Errors in documenting the subsoil and their impact on the investment implementation: Case study

Abstract: Improper recognition of the subsoil is the most common cause of problems in the implementation of construction projects and construction facilities failures. Most often, their direct cause is the mismatch of the scope of geotechnical diagnosis to the appropriate geotechnical category, or substantive errors, including incomplete or incorrect interpretation in the creation of a geological-engineering model and often overlooked hydrogeological conditions. In many cases, insufficient recognition and documentation of geotechnical and/or geological and engineering conditions leads to damage and construction failures, delays in consider construction, and the increase of the investment budget. That’s why, in order to avoid the above, particular attention should be paid to proper geotechnical and geological-engineering documentation at the design and construction stages. The selected example of the investment analyzed errors in the geological-engineering documentation, which mainly concerned the lack of recognition of locally occurring organic soils, the incorrectly determined location of the groundwater table and the degree of compaction of non-cohesive soils, and numerous errors of calculated values of soil uplift pressure. The detection of the errors presented in the paper made it possible to select the correct technology for the construction of the sanitary sewage system and to increase the thickness of the horizontal shutter made of jet grouting columns in the area of the excavation. In addition, the article discusses the principles of proper calculation of limit states and subsoil testing, which have a significant impact on the implementation of planned investments.

Keywords: subsoil documentation, geological-engineering documentation, geotechnical investigation, ultimate limit states, serviceability limit states

1 Introduction

The foundation of buildings includes not only the design of foundations, but also the way of transferring loads from foundations to the subsoil and preventing deformation of installations laid directly in the subsoil. Proper design requires precise identification of the subsoil in order to determine the existing soil and groundwater conditions. The design process should also take into account the purpose of the object, the type of construction, its deformation, production technology, and conditions of use [1–3].

The examples of problems in the implementation of construction works and failures of construction works known from engineering practice result from insufficient fulfillment of formal conditions. Their direct causes are most often substantive errors, including incomplete or incorrect interpretation in the preparation of geological-engineering and geotechnical documentation, including frequently overlooked hydrogeological conditions [4]. It also often happens that the scope of the subsoil research is not adjusted to the geotechnical category, i.e., the complexity of the planned investment [5,6].

There are inconsistent provisions in Polish legal regulations, which make it difficult to interpret them correctly. The greatest ambiguities occur in the case of documentation work on the recognition of the geological and engineering environment on the basis of subsoil tests [7]. Documentation issues are regulated in Poland by the following legal acts: the Construction Law Act [8], the Geological and Mining Law Act [9], and related ordinances: Minister for Transport, Construction, and Maritime Economy
of 25 April 2012 on determining the geotechnical conditions for the foundation of construction works [10], Minister of Environment of November 18 on hydrogeological documentation and geological-engineering documentation [11], Minister of the Environment of December 20, 2011 on detailed requirements for geological work projects, including works that do not require a concession [12] and standards: EN 1997-1:2004: Geotechnical design – Part 1: General rules [13] and PN-B-02479: 1998 Geotechnical documentation [14]. The choice of the procedure in accordance with the regulations depends on the purpose of the study, the stage of investment implementation, the complexity of soil conditions, and the geotechnical category of the building [4,7,15]. Therefore, in practice, the foundation conditions are elaborated in the form of geotechnical documentation [8,10] or geological-engineering documentation [9].

Geotechnical documentation is created on the basis of research activities performed to determine the type, properties, strength properties and deformability of soils, their variability, groundwater level, and stability of excavations and embankments [8]. However, geotechnical investigation, in accordance with [14], includes field works that do not cause negative environmental changes, such as small-scale geotechnical drilling, static and dynamic sounding, pressure and dilatometer tests, geophysical (no explosives), outcrop foundations, research excavations, and laboratory determination of physical, mechanical, and chemical properties of soils and groundwater, etc. [8]. However, in the Act on Geological and Mining Law [16], the definition of geological-engineering documentation is not provided, but it only indicates when the documentation should be prepared, what should be included, and who accepts it.

The design should include predicted geological profiles of designed boreholes, execution of boreholes or excavations, description of testing of boreholes and excavations, including the method of geological sampling, the scope, number, and size of geological samples to be taken, as well as description and justification of the scope of laboratory tests and the graphic part should provide geological and technical profiles (borehole structure) of designed boreholes or excavations, along with an indication of the intended location of sampling sites.

