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RIPPABILITY CLASSIFICATION FOR QUARTZITE BASED ON SPECIFIC ENERGY AND FIELD PRODUCTION RATE

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Abstract: When rock is deemed to be rippable, it is essential to classify how difficult to actually rip this rock on site. The rating on the difficulty is termed as *rippability classification*, and it is based on *mass* and *material* properties of the rock which contribute to its resistance against ripping. This paper highlights a study to establish a similar classification for quartzite which is based on specific energy (SE) and field production rate (Q_r). To facilitate in analysis of data, the study area (located in Dengkil, Selangor) is divided into 6 panels (A to F). Collected data are grouped according to these panels. Laboratory assessments include verification on cuttability and strengths of the rock samples. Seismic survey and *in situ* ripping test were field appraisals conducted to assess rippability of the *in situ* quartzite. Analysis of data indicates that besides its material properties, rippability of quartzite can be evaluated using its SE. Ranging between 3.19 and 6.19 MJ/m^3, the SE is related to the Q_r, which is between 147 and 292 m^3/hr. For the six panels investigated, it is found that the higher the SE, the lower is the Q_r (i.e. more difficult to rip). Based on the SE, Q_r and horsepower of ripper dozer, *rippability classification* for the quartzite is established. This classification is essential for planning and costing of major earthworks, particularly in estimating capacity of ripper dozer and duration of earthwork.

Keywords: *Quartzite, Specific Energy, Field Production Rate, Rippability Classification*

1.0 Introduction

Due to its mode of excavation, ripping is suitable for shallow excavation (surface stripping) of a large area, particularly in obtaining a required finished level (e.g. preparation of project site and road alignment). In earthwork, ripping is commonly used to excavate rocks that are relatively weak to be blast but, too strong to be removed by normal excavator. Despite of being a common excavation method, no proper classification is currently available to be used as basis in evaluating the degree of difficult to undertake the actual ripping work on site. At present, the rippability of rocks is often based on contractors' experience and trial ripping on site. With increasing number and size of earthwork and variation of rock types encountered on site, such a subjective approach is easily exposed to elements of dispute and exploitation, which may lead to lengthy industrial arbitration and expensive variation orders. This paper discusses some findings obtained from a study on rippability of a quartzite (a metamsediment) and focus is on the following scopes:

- SE as rock material property to evaluate rippability
- Correlation between SE and *in situ* rippability (Q_r)
- Rippability classification based on SE, Q_r and class of ripper dozer

2.0 Background of the Study

The ease of excavating earth materials must be properly assessed so that earthwork can be planned and priced accordingly (Legget and Hatheway, 1988). Different method of excavation uses different mechanisms to loosen a rock body, and diverse rock types exhibit different strengths in resisting the breaking effect. Hence, the rate of excavation varies significantly between methods and rock types. For costly excavation method like ripping, it is essential to know the rate at which the earth materials can be removed so that related cost and constraints can be verified. Even in terms of cost, this method may vary depending on the capacity of ripper dozer used and nature of site. As such if a rock body is found to be rippable, further verifications on rate at which it can be ripped on site must be known. With regard to this, a clear conception of the rock properties that are relevant to ripping must be addressed, for example its *toughness*, which represents work done to fracture the rock (Pettifer and Fookes, 1994). Descriptive terms used to indicate difficulty, e.g. *very difficult* or *very easy* to rip, must be substantiated with measurable parameters like rate of excavated volume and power required to excavate a given volume.

2.1 Rippability of rocks

Ripping is a mechanical method whereby rock mass is ruptured by dragging steel tines/shanks, which is attached to a dozer (Fig. 1), through it. As the tine is dragged it creates sets of stresses and eventually breaking the rock along the cut groove (Fig. 2) into smaller fragments. Further loosening is achieved by creating subsequent grooves that are parallel to each other. The rate of excavation depends on the strength of the *in situ* rock and capacity of the dozer.

