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Prediction of rotary drilling penetration rate in iron ore oxides using rock engineering system

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ABSTRACT

Prediction of the drilling penetration rate is one the important parameters in mining operations. This parameter has a direct impact on the mine planning and cost of mining operations. Generally, Effective parameters on the penetration rate is divided into two classes: rock mass properties and specifications of the machine. The chemical components of intact rock has a direct effect in determining rock mechanical properties. Theses parameters usually have not been investigated in any research on the rock drillability. In this study, physical and mechanical properties of iron ore were studied based on the amount of magnetite percent. According to the results of the tests, the effective parameters on the penetration rate of the rotary drilling machines were divided into three classes; specifications of the machines, rock mass properties and chemical component of intact rock. Then, the rock drillability was studied using rock engineering systems. The results showed that feed, rotation, rock mass index and iron oxide percent have important effect on penetration rate. Then a quadratic equation with 0.896 determination coefficient has been obtained. Also, the results showed that chemical components can be described as new parameters in rotary drill penetration rate.

1. Introduction

The ability to predict the performance and efficiency of drilling machines is very important in mining operations. The rock drillability is one of the most important parameters for mine planning, development and economics of mine operations. Also knowledge of drillability of rocks in engineering projects has key role to determine drilling costs. Drillability is a term used in construction to describe the influence of a number of parameters on the drilling rate and the tool wear of the drilling too. In this evaluation, the drillability term was defined as a penetration rate. The rough estimations of the rock drillability may cause a great risk in terms of mining operations, selection of mining machineries and equipment and final price of the product. Also the total drilling cost can be can be estimated by the drilling rate equations. These equations can be used to select the type of machine. Rock drillability depends on many parameters such as rock properties and specifications of drilling equipment. Although drilling equipment parameters are controllable, rock characteristics and geological conditions are uncontrollable and cannot be changed [1–4].

Rock drillability studies, mostly based on empirical methods and different parameters such as uniaxial compressive strength (UCS), tensile strength, quartz content, apparent porosity, p-wave rate and porosity can be used also to predict the drillability. Also, a wide range of empirical tests such as Schmidt rebound hardness, point load strength, Shore scleroscope hardness, Taber abrasion, cone indenter number, drilling rate index (DRI), coefficient of rock strength (CRS), rock brittleness, impact strength index (ISI), Cerchar abrasivity index (CAI), specific energy (SE), texture coefficient (TC) have been used to predict the drilling performance [4–17].

Some of effective parameters on rock drillability are investigated in the models as well as some of them have been modified. These models may be inferred from either one or more than one production sites, or from small experimental in laboratory. The models may not work in all situations and cannot be able to recognize and consider effective parameters on rock drillability. Rock Engineering Systems (RES) paradigm is a powerful approach to tackle this problem. This approach has been widely applied to various engineering problems such as slope stability of open pit mines, underground excavations, rock blasting and environmental studies such as regarding the disposal of spent fuel, river catchment pollution, forest ecosystems, radioactive waste management,

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traffic-induced air pollution risk of reservoir pollution [18–33]. The purpose of this research is to consider effective parameters on rock drillability in the iron ore mines using RES approach, so as to propose a model to predict rock drillability and classify rock drillability iron ore mines based on the rock engineering systems (RES) results.

2. Rock engineering system (RES)

The RES approach was first introduced by Hudson for solving the complex engineering problems. This approach can be used for the analysis of coupled mechanisms in rock engineering problems [18]. In fact the RES approach is the basic analytical tool and a presentational technique for characterizing the important parameters and the interaction mechanisms in a rock engineering system. The interactions between parameters in the RES approach are described using an interaction matrix. An interaction matrix, so it is the key element in the RES. The generation of the interaction matrix can help in evaluating the weighting of the parameters within the rock mass system as a whole.

