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Contents

An Evaluation of Excavatability Criteria for Sedimentary Rocks: A Correlation from Mechanical Properties

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ABSTRACT

Study of excavability criterion has been derived from empirical methods based on the specific condition of materials. This study aimed to evaluate excavatability criterions based on standard methods such as Franklin et al.,1971; Pettifer and Fookes, 1994;, and Equipment Handbook (Caterpillar and Komatsu). This study was undertaken through data collection on a similar geological condition on underdevelopment coal mining site. Sedimentary rocks formation, such as claystone, sandstone, and siltstone were the main rock-type investigated in this study. The parameters observed were Point Load Index (PLI), Fracture Index (FI), Unconfined Compressive Strength (UCS), and seismic velocity. The parameters were obtained from field testing and laboratory testing according to ASTM and ISRM standard. The investigated materials had a maximum value of PLI, UCS, and seismic velocity of 0.55 MPa, 15.75 MPa, and 2803 m/s, respectively. The evaluation of the prediction methods in this study undertaken by looking at the correlation of the selected parameters on the same set of samples. This study is continued on further study to provide more solid evaluation criterions.

INTRODUCTION

The prediction of rock excavations criteria usually stated as excavatability/rippability criterion. The correct prediction methods are subjects to the data sets and empirical approach on specified location around the world. The more understanding of rock behavior through its material properties for excavatability criterions will lead to the economic efficiency of the projects.

This study aimed to evaluate of excavatability criterions that commonly used in practices such as Franklin, Broch and Walton, 1971; Pettifer and Fookes, 1994; and equipment manufacture handbooks. This study is part of a series research of rippability criterions evaluations on the selected area of study. The research includes:

a. Data collection and evaluation of rock properties.
b. Database creations and analysis to determine the dominant factors which influence selected criterion.
c. Productivity evaluation on the on-going project in the same location where the database has taken.
d. Formulation and simulation of the proposed rippability criterion using numerical and mathematical modeling.

This research presented in this paper only focus on point (a) — the datasets obtained from a coal mining site concession in East Kalimantan Province, Indonesia.

METHODOLOGY

The primary methodology of this research was the indirect methods of excavatability criteria. Data collection obtained through primary methods; geological drilling in the designated research area. The sample obtained from geological drilling was selected according to the material type, depth, and core length. Field studies and laboratory tests are described in Table 1.

Table 1. Field Studies and Laboratory Tests

Field Studies	Laboratory Tests
Rock Quality Designation	Uniaxial Compressive Strength
Discontinuity spacing	Point Load Index
	Seismic Velocity

Regression analysis was conducted as an evaluation from field studies and laboratory test to show the correlation between field and laboratory test. Prediction methods used in this research were graphical methods and seismic velocity.

PREDICTION CRITERION STATE-OF-THE-ART

The prediction criterions of excavatability of materials have been conducted by research from multiple researchers based on indirect methods (Basarir and Karpuz, 2004). There are three main indirect methods as follows:

Graphical Method

Graphical methods pioneered by Franklin et al., 1971and updated by Pettifer and Fookes, 1994. The graphical method is not using the detailed field and laboratory experiments. The main parameter for graphical methods is Point Load Index (PLI – $I_{s(50)}$) and joint spacing (stated as Fracture Index – I_f)/Point Load Index is a method to determine rock mass strength based on applied pressure on a certain point of the rock sample (Hoek and Bray 1981). Fracture Index is a function of Rock Quality Designation (RQD) with fracture frequency (λ) from the result of log drilling. The fracture Index equation (Hudson and Priest 1983) shown as follows:

$$RQD = 110.4 - 3.68\lambda \quad (1)$$

$$\lambda = \sum \frac{1}{I_f} \quad (2)$$

The example of graphical methods of Franklin et al., 1977 and Pettifer and Fookes, 1994 are shown in Fig. 1 and Fig. 2, respectively.

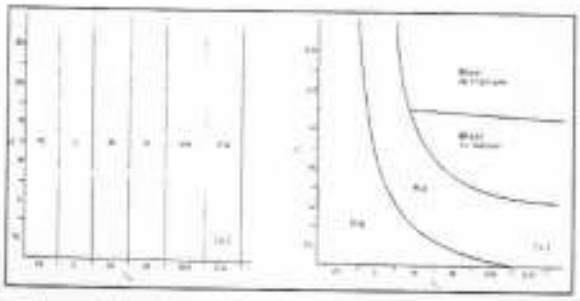

Fig. 1 Size-Strength Graphs (Franklin et al., 1971).