Figure 1: Single-shank CAT D6 ripper dozer

Figure 2: Cut groove produced by ripper dozer

For some shapes of excavation, ripping is known to be more suitable than blasting for breaking discontinuous and weak rock masses (Bell, 2004). This is due to some physical properties of rocks may give rise to difficult blasting (Pettifer & Fookes, 1994). Weaker sedimentary rocks (compressive strength < 15 MPa) such as mudstones are not readily removed by blasting, since they pulverized easily (due to low strength) when the blasting waves have dissipated. Rocks that possess marked anisotropy (e.g. schist) also give rise to difficult blasting as these rocks split more easily along the lineation rather than across it. Rocks displaying uniaxial compressive strength (UCS) in the range of 2 to 70 MPa are rippable however, the degree of difficulty increases with higher UCS (Pettifer and Fookes, 1994). Other rock properties that are known to affect their rippability include rebound number, point-load index strength and ultrasonic velocity (Gribble and McLean, 1985; Pettifer and Fookes, 1994; Singh and Goel, 1999).

Large-scale discontinuities like beddings and joints are also known to affect rippability of rocks, in particular the geometrical orientation and spacing of these weakness planes (Pettifer and Fookes, 1994). Field seismic velocity (V_f) is perhaps the most important property to indicate excavatability of *in situ* rock mass, for the propagation velocity of the wave depends on compactness of the *in situ* rock which is usually fractured and discontinuous. Rocks exhibiting V_f < 2000 m/s are more readily ripped using D7 and D8 ripper dozer (Caterpillar, 2008). Thin and well bedded sedimentary and metamorphic rocks, and highly weathered strong rock (UCS > 70 MPa) with horizontal close joints are likely to be rippable.

In assessing rippability of rocks it is important to appreciate the difference between *material* and *mass* properties. *Material* properties are properties of small (intact) rock samples, while *mass* properties are those of large (discontinuous) *in situ* rocks (Hudson, 1989). Consequently, small rock samples (as used in lab tests) tend to be stronger than its *in situ* rock mass. The difference between these scales of properties and the variations of properties of rock types that are rippable, signify the need to substantiate rippability in a more appropriate manner.

2.2 Rippability Assessments

Rippability or rock can be assessed using two approach; direct and indirect method (Anon, 1988). When direct method could not be undertaken then indirect method is the alternative.

Direct method: Conventionally, ease of ripping *in situ* rock mass is assessed by undertaking trial excavation on site using ripper dozer (e.g. Caterpillar and Komatsu) of suitable horsepower (HP). The ripper performance is evaluated based on field production rate (Q_r) in m^3/hour, which is estimated either using *volume by weight*, *volume by cross sectioning* or *volume by length method* (Basarir and Karpuz, 2004). Q_r depends on factors like ripper HP and properties of the *in situ* rock. In this study, the *volume by length method* is adopted for direct ripping test, and Qr is calculated as:

$$\text{Production rate, } Q_r = q_r\,[60/C_r]\,E_r \qquad (1)$$

where, q_r is production per cycle (on-bank volume, m^3/h), C_r is cycle or run time (min), and E_r is operator efficiency (80 to 100 % depending on nature of site).

Although this method is the most reliable as the Q_r is obtained by direct ripping on site however, it is costly and time consuming. Occasionally, it may not be possible to perform this test due to project constraint and availability of suitable machinery.

Indirect method: Termed as quick graphical method it is often used during initial planning of a major earthwork. The typical graphs/charts used are shown in Fig. 3 and Fig. 4. Less expensive and simpler in nature, each chart provides different levels of assessment, i.e. *mass* and *material* levels, as mentioned previously. Fig. 3 is used to assess excavatability of rock (by ripping or blasting) based on its *material* properties such as rebound number (R) and compressive strength (q_u). Performance of ripper dozer to excavate *in situ* rocks of various V_f (*mass* property) can be assessed using Fig. 4.

Rippability of rock based on Fig. 3 does not indicate degree of difficulty as the assessment is based on *material* properties. Further verification on ease of ripping is needed. This can be done by using graphs that accommodates *mass* properties of *in situ* rock like Fig. 4, where descriptive terms like ‘non-rippable’ and ‘marginal’ are used to substantiate difficulty of ripping. Pettifer and Fookes (1994) for instance, integrate discontinuity spacing in their revised excavatability graph to cater for the *mass* property. This indicates the importance of *mass* properties in classifying rippability. In addition to this, the ratings should also reflect on *in situ* excavatability of rock (e.g. field production rate) and its material toughness (e.g. work done) to rip/cut the rock samples.

