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Construction with reinforced precast concrete elements

Adaptation of an in situ solution into a precast one

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1 INTRODUCTION

In Portugal for the last few years the precast industry has seen a continuant growth although at an inferior rate when compared to the rest of Europe. This growth can be explained by the advantages that the construction companies see on this technique.

Precast solutions, when compared with in situ ones, present various advantages where we can distinguish: the possibility of the reduction of the global costs because of the lesser number of operations required on site, the less needs of shuttering and propping in the constructive process, the security during construction and the smaller impact on the environment.

Also the need of increasing production in the factory require the use of concrete with superior mechanics and durability characteristics than the ones used in traditional buildings which leads to a better quality and longevity of the precast buildings when compared with other concrete solutions.

Most of these advantages rely on repetition and good work organization that are not always easy to implement.

This work is intended to show different possible solutions that exist in this type of construction, as well as the way how the connections between different precast elements are designed and determined from a structural point of view, namely with precast elements in current buildings. An in situ structural solution is taken as a case study to be adapted to a precast one, being described the calculation models used in the design of the most important structural elements.

2 CONSTRUCTION WITH PRECAST ELEMENTS

The viability of the construction with precast elements depends on great part on the solution of the connections adopted. The impossibility of handling and transporting elements with big dimensions implies the division of these elements in small counterparts which leads to the necessity of creating connections between them that allows for the correct transfer of the applied loads to the structure and to its foundations.

In countries where the seismic actions have an important part on the design of the structures such as in Portugal, it's mandatory to conceive connections which grant a good ductility to the structure. One way of doing this is to use connections that have an infill part of in situ concrete. This technique leads to the construction of precast structures which have a very similar behavior, from a structural point of view, to a totally cast in situ one.

The construction phase plays a big role on the design of precast structures. While the in situ concrete is curing the structure elements relies only on the precast parts and its provisional supports to remain stable. This is valid for precast columns, beams, shear walls and floor slabs that have to be capable of resisting considerable forces while being pin jointed and having smaller sections than the ones considered on the final stage.

The connections designed must be the simplest as possible to avoid difficulties when assembling the elements together. Connections can be differentiated and grouped by many aspects, as pointed by Santos [1]:

- types of elements to connect (column to foundation, column to beam, slab to beam, etc.),
- execution process (glued, bolted, welded, etc.),

– the main type of stress transferred (compression, tension, shear, etc.),

– bending behavior (pined, continued or partially continued).

In this work it was taken focus on connections that allows the continuity as they play a more important role on seismic areas and some are presented in the case study.

3 CASE STUDY

The case study refers to a part of the structure of the Portimão hospital which was inaugurated in 1999 and was built using a current cast in situ concrete solution.

The hospital has a regular net of columns, typical on constructions of this type with big dimensions. The floor is supported by beams and as for the horizontal forces it has a moment resisting frame structure and some shear walls that improve its seismic performance. Because of its large dimension in the plan it was divided in several smaller structural blocks (A, B, C, D, E, F and G) that work independent from each other. The block D which can be identified on the Figure 3.1 was chosen to be studied.

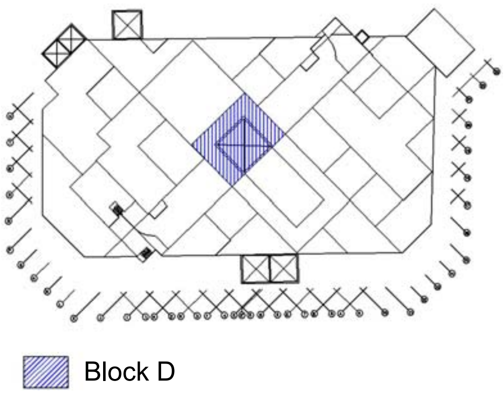

Figure 3.1 – Relative localization of the block D in the Portimão hospital compound

