Kriging interpolation to determine intermediate mechanical properties of soils

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Abstract. This study examines the application of interpolation technique using ArcGIS software to determine the average mechanical properties of soils in a specific area. The study of soil geotechnical properties plays an important role in construction design and reliability. However, constraints such as limited resources and difficulty in accessing test sites can make it difficult to conduct laboratory and field work on each soil sample. Therefore, the use of interpolation techniques can fill data gaps and provide a more comprehensive understanding of the soil layer characteristics. The proposed Kriging interpolation methodology allows setting the required depth and obtaining accurate values of geotechnical soil characteristics, which facilitates the assessment of engineering and geological conditions at the construction site. This can reduce the cost of survey work and provide data not only for idealized conditions, but also for realistic ground layering scenarios. The proposed methodology also serves as a practical tool for foundation base visualization, providing engineers with a complete understanding of the mechanical characteristics of the soil and helping to select optimal foundation types and sizes.

1 Introduction

The bearing capacity of a foundation, which is determined using the physical and mechanical properties of the soil, is a classical geotechnical problem [1]. Obtaining accurate soil characteristics and understanding them is challenging due to the spatial variability of soil properties [2].

The understanding of the importance of soils in human life and the preservation of its quality studied in soil science is similar to environmental education [3-4]. However, the development of the concept of attitudes towards soils lags behind the level of scientific

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understanding of environmental issues, making it difficult to access relevant characteristics to collect information [5].

It is not always possible to perform laboratory or field tests on every specimen due to various constraints such as limited resources, difficulty in accessing test sites, specific soil conditions, and safety requirements when working with certain soil types or testing under certain conditions [6]. Soil characteristics can significantly affect the stochastic result of the bearing capacity of foundations, which in turn will affect the deformation of the foundation [7]. Due to the limited number of wells and the spatial variability of site information, geotechnical and geologic characterization cannot be fully defined, making it difficult to analyze, design, and construct buildings and structures [8].

Innovative technologies are being developed to effectively monitor and manage the reliability of structures [9-10], with sensor applications [11-12] to identify potential problems and prevent accidents in the subsurface, improving the overall reliability of the infrastructure and reducing risks to the environment and human life. Thus, the use of interpolation techniques in geotechnical engineering contributes to more accurate data analysis, which allows prompt action to be taken to maintain the safety and effective functioning of the foundation-structure system [13]. These methods contribute to a finer and more continuous description of subsurface conditions, which in turn provides a more accurate and reliable understanding of the behavior of the soil foundation and provides a more complete understanding of the stability of underground structures [14].

Over the past two decades, the development of geographic information systems (GIS) has led to their widespread use in the collection, monitoring, and analysis of geospatial data [15]. GIS provides a platform for integrating different types of data and organizing information in the form of visualization using maps and three-dimensional models, allowing for efficient storage, sharing, analysis and modification of data, taking into account their geographical location and contextual requirements [16-17].

This study proposes the application of Kriging interpolation method in ArcGIS software to determine the average values of soil mechanical properties.

It is proposed to use the interpolation method using ArcGIS software to determine average mechanical properties of soils, which will fill data gaps and provide a more complete understanding of the characteristics of the soil layer without the need for laboratory and field tests on each sample.

2 Methods

The study area is a residential complex in Astana city in Yesil district. Syganak street. Topographic survey at a scale of 1:500 is shown in Figure 1. The territory is located in the steppe zone. The settlement of Yesil has coordinates 51.1057° north latitude and 71.425° east longitude.

Groundwater (type of high water table) in the study area, opened by all wells. The established groundwater level is 1.2÷3.6m. Absolute marks of the established level are 346,30÷348,20m. Groundwater distribution is sporadic. In Quaternary clayey sediments the aquifer is confined to lenses and interlayers of sand, in Mesozoic sediments to the system of cracks and lenses of tars. Groundwater is unpressurized, under natural conditions groundwater level is subject to seasonal fluctuations: the expected maximum rise of groundwater level in the flood period (early May), the minimum end of January, early February. The maximum groundwater level in the spring period should be assumed to be 1.5 m higher than measured during the survey period (August 2017). Type of groundwater regime - floodplain, the main groundwater supply is received by infiltration of atmospheric precipitation and in the spring period by absorption of flood runoff, as well as by the inflow of fracture water. The topographic survey is shown in Fig. 1.

