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Research paper

Essential georisk factors in the assessment of the influence of underground structures on neighboring facilities

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Abstract: In civil engineering, underground structures are exposed to various georisks and require greater attention and awareness of the need to identify them at the earliest possible stage of investment preparation and implementation. The assessment of the interaction of objects in the underground space is a task that requires the analysis of many influencing factors resulting from the geometry and characteristics of the constructed structure and existing buildings, in the context of soil and water conditions. The correctness of such an assessment and forecast of the range and scope of these impacts requires knowledge of both construction and geotechnical issues, as well as knowledge of using the experience gained, including the analysis of the results of observations and monitoring measurements. One of the main challenges associated with underground constructions is their impact on existing buildings and other structures adjacent to the developed site. As these structures are often highly susceptible to excavation-induced ground movements, their behavior have to be considered in a design as one of the geotechnical-related limit states. As in the analysis of limit states, various computational models can be used to assess the impact of investments, including analytical, semi-empirical or numerical models. In the process of assessing the impact of underground structures, it is also important to identify additional elements of potential georisks, e.g. the impact of accompanying works, which in certain situations may have a significant impact on the construction process, requiring preventive measures.

On a few examples from the construction of deep excavations and tunnels in different soil and water conditions, the article discusses the aspects of the role of the accuracy of the identification of soil and water conditions and the creation of a reliable and useful subsoil model as elements allowing for the identification and minimization of georisks and its proper management.

Keywords: underground object, geotechnical interactions, zones of influence, georisk

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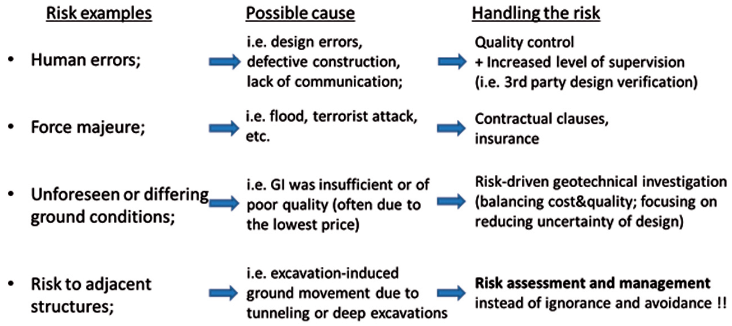
1. Introduction

Risk is the probability of harmful consequences and possible losses resulting from the interaction between natural or man-made hazards and the vulnerability of the exposed exposure elements [1,2]. Georisk is the determination of the probability of threats related to the variability of conditions in the ground for an investment at each stage of the investment process, along with a reference to the consequences they may cause [3,4]. Possible examples of risks associated with underground facilities are given in Fig. 1.



Risk examples		Possible cause		Handling the risk
• Human errors;	➡	i.e. design errors, defective construction, lack of communication;	➡	Quality control + Increased level of supervision (i.e. 3rd party design verification)
• Force majeure;	➡	i.e. flood, terrorist attack, etc.	➡	Contractual clauses, insurance
• Unforeseen or differing ground conditions;	➡	i.e. GI was insufficient or of poor quality (often due to the lowest price)	➡	Risk-driven geotechnical investigation (balancing cost&quality; focusing on reducing uncertainty of design)
• Risk to adjacent structures;	➡	i.e. excavation-induced ground movement due to tunneling or deep excavations	➡	**Risk assessment and management** instead of ignorance and avoidance !!

Fig. 1. Some risks related to underground obcject in the process of identification and management [5]

Design and construction of underground structures poses a significant risk to adjacent buildings and elements of infrastructure. It is commonly recognized that a construction of such structure may have a considerable impact on other structures located in its vicinity; especially, for deep excavations and shallow tunneling at highly urbanized areas, this is a subject of serious concern and a main geotechnical risk inherent in the execution of an underground project [5]. Limitations imposed by the need to ensure the serviceability of neighboring structures [6], in some cases, may even be a major factor governing the choice of a construction method, specific design solutions, or organization of construction activities at the site. As the subsoil is often composed of highly variable material provided by nature, and its behavior is often controlled by highly non-linear relationships concerning stress- and strain-dependence, the soil-structure interaction problem for underground structures is one of the most difficult issues to analyze. This complexity of the problem is further increased when considering the impact of the project on the surrounding area. The extent of the zone of influence, caused by the change of in-situ or groundwater conditions, may reach far beyond the area of a construction site, affecting other existing buildings and structures, as well as the interests of their owners and inhabitants [7].

