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GEOTECHNICAL RISK CLASSIFICATION FOR UNDERGROUND MINES

KLASYFIKACJA POZIOMU ZAGROŻENIA GEOTECHNICZNEGO W KOPALNIACH PODZIEMNYCH

Underground mining activities are prone to major hazards largely owing to geotechnical reasons. Mining combined with the confined working space and uncertain geotechnical data leads to hazards having the potential of catastrophic consequences. These incidents have the potential of causing multiple fatalities and large financial damages. Use of formal risk assessment in the past has demonstrated an important role in the prediction and prevention of accidents in risk prone industries such as petroleum, nuclear and aviation. This paper proposes a classification system for underground mining operations based on their geotechnical risk levels. The classification is done based on the type of mining method employed and the rock mass in which it is carried out. Mining methods have been classified in groups which offer similar geotechnical risk. The rock mass classification has been proposed based on bulk rock mass properties which are collected as part of the routine mine planning. This classification has been subdivided for various stages of mine planning to suit the extent of available data. Alpha-numeric coding has been proposed to identify a mining operation based on the competency of rock and risk of geotechnical failures. This alpha numeric coding has been further extended to identify mining activity under 'Geotechnical Hazard Potential (GHP)'. GHP has been proposed to be used as a preliminary tool of risk assessment and risk ranking for a mining activity. The aim of such classification is to be used as a guideline for the justification of a formal geotechnical risk assessment.

Keywords: underground mining, geotechnical risk, risk ranking, geotechnical hazard potential, risk assessment

Górnictwo podziemne pociąga za sobą różnorakie zagrożenia spowodowane przez uwarunkowania geotechniczne. Urabianie złoża w połączeniu z pracą w zamkniętej przestrzeni oraz z niepewnymi danymi geotechnicznymi powodować może zagrożenia, które w konsekwencji prowadzić mogą do wypadków, a te potencjalnie powodować mogą skutki śmiertelne dla osób oraz poważne straty finansowe. Wykorzystanie przepisowych metod oceny ryzyka w przeszłości wykazało ich istotną rolę w przewidywaniu i zapobieganiu wypadkom i zagrożeniom w dziedzinach najbardziej na nie narażonych, a więc w przemyśle naftowym, jądrowym oraz w lotnictwie. W niniejszej pracy zaproponowano system klasyfikacji operacji w górnictwie podziemnym w oparciu o poziom zagrożenia geotechnicznego. Klasyfikacji dokonano uwzględniając za-

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stosowana metodę urabiania oraz rodzaj urabianego górotworu. Przedstawiono kategorie metod urabiania o podobnym poziomie zagrożenia geotechnicznego. Zaproponowano klasyfikację górotworu na podstawie właściwości wytrzymałościowych określanych rutynowo na etapie planowania kopalni. Klasyfikacja ta podzielona jest na kilka pod-etapów odpowiadającym etapom planowania kopalni, tak by uwzględnić zakres dostępnych na każdym etapie danych. Zastosowano kodowanie alfanumeryczne dla wskazania metody urabiania w oparciu o dane o zwięzłości skały i ryzyko zagrożenia geotechnicznego. Kodowanie alfanumeryczne zostało następnie rozszerzone dla identyfikacji operacji górniczych w ramach kategorii „Poziom zagrożenia geotechnicznego". Wskaźnik ten wykorzystywany jest jako wstępne narzędzie oceny ryzyka wystąpienia zagrożenia oraz klasyfikacji poziomu zagrożenia związanego z działalnością górniczą. Celem takiej klasyfikacji jest jej wykorzystanie jako wytycznych i uzasadnienia dla stosowania formalnych metod oceny ryzyka geotechnicznego.