Based on the above-mentioned basic definitions, it follows that the provisions of the construction law and geological law are inconsistent, which creates a problem in the correct interpretation of the regulations and placing the boundary between the geological-engineering documentation and the documentation of subsoil tests. In engineering practice, the documentation of subsoil tests contains similar elements to the geological-engineering documentation developed to determine the geotechnical conditions of the foundation. If there are complicated soil conditions in the field (the third geotechnical category and the second in complex soil conditions), separate geological and engineering documentation should be prepared in accordance with applicable regulations and subsoil documentation (geotechnical foundation conditions) developed in accordance with the law regulations or increasingly Eurocode 7. Geotechnical-engineering documentation should include, among others, a forecast of the impact of designed objects on the environment, a description of geodynamic processes, if any, and information about the location and resources of mineral deposits that can be used in the implementation of the planned investment. In summary, there is no distinction in current practice, and the scope of geotechnical and geological works is often similar. Geotechnical documentation primarily concerns the characteristics of the subsoil of the designed object, and in geological-engineering documentation, problems related to environmental protection and the occurrence of geodynamic processes are also discussed in greater detail.

At present, significant development and growth of construction investments are observed all over the world, which in the case of emphasis on accelerated project implementation may be exposed to a number of threats. First of all, the importance of geotechnical investigations is underestimated at the design and implementation stages of construction works. In many cases, insufficient identification and documentation of geotechnical and/or geological and engineering conditions leads to construction failures, delays in the implementation of investments, and an increase in the investment budget. As a result of the implementation of a number of construction projects, the increase in expenditure in the initial stages of the construction investment process for geotechnical and geological research has significantly reduced the total construction costs. However, this approach to the planning and implementation of most investments is an exception [1,17–19]. Errors in the documentation regarding the recognition of subsoil conditions (soil and water) have contributed to many construction failures and disasters, among others collapse of tunnels [20–24], failure and collapse of foundations [19,25] and construction of buildings [24,26–28], damages to the surface and failures of road infrastructure and bridges [29–32], and damages and breakdowns of earthworks [3,31,33].

In connection with the above, this article indicates the need for proper geotechnical and geological-engineering documentation in order to avoid damage and
failure of the resulting engineering structure/building structure, increase of general construction costs, and exceeding deadlines for investment implementation. The main goal of this study is to show the errors in documenting the subsoil as a result of overinterpretation of field test result. On the example of the construction of a sewage pumping station and sanitary sewage system with a gravitational run, the principles of proper calculation of limit states were discussed and errors in the original geological-engineering documentation were presented, which had a significant impact on the time and costs of a given investment.

2 Site characteristics

The analysis of geological-engineering documentation and its impact on the implementation of the investment was carried out on the example of documentation for the construction of a sewage pumping station and a sanitary sewage system with a gravitational run located in the Masovian Voivodeship. The bottom plate of the sewage pumping station is 6.6 m below ground level, whereas the sewer cavity varies from 2.02 m below ground level at the point of connection with the existing sewage section up to 5.48 m below ground level at the entrance to the pumping station. The pumping station is located on an undeveloped plot of land with an area of 0.11024 ha entirely covered with grass. The designed pumping station consists of the following elements:
- reinforced concrete monolithic cuboid chamber with dimensions of $3.0 \times 4.0 \times 2.59$ m, covered with a ceiling made of two prefabricated panels,
- reinforced concrete prefabricated chamber with a circular cross section, diameter 3.0 m, and depth 6.8 m covered with a ceiling made of prefabricated slab,
- reinforced concrete prefabricated circular chamber, diameter 1.4 m and depth 5.3 m.

Gravitational sanitary sewage system is realized on a section of $L = 876$ m in stoneware pipes with a diameter of 0.2 m along a one-way street with an asphalt surface. In the road lane, there are utilities in the form of water supply, sewage, energy, and telecommunications networks. There are single-family housings on both sides of the street. Due to the existence of complicated soil conditions, the planned sewage section is divided into three sections different in terms of technology, i.e., in an open excavation, secured with steel sheet piles and horizontal shutter, trenchless method, and in an open excavation, protected with steel moldings or system shuttering. The section of the sewage network is armed with concrete wells from prefabricated elements with a diameter of DN 1.2 m, covered with cast iron manholes. The water supply connection for the area of the 10.9 m long compressor station with the water meter well is planned in the open excavation, with the reinforcement of the vertical walls of the shuttering, as required from steel moldings, plate reinforcements, or sheet piles made of steel.

