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# Project management for the construction sector in the field of foundation of buildings in complex conditions of the subsoil

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**Abstract:** Project management in the construction sector is a challenge for modern construction. The speed of implementation of construction projects becomes a priority and a very important factor affecting the financial result. The modularity and repeatability of building structure solutions nowadays turn out to be a very tempting stimulus, resulting in the integration of identical structures into different parts of the region, country and continent. Failure to use appropriate patterns and algorithm of proceedings during geotechnical analysis of the ground substrate may lead to catastrophic investment effects. The publication discusses wide geotechnical perspectives that affect the type, methods and technologies of the foundation structure of buildings and management of this investment stage. The foundation design scheme and the method of creating 3D ground substrate models were presented. The possibility of determining and selecting the appropriate design computing methodology for generous models for in situ methods and laboratory research of subsoi mechanics, actual layers of land was presented. The land model was generated in the Geo5 2022 program - 3D stratigraphy. The design was made in accordance with EC7 for all generated calculation models.

**Keywords**: Project management, design of buildings foundation structure, geotechnical models of soil substrates, models and methods of construction project management.

## 1. Introduction

Project management is the art of directing and coordinating experts, designers, architects, contractors and type and style of building materials resources throughout the life of a project by using modern management techniques to achieve predetermined objectives of scope, cost, time, quality and participation satisfaction. Successful managers of construction projects must be able to see the general large image of the project and make sure that the project is completed as part of the budget and on time. [7], [8], [11], [12] Managing the quality, scope and methodology of the geotechnic subsoil models give us an appropriate standard of output data to design the foundation structure of buildings. In addition, management of a construction project requires an analysis of compliance of geotechnic research and results of laboratory tests from subsoil mechanics, as well as analysis of design and executive compliance with all building codes in the aspect of the construction law, norms methodoly for foundations constraction and safety regulations. The foundation of a building is a very important field of science in construction. As defined by the construction law, is the lowest part of the building or the civil structure that is in direct contact with the soil which transfers loads from the structure to the soil safely. [3], [6], [10] Thus, the construction law and norms clearly states that without a foundation, a building cannot exist. Soil structure foundation models can be created in three dimensions. Model has its own set of boundary, calculation method and ultimately, advantages when applied to civil engineering calcuations. These models are the most accurate representations of reality. All of the dimensions are taken into account. [1], [2]

## 2. Legal and Methodological Aspects

### 2.1 Legal Aspects

The legal basis specifying the guidelines and principles of foundation are legal basis for the construction sector in Poland, accession treat, European directives, the mandate of the European Commission and regulation of the European Parliament and Council of the EU. Methodological foundations are in harmonized technical specifications and all main guidelines are approved in the law on standardization, construction law act (basic requirements, technical conditions), ordinance of on geotechnical foundation conditions

### 2.2 Methodological Aspects

The methodological foundations, i.e. norm PN-EN 1997-1 Eurokod 7. Geotechnical design. Part 1: General principles and PN-EN 1997-2 Eurokod 7. Geotechnical design. Part 2: Identification and testing of the subsoil. In the management of the construction investment, the legal and methodological grounds for creating construction projects and for the implementation of their provisions and indication are the basis for verifying and checking the basics of the created investment.

## 3. Limit States

The ultimate limit state is the design for the safety of a structure and its users by limiting the stress that materials experience. In order to comply with engineering demands for strength and stability under design loads, ULS must be fulfilled as an established condition. EN 1990 Eurocode – 'Basis of structural design' describes four ultimate limit states: EQU: Loss of static equilibrium of the structure. STR: Internal failure or excessive deformation of the structure, GEO: Failure or excessive deformation of the ground. FAT: Fatigue failure of the structure. The following limit states shall be considered:

- loss of overall stability;
- bearing resistance failure, punching failure, squeezing;
- failure by sliding;
- combined failure in the ground and in the structure;
- structural failure due to foundation movement;
- excessive settlements;
- excessive heave due to swelling, (frost and other causes);
- unacceptable vibrations.