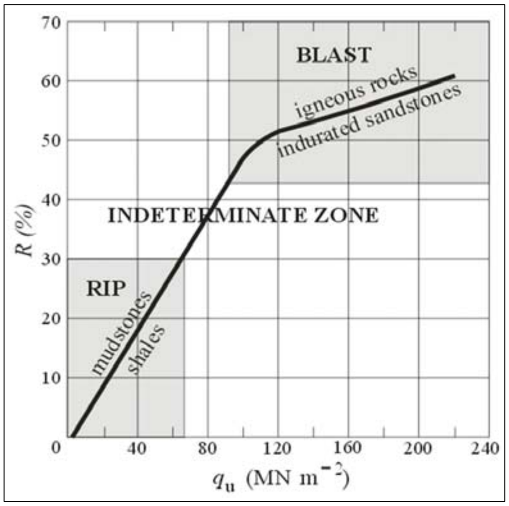

Figure 3 : Excavability based on Rebound no. & compressive strength (McLean & Gribble, 1985)

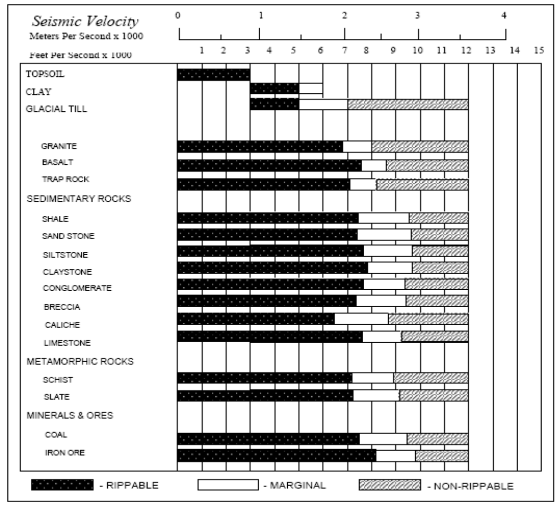

Figure 4 : Rippability (D8 ripper) based on seismic velocity (Caterpillar, 2008)

2.3 Lab ripping test and rippability classification

The mechanisms of ripping can be simulated in laboratory and it is a common approach used to evaluate performance of ripper dozer (Basarir and Karpuz, 2004) and cuttability of drag cutting tools in tunneling (Fowell and Johnson, 1991). The evaluation is conducted using lab ripping (direct cutting) machine which is designed to evaluate energy required to cut a groove in rock samples under controlled conditions. The machine used in this study (see Fig. 5) is designed to simulate ripping mechanism of single shank ripper dozer with engine rating of 1850 rpm (typical of CAT D6, D7 & D8 dozer) and cutting speed at 150 mm/s (Mohd For, 2008).

Figure 5 : Laboratory ripping machine rock sample

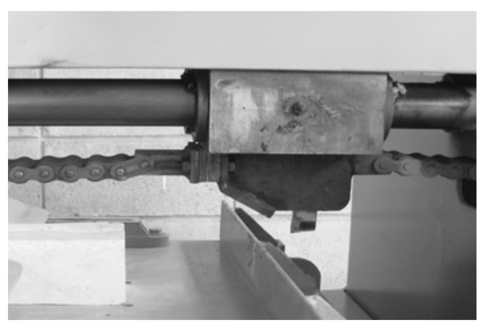

Figure 6 : Shank to create cut in

Specially shaped cutting shank, made from tungsten carbide and cobalt with rake angle of 5^0, is used to cut a V-shaped groove in rock sample (see Fig. 6). Appropriate devices (e.g. inverter and PLC) are used to measure power (Watt) required to produce that cut. Data obtained is the rippability/cuttability of the sample in terms of specific energy (SE) in MJ/m^3. Correlation between SE and Q_r can be established if sufficient data is available from lab and field assessments, and this is the basis for rippability classification of rocks. The typical classification for marl and lignite using CAT D8 ripper is shown in Table 1.

