 €/kg up to 0.9 €/kg.

Rebars implementation

It regards the labor for the implementation of the entire reinforcement, bars, wire meshes etc, with the exception of stirrups. The current price varies between 0.12 €/kg and 0.16 €/kg

Supply of stirrups[6]

It includes the supply of properly shaped, ready-to-use stirrups. At the present time, the price ranges from 0.75 €/kg up to1.0 €/kg

Stirrups implementation

It regards the labor for the stirrups implementation in the work. The current price varies between 0.20 €/kg and 0.30 €/kg

Spacers cost

It regards the supply and positioning of every type of reinforcement spacers, plastic, rebar chairs, etc. Nowadays, the price ranges from 4 €/ m^3 up to 5 €/ m^3

Social insurance of workmen and technicians

In a work, the social insurance cost is extremely large and therefore, it should be carefully evaluated. A low-priced workforce that requires a large number of wages might not be that economical when compared to an expensive workforce that requires a smaller number of wages. A solution that allows for fewer wages is the use of industrial formworks and industrial reinforcements, mainly industrial stirrup cages. Another important factor that affects the number of wages is the size and the difficulties of the work.

The labor cost for the formwork implementation varies between 0.4 and 1.2 wages/m³ and for the reinforcement implementation from 0.15 up to 0.3 wages/m³. This means that the total labor cost ranges from 0.50 up to 1.4 wages/m³ and if we consider an average cost for social insurance around 60 €/wage, the cost of the structural frame reaches 30 to 84 €/m³!

Apart from the cost of the basic materials and labor that were mentioned in the previous paragraphs, there are other quantities that have an effect upon the cost of the building's structural frame construction. These quantities are either considered as separate cost elements (e.g. the thermal insulation boards which are integrated inside the structural frame), or they are indirectly calculated in the cost of other quantities. In every case, these quantities constitute a large amount of the final cost no matter in which phase and in what labors they are apportioned to.

[6] The large fluctuation of the stirrups' cost which includes both the supply and the implementation labor, is caused mainly by the different types of stirrups available (see § 2.7). Furthermore, the decisive factor of the supply cost is whether the stirrup cage is industrially produced or not.

Filling

It includes the amount of soil or/and the amount of aggregates required for the foundation filling upon which the basement floor will be constructed.

The cost of the filling depends mainly upon its quantity, because in the case of the soil the cost is determined by the transportation and mainly by the required machinery. In the case of the aggregates usage, the supply cost is in the order of 35 €/m³

Miscellaneous

In case of extruded polystyrene usage in the form of boards for thermal insulation and since these boards are integrated inside the structural frame during the construction, the quantities are required in m² per board thickness. Apart from the cost for the material supply, which is in the order of 12 €/m² for a 5cm thick board, there is also the cost for their placement inside the moulds which ranges from 1 up to 2 €/m² .

In cases of ribbed slabs' construction with the use of enlarged polystyrene, the supply cost is in the order of 56 €/m³ for density equal to 20 kg/m³

The amount of common wire for tying together[7] rebars ranges around 2.0 kg/t of reinforcement and its cost is approximately 3.5 €/kg.

The amount of gas and oil, the transportations and the nails (when using conventional formworks) as well as every other required material, depend upon the contractor's equipment.

[7] If the reinforcement wiring is done by means of special machinery, the cost of the appropriate wire is much higher but on the other hand, the labor cost is much lower. Between those two solutions the one with the special machinery is by far more economical.

4.8 Electronic exchange of designs - bids - orders

The structural analysis and design are performed, almost exclusively, by means of a complete software package.

On the other hand, the detailing requires a software combination every one of which demands a different input. A part of that necessary data is re-inserted into every software while another part is inserted as the output of a previous software. As a consequence, the necessary amount of time and cost for the detailing are rather large.

Moreover, every data modification e.g. in the dimensions of the elevator, entails new successive data entries until we reach the final goal which is to estimate all the quantities of material and labors, by following the same time consuming procedure. Apart though from the high cost, the continuous data transferring from software to software is particularly precarious due to possible human errors.

The present situation regarding the reinforcement bids and orders is presented below:

(1) The rebars' order is made to the reinforcement supplier by sending numerous drawings, details and schedules. These require great attention and constitute a bureaucratic procedure often made manually.

(2) Every reinforcement supplier requires a large amount of time and money in order to send a reliable bid.

(3) The contractor faces difficulty in receiving reliable bids from numerous reinforcement suppliers.

All the above described procedures are time consuming, have a rather high cost and if we take into account the unavoidable human errors caused by the several number transfers, the resulting delays and the complaints, one will realize the difficulty that lays in managing the critical issue of the earthquake resistant reinforcement.

The solution to the complex problem of a quick and reliable bid sending and receiving or reinforcement ordering, is expected to be provided by the internet and the new advanced software.

The software included in the CD that accompanies this book intends to solve the problem with the electronic order (e-Order) and to open a new chapter in the international market regarding the extremely complex issue of the reinforcement order for the construction of reinforced concrete structural frames.