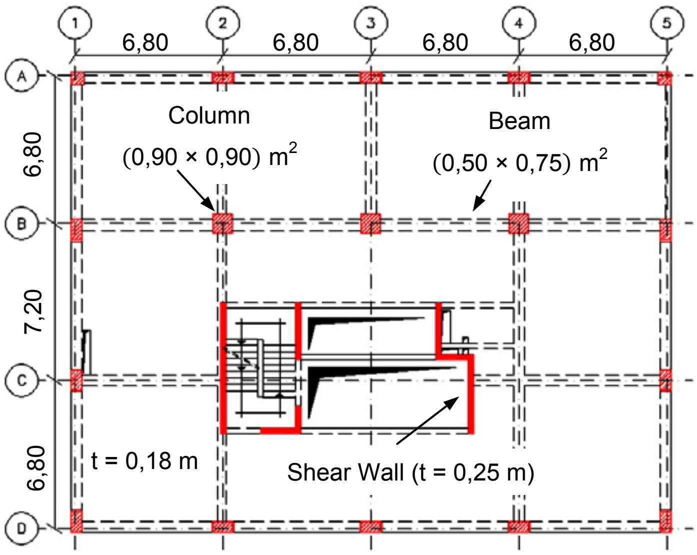

Figure 3.2 – Plant of a type floor on block D

This block has a dimension on plant of aproximally 28 × 21 m^2, its foundations are direct and has 10 elevated storeys with heights varying from 4,5 m until the 2^{nd} floor to 3,7 m in the rest. The distance between columns is 6,8m and the slab thickness is 0,18m as shown on Figure 3.2.

3.1 Slab

In most cases, the solution adopted for the slabs has direct implications on the rest of the structural elements as this represents the main structural element. It's important that these elements, when working together, are capable of providing a rigid diaphragm that can distribute the horizontal forces between vertical elements (shear walls or moment resisting frames) in an effective way. The diaphragm action of the structural slab can be provided through the structural topping and bracing of the floor elements [2].

In this case study the solution adopted for the slab is the precast minos slab shown on Figure 3.3. This solution has a behavior similar to a hollow core slab for a unidimensional behavior. During the construction phase this slab is designed as simple supported and has to support its self weight as well as the topping weight and a construction traffic load. During this phase this solution has the advantage of not needing the use of propping which allows to significantly reducing the construction time.

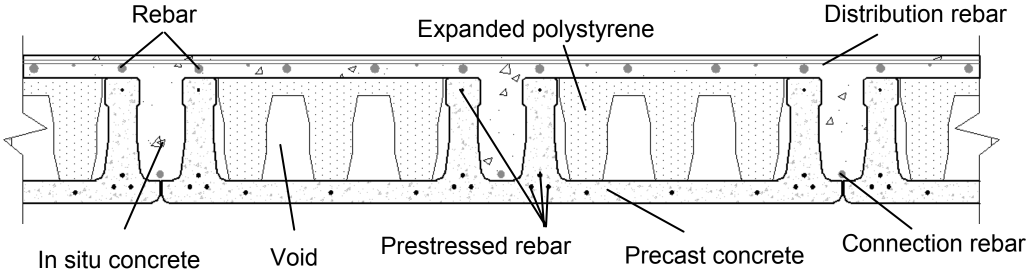

Figure 3.3 – Detail of the minos slab, developed by Prefabricados Castelo

The panels can be orientated in an alternated way to diminish the load on the beams in the construction phase as it's shown on the Figure 3.4. Otherwise some beams could be overloaded and be conditioned by this phase.

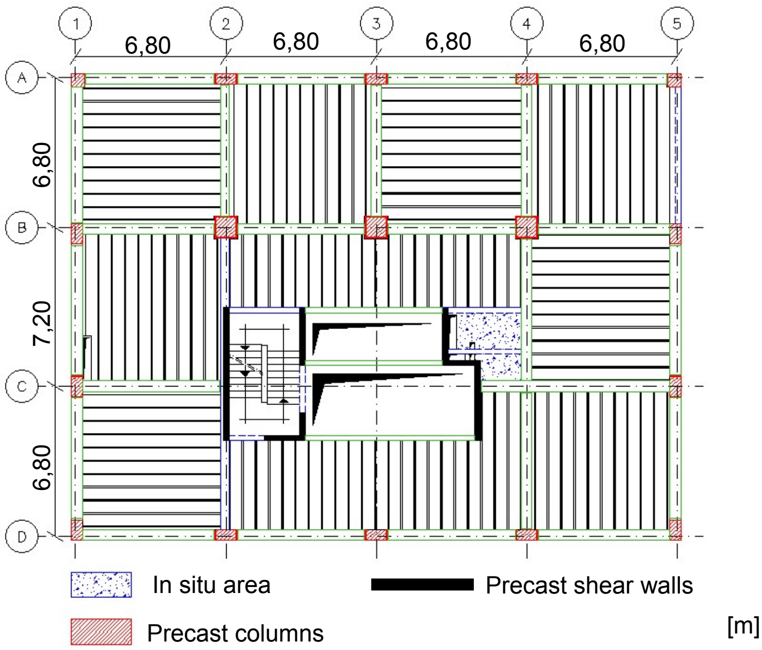

Figure 3.4 – Disposition of the precast minos concrete slab

For the final stage, in the design of the ultimate limit states, it’s normal not to consider the continuity of the slabs on the beam supports when two adjacent planks are not oriented on the same direction. This leads to obtaining moment distribution diagrams such as the ones presented on the Figure 3.5

