

MODERNIZATION OF HISTORICAL CONSTRUCTIONS FOR THE NEW SILESIAN MUSEUM CONSTRUCTION

ABSTRACT

The new building for The Silesian Museum in Katowice is situated on the former 'Katowice' coal-mine site. *The new building with three levels is almost completely situated below the ground level, what demanded the excavation up to 16m deep located directly next to the old post-industrial 19th and early 20th c. buildings.* Conversion of existing coal mine structures to a modern day museum facilities required also a substantial renovation of these buildings, which included among others lowered of the existing grade basement of as much as 4.0m, creating the tunnel under one of the building and significant increasing of structure loads.

In particular innovative foundation and excavation support concepts were utilized to accommodate the architects' requirements and the highly tight construction schedule. Very difficult geological conditions including complex soil layers configuration, post mine cavities, faults, loosened zones and dynamic activity were the additional and – what had been proven during the works – critical factor of the project.

Self-drilling injection micropiles, soil nails and anchored pile walls proved to be the key design and construction solutions for this project. Self-drilling injection micropiles: TITAN 52/26, TITAN 73/56 and TITAN 73/53 in total length of 1,400 running meters were used for underpinning the renovated historical buildings both as a temporary support – for the structures located in the excavation affected zone, and as permanent one – as the replacement for the original foundations in the building where new underground floor was created and where the structure was subjected to the arised loads. As the temporary and permanent excavation retaining structures for construction of the new building nearly 15,000 running meters of TITAN 30/11 and 40/16 soil nails were installed. As the more stiff retaining walls the DFF pile walls in conjunction with 30/11 and 40/16 TITAN ground anchors in the total length of 3,850 running meters were designed. The temporary micropile walls stabilized the trench for an elevator shaft and a tunnel inside the building and were used as a sacrificial scaffolding. Over the 9,000 m of TITAN 103/78 and 103/51 were used as the stabilization system of anchored micropile barriers in the area of dynamically active rock mass.

A comprehensive description of the problems of design and execution of geotechnical works for the stabilization of historical buildings in the vicinity of deep excavations and their modernization including the construction of new stories under the existing structure is presented in the case history. The complex geotechnical conditions of the post coal mine site are described. Moreover, details about the micropile materials and dimensioning, and the construction methods used to modernize and protection of the monumental buildings are presented. The main attention is put on the complexity of such a project and its execution as well as an extensive, multi-factored monitoring system crucial in these kind of projects. The anchored bored pile walls, soil nail walls, the temporary support system (mean and method) for underpinning existing walls and other various uses of micropiles are also discussed.

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INTRODUCTION

In the era of high density building with simultaneous considerable extent of territorial agglomeration, the most common direction of urban development takes place currently along the new urban axis and the intensity of such development direction is increasing. The evolution of the space includes new planes through the use of areas located both above and below the urban area surface. The effect of development are (already commonplace) high-rise buildings with extensive underground levels in urban centres, and a clear tendency for the recovery of space from existing facilities or their subterranean expansion. The design and implementation of such structures is already technically possible. However, it requires special attention and diligence. It must meet requirements related not only to the newly built structure, but also – and sometimes especially – to existing buildings in the immediate vicinity of the works for which it is usually necessary to perform deep excavations. The issue is especially difficult when one considers the historic nature of buildings located in centres of most major cities. Such buildings are extremely sensitive to movements of the substrate always associated with excavations, and their protection requires a number of specific activities.

In the geotechnical field, as renewals and refurbishment works have gained popularity, the demand for underpinning has increased steadily. This method is frequently used to reduce the settlement of structures, when existing foundations are disturbed by nearby underground involving soil excavation. The technique is also applied when the use of the structure has changed requiring additional support . Currently, the main reason for foundation underpinning is enhancement of the load-bearing capacity, because of extended loads due to, for instance, the construction of additional floors. Besides. it is also the only way to expand the space in depth below existing buildings (e.g. for underground parking garages), what is essential for the development of large cities.

GENERAL INFORMATION ABOUT THE PROJECT

The new building of the Silesian Museum - the first object defining the so-called “culture axis” - is located in Katowice on 6 Kopalnia Street, on the premises of the central facility of the liquidated "Katowice" coal mine.

The concept adopted for the project assumes a minimum interference with the existing terrain, and a close relationship and incorporation into the new structure of other amenities and buildings of the old mine. The architectural project was implemented by means of:

- Placement of the main facility - exhibition spaces, conference and technical rooms along with a parking area below the surface
- Adaptation of historic buildings of the former mine for the purpose of exhibition, for administration, catering and sightseeing, including the implementation of additional underground storey.

The main building with a three-storey underground car park was located in an open trench with a depth of up to 17m and an area of nearly 2 hectares. This deep trench ran directly by the three structures adapted to perform new functions, subject to conservator's protection (Figure 1):

- Building of the "Warszawa" shaft hoisting machine (structure MS-8) adapted for catering purposes
- "Warszawa" hoisting tower (structure MS-79) adapted to be an overlook, by the installation of a panoramic elevator and view terrace
- Clothing store (structure MS-15) adapted for exhibition purposes - Centre of Polish Stage Design.

Information about the project:

Localization: Katowice, Poland - on the site of former Katowice coal-mine

Investor: Silesian Museum in Katowice

Architectural Design: Riegler-Riewe, Graz, Austria

Structural Design: "STATYK" Engineering Centre, Katowice

General Contractor: Budimex S.A .

