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COMPLEXITY OF GEOTECHNICAL PROBLEMS IN THE PROCESS OF REVITALIZATION OF RESIDENTIAL BUILDINGS

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Abstract. *Revitalization of residential buildings is a process of renovation and improvement of the residential environment with the goal of providing users with a safe and healthy space in which to live. Through a series of necessary interventions and technical improvements, in the first phase of revitalization, the load-bearing structure, starting from the subgrade soil and foundations all the way to the top of the building, i.e. the roof structure, must be repaired and strengthened. The reinforced structure must guarantee the successful implementation of other planned phases of revitalization. The paper deals with geotechnical issues within which damages are registered, their causes are analyzed and measures for repairing the base soil and foundations are proposed. The problem is treated from the point of view of its complexity, the numerous causes of which are disscussed in the paper.*

Key words: *revitalization of residential buildings, damage, causes, remedial measures of the subsoil and foundations, geotechnical complexity*

1. INTRODUCTION

The most numerous buildings are buildings which are very often constructed on the ground different in terms of its geological composition, load-bearing capacity, sensitivity to changes in moisture content, oscillations of groundwater levels, as well as physical, mechanical and chemical changes. Many residential buildings were built at the beginning of the last century and earlier. Under the influence of various factors, they have lost their original value and significance over time, so they need to be renewed. In the period from the fifties to the middle of the sixties of the previous century, a large number of residential buildings were built according to the uniform designs without taking into account the geotechnical conditions

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of foundation building at the given location, so no exploration works were performed nor are there geotechnical investigations and reports.

Depending on the period of building, different construction systems, structural assemblies and materials were used, and very often these structures were extended or reconstructed. If we add the damage caused by non-maintenance, excessive subsidence, the impact of neighboring buildings, earthquakes and other sudden effects, then we can conclude how complex and extensive the process of their revitalization is, which basically aims to protect and preserve the housing stock. The first phase of revitalization is a constructive consideration, which results in a series of interventions and technical improvements on the structure of the building itself, in order to make it match the required load-bearing capacity and safety. Only a comprehensive and high-quality execution of the first phase can guarantee the successful implementation of the second phase of revitalization, which seeks to achieve a certain quality of housing.

In terms of structural considerations, according to the order and nature of things, geotechnical issues are in the first place, requiring an urgent analysis of the condition of the base and the condition of the foundation structure of the existing building. From the conducted geotechnical analyses, solutions should emerge that will enable safe, correct and cost-efficient solutions when repairing other parts of the structure.

2. GEOTECHNICAL ASPECT OF REVITALIZATION

Analyzing and solving the complete geotechnical issue in the process of revitalization of residential buildings can be divided into the following phases:

- Detecting building damage, registering and defining their character,
- Analysis of possible damage causes,
- Proposal of remedial measures of the foundations and the subsoil.

What makes the subsoil on which the buildings are built particularly problematic is that on the one hand it can be of poor quality, having insufficient load-bearing capacity and necessary stability, and on the other hand it is very susceptible to changes during construction and later during service. All this can cause damage to the foundation structure, on the walls, beams, columns, but also on the installations in the building.

2.1. Detecting building damage, registering and defining of their character

The process of assessing the condition of the building is approached according to a precisely determined methodological framework [1], which at the very beginning of a series of planned activities contains a visual inspection of the building and its surroundings (Fig. 1). An important task of this phase is the detection and registration of damage, which requires the use of necessary equipment and various accessories for non-destructive and destructive testing [1]. Conversations with building owners or tenants are especially useful, as they can provide information about the time of occurrence of the damage, the speed of their occurrence and the observed direct correlation with a specific cause.

Fig. 1 Detection and registering damage by the visual inspection of the building [2]

Cracks and fissures on the walls and other visible elements of the construction are most easily detected on the buildings. The most common causes of their occurrence are related to phenomena in the subsoil which can lead to more serious damage in the form of bulging walls, deformation of windows and doors, tearing and breakage of installations.

Fig. 2 Causes of damage of foundations and superstructure [1]

In order to predict the necessary repair works, it is convenient to categorize the damage according to their severity (from negligible to very severe) as proposed by Tomaževič [3]. Classification according to the basic parameters that define the nature of damage is also very useful, as shown in Table 1.