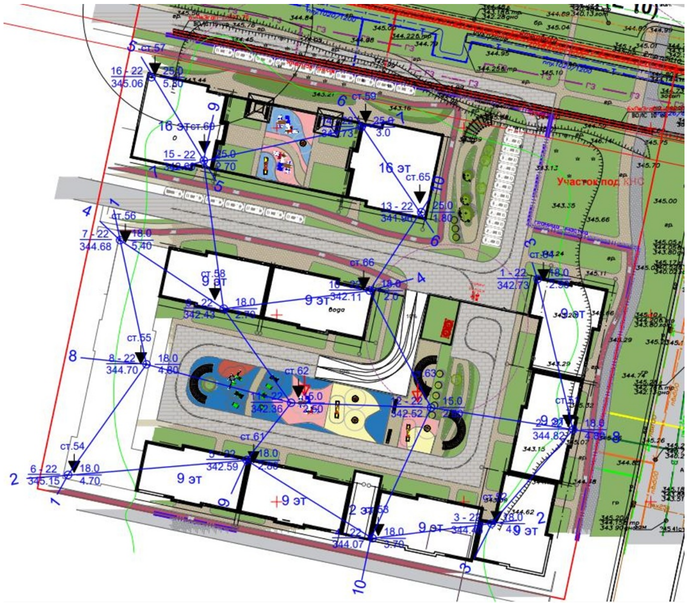

Fig. 1. Topographic survey of the object.

Physical and mechanical properties of soils by engineering-geological elements are given in Table 1.

Table 1. Physical and mechanical properties of soils by engineering-geological elements.

GE number	Sampling depth, m	Particle size distribution, % Particle size, mm: > 10 (pebbles, gravel)	gravel: 10–5	gravel: 5–2	sand: 2–1	sand: 1–0.5	sand: 0.5–0.25	sand: 0.25–0.1	sand: 0.1–0.05 (<0.1)	<0.002	The humidity is natural, W, %	Plasticity, %: yield point, W_L	rolling boundary, W_p	ductility number, I_p	Fluidity rate, I_L	Density, g/cm^3: natural, ρ	soil particles, ρ_S	dry ground, ρ_d	Porosity coefficient, e	Water saturation coefficient, S_r, ratio	Def. swelling, εSW,	Filtration coefficient, m/day.	Natural slope angle, °: when dry, α	underwater, α_W	Compression module in water-saturated state, Ecw, MPa	Angle of internal friction, φ, deg.	Specific adhesion, C, kPa
1	2.0	31.3	1.8	1.2	12.8	–	–	13.3	39.6	–	12.98	26.50	17.40	9.10	0.49	2.0	2.72	1.77	0.537	0.66	0.047	–	–	–	4.5		
2	1.5	–	–	–	–	–	–	–	–	–	44.13	39.60	28.20	11.40	1.40	1.71	2.72	1.19	1.286	0.93	0.05	–		–	–	12.9	24
3	6.0	–	0.1	1.3	32.5	–	–	19.4	46.7	–	25.69	25.40	17.30	8.10	1.04	1.88	2.71	1.50	0.807	0.86	0.058				3.3	12.7	20
4	4.3	–	–	–	–	–	–	–	–	–	22.95	22.50	17.20	5.30	1.08	1.99	2.70	1.62	0.667	0.93					7.5	21.8	18
5	13.0	1.6	6.4	15.5	23.2	33.7	15.9	2.3	1.4	–	11.86	–	–	–	–	–	–	–	–	–	–	14.51	–	33			
6	9.5	7.5	11.4	18.6	19.8	19.5	14.2	4.7	4.3	–	9.14	–	–	–	–	–	–	–	–	–	–	26.51	–	33			
7	13.2	6.4	8.9	11.5	22.4	–	–	7.9	42.9	–	32.34	35.80	32.10	3.70	0.06	1.75	2.70	1.32	1.045	0.84	–	–	–	–	–	26.2	17
8	22.0	–	–	–	–	–	–	–	–	–	18.23	36.70	23.80	12.90	0.43	2.00	2.73	1.69	0.615	0.81	–	–	–	–	12.4	22.9	60
9	10.5	43.3	8.9	5.7	10.9	–	–	3.3	27.9	–	26.75	32.50	24.90	7.60	0.24												

According to the results of desk processing of field documentation of boreholes and the results of laboratory tests, selected samples, the following engineering-geological elements were identified in the section of the survey area:

- *Engineering-geological element No. 1 (tQIV)* is a bulk soil consisting of crushed loam, dark brown and brown in color. This soil has a variable consistency, ranging from hard to soft-plastic, and contains construction debris with up to 4.70% organic matter admixture.
- *Engineering-geological element No. 2 (laQIII-IV)* is characterized by silty black and grey loam with consistency from soft-plastic to fluid. The organic matter content in this soil ranges from 10.10% to 29.9%.
- *Engineering-geological element No. 3 (laQIII-IV)* describes a gray and light brown loam with variable consistency and organic matter content from 3.90% to 9.0%, with interlayers of loam and sand up to 20 cm in thickness.
- *Engineering-geological element No. 4 (laQIII-IV)* is gray-brown sandy loam with variable consistency and organic matter content from 2.30% to 5.40%, with sand interlayers up to 20 cm thick.
- *Engineering-geological element No. 5 (laQIII-IV)* describes water-saturated coarse sand of brown and dark gray color with interlayers of loam and loose sand up to 20 cm in thickness.
- *Engineering-geological element No. 6 (laQIII-IV)* describes water-saturated brown and dark gray gravelly sand with interbedded loam and loose sand up to 20 cm thick.
- *Engineering-geological element No. 7 (eC1)* is sandy loam with gray and white colored gravels of variable consistency, with admixtures of iron galling and omarganization, as well as interlayers of loam up to 20 cm in thickness.
- *Engineering-geological element No. 8 (eC1)* describes a gray and white sandy loam with gravel with variable consistency, containing admixtures of yellowing and omarganization, and interbedded loam up to 20 cm thick.
- *Engineering-geological element No. 9 (eC1)* describes a woody soil with sandy loamy aggregate of gray, white, and reddish-red color. This soil contains the fractions: crushed stone 33%, driftwood 24%, and sandy loam aggregate 43%, with the aggregate being a gray and white colored loam with a firm and plastic consistency.

Based on the known depths of occurrence of engineering geologic elements (GE), an engineering geologic cross-section was constructed, shown in Fig. 2.

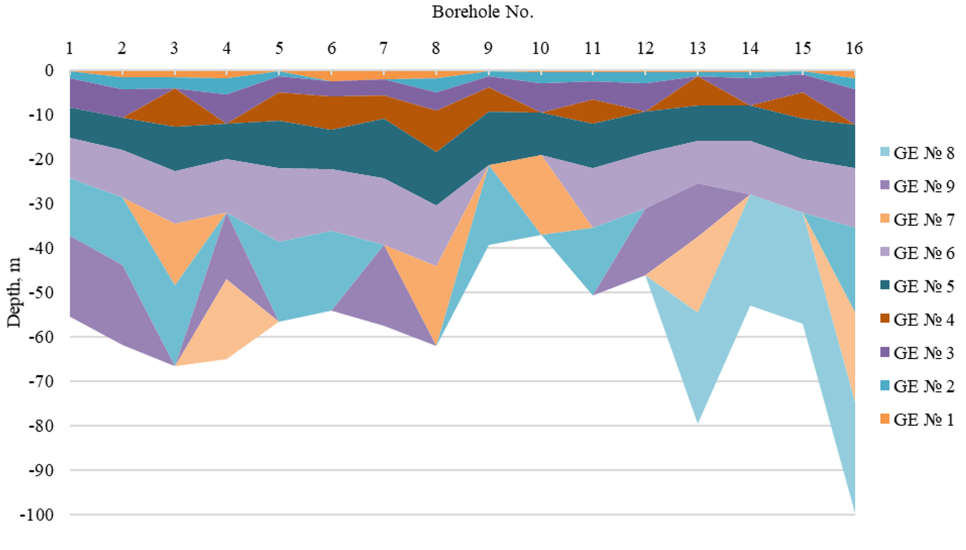

Fig. 2. Engineering geologic section.

As can be seen, Table 1 presents the physical and mechanical properties of the soils for various engineering geologic elements (EGEs), including particle size distribution, moisture content, plasticity, density, porosity coefficients, water saturation, relative strain swelling, filtration coefficient, natural slope angle, compression modulus, and other parameters. However, it should be noted that the mechanical properties of the soil were not determined at each borehole, which limits the completeness of the data and requires further analysis to account for the missing information when evaluating the engineering geologic conditions at the site.

The purpose of this study is to determine the average values of soil mechanical properties using data obtained from closely spaced boreholes.

The kriging interpolation method was applied to determine the average mechanical characteristics of the soil. This allowed to obtain the predicted values of each characteristic at each point of the study area in the form of continuous maps. The obtained results were integrated into 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 average soil mechanical properties based on available data. It is important to note that this method takes into account the layering and transition between soil layers, which further improves the accuracy and reliability of the results.

