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An investigating on the soil standard penetration test (SPT) variations, using geostatistical methods in Chehel Baze National Park of Mashhad city, North East of Iran

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Abstract

Nowadays in situ geotechnical tests are used by the geotechnical engineers in a variety of forms. The SPT test, due to the simplicity, low cost, and association with other soil parameters, is using widely in engineering projects. The results of this test are associated with only a point, while the project engineers need information about the whole project area, especially the places with not samples. Therefore, using of geostatistical and interpolation methods to produce maps of soil engineering parameters is very common. In this research, the examined results of SPT in 18 study boreholes within the area of Chehel Baze national park of Mashhad city, according to blows change from 10 to 50, using geostatistical methods and general Kriging tool, the map of SPT changes and the estimation error maps was prepared. According to the results, it seems that geostatistical methods due to the acceptable precision and nature of geotechnical parameters, is a useful tool for predicting the number of SPT for area that tested data is not available.

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Introduction

Geostatistics is the science that uses the particular behavioral characteristics (distance changes) which are related to the earth data, such as geophysical, geotechnical and geochemical data so it makes them in the context of statistical studies (Taghizadeh Mehrjerdi *et al.*, 2008). According to the researches that have been done in recent years, the effectiveness of geostatistical methods and notable features of it have been accepted completely (Hooshmand *et al.*, 2011). Today, due to many problems and dependence of soil sampling results of conventional in situ tests such as SPT which belong to a certain point, many new techniques are using beside. Application of geostatistical and interpolation methods and also zoning maps for determining the geotechnical parameters of the areas where sampling has not been performed is essential (Basarir *et al.*, 2010). Due to the nature of geotechnical parameters and according to geostatistical methods which consider the position of the sampling points, having high accuracy and also having the ability of calculating the estimation variance, geostatistical methods are the best and most effective methods for interpolation (Davidovic *et al.*, 2010). In this study, of the 23 total drilled boreholes in the study area, 18 boreholes which were performed at the desired depth by the SPT tests were selected. First, for assessing the normality of collected data, Kolmogorov-Smirnov test was used in SPSS software. After performing these steps, the data convert from point data type to area data by GS+ and Arc GIS 9.3 softwares and in the end by applying the geostatistical methods, the data were analyzed.

Location and geology of study area

Chehel Baze National Park is located in the west of Mashhad city. Mashhad city, within an area of approximately 320 square kilometers, has a population of about 3 million people and also a population of about 12 million pilgrims and tourists per year. Mashhad city is located on the plain with the same name. The plain with eastern longitudes of 58° 20´ to 60° 08´ and Northern latitudes of 36° 03´ to 35° 40´ is located in North-East of Iran. The plain in the north is limited by the Hezar Masjed ridges and on the south is limited by Binalood ridges (Lashkaripour *et al.*, 2007).

Mashhad plain sediments mostly consist of alluvial fan deposits, alluvial terraces and young alluvial sediments (Vatanpour *et al.*, 2011). These sediments have a maximum thickness of more than 300 meters and from the old to the new are: the alluvium of Hezar Darreh, young the alluviums of Mashhad plain and Holocene to present Covenant alluviums.

Mashhad city is tectonically located between active Quaternary faults, including south fault and north fault of Mashhad (Jahd Azma Consulting, 2013). The study area is in west of Mashhad city. The location of the study area is shown in Fig. 1.

Fig. 1. Study Area Location

Chehel Baze is known as one of the most unique national parks in an area of about 400 hectares that is being conducted in the west of Mashhad city. According to the fact that Chehel Baze park area has been used as a place for discharging of construction, therefore recognition and the exact calculation of soil engineering parameters for foundation design and construction of sustainable structures is essential. Location and the coordinates of drilled borehole which their SPT test results were used for this research is shown in Fig.2.