According to the EN 1997 standard, in justified cases (sometimes in all cases), it should be checked whether the following five ultimate (stability) limit states are not exceeded [7]:

- loss of balance of the structure or the ground, considered as rigid bodies - they ensure the bearing capacity of the soil (EQU limit state);
- internal damage or excessive deformation of the structure or structure elements (limit state STR);
- destruction or excessive deformation of the substrate (GEO limit state);
- loss of stability of the structure or subsoil due to water pressure (buoyancy) or other vertical actions (UPL limit state);
- hydraulic damming, internal erosion or hydraulic breakthrough in the ground caused by hydraulic drop (limit state HYD).

The SLS - servicability limit state is the design to ensure a structure is comfortable and useable. This includes vibrations and deflections (movements), as well as cracking and durability. These are the conditions that are not strength-based but still may render the structure unsuitable for its intended use, for example, it may cause occupant discomfort under routine conditions. SLS requirements tend to be less rigid than strength-based limit states as the safety of the structure is not in question. A structure must remain functional for its intended use subject to routine loading in order to satisfy SLS criterion.

## 4. Foundation Types

The choice of the foundation type is an important role in the foundation of the building and it depends on the structural system of the building and the ground conditions at the site of construction (plot). The foundation should fulfill the following objectives: * distribute the weight of the structure over a large area of soil, * increase structural stabilit, * avoid unequal settlement ang * prevent the lateral movement of the structure. The main division of foundations concerns the transfer of loads to the subsoil. [2]

In general, all foundations are divided into two categories, - shallow and deep foundations. The terms SF or DF refer to the depth of the soil at which it is placed. Generally, if the width of the foundation is greater than the depth, it is labeled as the SF - shallow foundation. If the width is smaller than the depth of the foundation it is called as DF - deep foundation.

### 4.1 Shallow Foundations

The direct foundations (foundations transmitting the load directly to the ground) are divided into:

- isolated spred footing foundation;
- wall footing;
- foundation plates;
- combined footing foundation;
- cantilever footing foundation;
- strap footing foundation;
- raft foundation;
- mat foundation.

**4.2 Deep Foundations**

Deep foundations (transmitting the load indirectly) are divided according to [2] into:

- foundation piles:
- normal piles - transfer the load to the soil through the friction on the side surface and the resistance under the pile foot;
- suspended piles - transfer the load to the ground through friction on the pile side;
- standing piles - transfer the load to the ground through the pile foot (eg piles resting on the rock with their foot);
- pier foundation;
- caissons foundation;
- columns;
- poles;

## 5. Foundation and Depth of Foundation

General factors to be considered for determining depth of foundation are:

- usage requirements
- ground freezing depth
- load applied from structure to the foundation
- bearing capacity of soil
- depth of water level below the ground surface.
- types of soil and depth of layers in case of layered soil
- economic feasibility

So the depth of the building foundation depends on many factors, In Poland, we have four separated soil freezing zones with specific minimum depths of buildings – Fig. 1.

