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Excavation Assessment in Wet Tropically Sedimentary Rock

Maybelle Liang[a*], Edy Tonnizam Mohamad[a], Ibrahim Komoo[b], Ma Chau-Khun[a]

[a]Geoengineering and Geohazard Research Group, Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, UTM Johor Bahru, Johor, Malaysia
[b]Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

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*Corresponding author
maybelle_liang@hotmail.com

Graphical abstract

Abstract

The selection of suitable methods to be employed for surface excavation works is particularly important in geotechnical engineering projects. Factors such as environmental constrains, rock properties and size of site may affect the selection of machine required for surface excavation. Wrong selection of equipment and technique can result in unrecoverable expenses and thus, should be avoided. Great challenges in excavation works are expected in sedimentary rock where the occurrence of discontinuity such as bedding thickness, foliation and the inhomogeneity of rock as well as effect of moisture can greatly affect its excavatability. This paper aims to identify and highlight the factors affecting the excavation works in wet tropically weathered sedimentary area as what have been experienced in Malaysia. Some of these factors, however, are not specified in the existing general excavatability assessments. Assessment by practical excavation was carried out at three sedimentary rock sites in Nusajaya, Malaysia, taking into account the related parameters. Statistical analysis by using SPSS was then being conducted in order to determine the correlation of each parameter with productivity of excavation and their significance in affecting the excavatability.Based on the results obtained, it was found that the parameters such as *Is50*, *R*, *UCS*, density, *ITS*, *Js*, *JL*, *Jd*, *IP* and moisture content play significant roles in affecting the excavatability of sedimentary rocks. Meanwhile, the existence of bedding, *Id2* and *Jn* are deemed to be neglected. It is believed that this study can help to enhance the knowledge on factors that complicate the excavation works in sedimentary areas.

Keywords: Wet tropical region; sedimentary rock; weathered; bedding; Inhomogeneity; excavatability.

Abstrak

Pemilihan kaedah yang sesuai untuk digunakan untuk kerja-kerja pngorekan adalah amat penting dalam projek-projek kejuruteraan geoteknik. Faktor-faktor seperti penghalangan alam sekitar, sifat batuan dan saiz tapak boleh mempengaruhi dalam pemilihan mesin yang diperlukan untuk kerja pengorekan. Pemilihan peralatan dan teknik yang salah perlulah dielakkan kerana ia akan mengakibatkan pembiayaan yang melebihi batasan terpaksa ditanggung. Kerja-kerja pengorekan batuan sedimen membawa kepada cabaran yang hebat, di mana ketakselanjaran batuan seperti ketebalan stratigrafi, foliasi dan ketakhomogenan batuan di samping kesan kelempaan boleh mempengaruhi pengorekan batuan. Kertas kerja ini bertujuan untuk mengenalpasti dan mengetujukan faktor-faktor yang mempengaruhu kerja-kerja pengorekan di kawasan sedimen berluluhawa tropika, seperti mana yang dialami di negara Malaysia. Sesetengah faktor ini tidak diketengahkan dalam penilaian pengorekan batuan yang sedia ada. Penilanan menerusi kerja-kerja pengorekan praktikal telah dijalankan di tiga tapak batuan sedimen di kawasan Nusajaya, Malaysia, dengan mempertimbangkan parameter-parameter yang berkaitan. Analisis statistik dengan menggunakan SPSS kemudiannya dibuat untuk mengenalpasti korelasi setiap parameter tersebut dengan produktiviti pengorekan dan kepentingan parameter tersebut dalam mempengaruhi pengorekan batuan sedimen. Berdasarkan keputusan kajian yang diperolehi, parameter-parameter seperti *Is50*, *R*, *UCS*, ketumpatan, *ITS*, *Js*, *JL*, *Jd*, *IP* dan kandungan lembapan memainkan peranan yang penting dalam mempengaruhi proses penggalian batuan sedimen. Sementara itu, pengaruh faktor-faktor seperti kewujudan perlapisan batuan, *Id2* dan *Jn* boleh diabaikan. Kajian ini dipercayai boleh membantu untuk mempertingkatkam lagi pengetahuan tentang faktor-faktor yang merumitkan kerja-kerja penggalian di kawasan sediman.