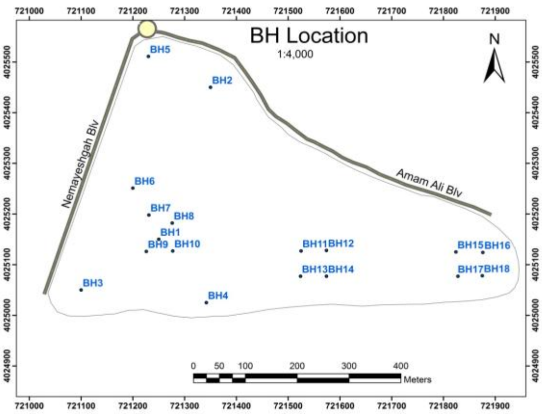

Fig. 2. Coordinates of Boreholes in The Study Area

Methods

Standard Penetration Test (SPT)

One of the most common in situ tests use in geotechnical studies, is Standard Penetration Test (SPT). For the first, in 1902, this method was invented by Konnel whom used sampling means with 25 mm diameter which was pushed into the ground by a hammer weighing 50 kg. A cloven cylindrical sampling tool that is currently used for SPT test is the result of Mohr attempts and then the Gow part of the Reymond Fletcher concrete pile company which finally was used in the standard way by Tarzaghi (Borms & Flodin., 1988). Due to the simplicity of this test, low cost, simplicity and minimal depreciation of equipment and also extensive relation between geotechnical parameters and penetration resistance, this method is widely use in Iran and other countries. This test determines the soil resistance against penetration of bivalve cylindrical sampling tool and provides a disturbed soil for the next identification. Test is based on the fall of a hammer weighing 5.63 kg from 76 cm height on a cylindrical cap. The number of blows required to penetrate the sampling tool about 30 cm in soil after the first 15 cm, is considered as penetration resistance (ASTM D 1586).

Geostatistics

Geostatistics is a branch of statistics that is based on the theory of regional variations so it investigates both the structural variations and random variations of the spatial variables. In geostatistical studies, where changes of variable could be determined by using variogram, calculation of estimation variance and evaluation of estimation efficiency is possible (Flipo *et al*., 2007). The geostatistical concept was first introduced in 1919 by Watermier with the publication of an article in the calculation of reserve estimation that was related to the South African gold mines (Hassanipak, 2006) and then in the next decades, "Krige" and "Matheron" by publishing different articles, founded the modern geostatistics (Krige, 1951; Matheron, 1962). The review processes in geostatistical branch is including the evaluation of geostatistical data in terms of normality, reliability, variogram drawing and process mapping and modeling of interpolation by the Kriging tools. If it is necessary to normalize the data it is possible to use from different methods including log, triple log and Cox – Box.

Discussion

In general, geostatistical assessing methods for variables include: a) the statistical analysis and data normality b) variogram and assess the reliability of data trend c) estimation by different geostatistical methods, and d) evaluate the accuracy of the estimate. In this study, in addition to a brief explanation of each step, SPT data at each step of the study are discussed.

Data normality

The first step in the geostatistical analysis is to evaluate the data normality. This feature is investigated by plotting histogram of data and assessing the skewness value, stretching and in most cases is evaluated by all these in different tests. In the histogram for normal conditions, the median and mean are equal; stretching about 3, skewness close to zero and the coefficient of variation is close to 2. If the data is not normal, it can be used by a method of converting normal logs or Cox - Box in order to be normalized (Hassanipak, 2006). In this study, we calculated the skewness and stretching and Kolmogrov - Smirnov test P value = 0.20 and Shapiro - Wilkie P value = 0.398 which showed that SPT data are not normal (in this study the significance level considered as 5%).Then, the data were normalized by using the logarithm and therefore the P value of the Shapiro - Wilkie test was changed from 0.398 to 0.741. The results are mentioned in Table 1 and the histogram are shown in Fig. 3.