Contractor of geotechnical structures Soley Sp. o.o., Balice near Cracow

Design of geotechnical structures Soley Sp. o.o. and TITAN Polska Sp. z o.o., Cracow
TITAN Polska Sp. z o.o., Cracow

Investment value: 324 millions PLN

The geotechnical works started in July 2011 and finished in 2013.

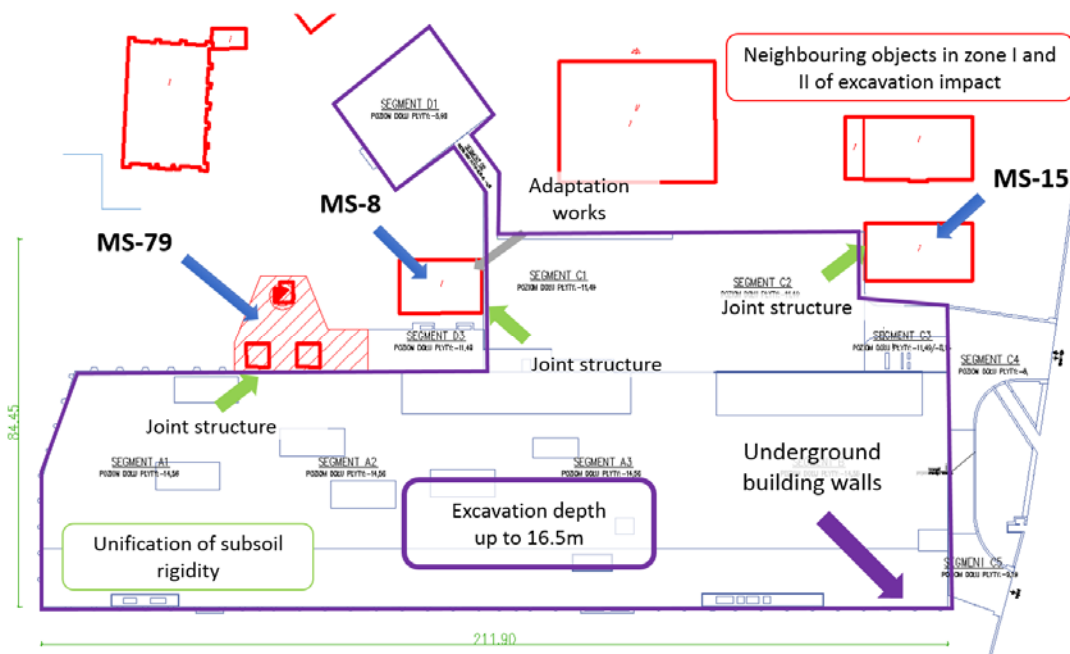


Figure 1. Construction site project plan

MAIN TECHNICAL SPECIFICATIONS FOR THE GEOTECHNICAL SUPPORT PROJECT

The implementation of the above-described architectural plans required solving a series of geotechnical engineering and design problems, focused around four major issues:

1. Protection of historic buildings located directly by the edge of the planned deep trench
2. Designing the geotechnical support in the existing building of MS-8, so the additional basement and an elevator shaft, and their connection with the main building through a tunnel under the gable wall could be safely performed.
3. Strengthening the foundation of the old shaft "Warszawa" hoisting tower, necessary for its adaptation to function as an overlook

4. Stabilization of a deep and broad trench with varying geometry.

When designing solutions, further relationships and associated circumstances, resulting from the considerable construction scale and tight schedule conditions, had to be taken into account.

GEOTECHNICAL AND HYDROGEOLOGICAL CONDITIONS

Geotechnical and hydrogeological conditions in the substrate were determined by "PROGEO" from Katowice. The results are shown in numerous studies: in the Geological and Engineering Documentation, as well as in Hydrogeological and Geotechnical Documentation along with their annexes.

Generally, in the substrate of the planned investment, quaternary formations of different origins were found (mainly anthropogenic and glaciofluvial) with different degree of lithology, as well as Carboniferous formations such as mudstone, sandstone, weatherings and carbon interbeddings. The exact division of geotechnical layers as per the Documentation³ is presented below.

Layer Ia - embankments made of a wide variety of components, such as stones, rubble, coal powder, slag, etc. They were formed in an uncontrolled manner. DPSH probe tests showed that this layer has different degrees of density within the range $ID = 0.41 - 0.78$, i.e. they are medium-compacted and compacted. The average degree of compaction is $ID = 0.58$. Layer Ia occurs almost throughout the entire documented area and has a maximum thickness of 5.0 - 8.5 m in the north-western part of the area.

Layer Ib - building embankments, such as asphalt and paving stones with underlying subcrust, basements, etc. The layer occurs only locally.

Ia layer is composed of medium and coarse sands, containing a variable admixture of gravel grains. These areas are medium-compacted, at $ID = 0.57$

IIB1 layer is composed of group C cohesive soils C. Lithologically, they are sandy clays, and loamy sands with hard plasticity and central degrees of plasticity at $IL = 0.10$. The layer occurs almost exclusively in the southern part of the area.

IIB2 layer is made of plastic materials and dusts interbedded with clays, with an average plasticity of $IL = 0.36$, classified in group B.