Based on the tests included in the project documentation, it can be concluded that there is humus on the analyzed area in the soil surface or the nonconstruction embankments with a maximum thickness of 0.8 m. The remaining part of the subsoil is dominated by sandy soils of the Pleistocene and Holocene ages associated with the river accumulation of the overflow terrace. Sandy soils are usually fine sands, but also silty sands and medium sands with areas of thick sands interbedding. In the subsoil, the presence of cohesive soils of the Holocene age, i.e., sandy clay, silt with organic mud interbeddings, and silty clay with sand, was also found locally. Moreover, in the western and central parts of the planned sewage section, on the roof of sands, there is a layer of cohesive soils represented by clayey sands and locally by silty clays. On the analyzed area, there is a free groundwater table at a depth of 1.7 m below ground level and of a tensed nature at a depth of 10.0 m below ground level.

3 Methods

In the countries of the European Union, the superior documents constituting a set of guidelines developed by the European Committee for Standardization (CEN) regarding the design of engineering structures are Eurocodes. The main purpose of the introduction of the Eurocodes was to harmonize the design practice across Europe and provide a uniform framework for the design of various types of engineering structures [5].

In the documentation of the recognition of the geological and engineering environment based on subsoil test, Eurocode 7 [13] is used most often in engineering practice. According to its content, during designing two kinds of limit states are required [13]:
- Ultimate Limit States (ULS),
- Serviceability Limit States (SLS).

The following Ultimate Limit States ULS of destruction are checked: EQU - equilibrium, STR - structural,
GEO – geotechnical, UPL – uplift, and HYD – hydraulic heave. The limit state of serviceability SLS refers only to the construction. Among the types of this state, mention is made of subsidence, settlement differences, structure rotation, and in special cases, additional impacts, e.g., caused by vibrations.

Geotechnical design according to Eurocode 7 is based on demonstrating in a way that there is no doubt that no limit state of load bearing capacity will be reached, which should refer to permanent, exceptional, and seismic computational situations.

In the case of designing engineering structures in which underground water is present or flows, its impact on the structure should be taken into account when designing. The influence of groundwater on engineering structures, including sewage pumping station and sanitary sewage system, can lead to limit states commonly referred to as hydraulic failure, which should be checked by design calculations. EN 1997-1:2004: Eurocode 7 [13] standard provides in Chapter 10 four types of hydraulic failure in the soil caused by water pressure in the pores or water flow in the soil, i.e., damage caused by displacement, hydraulic lifting of soil particles, internal erosion, and hydraulic failure. In the case of selected research objects, there is a limit state of uplift (UPL). Document states that “The displacement takes place when the value of the water pressure in the pores under the structure or below the soil layer with low permeability exceeds the average density (caused by the weight of the structure and/or obstructing the above soil layers)” The limit state of displacement should be checked by comparing the permanent holding effects (e.g., building weight or soil friction on the side walls) with permanent and variable destabilizing effects caused by water (Figure 1), which are given in a form of formulas (1) and (2) [13].

\[
V_{\text{dst,d}} \leq G_{\text{stb,d}} + R_d \\
V_{\text{dst,d}} = G_{\text{stb,d}} + Q_{\text{dst,d}}
\]

Where: \( V_{\text{dst,d}} \) – vertical destabilizing permanent and variable interactions, \( G_{\text{stb,d}} \) – vertical stabilizing permanent interactions, \( R_d \) – the calculated value of additional resistance to counteracting the displacement, \( G_{\text{dst,d}} \) – vertical destabilizing permanent interactions, \( Q_{\text{dst,d}} \) – vertical destabilizing variable interactions.