CHAPTER 5

Detailing drawings for the structural frame's construction

5. Detailing drawings for the structural frame's construction

5.1 General

The architectural, structural, mechanical design of a building, have three stages, the preliminary design, the final design and the detailing. The purpose of the preliminary design is to assess all the parameters of the building, to evaluate their effect both from a legislative and a practical point of view and to propose a solution. The final design presents the entire concept of the building, solves all issues regarding the designated proposal and determines the geometry and the way of construction. The detailing describes in every detail the constructional way of the building's erection and provides all technical information regarding its realization.

All the stages of every single design are presented in drawings. During the preliminary design they have the form of a draft drawing, during the final design they are accurate drawings and during the detailing they analytically present every detail.

In order to have a correct and economic erection of a building, the detailing is mandatory in all three design categories: architectural, structural frames', installations.

In the case of a structural frame that belongs to an earthquake resistant reinforced concrete building, the detailing is extremely complex and critical for the building's integrity. The complexity of the structural frame's detailing is caused mainly due to the hundreds of bars that compose its reinforcement. The rebar dimensions regard each individual structural frame and this distinctiveness of the thousands of pieces is unique in the entire building when compared to all the other elements e.g. the casings are met in tens of different types and dimensions. The accuracy of the reinforcements schedules is extremely crucial because every mistake jeopardizes the building's safety not during its usual service life but during the rare (but certain to come) moment of a strong ground motion.

When the building is relatively small, there is a large possibility to make changes during its construction. For instance, prior to the excavation and due to special soil conditions, the foundation may be modified or due to an alteration of a floor's use the formwork might be reformed. For this reason, when the work is small and there is a large possibility for changes it is preferred the detailing to follow the phase of the structural frame's erection.

The methodical and detailed supervision of the structural frame's erection is mandatory for the successful construction of a building. However, the proper supervision is feasible only when there is a meticulous detailing even if the supervisor engineer is the also the designer engineer.

The drawings are symbolic plans whose meaning must be comprehensible not only to the designer that composes them but also to all their users (supervisor engineers, foremen, contractors, quantity surveyors etc). The symbolic language of the drawings is used and in the examples mentioned in the previous chapters. The drawings that accompany this book show the detailing of the multi-storey building *<bkGR>*, which is examined in the various chapters, while the following pages concisely explain the terminology and the practices followed.

The construction of a building's structural frame requires two types of drawings: (a) the **carpenter's formwork drawings** which provide all the necessary geometrical information regarding the formwork's implementation and the concrete casting of the structural frame and (b) the **steel fixer's formwork drawings** that present all reinforcements with their necessary details.

Usually, the detailing drawings are presented in 1:50 scale, while the details are presented in 1:20 or 1:10 scale.

The carpenter's drawings have the prefix **C**, while the steel fixer's drawings have the prefix **R**. The numbering of the drawings may follow any rule. In this specific example every drawing is

numbered by integer multiples of ten. This numbering has the advantage that various versions of a drawing theme can be added without altering the numbering of the following drawings. For instance, if another version of the carpenter's drawing C.30 is created it can be numbered as C.31 and so on.

When there are more than one steel fixer's formwork drawings (like R.30 of the example drawings) these have the same number but with the addition of their characteristic (in this specific case R.30.B, is the detailing drawing[1] of the beams). The same thing also applies to the carpenter's drawings.

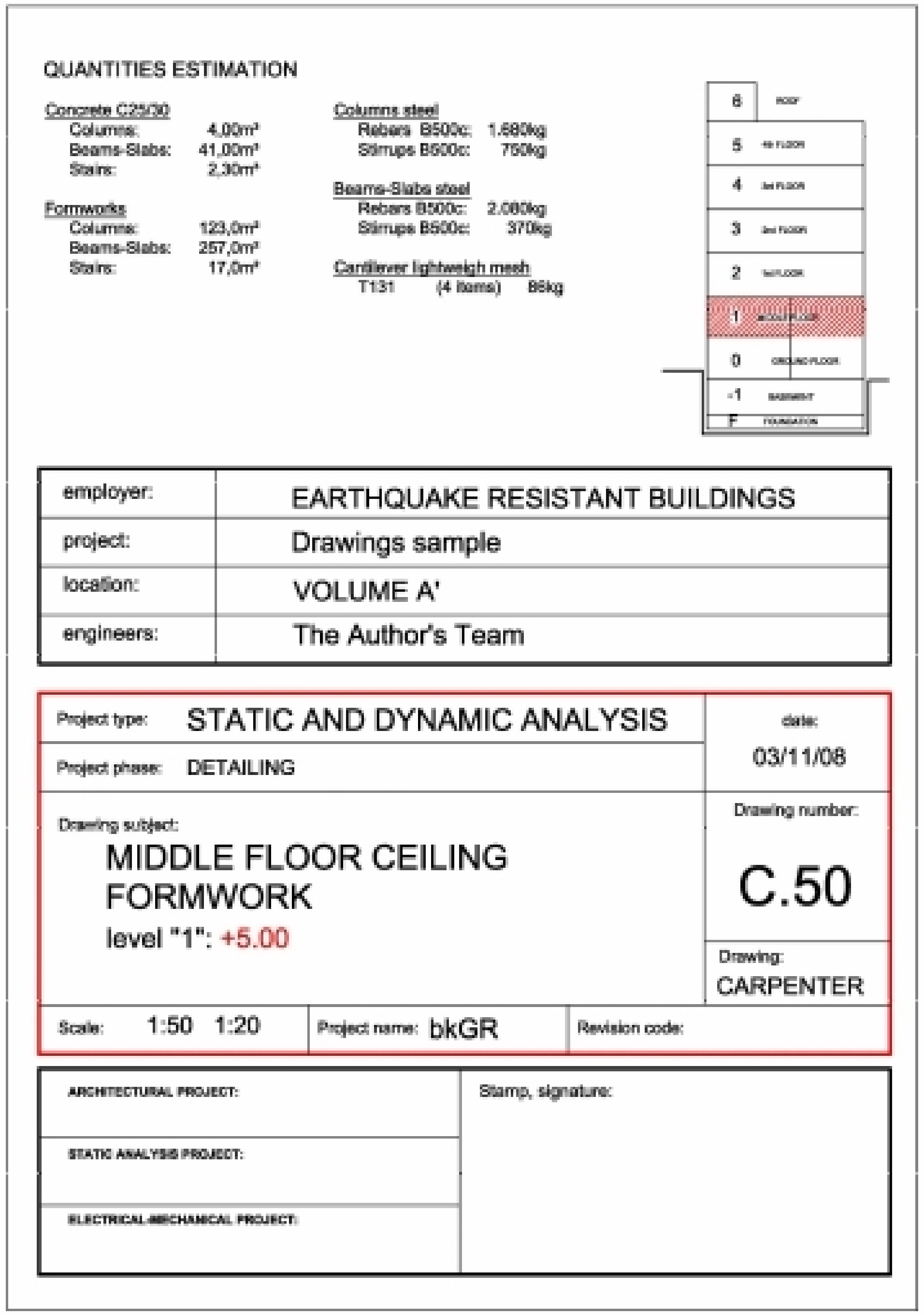
In every drawing C.xx, corresponds one R.xx and possibly a supplementary R.xx.yy.

