Smart Geotechnics for Smart Societies – Zhussupbekov, Sarsembayeva & Kaliakin (Eds)

Application of information modeling technology in geotechnics

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ABSTRACT: Geotechnics is an essential component of construction and engineering that involves studying how rock and soil interact with structures. Borehole drilling and sample collections are traditional methods used to collect subsurface data, but they are time-consuming, expensive, and only cover a small area. Information modeling technology can address these challenges by building intricate digital models of subsurface conditions that are more accurately and effectively used to design and analyze structures such as buildings, bridges, tunnels, and dams. This article discusses the main stages of creating an information model of a geotechnical object, including preparatory work, preliminary tests and work volume determination, field tests, and laboratory tests. The resulting digital engineering-geological model should include the geometric dimensions of the investigated soil mass and the physical and mechanical characteristics of the soils in the IFC data format.

1 INTRODUCTION

Any building or structure is built on a soil foundation or is located directly in the thickness of the soil. Its strength, stability and normal operation are determined not only by the structural features of the structure, but also by the properties of the soil, the conditions of interaction between the structure and the foundation (Talapov, 2021 & Talapo, 2015).

The cost of foundations is on average 12% of the cost of the structure, labor costs often reach 15% or more of the total labor costs, and the duration of the construction of foundations reaches 20% of the total construction time of the structure. In difficult soil conditions, these figures increase significantly. Therefore, the improvement of design and technological solutions in the field of foundation engineering will lead to large savings in material and labor resources, and a reduction in the construction time for buildings and structures (*https://www.planradar.com/ru/bim-tekhnologii-v-stroitelstve*).

With the assignment to the city of Astana of the honorary title - the capital of the Republic of Kazakhstan, the development of its territory is being carried out at an accelerated pace. Under these conditions, the analysis and optimization of one or more factors that are repeatedly repeated in production can provide a significant economic effect, as well as significantly improve and increase the efficiency of this type of work.

The territory of Astana is due to rather complex engineering and geological conditions, which is confirmed by a large variety of stratification of relatively weak soils in the upper part of the base, but at the same time, the bearing layers of the soil turn out to be quite reliable (*https://www.planradar.com/ru/bim-tekhnologii-v-stroitelstve*).

Designers in these conditions, when choosing foundations, often use pile foundations, the bearing capacity of which is not fully used in projects, and in some cases its underutilization reaches 40%. This leads to unjustified expenditure of funds, material and labor resources, due to the incomplete use of the bearing capacity of piles in terms of soil and material.

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The design and construction of economic structures of pile foundations is possible if there is sufficiently representative and reliable information about the conditions of occurrence and properties of soils at construction sites, which are obtained as a result of soil studies during engineering and geological studies.

The presence in the projects of excessive reserves of the bearing capacity of piles can be explained by the following reasons:

– inferior engineering and geological surveys.
– manifestation by designers of excessive caution due to the fact that the structures of pile foundations are assumed by them to be insufficiently reliable;
– the experience of previous construction, in similar soil conditions, is not taken into account.

Geotechnics is a crucial aspect of construction and engineering. It entails examining and comprehending how rock and soil behave and interact with structures. Construction projects might suffer from costly and deadly mistakes if subsurface conditions are not accurately or sufficiently disclosed. Borehole drilling and sample collection are two common traditional techniques for getting subsurface data, but they can be time-consuming, expensive, and only cover a small area.

These issues can be resolved using information modeling technology, which builds intricate digital models of subsurface conditions. These models can be used more accurately and effectively to build and analyze structures. This article examines the use of information modeling technology in geotechnics.

2 GEOTECHNICAL ENVIRONMENT OF ASTANA CITY

The mechanical composition of floodplain deposits is more or less uniform. This is unsorted gravel, sandy-clay and loamy material. The heaviest precipitation is observed in the floodplain of the Nura and in the narrowed sections of the Ishim valley. Floodplain deposits of Kulanutpes are usually sandy-loamy. The formation of spits and shoals is currently taking place. Deposit thickness up to 4m. In terms of studying the geological features of the territory of Astana, the results of studies obtained in the course of his work by Popov V. N. are also of particular interest (Zhussupbekov et al. 2023 & Zhussupbekov et al. 2021 & Zhussupbekov et al. 2019a & Zhussupbekov et al. 2019b & Zhussupbekov et al. 2020) and Alibekova N.T. (Alibekova et al. 2020 & Zhussupbekov and Alibekova. 2013).