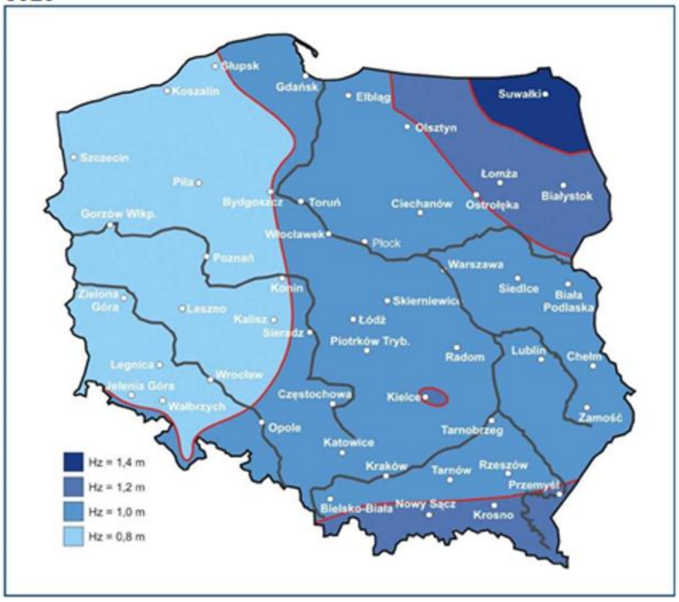


Fig. 1. Illustrating the depth of ground freezing in Poland by PN-81/B-03020

The minimum depth of foundation should be considered to ensure that the soil is having the required safe bearing capacity as assumed in the design. However, it is advised to carry out soil investigation before deciding on depth of foundation. Soil investigation report will suggest the foundation depth based on the type of structure, soil properties, depth of water table, and all other variable that should be considered. Soil investigation report provides bearing capacity of soil at different levels and at different locations. The arrangement of the bearing layers of the soil: the foundation, and more specifically its base, must rest on the ground ensuring the given bearing capacity. The arrangement and load-bearing capacity of the layers is determined on the basis of geotechnical analyzes (tests). Their result influences the basis for the choice of the foundation method Economic and management feasibility is one of the most important factors for selection of foundation system.

## 6. Foundation Desing By EC7

The main basis for the calculation of foundations is Eurocode 7 "Geotechnical Design" which clearly defines the design cycle. At the outset, it should be added that the Eurocode in the ultimate limit state method distinguishes between 2 groups::

- ULS - ultimate limit state;
- SLS – serviceability limit state;

### 6.1 Ultimate Limit State ULS

- Equ - Loss of Balance of Structure or Substrate
- Str - Internal Damage or Excessive Deformation of Structures or Structural Components
- Geo - Damage or Excessive Deformation of the Ground
- Opl - Loss of Substrate Stability or Construction Hyd- Hydraulic Lift of Ground Particles Internal Erosion or Hydraulic Break in the Substrate

### 6.2 Serviceable Limit State SLS

- Excessive Setting
- Excessive Polishing Caused by Frost or Other Factors Unacceptable Vibration

## 7. Geotechnic Ground Conditions

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 the construction investment management model, the analysis of the scope, type, quantity and method of testing geotechnical parameters interacting with the emerging construction structure is a key point, because bad foundation generates wolf problems for the entire project. Insufficient recognition and documentation of geotechnical and engineering conditions leads to damage and construction failures, delays in consider construction, and the increase of the investment budget. That's why particular attention should be paid to proper geotechnical-engineering documentation at the design and construction stages.

In fundament, one of the key aspects of selecting the calculation methodology is soil conditions depending on the degree of their complexity according to [5] where we have three main types of ground ground in admiration according to the category of condensation;

1) simple - occurring in the case of layers of genetically and lithologically homogeneous soils, lying horizontally, not including low-bearing mineral soils, organic soils and uncontrolled embankments, with the water table below the planned foundation level and the absence of unfavorable geological phenomena;
2) complex - occurring in the case of heterogeneous, discontinuous soil layers, genetically and lithologically variable, including low-bearing mineral soil, organic soil and uncontrolled embankments, at the groundwater table at the level of the planned foundation and above this level, and in the absence of unfavorable geological phenomena;
3) complicated - occurring in the case of soil layers subject to unfavorable geological phenomena, especially karst, landslide, suffosion, dust-like, glacitectonic, expansive and sinking soils, in areas of mining damage, with possible discontinuous deformations of the rock mass, in the areas of valleys and deltas rivers and sea areas;

The key aspect of selecting the foundation structure for the type of soil and the load it is to carry, and it is the geotechnical categories that clarify the above issues. We divide them into the first, the second and the third geotechnical category.