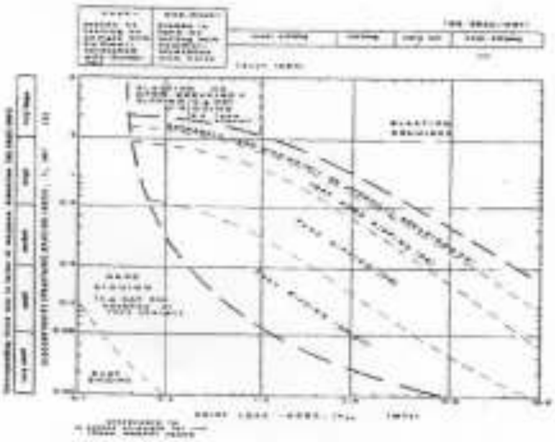

Fig. 2 Updated Size Strength Graph (Pettifer and Fookes, 1994)

Grading Methods

The former pioneer of grading method is Weaver, 1975 followed by a couple of researchers such as Scoble et al., 1984 and MacGregor et al., 1994. The principles of grading methods are similar with rock mass classification systems such as Rock Mass Rating (RMR) (Bienawski, 1989) and Q-system (Barton et al., 1974) except for the groundwater condition. Each parameter of rock mass are classified and graded in certain ways based on the researcher criterions. The excavatability class is determined from the cumulative grades. Rock strength and seismic velocity (P-wave velocity) are the dominant parameters used in the most grading methods. Rock strength is stated using UCS (Uniaxial Compressive Strength) to determine criteria for strength or weak rock. Seismic velocity is used to determine the fracture condition of the rock.

Seismic Velocity Based Methods

The seismic velocity of rock mass is related to geological and physical properties such as density, fracturing, and rock strength (Clark, 1996). Seismic velocity method pioneered by Atkinson (Atkinson, 1971). This method also commonly used by equipment manufacturers such as Caterpillar and Komatsu. The seismic criteria for Atkinson are shown in Fig. 3. Excavatability criteria from mining equipment separated by type of materials and type of the equipment, shown in Fig. 4 and Fig. 5.

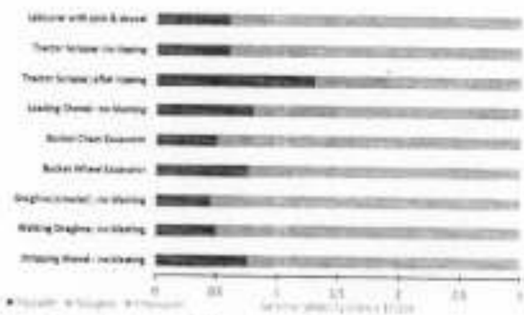

Fig. 3 Excavatibility Criteria (Atkinson, 1971)

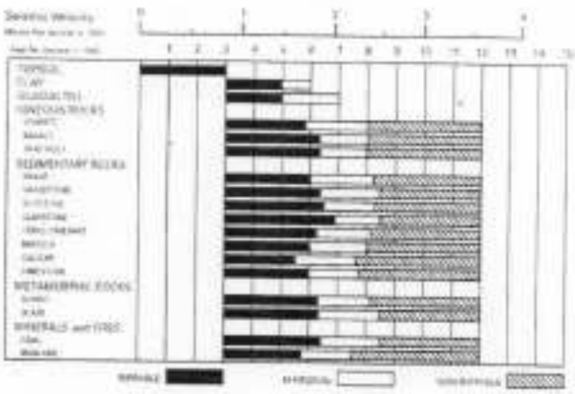

Fig. 4 Rippability Criteria for CAT D8R (Caterpillar, 2017)

Fig. 5 Rippability Criteria for Komatsu D155A (Komatsu, 2016)

GEOTECHNICAL DATABASE

The database for this study was taken in East Kalimantan Province, District of Kutai Kartanegara, Indonesia. The data was collected through a series of geological drilling in the coal mining concession in the same geological area. The location of the data collection is shown in Fig. 6.

Fig. 6 Geological Maps and Sampling Location

The datasets are classified as sedimentary rocks category that consist of claystone, sandstone, siltstone, carbonaceous claystone, and coal. The classification of the stratigraphy based on the physical properties obtained from geological drilling. There are 115 samples obtained with classification 35.65% claystone, 26.96% sandstone, 25.22% siltstone, 5.22% coal, 4.35% carbonaceous claystone, and 2.61% sandy sandstone (Fig. 7).

