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Uniaxial Compressive Strength spatial estimation using different interpolation techniques

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1. Introduction

Generally, site characterization starts with the process of refining the engineering geology properties throughout the spatial domain of any facility installation. In areas where the geological setting is well known, site characterization may be a straightforward procedure. However, where the weathering and alterations have intensively degraded rock strengths, site development and design may require extra attention in establishing rock slope stabilities. Utilizing the 3D spatial distribution of weathering or alteration on rock masses through some certain rock parameters is, therefore, useful in developing a standard rock mass description. The Uniaxial Compressive Strength (UCS) of intact rocks is an important geotechnical parameter required for the purposes of design in a variety of engineering applications.[1–3] Obtaining accurate estimates of rock mass UCS parameter throughout deposit 3D extent is vital for determining optimum rock slope stability, designing new exploratory and blast boreholes, mine planning, optimizing the production schedule and even designing the crushers feed size.

The main objective of this paper is to estimate the UCS parameter in the rock masses of the Sarcheshmeh copper deposit using commonly used interpolation techniques including statistical-structural (nearest neighbor, inverse distance weighting), linear (ordinary Kriging), nonlinear (indicator Kriging) geostatistical and artificial neural network methods employing UCS measurements obtained from borehole core samples. The results obtained by applying different interpolation techniques are validated, compared and discussed.

For estimating geotechnical parameters, so far, a number of methods such as simple and multiple regression, geostatistics and Artificial Neural Networks (ANNs) have been employed.[4–35] In addition, several traditional and widely used estimation methods have been described by a number of researchers.[36–38] These procedures include polygonal (such as nearest neighbor), triangular, regular and random stratified grid, inverse distance weighting ($1/d$, $1/d^2$, $1/d^{2.7}$, $1/d^3$, etc.) and contouring methods. The nearest neighbor and inverse distance weighting methods are two popular methods routinely employed in many fields of the earth sciences including geotechnical engineering.

Several researchers applied the simple and multiple regression analysis to estimate rock mass characteristics such as the UCS parameter.[4–12] For example a linear regression model has been used to obtain a correlation between Schmidt hardness and coefficient of restitution (COR) of rocks. The results showed that the normal COR was sensitive with examined parameters whereas tangential COR did not have any correlation with examined parameters.[12]

Several researchers applied the geostatistical approach to estimate rock mass characteristics such as the Rock Quality Designation (RQD), Rock Mass Rating (RMR), Geological Strength Index

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(GSI) and etc.[13–21] For example geostatistical technique (ordinary kriging method) has been used to estimate RQD values which has a direct relationship with weathering.[13] Also, the RMR index has been estimated using geostatistical analysis since 2004. Different geostatistical techniques (ordinary Kriging and sequential Gaussian simulation), using both bi-dimensional and almost three-dimensional approaches have been applied to estimate the RMR values in un-sampled locations. The validation results showed that Kriging tends to produce smoothened distributions, while conditional simulations allow respecting local extreme values.[21]

Soft computing techniques such as ANN have been preferred more than other methods for developing predictive models to estimate geotechnical parameters of intact rock.[22–35] The regression analysis and ANNs have been used to estimate the UCS and Elastic modulus (E) values by considering input parameters such as the P-wave velocity, point load index, Schmidt hammer and porosity. The results showed that the proposed ANN method could be applied as a new acceptable method for estimation the intact rocks UCS and E values.[30] The ANN algorithm has been used for predicting of UCS parameter from two/four-cycle slakes durability indices, clay contents as inputs.[31] The performances of Generalized Regression Neural Network (GRNN) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) methods for estimating UCS parameter of rocks have been compared. Based on network performance criteria such as correlation coefficient, mean absolute percentage error, root mean square error and variance, have been concluded that the GRNN model provides more geologically consistent results than the ANFIS model.[32] The performances of adaptive neuro fuzzy inference system (ANFIS) technique and normal regression system for estimating strength parameters of rocks have been compared. The results showed that the ANFIS method was comparatively better at prediction of geotechnical strength parameters when pitted against regression techniques.[34] The performances of Multivariate Regression Analysis (MVRA) and Artificial Neural Networking (ANN) methods for estimating the Cerchar Abrasiveness Index (CAI) and Penetration Rate (PR) related to rock excavation using simple geomechanical parameters as predictors have been compared. The results indicated that the ANN method could be applied for estimating the CAI and PR using UCS, Point load index, P wave velocity and Young's modulus as predictors.[35]

