REHABILITATION OF FOUNDATIONS OF OLD BUILDINGS USING MICROPILES

EXTENDED ABSTRACT

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1 INTRODUCTION

The use of micropiles to strengthen buildings’ foundations dates back to the 1950s post-war era and the reconstruction of cities in Italy [01].

Micropiles can be used either as a supporting structural element that receives applied loads directly, in which case they are known as type I micropiles, or as a loadbearing element to strengthen the ground in situ, when they are known as type II micropiles. In either situation they have always been associated with the structural strengthening of existing buildings, including for seismic strengthening, and today they are used as deep foundations for new buildings [02],

The micropile technique is widely used throughout Europe, notably in France and Germany but above all in Italy, where the technology was pioneered, with a huge building heritage to be rehabilitated. However, it is the United States that has seen a remarkable increase in the implementation and popularity of the technique in recent decades, backed by the Federal Highway Administration (FHWA).

In Portugal the technique has mostly been used for the deep foundations of major infrastructure works and to strengthen the foundations of old buildings. Micropiles have been used a great deal for the latter purpose in the past few years because of the growing number of rehabilitation projects prompted by increasing awareness of the need to restore our building heritage. There is a greater awareness, too, that such rehabilitation has go further than the merely cosmetic to include structural reinforcement, and seismic strengthening.

The purpose of this work was to study the use of micropiles in the rehabilitation of the foundations of old buildings.

The foundation element – the micropile – is characterized in point 2, where it is defined, its constituent materials are described, and its classification, structural function and execution phases are established.

To better understand the applicability of micropiles in rehabilitation and the advantages and drawbacks of using them in this specific area it was first necessary to review their range of application in general terms, with both cases covered in point 3.

Through the analysis of examples of the use of micropiles in the rehabilitation of foundations in Portugal it was possible to establish the terms in which their application in the restoration of old buildings (point 4). The case studies are: the rehabilitation of the Theatro Circo in Braga; the rehabilitation of the building where Rua Martens Ferrão crosses Rua do Viriato, in Lisbon;
the rehabilitation of the Hotel Lanidor on Avenida da Liberdade, in Lisbon, and the structural reinforcement of a masonry bridge in Vendas Novas.

Point 5 deepens the study of the use of micropiles in the rehabilitation of foundations through the analysis of a case study of a building rehabilitation in Lapa in Lisbon where the micropiles were used in the provisional retaining structure of its rear façade. The readings provided by the instrumentation and monitoring of the case study and the comparative 3D representations of the increased displacements of the existing building were used to assess the real impact of the technique, both on its own and compared with other rehabilitation and structural reinforcement techniques for old buildings.

Finally, conclusions are drawn with respect to the use of micropiles in the rehabilitation of old buildings.

2 MICROPILES – CHARACTERISTICS

Micropiles are ‘small-diameter piles drilled, sealed and/or injected with cement grout and incorporating steel reinforcement elements that withstand a higher proportion of all the design loads compared with conventional piles. The load is mostly supported by the steel and transferred via the cement grout to the surrounding ground through high lateral resistance’. [3].

In terms of classification, it is generally accepted that the sealing is important to the bearing capacity of the micropile, with the acceptance in various standards (FHWA - American standard (2000), DTU 13.2 - French standard (1992), for example) of 4 kinds of micropile (figure 1).

![Figure 1: Classification of micropiles, adapted from [1].](image)

Type A: injection performed by the micropile head using gravity pressure alone, since it has no casing, with or without reinforcement [3].
Type B: injection under pressure between 3 and 10 bar. The micropile is usually reinforced [4].

Type C: injection and sealing are executed in two stages, known as global unit injection (IGU). The hole is first sealed by gravity and then, about 15 to 20 minutes later the grout is injected into the pipe at a pressure of up to 10 bar (1 MPa). A ‘tube-à-­manchettes’ is usually used in the micropile’s base. The tube has valves at intervals of one metre and the grout is injected with the aid of a packer [1].

Type D: the injection process is known as IRS – repetitive and selective injection and it is very similar to Type C, but in this case packers are placed centred with the sleeve’s valves and the grout is injected at pressures between 20 and 80 bar (2 to 8 MPa). The process is repeated until the desired pressure is reached [3].

Regarding their structural function, the micropiles’ resistance is normally mobilized by lateral friction of the soil, since they are very often implemented in poor quality ground. However if the foundation is on solid rock and the micropiles are injected under pressure with an enlarged base being formed, they can work as an ordinary pile [5].

Predominantly resistant to axial strength, because of their small section, when they need to be resistant to lateral loads the micropiles can be executed in the spatial direction that favours the conversion of lateral strength into axial strength. Micropiles strongly mobilize the lateral friction of the foundation and allow effective control of the settlements and the small movements of the structure they support [06].

In terms of execution, micropiles can be: drilled, self-drilled (mainly used in the United States, with the implementation process involving only a few steps: drilling, injecting and sealing), or driven (less popular, mostly because of the vibration provoked in the ground, so its use is not recommended near other buildings).

