REMARKS ON THE USEFULNESS OF DEEP FOUNDATIONS FOR THE STRENGTHENING OF FOUNDATIONS IN HISTORIC AREAS

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ABSTRACT

The state of construction knowledge in the past; the lack of effective tools for measuring the mechanical parameters of the ground; and later building extensions and additions over the years have created a situation where there is insufficient load-bearing capacity in foundations laid down centuries ago. The traditional methods of reinforcing foundations – often ineffective and dangerous – have been systematically supplanted in recent years by new technologies based on the use of deep foundations in order to increase the load-bearing capacity of building foundations. The development of cities is inherently accompanied by rising ground levels. The former ground floors of buildings often end up below ground level. Old street surfaces, as well as their infrastructure, are frequently found at the same level or lower than the foundations of later structures. Therefore, it is essential to select foundation-strengthening technologies in order not to destroy precious historic structures which may be hidden deep in the ground waiting to be discovered. The article includes analysis of various deep-foundation technologies, taking as the main criterion their usefulness in preserving potential relics of the past buried in the ground, as well as their conformity with the principles of construction theory. This analysis is supplemented by original research carried out on injection piles.

Keywords: Deep foundation, Strengthening of foundations, Construction, Injection piles

1. INTRODUCTION

The state of construction knowledge in the past; the lack of effective tools for measuring the mechanical parameters of the land; and subsequent expansion and additions through the ages have created a situation where there is insufficient load-bearing capacity in foundations laid down centuries ago. Traditional underpinning methods, often ineffective and dangerous, have in recent years been systematically replaced by new technologies, based on the use of deep foundation to increase the load-bearing capacity of existing foundations.
bearing capacity of the structure’s foundation. Among these, the greatest use has been made of technologies based on the formation of deep foundation using cement grouting. The development of cities has always been accompanied by rising ground levels. The old ground floors of houses are frequently below ground level. Old street surfaces and infrastructure are now often in at the level of or below the foundations of later buildings. The original entrances to townhouses, with preserved decorative stone portals, are hidden beneath the surface. Figs. 1 and 2 show some examples of historic structures found below ground level during excavation work.

![Fig. 2 Plac Szczepański a) wooden path and wells b) 13th-cent. wells and septic tanks (Photo by E. Chroma-Dubis)](image)

In the historic urban buildings, many valuable premises built in ancient times as underground structures remain in the ground. An example is shown in the photographs (Fig. 3) – a partially filled block sewer.

![Fig. 3 Block sewer (author’s photo)](image)

The photo below (Fig. 4) shows the floor of a foundation with empty space below it, and the remains of an unsuccessful previous underpinning, located at the same level a few meters (2-3m) next to it. The introduction of pressure grouting under the foundation would cause cementation of the channel and a significant surrounding area.

In Poland’s current "Act on the Protection of Cultural Assets" [1], in article 3, point 2 of the first chapter, it states that "the protection of cultural assets depends on protecting them from destruction, damage, devastation." Consequently, in accordance with the prime rule for reconstruction: "Do not destroy", historic buildings cannot be saved at the expense of others which at that time have not yet been identified.

The choice of technology to strengthen the foundations thus becomes important in order not to destroy valuable historic structures embedded in the ground and waiting to be discovered. As a result of rapid development in the methods used to create deep foundations on the market there are many technologies available. The differences between them and their impact on the environment are often difficult to grasp for the conservation services responsible for the protection of historic assets. This article analyses different deep foundation technologies for strengthening the foundations of historic buildings.
2. COMPARISON OF SELECTED TECHNOLOGIES

The study has adopted three criteria by which the suitability of each technology can be classified according to the "do not destroy" principle. The first criterion adopted is the amount and direction of pressure applied to the cement grouting into the ground. Consequently, there is the possibility of cementation of underground structures. Depending on the amount and direction of grout supplied under pressure, different areas under the surface of the site can be irreversibly damaged. Jet grouting may be distinguished by the grout feed direction perpendicular to the direction of drilling (see Fig. 5).

