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Geotechnical interpolation methodology for determining intermediate values of soil properties

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Abstract. The article considers the application of geotechnical interpolation using ArcGIS software to determine the intermediate geotechnical properties of soils at a construction site in a residential complex in Astana, Esil district. The study is based on data from 8 boreholes drilled to a depth of 26 meters, and the purpose of the work is to use the kriging interpolation method to determine intermediate soil properties. The raw data include the results of analyzing the physical and mechanical properties of the soils from the boreholes, which served as a basis for interpolation and mapping. The results of the study are presented in the form of maps showing the intermediate mechanical properties of the soil at depths of 5, 10 and 15 m. The maps allow obtaining more accurate intermediate values. The proposed methodology not only facilitates the work of designers, but also provides data for realistic scenarios of soil strength and deformation characteristics, which significantly influences the selection of optimal types and sizes of foundations.

Keywords: geotechnical interpolation, ArcGIS software, Kriging, GIS, geotechnical engineering conditions, design optimization, data visualization.

1. Introduction

Over the past two decades, the development of geographic information systems (GIS) has led to their use for collecting, monitoring and analyzing geospatial data, providing a platform for combining different types of data and organizing information in visualizations using maps and 3D, allowing data to be stored, shared, analyzed and modified based on their actual location and requirements [1].

Geotechnical investigations play a key role in the civil engineering process but are often neglected due to various reasons such as ignorance, negligence or financial constraints [2].

However, geotechnical data collected by various organizations can be effectively used through GIS to map the geotechnical properties of the soil in an area, which helps reduce the time and cost of analysis and reduce construction delays [3].

GIS plays a critical role in developing data management systems to centrally store various soil properties and also facilitates data visualization and interpretation, making it a valuable tool for geotechnical engineering projects [4].

ArcGIS provides spatial analytics tools for interpolating data and identifying unknown data points, integrates with different domains depending on project requirements, is used by researchers to analyze location-based aspects such as land use and change detection, serves to store and manage geotechnical data, and enables the creation of three-dimensional data models, enhancing visualization and analysis capabilities in geotechnical projects [5].

The use of geotechnical data, including soils maps and zoning through ArcGIS, helps reduce the cost and time of engineering projects by guiding site investigation and preliminary design, emphasizing the importance of understanding subsurface conditions, such as soil type and resistance, to safely and economically complete a project, and highlights the potential of spatial geotechnical data in planning site investigations and informing foundation design, while recognizing the need to [6].

This paper [7] discusses a method to account for the spatial variability of soil properties in geotechnical design using random fields based on cone penetration test (CPT) data, which provides a more accurate representation of in-situ soil variability and makes efficient use of available field data, and investigates the effect of the number of CPT measurements on reducing spatial uncertainty and the optimal interval between CPT measurements to reduce this uncertainty.

Article [8] presents a GIS implementation for geotechnical data management in Athens, Greece, describing the integration of data from more than 2,000 exploration wells and test pits to create thematic maps with geotechnical engineering information, and a methodology for automated seismic microzonation of the southern part of the city based on GIS and multiple data sources to assess seismic ground motion variability.

The paper [9] investigates the use of GIS to create interpolated geotechnical zoning maps in Surfers Paradise, Australia, based on data from 35 locations and 1,754 soil stiffness values, where interpolation methods including IDW, kriging and spline were evaluated using ArcMap10, showing that IDW provides the best representation for zoning maps to facilitate decision making for geotechnical projects in the region.

The results of the study [8] emphasize the effectiveness of GIS-based systems in mapping soil properties, which provides valuable information for planning and preliminary design of construction and engineering projects. In addition, the system helps to identify areas suitable for development and areas with potential problems, which facilitates informed decision-making in feasibility studies and future development planning.

A study on creating spatial soil maps from geotechnical data revealed that maps produced using the IDW method in ArcGIS can be an important tool for engineers, providing rapid assessment of soil properties at various depths and improving the safety and cost-effectiveness of projects by developing models of soil conditions at new sites [10].