**7.1 First Geotechnical Category**

Geotechnical Category 1 should only include small and relatively simple structures for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations with negligible risk. Geotechnical Category 1 procedures should be used only where there is negligible risk in terms of overall stability or ground movements and in ground conditions, which are known from comparable local experience to be sufficiently straightforward. In these cases the procedures may consist of routine methods for foundation design and construction. Geotechnical Category 1 procedures should be used only if there is no excavation below the water table or if comparable local experience indicates that a proposed excavation below the water table will be straightforward.

The first geotechnical category includes small structures, with a statically determinable calculation scheme in simple ground conditions, for which it is possible to meet the minimum requirements based on experience and qualitative geotechnical research and belong to it [8]:

- one- and two-storey residential and utility buildings;
- retaining walls and trench struts, if the level difference does not exceed 2.0 m;
- excavations up to 1.2 m deep and construction embankments up to 3.0 m high, in particular for road construction, drainage works and laying pipelines;

**7.2 The Second Geotechnical Category**

Geotechnical Category 2 should include conventional types of structure and foundation with no exceptional risk or difficult soil or loading conditions. Routine procedures for field and laboratory testing and for design and execution may be used for Geotechnical Category 2 designs. The second geotechnical category are construction objects located in simple and complex ground conditions, they require quantitative and qualitative recognition of the obtained analyzes, as well as geotechnical data such as [8]:

- direct or deep foundations;
- other retaining walls or other retaining structures supporting soil or water;
- spread foundations;
- raft foundations;
- pile foundations;
- walls and other structures retaining or supporting soil or water;
- excavations;
- bridge piers and abutments;
- embankments and earthworks;
- ground anchors and other tie-back systems;
- tunnels in hard, non-fractured rock and not subjected to special water tightness or other requirements

**7.3 Third Geotechnical Category**

Geotechnical Category 3 should include structures or parts of structures, which fall outside the limits of Geotechnical Categories 1 and 2, and should normally include alternative provisions and rules to those in this standard. Geotechnical Category 3 includes the following examples:

- building structures founded in complex ground conditions
- very large or unusual structures;
- structures involving abnormal risks, or unusual or exceptionally difficult ground or loading conditions;
- structures in highly seismic areas;
- structures in areas of probable site instability or persistent ground movements that require separate investigation or special measures.
- atypical construction facilities, regardless of the complexity of the ground conditions, the execution or use of which may pose a serious threat to users (for example, power engineering facilities, chemical plants, dams)
- facilities whose construction designs contain new technical solutions that are not proven in national practice, which do not find any basis in the regulations

- construction objects classified as investments that can always have a significant impact on the environment
- high-rise buildings designed in the existing urban development
- tall structures with a direct foundation depth exceeding 5.0 m or with more than one storey buried in the ground
- tunnels in hard and non-cracked rocks, in conditions that do not require special tightness; critical infrastructure facilities; historical and monumental objects

## 8. Design Approach

### 8.1 Establishment of the Geotechnical Category - Research

The geotechnical category of the entire building structure or its individual parts is determined by the designer of the building structure on the basis of geotechnical investigations of the soil, the scope of which is agreed with the contractor of specialized geotechnical works. After determining other than assumed in the research geotechnical conditions of the ground, the designer of the building changes its geotechnical category, which allows for the application of optimal technical and construction solutions [4], [6]. All the conditions for the foundation are presented in the regulation [4], where in § 5 there is information that the geotechnical conditions of the foundation are determined, in particular, on the basis of the current results of geotechnical investigations of the soil, analysis of archival data, including the analysis and assessment of geotechnical, geological and geological documentation. engineering and hydrogeology, geodetic observations of the behavior of neighboring objects and other data on the substrate of the studied area and its surroundings.

The following paragraphs provide information that: §6.1. The scope of geotechnical investigations of the soil is determined depending on the geotechnical category of the building object. §7.1. In the case of construction objects of all geotechnical categories, a geotechnical opinion is prepared. §8. The geotechnical opinion should determine the suitability of land for construction purposes and indicate the geotechnical category of the building object. §9. Subsoil testing documentation in accordance with Polish Standards PN-EN 1997-1: Eurocode 7: Geotechnical design - Part 1: General rules and PN-EN 1997-2: Eurocode 7: Geotechnical design - Part 2: Ground identification and testing should include a description of the methodology of field and laboratory soil tests, their results and interpretation, a geological model and a summary of the derived geotechnical data values for each layer.