2. Investments in urban areas – considerations

Tunnels [8] and structures [9], which require a construction of a deep excavation in urbanized areas, should be designed and executed with the limitation of the subsoil deformation in mind, in order to:

- avoid excessive strains and additional forces in the adjacent structures, which can threaten their bearing capacity – considered as ultimate limit state ULS;
- avoid or limit the occurrence of damage or displacements to the adjacent structures, which can worsen the state or serviceability conditions of these structures in a noticeable way – considered as serviceability limit states SLS.

The impact of deep excavations and other construction activities may vary at different stages of the execution phase. The main factors affecting their behavior in practice are:

- unloading due to demolition of existing structures;
- unloading due to deep excavation;
- changes in water pressures due to dewatering;
- deformation of retaining walls and the stress changes in retained soil;
- loading from the new structure.

These factors may be limited on some projects, as well as they may include additional influences on the others [5, 10]. For relatively light-weight structures like Metro stations, the most critical influence will be due to the excavation and usually no additional loading will follow. While for a high-rise construction, excavation phase will be followed by incremental loading from the construction of the structure itself. The verification of the impact on the neighboring structures is composed of following main steps:

- assessing the extent of the zone of influence and identifying structures located within it;
- assessing the impact of the construction works on the ground displacements within the influence zone;
- investigating the type and the state of the structures in the influence zone, as well as the limiting values of their deformations;
- assessing predicted deformation of adjacent structures due to ground displacement, and the impact of those deformations on the condition and serviceability of the structures;
- verifying the limit states for adjacent structures;
- documenting the current state and damages of the existing structures located in the active zone of influence, as well as those located in vigilance zone which are in poor technical condition;
- design and preparation of the remediation measures, if necessary;
- recommendations for the monitoring program for execution and maintenance phase.

The ranges of zones depend on the type of soil and the depth of the excavation (Hw), without taking into account the support system [6, 10]. Additional influencing factors: dimensions of the excavation, lowering the groundwater table for the duration of the works, the length of ground anchors supporting the wall of excavation [11], etc.

For the purposes of potential claims or administrative needs, and mainly for the design of the 2nd and 3rd metro lines in Warsaw, the simplified limits of the impact zones (for averaged conditions in the ground) were adopted according to [10] – Fig. 2. It should be noted that the national experience in determining the extent of impact zones [6, 8, 12–14] takes into account the depth of the excavation/foundation of the structure and ground conditions. As shown by the local experience gathered during the construction of the

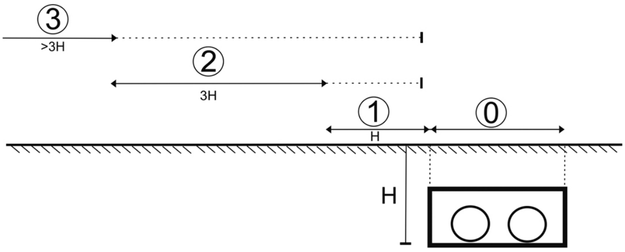


Fig. 2. Determining the limits of the zones of influence of stations and tunnels for the second metro line in Warsaw after [7], according to [10]. 0 – zone above the station and tunnel, 1 – direct influence zone, 2 – indirect influence zone, 3 – possible influence, H – depth of excavation or tunnel foudation level

metro in Warsaw, this has its justification and confirmation in the results of displacement measurements [14].

The settlement of the surface and buildings is caused by the excavation of soil during drilling with a shield with a volume greater than the volume of the tunnel. On the ground surface, these deformations are observed in the form of a subsidence trough, usually with the maximum value directly above the axis of the tunnel [14]. Depending on the mutual location of the objects on the surface in relation to the tunnel and their specificity (geometry, type of structure), various forms of deformation can be observed. In design works, they should be analyzed in the context of not only the duration of construction, but also subsequent operation, including the possibility of the appearance of new structures in the impact zone. The presented issues belong to the scope of the geotechnical design [3], as it is closely related to the ground conditions and is a part of the georisk.

3. Georisks in the assessment of the influence of geotechnical underground objects

3.1. Assumptions for the assessment of georisks

For underground objects, a conservative approach to the dimensioning of retaining structures, especially diaphragm walls, is widely accepted due to the ultimate limit state (ULS) [15]. Designers, aware of the risks associated with the project, often avoid over-optimization of these elements, making safety a priority. This is partly due to the poor identification of the geotechnical conditions of the subsoil provided by the investor in the pre-design stage, and often from the limited budget, which gives little possibility to carry out supplementary geotechnical tests. Although this design conservatism causes that even poor reconnaissance rarely has catastrophic consequences, the savings made in the design stage increase the expenses allocated to construction, e.g. repairing damage to objects in the zone of investment impact or overdimensioning of the structure [7].