Table 1: Rippability classification of rock based on CAT D8 (Basarir & Karpuz, 2004)

Specific energy, SE (MJ/m^3)	**Field production rate, Q_r (m^3/hr)**	**Classification**
> 9.00	0 – 250	Very difficult
7.00 – 9.00	250 – 400	Difficult
5.25 – 7.00	400 – 900	Moderate
3.75 – 5.25	900 – 1300	Easy
< 3.75	> 1300	Very easy

3.0 Rippability Classification of Quartzite

This study was undertaken at an excavation site located about 2 km to the west of Dengkil Town, Selangor. The *in situ* rock is a low-grade metasediment called quartzite. To facilitate correlation between field and lab data, the site was divided into 6 panels (A to E in Figure 7). Reliable correlations are ensured by grouping the collected data according to these 6 panels. Extensive field and lab assessments were conducted and they were carefully selected to serve as quantitative indicators on rippability of rocks at *material* and *mass* levels. Full report on the study is given in Mohd For Mohd Amin *et al*., (2009).

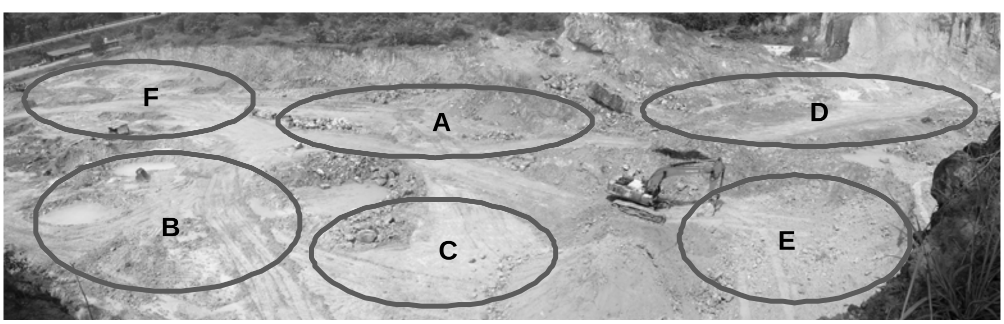

Fig. 7: Layout of the 6 panels within the study site

3.1 Laboratory Assessments

The rock material properties were verified from series of lab tests (based on ISRM, 1981) which essentially evaluate its relevant strength and resistance against ripping. Tests conducted include Schmidt's hammer, Point-load, Brazilian and Slake' durability tests. Data obtained for the samples from respective panel is summarised in Table 2.

Table 2: Material properties of quartzite for samples obtained from various panels

Panel	**Density (kg/m^3)**	**Rebound Hammer**		**Lab seismic velocity (m/s)**	**Point-load (MPa)**	**Tensile Strength (MPa)**	**UCS (MPa)**	**Slaking Index (%)**
		R (%)	q_u (MPa)					
A	2034 - 2154	19.4-27.9	22.8-34.6	1571-2162	1.23-2.12	3.56-5.48	23.2-38.3	69-75
B	2150-2198	27.6-31.2	34.1-41.1	2162-2396	2.08-2.78	5.13-6.66	37.9-46.8	72-78
C	2234-2355	33.8-42.6	47.3-78.1	2596-3063	2.65-3.87	7.14-8.54	48.9-66.8	81-87
D	2278-2360	36.8-42.6	55.9-78.5	2692-3036	2.52-3.87	7.26-8.56	46.9-65.2	80-91
E	2251-2388	35.2-43.5	51.0-84.0	2637-2960	2.77-4.15	7.36-8.56	48.9-66.3	80-89
F	2084-2182	22.9-30.5	26.9-39.4	1818-2341	1.39-2.87	4.23-6.23	25.9-46.9	71-80

Ease of ripping the rock samples in laboratory was verified using fabricated direct cutting machine (see Fig. 5). The cutting shank (see Fig. 6) is used to cut a V-shaped groove of 5 mm deep and 12 - 13 mm wide on block samples of dimensions 150×100×75 mm (see Fig. 8). For each test, 2 sets of data were collected; power (Watt) required for the shank to rip the sample, and power to drive the shank freely (without cutting). The difference between these 2 sets of data gives the mean power, P_m, needed to rip the sample, e.g. 295 Watt in Fig. 9. Using the density and weight rock fragments produced from the cutting test, the volume of cut (V in m^3) was calculated. The SE required in producing that cut is calculated using equation (2) below by taking 1 Watt = 1 Joule. Typical data obtained from the lab ripping test is shown in Table 3.