Kata kunci: Kawasan tropika lembap; batuan sediman; luluhawa; perlapisan; ketakhomogenan; penggalian

1.0 INTRODUCTION

In practicing surface excavation works in wet tropically weathered area, weathering states, lithology, structural and stratigraphy of the interbedding layers are particularly important. The complex structures of these materials, resulting from depositional, weathering, and tectonic history, make it a great challenge for engineers and geologists to simplify and adapt the existing general rock mass classification for excavation purpose. Weathering of surface rocks in wet tropical regions has produced thick weathering profiles which consist varying weathering states that require adequate judgement of their characteristics for efficient excavation [1, 2]. Often more than a rock type which has vast difference in their engineering properties are found in a sedimentary rock mass. Lower strength rock mass can also be found to be interbedded between high strength rock mass and thus causes difficulties in surface excavation works. Besides, discontinuities often present in sedimentary rock mass and other factors, such as thickness of bedding, spacing of joints, as well as orientation of lamination can also significantly affect the entire rock mass characteristics. The issues are even more critical and confusing especially in wet tropical climate, where the rate of excavation might susceptible to the weather or moisture content in the rock [3],[4].

2.0 STUDIED SITES

Studies have been carried out in three different sedimentary rock sites in Southern Johore, Malaysia from which the conclusions given in this paper are developed. The first site (SiLC 1) is currently developed by UEM (M) Berhad. Fourteen lithological zones covering from slightly weathered (SW) to completely weathered (CW) sandstone and SW to highly weathered (HW) shale have been investigated. The second site (Legoland) belongs to a private entity, Merlin Entertainments. In this site, 20 lithological zones covering from SW to CW sandstone and MW to CW shale were utilized. The third site (SiLC 2) which is also developed by UEM (M) Berhad, has 14 lithological zones covering from SW to CW sandstone and MW to HW shale. All of these sites are located in Iskandar region, Nusajaya of Southern Johore, Malaysia. The locations of these sites are located in the map of Figure 1.

2.1 Geology

The selected sites mainly comprise shale and sandstone layers of Jurong Formation with thickness varying from few centimeters to approximately 2.0 m. The sandstones are massive and interbedded with shale layers. Physical characteristics of the sandstone are generally random in colour and have very fine to medium sized grain. Plant fossils discovered in it have not yet been determined, but a number of fossil collections from Singapore demonstrate an Upper Triassic to Mid Jurassic age for the unit [5].

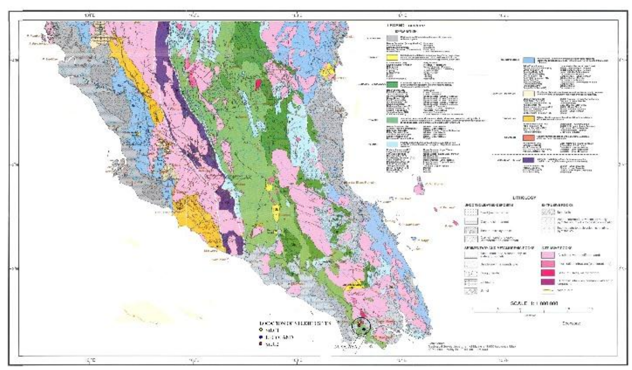

Figure 1 Location and geological map of studied sites

Several studies have been conducted in order to understand the geotechnical properties of weathered sedimentary rock in Peninsular Malaysia [1]. It was consistently reported that the properties of material deteriorate along the weathering courses, mainly due to the loosening of the bonding between grains [6].