3 Results and Discussion

The site has uneven soil layers and discontinuities in some boreholes, which may affect the mechanical properties of the soil. As a result of the analysis, 9 engineering geologic features were identified in 16 boreholes to a depth of 22 m, including bulk soils, clayey soils, and sandy soils.

A kriging interpolation method using ArcGIS software was used to predict soil mechanical properties at points where direct data were not available. This method estimates the values of mechanical properties at all other points in the study area based on the available data.

The results obtained were presented in Figs. 4-6, which show the distribution of different soil types using color ranges corresponding to soil types. This visualization helps to better understand the spatial structure of the soil in the study area and determine its characteristics for planning construction or other engineering works.

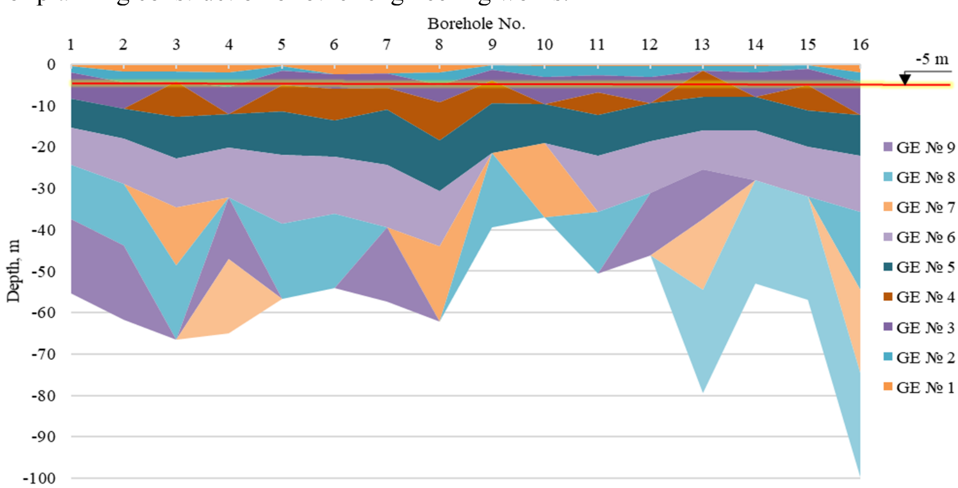

Fig. 3. Engineering geologic section with a cut line.

This study provides the possibility to cut the line at a certain depth (Figure 3), which allows the program to output the average values of mechanical properties at the selected depth. The resulting heat maps will display the spatial distribution of these properties at a given depth, which will allow a more detailed study of their relationship and influence on the engineering and geologic structure of the area under consideration.

The use of kriging method in ArcGIS software complex allows to obtain more reliable values of average soil parameters and more accurately analyze the spatial variability of its properties. The spatial maps presented in Figures 4-6 show the distribution of soil in the study area at a depth of 5m, using a color scheme to visualize the mechanical properties (c, φ, E_0).

Fig. 4 provides an opportunity to estimate values of specific cohesion that are close to known values. In this case, the specific cohesion level ranges from 3.2 to 32.9 kPa. For example, for well 11 at a depth of 5 meters, the specific cohesion is 17 kPa.

Figs. 5 and 6 show maps of the spatial variability of the known values of internal friction angle and strain modulus at a depth of 5 meters.

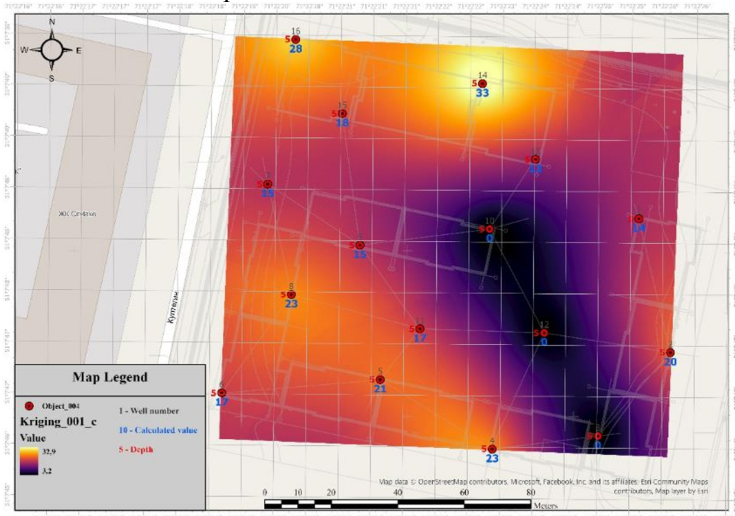

Fig. 4. Map of spatial variability of known values of specific cohesion at a depth of 5m.