Every structural element presented in the drawings has a number prefix which defines its level e.g. the label 2b12 specifies the beam b12 of the 2^{nd} floor. Usually, the prefix 1 corresponds to the 1^{st} floor, 2 to the 2^{nd} floor, -1 to the first basement and so on. This means that the beam prefix is numbered ...,-2,-1,0,1,2,.... In the example of the project <bkGR>, which has a mezzanine, the correspondence is presented at the title block of the following paragraph. The representation of every structural element with a unique way helps in the industrial cut and storage of the reinforcement order, for many floors at the same time without problems arising from confusions due to elements with the same name.

[1] The beams detailing drawings are the traditional constructional drawings that accompanied every detailing and they had two roles. The first and most important was to provide the exact dimensions of rebars and stirrups so as to compose the reinforcement schedules. The second role was to accurately define the precise position of the additional rebars when this was not entirely obvious. Nowadays, with the use of proper software, like the one included in this book, the reinforcement schedules are automatically created with great accuracy and the specialties of the additional rebars' implementation are shown upon the formwork drawing. Moreover, the simple 3D or the stereoscopic figures created by the software illustrate the exact reinforcement layout in all the critical parts. The same thing applies and for the rest of the traditionally accompanying drawings.

5.2 The drawings' title block

The title block is a very important element because it is the first page of a folded drawing therefore, it must provide, at a glance, all the necessary information that regard the drawing.



The title block of the drawing C.50

The sketch is very useful as it indicates the floor that each drawing regards and presents the construction's progress.

The title block provides information about the concrete grate and the steel class that will be used in the construction of that specific floor.

The quantities of each floor are very important not only for the materials' orders but also for the estimation of the labor required for the formwork and reinforcement implementation. It is helpful to mention, individually, the quantities of every constructional phase e.g. the columns have their own quantities because as a rule, they are constructed separately from the beams and the slabs.

5.3 Carpenter's drawings

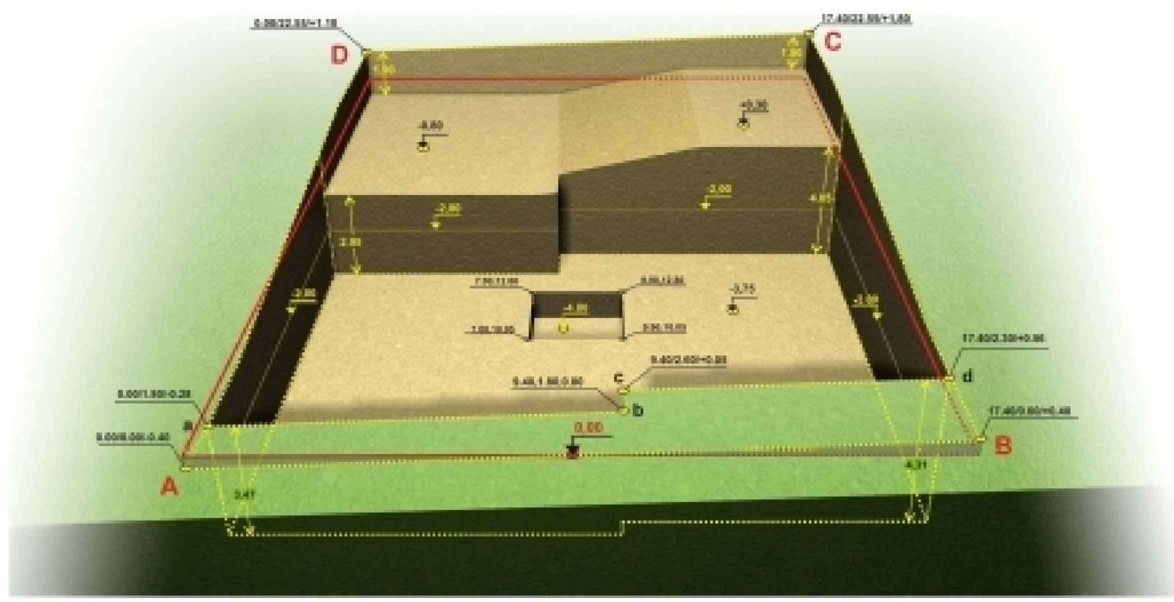
The carpenter's drawings present the construction of the structural frame from a geometrical point of view. Since they are closely related not only to the architectural but also the structural design of the building, they derive from the cooperation of the architect with the civil engineer.