Layer IIIa - loose soil weathered sandstone - sands of different grain size, mainly medium and coarse, with an admixture of sandstone rubble or sand-filled sandstones. The land is compacted with medium density: $ID = 0.70$.

Layer IIIa1 - weathered sandstone in the form of cohesive soils (Group B) - clayey sands and sandy clays with sandstone crumbs. Ground is semi-compact: $IL < 0$

Layer IIIA2 - weathered sandstone in the form of cohesive soil (group B) lithologically like IIIa1 layer, but hard-plastic and average cohesion value $IL = 0.08$

Layer IIIa3 - cohesive soils, like layer IIIa1, but a plastic consistency and an average degree of plasticity $IL = 0.32$

Layer IIIb1 - weathered claystone - group B cohesive soil, formatted as clay, compact clay, and sometimes sandy clay. The soils are semi-compact ($IL < 0$)

³ Engineering and geological documentation describing engineering and geological conditions, and geological background to cater for the designing needs of the New Silesian Museum, PROGEO, Katowice, 2006.

Layer IIIb2 - weathered claystone with its lithology like in layer IIIb1, but hard-plastic and an average degree of plasticity $IL = 0.07$

Layer Va – sandstones, mostly medium-grain. These rocks are generally strongly fractured, and with varying strength. Tests showed compression strength values of R_e within a range of 32.51 - 46.45 MPa, some clays have a higher strength ($R_e = 74.75$ MPa). Sandstones are the main element of the recognized part of the Carboniferous rock in the southern part of the area.

Layer Vb – mudstone, located mainly in the northern part of the documented area. Mudstone in the drill backfill is soft and cracked. A compressive strength test yielded R_c values within a range of 4.46 - 8.12 MPa.

An example of geological profile is shown in Figure 2.

In hydrogeological terms, the water conditions found during the analysis should be assessed as favourable. In the investment area, there were no continuous aquifers. In several openings slight filtration was observed, and at two test points, subsurface water was encountered (at depths of 1.7 and 2.8 m).

In tectonic terms, the area is characterized by a considerable complexity. There was one large fault crossing the trench wall detected on the site. During the works, a number of inconsistencies was also found, as well as minor tectonic disorders, which are always associated with disturbances (usually worsening) of the expected strength parameters.

Particular attention was paid to the characteristics and properties of the soil medium, resulting from its post-mining history. They manifested themselves in the presence of quasi-continuous tectonic disorders, the presence of post-mining voids, cracks and loosened zones. The area was covered by a shallow exploitation in the past, which left its traces in the form of old abandoned workings and crevices in the rock mass, which often disrupted the works by a violent initiation of geodynamic processes, such as relaxation or increased hydration in the excavation zone.

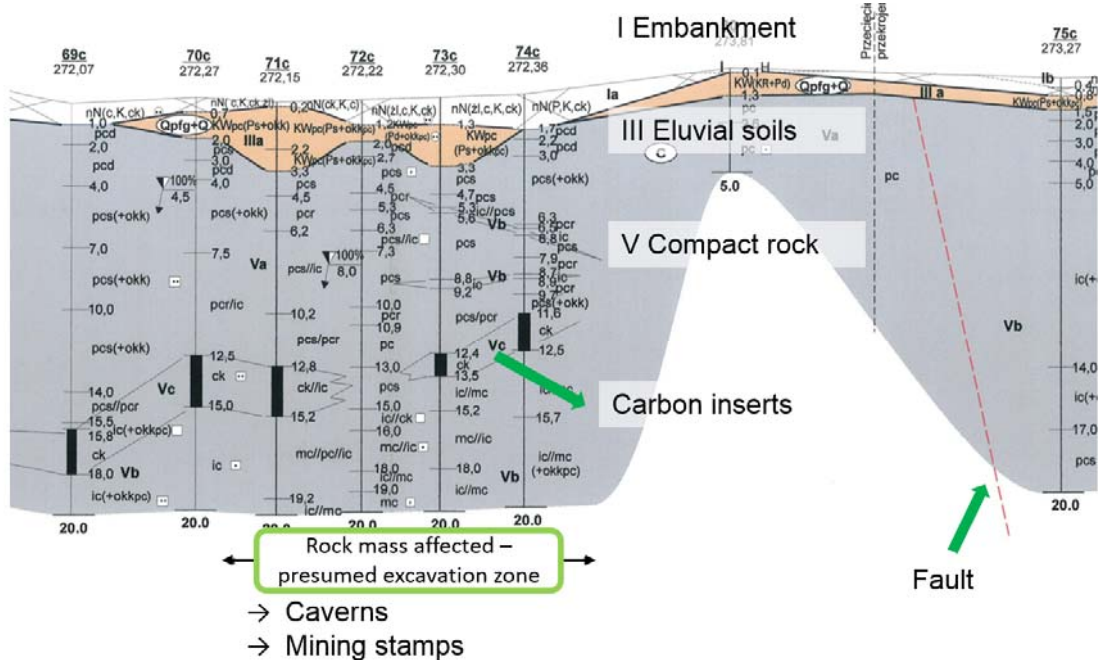


Figure 2. Example of a geotechnical cross section

PROJECT OF GEOTECHNICAL STRUCTURES

The accepted ground model

Summing up geotechnical conditions in the investment area, one should describe them as a very complex phenomena, which do not match the adopted traditional geotechnical rules and description models. The collection and verification of project input data was based therefore largely on the method of observation with a very large share of description criteria according to Hoek-Brown theory. In combination with geological and engineering knowledge about processes and geodynamic phenomena, this allowed a good prediction of realistic properties and behaviour of the rock mass.



