CLASSIFICATION AND RIPPABILITY OF DURICRUSTS

Mohd For Mohd Amin[1], Jerry Chua Kuo Sheng[2]
and Fauzilah Ismail[3] and Edy Tonnizam Mohamad[1]

[1] *Lecturer, Department of Geotechnic and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor.*
[2] *Project Engineer,K.H. Goh and Associates, Larkin Perdana, 80350 Johor Bahru, Johor*
[3]*Lecturer, Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor.*

Abstract: Strongly cemented or indurated sediments such as duricrusts exhibit certain properties that are similar to clastic sedimentary rocks. However, based on mode of formation, duricrusts cannot be classified as rock although their material properties bear a resemblance of rock. Consequently, excavation of this particular material in the field may lead to disputes between contractors and clients particularly pertaining to method of excavation and rate of payment for the excavation work. This paper discusses an initial study on duricrusts which emphasises on their mode of formation based on geological factors, and their material properties that are related to rippability. The initial study indicates that duricrusts can be classified according to their mode of formation and the types of cement matrix that are associated with their formation. In addition, duricrusts seem to exhibit similar properties as clastic sedimentary rocks consequently, ripping may be the suitable method for their excavation. A number of further assessments (laboratory and field tests) have been proposed for detailed verifications on the degree of rippability of these indurated sediments.

Keywords: *Duricrusts; rippability; mode of occurrence; material properties.*

Abstrak: Bahan sedimen yang tersimen kukuh seperti *keraktanah* memperlihatkan sifat-sifat tertentu yang mirip dengan batuan sedimen klastik. Walaubagaimanapun berdasarkan kepada mod pembentukan *duricrusts* tidak boleh dikelaskan sebagai batuan walaupun sifat-sifat bahannya mempunyai persamaan dengan batuan. Akibatnya pengorekan bahan ini di lapangan boleh menimbulkan pertelingkahan di antara kontraktor dan klien khususnya mengenai kaedah pengorekan dan kadar bayaran ke atas kerja pengorekan. Kertas kerja ini membincangkan kajian awal ke atas *keraktanah* dengan tumpuan kepada mod pembentukannya berasaskan faktor-faktor geologi dan sifat-sifat bahannya yang berkaitan dengan kebolehrobekan. Kajian awal ini menunjukkan keraktanah boleh diklasifikasikan berdasarkan kepada mod pembentukannya dan jenis simen matriks yang terlibat semasa pembentukannya. Di samping itu, *keraktanah* memperlihatkan sifat-sifat yang mirip kepada batuan sedimen klastik, oleh yang demikian robekan mungkin merupakan kaedah sesuai untuk pengorekan bahan ini. Beberapa kaedah penilaian lanjutan (makmal dan lapangan) turut disyorkan bagi meneliti secara terperinci tahap kebolehrobekan sedimen terkukuh ini.

Katakunci: *Keraktanah; kebolehrobekan;mod pembentukan; sifat-sifat bahan.*

1.0 Introduction

The ease with which the ground can be excavated (i.e. excavatability) should be assessed appropriately so that earthwork in civil construction work can be planned and priced accordingly. At present, the type and classification of earth materials are the main parameters used for selecting the appropriate method for excavation. The appropriate excavation method implies the method used to break the ground materials in the most effective way, in terms of time and cost. For material like rocks (e.g. granite) and loose sediments (e.g. residual soils), the recommended excavation method and rate of payment are clearly defined in Public Work Standard documents (JKR 1988). Depending on the method used, the rate for excavation ranges between RM1.50/m^3 and over RM50.00/m^3, and methods available include blasting, ripping, pneumatic drilling and conventional excavation.

When the origin of a material implies that it cannot be classified either as soil or rock, the existing terms and definitions on excavation in tender document may become disputable. Further complication may arise if the associated material is relatively hard and requires a costly method such as blasting and ripping. Usually it is the terms and assessment procedures used in determining the appropriate method of excavation for these 'unclassified' materials that trigger prolonged disputes between parties and often lead to unnecessary delays in construction work. It is often the case that when method of excavation for hard material is not clearly defined in tender document, contractor tends to opt for a more expensive method (e.g. blasting) although other equally effective and cheaper method is available (e.g. ripping).