2. Methodology

The UCS values available to the current study, along with other qualitative geological properties including rock type, the weathering and alteration type and intensity were measured on core samples taken from 647 boreholes at the Sarcheshmeh copper deposit. The aim of current study, is to estimate the UCS parameter at the centre of each block in the 3D geological solid model with a block size of $12.5\times12.5\times6.25$ m (the number of blocks in the x, y and z directions are 319, 244 and 171 respectively) throughout the ore body extent. In order to find the best method for estimating the UCS parameter in terms of accuracy and consistency with the governing geology, the performance of different widely-used estimators or interpolators are evaluated. Primarily, the statistical-structural (including nearest neighbor and inverse distance weighting techniques), geostatistical (ordinary Kriging and indicator Kriging) and artificial neural network methods are employed to determine the spatial variability of the UCS parameter, which often shows a direct relationship with rock type, weathering and alteration type and intensity. Following the estimation of the UCS parameter at block centres using different methods, the obtained results and performance of each method are compared and validated through by employing twenty-one set-aside borehole data. The comparison of the results obtained by the above-mentioned methods is based on scatter plots of the observed data versus the estimated data plus the Root Mean Square Error (RMSE) statistics of the differences between the observed values and the estimated values of twenty-one set-aside borehole data. The methodology used in present study is shown in Fig. 1.

2.1. Statistical-Structural methods

In this section, the fundamental bases of two popular interpolating methods, namely the Nearest Neighbor (NN) and Inverse Distance Weighting (IDW), are discussed first. In the NN method, the centre of the block is assigned the value of the nearest sample,

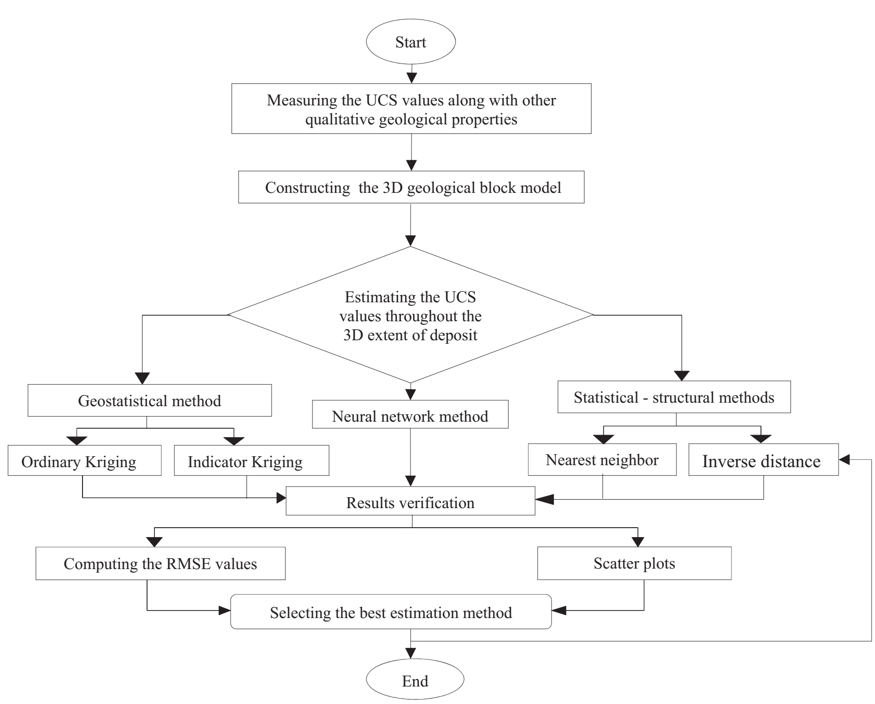

Fig. 1. Proposed workflow for selecting the best method in estimating the 3D distribution of the UCS parameter.