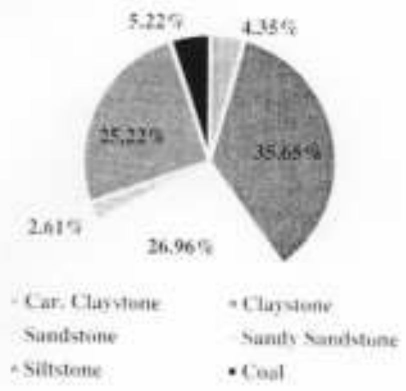

Fig. 7 Material Distribution in the Research Area

RESULT AND DISCUSSION

Data Distribution

The data distribution from the laboratory testing and field studies shown in the Fig. 8. The datasets have relatively low strength material based on the laboratory tests result (PLI, UCS, and seismic velocity). Based on the literature review, relatively low strength material is classified to easy-digging with typical excavator used in mining operation (i.e. Komatsu PC-200) and easy-ripping with a typical mining equipment such as CAT Dozer D8R and Komatsu Dozer D115A.

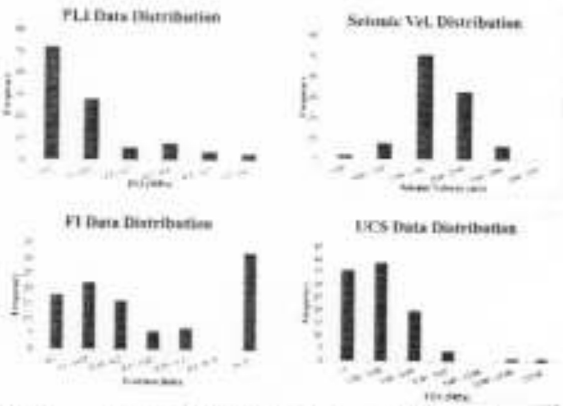

Fig. 8 Data Distribution from Field Studies and Laboratory Test Result

Correlation Analysis

Correlation analysis observed a relationship between field parameter and laboratory tests. The dependent variable is the Fracture index as a representative from field parameter. The result of regression model is displayed in Fig. 9. In general, fracture index has a low correlation to the laboratory tests (PLI, seismic velocity, and UCS) and dominated with negative correlation coefficient. The only positive correlation occurs on regression model of seismic velocity and in Sandstone material. This explained that the higher the seismic velocity will be followed by fracture index. The degree of correlation (R^2) for any regression model is indicates small strength of association between field parameter and laboratory tests. The highest R^2 occurred on regression model for PLI versus fracture index in Sandstone material. The result also indicates and confirms that Sandstone samples are denser and more compact than the other. Based on regression analysis, indirect prediction method of excavatability may have an unfortunate result from the direct methods although it should be investigated for further studies.

The multi-variate regression using linear model is conducted to investigate the relationship between field parameter with three variables from laboratory tests. The result of multi-variate regression shown in the Table 2.

Table 2. Multi-variate Regression Result

Parameter	Material		
	Claystone	Sandstone	Siltstone
UCS	-0.159	-0.508	-0.237
PLI	-0.135	-0.293	-0.075
Seismic Vel.	-0.024	0.241	-0.269