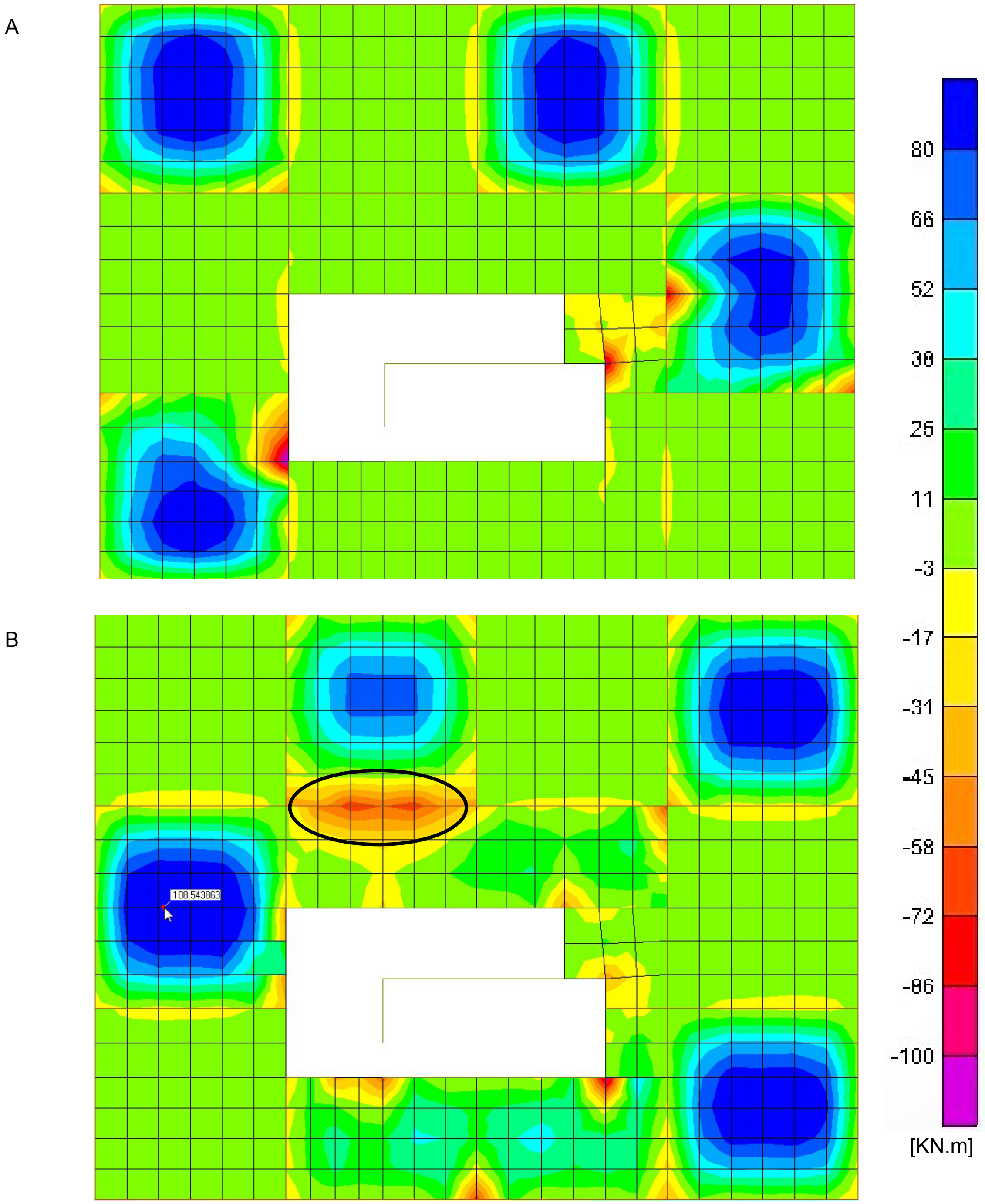

Figure 3.5 – Moment distribution diagrams on the minos floor slab (m_{11} upper image and m_{22} lower image)

Notice that in the marked zone of the B diagram on Figure 3.5 there are some significant negative moments that are explained by the orientation of the planks on the same direction, which grants the continuity on this support.

For cracking control it's wise to consider some reinforcement on the supports of planks oriented on different directions as there are some negative moments due to the partial continuity. It's presented on the Figure 3.6 some details of the proposed connections between the slab and the beams.