Słowa kluczowe: górnictwo podziemne, zagrożenia geotechniczne, ranking poziomu zagrożenia, ocena potencjalnego ryzyka wystąpienia zagrożeń geotechnicznych

1. Introduction

Mining industry has been well known for the potential of risks that exist in its operations. The mining environment includes large equipment working along with people. The risk of accidents is compounded in case of underground operations due to confined space of working. Confined space in itself is accounted as a high risk working in normal risk assessment practices. Over time, the amount of information that is collected prior to a mining operation has increased significantly due to the development of advanced instrumentation, modelling tools and data analysis practices. The nature of underground mining operation is dominated by extraction of economic minerals in a selective manner leading to a profitable outcome. This selective underground mining thus involves excavations at intervals in a rock mass. The nature of such intervals and extent of excavation varies depending on the mining method employed. However, irrespective of the mining method used, this selective excavation combined with the inherent heterogeneous nature of rock mass results in large variability in geotechnical parameters.

Risk assessment practices have established themselves as an effective tool in preventing an accident through foresight. Given the potential adverse impact a major geotechnical accident in the form of roof collapse, subsidence, rock burst etc. can have on an industry prone to high fluctuations in metal prices; it is becoming increasingly important to evaluate a mine design from geotechnical risk perspectives. It is established that geotechnical consideration from early stages of mining can prove effective in accident prevention (Hanson et al., 2005).

This paper proposes a classification system which identifies all underground mining operations based on their geotechnical risk potential.

2. Methodology of classification

The sub-classification has been divided into its two elements namely:

1. Sub-classification of mining method,
2. Sub-classification of rock body.

2.1. Sub-classification of mining method

Underground mining methods have been classified in the past based on type of support used as artificial, natural, and caving methods (Brady & Brown, 1993). The type of rock (soft rock/hard rock) can also be used to classify mining methods. Another form of classification is conventional mining versus novel mining practices (Harmin, 2001). For risk based classification, the various categories of underground mining methods are as mentioned below:

Open stoping methods (O): This mining method uses open stope creations which are either naturally supported by rock pillars or are artificially supported by reinforcement (rock bolts, mesh, shotcrete etc). This method is characterised by the low country rock displacement and high stored strain energy in the rock (Brady & Brown, 1993). This is attributed to the fact that the redistribution of stress created by excavation is either not compensated at all (stress transferred to rock pillars in naturally supported methods), or is partially compensated (load taken by bolts, mesh, back fill etc.) The degree of compensation directly determines the stored stress in the rock and thus influences the geotechnical risk. The mining methods which are included in this category are – sublevel stoping with and without backfill, vein mining, cut and fill mining, shrinkage stoping, vertical crater retreat and bighole stoping (Harmin, 2001). For the purpose of classification, all mining methods under 'open stoping' are assigned the alphabetical code '***O***'.

Caving methods (C): This involves all the underground mining methods where the mined out area is allowed to cave/collapse. The characteristic of mining methods under this category are high country rock displacement and low stored strain energy. From active stress point of view, these methods help to release stress by caving of rock. However, the extent and timing of caving and its uncertainty are one of the prominent geotechnical risks in such mining methods. Secondary hazards in the form of airblast and subsidence are also risks in caving methods. The mining methods in this category are – sublevel caving, block caving, panel caving (Harmin, 2001). For the purpose of classification, all mining methods under 'caving' are assigned the alphabetical code '***C***'.

Longwall mining method (L): This method comes in the transition zone of artificially supported and caving methods (Harmin, 2001). This method is more popular for coal seam mining but has found its operation in few metalliferous mines like platinum as well. This mining method uses support at face followed by caving. Due to the combination of methodologies, the mining method results in geotechnical risk similar to both category O and C mining methods. For the purpose of classification, longwall mining method is assigned the alphabetical code '***L***'.

