Continuous Rating for Diggability Assessment in Surface Mines

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Abstract. The rocks can be loosened either by drilling-blasting or direct excavation using powerful machines in open cast mining operations. The economics of rock excavation is considered for each method to be applied. If blasting operation is not preferred and also the geological structures and rock mass properties in site are convenient (favourable ground conditions) for ripping or direct excavation method by mining machines, the next step is to determine which machine or excavator should be selected for the excavation purposes. Many researchers have proposed several diggability or excavatibility assessment methods for deciding on excavator type to be used in the field. Most of these systems are generally based on assigning a rating for the parameters having importance in rock excavation process. However, the sharp transitions between the two adjacent classes for a given parameter can lead to some uncertainties. In this paper, it has been proposed that varying rating should be assigned for a given parameter called as “continuous rating” instead of giving constant rating for a given class.

1. Introduction

The ease of excavation in surface mines should carefully be assessed so that the equipment to be selected by considering the field conditions can productively be operated in mining operations. The initial selection of such equipment should optimise productivity and avoid subsequent revisions practice with the resulting additional expenditures, production delays and losses [1]. The success of equipment selection in surface mining is primarily depends on determination of ease of excavation in site. The assessing of ease of excavation of rocks has been based on empirical and intuitive processes. Traditionally the problem has been reduced to determining whether blasting or ripping is required prior to mechanical excavation. The increased power and capability of new powerful excavating equipment has resulted in a need to re-evaluate this approach.

Empirical approaches to the determination of the ease of excavation can involve rock classification schemes. Classification systems have recently become quite popular and are widely employed in rock engineering [2]. The most common disadvantages of currently used classification systems are its subjective uncertainties resulting from the linguistic input value of some parameters, low resolution, fixed weighting, sharp class boundaries, etc. [3]. Despite their widespread use in practice, classification systems have some common deficiencies leading to uncertainties in their practical applications. These deficiencies are particularly related with the existing sharp transitions between two
adjacent excavation classes and the subjective uncertainties on data that are close to the range boundaries of rock classes.

Some efforts have been made for overwhelming the deficiencies in the classification systems applying soft computing methods such as artificial neural networks, fuzzy sets, adaptive neuro fuzzy inference system etc. However, practical application of these methods by engineers who work in the field is not so easy.

In this paper, it was aimed to offer a practical solution to the deficiency available in the current classification systems used for assessing ease of excavation of rock mass in surface mines. If the proposed logic is applied for current classification systems which are mainly based on giving ratings to the parameters involved in, it is able to provide an opportunity to assign continuous rating and to carry out more realistic evaluation.

2. Excavation Classification Systems

Common to most classification systems is the assignment quantifiable values to rock mass characteristics and the attempt to use standardised procedures to determine the material properties. Classification systems are generally based on gathered geotechnical data and observations made in the field for a variety of excavation processes. The adopted procedure in most of these classification systems is the quantification of geotechnical parameters that are related to machine performance, leading to a single rating or index. The ratings obtained by this way are then related to the ease of rock excavation classes and machine types to be used.

The necessity to rationalise the use of excavating equipment in different geological environments led to various classification systems as shown in Table 1.

Table 1. Geotechnical parameters in various classification systems for excavating purposes [1]
The significance awarded to rock strength is apparent by its inclusion in all surface excavation classification systems: in the form of uniaxial compressive strength or point load strength. Also, joint orientation and joint spacing have received the most prominence for diggability prediction since they determine ease of excavation in terms of the dimensions and shape of rock mass. Weathering degree of the rocks is of significant importance in nearly all excavating classification systems, too.

Karpuz proposed a classification system for excavation of surface coal measures employing uniaxial compressive strength, average discontinuity spacing, seismic velocity, degree of weathering and Shore hardness [4]. Basarir and Karpuz developed an indirect rippability classification system in which seismic P-wave velocities of rocks, intact rock strength, average discontinuity spacing and Schmidt hammer hardness value have been employed [5]. Kirmanli and Ercelbe developed a diggability classification system for the hydraulic excavator-truck selection expert system considering uniaxial compressive strength, weathering degree, seismic velocity, average discontinuity spacing and bedding thickness [6]. Hamidi et al. applied rock mass excavability (RME) classification to verify the applicability of fuzzy rock engineering classifications since classification systems which assign quantifiable values to predefined classified geotechnical parameters of rock mass have subjective uncertainties [3]. Liang et al. developed an excavability classification system for surface excavation of weathered sedimentary rock based on practical excavations at Iskandar region, South Johore, Malaysia [7]. The whole excavation classification system mentioned above is mainly based on assigning a rating for geotechnical parameters and arriving at a final rating.

