Approximation of strength and deformation properties of soils by ArcGIS Topo to Raster tool

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Abstract. Abstract: This study examines the application of Topo to Raster interpolation technique in ArcGIS software to analyze the strength and deformation properties of soil at a construction site in Astana. Topo to Raster methodology allows converting topographic data into raster format, which provides a more detailed view of the landscape and its characteristics. In optimizing the design of foundations and making design decisions in complex ground conditions, the use of this technique allows to take into account the spatial variability of soil properties at different depths. The results of the study show that the Topo to Raster interpolation technique in ArcGIS provides more accurate and reliable predictions of strength and deformation characteristics in the study area. The created heat maps based on this methodology allow taking into account realistic scenarios of soil behavior and improve the accuracy of predicting foundation settlement, which is critical for comparison with the limit values recommended in the SP RK [1].

1 Introduction

In the long-term development strategy of the Republic of Kazakhstan, much attention is paid to the development of the construction sector [2].

At the present stage, construction takes place in a variety of ground conditions, including unfavorable ones, and is accompanied by increased loads on foundations due to the increase in the number of storeys of buildings [3-4].

This requires the frequent use of displacement foundations, which have a higher load-bearing capacity and are better adapted to such conditions [5].

The region of Central Kazakhstan, where intensive construction is currently taking place, is characterized by difficult ground conditions. This is due to the presence of sharply heterogeneous soils alternating in depth, as well as the impact of groundwater [6]. Long-term scientific research confirms that soil displacement foundations are effective in such conditions [7]. The combination of excavation and local compaction of the surrounding soil

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allows to ensure sufficient operational reliability and high technical and economic indicators of foundations made of driven piles, piles in pierced and bored boreholes [8-9].

Soil settlement is a complex physical and chemical process that results in the compaction of soil due to the movement and more compact packing of its particles and aggregates [10]. In this case, the total porosity of the soil is reduced to a state corresponding to the acting pressure. The increase in the degree of soil density after settlement leads to an increase in its strength characteristics [11]. At further increase of pressure the process of soil compaction continues, which is accompanied by increase of its strength and change of its initial mechanical properties [12].

To date, the mechanical properties of soil have been determined through field and laboratory testing [13-14]. The basic mechanical characteristics are established at a certain depth depending on the composition of the monolith and the design load acting on the ground, taking into account the choice of the dimensions of the notional foundation [15].

Mechanical properties are not always determined over the entire depth of the borehole, and calculations often use known values of [16].

Given the potential structural changes and settlement of the subgrade as a result of actual moisture and loading, it is important to have an accurate approximation of the mechanical properties of the subgrade at a particular depth for subsequent analyses and calculations [17].

To solve this problem, interpolation techniques are often used to derive intermediate values from the available data [18].

In modern times, robust geographic information systems that are equipped with specialized algorithms are being actively developed [19]. These systems help to understand the geomorphology of the earth. A variety of mathematical and statistical analyses of data from IoT sensors enable rapid response to faults in engineering networks and a better understanding of foundation stability [20].

Thus, these methods provide the ability to analyze and model spatial data, which allows for a more complete understanding of the soil foundation and groundwater resources [21-22].

The purpose of the study is to develop an effective engineering methodology for determining approximate values of strength and deformation properties of soil to optimize design decisions. This is necessary to ensure operational reliability, environmental safety and durability of buildings.

2 Methods

For practical application of the concept of approximate values we have carried out a detailed analysis of geotechnical investigation reports at the construction site of Astana (Kazakhstan). The borehole data were scrutinized, the name and properties of soils were determined by engineering-geological elements, which are presented in Table 1.

Six boreholes were drilled at the construction site and soil samples were collected from various depths. The physical properties of these samples are summarized below (Table 1).

Table 1. Basic physical and mechanical properties of soils.