There are several strongly cemented sediments that exhibit strengths and properties similar to rock, however their geological origins do not fulfil the classification criteria for rock. Laboratory test results from Fauzilah Ismail (2002) and Jerry Chua Kuo Sheng (2004) for example, indicate that these materials display the typical properties of clastic sedimentary rocks. Excavation work on these materials has been noted at several construction sites in Johore and Selangor (Mohd For and Muhd Zaimi, 1993) and it should be noted that these are the states where extensive construction activities are being undertaken. Due to the subjective nature of the definition and terms in the tender document, the associated earthwork at these sites has triggered costly and lengthy arbitration disputes between contractors and project owners. Thus, this paper discusses the initial part of this 2-years research on these cemented sediments, specifically on their geological origin, mass and material properties that are related to excavatability.

2.0 Duricrusts

The most common indurated sediments are duricrusts (also referred to as hard-pans or 'weathering crusts'). Geological studies on duricrusts are mainly associated with geomorphological processes, past climatic regimes and landforms of an area (e.g. Fauiran and Jeje (1983); Wilson (1983); Macias and Chesworth (1992)). Layers of hard-pans may reach thickness in the range of 1 to 10 m. They are shallow seated layers (several metres below surface) and consequently, are easily exposed on the surface by rapid and continuous weathering of the loose and less resistant overlying sediments. With regard to civil engineering, the problem pose by duricrusts is their excavatability and this is mainly due to their rock-like properties, distribution and mode of occurrence on site.

2.1 Mode of formation

Formation of duricrusts is invariably associated with the indurated zones in thick weathering profiles and hence, duricrusts are widely developed in tropical areas, though they are not confined to those localities. Principally, duricrusts are related to the process of deep chemical weathering that operates almost exclusively in humid tropical regions (Fauiran and Jeje, 1983).

Duricrusts of great geological age (Mesozoic mid-Tertiary era) cover many tropical uplands or survive as caprock on residual hills (see Figure 1). They erode slowly and resist weathering, thus playing a significant role in landscape development of an area. When eroded, duricrust slabs can collect in poorly drained lowlands, where they may be re-cemented together to form secondary duricrusts (see Figure 2). Thus, the terms primary and secondary duricrusts imply weather the indurated sediments are transported or *in situ* sediments, respectively.

Figure 1: Duricrust occurring as caprock in Dengkil, Selangor.

Figure 2: Secondary duricrust in Pasir Gudang, Johor.

The strength and hardness of duricrusts are the result of cementation of loose sediments by cementing materials and therefore, the chemical compositions of the cementing materials dictate the name and classification of duricrusts (Table 1). Iron- and aluminium-rich duricrusts are known respectively, as *ferricrete* and *alcrete*. These iron- and aluminium-rich weathering deposits are more commonly termed as *laterite*. Another common duricrusts is *bauxite* that refers to deposits containing economically extractable concentrations of aluminium. Many laterites and bauxites are, however, relatively weak materials and the terms *ferricrete* and *alcrete* are reserved for the indurated forms (Macias and Chesworth, 1992).

Siliceous duricrusts, or *silcrete*, are commonly composed of more than 95 % SiO_2 and found both in humid and arid tropical environments. In some cases they occur in weathering profiles in close association with *ferricretes*, while in more arid regions they are found in conjunction with calcium carbonate crusts or *calcretes*, with an average $CaCO_3$ content around 80 %. Distribution of *calcretes* generally coincides with areas of current mean annual precipitation between 200 and 600 mm (Macias and Chesworth,1992).

Table 1: General classification of duricrusts based on cementing materials.