In checking the conditions (1) and (2), the calculation values obtained on the basis of the characteristic values and coefficients given in Annex A of EN 1997-1:2004: Eurocode 7 of partial factors for the impacts and geotechnical parameters of the subsoil should be used. The evaluation of the possibility of the limit state of displacement is carried out by calculating the degree of utilization according to the formula [13]:

\[
\Lambda_{\text{UPL}} = \frac{V_{d,\text{dst}}}{V_{d,\text{stb}} + R_d} \cdot 100\%
\]

The degree of utilizations (safety coefficients) as the final effect of the design calculations are also determined by adopting calculation values.

4 Results

Taking into account the existing geological-engineering documentation of the analyzed objects, supplementary tests were carried out to randomly check the identified groundwater conditions with actual conditions. As part of supplementary tests, the following works were carried out: 1 drilling to a depth of 16.0 m, installation of 1 piezometer for observing the position of groundwater table, and 3 cone penetration tests CPT to a depth of 10.0 to 19.0 m (CPT-1, CPT-2, CPT-3). On the basis of the obtained test results and design documentation, calculations of the bearing capacity of the subsoil were made due to hydraulic failure – limit state of uplift (UPL) regarding the horizontal stability of the shutter from the columns planned to be made by high-pressure injection technique (the so-called jet grouting) in the subsoil of planned investments.

Drilling was made with a rotary-mechanical, mechanical, and semi-mechanized system in casing pipes. During the drilling conducted under the supervision of an authorized geologist, macroscopic soil studies were performed.
and their type and condition were recognized (Figure 2). Observations and measurements of the groundwater table were also carried out. A free groundwater table was drilled at a depth of 1.7 m below ground level and tensed at a depth of 10.0 m below ground level. The CPT-1 probes were made to a depth of 10.0 m. CPT-2 probing was made to a depth of 18.0 m, and CPT-3 probing to a depth of 19.0 m. When pressing the tip of the probe at a constant rate of 0.02 m/s, resistance values of the cone ($q_c$) and friction on the sleeve ($f_s$) were determined. These values were used to determine the condition of sandy and cohesive soils and to estimate the strength parameters of the subsoil of the analyzed object. The results of the tests are summarized in Table 1.

The calculations were carried out in order to check whether the designed aperture from the horizontal columns planned for jet grouting presented in the design documentation has sufficient thickness to balance the
The results of complementary field tests (drilling and CPT) partially confirmed the general nature of the subsoil described in the design documentation (Table 1). The results of these tests were taken into account in the technology of making a vertical diaphragm using steel sheet piles and a horizontal shutter from the jet grouting columns of the planned sewage pumping station. The piezometer installed in the borehole showed that the confined groundwater drilled at a depth of 10.0 m below ground level stabilized initially at a depth of 1.7 m. After rainfall, the groundwater level in the piezometer stabilized at a depth of 0.7 m. The result of this 

| No. | Corresponding calculation point | Depth of diagnosis (m) | Type of soil | Design documentation |
|-----|---------------------------------|------------------------|-------------|----------------------|
| CPT-1 | W11                             | 10.0                    | In the subsoil to a depth of approx. 10.0 m there are alternating layers of cohesive and organic soils and permeable non-cohesive soils. Below is a layer of compacted non-cohesive soils | 6.45 | Organic soil at a depth of max. 0.8 m, below to a depth of 6 m MSa, no interbedding |
| CPT-2 | W5                              | 18.0                    | In the subsoil up to a depth of approx. 6 m, there are alternating layers of cohesive and permeable non-cohesive soils, less than 13 m there is a layer of non-cohesive soils, the last 2 m of the soil is a cohesive layer. Below 13 m there is a non-cohesive layer | 8.0 | Organic soil at a depth of 0.3 m, below to a depth of 5.4 FSa, to a depth of 3 m cSa, below FSa to a depth of 8 m |
| CPT-3 | SD                              | 19.0                    | Up to 14.5 m there is a layer of permeable non-cohesive soils with interbedded cohesive soils. Below it is 3.5 m thick non-cohesive soils | 10 | Organic soil at a depth of up to 0.4 m, below to a depth of 1.9 m cSa, below sSa to a depth of 3 m, organic soil, to a depth of 7.1 m MSa to a depth of 9 m and below cSa |