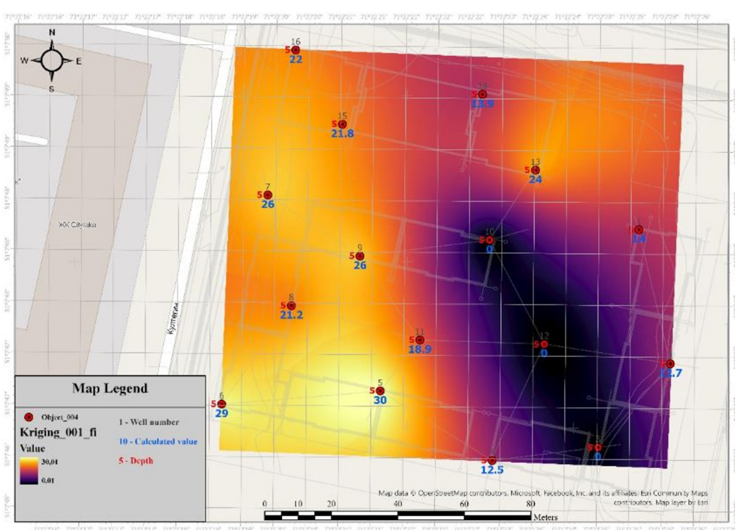

Fig. 5. Map of spatial variability of known values of the angle of internal friction at a depth of 5m.

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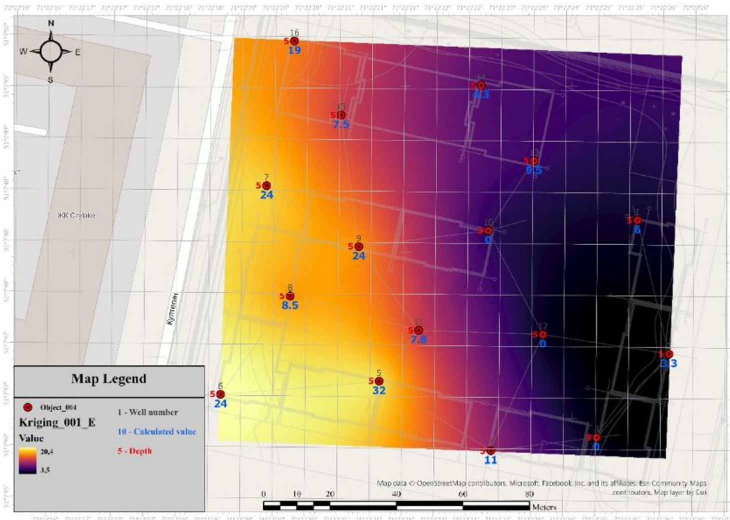

Fig. 6. Map of spatial variability of known strain modulus values at a depth of 5 m

Figs. 4-6 show a gradient scale, where darker shades allow estimating values closer to known values, while lighter shades indicate the range between these values, which is determined by interpolation. Both homogeneity class and heterogeneity of the soil are taken into account, which allows for a more accurate determination of characteristic values depending on the specific soil class at different depths.

This approach to analysis allows engineers and designers to gain a better understanding of the mechanical characteristics of the soil at the construction site, which contributes to more accurate selection of foundation types and sizes and improves construction reliability. In addition, gradation areas help to accurately define the limits of variability in soil mechanical properties. Color gradations on heat maps show transitions from minimum to maximum property values, which helps identify areas where there are significant variations in soil mechanical properties over short distances. This is important to engineers because it allows them to more accurately identify areas where special attention is needed in the design of foundations and other engineering structures. This gradation analysis helps to account for the heterogeneity of the soil layer and prevent potential problems associated with differences in its mechanical properties in different areas of the construction site.

4 4. Conclusions

In conclusion about the application of geotechnical interpolation using GIS in foundation design, the following should be noted:

- The use of interpolation methods, such as kriging, in ArcGIS software allows for the effective determination of average mechanical properties of soils at a construction site
- the kriging method provides accurate predictions of the values of average mechanical properties of soil based on available data.
- The development of geotechnical interpolation methodology and its integration into geotechnical engineering practice appears to be a promising direction for future research and development.

Thus, the study emphasizes the importance of applying geotechnical interpolation and GIS in the design of footings and foundations, which contributes to improving the quality and safety of engineering structures construction.

Acknowledgments

This study was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant No. AP19676116).

Gratitude is expressed to "Geocenter Astana" LLP for providing the data from engineering-geological surveys used in this study.

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