Figure 3. Panorama of the construction site

The adopted project model

Taking into account the nature and scope of necessary works, as well as the geotechnical conditions, it was found that the only method that can ensure suitable quality of technical solutions, the required level of safety, appropriate pace of works and the anticipated economic effect is the active project method (observation method), in which - through a continuous verification through monitoring – the introduced solutions were matched with the actual conditions encountered.

Protection of neighbouring buildings

The problem as important as ensuring the stability of the excavation walls was suitable protection of the existing historic buildings located in close proximity, just by the edge of the trench, exposed to its strong impact. These buildings, due to their technical condition (defined in the inventory as sufficient) and the construction nature (brick masonry buildings) were particularly vulnerable to damages induced by displacements, associated with the relaxation zone in the soil. In order to minimize the destructive impact of the excavation on the existing buildings, strengthening their foundations by micropiles was designed. The placement of an appropriately selected micropile system allows the transfer of loads from the building to the area least exposed to the influence of the excavation, under its bottom. Thereby, the load put directly on the trench formwork is minimised and with a suitably selected stiffness, the desired effect of a minimal impact of the trench on an adjacent structure is achieved. In this case, the problem was complicated additionally by the fact that

structures MS-79 (shaft hoisting tower) and MS-8 (engine room), after proposed modernization, were to perform new functions (respectively, a view terrace with a panoramic lift and a catering facility). MS-8 building was also expanded inside: a new underground floor was created, which meant lowering of the current foundation level by around 4m, and the deep elevator shaft inside the building was constructed with a tunnel leading from the elevator to the neighbouring Main Building, passing under the building gable wall was excavated. Thus, when designing strengthening of the foundation, apart from the protective function inducing securing against excessive, harmful movements, deepening of the building should be allowed, as well as the changing load and working conditions in micropile foundations should be provided. In addition, the adaptation works were carried out simultaneously with the deepening of the trench under the Main Building, which became an additional difficulty (both structures and complexity of the problems associated with their protection are shown in figure 4). Furthermore, the works in the interior of the MS-8 building were hampered by the very limited space for the equipment and the lack of agreement on the expansion of the wall size to the inside of the building, so that all additional foundation structures could be installed only from the outside.



Figure 4. A view towards MS-8 structure and Warszawa shaft

Traditional techniques of underpinning are considered to be expensive, and subjected to the high risk, due to the limitations of conventional piling techniques. In the discussed project, due to the reduced working space, significant loads with a non-favourable configuration (resulting from unilateral foundation seizing), the need to minimize vibrations, rapid pace of installation and difficult ground conditions, it was decided to use self-drilling injection micropiles to secure and strengthen the foundations in the existing buildings.

Self-drilling injection micropiles are installed using a complete set, which includes: drill bit, bars of suitable strength, connectors (coupling nuts) and elements forming the micropile head: washer plate and collar nuts. Bars with connectors and drill bit form a stay-in-place set, used at the same time to drill holes (drill duct) and inject (injection line). During the drilling the cement flushing medium is used - cement grout with water-cement ratio $W/C = 0.7$. Grout is fed via the inner opening in the rod, is pushed into the well through the nodes in the drill bit. Supply pressure values are within the range of 5-20 bar and depend on ground and technical conditions (the length of the micropile). Drilling is done without casing pipes. After drilling the preset depth, the final injection begins. Through the rotating drill line, the final grout is injected – cement suspension at $W/C = 0.4$. The final injection pressure is typically 20-40 bar (depending on ground and technical conditions). The hole is filled with cement from the bottom to the top. This ensures accurate filling with grout, along with all the slots, caverns and cracks in the soil. The whole set is left in the opening, and acts as a reinforcement of the micropile.

The use of self-drilling injection micropiles without protecting pipes allows the achievement of very good strength parameters. Grout has the ability to freely penetrate into the soil, which forms a "ragged", rooted injection poker, perfectly bonded with the ground. The migrating grout further strengthens (petrifies) the soil around the micropile.

In this difficult soil environment, the technological factor played a huge role - drilling with simultaneous injection - which allowed (apart from elements at a certain unit load-bearing capacity) injection-merging, petrification of the rock mass within the micropile system. This effect, achieved thanks to filling any gaps, cracks and substrate loosened zones with grout allows treatment of this type of foundations as deep, monolithic, geo-composite lumps. Bearing in mind the risk signalled by geodynamic processes, this method of structure foundation seems the most rational. The spatial structure of underpinning micropiles and deep range of the injection associated with their structure, allowed integration and strengthening of the loosened and susceptible subgrade.

For MS-79, taking into account the type of construction, the range of loads acting on the hoisting tower structure and the engineering and geological conditions within, the analysis assumed the use of TITAN 73/53 micropiles. Verification of the strength and external micropile load-bearing capacity was performed according to EC 7 for maximum vertical force, acting on brace blocks. It was assumed that micropiles will transfer extracting and thrusting forces acting on the structure.