**5 Discussion**

The results of complementary field tests (drilling and CPT) partially confirmed the general nature of the subsoil described in the design documentation (Table 1). The errors in documenting the subsoil and their impact on the design of the trench housing and the sewage pumping station for the designated forces that affect the excavation bottom for the designed pumping station and sanitary sewage system.
study influenced the adopted design solutions, because in the previous documentation it was found that confined groundwater table occurs at a depth of about 2.0 m below ground level.
The analysis of the results of calculations consisting in checking the limit state of bearing capacity due to hydraulic failure (displacement) shows that the originally designed thickness of the horizontal shutter was appropriate in the case of W1–W3, W18–W23, and BH3–BH8. Calculations for the above-mentioned excavations showed that the load degree of utilization due to hydraulic failure with the design scheme adopted in the project was above 94%, except for the BH3 excavation, for which the degree of utilization was 76%. It should be noted that the calculated values of degrees of utilizations indicate a small safety margin. If the degree of utilization exceeds 100%, stability to hydraulic failure is not maintained and the thickness of the shutter should be increased. In the case of excavations

| Designed housing | The thickness of the horizontal shutter from the jet grouting columns according to the design (m) | The depth of the water table adopted for calculations below ground level (m) | Weight of the well (kN) | Value destabilizing force (kN) | Value of stabilizing force (kN) | Utilization factor (%) | The proposed thickness of the horizontal shutter from the jet grouting columns (m) | Degree of utilization for the proposed thickness of the jet grouting column (%) |
|------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------|-----------------------------|-----------------------------|------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| W1               | 4                                                                                 | 0.95                                                            | 6.53                 | 2900.92                     | 2917.39                     | 95.67                  | —                                                                               | —                                                                               |
| W2               | 4                                                                                 | 0.95                                                            | 6.88                 | 2900.92                     | 3032.59                     | 95.66                  | —                                                                               | —                                                                               |
| W3               | 4                                                                                 | 0.95                                                            | 7.99                 | 1352.87                     | 1448.59                     | 93.39                  | —                                                                               | —                                                                               |
| W4               | 3                                                                                 | 1.6                                                             | 6.39                 | 1126.0                      | 1026.81                     | 109.66                 | 3.8                                                                              | 94.71                                                                            |
| W5               | 3                                                                                 | 1.75                                                            | 8.09                 | 2743.04                     | 2536.57                     | 108.14                 | 3.7                                                                              | 95.02                                                                            |
| W6               | 3                                                                                 | 1.6                                                             | 7.45                 | 1130.41                     | 1028.34                     | 109.93                 | 3.8                                                                              | 94.96                                                                            |
| W7               | 3                                                                                 | 1.6                                                             | 7.66                 | 1129.31                     | 1027.95                     | 109.86                 | 3.8                                                                              | 94.90                                                                            |
| W8               | 3                                                                                 | 1.6                                                             | 8.02                 | 1127.10                     | 1028.27                     | 109.61                 | 3.8                                                                              | 94.69                                                                            |
| W9               | 2.5                                                                               | 1.6                                                             | 7.12                 | 1047.62                     | 926.187                     | 113.11                 | 3.4                                                                              | 95.51                                                                            |
| W10              | 2.5                                                                               | 1.6                                                             | 7.89                 | 1039.90                     | 926.88                      | 112.19                 | 3.3                                                                              | 95.50                                                                            |
| W11              | 2.5                                                                               | 1.6                                                             | 7.85                 | 1032.17                     | 926.84                      | 111.36                 | 3.3                                                                              | 94.79                                                                            |
| W12              | 2.5                                                                               | 1.6                                                             | 7.85                 | 1017.81                     | 926.84                      | 109.81                 | 3.2                                                                              | 95.24                                                                            |
| W13              | 2                                                                                 | 1.6                                                             | 6.32                 | 953.79                      | 824.19                      | 115.72                 | 2.9                                                                              | 94.76                                                                            |
| W14              | 2                                                                                 | 1.6                                                             | 7.01                 | 935.02                      | 824.81                      | 113.36                 | 2.8                                                                              | 94.75                                                                            |
| W15              | 2                                                                                 | 1.6                                                             | 6.74                 | 914.05                      | 824.57                      | 110.85                 | 2.7                                                                              | 94.59                                                                            |
| W16              | 2                                                                                 | 1.6                                                             | 6.54                 | 878.72                      | 824.39                      | 106.59                 | 2.5                                                                              | 94.93                                                                            |
| W17              | 2                                                                                 | 1.6                                                             | 6.00                 | 848.91                      | 823.90                      | 103.04                 | 2.3                                                                              | 95.96                                                                            |
| BH1              | 4                                                                                 | 0.7                                                             | —                    | 715.73                      | 692.55                      | 103.35                 | 4.6                                                                              | 95.60                                                                            |
| BH2              | 4                                                                                 | 1.0                                                             | —                    | 2008.85                     | 1963.56                     | 102.31                 | 4.6                                                                              | 94.63                                                                            |
| BH3              | 4                                                                                 | 1.6                                                             | —                    | 2302.11                     | 3027.92                     | 76.03                  | —                                                                               | —                                                                               |
| W18              | 3.5                                                                               | 1.2                                                             | 5.82                 | 1073.17                     | 1168.40                     | 91.85                  | —                                                                               | —                                                                               |
| W19              | 3.5                                                                               | 1.2                                                             | 5.86                 | 1082.88                     | 1168.43                     | 92.68                  | —                                                                               | —                                                                               |
| W20              | 3.5                                                                               | 1.2                                                             | 7.00                 | 1101.33                     | 1169.46                     | 94.17                  | —                                                                               | —                                                                               |
| W21              | 3.5                                                                               | 1.2                                                             | 6.40                 | 1109.10                     | 1168.92                     | 94.88                  | —                                                                               | —                                                                               |
| W22              | 3                                                                                 | 1.2                                                             | 7.05                 | 1061.51                     | 1080.41                     | 98.25                  | —                                                                               | —                                                                               |
| W23              | 3                                                                                 | 1.2                                                             | 6.90                 | 1072.19                     | 1080.27                     | 99.25                  | —                                                                               | —                                                                               |
| W24              | 3                                                                                 | 1.2                                                             | 6.17                 | 1086.76                     | 1079.61                     | 100.6                  | 3.4                                                                              | 94.43                                                                            |
| BH4              | 3.5                                                                               | 1.6                                                             | —                    | 1408.22                     | 1516.10                     | 92.88                  | —                                                                               | —                                                                               |
| BH5              | 3.5                                                                               | 1.6                                                             | —                    | 1437.17                     | 1487.13                     | 96.64                  | —                                                                               | —                                                                               |
| BH6              | 3.5                                                                               | 0.5                                                             | —                    | 2340.00                     | 2353.10                     | 99.44                  | —                                                                               | —                                                                               |
| BH7              | 3.5                                                                               | 0.79                                                            | —                    | 1990.79                     | 2023.13                     | 98.40                  | —                                                                               | —                                                                               |
| BH8              | 3.5                                                                               | 0.95                                                            | —                    | 1653.26                     | 1693.16                     | 97.64                  | —                                                                               | —                                                                               |
| SD and press     | 4.4                                                                               | 0.7                                                             | 11.66 + 33.80         | 5868.88                     | 5985.41                     | 98.05                  | —                                                                               | —                                                                               |
| Valve house      | 4                                                                                 | 0.7                                                             | 50.31                | 377,121                      | 3316.73                     | 113.70                 | 4.9                                                                              | 94.25                                                                            |