$$SE = P_m / V \quad (2)$$

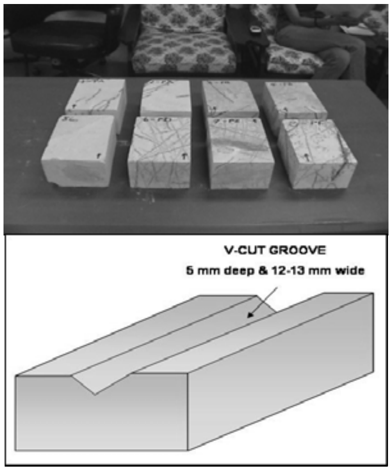

Figure 8 : Block samples and v-cut ripping test

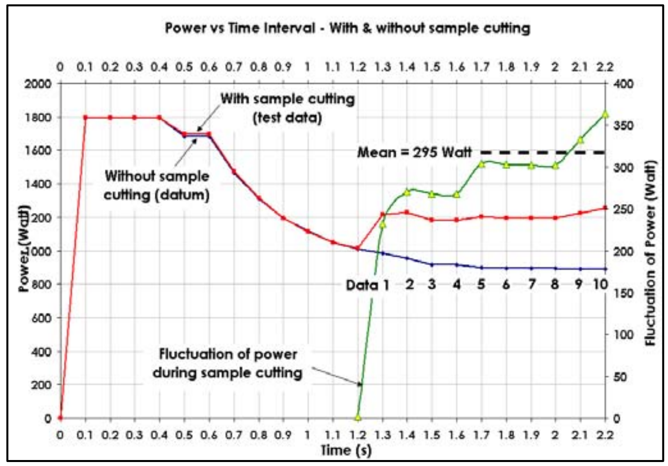

Figure 9 : Typical output data from lab

Table 3: Laboratory ripping tests results of samples obtained from various panels

Panel	A	B	C	D	E	F
Specific Energy, SE (MJ/m^3)	3.70	4.53	6.14	5.06	5.85	4.56
	3.19	4.33	5.52	6.07	5.64	4.01
	3.69	4.57	5.94	6.23	5.32	4.46
	4.39	5.07	5.50	6.30	5.59	4.29
	4.01	4.62	5.90	5.91	5.88	3.75
	3.45	4.71	5.73	6.19	5.32	3.71
	3.39	4.50	5.68	5.51	6.07	4.42
	4.15	4.88	6.07	4.80	5.57	4.59
	4.08	4.67	5.89	5.99	5.88	4.35
	4.17	4.52	6.06	5.91	5.36	4.22
Mean	**3.82**	**4.64**	**5.84**	**5.80**	**5.65**	**4.24**
Std. dev.	**0.39**	**0.16**	**0.18**	**0.55**	**0.33**	**0.34**

3.2 Field Assessments

Field assessments carried out on the *in situ* rock include seismic refraction survey and field ripping test. The former is to evaluate ease of ripping this rock on site.

Field seismic velocity (V_f) of the *in situ* quartzite was verified using 24-channel Geometrics ES-3000 seismograph. The typical V_f for the upper substrata materials in panel B and C is shown in Fig. 10, which lies between 1000 and 2000 m/s.

To evaluate the Q_r, actual ripping was carried out on site using single-shank CAT D6 (165 HP) ripper dozer. The production rate was estimated by measuring volume of cut per ripping cycle (the *volume by length method* by Basarir and Karpuz, 2004). For each panel, 10 rip lines were carried out and their length varies between 20 and 30 m. However, for reliability of data only the middle portion of 15 m length (L) was considered in the assessments. At this portion, the ripper dozer is thought to have achieved its steady speed of 0.6 to 0.8 m/s. Time (min) taken to complete one ripping cycle (C_r) was recorded and the volume of rip was estimated from the length L and the dimensions W and D shown in Fig. 11. Using equation (1), the Q_r for each rip line was estimated (note: for simple manoeuvre like single rip line the operator efficiency $E_r \approx$ 100 %). The field production rates obtained for the 6 panels are listed in Table 4.