The assessment of the interaction of objects in the underground space is a task that requires an analysis of the impact factors resulting from the geometry and characteristics of the constructed structure and the existing buildings in the context of soil and water conditions [7]. The correctness of such an assessment and forecast of the range and scope of these impacts requires knowledge of both construction and geotechnical issues, as well as knowledge based on the use of already gained experience based on the analysis of the results of observations and measurements made. In the event that the preliminary (qualitative) impact assessment, consisting in determining the extent of the excavation impact zones, allows to determine which objects are potentially endangered, it is most often necessary to conduct a quantitative analysis afterwards. Such analysis should be treated as one of the serviceability limit states (SLS) related to the designed structure [10].

The first step to deep excavation impact assessment, related to the identification of hazards, should be to determine the permissible values of displacements for neighboring objects [6], taking into account their technical condition, type of structure, level of foundation and possible additional requirements for maintaining their serviceability (e.g. displacement of the building [12] – example 1, displacement of tracks for rail transportation systems [16] – example 2). As in the analysis of limit states, various calculation models can be used to assess the impact of the new investment, including: analytical, semi-empirical (e.g. the model from [10]) or numerical (e.g. based on FEM). In national practice, in order to assess this impact, the method presented in the [10] is most often used. Work is currently underway on similar guidelines for the assessment of the impact of shield bored tunnels, based on experiences in Quaternary soils conditions in Warsaw [14].

However, due to the construction of more and more complex structures, as well as the need to predict displacements as accurately as possible, e.g. in the vicinity of metro stations or tunnels, there is a growing need to use numerical methods. The finite element method (FEM) is currently the most frequently used method of numerical analysis for the purposes of impact assessment (commercial software: GEO5 FEM, Plaxis, ZSoil, Midas GTS). In the case of analyses, in which the structural strength of the structure (e.g. tunnels) should be additionally taken into account in complex ground conditions (spatial variability of layers), it becomes necessary to use 3D modeling [17] – example 3 and 4. The main advantage of spatial modeling is a more reliable reflection of the behavior of the structure in the case of a complex arrangement of its elements and its surroundings [18].

3.2. Identification of subsoil conditions for proper impact assessment

Correct and complete identification of the building subsoil is the basis for reducing the risk associated with the construction of investments in dense urban development [19]. In terms of ground identification and testing according to EC7 [20], in the context of the entire investment process, properly determined geotechnical parameters and quality control of works performed on the construction site are more important for meeting the basic requirements of the project than the accuracy of calculation models and values of partial factors.

For this purpose, it is necessary for geotechnical design to determine a reliable geotechnical parameters of the soil. The factors of influence include: appropriate selection of field tests, quality of the equipment used for testing, level of education and solicitiude of the test operator, randomness of measured parameters during the test, quality of samples for calibration tests in the laboratory. The evaluation of the credibility of the testing must be based on the knowledge of the variability of the measured characteristics. Subsoil, as a product of nature, has assigned variability resulting from its genesis, history and current conditions (e.g. geomorphological situation). Hence the need to use soil tests interpreted on the basis of local dependencies, adjusted and checked (e.g. by validation with other methods) in the local soil conditions [21].

At the end of this cognitive process is the selection of an appropriate calculation method. The selection of the computational model is determined by the type of task (structure type), while the model type determines the parameters necessary for calculations, which consequently determines the test methods for their determination (such an approach will be obligatory in the new generation of Eurocode 7). Here, unfortunately, the problem of routine documentation of the ground conditions often arises, without taking into account the purpose of the parameters specified during the diagnosis.

Eurocode 7 [9] requires that the stiffness of the subsoil and structural elements as well as the sequence of execution of construction works should be taken into account in the calculation of displacements. Moreover, it is recommended to use calculation models describing the full stress-strain relationship of the soil or to assume stiffness corresponding to the expected range of deformations, in the case of applying linear-elastic models. These conditions are fully met in the case of numerical FEM analysis, especially when advanced soil constitutive models are used, such as Hardening Soil with small strain stiffness (HSS) [7, 16] or Hypoplastic clay [13, 18, 22, 23]. These models allow for a better prediction of the calculated displacement values to those later observed on site in relation to other simplified constitutive models. This approach becomes common in urban development conditions, which is confirmed in practice – Section 5.