After the combination of design loads, for the computational scheme adopted for an 8 micropile system, the maximum axial load on the micropile: $E_k = 415$ kN was adopted. The minimum length of the micropile must produce an injection shank at a suitable length in load-bearing soils and allow free formation of heads. In addition, the minimum depth of micropiles below the trench bottom 1.50 m was assumed. In the calculations of the active length of the micropile, the first 1.50 m of the micropile was omitted- this section forms anchoring in the foundations. The verification of the strength of the internal and external micropile load-bearing capacity was carried out with DC-Pile software. As a result of calculations 73/53 18m long micropiles with the outer diameter of 175mm were designed (fig. 5). Tension loads were transferred from the structure to the micropiles through their heads encased with a reinforced-concrete top plate filling two starting blocks (holes in brick foundation blocks, from which micropiles were made), connected with the foundation blocks by bonded anchors. The transfer of compression loads was provided by means of skin friction at the interface of the core drilling in foundation blocks and the injection micropile grout body (thickness of the foundation blocks at micropile locations was approximately 1.5m).

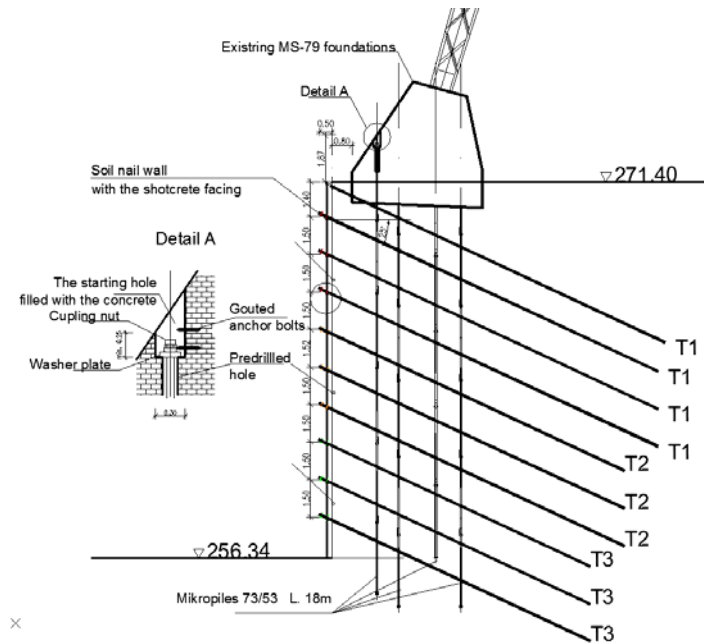


Figure 5. The section of MS-79 foundation (combination of underpinning and soil nail wall presented) with the detail of attachment the micropiles to the existing structure.

For MS-8, strengthening of the foundations was assumed with the underpinning in that part of the building in which an additional underground level had to be made (Fig. 6). Due to limitations imposed by the architectural design, micropiles could only be placed along the outer contour of the building, which significantly worsened the static parameters of the structure. A seizing micropile system was designed, aiming at the transfer of full load from the walls to the soil layer below the trench bottom, and shorter underpinning micropiles forming a filling in the new foundation wall in the deepened section, what allowed the excavation of the whole interior in one step. Taking into account the type of construction, the range of loads acting on the structure of MS-8, the planned deepening of the building by one storey, as well as engineering and geological conditions within, the analysis assumed the use of seizing micropiles:

- Under the external walls in the deepened section of the building - TITAN 73/53;
- Under the remaining external wall sections - TITAN 73/56.

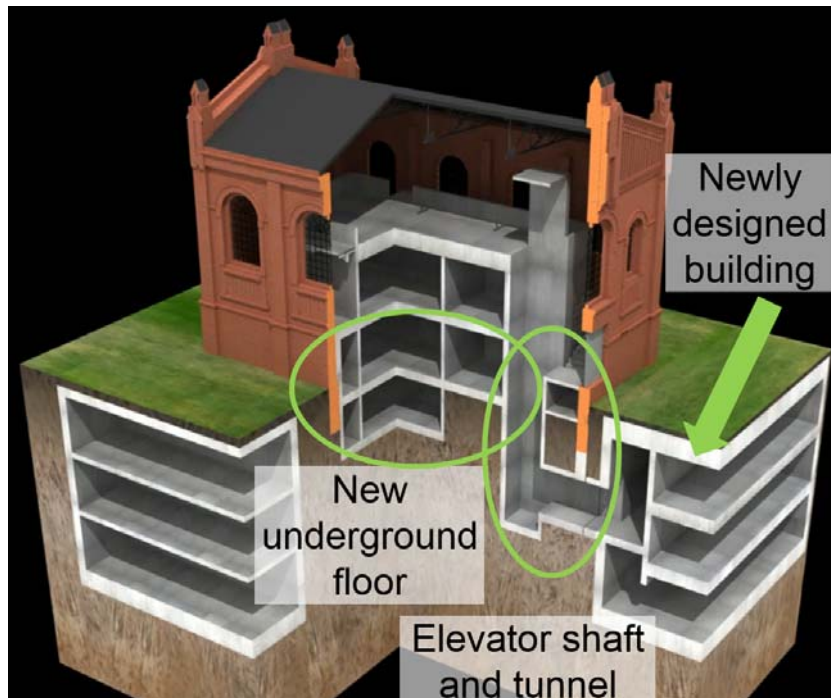


Figure 6. Visualization of the final shape of MS-8, with indicated sections introduced in the adaptation (new underground storey, lift shaft with the tunnel passing under the gable wall to the main building) and fragments of stories of the adjacent building in the newly designed Main Building.