Generally, sedimentary rock mass consists of more than one type of rock and always forms alternate laminated due to natural forming process and also exposed to tectonic effect and pressure. The moderately weathered rock has always been the grey area in excavation as it is often found to be interbedded or sandwiched with highly weathered rocks.

3.0 STRENGTH INHOMOGENEITY

The weathering grade difference between different rock materials formed in the same rock mass can pose great challenge in excavation works. The behavior of sandstones and shale to weathering agent are different due to their genesis. Fresh sandstone has minimal foliation as compared to shale because of the well cementation, and thus, excavation in sandstones is relatively difficult. On the other hand, shale has always been known to have lamination or fissile. This provides spaces for weathering agents to be in contact with the material. Furthermore, shale is composed of clay size material that is smaller than 0.062 mm in size and some of clay types such as illite and montmorillonite may absorb water aggressively and will degrade easily on exposure to weathering agents, as compared to sandstone.

Mohd For *et al*. [8] and Tajul and Sundaram [9] reported that, hard material has always become an argument issues by contractors and clients if it cannot be classified as rock or soil. This statement always refers to grade III (moderately weathered) to V (completely weathered) in the weathering scale. Existing excavation assessments have always considered the strength factor to be one of its major factors in deciding whether the material can be ripped or otherwise. However if strength is the only parameter considered, overall results may be ambiguous especially if sandstone and shale is evaluated separately as both materials may not have the same strength even though they are in one massive rock body. The sandstone may be in Grade III but the shale may have further deteriorated to grade V, as shown in Figure 2. Shale, which is interbedded with sandstone, might have lower strength compared to the sandstone and their weathering grade might varies even though exist in the same rock mass (Figure 3).

Figure 2 Geological model of weak shale with strong sandstone

Table 1 Description of the weathering zones of the in-situ rock [7]

Descriptive terms	Material description and likely engineering characteristics
Residual soil	Completely degraded to a soil; original rock fabric is completely absent; exhibit large volume change; the soil has not been significantly transported. Stability on slopes relies upon vegetation rooting and substantial erosion & local failures if preventive measures are not taken
Completely weathered	Rock is substantially discolored and has broken down to a soil but with original fabric (mineral arrangement & relict joints) still intact; the soil properties depend on the composition of the parent rock. Can be excavated by hand or ripped relatively easily. Not suitable as foundation for large structures. May be unstable in steep cuttings and exposes surfaces will require erosion protection.
Highly weathered	Rock is substantially discolored and more than 50% of the material is in degraded soil condition; the original fabric near to the discontinuity surfaces have been altered to a greater depth; a deeply weathered, originally strong rock, may show evidence of fresh rock as a discontinuous framework or as corestone; an originally weak rock will have been substantially altered, with perhaps small relict blocks but little evidence of the original structure. Likely engineering characteristics are as in Zone 5.
Moderately weathered	Rock is significantly discolored; discontinuities will tend to be opened by weathering process and discoloration have penetrated inwards from the discontinuity surfaces;
Slightly weathered	Some discoloration on and adjacent to discontinuity surfaces; discolored rock is not significantly weaker than undiscolored fresh rock; weak (soft) parent rock may show penetration of discoloration. Normally requires blasting or cutting for excavation; suitable as a foundation rock but with open jointing will tend to be very permeable.

Figure 3 Interbedding of shale between sandstone layers

4.0 PRESENCE OF DISCONTINUITIES AND DIRECTION OF EXCAVATION

A discontinuity represents a plane of weakness within a rock mass which the rock material is structurally discontinuous. Discontinuities vary in size from small fissures on the one hand to huge faults on the other. The most common discontinuities present in sedimentary rock mas include joints, bedding planes and lamination. Mechanical properties of rock mass may be adversely affected by formation of discontinuities. Discontinuities may also help in easing mechanical excavation, since their orientation and frequency can ease cutting strong materials. The fact that these weakness zones can have major impact upon stability, as well as on excavation process, necessitates that special attention and investigations often are necessary to predict their effect on the behavior of rock mass. Therefore, prior to excavation in rock mass, assessment of properties of discontinuities like spacing, trace length and orientation, is required.