Variogram

Variogram is one of the most basic tools of geostatistics that evaluate the spatial variability and characteristic of parameters. It is a function that can be adapted according to the distance and direction of the spatially structured displacement variables. In other words, these charts will show how the change in the values of the sample points located at different distances and directions may occur. Variogram is defined by Equation 1, that is achieved by mean squared difference between pairs of points where the points are in the distance of h from each other. The graph of experimental variogram is draw according to variogram values that are plotted against the h distance.

In this equation,

$$2\gamma(h)=\frac{1}{n}\sum_{i=1}^{n}\left[z(xi+h)-z(xi)\right]^{2}$$

2γ : Variogram

n: The total number of paired points

h: Constant distance between the points

$z(xi)$: The observed variable in the x point

$z(xi+h)$: The observed value of a variable that is in the h distance from x point.

Table 1. Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Layer2(SPT)	.132	18	.200*	.948	18	.398
Layer1	.098	18	.200*	.967	18	.741

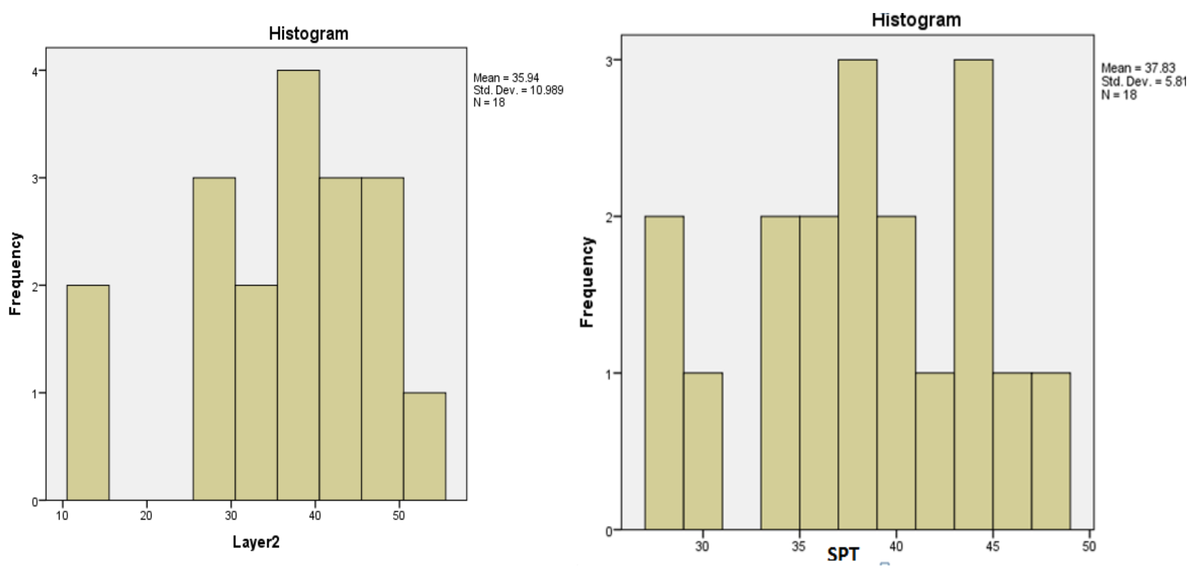

Fig. 3. Histogram of SPT Data

The variogram value at zero distance called nugget effect (C_0), the maximum value of variogram called threshold (C) and a distance equal to the threshold value is named as the radius of influence (α). To investigate how the variable changes in different directions and distances, different experimental variogram models are used. These types of models are including Gaussian model, circular, exponential and linear models (Hassanipak, 2006). Strength of spatial structure or spatial correlation criterion in variable is determined based on the $\frac{C_0}{C+C_0}$ ratio in which the (C_0) is nugget effect and (C) is threshold. With increasing the C value the C_0 content decreases. If this ratio is less than 25% the data show good spatial correlation and if this ratio is greater than 75%, the spatial correlation is weak. Between these two values, 25% -75%, there is average correlation. Also, to assess the reliability and trend of variables, the shape and the changes in the variogram curve is studied (Hassanipak, 2006). The variogram investigated in this study showed that SPT with a threshold of 2.993 and a nugget effect of 0.89 has a strong spatial strength of 0.012. The radius of influence is equal to 142 meters. The best model that was fitted to the experimental variogram with above information is exponential model. This model has a linear behavior near the source coordinates, but the increasing trend of model is exponentially. The model equation is as follows:

$$y_h = \sigma^2[1-\exp(-\frac{h}{L})]$$

In this equation, σ^2 is the variance, h, is distance and the L radius of influence. In this model, 95% of the maximum value obtained from the experimental variogram range is assumed as the roof covering of variogram and the distance corresponding to it considered.as the radius of its effect. Variogram graph in is shown Fig. 4. Variogram did not reach the fixed roof so investigates showed that it is needed to remove data interpolation trend in the software.

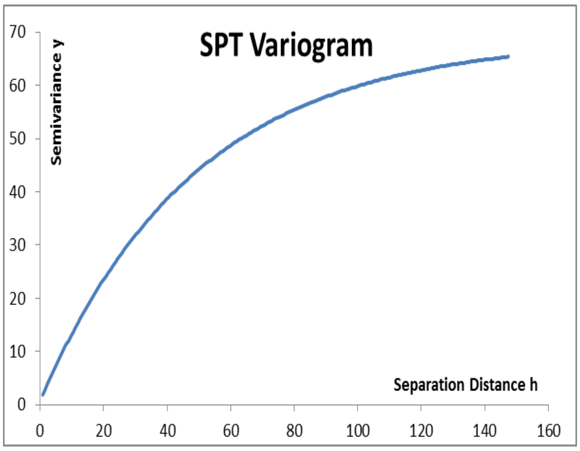

Fig. 4. Variogram of Chehel Baze International Park SPT

Data evaluation and interpolation

The geostatistical interpolation is a process that can be used to find the value of the points with unknown coordinates by using the other points with known coordinates (Flipo *et al.*, 2007). Among different types of estimators, the kriging method is the best and most common (Walter & McBratney., 2001). Another important feature of these estimators is that for every estimate, we can calculate the associated error and for each value that is estimated, the confidence domain can be calculated while other methods do not have this ability. The two interpolation methods including geostatistical and certain methods are shown in Table. 2.

Table 2. Interpolation Methods

Radial functions General polynomial Subjective Polynomial $\sum_{i=1}^{n} w_i[F(x_i, y_i) - Z_i]^2$ Inverse square of the distance $\lambda_i = d_i^{-a}$ $Z^*(x_i) = \sum_{i=1}^{n} \lambda_i z_i$		The Certain methods
point kriging block kriging	Based on the spatial structure	The Geostatistical methods
General kriging $m(x) = \sum_{j=1}^{k} \mu_i f_j(x)$ $z(x) = m(x) + \varepsilon(x)$ Simple Kriging $z^*(x_0) = m + \sum_{i=1}^{n} \lambda_i[z(x_i) - m]$ Ordinary kriging $z^*(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i)$ Index Kriging $F(x_0; z_k(n)) = \sum_{i=1}^{n} \lambda_{ik} I(x_0; z_k)$ Residual kriging $z(x) = z^*(x) + \varepsilon(x)$ Co-kriging $z^*(x_0) = \sum_{i=1}^{n} \lambda_{1i} z_1(x_i) + \sum_{i=1}^{n} \lambda_{2i} z_2(x_i)$ Log Kriging	Based on Total size	
$z^*(x_0)$:The estimated value of the Z variable in unknown place x_0 $z(x_i)$:The Value of Z variable in Known place x_i λ_i :Weight attributed to the Z variable in the known place x_i n: The total number of observations m : Mean of variables		

After analyzing the data with variogram and removing data trend, the data were interpolated by different methods and based on cross validation and evaluation criteria MS and RMSS methods, various results were evaluated. Finally, universal Kriging with evaluation criteria values of MS and RMSS was selected, respectively 0.003553 and 0.9119. It should be noted that if the criteria of MS be as close to zero and RMSS be close to one, a more accuracy estimate is obtained. Finally, the SPT change map, standard error of estimation map and chart Q-Q to investigate the estimate error, were plotted (Fig. 5).