Popov V.N. in his work (Zhussupbekov et al. 2023 & Zhussupbekov et al. 2021 & Zhussupbekov et al. 2019a & Zhussupbekov et al. 2019b & Zhussupbekov et al. 2020), conducted research to assess the geotechnical conditions of the territory of Astana, the results of which include:

– description of geomorphological characteristics, within the boundaries of the city, on the basis of which a geomorphological map was compiled at a scale of 1: 100,000;
– hydrological conditions were described and a hydrological map was drawn up at a scale of 1:100,000;
– the geological conditions were studied taking into account the influence of geotechnical loads and a geotechnical map of the scale 1:100000 was compiled, with an explanatory table to it;
– an assessment of the physical and mechanical properties of soils was made by conducting a complex of field and laboratory studies;
– an assessment of the geo-ecological state of the territory was given.

The predominant geomorphological type of terrain in the region of Astana and the adjacent territory is the watershed plain. The southwestern part of the territory is characterized by two types: high and low floodplains.

The floodplain terrace separates the high floodplain from the watershed plain, which can be classified as a river terrace (Figure 1).

In addition, on the basis of the geomorphological map, a geotechnical map (Figure 2) of the territory of Astana was compiled.

On the basis of the geophysical surveys and reference drilling with a depth of up to 40 m, Popov V.N. indicated that along the Astana-Rozhdestvenka highway there is a zone of a sharp drop in the depth of the roof of sedimentary rock, extending in the meridional direction (Figure 1), which should be addressed attention when designing high-rise buildings in the area.

Alibekova N.T. (Zhussupbekov et al. 2023 & Zhussupbekov et al. 2021 & Zhussupbekov et al. 2019a & Zhussupbekov et al. 2019b & Zhussupbekov et al. 2020 & Alibekova et al. 2020 & Zhussupbekov and Alibekova. 2013), together with Japanese geotechnicians, for the first time created the Geoinformation Database program based on the materials of engineering and geological surveys to assess the engineering and geological conditions of the built-up area of the city.

This program, at the time of its creation, included data from 1200 boreholes, 402 static sounding points and 125 dynamic sounding points and static and dynamic load pile tests, which made it possible to analyze the regional soil conditions before a detailed study (Figure 2) (Buranbayeva et al. 2023 & Zhussupbekov et al. 2022 & Buranbayeva et al. 2021 & Omarov et al. 2021 & Zhussupbekov et al. 2021 & Zhussupbekov et al. 2020a & Zhussupbekov and Omarov 2020 & Zhussupbekov et al. 2020b & Zhussupbekov et al. 2019a & Zhussupbekov et al. 2019b & Zhussupbekov et al. 2019c & Zhussupbekov et al. 2018 & Zhussupbekov et al. 2015 & Zhussupbekov et al. 2016a & Zhussupbekov et al. 2016b).

Figure 1. Geomorphological map. (Popov).