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W4–W17, W24, BH1, and BH2 and gate valve chambers, the value of degree of utilization exceeds 100%, which indicates the possibility of exceeding the limit state of hydraulic displacement.

The calculations carried out on the basis of supplementary tests showed that the thickness of the horizontal shutter from the jet grouting columns in the area of excavations W4–W17, W24, BH1, and BH2 should be increased according to the values given in Table 2. For given values of horizontal thickness of the shutters, utilization ratio is around 95%. Increasing the thickness of the horizontal shutter from the jet grouting columns in the area of excavations W4–W17 and W24 as well as BH1 and BH2, as well as digging into the gate valves chamber in relation to the original concept, resulted from erroneous recognition of the subsoil in the existing documentation. In 18 research points, safety factors were exceeded, which accounted for more than 50% of test openings. The average thickness increase of the proposed jet grouting column was increased by 0.7 m (minimum 0.3 m for the W17 test point, maximum 0.9 m for S9 and W13 and the gate valve chamber). In addition, the variable trench width, on average, around 3 m at the excavation length from 1.81 to 7.41 m, increased the concrete mix volume needed by the aperture to approximately 109 m³. In the cost calculation, after adopting the average price of a concrete mix in the amount of 177 PLN/m³ and the norm of material inputs for 1 m³ of concrete mix 1.03 m³, the value of materials increased by about PLN 20,000, and thus additional costs of the planned investment increased the value of the works by approximately PLN 46,000 (Table 3).