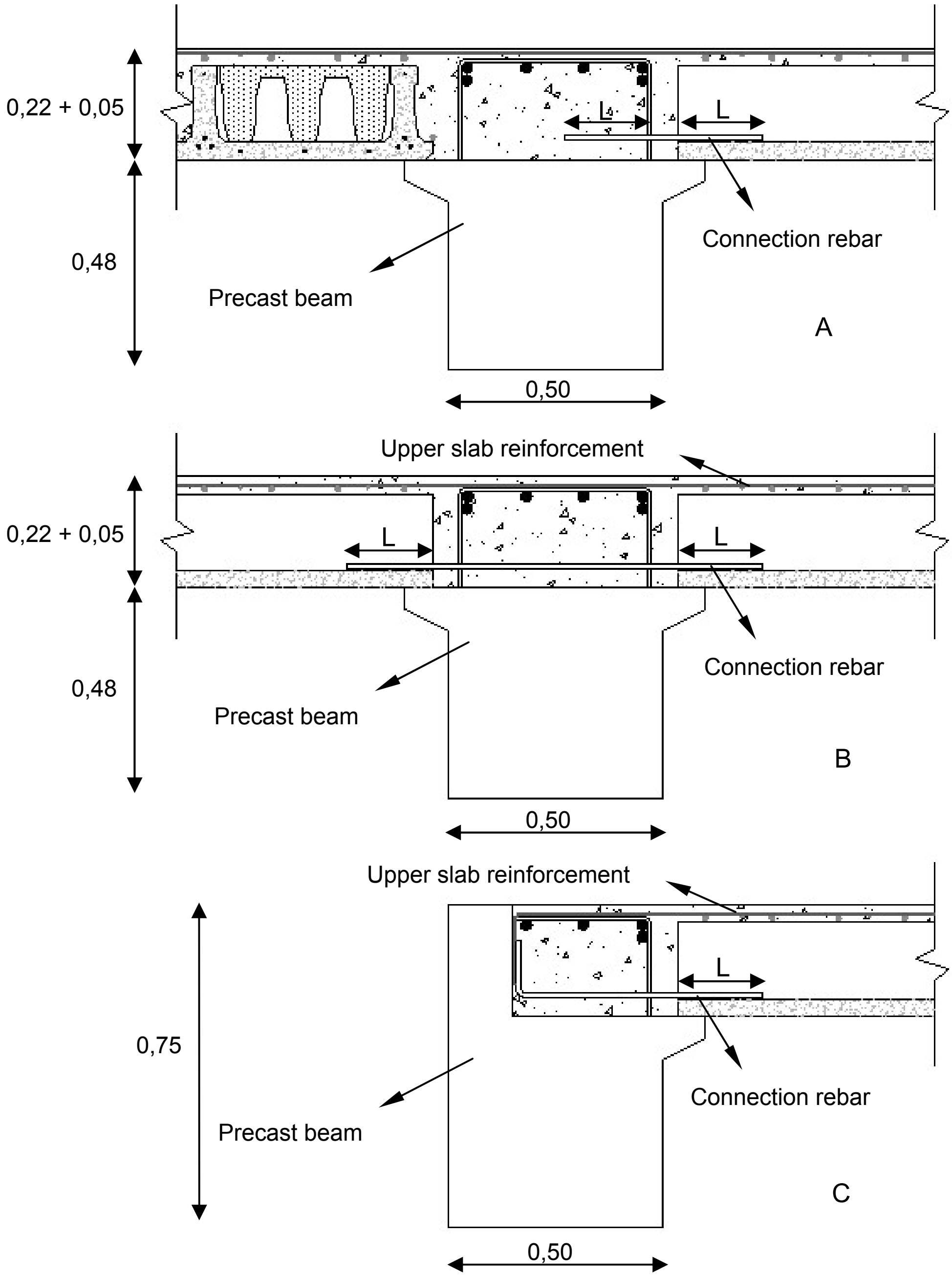

Figure 3.6 – Slab – beam connection

3.2 Beam

The beam section proposed is shown on Figure 3.7. The idea of this design is to permit the upper and lower reinforcement continuity on the joints between beams and columns and at the same time allow the beam to achieve the spans required without the need of propping. The U shape sections on the edges are designed to accommodate the lower reinforcement specially important in seismic areas while the upper reinforcement is inside the topping area.