It was assumed that micropiles would transfer the compression forces acting on the wall structure. Analysis of loads under building MS-8 was carried out on the basis of the data from the designer of the New Silesian Museum (STATYK engineering company). After the combination of the above loads for the computational scheme regarding the micropile system under the walls in the deepened section, at a spacing of 1.60 m, the maximum axial load on TITAN micropile 73/53 was assumed to be 452 kN, and in the other TITAN 73/56 - 412 kN.

In the calculation of the micropile active length, we omitted the first 1.50 m - this section forms anchoring in the foundation wall. The calculations carried out in DC-Pile software indicated that 73/56 and 73/53 15m long micropiles fulfil the requirements concerning the transfer of loads from MS-15 on the soil layer below the trench bottom. Along the northern and western walls (not adjacent to the excavation, the placement of micropiles along the west wall is shown in Figure 6), the sufficient length of micropiles was 9m for types 73/53 and 73/56. The diameter of the grout body of these micropiles was at least 175mm. The allowable capacity was 680kN kN and they were drilled through the existing walls and were inclined about 5° to the vertical. The stiffness of micropiles in the deepened section of the building assured safe operation (without buckling), provided that the required technological regime was observed. The assumed settlement did not have a negative impact on the load-bearing capacity and serviceability of building MS-8.

To enable fast and secure implementation of the basement under the entire building at the same time (no staging), except for seizing micropiles, additional underpinning was designed, in a variant using micropiles with lower rigidity. Underpinning the walls was carried out with shorter TITAN 52/26 micropiles, at a spacing of 0.40m, filling the spaces between underpinning micropiles.

The final aspect of the protection project for building MS-8 was to solve the structure intermediary in the transfer of loads from the walls to the micropiles. This structure should ensure an even distribution of stress, which is important especially in the case of the discussed brick foundations. In order to ensure the stability of the foundation-micropiles system, and to minimize and compensate settlement, a system was adopted, consisting of a reinforced concrete top-plate beam on the outer side of the walls, and steel sections connecting both sides of the foundation walls inside. The structure with the top-plate beam and foundation wall was joined with compressed bowstrings.

An additional application for drilling micropiles was micropile contiguous wall made inside building MS-8, in order to enable the construction of an elevator shaft in MS-8 and a tunnel passing from the elevator to building C1 under the gable wall of building MS-8. The palisade, made of 103/78 micropiles in a continuous system was fully spread inside with a steel frame. The choice of structural components was based on calculations carried out by computer software. The use of micropiles in the construction of palisades was dictated by a significant reduction in the working space and the lack of access for heavy equipment into the building. The palisade was used as a single-sided, stay-in-place formwork under the walls of the shaft and tunnel. The complete system of micropiles designed for the building is show in the figure 7, 8 and 9.

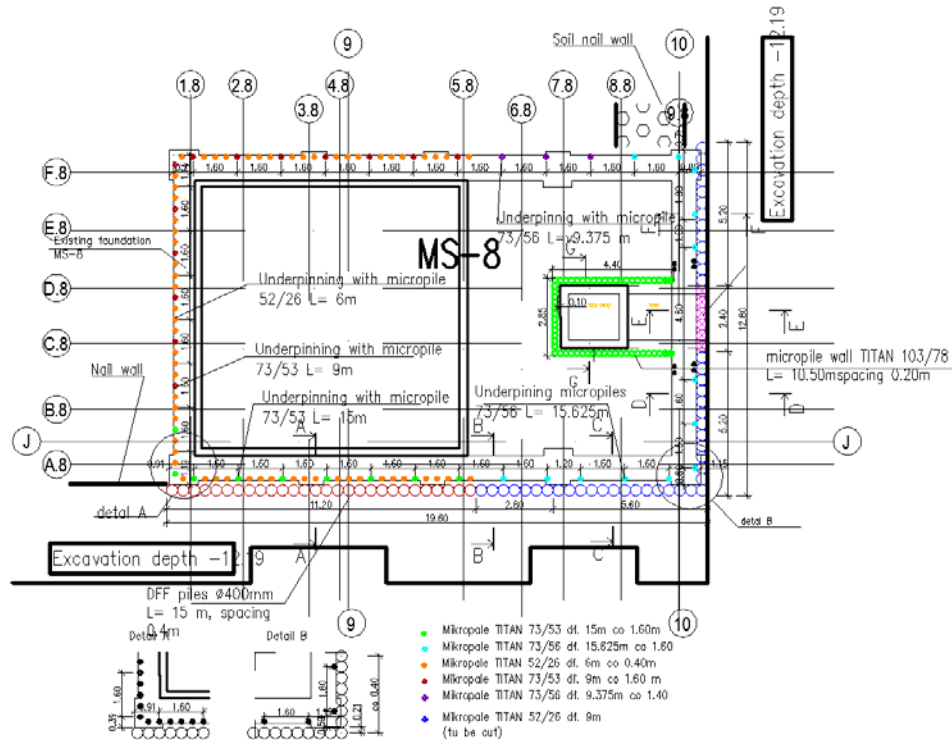


Figure 7. The Underpinning micropiles and other structures (DFF pile wall around the building and temporary micropile wall for the excavation and tunnel shaft) in the MS-8 building layout