In this study, we used the kriging method and ArcGIS software to assess the geotechnical properties of soils in Astana, which allowed us to create a methodology for determining intermediate strength and deformation properties with useful information for future projects and construction planning. The purpose of the study is to apply the method of kriging interpolation in ArcGIS software to determine the intermediate geotechnical properties of soil at the construction site in a residential complex in Astana.

2. Methods

The study area is a residential complex in Astana city in Yesil district. Street E 116. Topographic survey at a scale of 1:500 is shown in Figure 1. The territory is located in the steppe zone. Esil settlement has coordinates 51.1057° North latitude and 71.425° East longitude.

Under the conditions of natural regime groundwater level is subject to seasonal fluctuations: the minimum standing is observed in March, the maximum falls on the beginning of May.

The amplitude of level fluctuation in the studied area amounted to 1.20-1.50 m.

At spring maximum it is necessary to expect groundwater level rise by 1.0 m, higher on the date of one-time groundwater level measurement on 23.09.2021.

The survey site is classified as potentially waterlogged.

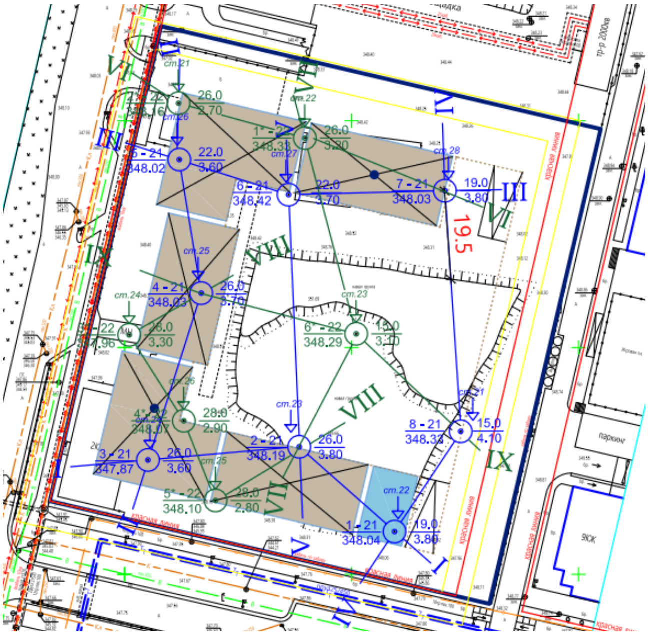


Figure 1 – Topographic survey of the object [11]

The topographic survey data shows that the spacing between boreholes exceeds 25 meters and the changes in absolute elevations range from 348.04 to 348.19 meters. As can be seen, the large distance between boreholes, which may complicate the accurate modeling of geologic structures and soil distribution at the site and require additional studies or survey methods to obtain a more complete picture of the geologic structure.

Based on the results of the analysis of physical and mechanical properties of soils by engineering-geological parameters, the following layers of soil occurrence are defined:

Engineering-geologic element No. 1 (tQIV): Bulk soil, dark brown in color, with hard consistency, containing construction debris and impurities of organic matter with a volume of 3.6%.

Engineering-geologic element No. 2 (aQII-III): A loam with a variable consistency ranging from firm to fluid-plastic, characterized by light brown and gray tints, with admixture of carbonates and interlayers of sand and loam up to 20 cm thick. The organic matter content varies from 3.20% to 5.70%, with an average value of 4.10%.

Engineering-geologic element No. 3 (aQII-III): Loam with hard and plastic consistency, light brown in color, with carbonate phenocrysts and sand interlayers up to 20 cm thick. The organic matter content varies from 2.30% to 3.50%, with an average value of 3.0%.

Engineering-geologic element No. 4 (aQII-III): Medium coarse sand, brown in color, saturated with water, with interlayers of loam up to 20 cm thick.

Engineering-geologic element No. 5 (aQII-III): Gravelly sand of brown color, saturated with water, with interlayers of loam up to 20 cm thick.

Engineering-geologic element No. 6 (eCI): Loam of various shades, ranging from maroon to greenish-yellow to dark red, with a firm to semi-hard consistency, containing up to 10 percent silt loam, as well as patches of ogeolensis and omanganeseization. There are interlayers of clay and sandy loam up to 20 cm thick.