3.3. The influence of accompanying works

When analyzing the possible impacts related to the construction of the investment on the neighboring objects, other additional factors, apart from the construction of the excavation itself, should also be taken into account, which may have a significant impact on the size of registered displacements. It requires separate analysis with the use of comparable experience or numerical calculations modeling the sequence of execution of individual works. On the other hand, the results of these analysis should be related to each other, indicating the total scope of possible impacts, thus providing the basis for taking the necessary actions to limit individual impacts (risk management) [3, 7, 10]. Other factors, apart from the excavation itself, that have a significant impact on the size of the recorded displacements include [10]:

- any accompanying works performed within the excavation impact zone, which by their nature violate the existing state of stress in the soil – these include:
  - excavations for utilities (especially parallel to the excavation),
  - specialized geotechnical works being a part of the project, (e.g. creating a horizontal barrier in high-pressure grouting technology),

  - additional strengthening of the wall or securing the building (e.g. reinforcing the foundations, additional vertical partitions, e.g. made of sheet piles, etc.) made nearby,
  - dewatering for the time of construction (carried out incorrectly or too intensively, failure cases);
- the influence of the construction of other investments (including deep excavations) in the vicinity of the project, where overlapping of impacts may occur.

3.4. Risks from geodynamic processes

Geodynamic processes include many factors like: mass movements, swelling, shrinkage, suffosion, clogging, collapsing, karst and others [2,4]. The scope of influence depends on the type of underground object, the complexity of geotechnical conditions, morphology and land development (structure, method of foundation) in the zone of impact of the underground object. Such a wide range of factors influencing the scale of impacts makes it necessary to perform a georisk analysis for all new underground structures. Estimation of the value of terrain deformation, implemented e.g. in the Plaxis program, is based on the parameters describing the width of the subsidence trough (k) or the loss of soil volume (V_L). The value of “k” comes from the analysis of the results of empirical experiments because, as shown in [3], it depends mainly on the depth of the tunnel and the type of subsoil [8, 14].

An interesting case is the impact of an underground structure (tunnel) on natural and manmade slopes. In this case, the geological analysis should refer to the ultimate limit states of the GEO type (Table 1). The loss of general stability can be considered as unlikely if the following condition is: $E_d \leq R_d$; where: E_d – design value of the effect of actions destabilizing the slope, R_d – design value of soil resistance against loss of stability.

Table 1. Matrix of risk levels when assessing the impact of tunnel construction on the slope

Expected threat level	Consequences of exceeding the general stability limit state			
	small (CC1)	medium (CC2)	serious (CC3)	very serious (CC4)
Very unlikely F > 1.5	N	N	A	ND
Unlikely 1.3 < F < 1.5	N	A	ND	ND
Likely 1.0 < F < 1.3	ND	ND	NA	NA
Very likely F < 1.0	ND	NA	NA	NA

Explanations: NA – not acceptable; reduction of impacts or their effects required (e.g. strengthening the foundations or the structure); ND – undesirable; the reduction of impacts or their effects should be considered; A – acceptable; reduction of impacts or their effects not required, but the repair after completion of works may be necessary; N – insignificant; no additional funds required.

Safe values of the equilibrium state coefficient for characteristic parameters should be taken not less than F = 1.3. The range of the slip surface with the value F = 1.5 can be considered the maximum range of landslide risk. For the general stability assessment, both the limit equilibrium methods and the finite element method can be used. The results of the slip surface ranges, depending on the equilibrium method, may be different as well as the result obtained by FEM. In this situation, the risk level for stability reasons can be defined differently. The solution is a joint stability analysis taking into account the effects of tunneling affecting the long-term impact of the tunnel on the slope, including the vibrations – example 5.

4. Investment risk identification and management

The investment risk analysis for the processes of construction of deep excavations or tunnels [3] in urban areas mainly include the assessment of the so-called georisks. These are new issues in Polish national practice, but crucial and current in the field of underground construction, including the protection of buildings in the vicinity of deep excavations and tunnels (Fig. 3).

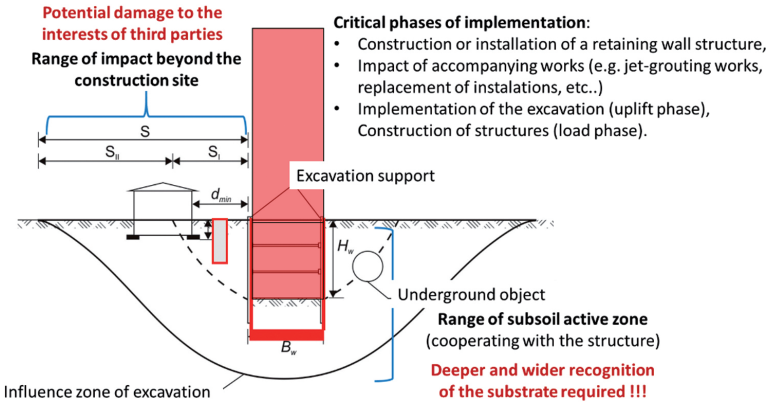


Fig. 3. An example of risk identification in the area of impact of a deep excavation construction after [7], according to [10]. S – influence zone (S_I – direct, S_{II} – indirect), B_w – width of the excavation, H_w – depth of excavation, h_f – foundation depth, d_{min} – distance min, [m]