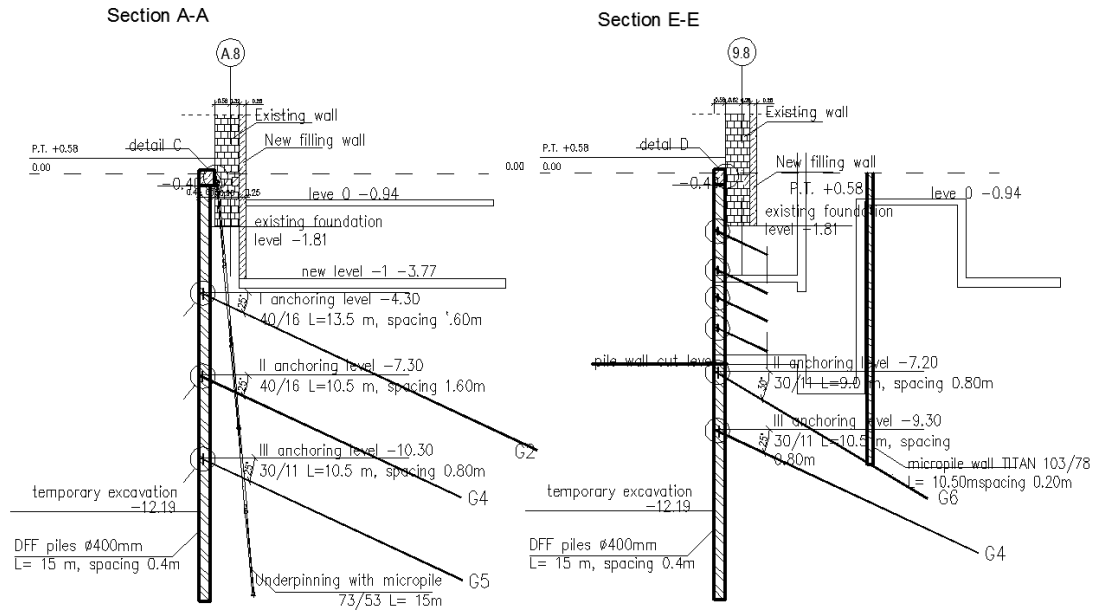


Figure 8. The typical sections of geotechnical structures in MS-8 building

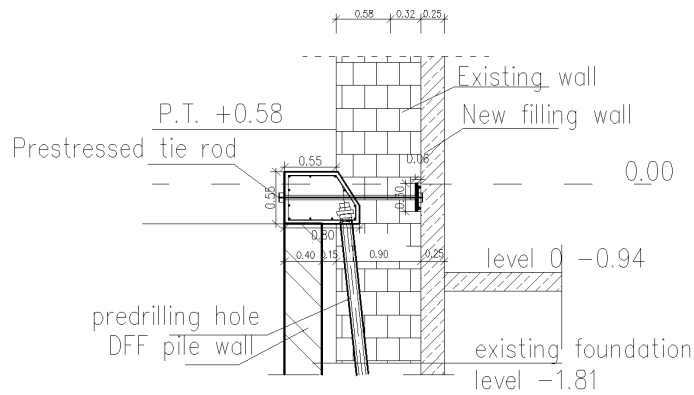


Figure 9. The detail of attachment the subsurface work to the existing structure of MS-8.



Figure 10. Installation of underpinning micropiles along the building wall

Stabilization of excavation walls

Analyzing the geotechnical and logistics conditions with respect to works in a deep trench, it was assumed that the slope on critical sections will be secured by soil nailing, and the assumed inclination of all slopes was 75° or 90° . Nails were designed as self-drilling injection elements, so in the same technology as micropiles used for underpinning, as the most adequate for the geological conditions.

Due to the temporary nature of the proposed excavation slopes, it was assumed that the factor of safety should not be less than 1.30. In the area of geodynamic activity, the permanent soil nail walls were designed with the factor of safety value minimum 1.50. The basic calculations concerning the stability of excavation slopes, a limit equilibrium method was used, i.e. the method with "strips" GGU-STABILITY v. 9.28 with module GGU NAIL, to analyse nailed structures. Usually, the "classic" nail layout was adopted, whereby upper nails have a length necessary to maintain instantaneous stability, while the overall stability in the system is provided by lower nails, which are longer, and reach beyond the slip surface. An example result of calculations is shown in Figure 11. The nails were installed at 25° below the horizontal using TITAN 30/11 and 40/16 with the drilling diameter 75mm or 90mm. These were typically between 6m and 15m in overall length depending on loadings (between 90kN and 360kN) and the depth of slip surface.



Figure 12. Installation of DFF piles along the walls of building MS-8



Figure 13. Installation of micropiles anchoring the palisade along MS-15; in the background, building MS-8 and hoisting tower MS-79

MONITORING SYSTEM

Buildings adjacent to the excavation and the excavation walls protected structurally were covered by a monitoring system. Monitoring included the measurement of vertical displacements in the indicated objects adjacent to the excavation, measurement of horizontal displacement in the excavation walls and horizontal displacements inside the rock (inclinometer measurements). To enable the observation of forces in the nails on the most heavily loaded vertical slopes, system load indicators were installed.

Measurements of geotechnical structures and existing buildings allowed the observation and supervision of their work, so the verification of design assumptions was enabled. In this procedure, there is the possibility to diagnose adverse events early enough and intervene sufficiently early to eliminate potential hazards.