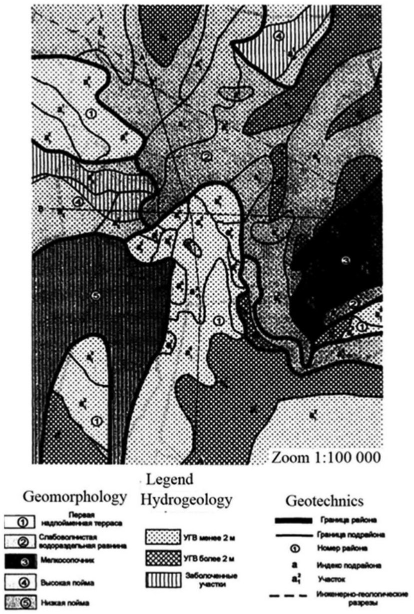


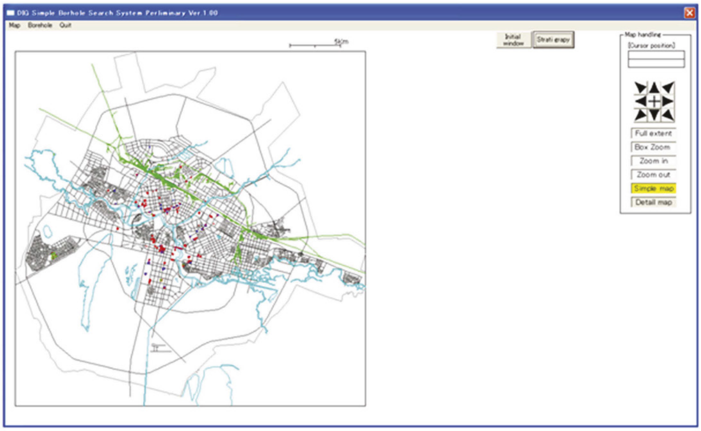
Figure 2. Geotechnical map of Astana.

With the help of the "Geoinformation Database" program, six main engineering-geological elements (EGE) of various origin and age were identified, and maps were built for them by thickness [9]:

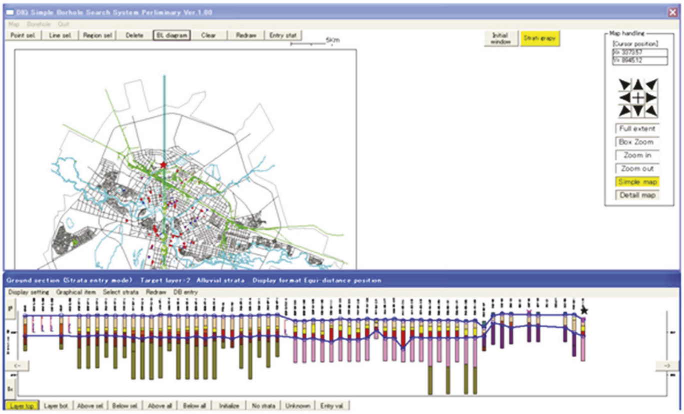
- EGE-1 - technogenic deposits (tIV) are represented by a soil-vegetation layer (EGE-1a) and bulk soil (EGE-1b). The loamy soil-vegetation layer has a thickness of 0.2 to 0.5 m. Bulk soils are composed of Quaternary loams, construction and household waste, the thickness varies from 0.2 to 2.0 m.
- EGE-2 - alluvial mid-Quaternary modern deposits a (QII-IV) are represented by clayey soils, consisting mainly of loams (EGE-2a) with intercalation of sandy loams (IGE-2b), clays (IGE-2c) and silt (IGE-2g), throughout their thickness they have lenses and interlayers of sands of various sizes up to 1-3 cm, sometimes up to 10 cm. The thickness of these soils varies from 0.9 to 10.0 m.
- EGE-3 - alluvial mid-quaternary sand and gravel formations a (QII-IV) consist of sands of various sizes (EGE-3a), gravel sands (EGE-3b) and gravel soils (IGE-3c). The thickness of

sands of various sizes varies from 0.4 to 8.3 m, gravelly sands from 0.5 to 6.5 m, gravel soils from 1.0 to 9.2 m.

– EGE-4 - eluvial formations of the weathering crust e(C1) are presented in the form of loams and clays with lenses and interlayers of sandy loams and inclusions of gruss-rubble soils occurring at depths of 6.0-10.0 m.
– EGE-5 - eluvial formations in the form of gruss-rubble soils e(C1) are widespread in the study area and they were found at depths from 7.0 to 23.0 m.
– EGE-6 - sedimentary rocks of the Lower Carboniferous (C1) are represented mainly by sandstones, which are interbedded with siltstones and mudstones of the same age throughout their thickness. They occur at depths from 11.6 to 26.2 m.



a) a map of the city territory showing engineering and geological wells



b) geological and lithological section South-West

Figure 3. General view of the program “Geoinformation database” (Alibekova et al. 2020).

In addition, with the help of the Geoinformation Database program, engineering-geological sections were built, which made it possible to assess the conditions of soil occurrence, on the basis of which it was revealed that these elements form about eight types of foundations up to bedrock (Figure 4).