In the interaction matrix for a given rock engineering system, all parameters influencing the system (for example, a rock drillability system) are arranged along the leading diagonal of the matrix, called the diagonal terms. Otherwise, the influence of each individual parameter on any other parameter (interaction) is included at the corresponding off-diagonal position of the matrix. The off-diagonal terms are assigned numerical values which describe the influence degree of one parameter on the other parameters. Assigning these values is usually referred to as “coding the matrix”. Several methods have been developed for this purpose, such as the 0–1 binary, expert semi-quantitative (ESQ) method and the continuous quantitative coding (CQC) method [18,32,34,33]. The most common coding method is the ESQ which has been used in nearly all previous mentioned works. In this method, one unique code is assigned to each interaction, thereby expressing the influence of a parameter on another in the matrix. Typically, coding values vary between 0 and 4 with 0 indicating no interaction and 4 indicating the hyper level of interaction “critical interaction”. The general concept of the influences in a system is described by the interaction matrix, which is shown in Fig. 1. Here, the influence of “A” on “B” is not the same as the influence of B on A, which means the matrix is asymmetric (Fig. 1a). Thus, it is important to put the parameter interactions in clockwise direction in the matrix. Also, a general view of the coding of interaction matrix is shown in Fig. 1b. The row passing through Pi represents the influence of Pi on all the other parameters in the system, while the column through Pi shows the effects of other parameters, or the remaining of the system, on Pi. In principal, there is no limit to the number of parameters that may be included in an interaction matrix (as an example Table 5).

After coding the interaction matrix by inserting the appropriate values for each off-diagonal cell of the matrix, the influence of each parameter on the system is named “cause” (Ci) and the effect of the system on each parameter is named “effect” (Ei). For each parameter, the cause obtain from the sum of its row values, whereas the effect the sum of its column values is called (Ei) value (Fig. 1b). The cause-effect diagram is formed by (C_i, E_i) coordinate values plotted in cause and effect space. The diagonal line with equation C = E (C = E line) represents the locus of points in which all the parameters have equal dominance/subordination; the dominant parameters, C > E, plot to the right of the C = E line while the subordinate parameters, C < E, plot to the left of the C = E line. With such a plot, it is therefore possible to recognize which parameter plays an important role in influencing the system (as an example Fig. 10). The level of interactivity of parameters can be used to identify parameters to be kept under control, as their variation is likely to induce significant changes in the system. The interactive intensity value of each parameter is denoted as the sum of the C and E values (C + E), and it is used as an indicator of the parameter significance in the system (as an example Fig. 11). The percentage value of C + E is used as the parameter weighting factor [18,19,35,21].

3. Research method

3.1. Geology and mineralogy of Chadormalu iron ore mine

Chadormalu iron ore mine is located 165 km west of Yazd city in the center of Iran. From geological and tectonics point of view, this mine is one of the most complicated areas of Iran. The Chadormalu iron oxide-apatite system (Bafq District, Central Iran)

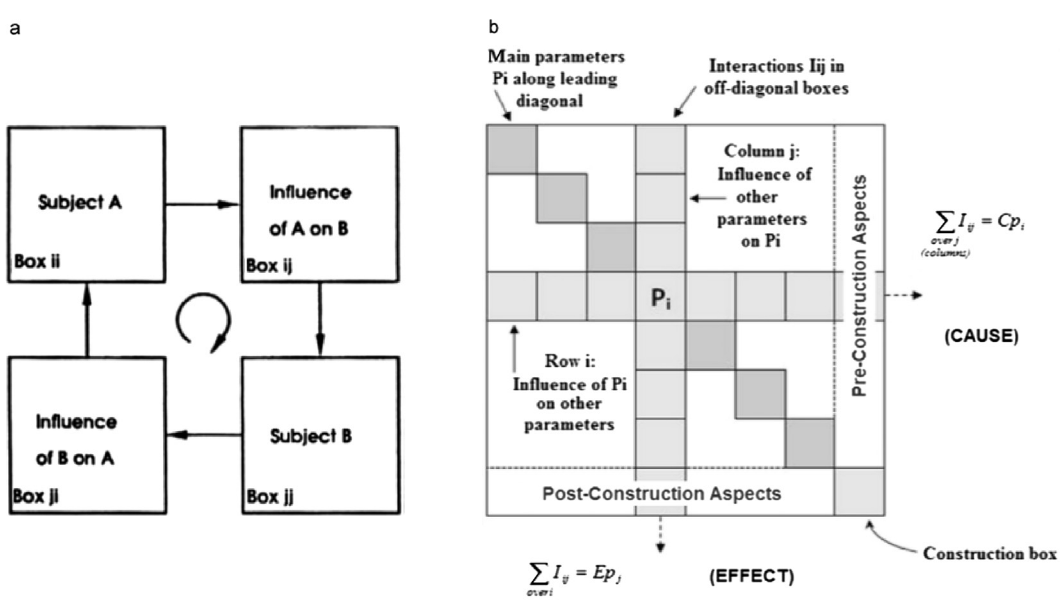

Fig. 1. (a) General Illustration of the interaction matrix in RES for two factors. (b) Generation of the ‘cause’ and ‘effect’ coordinates for the ith parameter in the interaction matrix [18].