The formwork's detailing includes accurate drawings, plans views and sections and if necessary 3D drawings-figures. These drawings also include the necessary quantities of materials-labor.

5.3.1 EXCAVATIONS and FOUNDATION FLOOR (Drawing C.10)

The personnel responsible for the formwork's assembling must be notified of the excavation drawing because every possible mistake during the excavations will have an effect upon the formworks' implementation.

The building's foundation is faintly presented in the excavation drawing so as to confirm the general dimensions of the excavation. Moreover, this helps the growth of the building's entire concept in all the materialization bodies involved in the work.



The coordinates x, y, z [2] of the chosen system are marked upon every corner of the excavation's peripheral polygon. In this specific example, the origin of the coordinate system (x,y) has been defined as the lower left edge of the building land and the origin of the z axis as the middle of the forefront's side walk which coincides with the 0.0[3] as set in the urban planning drawing.

The final excavation level is defined by a value upon the z axis.

In the case of a bench, only the two coordinates x and y are written upon the polygon points e.g. in the deepened excavation around at the elevator's area.

The sections present the excavation in a simple way. The thickness[4] of the leveling concrete[5] is also displayed while it is very helpful to show with a faint line and the structural frame of the building that is going to be erected.

The excavation[6] volumes, the filling quantities and the amount[7] of the leveling concrete are written upon the drawing.

The excavation volume is separated into two quantities, the first regards the excavation below the lowest point of the ground and the other regards the excavation above the lowest point of the ground. The estimation of the first quantity is more reliable than the estimation of the second quantity.

The filling is also separated into two quantities, the first regards the quantity required for the foundation filling (upon which the basement floor will be constructed) and the second will be required for the backfill of the excavation part that extends beyond the structural frame, after the construction of the basement shear walls.

In this phase of the construction, the filling quantities must be mentioned in order to be possibly combined with the collection/storage of the excavation spoil.

The amount of the leveling concrete depends upon the average necessary thickness required for the formation of a horizontal floor upon which the foundation will be sited. A higher depth accuracy and a more horizontal excavation floor surface leads to the use of a thinner concrete layer. The leveling concrete's surface must be completely horizontal without humps because upon that surface the foundation elements will be marked and the foundation reinforcement and moulds will be positioned. Under no circumstances must that leveling take place after the construction of the foundation by adding excavation spoil, e.g. leveling by means of an excavator, especially in the surrounding surfaces of the foundation elements. This happens so as to avoid alterations in the soil conditions that the designer engineer has included in the structural calculations.

[2] During the excavation, the final floor must be defined based upon an accurate measurement in two phases: 1st) when the excavation has advanced enough, we take a measurement e.g. at -2.0 and we mark a clearly defined line around the perimeter of the pit (see the 3D figure of the excavation), 2nd) when the excavation is almost finished, we must confirm its final depth and the floor's horizontality.

[3] It is recommended to set the origin of the height measurements (0.00) as the upper level of the ground floor's floor slab, because if we change the relative position of the building, the topographic drawing will be the only one to modify. Moreover, the technicians will easily measure the floor heights from the same level without the danger of errors.

[4] The thickness of the leveling concrete layer is an average value, this means that no matter how meticulous the excavation is, if the mean value of the concrete thickness is 10cm, the actual thickness in the various parts will range e.g. between 5 and 15 cm.

[5] The leveling concrete is indented to level the excavation floor's anomalies and not the anomalies of the ground's texture, e.g. a surface that has been grooved (and disrupted) by the bucket teeth of an excavator. The leveling concrete must be casted after we firstly eliminate these marks by a mechanical or manual way.

[6] As a rule, the altitudes z of the natural ground are approximate values therefore the volume of the superjacent soil is also an approximate estimation. The word Estimation of quantities includes every calculable or incalculable approximation considered in almost every work.

[7] The leveling concrete must extend along the entire excavation area and not only in the erection area as it serves other reasons as well like the avoidance of a muddy surface due to rain or a faucet left open.

5.3.2 FORMWORK OF THE FOUNDATION and the basement floor (Drawing C.20)

Upon the surface of the leveling concrete, one must mark (a) the columns, (b) two points of every axis x0,x1, ...,y0,y1,... , (c) the sides of the strip foundation and shear walls as well as the footings' sides of the strip or the spread footings foundation. This can be done by means of a thick pencil, a special marker pen, steel pins or small wooden laths (which will be removed prior to the concrete casting), or by means of any other way.