Site experience in Nusajaya, Johor showed that excavation production varies if direction of excavation is towards discontinuity dominated prone direction even if it is within the same rock mass. It was also found that softer rock zones having much closely-spaced joints led to relatively higher productivity as compared to zones of the same lithology and weathering state, having less joints. Not surprisingly, sometimes very strong rock can be excavated due to closely spaced discontinuities (Figure 4). This shows that discontinuity play a significant role in material excavatability.

Figure 4 Closely spaced joints help in easing the excavation progress

5.0 EFFECT OF MOISTURE

Moisture content is another factor which can affect the strength of the material. The effect is greater on highly weathered materials, where the dry and wet condition of the materials can significantly affect the productivity of excavation works. Thus, it should be carefully taken into account that the same materials tested during initial assessment may have different strength after heavy rain or during dry conditions.

Table 2 shows the results of the point load test on rock samples of sandstone and shale when soaked in water for 15 minutes. Generally, the results shows decreasing of point load strength with increase of moisture. Broch [10] explained that the reduction of strength with increase of moisture content is due to the reduction in the internal friction and their surface energy. The moisture within the grains acts as grease and reduces the strength of the material.

Table 2 Summary of point load test on 15 min soaked samples

Rock Type	Weathering state	Increase of moisture content (%)	Decrease of point load (%)
Sandstone	SW	<5	5 – 12
	MW	<5	16 – 20
	HW	5 - 10	20 – 40
		10 -15	41 – 45
	CW	10 – 15	50 – 60
		15 - 25	60 – 85
		25 - 35	85 – 100
Shale	MW	<5	15 - 22
	HW	<5	20 – 30
		5 -`10	30 – 52
	CW	<5	50 – 75
		5 - 15	75 – 95

This problem will lead to misjudgement during the excavatability study as some materials can be easily excavated during wet condition but relatively hard to be excavated during dry weather. A highly moisturized rock could be easier to be excavated compared to dried ones, even though they are of the same material. Although it can be interpreted easily by the strength of rock, the moisture content parameter is important to be taken into account in the excavatability assessment, especially in tropical climate.

6.0 INFILL MATERIAL

Discontinuities, especially joints, may be open or closed. Chemical weathering, which is crucial in tropical region, leads the transportation of mineral substances in rock which then accumulate at the joints opening. Some joints may be partially or completely filled. The type and amount of filling not only influence the effectiveness with which the opposing joint surfaces are bound together, thereby affecting the strength of the rock mass. One of the most common secondary products which often found to be accumulated at the opening of joints in sedimentary rock is the iron pan. The presence of iron pan can complicate the prediction of excavatability, where productivity of excavation might be decreased due to the strong resistance of iron pan filling, hence disallowing or complicating the excavatability works.

7.0 ASSESSMENT BY PRACTICAL EXCAVATION

Practical excavation was performed in the studied sites on excavatable zones, which include MW, HW and CW for both sandstone and shale. It should be noted that the SW zone is impossible to be excavated as the material was found to be too hard and strong. The practical excavation rate (Q) in each lithological zone was calculated in the average of three continuous excavations of two minutes. The excavation operation was carried out by Komatsu PC300-6 hydraulic excavator in respective studied sites. The properties and operational specifications of the selected excavator are presented in Table 3.