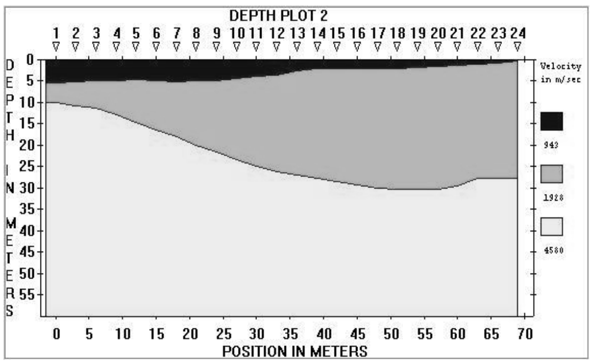

Figure 10: Typical profile and seismic velocity for panel B and C (V_f is 1000 to 2000 m/s)

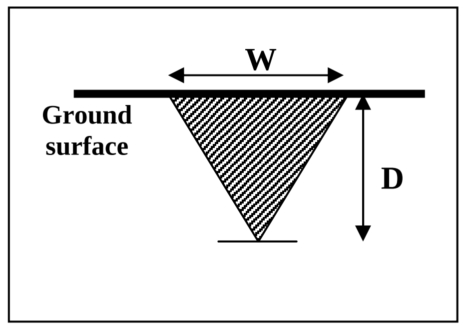

Figure 11: Dimensions for V-shape cut produced by single-shank ripper

Table 4: Summary of production rate obtained from field ripping test at various panel

Panel	A	B	C	D	E	F
Field Production Rate, Q_r (m^3/hr)	282	241	147	183	184	229
	298	244	204	145	132	239
	277	239	178	149	173	275
	242	221	183	146	196	272
	264	227	180	150	183	248
	287	229	175	178	175	267
	292	237	164	145	160	255
	260	232	173	178	178	254
	261	228	188	179	164	248
	263	236	181	173	145	249
Mean	**273**	**233**	**177**	**162**	**169**	**254**
Std. dev.	**15**	**4**	**9**	**14**	**13**	**8**

4.0 Result and Discussion

The material properties of the quartzite like rebound number (R) and compressive strength (q_u) (see Table 2) can be plotted against Fig. 3 to verify its excavatability. Based on range values for the 6 panels (R: 19.4 to 43.5 % and q_u: 22.8 to 84.0 MPa) this rock requires ripping for excavation but no indication on difficulty can be verified. If the *in situ* V_f of 1000 to 2000 m/s is plotted against Fig. 4, it shows that the quartzite is 'rippable' using D8 (185 HP) ripper dozer.

Comparing the mean Q_r for the 6 panels (160 to 270 m^3/hr in Table 4) with the *rippability classification* in Table 1, implies that the *in situ* quartzite falls in class of 'difficult' and 'very difficult' to rip. Although this is an 'over-estimate', as ratings in Table 1 are based on D8 (more powerful than D6) however, it does indicate the degree of difficulty to rip the *in situ* rock. Appropriate *rippability classification* for the quartzite will be discussed later.

Table 5 shows the correlations between the material properties and SE, with most correlations displaying $R^2 > 0.8$. The best one is between SE and tensile strength (see Fig. 12) with $R^2 > 0.9$ and this is expected as this strength is the most indicative property for excavatability of rocks. The correlations clearly indicate that besides its material properties, rippability of quartzite can also be evaluated using its SE value, a parameter that can be evaluated in laboratory.

Correlations between Q_r and V_f and SE are listed in Table 6. The correlation between SE and Q_r shows R^2 of 0.85 (see Fig 13). This verifies the fact that, for a given rock type, the energy to rip its sample in laboratory (SE) is closely related to its *in situ* rippability (Q_r). The poor correlation between V_f and Q_r (with $R^2 < 0.7$) can be attributed to the variations of the *in situ* quartzite. A better result could have been obtained if the seismic survey were conducted along the ripping lines.

Table 5: Correlation between Specific Energy (SE) and material properties of quartzite

Correlation	**Equation**	**Coefficient, R^2**
SE and Tensile Strength (σ_t)	SE = 0.5419(σ_t) + 1.440	0.903
SE and Laboratory Seismic Velocity (V_L)	SE = 0.0019(V_L) + 0.384	0.861
SE and Rebound Value (%)	SE = 0.1182(R) + 1.154	0.866
SE and Uniaxial Compressive Strength (UCS)	SE = 0.0651(UCS) + 1.882	0.790

Table 6: Correlation between field production rate (Qr) and seismic velocity and SE of quartzite