When analyzing the impact of the constrauction of a deep excavation on the neighboring buildings, one should take into account not only the very possibility of a threat to this development, but also the related consequences – which is the stage of risk identification. Further, depending on the type and purpose, all objects located in the impact zone should be assigned appropriate destruction consequence classes (CC) [15, 24, 25]. Then, as an element of risk management, when assessing the impact of the excavation on neighboring objects, different requirements for individual objects located in the area of impact of the excavation can be used, depending on the geotechnical category (GC) assigned to them and the stage of project construction.

An important role in the assessment of the impact is played by the complexity of the interaction of the constructed structure with the ground and neighboring objects. The risk profile can be expressed qualitatively by the classification of the object into the geotechnical category. A rational (safe) approach to the design requires an appropriate selection of the level of analysis accuracy and the criteria for the serviceability and bearing capacity analysis in relation to the design phase and the degree of complexity of the analyzed problem. The most commonly used methods of semi-empirical impact assessment should be gradually supplemented in the investment process by numerical modeling (FEM 2D and 3D). The scope of possible applicability of such analysis depending on their complexity is presented in Table 2.

Table 2. The applicability of the described levels of analyses accuracy in various problems of geoengineering [7]

Description		Simplified empirical methods	Advanced empirical methods	Numerical methods	
				Plain strain (2D)	Spacial analysis (3D)
Tunnels	Stiffness of the lining	D	D	A–C	A–C
	Hinged connections of the lining	D	D	A–C	A–C
	Construction	D	C	B–C	A–C
Deep excavations	Effects of wall installation	D	B–C	C–D*	A–D*
	Deformation of the wall	D	B–C	A	A
	Method of support	D	C–D	B	A–B
	Final loading from the structure	D	D	B–C	A–C
Soil	Required level of soil recognition	None or quality	Qualitative or preliminary quantitative	Detailed quantitative	Detailed quantitative
	Complexity of geotechnical conditions	C–D	C	B	A
	Nonlinier soil behavior	D	D	A–B	A–B
Neighbouring structures	Surcharge on the subsoil	D	C–D	A–C	A–C
	Stiffnes of the structure	D	C–D	A–D*	A–D*
	Strength of structural elements	D	D	A–D*	A–D*
	Location in relation to the analyzed structure	D	C–D	B	A
	Foundation mehtod	D	C–D	A–C	A–C

Explanations: A – possible modelling in an exact manner; B – simplified modelling possible; C – possible indirect or very simplified modelling; D – no modeling possible or omitted* .

When analyzing the impact of planned works and adopted design solutions on the serviceability conditions of neighboring structures, while making a decision to apply measures reducing negative effects (e.g. foundations or structure strengthening, increasing the stiffness of the lining). The decision on the adopted solution should depend on potential consequences for the structure and the expected scope of damage that the excavation may cause. Of the available risk management methods, in the case of deep excavations, the most frequently used approach is based on reduction of the risk or the consequences associated with it. An overly conservative risk assessment may result in the use of costly and not always proper design solutions (e.g. *reinforcement of foundations*) in a situation where it is possible to reduce the impacts less costly (e.g. *by changing the excavation wall support or its stiffness)* or allowing for a temporary deterioration of serviceability conditions (*assuming the later need to repair additional cracks at the level of slight architectural damage, not dangerous to the structure itself*) [10].

5. Examples from engineering practice

Selected examples regarding the assessment of the impact of underground structures in complex soil and water conditions and in a complex urban development or morphological conditions (slope) are presented below, where the georisk elements indicated in the paper had to be taken into account. Due to the limited size of the article, the descriptions have the character of a mention with a reference to source materials (available from the Authors).