Room and pillar mining method (R): This like longwall mining can be of both supported and caving type (Harmin, 2001). Such mining method involves large rooms supported by pillars. This results in risk arising from very high stored strain energy owing to large excavation dimension. Such mining method can have a variant which includes pillar mining to extract pillars done by means of artificially supporting the excavation or allowing systematic caving. Hence, this mining method also results in geotechnical risks from both O and C category. Similar to longwall mining, this method is popular in coal but has found use in metalliferous mines with massive tabular ore. For the purpose of classification, room and pillar mining method is assigned the alphabetical code '***R***'

The term 'Core risk' introduced by Bruce Hebblewhite (2003), emphasises and explains the generic risk which exists in each of the above mentioned mining method groups. In this classification however, the mining methods in itself have not been compared for geotechnical risks in one mining method over another. This is largely owing to the fact that the selection of the right mining method is a combination of both economic and geotechnical parameters and they are duly considered using established mining method selection tools. The heterogeneous nature of rock mass properties on the other hand makes some sections of a mine more prone to geotechnical risk than others. Hence the rock mass is subdivided into various rock competency levels under this classification and are mentioned in section 2.2.

2.2. Sub-classification of rock body

The risk based classification uses existing rock mass classification methods in their original form or with slight modification to represent a rock's competency against forces causing collapse. It uses simple classification methods where rock mass properties under consideration can be measured with relative ease. This simplicity is required for the fact that complex classification system are time consuming and requires resources for the same which will be discouraging for a company for risk assessment purposes. The bulk rock mass properties which form part of the classification system and have a large influence on geotechnical risks are:

1. In-situ strength of rock: This is the direct measure of the ability of an intact rock to withstand in – situ stress and mining induced stresses.
2. Depth of rock mass: This influences the active stress acting on the rock mass and is among the reasons behind stress related geotechnical failures.
3. Mining induced stress: These are stresses caused by mining activity due to excavation. Analytical methods such as modelling can give a rough picture of the overall stress acting on the rock mass during planning stage while field tests such as over-coring can give inputs regarding stress once the mine is in operation.
4. Discontinuities and their conditions: This is the biggest source of uncertainty in rocks behaviour. Zones of weaknesses reduce the capacity of a rock to withstand geotechnical risks such as fracture, swelling, slabbing, fallouts etc.
5. Groundwater: This affects the friction conditions of joints and their cohesion. The impact of groundwater however is not adverse in deep underground mines and is not considered in major mining based rock mass classifications such as modified RMR (RMR_{89}), GSI etc.

Apart from the above mentioned parameters, there are detailed characteristics of rock which govern local risk and needs to be studied in detail while doing detailed on site risk analysis. Based on the various parameters that affect a rock quality, the classification must be made depending on the amount of data available. The level of confidence in the data increases as the project progresses from pre-feasibility stage to actual operation. For this purpose, the sub-classification of rock body has been designed for three different stages of mining as mentioned below with each stage having a numeric code (indicated in parenthesis).

1. Pre-feasibility stage (1),
2. Bankable feasibility stage (2),
3. Mine operation stage (3).

2.2.1. Sub-classification of rock body for risk assessment at pre-feasibility stage

Availability of geotechnical data at this stage is limited to few exploratory drill holes and reconnaissance survey. Work has been carried out in the past to use borehole data to ascertain rock mass properties (Yaserabi et al., 2014). The aim of classification at this stage is to establish a general understanding of geotechnical risk that will be needed to be dealt with when mine starts operation. This can help plan economic contingencies. *Q* classification system as proposed by Barton (1974) has been used at this stage for rock competency classification. *Q* is given as:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \tag{1}$$

where: *RQD* is Rock Quality Designation index (Deere, 1963), J_n is the joint set number, J_r is the joint roughness number, J_a is the joint alteration number, J_w is the joint water reduction factor (fixed as 1 for risk based classification), *SRF* is the stress reduction factor.

Based on *Q*, the rock mass has been classified into 5 levels of rock competency against geotechnical risk. Each level is coded with Roman numeral I to V with V being highest rock competency. They are given a prefix 1 to indicate classification at pre-feasibility stage as shown below in table 1.