Geological index	Depth of sampling, m	Description of soils	Porosity coefficient, e	Water saturation coefficient Sr, fraction of unit	Compression modulus in in/n condition, Eqv, MPa	Angle of internal friction, φ, degree	Specific adhesion, C, MPa
aQIII-IV	1,6	Loam, light brown and	0,585	0,39	2,6	9,7	30

		brown, in some places grayish-brown, from hard to tight plastic consistency, with admixture of organic matter up to 5.16%, with interlayers of sandy loam and fine sand up to 20 cm thick.					
aQIII-IV	3,2	Brown-colored sandy loam, hard and plastic consistency, with admixture of organic matter up to 4.0%, with interlayers of fine and medium coarse loam and sand up to 20 cm thick.	0,436	0,92	13,1	39,6	18
aQIII-IV	8,3	Sand is coarse, brown in color, water-saturated, polymictic, with lenses of loam and interlayers of sand of different coarseness up to 20 cm thick.	-	-	30	35	1
aQIII-IV	14	The sand is gravelly, brown, water-saturated, polymictic,	-	-	30	38	0

		with interlayers of sand of different fractions up to 20 cm thick.					
N2-QII	16	Loam, gray, dark gray and greenish-brown in color, hard consistency, with spots of yellowing and omarganization, with inclusions of silt loam and interlayers of sandy loam up to 20 cm thick.	0,554	0,64	10,3	32	96
N2-QII	18	Clay, variegated, of hard consistency, with spots of yellowing and omarganization, with inclusions of tares and interlayers of loam up to 20 cm thick.	0,864	0,92	3,8	18,1	62

We developed an Excel expression that relates the values of the studied properties to the depth of interest, providing a systematic approach to organize and spatially interpolate intermediate values. For each i-th well, the expression selects values of the j-th parameter from Table 1 that satisfy the condition of Equation 1 and populates Table 2 with the corresponding data.

$$e_i < D \leq e_{j+1} \quad (1)$$

Table 2. Soil properties at certain depth

No.	***e***	S_r	E_D	c_D	φ_D
1					
2					

…					
i					

The obtained results were implemented in ArcGIS software using the Topo to Raster interpolation method.

3 Results and Discussion

Figure 1 below shows a geologic cross-section of the soil layers underlying the construction project under consideration, showing the shear line.

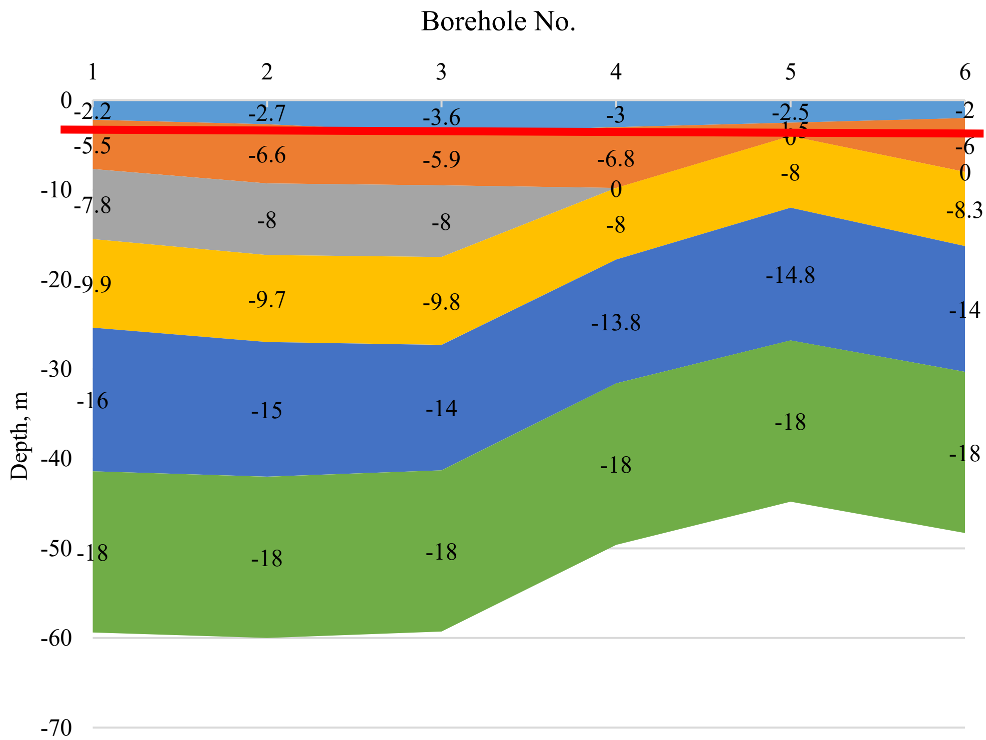

Fig. 1. Geologic section with a section mark at a certain depth.