Example 1 – construction of a deep excavation at historic tenement houses

Another example is the multi-stage numerical FEM analysis in the 2D space of the displacement of the diaphragm walls of the deep excavation and the settlement of historic tenement houses surrounding the excavation on three sides. The calculations were performed both before the construction of the building/excavation, at the design stage, and after the completion of construction. Fig. 4 shows the outline of the excavation in relation

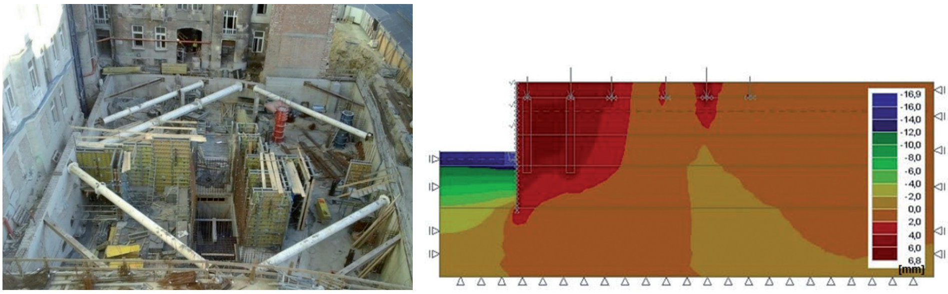


Fig. 4. Construction of the basement of the building in the immediate vicinity of historic tenement houses: excavation in progress (left), numerical analysis of the impact of the excavation – second stage taking into account the designed soil reinforcement (right) [12]

to the existing tenement houses. The shortest distance from the excavation to the building wall was 0.47 m.

Performing step-by-step numerical analysis enables the selection of appropriate construction methods and safety measures, ensuring the safety of buildings adjacent to the constructed structure. On the basis of the FEM analysis carried out before the commencement of construction, it was found that there is a need to reinforce the soil under the foundations of tenement houses by high pressure grouting. In the second stage of the analysis, calculations were carried out taking into account the designed improvement, determining the predicted settlement of buildings [13].

Their values were considered acceptable in terms of meeting the ultimate and serviceability limit states. Precise monitoring of displacements of both the walls of the excavation (inclinometers) and sensitive buildings in its vicinity, initiated before the start of construction, allowed to confirm the correctness of the adopted design solutions. It also made it possible to verify numerical analysis. The results of the analysis carried out with consideration of jet-grouting columns were verified by comparing the horizontal displacements of the diaphragm wall and settlements of foundations measured on the site with the corresponding theoretical values.

Example 2 – Analysis of the impact of extensive and deep excavation on the existing railway tracks – selection of analysis methods appropriate to the complexity of the issue

Numerical modeling of the extensive and deep excavation close to existing railway line allowed for the impact assessment, displacements reduction and the full functionality of the railway line during construction [16]. A simplified FEM numerical analysis (2D model) of the investment's impact on the existing railway tracks was performed. It was necessary to confirm the possibility of continuing the operation of the railway line during the construction of the excavation and the structure, in the complicated geotechnical conditions – Fig. 5.

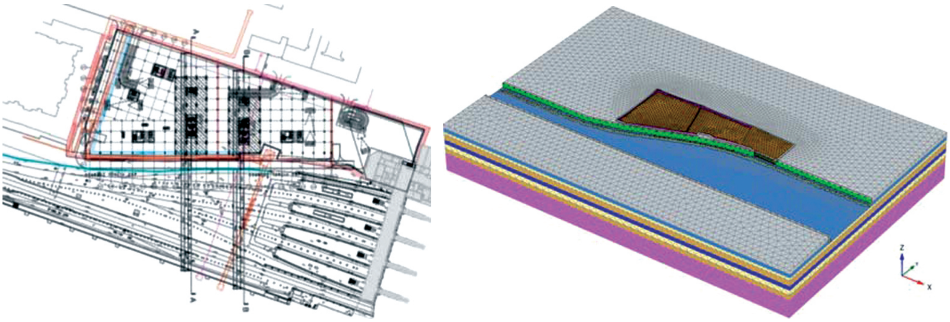


Fig. 5. Deep excavation in the vicinity of active railway tracks: situational plan (left) and spatial model of the subsoil and objects (right)

As a result of the analysis, theoretical displacements of the subsoil in the subsequent stages of construction and operation of the investment were obtained. These displacements were considered acceptable in accordance with table 15 of the standard [26]. The construction has started, during this process a number of technological changes were made in the stages of the excavation, which significantly influenced the actual behavior of the soil massif around the excavation (uplift). The issue that could be (to a large extent) analyzed in 2D space became a full spatial issue.

Therefore, the FEM 3D analysis of the case was performed. The calibration of the new model was carried out on the basis of the results of measurements of the actual displacements of the subsoil in the construction stages completed to that point. Calibration showed that not only a more complex three-dimensional model but also a more advanced numerical model of the soil (HSS) must be used for the analysis. As a result of the supplementary analysis (3D), higher values ??of the theoretical displacements of the subsoil in the final excavation stage were obtained. However, due to their even distribution along the excavation wall (which could be stated in the spatial analysis), they were considered acceptable and safe with regard to uninterrupted and very intensive use of the railway tracks. Adopting the appropriate method of analyzing geotechnical issues, in particular the interaction of built objects with existing ones, is a necessary condition for ensuring the safety of the structure and the possibility of proper prediction of the risk associated with the construction.