Table 1 Basic parameters of classification and nature of damage [4]

Basic parameters of classification	Nature of damage
Speed of occurrence	Gradual and sudden
Affected area and risk	Gradual and partial higher critical and lower
Manifestation	Visible-predictable, sudden, hidden
Cause and time of damage occurence	Damage due to the external or internal factors, damage during construction, damage during service
Elements on which they occur	Foundations, columns, slabs, beams, roof, insulation, cladding, installations

In many European countries, there is a number of classifications, as stated in [4] and [5], according to different parameters for a detailed assessment of damage to buildings. The goal is to provide sources of financing for the renovation of housing in old and damaged buildings, which is included in a number of legal measures and national development programs of these countries.

2.2. Analysis of possible damage causes

The causes of damage are very numerous, so, in order to conduct detailed analyses, they are also classified into certain categories. Those that arise from the nature of the building itself are internal factors, related to the local soil conditions on which the building was constructed and the type of structure implemented. Causes originating from the nature itself, intentional or unintentional human activity are external factors and they can be: long-term microbiological, physical or hygienic processes, natural random events - earthquakes, storms, weather effects, causes from the domain of human activity when using buildings or performing works in their surrounding.

As the effects of detrimental factors, as the cause of damage, often overlap, it is difficult to establish the predominant cause. Also, a special problem is damage whose causes are unknown. Therefore, more detailed examinations and analyses of experts of certain specialties are needed in the expert team that will have to find a balance between individual solutions and the existing technical regulations in reaching the final conclusions.

Since the paper deals with issues from the geotechnical aspect, the analysis of possible causes of damage to buildings will be related to the soil as their base and foundations as immediate supports.

In practice, the most common damage to buildings is related to the causes that originate from various phenomena in the soil, i.e. the base below and around their foundations. The soil is a three-phase system in its composition, composed of a solid, liquid and gaseous phase, so its compressibility and deformability under load become prominent [6]. The result of the resulting complex processes are displacements in the ground that lead to the settlement of buildings and their foundations. Differential settlement is especially harmful, as a result of which cracks can appear, their individual parts can separate, tilt, and even collapse. The degree of severity and the nature of the damage depend on the size and shape of the building foundation, number of storeys and the size of the resulting differential settlement (Fig. 3a).

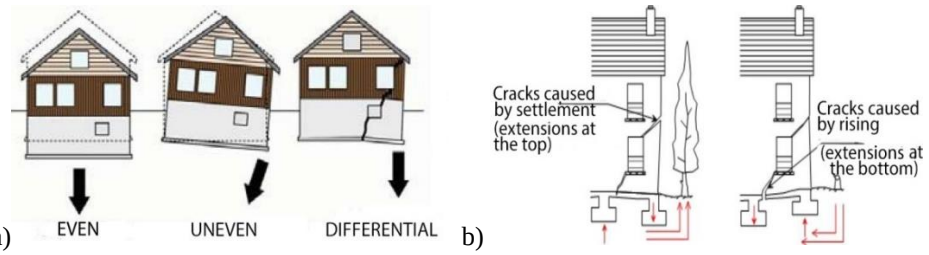


Fig. 3 a) General types of settlement of foundations and b) occurrence of cracks on the buildings [6]

One of the most common causes of changes in the soil that leads to settlement and serious damage is water. In coarse-grained soil, due to larger cavities and pores, water

moves and is squeezed out more rapidly and easily, so that under the load the settlement takes place quickly. In fine-grained materials, water moves and is squeezed out very slowly, so that the settlement process lasts long but the changes are considerable and usually larger than in coarse-grained soils. It is especially unfavorable if the building is located on clay soil that is prone to swelling and shrinkage due to the increase or decrease of moisture content. The absorption of moisture by the roots of trees can cause the sudden drying and shrinkage of the soil, which leads to a greater settlement in some places, and due to the difference in settlement also leads to damage of the foundation (Fig. 3b).

There are very unfavorable terrains in which the groundwater level can oscillate significantly over time, and in which the soil is sensitive to changes in moisture content. The oscillation of the groundwater level is characteristic for the areas with the change of rainy and dry seasons and for the areas where the groundwater level is related to the change of the water level of the neighboring rivers, lakes or wells. Alternating cycles of soil shrinkage during drying and swelling during wetting mean alternating settlement and rising of soil under the foundations of buildings, which results in severe damage in the form of characteristic cracks on both the foundations and the walls.