The legal significance of Eurocode standards for the design and calculation of the foundation structure in § 10 is of key importance, where it is specified that:
Geotechnical design in accordance with Polish standards PN-EN 1997-1: Eurocode 7: Geotechnical design - Part 1: General rules and PN-EN 1997-2: Eurocode 7: Geotechnical design - Part 2: Ground identification and testing should include:

a. a forecast of changes in the properties of the subsoil over time;
b. determination of computational geotechnical parameters;
c. determination of partial safety factors for geotechnical calculations;
d. determination of ground-related actions;
e. adoption of the subsoil computational model, and in simple cases, the design geotechnical cross-section;
f. calculation of the bearing capacity and settlement of the subsoil as well as general stability;
g. determining the data necessary to design the foundations;
h. specification of tests necessary to ensure the required quality of earthworks and specialized geotechnical works;

The regulation [5] clearly presents the cause-and-effect cycle, which is determining the suitability of land for construction purposes, and clearly defines the principles and description of the methodology of conduct during the in situ work cycle, also clearly presents the composition of the elementary components of the geotechnical design. [6]

### 8.2 Determination of the Geotechnical Category - Research Methods

The subsoil method and the documentation of the technical data carrier for the subsoil, carried out by the geotechnical subsoil, contain detailed information on the material properties and the subsoil. The next substrate has access to security information that can be obtained on materials that can be inserted to allow access to the bank. They constitute the terrain in the local itinerary. [6] As a result of the diagnosis, the parameters of reliable soil parameters, for which it is known, should be obtained:

Table No. 1. Subsoil parameters [6].

| **Reliable Soil Parameters** | | |
|---|---|---|
| **A** | **B** | **C** |
| quality of the parameter in terms of statistical analysis for the conducted research in situ | quality of the sample intended for laboratory testing | the impact of the heterogeneity of the soil medium on the determination of a representative parameter for the separation in the substrate, the so-called geotechnically homogeneous layer |

**8.3 Establishment of the Geotechnical Category - 3d Model**

Appropriate input data characterizing the primed subsoils are used to create a multi-zone model of the subsoil, on the basis of which its load-bearing capacity is estimated, and thus determines the conditions necessary for the design of the foundation of the structure and architectural solutions of buildings. [6], [9]

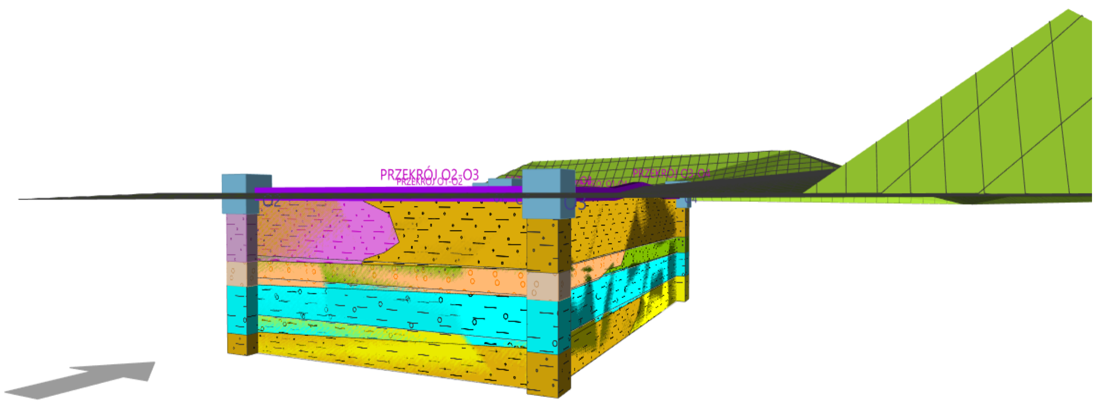


Fig. 2a. 3D Model 1/4 [9]