Example 3 – complex construction systems and complicated ground conditions

An example of a numerical analysis for the newly designed development next to the existing metro station is shown in Fig. 6. A spatial analysis (3D) was performed mapping the complicated spatial structure and soil arrangement. The analysis of the risk related to the construction was possible thanks to obtaining the most probable values of the anticipated displacements taking into account all necessary interaction aspects. Carrying out an accurate, quantitative assessment of the displacements of neighboring structures with the use of advanced computational models allowed to estimate the risk related to the construction and manage it effectively. Based on the distribution of displacements along the

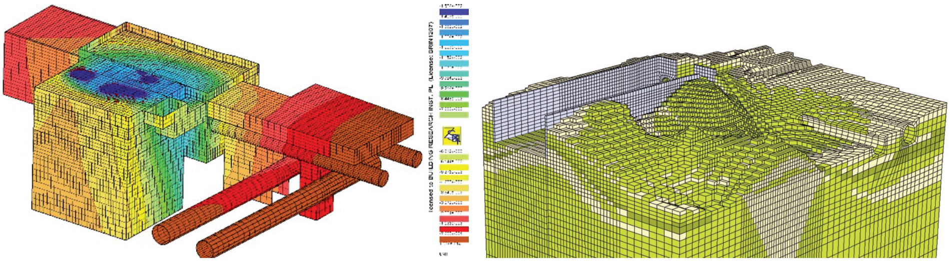


Fig. 6. FEM 3D analisys: spatial model of the structure (left) and location of the top boundary of glacitectonically disturbed (uplifted and folded) Myo-Pliocene clay deposits (right) [5]

foundation structure of the route track, it was possible to determine the expected differential track displacements in relation to the values allowed by the metro Authorities.

The knowledge of the predicted displacement distribution not only enables the analysis of the serviceability limit state for the neighboring buildings and infrastructure, but also serves as the basis for determining the scope of, the area and the elements to be monitored.

Example 4 – passage of tunnels under the existing structure and development of the subsidence trough

Analysis of the relaxation of the soil and tunnels of the first metro line as a result of the transverse excavation for the sewerage collector was performed, the displacements of linings (upwards) and their deformations were found (Fig. 7). By assessing the excavation options: at once or in sections (8 m), it was shown that the uplift due to flexible soils (clays) will be temporary and that after the backfilling of the excavation, the final displacements of tunnels will not be greater than ±1 mm.

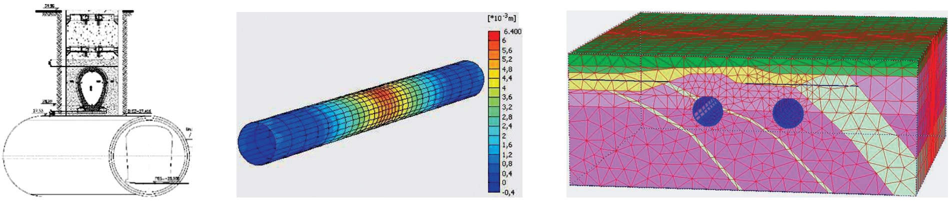


Fig. 7. FEM 3D analysis: the geometry model of the tunnel and the collector (left), the spatial model of the underground structure showing total displacements (in center) and location of the top boundary of glacitectonically disturbed (uplifted and folded) Myo-Pliocene clay deposits (right) [own materials]

The use of the spatial (3D) model allowed to take into account the structural strength of the tunnel lining, indicating more realistic (in line with the observations) displacement results.

Example 5 – The foundation of the church on the natural slope near the road tunnel

For the safety of the structure built in the edge zone of the slope, deformations of the ground, especially horizontal displacements on the side of the slope and stress distribution [27] are fundamental. Calculations of soil displacement and stress distribution (Fig. 8) in the subsoil subjected to loads from the building, founded on slope, close to the planned road tunnel, were performed using the finite element method by the CRISP numerical program. The elastic-plastic soil model with hardening, such as a modified Cam–Clay model was used.

The obtained modeling results were used in the design of the foundation of the facility and in the design of the slope protection. When the building is located in the vicinity of the slope, such protection is also necessary for its safe long-term operation [28, 29]. Retaining structures in the central part of the slope were designed as well as the drainage system of the building, also as a kind of protection from impact zone of the road tunnel.