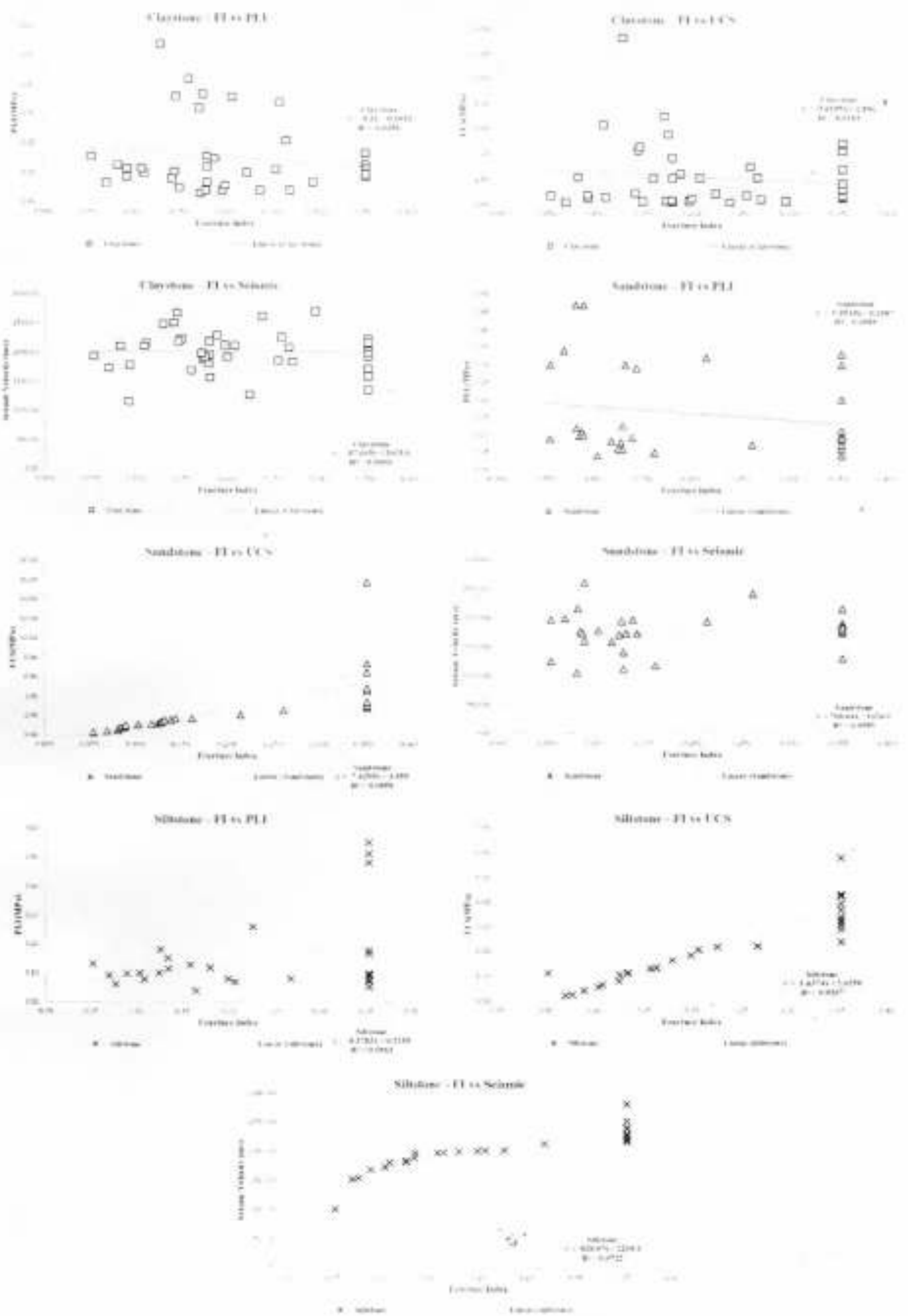

Fig. 9 Linear Regression Model for Correlation Analysis of Field Studies and Laboratory Test Result

Prediction Methods

The prediction methods used in this research refers to the result of correlation analysis and the availability of data. Graphical methods and seismic velocity based methods is used for excavatability criterion.

Graphical Methods

The graphical method used on this research refers to Pettifer and Fookes, 1994 since they stated the most updated chart for excavatability criterion. The result shown in Fig. 10.

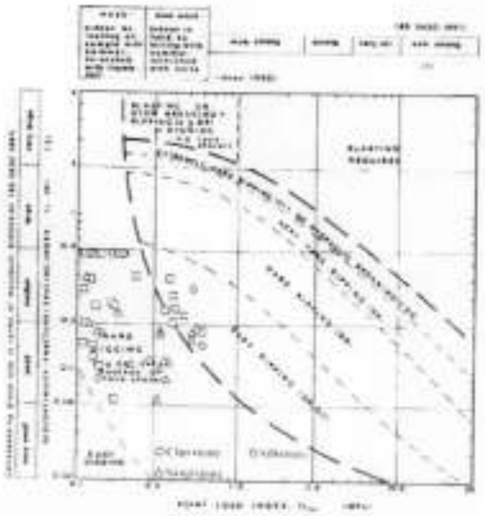

Fig. 10 Excavatability Prediction Result (chart based on Pettifer & Fookes, 1994).

Claystone materials (85.37%) are suitable for digging, meanwhile 14.63% are suitable for ripping. 93.55% of Sandstone materials are suitable for digging meanwhile 6.45% are suitable for ripping. 89.65% of Siltstone materials are suitable for digging meanwhile 10.35% are suitable for ripping. Based on the result above, the materials (claystone, sandstone, siltstone) are suitable for digging and ripping.

Seismic Velocity Based Methods

Seismic velocity based methods in this research refers to rippability criteria from the mining equipment manufacture. The predictions based on criteria for Dozer CAT D8R and Komatsu D155A (Fig. 11).

Seismic velocity criterion on Caterpillar D8R and Komatsu D155R displayed different result from Graphical Methods. Using seismic velocity criterions, there are a couple of materials datasets which may need blasting (non-rippable criteria) especially from Caterpillar D8R.