The engineering-geological, geomorphological and hydrological description of the territory of Astana considered above by various authors in their works V.I. Dmitrovsky, Popov V.N. and Alibekova N.T. (Figure 4) provide a cartographic display of the construction characteristics of the geological environment and make visual results of engineering and geological surveys, and

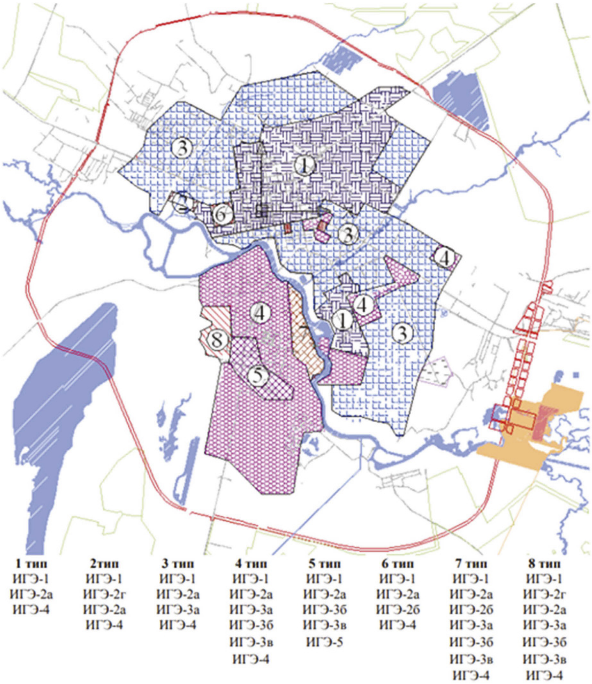


Figure 4. Zoning of the territory of the city of Astana by types of grounds (Zhussupbekov and Alibekova 2013).

can also serve as the basis for the analysis of the geological environment in order to optimize the length of the piles.

3 GEOTECHNICAL USE OF INFORMATION MODELING TECHNOLOGY

The creation of digital models of subsurface conditions is a step in the application of information modeling technology in geotechnics. The process includes collecting data on soil and rock layers, groundwater, and other geological features, and creating a three-dimensional digital model using specialized software. The digital model can then be used to design and analyze structures, such as buildings, bridges, tunnels, and dams.

The step of data collection entails boring holes, gathering samples, and performing laboratory tests. A three-dimensional model of the subsurface conditions, including soil and rock layers, groundwater, and other geological elements, can be made using the data gathered. To build a more complete model, this digital model might also include additional data, such as topographical and environmental data.

The digital model can be used to design and examine structures once it has been constructed (Liam et al. 2016). The behavior of the rock and soil layers and their interactions with the structure can be simulated by the software. This can assist identify potential problems before construction and offer insightful information on the structure's performance.

Let's consider the main stages of creating an information model of a geotechnical object:

1. Preparatory work.
   Create a project. Enter the site plan of the survey area. Enter the technical characteristics of the object. Enter the locations of the boreholes and field tests. Choose a method of field testing and enter equipment parameters. Choose the type of correlation equations.
2. Preliminary tests and determination of work volumes.
   Perform preliminary static penetration tests at four points at the corners of the survey area,

determine the type of soils (engineering-geological element), physical and mechanical properties of soils, and the depth of compressible strata. Refine the number of boreholes and field test locations, the volume of field and laboratory soil tests. Make changes to the site plan.

3. Field tests.
   Static probing. Dynamic probing. Testing with a flat or helical stamp.
4. Laboratory tests.
   Using the data from field and laboratory tests, develop a digital engineering-geological model (DEGM) of the survey area (in IFC data format). The model should include the geometric dimensions of the investigated soil mass and the physical and mechanical characteristics of the soils. An example of such a model created in the Geotek Field program is shown in Figure 5.