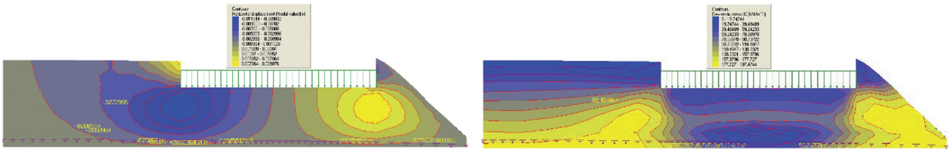


Fig. 8. Distribution of stresses and displacements in the soilbase of the church building at on the slope: isolines of horizontal displacements (left) and isolines of stress deviator distribution (right)

6. Conclusions

Geotechnical analysis of the impact of the investment being constructed on neighboring structures located in the zone of its impact, is an indispensable element of geotechnical design in highly urbanized areas. It does not differ from the analysis of other serviceability limit states, which are an important factor influencing design decisions. Also in this case, an appropriate calculation model, representative of the risk profile related to the investment, should be used. Particularly, underground structures, such as tunnels, deep excavations or large-diameter underground installations, are exposed to georisk factors and require more attention and the need to identify them.

It also requires the proper selection of testing methods and setting the scope of the investigation of the geotechnical conditions of the subsoil. So far, the (updated) ITB Instruction No. 376 [10] is widely used in Polish practice. Along with the increasing complexity of projects built in urban areas, in some cases it should only be an introduction to the assessment of geotechnical risk related to their construction. In the case of structures with complex geometry of the underground part and in complex soil conditions (geotechnical category III), such assessment should be supplemented with detailed analysis using advanced calculation models based on numerical methods. This type of approach is already obligatory in the case of new developments in the vicinity of the existing metro facilities in Warsaw [5, 10].

The most widely used methods of semi-empirical impact assessment should be gradually supplemented in the investment process by 2D & 3D numerical modeling (e.g. FEM), as shown in the examples.

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Istotne czynniki georyzyka w ocenie wpływu konstrukcji podziemnych na sąsiednie obiekty

Słowa kluczowe: obiekt podziemny, oddziaływania geotechniczne, strefy wpływu, georyzyko

Streszczenie:

W inżynierii lądowej obiekty budownictwa podziemnego narażone są na różne georyzyka i wymagają większej uwagi oraz świadomości potrzeby ich identyfikacji na możliwie najwcześniejszym etapie przygotowania i realizacji inwestycji. Ocena wzajemnego oddziaływania obiektów w przestrzeni podziemnej to zadanie wymagające analizy wielu czynników wpływu wynikających z geometrii i charakterystyki konstrukcji budowanej oraz istniejącej zabudowy, w kontekście warunków gruntowo-wodnych. Poprawność takiej oceny i prognozy zasięgu oraz zakresu tych oddziaływań wymaga znajomości zagadnień zarówno z zakresu konstrukcji jak i geotechniki oraz wiedzy wykorzystującej zebrane doświadczenia, w tym analizy wyników obserwacji i pomiarów z monitoringu. Jednym z głównych wyzwań związanych z konstrukcjami podziemnymi jest ich wpływ na istniejące budynki i inne obiekty przylegające do zagospodarowanego terenu. Ponieważ struktury te są często bardzo podatne na ruchy gruntu wywołane wykopami, ich zachowanie należy uwzględnić w projekcie jako jeden ze stanów granicznych związanych z geotechniką. Podobnie jak w analizie stanów granicznych, do oceny oddziaływania inwestycji można wykorzystać różne modele obliczeniowe, w tym modele: analityczne, półempiryczne (np. z Instrukcji ITB nr 376/2020), czy numeryczne (np. MES). W krajowej praktyce, na potrzeby oceny oddziaływania, często wykorzystywana jest metoda przedstawiona w Instrukcji ITB, jednak w przypadku realizacji bardziej skomplikowanych inwestycji i potrzebie uzyskania dokładniejszej predykcji przemieszczeń, np. w sąsiedztwie obiektów metra, występuje celowość lub wręcz konieczność zastosowania metod numerycznych.

Na przykładach z realizacji głębokich wykopów i tuneli w odmiennych warunkach gruntowo-wodnych w pracy omówiono aspekty dotyczące roli dokładności rozpoznania warunków gruntowo-wodnych oraz tworzenia wiarygodnego i użytecznego modelu podłoża, jako elementów pozwalających na identyfikację i minimalizację georyzyka oraz odpowiednie nim zarządzanie.

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