TABLE 1

Rock mass classification for risk for pre-feasibility stage

Range of *Q* value	Classification code	Rock competency
0.001-1	1I	Very poor
1-4	1II	Poor
4-10	1III	Fair
10-40	1IV	Good
40-1000	1V	Very good

The availability of geotechnical data is very limited at this stage and doesn't accurately predict the local nature of rock mass. Especially the occurrence of local discontinuities cannot be judged at this stage and hence the scope should not be extended to rigorous details which will increase the time taken but will not have a substantial addition to the level of confidence in the assessment of geotechnical risk of rock.

2.2.2. Sub-classification of rock body for risk assessment at bankable feasibility stage

This stage of mining aims at justifying the economics behind a mining project. Consideration of geotechnical accident costs at this stage can thus help plan contingency in investment as a means of economic risk mitigation. At this stage, the mine is still in the planning stage and site information is limited. For this reason, the classification is relevant to the entire underground mine or a large section of the mine, which can be differentiated geotechnically based on the collected data. The measure of rock strength against the major principle stress can be included in the classification at this stage by the use of safety margin (*SM*) which is given by:

$$Safety\,Margin\left(SM\right)=\frac{in-situ\,rock\,strength}{major\,principle\,stress}-1 \quad (2)$$

SM gives the measure of the active stress acting on the rock against its natural competence. For the purpose of classification it is assumed that the data available is sufficient to do a speedy *Q* classification for the mine. Quality of a rock can be divided from very low to very high based on SM. For the purpose of classification, both *SM* and *Q* are measured and the worst of the two gives the rock competency. For e.g. if quality of rock is low based on *SM* and rock competency is very low based on *Q* classification (Table 2), the rock competency would be taken as very low (based on *Q*) for it being the worst of the two.

TABLE 2

Rock mass classification for risk for bankable feasibility stage

Range of SM	SM based quality of rock	Q based rock competency	Classification code	Rock competency (worst of *SM* and *Q*)
–1 to –0.8	Very low	Very low	2I	Very low
–0.8 to 0	Low	Low	2II	Low
0 to 0.5	Fair	Fair	2III	Fair
0.5 to 2	High	High	2IV	High
2 and above	Very high	Very High	2V	Very high

2.2.3. Sub-classification of rock body for risk assessment at mine operation stage

The extent of geotechnical information available at this stage is at the highest level. Classification can be done for an entire mine. Alternatively, various sections of the mines can be identified for differing rock competency. Stability number (*N*) as proposed under Mathews stability graph method (Mathews et al., 1980) has wide spread use in predicting open stope stability. For the classification at this stage, a function of modified stability number N_{r} and safety margin similar to bankable feasibility stage classification, is used to classify rock competency. The factor 'A' from the original stability number *N*, is dropped in N_{r} because SM takes into account the stress acting on the rock. The modified stability number N_{r} is given by:

$$N_r = Q \times B \times C \quad (3)$$

where: *Q* is the Barton's *Q* number with *Jw* taken 1. Factor B which deals with the influence of discontinuity on rock stability is calculated using the chart proposed under Mathews stability graph method as given in Fig. 1 below.

Factor C can be calculated as proposed in the stability number *N* calculation as:

$$C = 8 - 7\,\mathrm{cosine}\,\alpha \quad (4)$$

where: α is the dip of excavation of the surface of excavation. Of the *C* value from all surfaces, the lowest must be taken.