Water can escape from damaged plumbing and sewer installations or damaged gutters for a long time, as can be seen in Figure 2, and imperceptibly wet and wash away the soil, so that compromised parts of foundations and other parts of buildings begin to considerably settle and fail.

The occurrence of capillary rise from the ground through foundations and foundation walls, as seen in Figure 4, is detrimental for the building walls by damaging facade cladding, finish layers of walls and wood and metal elements.

Fig. 4 Capillary moisture, initiator and cause of damage occurring on the walls and foundations [7]

2.3. Proposal of remedial measures of foundations and subsoil

Nowadays, there is a large number of methods for interventions on the foundations themselves, the subsoil under and around the foundation, or a combination of both the subsoil and the foundations. The choice of an adequate method depends on several factors. The ground under the foundation must meet the required safety against failure and allow subsidence that will be within the permissible limits for the undisturbed and safe operation of the facility. Soil improvement methods achieve better bearing capacity and reduce soil subsidence. That is why these methods are called soil stabilization methods in the professional literature.

The *"Jet grouting"* method provides the option of strengthening the existing shallow foundations, whereby drilling is performed from the ground surface through the existing foundation footings, and the columns of stabilized material are formed just below the

foundation (Fig. 5). A water-cement mixture or a mixture of water, cement and bentonite is most often used as an injection mass. In the formed borehole, through a rotating drilling rod equipped with nozzles, the injection mass is inserted under great pressure, which breaks up the soil material and with intensive rotation forms a column that is a mixture of soil and binder - injection material. The obtained mass is characterized by high compressive strength and low water permeability.

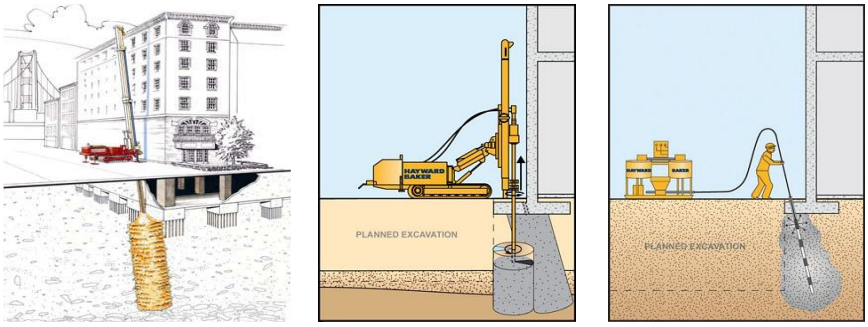


Fig. 0 Stabilization of soil under the existing foundations by jet grouting (Novkol) [1]

Deep injections is a method based on a similar procedure as the ***"Jet grouting"*** method. Namely, in the area where the settlement occurred, drilling directly through the foundations is used form a system of boreholes with a diameter of about 30 mm, a distance of 50-150 cm and a depth of up to 15 m. A special liquid resin is inserted into the boreholes, which soon after injection turns into a solid state and expands, increasing the volume up to 30 times. In this way, the soil is compacted and the foundation is pushed upwards, which is controlled by a laser.

The methods of strengthening the soil involve enlargment of the foundation base dimensions or foundation depth in order to reach the soil layers of higher bearing capacity. Strengthening of foundations solely with enlargment of the foundation base dimensions is performed if increasing the foundation depth is not possible. The additional lateral parts must be well connected with the existing footing, which is achieved by adding the necessary reinforcement (Fig. 6).