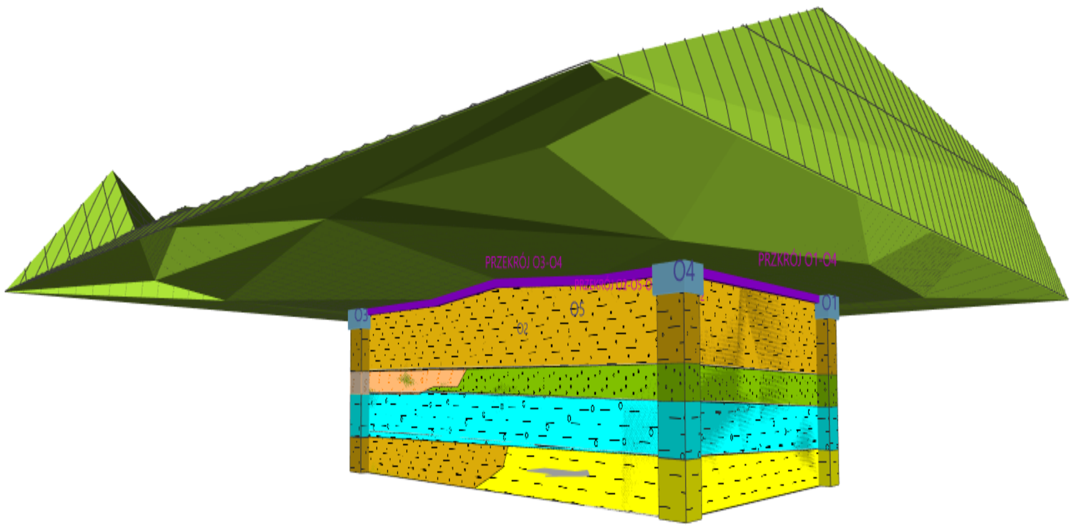


Fig. 2b. 3D Model 2/4 [9]

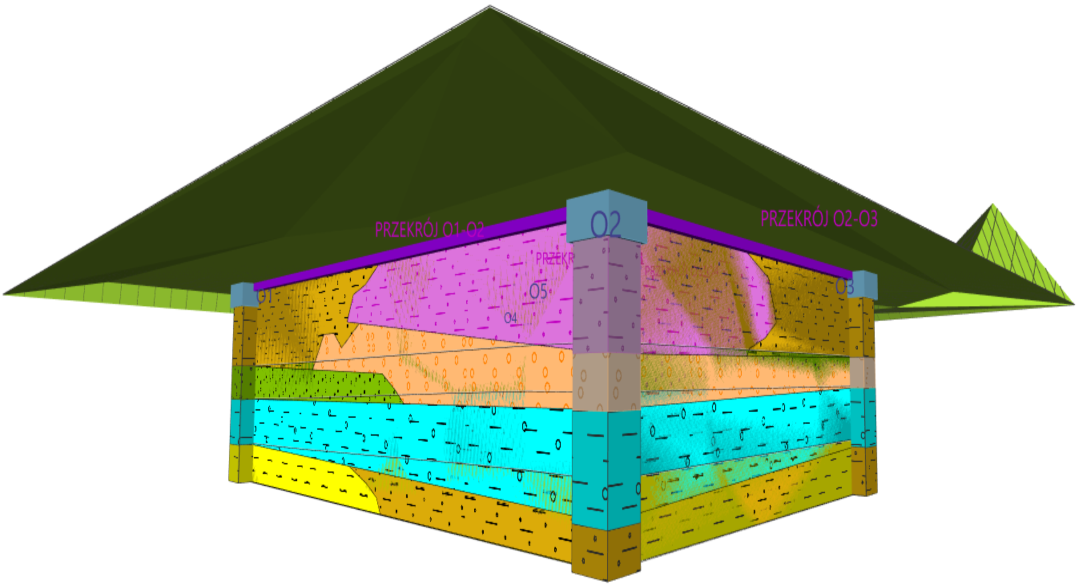


Fig. 2c. 3D Model 3/4 [9]