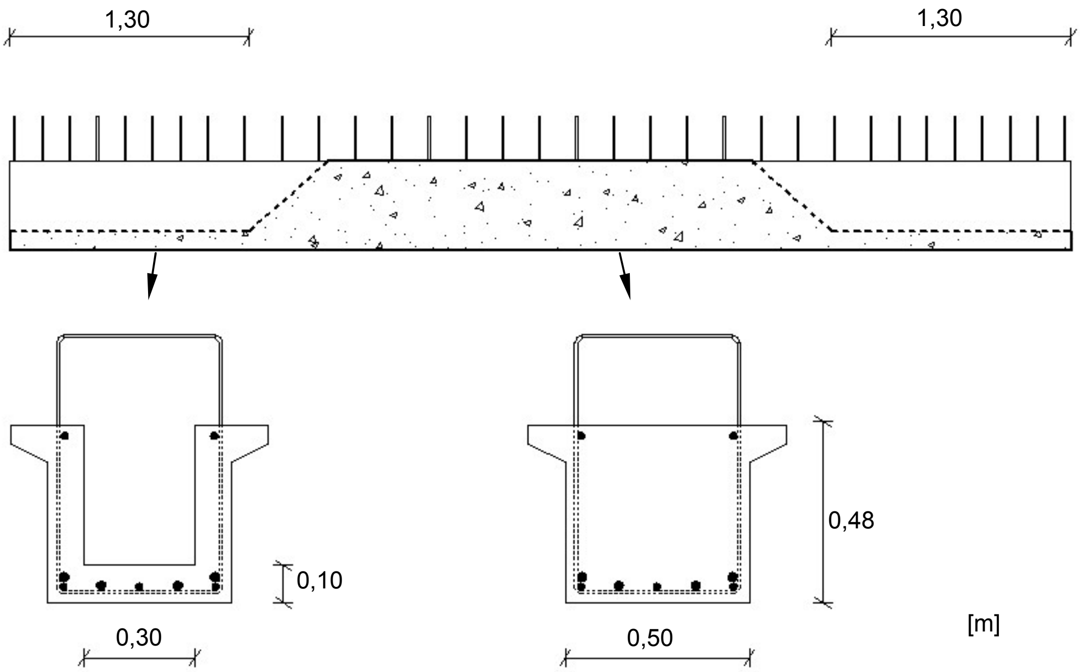

Figure 3.7 – Adopted beam section

During the construction phase the beams are simple supported by corbels on the columns while on the final stage, after the curing of the in situ concrete, the beams have full continuity in the connection with the columns, for both negative and positive moments. The column reinforcement is continuous and the gap in the columns is fulfilled with in situ concrete at the same time as the topping of the slab. The detail adopted that guarantees this behavior is shown on Figure 3.8.

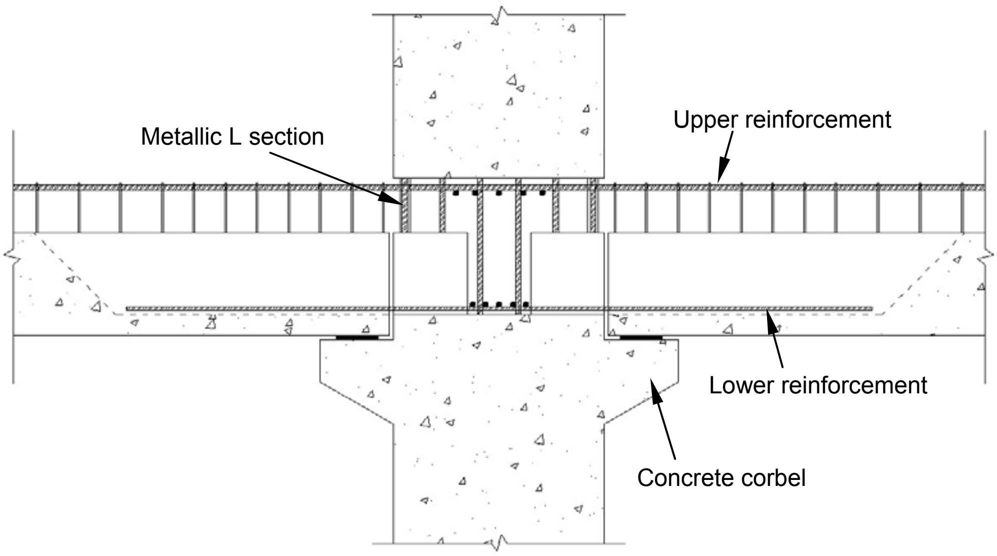

Figure 3.8 – Beam – column connection

It's also possible to use this same philosophy on other connections such as the beam to beam connection shown on Figure 3.9. The U shape on both beams allow for the continuity of the positive reinforcement on the secondary beam. Notice that this connection requires some propping during the construction phase as the section of the main beam alone is not enough to resist the imposed loads.

