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Abstract

Three-dimensional prefabrication of housing has been the subject of extensive literature, but few houses have actually been built. However, the numbers are now high enough to carry out an on-site analysis, in order to confirm or refute the expectations of fully or nearly fully prefabricated structures. It was surprising to find that many or most of the buildings' foundations were constructed in situ, even though prefabricated solutions exist in the industry.

This article presents available solutions for prefabricated foundations, critically describes the foundations of 3D modular housing that has recently been constructed in Catalonia, and analyses the advisability (or inadvisability) of industrializing the foundations of this type of building.

1. Prefabricated foundations

1.1. Precast concrete pile

- Precast concrete piles are normally used in buildings of more than 4 storeys and soils can have a low bearing capacity.
- They are driven until refusal. Greater lengths can be obtained by utilizing joints.
- Pile driving avoids the removal of soils and improves the bearing capacity of surrounding soils.
- Noise and vibration are generated. Driven piles cannot be utilized on sites with dividing walls.

Figure 1. Precast concrete pile

1.2. Precast strip footing (1)

- Precast strip footings (1) are normally used in one or two storey buildings and in good bearing capacity soils.
- They can be placed on the surface or buried under the ground.
- This type of foundation has precast tie beams.

Figure 2. Precast strip footing (1)

1.3. Precast strip footing (2)

- Precast strip footings (2) are normally used in one or two storey buildings and in good bearing capacity soils.
- They can be placed on the surface or buried under the ground.
- This type of foundation does not have tie beams.

Figure 3. Precast strip footings (2)

1.4. Precast isolated footing

- Precast isolated footings are normally used in one or two storey buildings and in good bearing capacity soils. They can also hold higher buildings.
- They are normally buried under the ground.
- If required, tie beams can be precast or built in situ.

Figure 4. Precast isolated footings

1.5. Screw pile

- Screw piles are normally used in one or two storey buildings and in good bearing capacity soils. They can also hold higher buildings.
- Deeper lengths can be obtained by utilizing joints.
- They must be protected from corrosion.

Figure 5. Screw piles

2. Three-dimensional modular housing in Catalonia
2.1. Apartment building for rental use in Torelló

Figure 6. South view

Architects: TAC Studio, Eduardo Gascón and Jordi Roig [3]
System: TAC, constructed by the firm Modultec [3]
Developer: INCASOL (Institut Català del Sòl). [1][2]
Project completion date: 2010
Location: Torelló (Spain)

2.2. Social apartment building for rent to young people in Banyoles

Figure 7. Southeast view

Architects: Xavier Tragant and Miguel Morte
System: Compact Habit [3]
Developer: INCASOL (Institut Català del Sòl) [1]
Project completion date: 2011
Location: Banyoles (Spain)

2.3. Student Dorm on Montiliví Campus

Figure 8. North view

Architects: Xavier Tragant
System: Compact Habit [3]
Developer: UdG (Universitat de Girona)
Project completion date: 2011
Location: Banyoles (Spain)

2.4. Student Dorm on ETSAV Campus

Figure 9. Interior zone view

Architects: Harquitectes Area Productiva SLP i Data AE
System: Compact Habit [3]
Developer: UPC (Universitat Politècnica de Catalunya)
Project completion date: 2011
Location: Sant Cugat del Vallès (Spain)

3. Foundations of 3D modular housing in Catalonia
3.1. Apartment building for rental use in Torelló

The foundation for this building consists of isolated footings, continuous footings around the perimeter and tie beams cast in situ.

Some of the reasons why the foundations were not precast are given below:
3.1.1 No company was found that could fabricate all of the foundation.
3.1.2 A specific connector is needed between the foundation and the overlying modules.
3.1.3 Costs.

One of the first unforeseeable conditions was the hardness of the subsoil. The soil study had already indicated that the soil was rocky. However, the rockiness was not expected to be so extreme. In some places, over four metres needed to be excavated to construct a basement and to lower the site to street level. A tracked excavator was used, as well as equipment to drill and inject expansive mortar. This caused delays and increased project costs considerably.

Foundations were constructed in situ. Steel plates were left on the top surface to weld the connectors or bolts were inserted to join the foundation to the overlying modules. However, when the modules arrived at the site, some did not match the foundation bolts, so various solutions had to be improvised, depending on the location of the bolts. In general, the bolts were cut and the modules were directly welded to the plates.


Figure 10. Reinforced and shuttered footings, tie beams and plates for connection to the modules. Figure 11. The cutting of offset connector bolts with a grinder.

3.2 Social apartment building for rent to young people in Banyoles.

The foundation for this building consists of CPI-8 piles, semi-prefabricated foundation beams, and tie beams cast in situ.

The upper parts of the beams were factory-made. They were transported to the site and suspended above trenches, to be completed in situ. These prefabricated members already had connection elements laid out and provided in order to avoid possible intolerances when the modules were placed on top.