**6 Conclusion**

The legal provisions in force in Poland are inconsistent and require uniformity in determining the difference between geological-engineering documentation and documentation of geotechnical subsoil research.

Incorrect interpretation of the regulations may lead to improper documentation, identification, and testing of the subsoil. Errors in the documentation result mainly from the lack of the obligation to perform subsoil tests for the majority of facilities. Therefore, these studies are very often marginalized and the funds allocated from the investment budget for this purpose are very low, which in turn leads to a significant reduction of their scope.

### Table 3: The value of the increase in the price of the jet grouting columns based on the Norma-Pro program

| No. | Base | Description | UM | Outlays | Unit cost | R | M | S |
|-----|------|-------------|----|---------|-----------|---|---|---|
| **Quantity survey** | | | | | | | | |
| 1 | KNR 2-02 1101-01 | Concrete foundation on the subsoil BOQ = 109,000 m³ | m³ | | | | | |
| 1* | –R– | Work hours | 573.340 | 123.87 | 13502.16 |
| | –M– | Labor | 5.26 r g/m³ · 23.55 PLN/work hour | | | | |
| 2* | | Plain concrete from natural aggregate 1.03 m³/m³ · 177.25 PLN/work hour | m³ | 112.270 | 182.57 | 19899.91 |
| 3* | | Support materials 1.5% (from M) | | 1.500 | 2.74 | 298.55 |
| | | Total direct costs: 33700.62 | | 309.18 | 13502.16 | 20198.46 |
| | | Total with markups: 46051.41 | | 422.49 | 25852.95 | 20198.46 |
| | | Unit price: 422.49 | | 237.18 | 185.31 | 0.00 |
Incorrect or incomplete subsoil test results may constitute a direct cause of nonissue of building permits, delays in the schedule and implementation of the investment, increase in the costs of the undertaking to carry out additional research and development and/or change of technology, or the occurrence of damage or failure in the resulting structures. Therefore, the solution may be to apply Eurocode 7 guidelines in the engineering practice. According to its provisions, it is required to properly design, implement, interpret, and evaluate the results of field and laboratory tests in order to properly document the subsoil conditions.

In the analyzed case, errors in the geological-engineering documentation included mainly the lack of recognition of locally occurring organic soils, the incorrectly determined location of the groundwater table, and the degree of compaction of non-cohesive soils. Early detection of the above errors contributed to the correct adoption of the sanitary sewer construction technology and the increase in the horizontal thickness of the jet grouting columns (in the range from 0.2 to 0.9 m) in the area of W4–W17, W24, BH1, and BH2 excavations. Completed calculations to check the UPL limit states showed that the load degree of utilization due to hydraulic failure with the design scheme adopted in the project was 76% to over 100%. In the case of excavations for which this index exceeded the value of 100%, the thickness of the horizontal shutter was increased in order to increase the safety level of the planned project. In complementary test in 18 per 34 test points, safety factors were exceeded, which accounted for more than 50% of test boreholes. The solutions adopted, taking into account the results of supplementary tests, prevented the difficulties with maintaining the stability of the structure and the occurrence of sewer deformations during its construction and/or operation. The adoption of the calculated values of the horizontal thickness of the apertures from the jet grouting columns increased the cost of the analyzed investment by approximately PLN 46,000. The necessity to carry out supplementary tests and the resulting change in the works technology extended the time of the planned investment by about 1 year.

The case study confirmed the need to properly document the subsoil in order to prevent the increase of costs and time of the planned investment and possible failures during construction works and during the period of operation. The most frequent cause of errors in documentation is the human factor resulting from incorrect interpretation of legal provisions, non-adjustment of the scope of subsoil diagnosis to soil conditions, and lack of experience of persons responsible for field research. The solution may be the unification of legal provisions regarding the documentation of the subsoil and the development of detailed guidelines defining the method of conducting the subsoil tests.

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