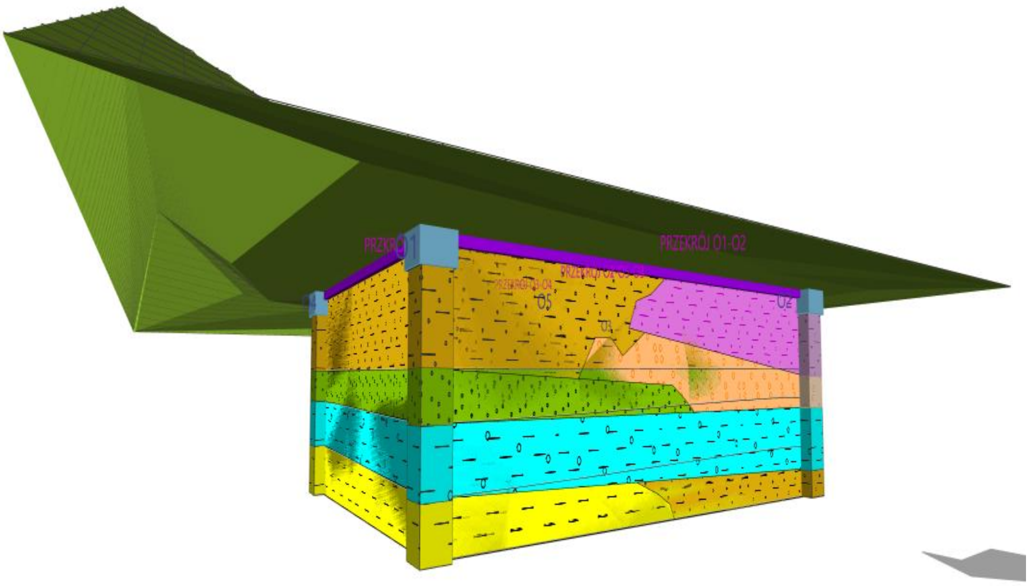


Fig 3d. 3D Model 4/4 [9]

This method allows for representation of the layer system in a cross-section, possible in a 3D model, and thus the possibility of determining and selecting an appropriate calculation method in presented subsoil layers. [9] The adoption of geotechic output parameters to the design procedure of the foundations has the appropriate basis for estimating medium parameters with an investment rice [10], [11].

## 9. Discussion

The geotechnic 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. This is from the main versions of the implementation of the construction investment in Poland. Incorrect or incomplete subsoil test results which you can see on 3D models with the appropriate tables (medium, maximum, mimal or median values of geotechnic parameters), constitute a cause of building permits, delays in the schedule and implementation of the investment. The money saved for laboratory research and to create full ground ground models for planned construction investments aren't very often an economic solution. The geotechnic 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. Incorrect or incomplete subsoil test results which you can see on 3D models with the tables of values of geotechnic parameters, constitute a direct cause of nonissue of building permits, delays in the schedule and implementation of the investment. [11], [12]

The apply Eurocode 7 guidelines in the engineering practice gives an optimal approach with low investment risk when managing construction. 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.

Completed calculations to check the EQU, STR and GEO limit states showed that the results of checked border states for geotechic parameters estimated and accepted by the same in situ research method for: a) model from 1 well, b) model with 2 wells c) model with 4 wells d) model with 5 wells, illustrate the most profitable solution for model with 5 wells. The five -point study gives confirmation of the assumed values in the stopping between research points. The risk of error when estimating average computing values is the smallest [10], [11].

The results of the implemented diploma thesis [9] 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
- the development of detailed guidelines defining the method of conducting the subsoil tests
- connecting the 3D modeling standard for construction investments for the optimal solution regarding the type, quantity and quality of in situ tests and laboratory tests of land mechanics parameters

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