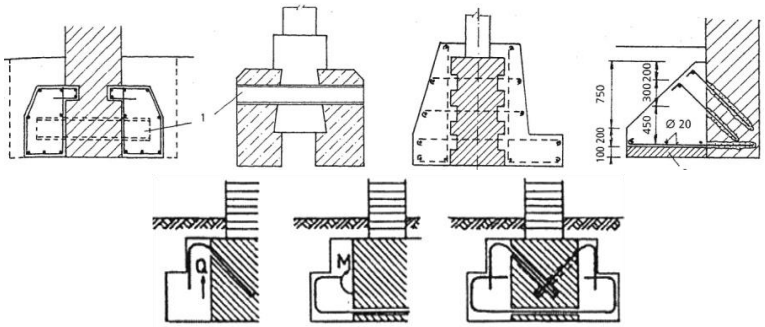


Fig. 6 Enlargment of the foundation base dimensions by casting lateral concrete parts on and connecting to the existing foundation footing with specially anchored reinforcmeent [5]

Excavation under the existing foundation for the purpose of concreting beneath the foundation is a very risky part of the entire procedure, as it may lead to increased settlement and damage to the whole structure. For that reason, the excavation and concreting beneath the existing foundations must be performed in sequences not wider than 1.5 m along the foundation length in an alternate order, until the foundation is constructed in full length.

If the strengthening of shallow foundations, due to the high soil compressibility and settlements, cannot be accomplished by increasing the foundation base dimensions, or by deepening the foundations or depth or by soil grouting, then the load can be transferred to the deeper layers of soil with a higher load-bearing capacity by using piles. When repairing and strengthening the foundations of existing buildings, several types of special piles are used, and these are the most common: "mega" piles, micro piles or root piles and prefabricated reinforced concrete piles. The micro piles were created on the basis of the request to repair the foundations of the existing buildings without shocks and vibrations, the eviction of the tenants, the excavation of the foundations and the construction of large construction sites around the building. Using a special drilling technique through the existing foundations of concrete, stone or brick, boreholes are made for micro piles into which firstly reinforcement and then very liquid concrete or cement mortar under pressure is inserted (Fig. 7). The pipe that was used to make the borehole is slowly pulled out during the making of the pile. In some types of piles, the metal pipe that was used for drilling, after reaching the desired depth, remains in the mass and serves as the reinforcement of the pile. Modern technologies of making these piles enable their diameter to range from 8 to 15 centimeters, and the length is usually up to 6 meters. Considerably greater depths can be reached by special drilling techniques which are presented in details in references [8] and [9].

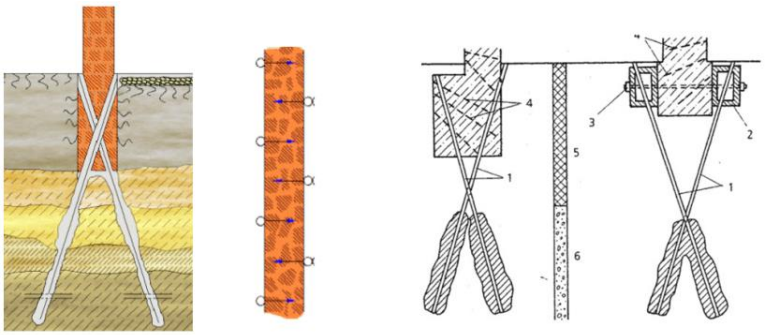
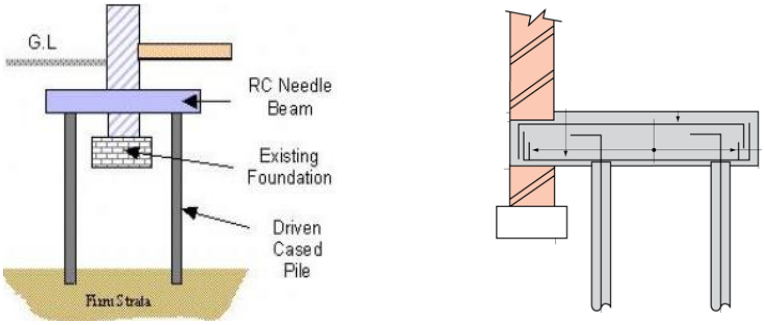


Fig. 7 Strengthening of foundations using micro-piles drilled through foundations [5], [10]

Some more modern approaches and technical solutions include a combination of piles and beams. One such solution, shown in Figure 8a, consists of a horizontal reinforced concrete beam, passed through the foundation wall perpendicular to its direction in which it lies. At the ends of the beam, there is a small pile of small diameter, which transfers the load of the structure to the deeper soil layers of a higher load bearing capacity. These structures, made of piles and beams, are placed at a distance of 1.5 m from each other. In case the access to the foundations is not possible from the inside of the building, or it is more complicated to build, both piles are placed on the same, external side (Fig. 8b).