Engineering-geologic element No. 7 (eCI): Woody loam of various shades, with hard and semi-hard consistency, containing patches of yellowing and omarganization, as well as interlayers of woody soil.

Engineering-geologic element No. 8 (eCI): Loamy sandy loam with various shades of gravel, with a hard consistency, containing patches of tin-ironing and omarganization.

The geologic data obtained show that the soil strata layering does not follow the order of geotechnical engineering elements (GEI). For example, in some boreholes, such as No. 5, it can be observed that the engineering geologic element No. 2 follows the engineering geologic element No. 5, while in other boreholes the soil layers are presented in the expected order.

In order to analyze the structure of the soil foundation, it is required to conduct additional research, process the obtained data, and adjust the design solutions taking into account the heterogeneity of the soil.

We used the method of kriging interpolation to determine the intermediate geotechnical properties of the soil, which allowed us to obtain predictions of the values of each property at each point of the studied area in the form of continuous maps. The results obtained were implemented in ArcGIS software using the kriging spatial variation method to accurately predict values in other areas. Thus, the kriging method provides us with useful and accurate predictions of intermediate geotechnical soil values based on available data. It is important to note that this method takes into account the characteristics of soil layering and transition between layers, which further improves the accuracy and reliability of the results obtained.

3. Results and Discussion

Based on the available data, which includes the results of soil samples from 8 wells, we use the Kriging interpolation method in ArcGIS to determine soil property values between these wells where the data are unknown. This method allows us to predict soil property values at all other points in the study area. We processed and loaded the soil mechanical property data into a map database and presented the results in Figures 3-5. Using this approach helps to reduce resource and time costs while providing reliable results of the study.

Figure 2 displays the distribution of different soil types in the study area using a variety of color ranges corresponding to soil types.

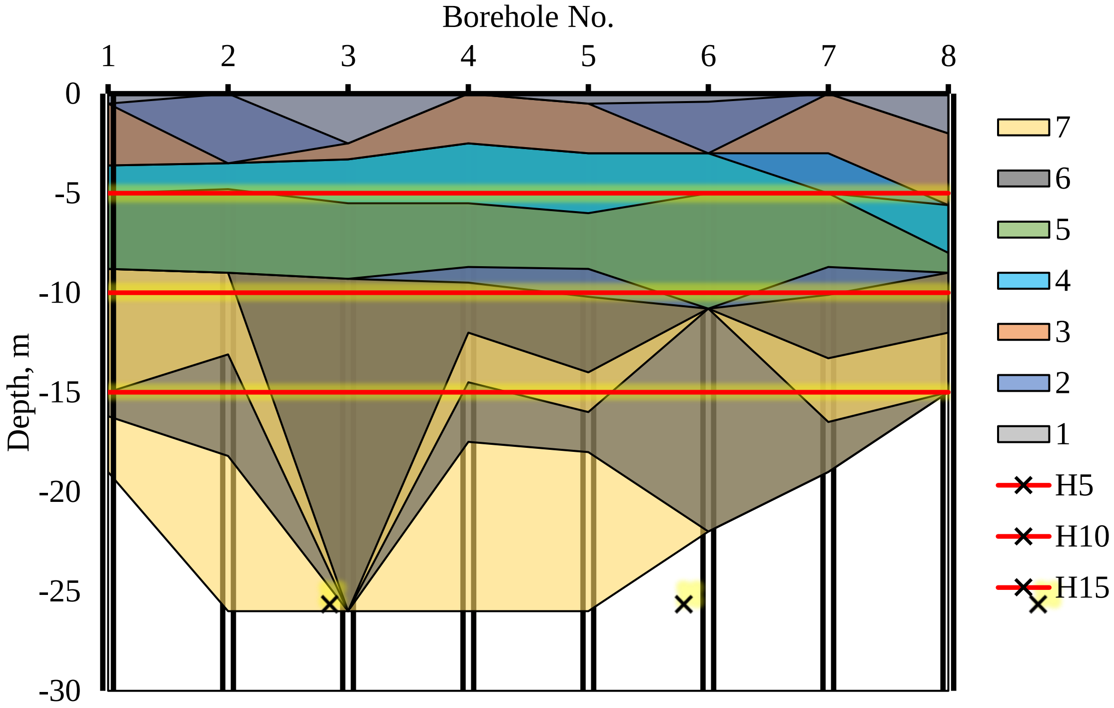
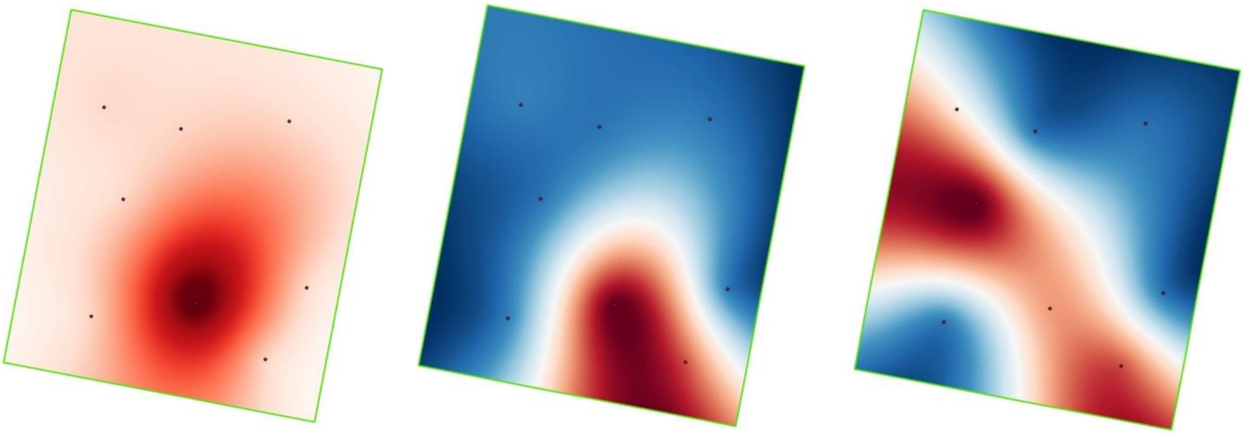