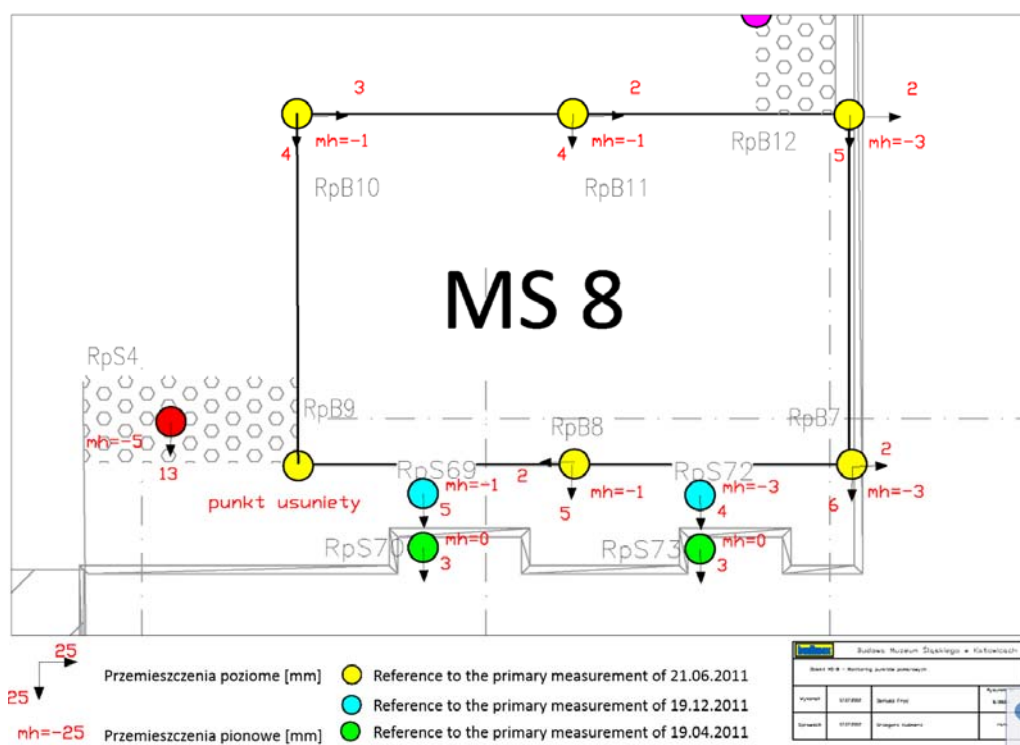


Figure 14. Sample report with results of a one-day geodetic monitoring for building MS-8

It should be noted that the provided geotechnical solutions proved to be excellent: for example, the maximum settlement of MS-8 building was estimated to be 6mm – measurement showed only 3mm. Theoretical horizontal displacement in the anchored palisade, protecting the excavation in this part, were, according to calculations - 36mm, and measured to be 7mm (Fig. 14).

As a fully-fledged component of the monitoring system, geotechnical monitoring was introduced in the project. This concept assumes a number of observations made within the rock mass, when uncovering each subsequent working level the regular assessing of the compatibility of the design assumptions with the actual geotechnical conditions were performed. The results of such monitoring allowed a customisation of the trench security structure, to ensure an appropriate technical and economic level.

QUANTINTY SURVEY EXCERPT

In the course of works described in the article, company Soley sp. z o.o. carried out specialized geotechnical works collectively summarized in Table 1 for the General Contractor - Budimex S.A.

Table 1. Quantities of the completed geotechnical works

Description	Unit	Total amount
Nails	m	14 691.0
Drilled drainswycią	m	362.0
Shotcrete facing	m ²	2 865.5
Flexible facing - Tecco mesh	m ²	1 200.0
Micropiles	m	11 261.5
Anchoring micropiles	m	3 852.0
DFF piles	m	1 912.5
Jet-grouting columns	m	695.8
Inclinometers	m	150.0

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SUMMARY

The described implementation was very demanding both in terms of design and workmanship. The complexity of the design challenges, resulting from difficulties associated with the recovery of spaces from under the existing historic buildings, with simultaneous performance of a deep excavation with complex geometry, directly adjacent to these buildings meant that the variety of necessary types and functions of geotechnical protection exceeded industry standards (fig. 15). In conjunction with the extremely complicated geotechnical conditions, it meant that the challenge the designers faced was enormous.



Figure 15. A view of the north wall of the trench with different stabilization

The successfully completed project proved that self-drilling injection micropiles enable a safe, technically and economically efficient solution to seize foundations in all soil conditions, both for protection from adverse effects in the excavation, as well as to enable the implementation of underground floors. In protection of historic monuments, the use of such micropiles has such advantage that it leaves unchanged external appearance of the walls, with no visible traces interference in the structure. This technology does not endanger foundation walls (that are often in a poor condition) with further damage. They are made nearby, with light equipment, minimising noise and vibration. The very good load-displacement characteristics has to be taken into account as well.

In such complex projects, the necessary condition for success is the combination of three components: technology, design approach based on geotechnical and structural knowledge and experience, exceptional flexibility and creativity, as well (and perhaps primarily) as execution requiring special diligence and competent staff working closely with the designer and general contractor.

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