a) beam passed through the foundation b) beam placed on the external side

Fig. 8 Strengthening of foundations by applying beams and piles [10]

Another variant solution comprises the application of a beam, which is cantilevered above the foundation and a pair of mini piles (Fig. 9). The cantilever beam can be reinforced concrete or I-section steel. The system is designed so that the piles that are closer to the inner side are loaded with compression, and the outer row of piles with tension [10]. After the installation of cantilever beams and mini piles, the entire surface along the wall is concreted, thus connecting all the elements into a continuous, single structure.

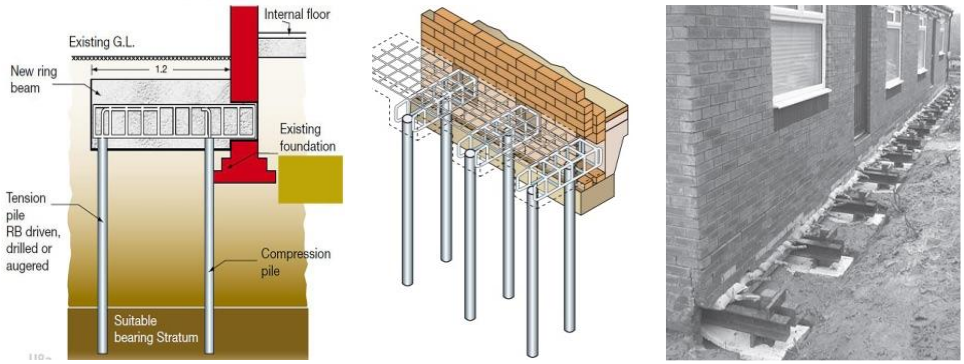


Fig. 9 Strengthening of piles using cantilever beams and pairs of piles [10]

3. MOST FREQUENT CAUSES OF COMPLEXITY OF GEOTECHNICAL ISSUES IN REVITALIZATION OF RESIDENTIAL BUILDINGS

Geotechnical issues, in general, occupy a very important place in the construction of buildings and include activities before the start of construction, during construction and during the service of building. The phase before the start of construction is planned for the implementation of geotechnical exploration works at the given location, on the basis of which the geotechnical conditions of the foundation should be defined. These include the layout and characteristics of the determined soil layers, the groundwater level and its possible oscillations, the bearing capacity of the soil for the proposed foundation depth

and the method of foundation. In this phase, other relevant data for the observed location are collected: geological, seismological, hydrogeological and data on possible underground structures, abandoned excavations and wells and underground installations. Based on all of the above, the choice of the type of foundation structure and the choice of soil excavation methods and securing the foundation pits are made.

When it comes to existing, old buildings, which are about to be revitalized, there is a number of aggravating circumstances that make the already complex geotechnical issues even more complex.

3.1. Lack of original design documentation

The lack of basic, original design documentation of the building, as well as of the study on geotechnical investigations and possible earlier repairs of the foundations is a major shortcoming in the case of revitalization of the observed buildings. The mentioned documentation has usually not been preserved through the decades-long period of time or geotechnical investigations has not been done at all. It often happens that there are some scarce data and results, but they are taken from the documentation of other important facilities in the immediate vicinity, which is inadmissible. Sometimes it is necessary to conduct some kind of "technical investigation", as stated in [11], in order to obtain documentation on previous geotechnical investigations or possible repairs of the foundations of the building. The results of these earlier studies would be invaluable for comparison with the results of the new investigations. This would make it easier to answer the question of what changes occurred in the soil, [1] and [8] and what could be the cause of the greatest damage to the building.

3.2. Problems related to performing new geotechnical investigations and determining the predominant causes of foundation damage

The carrying out of new geotechnical investigations is mandatory and must be very carefully planned and performed, bearing in mind several aggravating circumstances. Very limited space due to the proximity of neighboring buildings and their sensitivity and their condition, as well as the building being repaired, make this first phase of field work complex. There are cases where the adjacent building is immediately next to the one that is being repaired, so that side is completely inaccessible from the outside. Excavation of bore pits and drilling of boreholes must not cause additional settlement and compromise the stability of facilities in the immediate vicinity.