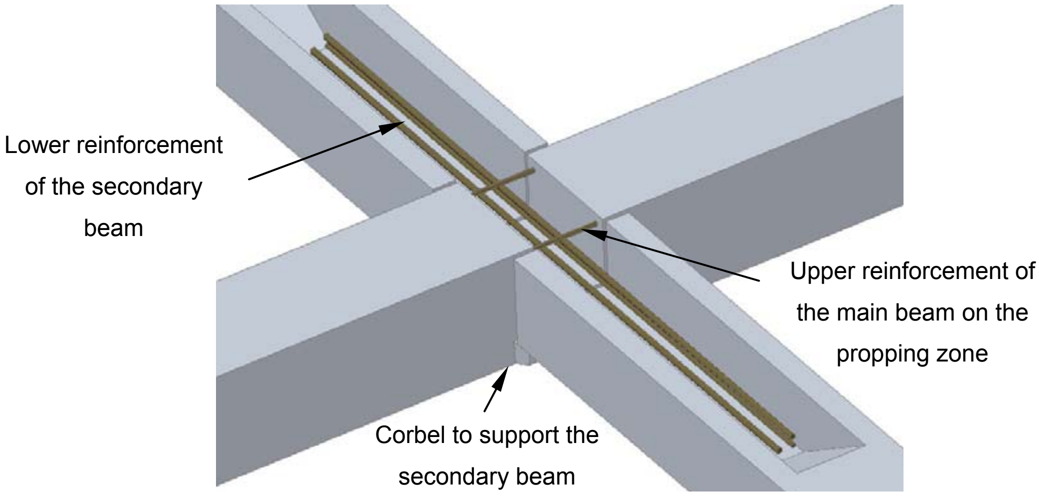

Figure 3.9 – Beam – beam connection

3.3 Column

To minimize the number of precast elements the columns have up to 3 storyes height. The column splices are localized in between floors to simplify the beam to column connection, at the same time this allows for a simpler column to column connection as the bending moments acting on these areas are substantially lower. It's shown on Figure 3.10 the portal frame of the building and the correspondent moment diagram.

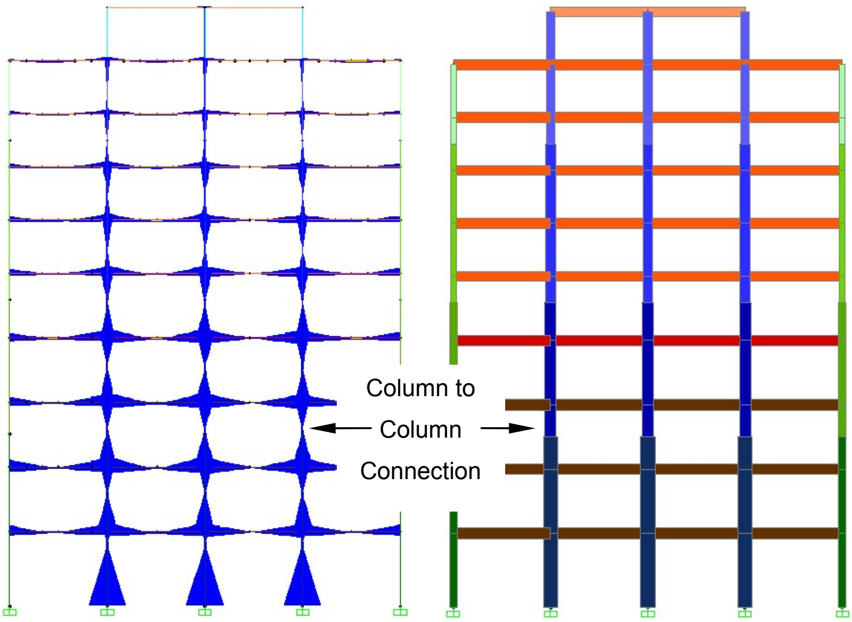

Figure 3.10 – Moment diagram on the portal frame and respective SAP2000 model

The connections between columns are made through bars left from the lower column that connect to the grouted sleeves of the upper column (as shown on Figure 3.11). The gap between the bars and the surface of the tube is then filled with grout. This connection has the advantage of providing the confinement of the concrete and is also easy to manufacture and fix. It should also be stressed that the surface of the grouted tube should not be smooth.