Modern mapping techniques, with the application of GIS, offer new opportunities to create accurate maps by using digital data and analyzing information in real time. The integration of different types of data, including geographic, demographic, and environmental data, greatly improves the efficiency of the mapping process.

Using the Topo to Raster interpolation method in ArcGIS software to analyze soil strength data provides more accurate and reliable predictions of strength and deformation characteristics throughout the study area. This approach accounts for the spatial variability of soil properties and provides valuable data for informed engineering decisions. The analysis results presented in Figures 3-5 demonstrate the importance of using geotechnical interpolation to optimize design and construction.

Figure 2 shows a map of the study area showing the spatial variability of soil specific cohesion at a depth of 5 meters, the analysis of which identifies zones with different levels of specific cohesion, which is important in foundation design.

 https://doi.org/10.1051/e3sconf/202455901009

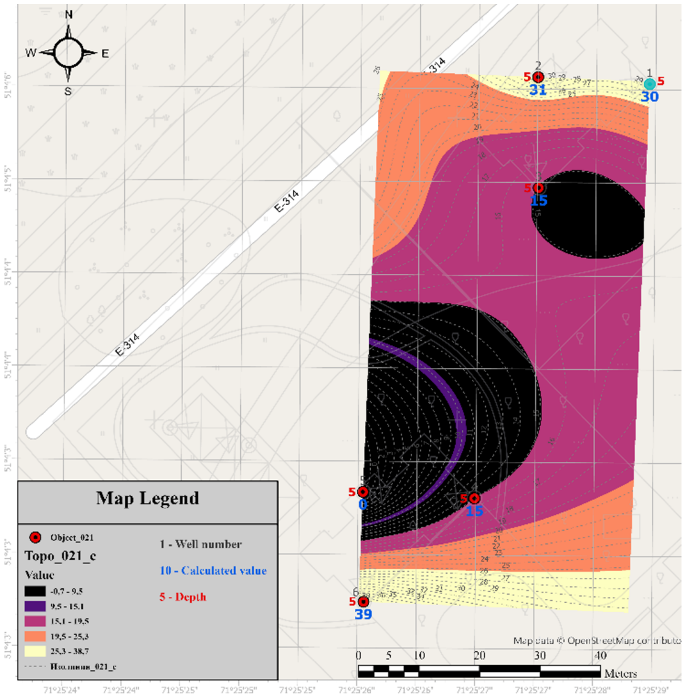

Fig. 2. Spatial variability of specific cohesion at a depth of 5 meters

Figure 3 illustrates a map of the study area with spatial variations in the angle of internal friction at a depth of 5 meters, which plays an important role in assessing the soil's ability to resist shear stresses.