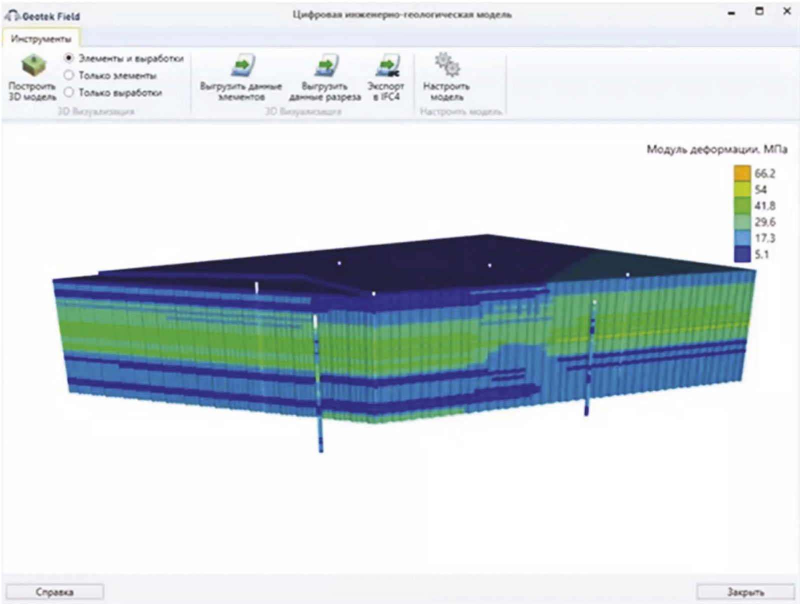


Figure 5. Digital engineering-geological model of the base of the building.

The file with the IFC extension contains an information model of a building or structure and is used to exchange model data between different computer-aided design systems that support the Building Information Modeling (BIM) standard. The file includes data on spatial elements, materials, and forms of the construction object model. Programs such as Graphisoft ArchiCAD, Autodesk AutoCAD, FreeCAD, and others support working with IFC files.

From the point of view of the authors of the article, which explores the potential use and benefits of BIM technologies in the construction sector (Bryde et al. 2013), a BIM model should include at least the following geotechnical information:

1. Information on geological workings.
2. Rules for constructing engineering-geological sections between wells.
3. A table of the main indicators of physical and mechanical properties of soils, determined in accordance with the current normative literature.

The following information may also be present:

1. Results of static probing performed directly at the construction site.
2. Results of soil testing with screw stamps or pressiometric tests.
3. Protocols for conducting soil tests, including triaxial tests.
4. Results of determining additional characteristics (RQD, OCR, data from dynamic probing, data from geophysical studies, etc.).

5. Data from hydrogeological studies.
6. Alternative data on the main indicators of physical and mechanical properties of foundation soils as a result of additional surveys.
7. Data on work performance (including ground freezing, excavation of the pit, discrepancies in the actual geological structure compared to the results of engineering-geological surveys, deviations of piles from design positions, presence of a sludge layer, defects in piles, results of concreting, lack of contact between the foundation and the base, defects in waterproofing, etc.).
8. Information about communications.

Note that the engineering digital terrain model usually includes information about communications that are located close to the surface. However, part of the communications on it cannot be shown for various reasons.

When constructing foundations, the possible number of adjustments to the design documentation is significantly higher than when constructing aboveground structures. This is due to the difference in the actual geological structure of the site from the results of surveys, the presence of hidden voids in the soil, and the impossibility of accessing all areas of the constructed structures (primarily this applies to piles and structures constructed using the "wall in the ground" method). From this perspective, the implementation of information technologies in the production of work on the construction of all types of foundations is a relevant task.

3.1 *Conclusions*

The analysis of the engineering-geological conditions of the territory of the city of Astana and the experience of building pile foundations in the territory of Astana in the conditions of a variety of building complexes and soil stratification made it possible to establish that the engineering-geological conditions of the construction area and the characteristic features of buildings and structures are not sufficiently taken into account when forming the development of quarters, choice of foundation designs and technology of their construction. These circumstances lead to a significant rise in the cost of foundations and lengthening the construction of buildings and structures.

The application of BIM technology in geotechnical engineering provides a collaborative platform for collaboration among all stakeholders, from the geotechnical engineer to the architect, contractor and owner. It provides a 3D model that can collect and visualize geotechnical data, including soil profiles, well logs, and geophysical surveys. This data can be used to make informed decisions during the design phase, such as choosing the best type of foundation or slope stabilization measures. Geotechnical engineers can model soil and structure behavior, analyze the effects of various loads, and optimize the structure accordingly. During the construction phase, BIM technologies can be used to create a virtual construction site that allows contractors to plan construction sequences, visualize earthworks and identify potential hazards. The use of BIM technology allows you to increase efficiency, as well as reduce the number of errors and rework. In conclusion, the use of information modeling in geotechnical engineering has revolutionized the industry by providing a collaborative platform for all stakeholders from the design phase to construction, maintenance and management. By incorporating geotechnical data into the BIM model, engineers can design more efficiently, reduce errors, and optimize designs for safety and sustainability.

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