This method is highly invasive. After the drill rod enters the ground, ground petrification occurs with the cement paste (single fluid system), and gradual extraction of the rod by rotating it. In this way, a column of soil mixed with cement slurry is created. Depending on the jet injection system, the grout can be injected under pressure up to as much as 800 bar. The columns formed in this way, depending on the type of soil, can reach a diameter of 5m. Buildings from the past that are now underground are in most discovered in layers of non-construction banks, with low tensile parameters or voids. This is the direct consequence of technologies available in the past for creating foundations. In such weak soils, the petrification range is even greater. This causes the complete destruction of the historic structure by the action of both the high pressure and cementation.

Micropile moulding (e.g. Titan) may also be distinguished. The direction is as in the case of jet grouting, but the pressure is lower. In this method, a steel rod is drilled into the ground (Fig. 6). Then, through the injection valves, the grout, which is pumped under pressure, as a result of which the outer diameter of the micropile can be increased depending on soil type (see Fig. 7), is introduced in several stages. When a weak layer of soil is reached, there is increased penetration of the soil with cement slurry. Similarly, if a void is reached, it will be totally cemented.
Unlike the two previous methods, traditional micro injection moulding is characterised by a pressure of several atmospheres in the same direction as the direction of drilling. The grout is introduced into a previously made borehole by injecting tubes (see Fig. 8).

The hydrostatic pressure of the cement slurry column alone acts on the walls of the borehole. There is no pressure here which would increase the diameter of the micropile. The water/cement ratio for this type of micropile is not more than 0.55 and in practice it is 0.5, and therefore the grout does not penetrate the soil, and only seals the edges of the excavation. Only the occurrence of a void in the soil might cause an increase in the penetration area of the grout. This technology does not use much pressure, so there is no risk of damage to underground structures, as is the case with jet grouting. Of these three technologies for strengthening the subsoil, because of the possibility of irreversible damage to historic structures, this method, in accordance with the “do not destroy” principle seems most inappropriate.

**Fig. 6** TITAN micropile [3]

**Fig. 7** a) Cross section of TITAN pile, b) micropile diameter, depending on the soil [3]

<table>
<thead>
<tr>
<th>Grout Body Diameter, D, in different Soils</th>
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<tr>
<td>D ≥ 2.0 x d for medium &amp; coarse gravel</td>
</tr>
<tr>
<td>1.5 x d for sand &amp; gravelly sand</td>
</tr>
<tr>
<td>1.4 x d for cohesive soil (clay, marl)</td>
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<tr>
<td>1.0 x d for weathered rock</td>
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d: Drill bit diameter
The second criterion adopted was the drilling method. Depending on the geometry of the screw used (see Fig. 9), it is possible to drill either with extraction of earth to the surface or without it. Concurrent verification of the substances extracted to the surface is the only test for the existence of relics of old buildings. In the case of jet injection, only the rod ending with an injecting nozzle is inserted. During the moulding of a column, it is virtually impossible to verify the existence, much less the depth, of a relic. Only during the sinking of the rod is the operator able, seeing increased resistance to drilling, to indicate the location of the inclusions which might prove valuable. Similarly, in the case of jet grouting earth is not brought to the surface. Drilling does not use screws, but only rods ending in a crown. There is, therefore, no way to verify the existence of monuments under the surface in situ, because the earth is pushed sideways and not extracted.

Given the technology traditionally formed micropiles, where drilling screws are used, and during the drilling spoil is extracted to the surface, the depth and structure of any underground obstacles can be relatively accurately determined. At the same time, during drilling it is possible to confirm major or minor resistance at the drill bit, which is a preliminary verification. This method also seems to be the most appropriate in the case when the material is able to be verified in situ, giving the contractor the best opportunity for verification.