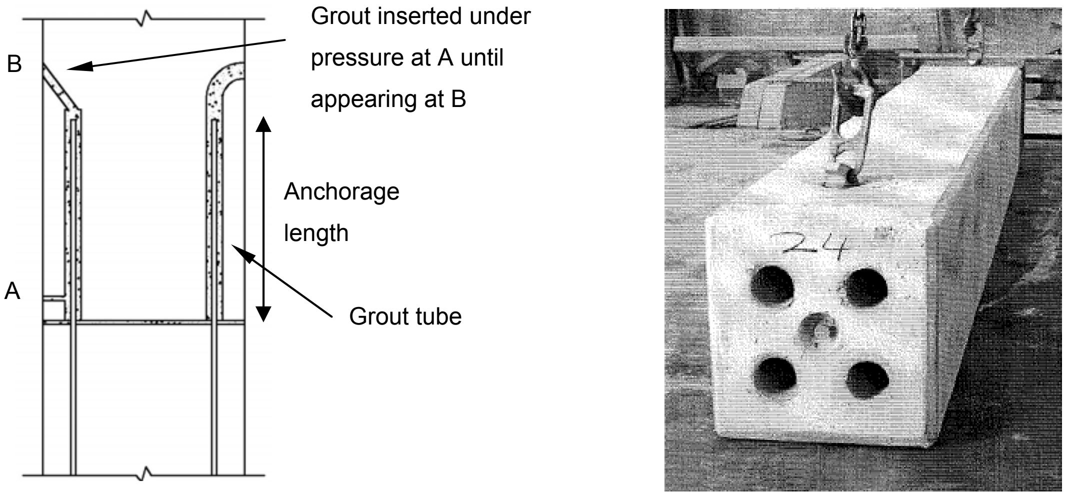

Figure 3.11 – Grouted column to column connection (adapted from [4])

Moment resisting connections of columns to pad footings and other in situ (or precast) foundations are of three main types [4]:

a) grouted pocket,
b) base plate; greater or equal in plan dimension then the dimensions of the column,
c) grouted sleeve

In this study the column to foundation connection adopted is the grouted sleeve as this helps to uniform the types of connections on site. The projecting bars are localized on the pad footings and the diameter of the grouted sleeves on the column may vary depending on the site tolerances need. This connection may be treated as if it was totally cast in situ. The detail of this connection is shown on Figure 3.12.

Confinement reinforcement (in the form of links) around the sleeves is usually required especially for columns with high base moments.

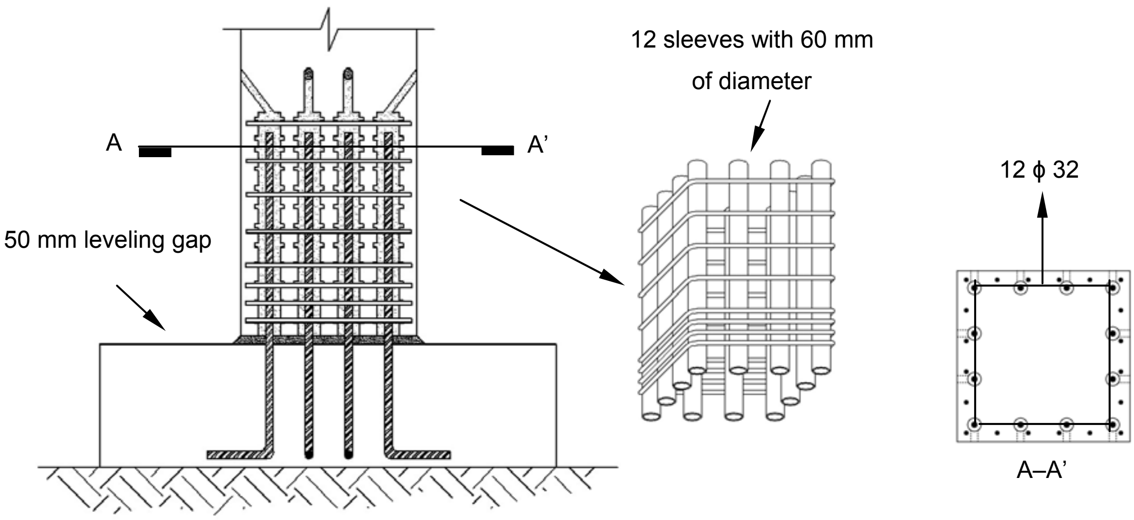

Figure 3.12 – Column – foundation connection through grouted sleeves

3.4 Shear Wall

There are two types of joints between two adjacent wall panels, the vertical joint and the horizontal joint. Due to the necessity of the wall panels to work together as a single shear wall, these joints have to resist shear, tensile and compression forces as illustrated on Figure 3.13.