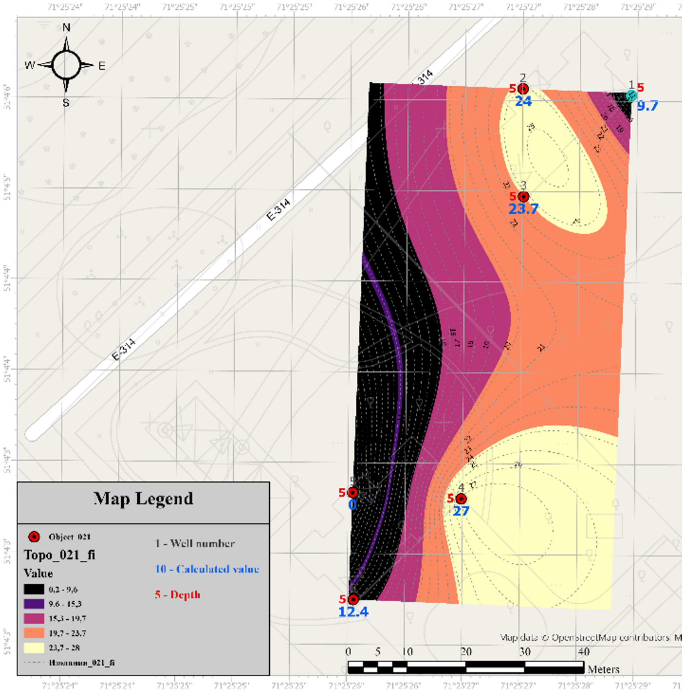

Fig. 3. Spatial variability of the angle of internal friction at a depth of 5m

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Figure 4 illustrates the spatial variability of the total strain modulus at a depth of 5 meters, which allows us to assess the level of deformation in the soil and predict its behavior under different loading conditions.

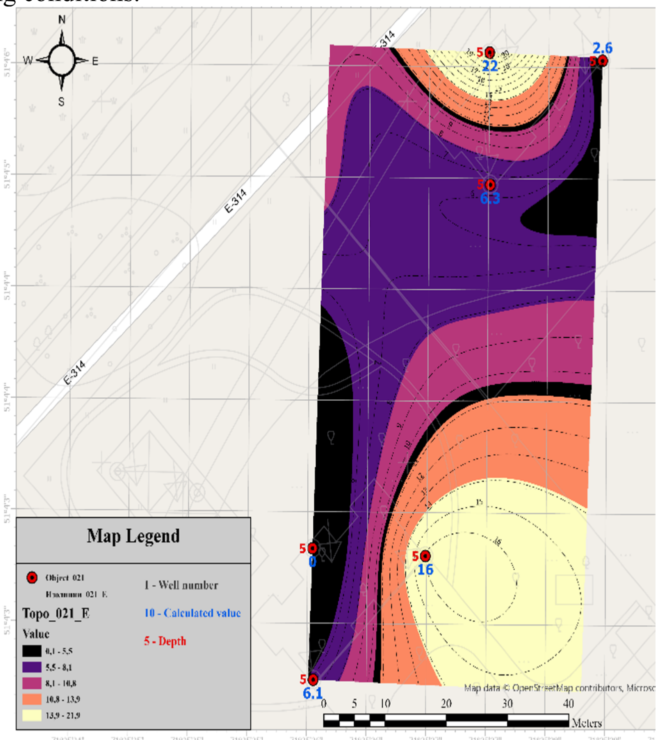

Fig. 4. Spatial variability of the total deformation modulus at a depth of 5m

Analysis of the data of Figures 2-4 allows us to identify zones with different values of specific adhesion, internal friction angle and deformation modulus. Yellow shades on the maps indicate maximum values and dark shades indicate minimum values. Multicolored areas show areas in the territory where the values of strength and deformation properties of the soil are at an intermediate level, which indicates their comparability with known data. All information is based on known values obtained through field and laboratory studies, as well as using the tables of SP RK [1].

By using the Topo to Raster interpolation technique in ArcGIS, we can obtain approximate values of soil mechanical properties at different depths, taking into account the nature of changes in soil conditions. By specifying the desired depth, we can obtain data that will help us evaluate the engineering geologic conditions at the construction site. This is important for making informed decisions and optimizing the construction process. The information obtained from the heat maps created using this technique will allow realistic scenarios of ground behavior to be considered. This will increase the accuracy of prediction and determination of the base settlement value, which is critical for comparison with the limit values recommended in the SN RK [23].

4 Conclusions

- The research has shown that the region of Central Kazakhstan is characterized by complex soil conditions that require a special approach to the selection of the type of foundations for construction.

- Application of systematic approach to organization and spatial interpolation of values of soil properties at different depths allows to optimize the process of foundation design.
- Application of Topo to Raster interpolation technique in ArcGIS software allows to obtain more accurate and reliable forecasts of strength and deformation characteristics in the investigated area.
- The obtained heat maps based on the Topo to Raster methodology in ArcGIS allow taking into account realistic scenarios of soil behavior, which increases the accuracy of prediction and determination of the value of foundation settlement, which is critical for comparison with the limit values recommended in building codes.
- The use of Topo to Raster interpolation methodology in ArcGIS is an effective tool for analyzing soil strength data at different depths, which helps to assess engineering and geological conditions at the construction site and make informed design decisions.

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