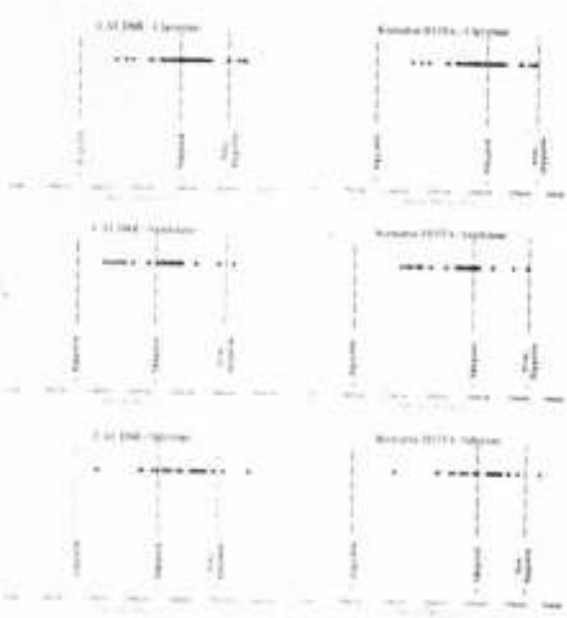

Fig. 11 Seismic Velocity Prediction Methods (Caterpillar, 2017 and Komatsu, 2016)

The discrepancy between graphical methods and seismic velocity-based methods aligned with the correlation analysis result. The seismic velocity- based prediction methods only based on laboratory parameters and the graphical methods is merely combination of field and laboratory parameters. The correlation analysis stated that the relationship between field parameter and laboratory test parameters are relatively low ($R^2 < 0.25$). The difference needs to be investigated for the further study.

CONCLUSION

The excavability/rippability research study on this paper has a conclusion as follows:

a. The correlation analysis shows a relatively low correlation between field parameters and laboratory tests result. Sandstone has the highest correlation coefficient from the other materials.
b. There is a difference of excavatability criteria based on graphical and seismic velocity prediction methods that need to be investigated in the future.

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REFERENCES

Atkinson, T., Selection of Open Pit Excavating and Loading Equipment, Trans. Ins. Of Mining and Metallurgy, 80, pp.101-129 (1971).

Barton, N., Lein, R., and Lunde J., Engineering Classification of Rock Masses for The Design of Tunnel Support, Rock Mechanics, pp.189-239 (1974).

Basarir, H., and Karpuz, C., A Rippability of Classification System for Marls in Lignite Mines, Engineering Geology, 74, pp.135-142 (2004).

Bienawski, E.T., Engineering Rock Mass Classifications: A Complete Manual for Engineers and Geologists in Mining, Civil, and Petroleum Engineering. New York: John Wiley and Sons (1989).

Braybrooke, J. C., The State-of-the-art of Rock Cuttability and Rippabiity Predictions, Fifth Australia New Zealand Conference on Geomechanics, pp.13-42 (1988).

Caterpillar, Caterpillar Performance Handbook 47, Peoria (2017).

Clark, Phillip B., Rock Mass and Rippability Evaluation for A Proposed Open Pit Mine At Globe-Progress, Near Refton, University of Canterburry (1996).

Fowell, R. J., The Mechanic of Rock Cutting, In Comprehensive Rock Engineering, Principles, Practice, and Project by Hudson, J. A., Oxford: Pergammon Press (1993).

Franklin, R. J., Broch, E., and Walton, G., Logging The Mechanical Character of Rock, Transactions of The Institution of Mining and Metallurgy, 80A, pp.1-9 (1971).

Hoek, Evert and Bray, Jonathan., Rock Slope Engineering 3th, New York: Spoon Press (1981).

Hudson, J., and Priest, S.D., Discontinuity Frequency in Rock Masses, Int. Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstract, 20(2), pp. 73-89 (1983).

Komatsu., Komatsu Performance Handbook (2016).

MacGregor, F., Fell, R., Mostyn R., Hocking, G., and McNally G., The Estimation of Rock Rippability, Quarterly Journal Of Engineering Geology, 27, pp. 123–144 (1994).

Pettifer, G. S., and Fookes, P. G., A Revision of The Graphical Method for Assessing Excavatability of Rock, Quarterly Journal of Engineering Geology, 27, pp.145–164 (1994).

Scoble, Malcolm and Muftuoglu, Y. V., Derivation of A Diggability Index for Surface Mine Equipment Selection, Mining Science and Technology, pp 305 – 322 (1984).

Weaver, J. M. Geological Factor Significant in The Assessment of Rippability, Civil Eng. In South Africa, 17, pp.131-136 (1975).