When it comes to determining the level of groundwater and its possible oscillations, no mistake must be made. The highest level of groundwater, due to the effect on the foundation structure, should be determined during the period of the greatest precipitation or the period of the greatest wetting of the subgrade soil for other reasons.

Due to the simultaneous action of several different, detrimental influences, which cause damage to the foundations and other parts of the building, it is difficult to single out the predominant influence. The solution is to form an expert team, which would consist of civil engineers, especially geotechnicians, geologists, hydrogeologists, hydrologists and others. Through a comprehensive review of the problem, additional investigations and consultation with building owners or tenants on possible changes and other important observations, the expert team should propose an appropriate solution.

3.3. The complexity of the issue related to the implementation of rehabilitation measures of foundations and subgrade soil

The most complex works in the construction of buildings are foundation works. Due to the variability and diversity of soil layers and the fact that the soil cannot be fully known in all parts, due to the presence of water and the proximity of neighboring structures, there are great risks in the construction phase and later in service. It is necessary to have extensive experience and practice as an important complement to the foundation engineering principles so as to address the issue of foundation construction, both during design and during construction phases [12]. Therefore, specialized companies and experts in the field of construction geotechnics must be hired to perform works on interventions in the foundation structure and the subsoil.

The most suitable way to strengthen the subsoil underneath and around the foundation is to grout the soil. Special equipment and grout are needed and works are carried out from the ground surface. Due to the impossibility of monitoring the movement of the grout mixture in the ground, damage to underground installations is possible. Careful preparation and professional execution of works is required.

Traditional methods of foundation strengthening, by increasing foundation base dimensions and depth, require larger excavations and carry a high risk both during construction and later in operation to cause subsequent settlement.

For a long time in our country and other developed countries, the use of Mega piles in foundation repairs has been widespread. Their construction was quite complex, but the load-bearing capacity of the foundation structure was significantly increased. However, long-term of soil suffosion from damaged water supply and sewerage pipes and the unresolved issue of atmospheric water drainage can lead to later settlement of Mega piles and rupture of their connection with the existing foundation structure, which requires its remediation. An example of one such situation where not all changes in the surrounding soil were observed in time is given in [11].

That is why the use of micro piles has found a wide application in the revitalization of residential buildings. There is much less risk, simpler execution of works and the possibility of resisting both vertical and horizontal loads.

4. CONCLUSION

The process of revitalization of old residential buildings, but also protected buildings of historical and cultural heritage, is in full swing today. The first thing that professional teams encounter is damage to almost all parts of the building. They must be carefully registered and analyzed in order to find their causes. The largest number of severe damages originates from the processes that took place in the ground below the building, especially causing damage to the foundation structure.

The paper emphasizes the importance of this geotechnical aspect of revitalization, within which, after a detailed analysis of the causes of damage, a proposal for measures to repair the foundation structure and the soil underneath and around the building is given. The causes of complexity and risks that accompany the solution of geotechnical problems are especially emphasized. The goal is for the rehabilitated subgrade soil and the foundation structure to be a reliable support for the rehabilitation of the superstructure and the new service of the building.

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SLOŽENOST GEOTEHNIČKE PROBLEMATIKE U PROCESU REVITALIZACIJE STAMBENIH ZGRADA

Revitalizacija stambenih zgrada je proces obnavljanja i unapređenja stambene sredine sa ciljem da korisnicima pruži siguran i zdrav prostor u kome će živeti. Nizom neophodnih intervencija i tehničkih unapređenja, u prvoj fazi revitalizacije, mora se sanirati i ojačati noseća konstrukcija, počevši od podloge i temelja pa sve do vrha objekta, odnosno krovne konstrukcije. Ojačana konstrukcija mora garantovati uspešno sprovođenje i ostalih predviđenih faza revitalizacije. U radu je tretirana geotehnička problematika u okviru koje se registruju oštećenja, analiziraju njihovi uzroci i predlažu mere sanacije podloge i temelja. Problematika je tretirana sa stanovišta njene složenosti čiji su brojni uzroci sagledani u ovom radu.

Ključne reči: *revitalizacija stambenih zgrada, oštećenja, uzroci, mere sanacije temelja i podloge, složenost geotehničke problematike.*