Underpinning solutions of historical constructions

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ABSTRACT: The aim of this paper is to present the main design and construction criteria considered on some underpinning solutions performed by Tecnasol FGE. After a brief description of micropiling and jet grouting underpinning techniques, some practical case histories where these techniques were adopted are presented. Finally the main advantages and limitations of the presented techniques are pointed out.

1 INTRODUCTION

The development of new underpinning techniques has allowed the adoption of a wide number of solutions, progressively more adapted to the singularities and restraints of each scenario, specially when sensitive, old or historic, constructions founded on weak soils have to be underpinned. In this context, the solutions comprising micropiling and jet grouting techniques should be pointed out due to their versatility and advantages related to the limitation of vibrations, as well as the possibility to be adopted in small spaces with low head rooms and restricted access. These techniques also allow the soil improvement, minimising the soil disturbance due to the boreholes small diameter, drilled with suitable equipment (Bullivant and Bradbury 1996).

On the following chapters, after the presentation of the main aspects of these two techniques, some practical case histories, where micropiling and jet grouting underpinning techniques were used, are presented. In each case, the following topics are presented: scenario, main restraints, main conception and execution criteria.

2 UNDERPINNING TECHNIQUES

2.1 Micropiling

Micropiling is a very old technique initially adopted with wood driven piles, which has been developed in the last years mainly due to the bearing capacity improvement (lateral friction at the bond length) related with the use of high pressure grout injection techniques (bigger than 4MPa) and high resistance steel hollow tubes (see Fig. 1). These improvements have allowed to design micropiles with steel hollow tubes (external diameter lesser than 130mm) to carry axial service loads greater than 700kN (Bustamante et al. 1997, Bustamante and Doix 1985).

2.2 Jet Grouting

Jet grouting technology have initially been developed in Japan, the UK and Italy. For about 20 years it has been applied worldwide. In Portugal the technology has been applied in the last 6 years, mainly on Lisbon Metro extension works. Recently, vertical jet grouting solutions have
also become competitive and advisable in several and more usual scenarios, like foundations, earth retaining and underpinning works (Falcão et al. 2000, Greenwood 1987). According to the definitions of the European Standard on Jet Grouting (CEN/TC 288), jet grouted structures consist of interlocking jet grouted elements. An element is the volume of soil treated through a single borehole, which may be a cylindrical jet grouted column or a planar jet grouted panel (Kutzner 1996).

Jet grouting has nothing to do with common grouting, as according to the jet grouting technique the soil is disintegrated by a jet of water or grout at very high pressure (bigger than 30MPa), obtained through the transformation of the high pressure flow (potential energy) into the high speed jet directed to the soil (kinetic energy) due to the very small diameter nozzles effect, and is subsequently mixed with the grouting material (see Fig. 2). A part of the mixed material returns to the surface along annular space around the drill rods or along neighbouring boreholes, serving for necessary pressure relief.

Figure 1: Micropiling: technology and main construction phases.

Figure 2: Jet grouting: technology and main construction phases.

3 CASE A – UNDERPINNING THE FAÇADES OF AN OLD BUILDING IN LISBON

3.1 Scenario

The building is located in Lisbon at the historic quarter of “Bairro Alto”, close to “S. Pedro de Alcântara” terrace. The construction of a basement with 3 floors above ground level, inside (12 x 20 m²) and outside the existent building, demanded the demolition of the existent brick and masonry structure, persevering, for architectural reasons, the external façades (Pinto et al. 2000).
3.2 Main restraints

As main restraints could be pointed out: the geological conditions, the surrounding conditions (site at the historical quarter of “Bairro Alto”), as well as the geometry and degradation of the façades to be persevered, which had to be braced during the excavation works (see Fig. 3).

Figure 3: Site localization and view of the existent façades at the beginning of the works.

3.3 Main conception and execution criteria

Due to the building structure and degradation (see Fig. 3), as well as its tight geometry and low head room, restricted by the façades bracing system, the façades were underpinned with two reinforced concrete walls, supported vertically by micropiles and horizontally with tie rods. The excavation and construction of both walls followed the “Berlin” technique (see Fig. 4).

Figure 4: Excavation phases: underpinning and earth retaining solutions.
4 CASE B – UNDERPINNING OF AN HISTORIC BUILDING IN AVEIRO

4.1 Scenario

The building with brick and masonry structure, 4 floors and an area of 14x32m² is located at the downtown of Aveiro. The construction of a basement with 1 floor above ground and water level on a 12x12m² lateral area demanded, by architectural reasons, the demolition of 2 existent masonry columns and the construction of 3 new reinforced concrete columns (see Fig. 5).

4.2 Main restraints

As main restraints could be pointed out: the geological conditions, which demanded the excavation above ground water table and the building structure and low head room, as works had to be done inside the building (see Fig. 5).
4.3 Main conception and execution criteria

Due to the building geometry (low head room) the façades were underpinned with a watertight single row jet grouting wall, formed by columns $\emptyset 0.80 \text{m}$, spaced 0.70m. The demolition of the internal columns was done just after the excavation and the execution of the 3 new reinforced concrete columns, which demanded the underpinning of the existent columns with two $\emptyset 1 \text{m}$ jet grouting columns (see Fig. 6 and 7) (Pinto et al 2000).