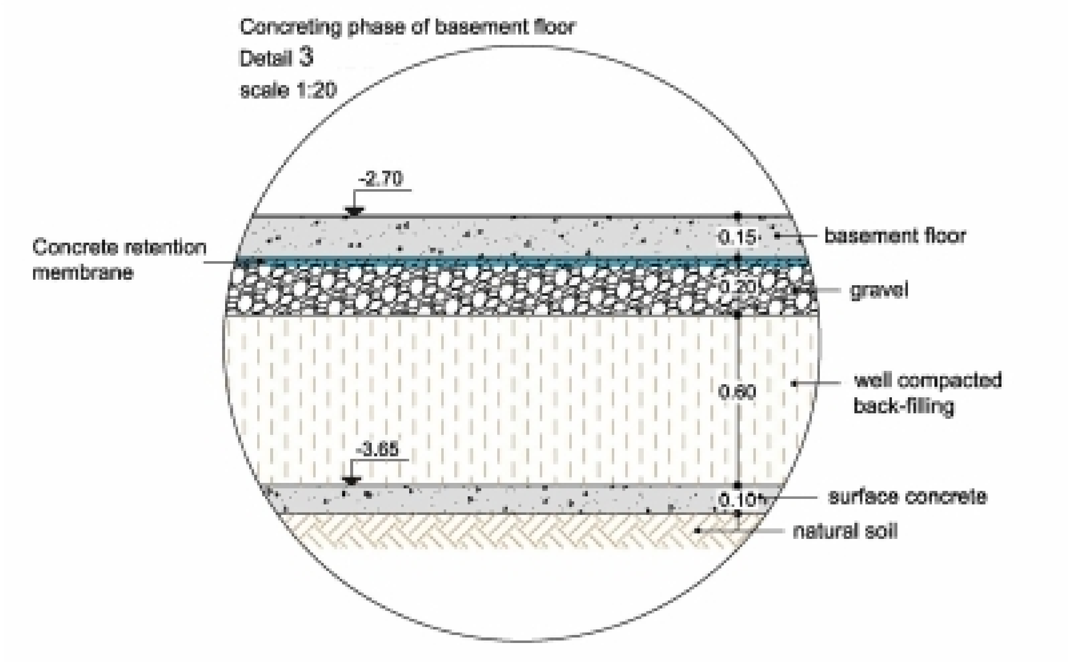
It is recommended to temporarily define xi and yj axes either naturally (with properly fitted strings, in Greece these are called "stitches") or electronically, so as to facilitate the determination/confirmation of the remaining points and axes.

Specialized topographic personnel must determine at least the fixed points; however the lining must be confirmed with properly fitted strings and a surveyor's tape, both by the supervisor engineer and by the contractors responsible for the structural frame's erection.

When the elevator stops at the basement, its foundation must be placed around 1.40m lower than the basement level. The most effective way of construction is to normally implement the reinforcement of the elevator's foundation together with the rest of the foundation reinforcement and before any formwork assembling, to concrete only the spread footing of the elevator. Later this will help in the proper and well-balanced positioning of the elevator's shear wall moulds and in securing the accurate continuation of the available working space at the other floors.

This drawing also shows the foundation filling[8] which can be composed of soil, debris, debris with a final layer of gravel, or of soil and a final layer of gravel. In every case, the filling's layers must be thoroughly compacted by means of mechanical equipment and constant water spraying. It is recommended to cover the final layer with a waterproof membrane (e.g. thick plastic sheet) so as to isolate waters from the substructure and to avoid absorption of the concrete's water during the casting process.

[8] Lately the foundation filling is composed of expanded polystyrene. The polystyrene pieces (of a large volume e.g. 2.0x1.0x0.5 = 1m³) might be also used for the side moulds of the foundation. However, such a case requires great attention and preliminary work in order to secure the side cover depths of the reinforcements, e.g. with the use of small steel pins, placed at pre-defined points upon the footings' edges. If at the basement, there are drainage pipes, the channels for the piping installation can be easily opened with a saw. In is strictly forbidden to use a blow torch!



Detail of the drawing C.20

All the channels required for the piping placement of every type of installation e.g. drainage must be opened and covered prior to the final filling layer and at least before the compaction and the formation of the final surface. The installations of the foundation's floor must be presented in a separate drawing in every detail. Extra attention must be paid when defining and presenting the required vertical holes in the foundation beams for the positioning of the installation pipes.

The concrete grate of the basement floor must be the same as the one used for the structural frame because it also covers the columns' and shear walls' layer (see §3.7.5).

All concrete surfaces must be thoroughly cleaned and washed prior to the concreting of the basement's floor. In the peripheral shear walls it is possible to use an adhesive emulsion, which will be placed after the meticulous cleaning and right before the concreting (see and the relevant detail in drawing C.30).

During an earthquake, the building's sway up to the basement's ceiling is considered zero and therefore, there is no obligation for a joint at the foundation and the basement. However, its position must be indicated in these drawings because the reinforcement of the columns' and shear walls' must have the proper layout in order to be connected with the reinforcement of the corresponding vertical elements of the ground floor and the upper storeys.