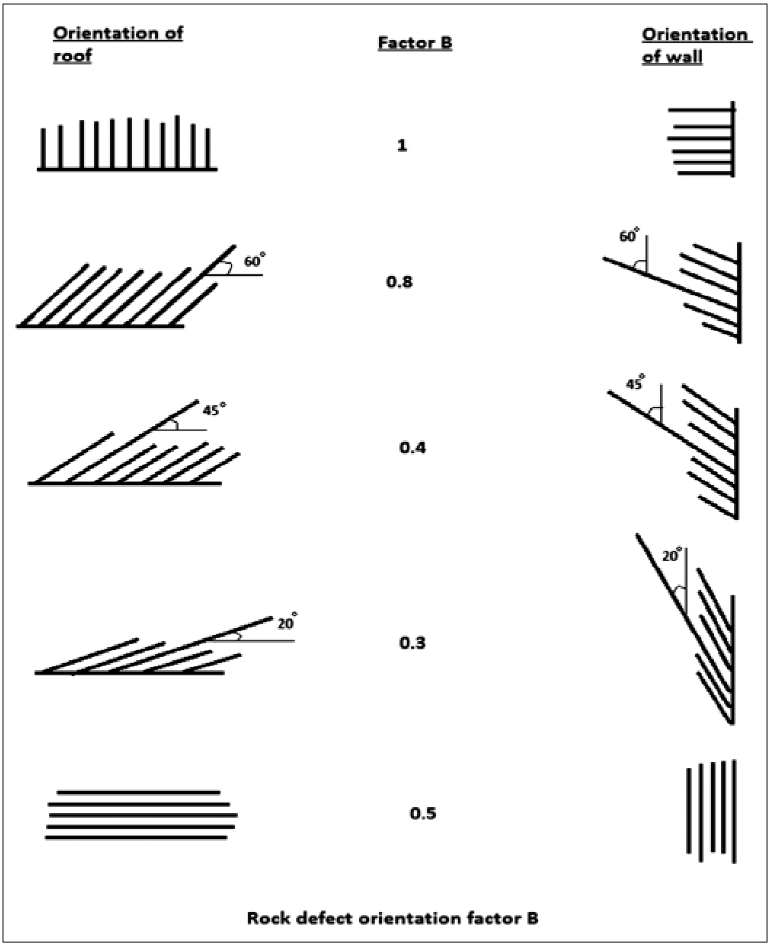

Fig. 1. B parameter calculation (Mathews et al., 1980)

Classification based on *SM* and N_r is shown below in table 3. They are divided into classes with roman numerals I to V with a prefix 3 indicating classification done at mine operation stage.

TABLE 3

Rock mass classification for risk for mining operation stage

Range of N_r	N_r based quality of rock	*SM* based quality of rock	Classification code	Rock competency (Worst of *SM* and N_r)
0.0001-0.6	Very low	Very low	3I	Very low
0.6-7	Low	Low	3II	Low
7-30	Fair	Fair	3III	Fair
30-250	High	High	3IV	High
250 and above	Very high	Very high	3V	Very high

3. Result of the classification system

A mine or a section of a mine can be coded with the mining method – rock mass combination as O2III, C1V etc. The alphabet in the coding represents the mining method used (open stoping in case of O2III), the number represents the stage of mining (bankable feasibility stage in case of O2III) and the Roman numeral represents the rock competency (fair in case of O2III). Based on the above format all the possible classifications are mentioned below in table 4 to 6.

TABLE 4

Pre-feasibility stage risk based classification

Mining Method	Rock competency – High to low				
Open stoping	O1I	O1II	O1III	O1IV	O1V
Caving	C1I	C1II	C1III	C1IV	C1V
Longwall	L1I	L1II	L1III	L1IV	L1V
Room & pillar	R1I	R1II	R1III	R1IV	R1V

TABLE 5

Bankable feasibility stage risk based classification

Mining Method	Rock competency – High to low				
Open stoping	O2I	O2II	O2III	O2IV	O2V
Caving	C2I	C2II	C2III	C2IV	C2V
Longwall	L2I	L2II	L2III	L2IV	L2V
Room & pillar	R2I	R2II	R2III	R2IV	R2V