![Figure 7: Excavation and underpinning phases of existent columns.](image)

5 CASE C – UNDERPINNING OF AN OLD CHIMNEY IN LISBON

5.1 Scenario

The chimney with more than 30m height, brick and masonry structure, belonged to an old chemical factory, named “União”, and is located at the quarter of “Alcântara”. The construction of a new residential and commercial complex with 2 floors above ground level for parking purpose, intersecting partially the chimney masonry foundation, demanded the underpinning of the chimney, which, for architectural reasons, had to be refurbished (see Fig. 8 and 11).

![Figure 8: Localization plan and cross section.](image)

5.2 Main restraints

As main restraints could be pointed out: the geological conditions, the bed rock (Volcanic Complex) is located at a depth of 17m and the execution of a 7m depth excavation located 1m from the chimney shaft, intersecting the chimney original brick and masonry foundation.
5.3 Main conception and execution criteria

Due to the chimney structure and slenderness, the underpinning solution comprised the execution of 16 micropiles with 24m length, including 6m of bond length on Volcanic Complex. The micropiles were capped by concrete beams, which were connected to the chimney structure with prestressed tie rods (see Fig. 9). The performance of the chimney was analysed through a Monitoring and Survey Plan, comprising reflective targets located at different levels at the chimney shaft. During excavation works data was collected at least once a week (see Fig. 10).

Figure 9: Underpinning solution.

Figure 10: Chimney Monitoring and Survey Plan.

Figure 11: Excavation works and perspective of the chimney at the end of the works.
6 CASE D – UNDERPINNING OF AN OLD PALACE IN LISBON

6.1 Scenario

Built at the beginning of the XX\textsuperscript{th} century, with French classic style, brick and masonry structure, the Palace has 3 floors, an area of 30x30m\textsuperscript{2} and is located in the center of Lisbon, being surrounded by important streets, like F.P.Melo Avenue (see Fig. 12). In order to face the new project, which demanded a 24m average height excavation on Lisbon Miocenic soils around the Palace (see Fig. 14), as well as the construction of one gallery below its structure, the Palace was underpinned internally with micropiles and externally with contiguous bored piles (see Fig. 13). According to the new project, the Palace will become an hotel and the underground areas will be used mainly for parking and shopping purposes.

![Figure 12: Palace localization and view from Palmeiras Square at the beginning of the XX\textsuperscript{th} century.](image)

6.2 Main restraints

As main restraints could be pointed out: the geological conditions, the surrounding conditions, the Palace structure and geometry and the construction schedule (see Fig. 15 and 17).

6.3 Main conception and execution criteria

Due to the Palace structure and geometry (low head room), the internal walls were underpinned with micropiles capped by a grillage of prestressed concrete beams, which were connected to the masonry walls with pairs of prestressed “Gewi” bars (see Fig. 13).

![Figure 13: Grillage of cap beams and internal underpinning works.](image)
The underpinning of external walls was done with a contiguous bored piles (Ø0.80m spaced 1.0m) wall, connected to the masonry walls through the piles cap beam. The piles were lined with sprayed concrete. Due to Palace geometry and the existence of the internal micropiles, the piles were braced at 6 levels by concrete ring beams. These beams were cast against the ground and their levels were defined in order to coincide with the final underground slabs. The beams were supported by vertical steel profiles in order to restrain their deformation (see Fig. 14).

Figure 14: Underpinning solution for external walls.

Figure 15: Sequences of excavation and construction of the underground slabs around the Palace.

The Palace performance was analysed through a wide Monitoring and Survey Plan, comprising: topographic marks (reflective targets) and inclinometers (located inside the bored piles). Data was collected at least once a week (see Fig. 16).

Figure 16: Palace Monitoring and Survey Plan.
7 MAIN CONCLUSIONS

The demand for underpinning has increased steadily in the last years as renewals and refurbishment works have gained popularity. As example, the presented cases proved how the versatility of some underpinning techniques can fit the uniqueness and restraints of complex scenarios, involving old and historic sensitive buildings, sometimes founded on weak soils. On the figures below two comparative analyses between micropiling and jet grouting technologies (see Fig. 18) and between these techniques and the conventional ones are presented (see Fig. 19).
In this context, it is also important to point out that underpinning works requires expertise at the design and execution levels, along with safe working practices, specially when the underpinned building has an old structure and a special architectural/historical interest and therefore is protected from demolition or alteration. In these situations, considerable care is required on previous tasks, as for example: monitoring and survey, geological and geotechnical site investigation, stiffen, grout, shore struct, in order to prepare these old buildings and their original foundations for the underpinning works. As example, some of the presented cases proved how important is the role of the Monitoring and Survey Plan in this kind of works, mainly as a risk management tool, allowing to survey and predict the performance of the underpinned structures and, if necessary, to adjust in time the initial solution.

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