The processes for drilled micropiles mostly used in Portugal (Types C and D) (Fig. 1), involves the following 5 basic stages: drilling, reinforcement placement, sealing, injection and connecting to the superstructure.

3 General applications, and use in rehabilitation

The first applications of micropiles were in the reinforcement of foundations, controlling excessive settlement, strengthening foundations to enable the load to be increased with the addition of extra floors, or to reinforce the existing structures against earthquakes. They have also been used for ground improvement, embankments and supporting walls where anchors cannot be used because of the soil characteristics or because with these techniques it is difficult, to estimate the amount of material to be injected.

Their use in the construction of new buildings consists of a general mat foundation of buried buildings through the contribution to withstanding lifting due to a high water table, or where foundation soils are particularly difficult. In both cases, contrary to other techniques, the lateral friction effect of micropiles leads to the mobilization of a very reasonable load-bearing capacity. They are also used in the foundations of very slender structures where they are
effective against earthquakes, because they function under both compression and tension strengths [7].

In the area of rehabilitation, micropiles have been used to underpin foundations that exhibit excessive settlement, where the ground resistance is not enough to sustain the load of the superstructure or an additional load. Such load may be imposed by the construction of extra storeys or change of type of use, when it is not economically feasible to improve the existing foundations or the adjacent ground or even when foundation underpinning is too difficult (high water level table, soft soil, etc...) [7].

They are also used for the seismic strengthening of existing structures, to execute enlargements under an existing structure (such as including basement floors in existing buildings), and also in neighbouring works (excavations, tunnels, adjoining buildings whose foundations are on a lower level), which could affect existing foundations. They may be implemented in two ways: (i) with underpinning by means of steps or plinths helping the micropiles to connect to the existing foundations, or (ii) without underpinning, crossing the existing masonry elements, provided they are long and strong enough to anchor the micropile (figure 2) [8].

Nowadays micropiles are often used when rehabilitation involves strengthening foundations. They are easy to execute in relatively confined spaces with low ceilings; they have a small diameter, can be implemented at various angles, do not usually require working chambers to be created under the existing foundations and can be made to intersect existing foundations, being executed at a higher level so that there is no need for prior excavation to the bottom of the existing foundation [9].

Figure 2: Load transfer without underpinning (top) and with underpinning to strengthen foundations (below) [10].

4 Use of micropiles in rehabilitation in Portugal

The use of micropiles in rehabilitation is widespread throughout Portugal. This solution is often used in urban centres to restore buildings and also in the rehabilitation of old transport
infrastructures, such as the masonry bridge in Vendas Novas (figure 3). This project shows one of the main advantages of the micropile solution: minimal interference to existing structures, both because of the small diameter of micropiles, enabling them to be implanted from within the existing structure, and because the method causes little vibration, and they can be executed passing through the structure, thereby completely preserving its integrity and appearance.

Figure 3: Structural strengthening of masonry bridge in Vendas Novas, using micropiles (Author’s photo)

Meanwhile, in the rehabilitation of the residential building at the intersection of Rua Martens Ferrão with Rua do Viriato (Lisbon) (figure 4), and of no. 164 Avenida da Liberdade in Lisbon, converting it to a hotel, the micropiles used to strengthen the foundations of the existing structures made it possible to ‘re-cast them’ in ground that had better characteristics. The settlements could then be controlled and/or excavation carried out under existing structures without them being affected by settlements, thus preventing new structural anomalies and rapid degradation.

Figure 4: Underpinning existing façades with jet-grouting columns, crossing the façade on the diagonal and micropiles in the inner and outer provisional retaining structure of the façade [11].

In certain situations, such as the rehabilitation of Braga’s Theatro Circo (figure 5), micropiles have been submitted as virtually the only solution for the temporary retention of the existing structures so that new uses can be accommodated under them. Their integrity can be maintained as they incorporate the rehabilitation of the old buildings, but without affecting
their adequacy in terms of safety and comfort requirements, truly making it possible to regenerate our historic heritage.

Figure 5: Excavation under the main entrance: blocks underpinning the existing structure relying on the micropiles (left); micropiles seen from the bottom of the excavation with intermediate bracing blocks and underpinning bedding blocks (right) [12].

Finally, in the case study on the rehabilitation of an old building in Lapa (figure 6), as in so many other examples of rehabilitation of residential buildings, micropiles make it possible both to temporarily retain the rear façade and, thanks to their small diameter, to do so such that a basement floor for car-parking can be implemented underneath. This made it possible and attractive to use the building once again for residential purposes, given today’s requirements of comfort and convenience.

Figure 6: Rear façade under temporary retention by the system: underpinning beams and micropiles (Author’s photo).

Because they entail minimum disturbance to the ground and in existing structures (those to be strengthened and neighbouring ones), and as they can be implemented using light machinery appropriate to, relatively confined spaces, micropiles are the natural, leading solution for strengthening the foundations of old buildings.
5 Rehabilitation of the foundations of an old building in Lapa, using micropiles

In the case study, a smaller occupation of the foundation space was required of the temporary retention solution for the rear façade, so that excavation could be carried out underneath the existing façade, with the passage of the excavation equipment to inside the building and a high load bearing capacity to support the existing masonry façade.