TABLE 6

Mining operation stage risk based classification

Mining Method	Rock competency – High to low				
Open stoping	O3I	O3II	O3III	O3IV	O3V
Caving	C3I	C3II	C3III	C3IV	C3V
Longwall	L3I	L3II	L3III	L3IV	L3V
Room & pillar	R3I	R3II	R3III	R3IV	R3V

4. Geotechnical Hazard Potential

Classification of mining operations based on rock competency gives a relative estimate of possible geotechnical risks. The above mentioned classification system can be translated into a preliminary risk assessment of geotechnical risks. Geotechnical hazard potential (GHP) is an indicative ranking of mining operations based on the potential it has in causing a geotechnical hazard. It is to be noted that a competent rock does not necessarily mean absence of geotechnical hazards as caving and long wall mining methods require the rock mass to collapse for stress release. The strength of the rock in such cases should be optimum to avoid large overhang. Table 7 below classifies mines under GHP scheme.

TABLE 7

Geotechnical Hazard Potential (GHP) of mines

GHP	Description	Mining Category
Very Low (1)	• Negligible chances of hazards arising from bulk rock mass property. • Hazards can largely arise from random natural events, unforeseen discontinuity, human error etc.	O1V, C1V (for footwall), C1II (for hanging wall), L1V (for footwall), L1II (for hanging wall), R1V
		O2V, C2V (for footwall), C2II (for hanging wall), L2V (for footwall), L2II (for hanging wall), R1V
		O3V, C3V (for footwall), C3II (for hanging wall), L3V (for footwall), L3II (for hanging wall), R3V
Low (2)	• Minor chances of hazards arising from bulk rock mass property. This can be in terms of minor ravelling and spalling. • Hazards arising from random natural events, unforeseen discontinuity and human error. The extent of damage from such random event is noticeable but doesn't hamper routine mining activity.	O1IV, C1IV (for footwall), C1I (for hanging wall), L1IV (for footwall), L1I (for hanging wall), R1IV
		O2IV, C2IV (for footwall), C2I (for hanging wall), L2IV (for footwall), L2I (for hanging wall), R2IV
		O3IV, C3IV (for footwall), C3I (for hanging wall), L3IV (for footwall), L3I (for hanging wall), R3IV
Fair (3)	• Fair chances of hazards arising from bulk rock mass property. This can be routine if the rock mass is not supported/reinforced. • Hazards arising from random natural events, unforeseen discontinuity and human error. The extent of damage from this can be higher than the routine visible failures. This can cause substantial damage to production. Loss in productivity is recoverable over a short span (couple of weeks)	O1III, C1III (for footwall), C1III (for hanging wall), L1III (for footwall), L1III (for hanging wall), R1III
		O2III, C2III (for footwall), C2III (for hanging wall), L2III (for footwall), L2III (for hanging wall), R2III
		O3III, C3III (for footwall), C3III (for hanging wall), L3III (for footwall), L3III (for hanging wall), R3III
High (4)	• High frequency of hazards arising from bulk rock mass property. Accidents cause productivity loss recovered over weeks. • An unsupported site may not be safe for onsite risk assessment itself. • Hazards arising from random natural events, unforeseen discontinuities and human error. Such hazards cause major damage to production. May lead to closure of area. Loss of productivity needs couple of months to be recovered. Financial damage may affect short term profits.	O1II, C1II (for footwall), C1IV (for hanging wall) L1II (for footwall), L1IV (for hanging wall), R1II
		O2II, C2II (for footwall), C2IV (for hanging wall) L2II (for footwall), L2IV (for hanging wall), R2II
		O3II, C3II (for footwall), C3IV (for hanging wall) L3II (for footwall), L3IV (for hanging wall), R1II
Very High (5)	• Very high frequency of hazards arising from bulk rock mass property. Accidents cause loss in production which may not be recovered over the year. • Site for risk assessment must not be visited without reinforcement and couple of days of observation. • Hazards arising from random natural events, unforeseen discontinuities and human error. Such hazard may cause permanent loss of raw material in the form of trapped ore. Severe financial loss and overall net present value (NPV) of project may be affected.	O1I, C1I (for footwall), C1V (for hanging wall), L1I (for footwall), L1V (for hanging wall), R1I
		O2I, C2I (for footwall), C2V (for hanging wall), L2I (for footwall), L2V (for hanging wall), R2I
		O3I, C3I (for footwall), C3V (for hanging wall), L3I (for footwall), L3V (for hanging wall), R3I