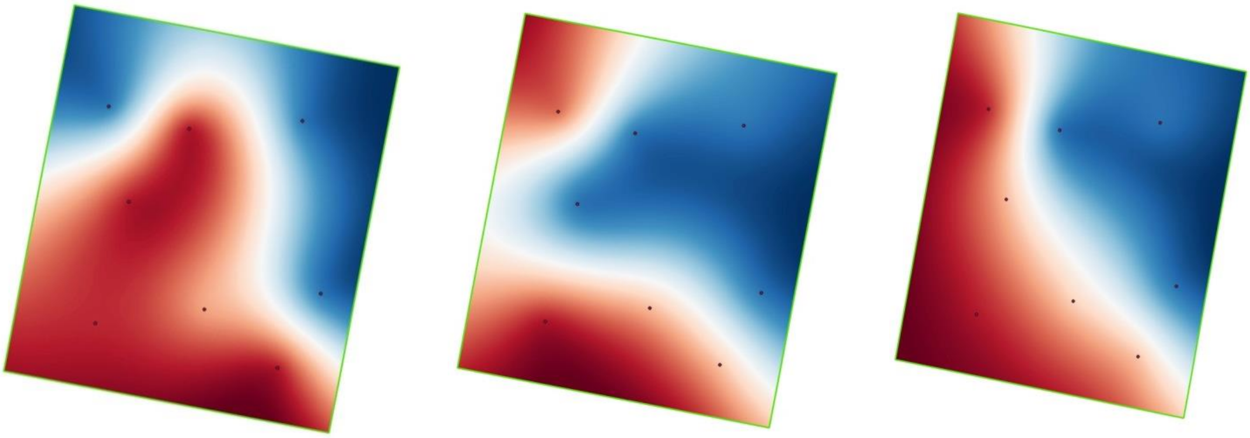
Figure 2 – Geological cross sections with

Figures 3-5 show the distribution of soil over the study area at different depths (5m, 10m, 15m), using a color scheme to visualize the results of the analysis of its mechanical properties (E_0, c, φ). In these schemes, the red color corresponds to the maximum values of the soil mechanical properties and the blue color corresponds to the minimum values. Areas with shades of gray and white show locations in the area where the values of soil mechanical properties are at an intermediate level, indicating their comparability with known data. Transparent areas on the map indicate minimal difference in the values of soil mechanical properties compared to known data.