The suspension of the rear elevation of the building was then achieved with a system comprising a series of beams and micropiles which were executed on each side of the wall; they are to support the existing façade during the course of the excavation work and will be demolished once the final structure is in place, since this will then sustain the rear façade (figure 7).

![Temporary retention of the façade and excavation under it to add a basement car-park, in the rehabilitation of an old building in Lapa (Author’s photo).](image)

Based on the monitoring and observation programme, three-dimensional representation models were built of the displacements observed (increased such that they have a clear expression and representation). They were then compared with one another and with the stage of the works at the date of the reading. It was through these comparative 3D representations that the real impact of the micropiles on the deformation of the existing building could be perceived, concluded which demolition, excavation and foundation techniques, including micropiles, have the greatest impact on the existing buildings.

Analysis of the 3D comparative representations with the increased displacements showed that it was during the demolition of the core of the building that the greatest displacements occurred. This was probably because of the decompression in the four existing masonry façades caused by the demolition of the interior, which was not wholly balanced by the temporary metal retention system.

Significant movements could also be seen at the side walls and the main façade at the excavation next to them, by the time the Berlin-type retention walls were executed, and in the excavation of the various foundation levels. However, the execution of the micropiles did not
show any impact in terms of movement and/or settlement of the structures to be rehabilitated.

It is further noted that the micropile technique associated with the underpinning beams of the rear façade, as a temporary retention system for this façade, did not exhibit any interference in its displacements. The façade (whose lower section was to be completely demolished) remained in the same position, without any settlements, or abnormal or additional movement, compared with the movement of the other exterior walls of the building (figure 8).

![Figure 8: Plan showing works locations, and where instruments for monitoring were installed (left). Three-dimensional representation of reading 19 of 26 July 2012 (last reading available) superimposed on the representation of reading 0 (initial reading 9, of 18 October 2012) (right).](image)

In fig. 8 it can be seen that the displacement of the rear façade during the course of the structural rehabilitation works was equivalent to the movement of the other exterior walls, even though a basement car park has been installed underneath this façade.

### 6 Conclusions

The micropile technique is now widely used in rehabilitation works and is likely to be used even more in the future for strengthening and foundations.

Such prospects amply justify the study of this technique, its characteristics, special features, method of execution, potential and limitations, so that we can understand the relevance of its use today and its future use in the construction sector in Portugal, especially in the rehabilitation of the foundations of old buildings, such as:

- in structural strengthening, with minimum interference to existing structures, because their small diameter enables them to be implanted through the inside of the building, and because the low levels of vibration generated enables them to be executed via the existing structure, thereby maintaining its integrity and appearance, as in the case of the masonry bridge in Vendas Novas;
- in the strengthening of the foundations of existing buildings, enabling them to be ‘re-cast’ on substrates with better characteristics, controlling the settlements, as in the rehabilitation of the hotel at 164 Avenida da Liberdade, in Lisbon;

- in the temporary retention of façades that occupy a small area on a public thoroughfare, without excessive vibrations affecting the structures to be preserved, as in the retention of the façade of the residential building on Rua das Trinas, also in Lisbon;

- in the temporary retention of existing structures to accommodate new uses beneath them, but enabling them to retain their integrity, during the rehabilitation of old buildings such as the rehabilitation of the Theatro Circo in Braga, or in the case study of the rehabilitation of an old building in Lapa, Lisbon.

The monitoring of the preparatory works in the case study, the execution of the micropiles, and all the other techniques used for foundations and temporary retention in the preparatory works, excavation and its completion, provided an overview of them. It was thus possible, with the aid of weekly topographic monitoring and comparative three-dimensional representations of the increased displacements, to undertake an overall assessment of the micropile technique along with all the other techniques for foundations deployed on the foundation ground.

It was found that the execution of the micropiles had no impact in terms of movement and/or settlement on the structures to be rehabilitated. Furthermore, the 3D comparative representation of the displacements of the existing building showed that using the micropile technique together with underpinning beams to temporarily retain the rear façade in no way interfered with its displacements; the façade (whose lower section was completely demolished) remained in the same position, without any settlement, throughout the period of the works.

The micropiles were thus crucial to the solution whereby a basement car park floor was to be installed, thus effectively solving the problem of adding a car park underneath urban sites previously occupied by old buildings whose façades can thus be kept intact.

The adoption of the technique in more and more rehabilitation works on old buildings in Portugal in recent years is due to enhanced awareness of the need to restore our building heritage not just from the cosmetic perspective, but from the structural and seismic strengthening perspectives, too.

While, on the one hand, how we remember our cities is related to the image we have of its buildings’ façades, on the other it is intervention at the structural level that will enable us to preserve this heritage, protect it from harmful actions such as earthquakes and control its settlements.

In addition, the need to update and re-use building heritage is bound to require car parking areas within urban sites and it is up to the micropiles to support the façades so that it becomes possible to ‘bury car parks’, making it possible once again to dwell in historic centres and yet enjoy today’s standards of convenience and comfort.
References


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