3. Scoble and Muftuoglu Diggability Index Rating Method
The diggability index rating method devised by Scoble and Muftuoglu defines five rock classes based on four geotechnical parameters; namely, uniaxial compressive strength, bedding spacing, joint spacing and weathering (Table 2) [8]. The index which is derived by summation of the rated values of these input parameters considers both geotechnical factors and excavating equipment capabilities (Table 3).

### Table 2. Diggability index rating method

| Parameter       | Rock Class |
|-----------------|------------|
|                 | I          | II         | III         | IV          | V           |
| Weathering      | Completely| Highly     | Moderately  | Slightly    | Unweathered |
| Rating (W)      | 0          | 5          | 15          | 20          | 25          |
| UCS\(^a\) (MPa) | <20        | 20-40      | 40-60       | 60-100      | >100        |
| Is(50)\(^b\)   | <0.5       | 0.5-1.5    | 1.5-2       | 2-3.5       | >3.5        |
| Rating (S)      | 0          | 10         | 15          | 20          | 25          |
| Joint Spacing (m)| <0.3      | 0.3-0.6    | 0.6-1.5     | 1.5-2       | >2          |
| Rating (J)      | 5          | 15         | 30          | 45          | 50          |
| Bedding Spacing (m)| <0.1  | 0.1-0.3    | 0.3-0.6     | 0.6-1.5     | >1.5        |
| Rating (B)      | 0          | 5          | 10          | 20          | 30          |

\(^a\)Uniaxial Compressive Strength, \(^b\)Point Load Strength

### Table 3. Diggability classification chart

| Excavation Class | Ease of Digging | Index (W+S+J+B) |
|------------------|-----------------|-----------------|
| I                | Very Easy       | <40             |
| II               | Easy            | 40 - 50         |
| III              | Moderately Difficult | 50 – 60         |
| IV               | Difficult       | 60 - 70         |
| V                | Very Difficult  | 70 - 95         |
| VI               | Extremely Difficult | 95 - 100        |
| VII              | Marginal Without Blasting | >100           |
Except weathering degree, the rating on each input parameter is a fixed numerical score for a given rock class interval. In other words, same numerical scores are applied in the regions of both the lower and upper boundaries of class intervals. In this paper, a **continuous rating** method was proposed to be able to overwhelm this uncertainty and deficiency available in the conventional rock excavation classification systems.

4. Results and Discussions

It was thought that the centre of interval defined in a class of geotechnical parameter should have the highest rating. Besides, the rating assigned for a parameter whose numerical value is close to lower boundary should decrease and also it should increase when it is near to upper boundary. In this way, if the value of any geotechnical parameter in the classification system is near to lower boundary of an interval, its rating will relatively be low when the centre of an interval is considered. On contrary, the assigned rating for any geotechnical parameter whose value is near to upper boundary of an interval will tend to increase. In order to make such an assessment, continuous rating charts were prepared (Figure 1). The proposed continuous rating charts have also been converted into simple equations (Table 4) considering the centre value of each interval defined in Scoble and Muftuoglu [8] diggability classification system. These proposed charts and simple equations in Table 4 can offer more realistic rating procedure preventing sharp transitions between rock classes in the assessment of ease of digging and related equipment.