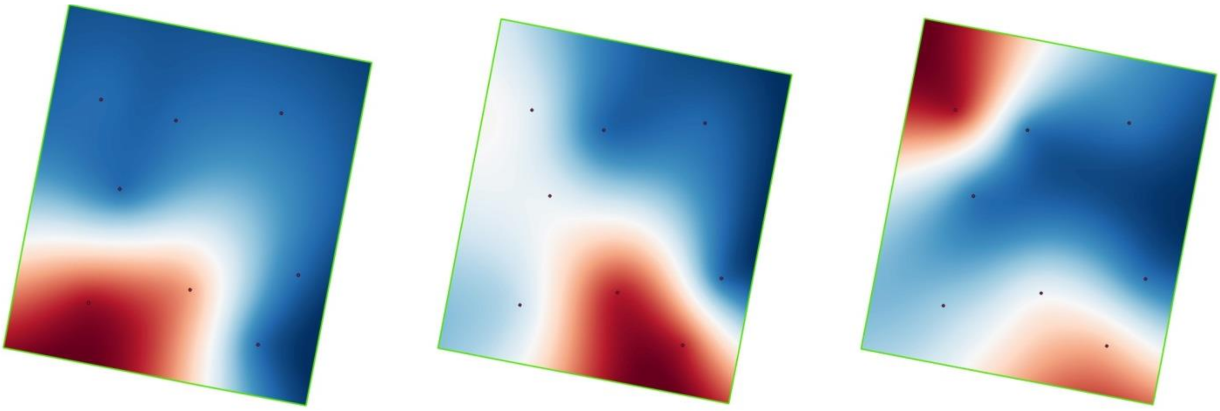
a) b) c)

Figure 3 – Map of the study area showing the spatial variability of known values of total strain modulus “E_0” at depths of a) 5 m; b) 10 m; c) 15 m



a) b) c)

Figure 4 – Map of the study area showing the spatial variability of known specific gravity values “c” at depths of a) 5 m; b) 10 m; c) 15 m



a) b) c)

Figure 5 – Map of the study area showing the spatial variability of known values of internal friction angle “φ” at depths of a) 5 m; b) 10 m; c) 15 m

By specifying the required depth and applying the recommended interpolation method, we can obtain intermediate geotechnical soil characteristics. This approach allows us to specify any depth and obtain accurate values of characteristics, which greatly facilitates the correct assessment of engineering-geological conditions at the construction site. This, in turn, can lead to a reduction in the cost of survey work. In addition, using information on soil conditions from known boreholes, we can obtain data not only for idealized conditions, but also for realistic soil layering scenarios.

The proposed methodology serves as a practical tool for foundation footing visualization. It provides engineers with a comprehensive understanding of the mechanical characteristics of the soil, making it easier for designers to select optimal foundation types and sizes.

4. Conclusions

To conclude the study on the application of geotechnical interpolation using GIS for foundation design, the following can be noted:

- the use of interpolation methods such as kriging in ArcGIS software can effectively determine the intermediate geotechnical properties of soils at the construction site, which allows engineers to obtain accurate values of soil characteristics at different depths, which facilitates the process of selecting optimal types and sizes of foundations;
- the kriging method provides accurate predictions of the values of geotechnical soil properties based on available data, which allows predicting the values of soil properties at all points in the study area, which facilitates more accurate planning and design;
- the use of GIS-assisted geotechnical interpolation is an important tool for visualizing foundation footings and provides engineers with a comprehensive understanding of soil mechanical properties, which not only improves the evaluation of geotechnical engineering conditions at the construction site, but can also lead to lower survey costs and optimize the foundation design process.

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