Table 3 Specification of Komatsu PC300-6 hydraulic excavator

Specification	Value
	Komatsu PC300-6
Engine power	128 kw
Operating weight	28850 kg
Max travel speed	5.5 km/h
Track gauge	2590 mm
Reference bucket capacity	1.3 m^3

8.0 STATISTICAL ANALYSIS FOR PREDICTION OF PRODUCTIVITY

In order to analyse the correlation of all tested parameters (recorded from laboratory tests and field study), all the parameters, together with Q obtained from field excavation, were processed through a statistical model versus Q in SPSS. The Q was introduced as dependent variable, whilst all other parameters were introduced as independent variables. It should be noted that the model was analysed by using multiple linear regression method. The processed parameters include point load strength (Is50), Schmidt Rebound hammer value (R), uniaxial compressive strength (UCS), density (Density), indirect test strength (ITS), second-cycle of slake durability index (Id2), joint number (Jn), joint spacing (Js), joint length (JL), joint direction (Jd), existence of iron pan (IP), moisture content (Mc), and existence of bedding (Bedding). Table 4 shows the results of practical excavation in this study.

Based on the results of multiple linear regression in SPSS, it was found that some parameters can be excluded from the list of predictors where the accuracy of model is still guaranteed. Table 5 shows the summary of the statistical analysis in SPSS, while Table 6 and 7 show the coefficients of predictors and excluded parameters, respectively. It should be noted that in these tables, only model 4 is presented as it was chosen in the development of rock mass classification system later.

Table 4 Results of field excavation at studied sites

(a) SiLC 1

Weathering Grade	Rock Type	Bedding	Number of Bucket			Q (m^3/kWh)			Mean Q (m^3/kWh)
			1	2	3	1	2	3	
HW	Sandstone	No	4	4	4	0.99	0.99	0.99	0.99
HW	Sandstone	Yes	4	5	4	0.99	1.24	0.99	1.08
HW	Sandstone/Shale	Yes	5	5	6	1.25	1.25	1.50	1.33
HW	Shale	No	5	4	6	1.24	0.99	1.50	1.24
MW	Sandstone	Yes	2	2	3	0.5	0.5	0.75	0.58
MW	Sandstone/Shale	Yes	2	4	3	0.5	0.99	0.75	0.75
MW	Shale	No	5	4	5	1.25	1.0	1.25	1.17
MW	Sandstone	No	2	2	2	0.5	0.5	0.5	0.5
CW	Sandstone	No	7	7	7	1.75	1.75	1.75	1.75
MW/CW	Sandstone	No	5	4	5	1.24	0.99	1.24	1.16

(b) Legoland

Weathering Grade	Rock Type	Bedding	Number of Bucket			Q (m^3/kWh)			Mean Q (m^3/kWh)
			1	2	3	1	2	3	
MW	Sandstone	No	2	2	3	0.5	0.5	0.75	0.58
MW/HW/MW	Sandstone/Shale/Sandstone	Yes	2	2	2	0.5	0.5	0.5	0.5
HW	Sandstone	No	4	3	3	0.99	0.75	0.75	0.83
MW/HW	Sandstone	Yes	2	2	3	0.5	0.5	0.75	0.58
HW/CW	Sandstone	Yes	6	5	6	1.42	1.18	1.42	1.34
CW	Sandstone	Yes	8	7	8	2.0	1.75	20	1.92
MW	Sandstone	No	2	2	1	0.5	0.5	0.25	0.42
CW	Shale	No	7	7	8	1.75	1.75	2.0	1.92

(c) SiLC 2

Weathering Grade	Rock Type	Bedding	Number of Bucket			Q (m^3/kWh)			Mean Q (m^3/kWh)
			1	2	3	1	2	3	
HW/MW	Shale	No	4	4	4	1.0	1.0	1.0	1.0
HW/MW	Sandstone	No	2	2	2	0.5	0.5	0.5	0.5
MW/CW	Sandstone	Yes	6	5	5	1.5	1.0	1.0	1.17
CW/HW	Sandstone	Yes	6	5	6	1.42	1.18	1.42	1.34
HW	Sandstone/Shale	Yes	4	3	3	1.0	0.75	0.75	0.83
HW/MW	Shale	No	4	4	5	1.0	1.0	1.25	1.08
HW/MW	Shale	Yes	4	4	4	1.0	1.0	1.0	1.0
HW	Shale	No	5	6	6	1.25	1.5	1.5	1.42
CW	Sandstone	No	8	7	7	2.0	1.75	1.75	1.83