5.3.3 **FORMWORK of the BASEMENT'S ceiling** (Drawing C.30)

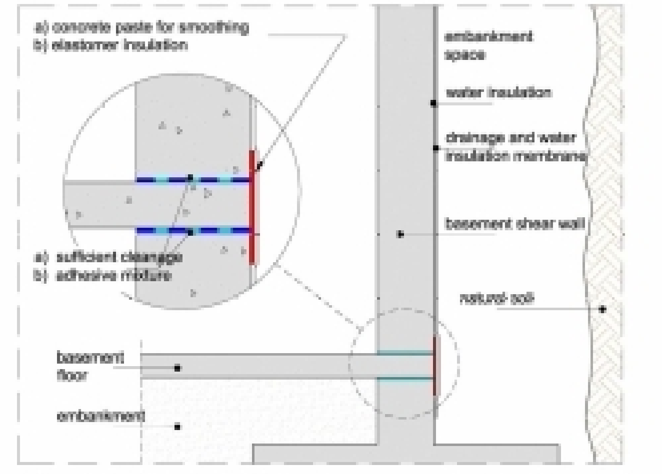
The drawing of the basement ceiling's formwork includes the formwork plan view and a characteristic elevation, both in 1:50 scale. Moreover, it shows the details of the two staircases in 1:20 scale and the details of the peripheral shear walls' waterproofing in scale 1:10.

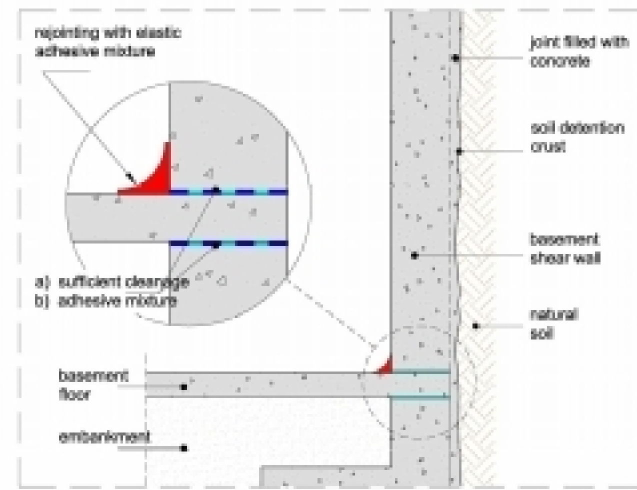
The axes and the fixed points of the columns must be re-defined in the basement level.

Two heights are mentioned upon the formwork drawing, the first regards the height of the slab's covering and the second refers to the height of the concrete's upper surface. Although many of these altitudes appear to be unnecessary they are written in order to avoid confusion during the formworks' implementation.

Normally, the channels required for the positioning of the installations, must be clearly indicated upon a special drawing however, if they are not extensive and complex they can be presented only upon the carpenter's drawing. In case a pipe has to pass through the wall of a strip foundation, the designer engineer must be notified.

The detail that regards the proper waterproofing of the two joints formed at the base of the peripheral shear walls where the layers of the final three concrete castings meet, is quite important. When it is possible to work at the outer surfaces, the solution is shown at the first figure while when there is no such possibility, we are limited to the internal sealing. It is noted again that the solutions mentioned in this paragraph constitute some of the numerous, analogous solutions.





5.3.4 FORMWORK of the GROUND FLOOR'S ceiling (Drawing C.40)

The formwork drawing of the ground floor ceiling includes the formwork and a characteristic elevation, both in 1:50 scale. The dashed line in the elevation is the cross section of the mezzanine that is going to be constructed in a following phase.

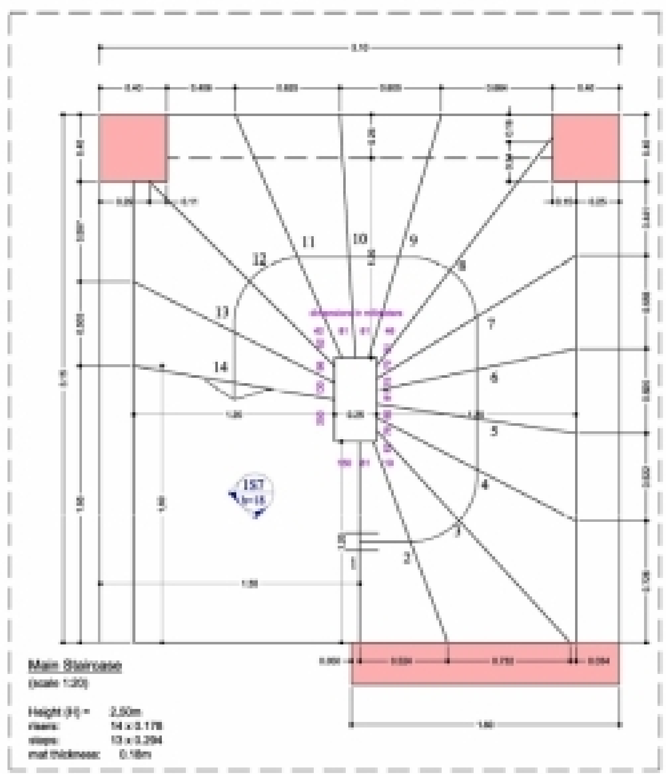
The drawing also includes the details of the two ground floor staircases presented in scale 1:20.