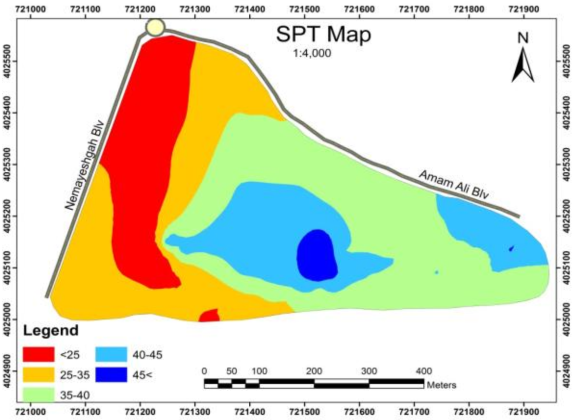

Fig. 5. Map of SPT Value Changes Within Chehel Baze National Park

According to the Fig. 5, the standard penetration in most parts of the region is between 45-25 and in a significant portion of the area is above 30 which indicate the density and high bearing capacity of the area. According to the figure the values of test were high in the center of the study area and were decreased the North West part. According to the map of estimation error, the error value in the no sample sites is about 8 or less (Fig. 6).

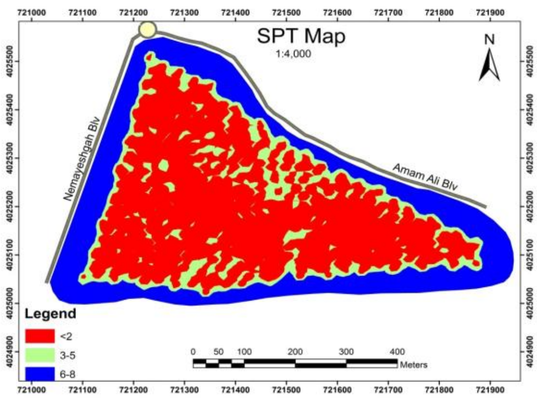

Fig. 6. Map of SPT Estimation Standard Error Chehel Baze National Park

Normal plot of estimation error for SPT number within the national park of Chehel Baze is shown in Fig. 7. As can be observed in the diagram the estimation has a high level of accuracy.

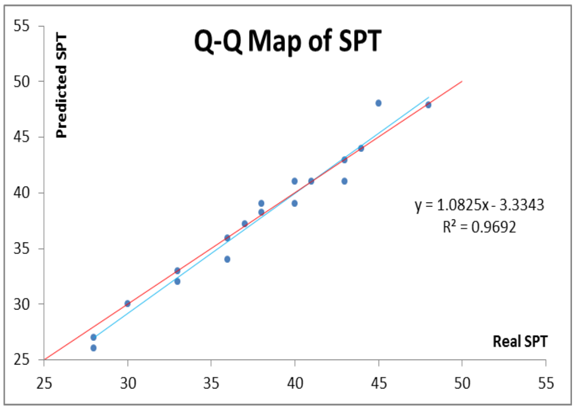

Fig. 7. Diagram QQ estimated error rate

Conclusions

Due to the increasing use of SPT because of its simplicity, low cost and a general overview of soil strength and bearing capacity and assessing some geological hazards, the conversion of the point results to regional data is essential. According to the studies, the high accuracy of geostatistical methods and nature of geotechnical parameters cause this method be a useful tool for conversion. According to the findings, the standard penetration in most parts of the region is more than 30 blows that indicate the high density and bearing capacity of the soil within the Chehel Baze national park.

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