Correlation	Equation	Coefficient, R^2
Q_r and Field Seismic Velocity(V_f)	$Q_r = -163.19 Ln(V_f) + 2798.4$	0.730
Q_r and Specific Energy (SE)	$Q_r = -235.27 Ln(SE) + 586.22$	0.850

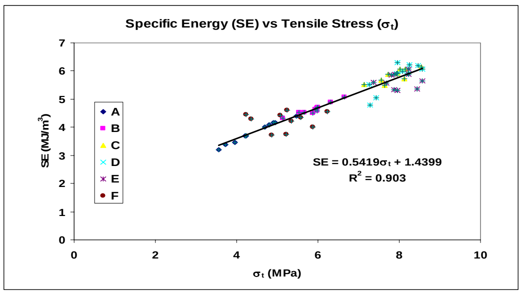

Figure 12: Specific Energy vs. Tensile Strength Specific Energy

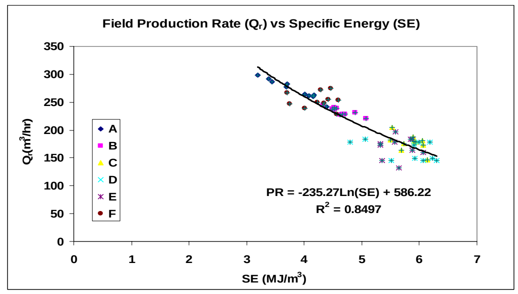

Figure 13: Field Production Rate vs. Specific Energy

The SE and Q_r for the respective panel are shown in Table 7 which clearly indicates that the higher the SE the lower is the Q_r, i.e. more difficult to rip the *in situ* rock. The rock samples collected from Panel C, D and E, show a higher SE (> 5.5 MJ/m^3), consequently these panels exhibit a lower Q_r (< 180 m^3/hr). Similarly, the samples from Panel A display the lowest SE of 3.82 MJ/m^3, accordingly this panel shows the highest Q_r of 273 m^3/hr. This trend proves that SE (a *material* property) is directly related to Q_r (a *mass* property). The good correlation between these two parameters and their indicative nature to substantiate rippability, signify their suitability as basis for rippability classification of rocks.

Table 7: Specific energy and field production rate for the various panels

Panel	Specific Energy (SE), MJ/m^3	Field production rate (Q_r), m^3/hr
A	3.82	273
B	4.64	233
C	5.84	177
D	5.80	162
E	5.65	169
F	4.24	254

Based on the range of SE and Qr obtained, *rippability classification* for the quartzite using CAT D6 (165 HP) ripper is proposed and this is shown in Table 8. The descriptive terms used to define the difficulty of ripping are based on Basarir *et al.* (2008) and Caterpillar (2008). The proposed classification is also applicable to other rock types that are comparable (in terms of strength) to quartzite. From Table 8 it can be seen that rock displaying SE > 7.00 MJ/m^3 will exhibit *in situ* Q_r < 130 m^3/hr, and the rock is termed as *difficult* to rip using D6 ripper. In such situation a number of alternatives are available; either to opt for a more powerful dozer (e.g. D7 or D8) as to increase production or, to maintain the dozer class but extending the contract duration for the earthwork. In planning, availability of options particularly those related to the most critical project constraints such as cost and time, is important in decision making.

Table 8: Rippability classification of quartzite using D6 ripper dozer (165 HP)

Specific energy SE, MJ/m^3	**Field production rate Q_r, m^3/hr**	**Rippability description**
>7.00	<130	Difficult
5.25 – 7.00	130-200	Moderate
3.75 – 5.25	200-270	Easy
< 3.75	>270	Very easy

5.0 Conclusions

The following conclusions can be derived from this study:

i. Besides its material properties and strengths, resistance of rock against ripping can also be substantiated using its SE, a parameter that can be evaluated in laboratory.
ii. SE (material property) is found to be related to Q_r (mass property) and both parameters are direct indication on rippability of rock. As such they form essential components for rippability classification.
iii. Rippability classification for quartzite is proposed which is essential for planning and costing of major earthwork, particularly in selecting suitable dozer and duration of an earthwork.

Finally, a more comprehensive rippability classification is essential to cover various rock types (the rippable ones) and classes of ripper dozer commonly used in local construction.

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