The procedure for suspending the partial beams allowed the precise positioning of the bases of the modules within the required tolerances.

The site is located in Banyoles city centre, close to a streambed. The main reason for selecting CPI-8 piles was the soil study result, which identified a low bearing capacity in the upper layers of soil and a high water table.

The beams were not completely prefabricated because, according to the contractor, they would have had a very large cross section and would have been difficult to transport and handle. The in situ construction also resolved the problem of connection between the CPI-08 piles and the beams.

Figure 12. Suspension of partial prefabricated beams to be completed with in situ concrete. Figure 13. Concreting of the lower part of the partial beams and of the tie beams.

3.3 Student Dorm on Montiliví Campus

This student residence is made up of two buildings. Both were built on semi-prefabricated beams that run the length of the modules, which were braced in situ.

As in the Banyoles project, the semi-prefabricated beams had the elements to connect with the modules laid out and provided. They were also suspended above the trenches to construct the lower part of the beams in situ.

Unlike the Banyoles project, piles were not needed, as the resistant soil was found in the upper layers and there was no groundwater present. In addition, the lower beam parts, which were built in situ, were reinforced with steel.

According to the soil study, the soil was generally cohesive, although not uniform, yet the soils in the area of the buildings had quite similar bearing strengths and deformations. Consequently, the same system was selected for the entire foundation.

Nevertheless, variations in soil bearing strength around the site required different foundation sections. This made standardization difficult, which would have had a cost impact. It was therefore decided to construct the lower, variable parts of the beams in situ.

Figure 14. Lower beam parts were built in situ. The section was variable. Figure 15. Lower beam parts were reinforced with steel.

3.4. Student Dorm on the ETSAV Campus

The foundation for this building was built with braced in situ beams. The beams were built perpendicular to the modules and were braced with tie beams every three modules.

In this project, the foundation scheme was reversed: the beams were placed along the width of the modules. There were two reasons for the change in scheme. The first was cost. Reversing the scheme led to cost savings, which were possible in this project due to the fact that the building did not have many floors. The second was the characteristics of the modules, which were heavier at the ends. Consequently, an element such as a beam was required to bear the weight of these point loads.

Prefabricated concrete slabs were placed above the reinforcing steel of the beams that had the module connectors laid out and provided. Two layout systems were used for these plates: the first system levelled the plates vertically. A second system laid out the plates horizontally, by means of steel profiles and steel supports.


Figure 16. Steel supports help to position slabs accurately. Figure 17. Beams and tie beams that have already been concreted.

Conclusions

A highly industrialized solution can be competitive with conventional construction methods in the following areas: time and cost reduction and quality improvement. The first two areas are highly interrelated, since an increase in time implies an increase in cost.
All the projects were prefabricated, that is, their industrialization index was very high. Nevertheless, the foundations were mainly constructed in situ, with no advantage obtained from prefabrication.
The main factors that led to this lack of coherence can be summarized as follows:

4.1 Recommendations from soil studies only consider foundation solutions constructed in situ. The guidelines, which are generally more conservative than regulations require, often call for the adoption of disproportionate solutions, particularly when foundations are in soils of high bearing strength, such as bedrock.

4.2 As there is no culture of precision in construction, complex devices must be used to attain the tolerances required in prefabrication. One example is the case of the connections between the modules and the bolts embedded in the foundations.

4.3 The usual method for comparing the short-term costs of individual line items in the project bill of quantities does not achieve optimal quality. From the observed cases we can deduce that industrial solutions may appear to be more expensive, but the consequences of not adopting them result in even higher costs.

To sum up, the execution of the foundations took longer and had higher costs than necessary in most of the cases discussed above. To avoid these increments, greater care should be taken with relevant aspects of the soil study, the foundation design, and the design of the connectors. Comparative cost studies should be carried out, taking into consideration the impact of each solution on the execution, the subsequent work items, and the desired quality.
These conclusions should be made available to the development companies, the architects and the construction companies involved in the works under study.

References

[1] INCASOL – *CIT: Tender for technical innovation: tender for project designs and the construction of social housing buildings, incorporating new systems and innovative technologies.* [online] Barcelona: INCASOL, 2008 [Consulted on 1 April 2009]. Available at: http://www20.gencat.cat/docs/incasol/Home/INCASOL/Documentació/Publicacions/LLibre_CIT_ok.pdf

[2] INCASOL – *INCASOL applies new technologies in the construction of social housing.* [online] Barcelona: INCASOL, 2009 [Consulted on 1 April 2009]. Available at: http://www20.gencat.cat/docs/incasol/Home/INCASOL/Que%20fem/Innovació/Torelló/260509%20NP%20Torelló%20Moduls.pdf

[3] A.A.V.V. – *Modular construction, an innovative alternative during the housing crisis.* Conference given on 17 February 2009. Mataró chapter of the Catalonian Association of Quantity Surveyors, Mataró.