The axes and the columns' fixed points must be re-defined in every floor so as to avoid an increase in the error caused by the successive point-transfers from the lower floors.

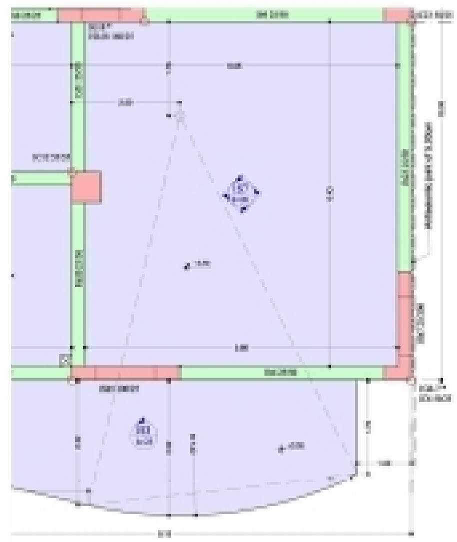
5.3.5 FORMWORK of the MEZZANINE'S ceiling (Drawing C.50)

The formwork of the mezzanine's ceiling includes the formwork of the ground floor and a characteristic elevation, in 1:50 scale.

Moreover, it includes the details of the two staircases in 1:20 scale.

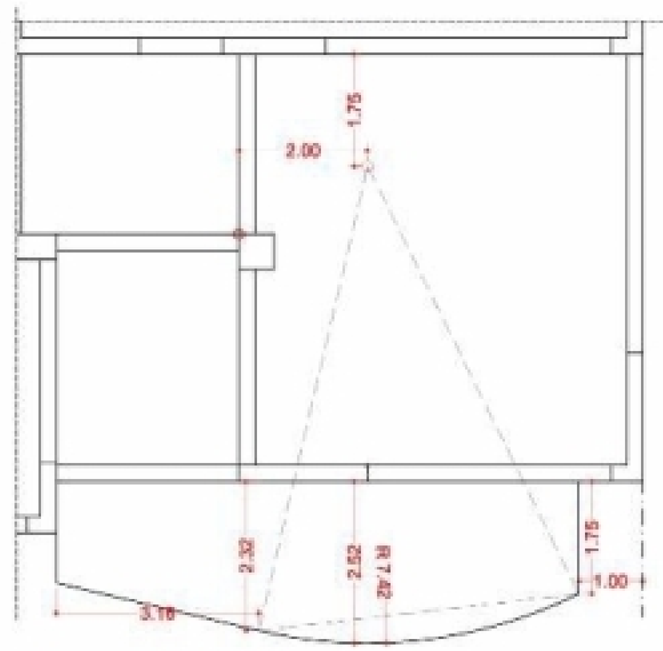


Detail of the central staircase, of the drawing C.50



When the formwork includes curved sections, the information required for their design must be provided. For instance, in the case of a circle's arc, the center of the circle, its radius and two points upon its circumference can be indicated.

For an effortless and accurate implementation of the arcuate side of the slab's formwork, when the circle's radius is known, small wooden, plastic or steel models can be created in natural size (fids) with a length around e.g. 50cm, which can be used as drivers for the support of the flexible side mould.



Lining of the balcony's arc in the drawing C.50

5.3.6 FORMWORK of the MEZZANINE'S ceiling with thermal insulation (Drawing C.55)

The formwork's plan view is the same with the one previously mentioned. The only difference is that the former has thermal insulation integrated inside the structural frame. This drawing is provided indicatively, as a different version. However, if the structural frame is going to be constructed with an integrated thermal insulation, then all the drawings must include the thermal insulation as well.

THE REST OF THE FLOORS (Drawings C.60,70,...) are almost alike and therefore are not included in the drawing samples.

Steel fixer's drawings

The steel fixer's drawings are rather complex and include a wide variety of details. The intention of this book is to present all the phases of the detailing procedure therefore, the samples of the steel fixer's drawings include a number of details. However, these details are only a part of the details that should normally accompany the drawings.

The number of the constructional details that follow the detailing drawings of a building depends upon the size and the complexity of the work as well as upon the experience of the construction team. Many of the constructional details usually met in practice, are included in the various chapters and can be used as an example for the practically unlimited cases that one may be called to face.

The symbols of the steel fixer's drawings have been analyzed in the previous chapters consequently bellow are mentioned only the titles of the drawings:

FOUNDATION FORMWORK (Drawing R.20)

FORMWORK of the BASEMENT'S ceiling (Drawing R.30)

DETAILING OF THE BASEMENT'S BEAMS (Drawing R.30.B)

FORMWORK of the GROUND FLOOR'S ceiling (Drawing R.40)

FORMWORK of the MEZZANINE'S ceiling (Drawing R.50)