![Continuous rating charts](image-url)
### Table 4. Continuous rating equations for geotechnical parameters in classification system.

| Parameter                  | Uniaxial Compressive Strength (UCS, MPa) | Point Load Strength (I₅₀, MPa) | Joint Spacing (J, m) | Bedding Spacing (B, m) |
|----------------------------|-----------------------------------------|--------------------------------|----------------------|------------------------|
|                            | 20 – 40                                 | 0.5 – 1.5                      | 0.3 – 0.6            | 0.1 – 0.3              |
|                            | 40 – 60                                 | 1.5 – 2                         | 0.6 – 1.5            | 0.3 – 0.6              |
|                            | 60 – 100                                | 2 – 3.5                         | 0.6 – 1.5            | 0.6 – 1.5              |
|                            | >100                                    | >3.5                            | >2                   | >1.5                   |

#### Uniaxial Compressive Strength (UCS, MPa)

| Interval | Equation |
|----------|----------|
| 20-30    | UCS20/4 +2.5 |
| 30-40    | UCS20/4 +2.5 |
| 40-50    | UCS20/4 +2.5 |
| 50-60    | UCS20/8 +10  |
| 60-80    | UCS20/4     |
| 80-100   | UCS20/4     |

#### Point Load Strength (I₅₀, MPa)

| Interval | Equation |
|----------|----------|
| <0.5     | 2L₅₀-10  |
| 0.5 - 1  | 5L₅₀+5   |
| 1 - 1.5  | 10L₅₀-2.5|
| 1.5 - 1.75 | 10L₅₀+32.5|
| >1.75    | 20L₅₀+5  |

#### Joint Spacing (J, m)

| Interval | Equation |
|----------|----------|
| <0.3     | 100J-30  |
| 0.3 - 0.45 | 50J/3 +12.5 |
| 0.45 - 0.6 | 50J/3 +12.5 |
| 0.6 - 1.05 | 50J/3 +12.5 |
| 1.05 - 1.5 | 30J-7.5  |
| >1.5     | 20J+10   |

#### Bedding Spacing (B, m)

| Interval | Equation |
|----------|----------|
| <0.1     | 50B-5    |
| 0.1 - 0.2 | 50B/3 +2.5 |
| 0.2 - 0.3 | 100B/3 -5 |
| 0.3 - 0.45 | 100B/3 +10 |
| 0.45 - 0.6 | 200B-30  |
| >1.5     | 90B/9    |

In order to verify the proposed continuous rating system, a hypothetical evaluation and comparison has been made in Table 5 for 4 different rock masses which the values of their geotechnical parameters are near to lower and upper boundaries of intervals in rock classes given in Table 2.

### Table 5. Comparison between the 4 different rock masses in terms of diggability

| Parameter | Rock Mass Properties | Conventional Ratings | Continuous Ratings |
|-----------|----------------------|----------------------|--------------------|
| W         | Mod.                 | 15 15 15 15          | 15 15 15 15        |
| S         | 41 59 19 21          | 15 15 15 15          | 15 15 15 15        |
| J         | 0.6 1.49 0.59 0.61   | 30 30 15 30          | 22.5 37.33 22      |
| B         | 0.3 0.59 0.29 0.31   | 10 10 5 10           | 7.25 14.67 7.25    |
|          |                      |                      |                    |
| Final Rating | 70 70 35 65          | 57.75 84.25 44.25 46.32 |
| Excavation Class | IV IV I IV III V II II |

As it can be seen from Table 5, rock mass 1 and 2 falls within the same excavation class owing to same ratings have been assigned to geotechnical properties although they have completely different features. However, continuous rating process can distinguish rock mass 1 and 2 by assigning relative rating according to the value of input parameters. In addition; although rock mass 3 and 4 have nearly the same geotechnical parameters, they are classified in completely different excavation class such as I and IV, respectively. When continuous rating is applied, rock mass 3 and 4 will be in the same excavation class II as expected.
5. Conclusions
Most of diggability or excavability classification systems are generally based on assigning a rating for the parameters having importance in rock excavation process. The final rating obtained from this type of classification systems can enable the engineers or decision makers to determine excavator or ripper type to be used for the considered site. However, the sharp transitions between the two adjacent classes for a given parameter can lead to some uncertainties. Owing to this abrupt transition, the assigning rating for a given parameter has been dramatically increased or decreased if the numerical value of the parameter is very near to the upper or lower boundary of the classes. This increase or decrease directly affects the final rating and the determined machine type for the evaluated site by employing diggability classification systems. The above mentioned uncertainties or fuzziness encountered in the practical application of conventional rock excavation classification systems can be handled by employing “continuous rating” which enables a soft and gradual transition between the classes. In this way, it is possible to make more realistic evaluation about the ease of excavation of rocks.

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