5. Conclusion

Formal geotechnical risk assessment along with mine design can help in identifying potential underground threats in advance. Mitigation measures can thus be planned in advance and resources can be allocated to areas under high risk. Risk based classification of mines can be the preliminary step in a formal geotechnical risk assessment. The following are the key benefits of using such a system:

1. Mining operations with similar geotechnical risks can be grouped together. This enables designing a broad risk assessment guideline which is applicable to large number of mines. These can later be adapted on local scale based on site requirement.
2. Geotechnical hazard potential can be used as a common benchmark for classifying all underground mining operation for geotechnical risk. Information sharing among different mines towards risk prevention can thus be easier.
3. Different sections of a mine can be classified under this system for high/low risk. This helps to rank the risk and divert resources to high risk areas. This can also assist in communication among work force regarding areas where precaution must be taken while carrying out work.
4. It is fast and cheap. This can hence be used for identifying areas which may require a formal geotechnical assessment for hazard/hazards.

The classification parameters can be modified based on site experience. The prime objective is to encourage risk planning from the earliest stages of mining. With the legislation regarding work related accidents getting stringent across all the countries, risk based classification can form a significant step in design of underground mines based on its risk prevention capabilities. Such risk based classification can also be developed across specific mines which have repeated failures of a certain kind such as rock burst, seismicity etc. Such specific classification methods will help justify a formal hazard specific risk assessment for an area and will aid in predicting and preventing geotechnical accidents.

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References

Barton N.R., Lien R., Lunde J., 1974. *Engineering Classification of Rock Masses for the Design of Tunnel Support*. Rock Mech., p. 184-239.

Brady E.H., Brown E.T., 1993. *Rock Mechanics for Underground Mining* (2nd ed.). London: Chapman & Hall.

Deere D.U., 1963. *Technical Description of Rock Cores for Engineering Purposes*. Felsmechanik und Ingenieurgeologie, Vol. 1, No. 1, p. 16-22.

Hamrin H., 2001. *Underground Mining Methods and Application*. [In:] W.A. Hustrulid, R.L. Bullock, *Underground Mining Method: Engineering Fundamentals and International Case Studies* (p. 3-14). Littleton, Colorado: Society of Mining, Metallurgy and Exploration, Inc.

Hanson C., Thomas D., Gallagher B., 2005. *The Value of Early Geotechnical Assessment in Mine Planning*. Coal Operators Conference (p. 17-30). New South Wales: University of Wollongong & the Australasian Institute of Mining and Metallurgy.

Hebblewhite B.K., 2003. *Management of Geotechnical Risks in Mining Projects*. Retrieved 04 18, 2012, from UNSW, School of Mining ENgineering: http://www.mining.unsw.edu.au/sites/default/files/hebblewhite3.pdf

Mathews K.E., Hoek D., Wyllie D., Stewart S., 1980. *Prediction of Stable Excavation Spans for Mining at Depths Below 1000 Metres in Hard Rock - Report to Canada Centre for Mining and Energy Technology (CANMET)*. Ottowa: Department of Energy and Resources.

Yaserabi A.B., Wetherelt A., Foster P.J., Afzal P., Coggan J., Ahangaran D.K., 2014. *Application of RQD-Number and RQD-Volume multifractal modelling to delineate rock mass characterisation in Kahang Cu-Mo porphyry deposit, central Iran*. Arch. Min. Sci., Vol. 58, No 4, p. 1023-1035.

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