The third criterion adopted was the potential effectiveness (predictability) of deep foundation created, and therefore compliance with the principles of the theory of construction or empirical knowledge. So as not to unduly affect the underground structure using inefficient technology which does not meet the conditions imposed on it and causes damage. Jet grouting technology is based on experience; there are no methods of calculating the load-bearing capacity of such a foundation. The tensile parameters of soil cement are initially adopted based on nomograms and experience from previous work. This parameter is strongly dependent on the selected injection process, as well as the type of land and its homogeneity. In the case of historic areas, where the process of site raising was associated with the formation of a non-construction embankment layer, which is characterized by a strong heterogeneity, the process of assessing the soil tensile parameters is highly random. Collecting of random samples, which is required by the standard for performing jet grouting [5], may distort the actual tensile parameters both at the top and bottom. In such soils, the diameter of the column is also unpredictable.
This is similar in the case of stream-moulded micropiles, where the diameter is formed by the pressure of the cement slurry being fed. When forming micropiles in non-native land (non-construction embankments) the micropile diameter cannot be accurately predicted. The planning process also involves an initial assumption of the diameter based on research and experience with different types of soil.

In the case of micro formed traditionally, when planning, procedures specified by the standards relevant to the pile are used. Estimating the load-bearing capacity in this case is fairly accurate with a considerable margin. Since the injection is performed in a hole made by drill rods, the pile geometry is predictable (see Fig. 10).

The standard for performance injection micropiles allows the use of various technologies of micropile reinforcement [6]. Steel sections can be used (such as pipes, beams), and reinforcing baskets. In addition to the recommendations contained in the standard, a number of additional standards are referred to, including the standard for composite structures [7]. In engineering practice, steel pipes are often used for micropile reinforcement. The research results presented in papers [8-11] indicate that in many cases, the load-bearing capacity of a fusion of steel pipe with cement slurry is not sufficient. In studies conducted on a series of 140 samples, it was found that in certain soils the load-bearing capacity of the fixing is less than the relevant soil bearing capacity. Similar fixing defects affect the load-bearing capacity of piles reinforced with I-bars. Figs. 11 and 12 show the range of applicability of injection micropiles reinforced with steel pipes and structural shapers in cohesive and non-cohesive soils, respectively.

**Fig. 10** Micropile excavated during reinforcement works (photo by author)

**Fig. 11** Scope of applicability of the injection micropiles with steel structural shapers in cohesive soils [10]
It should be noted that each technology has its limitations and scope of its applicability. Micropile reinforcement with steel structural shapers without corresponding connectors on the surface leads to a reduction in micropile load-bearing capacity, which gets damaged as a result of loss of fixation, and not exceeding the load-bearing capacity of land along the side surface. This is confirmed by studies conducted on micropiles performed in their natural working conditions under axial force [11]. Thus the use of composite piles in many cases is useless and destroys the structure of the substrate. This is confirmed by uncovering work carried on foundations strengthened by micropiles reinforced by steel pipes. In many case the pipe coating is completely separated from it (see Fig. 13).

Fig. 12 Scope of applicability of the injection micropiles with steel structural shapers in non-cohesive soils [10]

Fig. 13 Examples of excavated micropiles reinforced with steel tubes

3. CONCLUSIONS

The paper presents an analysis of different technologies for creating deep foundations, noting their negative effects on underground structure of historic buildings. Three of the methods most commonly used by designers for strengthening the foundations of buildings in historic areas were analysed. The technologies were analysed in terms of the rule governing the restoration of historic buildings – "do not destroy". The authors’ analysis of different technologies and own experience make it possible to
conclude that the most appropriate method to use in compact historic buildings is the least invasive technology. Of the three methods analysed, the least invasive method is the traditional moulding of micropiles. The paper also presents results of research conducted recently on the usefulness of steel shapers as reinforcement for injection micropiles. The results of this work indicated the scope of applicability of this reinforcement in different soils. The conclusions presented in this article may serve conservation departments when analysing projects submitted when obtaining a building permit.

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REFERENCES