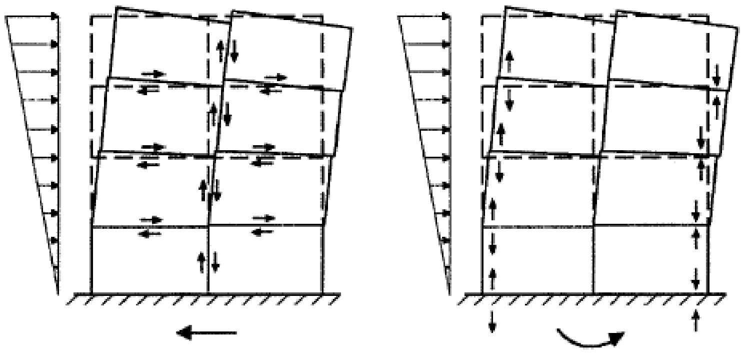

Figure 3.13 – In-plane action of precast shear walls, A – shear forces, B – tension and compression forces [4]

The connections of the walls panels adopted in this study are of type shown on Figure 3.14 . The principle on the joint of figure A is similar as the grouted sleeves joints described above, where the horizontal shear is resisted by the dowel action of the projecting bars. As for the joint shown on figure B the vertical shear is resisted by projecting loops from the wall. It's also to notice that the interface between the panels should be indented to further improve the transmission of the shear force between them as shown on Figure 3.15.

A

B

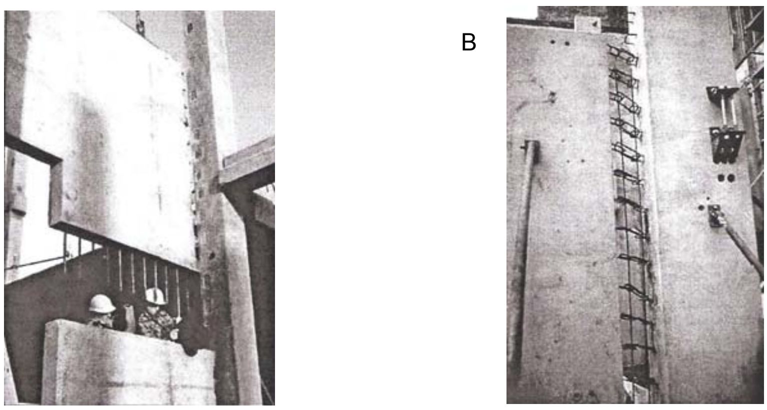

Figure 3.14 – Vertical (A) and horizontal (B) joints of shear wall panels [3]

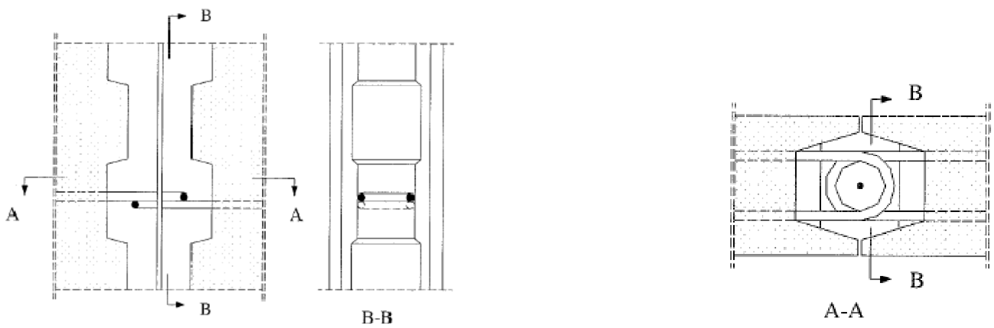

Figure 3.15 – Typical Indented joint between shear wall panels [4]

4 CONCLUSIONS

With a good articulation between designers, the precast companies and the constructors it's possible to conceive ingenious solutions with a good esthetic value, that are economical to build and efficient from the structural point of view, taking all the advantages of the prefabrication industry.

The use of precast solutions with cast in situ concrete on site is beneficial, because one can take the main advantages from both techniques like the faster execution rates obtained in the precast solutions and the flexibility of the cast in situ ones.

From a part of the structure from the Portimão hospital compound it was studied and presented the implementation of a precast solution that secures the same characteristics of resistance and ductility as the based cast in situ solution. It was verified that it would be a viable solution and would certainly bring advantages in terms of quality, time of construction and possible economics.

In conclusion the design of precast structures have to be thought in a way of taking the most benefits from the advantages of this technique and presenting a valuable alternative to the traditional type of buildings.

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