Table 5 Summary of the statistical model for dependent Q

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.968[a]	0.937	0.873	0.247
2	0.968[b]	0.937	0.882	0.238
3	0.967[c]	0.935	0.888	0.233
4	0.965[d]	0.932	0.889	0.231

a. Predictors: (Constant), Bedding, Is50, IP, JL, Jn, Jd, Density, R, Mc, Js, ITS, UCS, Id2
b. Predictors: (Constant), Is50, IP, JL, Jn, Jd, Density, R, Mc, Js, ITS, UCS, Id2
c. Predictors: (Constant), Is50, IP, JL, Jn, Jd, Density, R, Mc, Js, ITS, UCS
d. Predictors: (Constant), Is50, IP, JL, Jd, Density, R, Mc, Js, ITS, UCS

Table 6 Coefficients of predictor parameters for dependent Q

odel		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
4	(Constant)	8.069	1.606		5.026	0.000
	Is50	-1.371	0.726	-0.557	-1.888	0.077
	R	-0.060	0.024	-0.271	-2.474	0.025
	UCS	-0.080	0.035	-0.939	-2.306	0.035
	Density	-0.211	0.066	-0.256	-3.210	0.005
	ITS	0.657	0.361	0.620	1.820	0.088
	Js	4.566	1.369	0.528	3.335	0.004
	JL	-0.282	0.074	-0.508	-3.833	0.001
	Jd	-0.024	0.010	-0.255	-2.449	0.026
	IP	-0.816	0.178	-0.579	-4.598	0.000
	Mc	0.720	0.158	0.705	4.553	0.000

a. Dependent Variable: Q

Table 7 Excluded parameters from the model

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
4	Bedding	-0.025c	-0.313	0.759	-0.080	0.718
	Id2	0.272c	0.483	0.636	0.124	0.014
	Jn	0.079c	0.906	0.379	0.228	0.562

a. Predictors in the Model: (Constant), Is50, IP, JL, Jd, Density, R, Mc, Js, ITS, UCS
b. Dependent Variable: Q

9.0 CONCLUSION

This paper aims to identify and study the factors affecting the excavation works in wet tropically weathered sedimentary area as what have been experienced in Malaysia. Conclusion that can be derived from this study are listed below:

1. Sedimentary rocks constitute the greatest variation in strength and behavior. This type of rock usually contains bedding and lamination or other sedimentation structures and therefore, may exhibit significant anisotropy in their behavior, depending upon degree of their development.
2. More than a type of rock are often found to be interbedded within the same rock mass. Shale, which is interbedded with sandstone would have lower strength compared to the sandstone. However, due to its existence in the rock mass which is interbedding between the dominancy of low or high strength of rock, the actual performance could differ from the assessment method. Thus, the percentage of dominancy of competent and incompetent rock, in terms of strength, needs to be taken into account in the assessment to avoid problems arising during excavation works.
3. Apart from that, some characteristics of discontinuity which always present in the sedimentary rock, such as existence of bedding and orientation of joints are not specified in the assessments but found to play significant role in affecting the excavation works.
4. A more specific approach for excavatability assessment, specifically for sedimentary area is needed as the assessments of material properties alone does not provide accurate result to assess the excavatability of the whole rock mass. Based on the practical excavation carried out in sedimentary zones and extensive statistical analysis, it was found that the parameters such as Is50, R, UCS, density, ITS, Js, JL, Jd, IP and moisture content play significant roles in affecting the excavatability of sedimentary rocks. Meanwhile, the existence of bedding, Id2 and Jn are deemed to be neglected. It is believed that with this analysis, it can enhance the knowledge on factors that complicate the excavation works in sedimentary areas.

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