TABLES

TABLE 1

Ø mm	Mass kg/m	Section's area in cm²								
		1 pcs.	2 pcs.	3 pcs.	4 pcs.	5 pcs.	6 pcs.	7 pcs.	8 pcs.	9 pcs.
5	0.154	0.20	0.39	0.59	0.78	0.98	1.18	1.37	1.57	1.76
6	0.222	0.28	0.57	0.85	1.13	1.42	1.70	1.98	2.26	2.55
8	0.395	0.50	1.01	1.51	2.01	2.52	3.02	3.52	4.02	4.53
10	0.617	0.79	1.57	2.36	3.14	3.93	4.71	5.50	6.28	7.07
12	0.888	1.13	2.26	3.39	4.52	5.65	6.78	7.91	9.04	10.17
14	1.210	1.54	3.08	4.62	6.16	7.70	9.24	10.78	12.32	13.86
16	1.580	2.01	4.02	6.03	8.04	10.05	12.06	14.07	16.08	18.09
18	2.000	2.54	5.08	7.62	10.16	12.70	15.24	17.78	20.32	22.86
20	2.470	3.14	6.28	9.42	12.56	15.70	18.84	21.98	25.12	28.26
25	3.850	4.91	9.82	14.73	19.64	24.55	29.46	34.37	39.28	44.19
28	4.833	6.16	12.32	18.47	24.63	30.79	36.95	43.10	49.26	55.42
32	6.310	8.04	16.08	24.12	32.16	40.40	48.24	56.28	64.32	72.36

Example: 4Φ14 correspond to a section of 6.16cm² and have a mass equal to 4*1.21=4.84kg

Example: 2Φ20 correspond to a section of 6.28cm² and have a mass equal to 2*2.47=4.94kg

TABLE 2

Light structural wire meshes - B500A - ELOT 1421-2

Sheet dimensions	Mesh type	Cross wires			Longitudinal wires			Theoretical sheet mass
		No.	Diameter	Distance	No.	Diameter	Distance	
(m)			(mm)	(mm)		(mm)	(mm)	(Kg)
5,00 x 2,15	T131	33	5,0	150	15	5,0	150	21,5
5,00 x 2,15	T188	33	6,0	150	15	6,0	150	32,4
5,00 x 2,15	T196	50	5,0	100	22	5,0	100	33,5

Example: one wire mesh T188 has square openings 15x15 cm and rebars Φ6/15 which corresponds to 1.88 cm²/m, in both directions. Its mass is equal to 32.4kg

TABLE 3

Distances in cm	Reinforcement's section in cm^2							Pieces per m
	Ø 6mm	Ø 8mm	Ø 10mm	Ø 12mm	Ø 14mm	Ø 16mm	Ø 18mm	
6.00	4.71	8.38	13.09	18.85	25.66	33.52	42.41	16.70
6.50	4.35	7.73	12.08	17.40	23.68	30.95	39.15	15.40
7.00	4.04	7.18	11.22	16.16	21.99	28.73	36.36	14.30
7.50	3.77	6.70	10.47	15.08	20.52	26.81	33.93	13.40
8.00	3.53	6.28	9.82	14.14	19.24	25.14	31.81	12.50
8.50	3.33	5.91	9.24	13.31	18.11	23.66	29.94	11.80
9.00	3.14	5.59	8.73	12.57	17.10	22.34	28.28	11.10
9.50	2.98	5.29	8.27	11.90	16.20	21.17	26.79	10.50
10.00	2.83	5.00	7.85	11.31	15.39	20.11	25.45	10.00
10.50	2.69	4.79	7.48	10.77	14.66	19.15	24.24	9.50
11.00	2.57	4.57	7.14	10.28	13.99	18.28	23.14	9.10
11.50	2.46	4.37	6.83	9.84	13.39	17.49	22.13	8.70
12.00	2.36	4.19	6.54	9.42	12.83	16.76	21.21	8.30
12.50	2.26	4.02	6.28	9.05	12.32	16.09	20.36	8.00
13.00	2.17	3.87	6.04	8.70	11.84	15.47	19.58	7.70
13.50	2.09	3.72	5.82	8.38	11.40	14.90	18.85	7.40
14.00	2.02	3.59	5.61	8.08	11.00	14.36	18.18	7.10
14.50	1.95	3.47	5.42	7.80	10.62	13.87	17.55	6.90
15.00	1.89	3.35	5.24	7.54	10.26	13.41	16.97	6.70
15.50	1.82	3.24	5.07	7.30	9.93	12.97	16.42	6.50
16.00	1.77	3.14	4.91	7.07	9.62	12.57	15.90	6.30
16.50	1.71	3.05	4.76	6.85	9.33	12.19	15.42	6.10
17.00	1.66	2.96	4.62	6.65	9.05	11.83	14.97	5.90
17.50	1.62	2.87	4.49	6.46	8.79	11.49	14.54	5.70
18.00	1.57	2.79	4.36	6.28	8.55	11.17	14.14	5.60
18.50	1.53	2.72	4.25	6.11	8.32	10.87	13.76	5.40
19.00	1.49	2.65	4.13	5.95	8.10	10.58	13.39	5.30
19.50	1.45	2.58	4.03	5.80	7.89	10.31	13.05	5.10
20.00	1.41	2.51	3.93	5.65	7.69	10.05	12.72	5.00

Example: the reinforcement Φ12/15 corresponds to a section of 7.54 cm^2/m. The equivalent reinforcement is Φ10/10 which corresponds to a section equal to 7.85 cm^2/m

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