Cementing materials	**Duricrusts**	**Nature**
Aluminium (Al)	Alcrete	Indurated
Iron (Fe)	Ferricrete	Indurated
Siliceous (SiO_2)	Silcrete	Indurated
Calcium Carbonate ($CaCO_3$)	Calcrete	Indurated
Iron (Fe)	Laterite	Loose
Aluminium (Al)	Bauxite	Loose

Formation of duricrusts is closely related to the pedogenic regimes of soil forming processes (Fauiran and Jeje, 1983). With regard to our past and present climatic conditions are concerned, the important regimes are *laterization* and *calcification*. *Lateralization* is formation of soil in an environment of prevailingly warm temperatures and abundant annual precipitation (tropical and equatorial regions). In contrast, *calcification* is a pedogenic regime characteristic of soils in regions deficient in soil moisture (semi-arid and desert areas). Thus, formation of the two most common duricrusts, calcrete and ferricrete, are as follows:

Calcrete: Duricrust formed by cementing agent $CaCO_3$ (see Table 1). The associated regime is *calcification*, where annual evaporation exceeds annual precipitation. During dry periods soil water rises towards the surface and is evaporated, leaving behind concentration of $CaCO_3$. This zone of carbonate accumulation will eventually form layer of duricrust with carbonate as cementing agent. The occurrence of calcrete in certain parts of Peninsular

Malaysia must have been formed during Lower Pleistocene age (about 1.5 million years ago) when the prevailing climate was semi-arid (Burton, 1973).
Ferricrete: Duricrust formed by cementing agent Fe (see Table 1). The pedogenic regime is *laterization*, which operates in an environment of equatorial regions. In humid low latitudes the percolation of rainfall through the soil causes unstable minerals like silica to be removed. What finally remain in these tropical soils are highly stable hydroxides of iron and aluminium. Excessive accumulations of hydroxides act as cementing agents that lead to the formation rock-like layers called ferricrete.

2.2 Local Occurrences

Duricrusts have been encountered at several construction sites in Selangor (e.g. Dengkil, Salak Tinggi and Jeram), Johor (Pasir Gudang and Johor Bahru) and Malacca (Alor Gajah). Preliminary field study conducted in November 2004 does indicate the occurrence of both primary and secondary duricrusts in Johor and Selangor. Majority occurs as capping of loose sediments and with thickness varying between less than 1 m to more than 3 m. Particularly in Dengkil the occurrence is relatively widespread and majority has been exposed on the surface (Figure 1) due to intensive erosion and weathering. No verification on the mineral composition of the cementing material has been undertaken yet however, based on the surrounding rock masses in both study areas, which is mainly granite, the composition is probably iron and aluminium. Hence the duricrusts are likely to be alcrete and ferricrete.

2.3 Typical Properties of Duricrust.

A number of laboratory studies have been carried out on duricrust particularly in Johor areas that include Pasir Gudang and Bandar Baru Uda (see Jerry Chua Kuo Seng, 2004 and Fauzilah Ismail 2002). The focus of the studies is mainly on their properties that are related to excavatability (see Table 2 below).

Table 2: Typical properties of duricrusts (after Jerry Chua Kuo Seng, 2004 and Fauzilah Ismail, 2002).

Properties	**Range of value**	**Range of value**
Uniaxial compressive strength (UCS).	4.8 to 6.6 MPa	7.4 to 12.9 MPa.
Slake's durability index (I_{ds} after 2nd cycle).	73.2 to 81.8 %	68.5 to 89.0 %.
Point-load index strength (I_s)	0.29 to 0.52 MPa	-
Surface hardness / Schmidt Hammer test (R).	18.3 to 21.9 MPa	17.4 to 20.4 MPa.
Tensile strength / Brazilian test.	-	0.44 to 0.94 MPa.
P-wave velocity / Ultrasonic velocity (Vp).	1985 to 2120 m/s	1800 to 2200 m/s.

As mentioned earlier duricrusts display certain properties that are similar to medium strength rocks. Comparing the properties listed in Table 2 with typical properties of rocks, the following arguments can be made:

- Rocks exhibiting UCS value between 5 and 15 MPa are classified as rocks of *Moderate Strength* by Farmer (1983), and these are mainly weakly compacted sedimentary rocks and foliated metamorphic rocks (McLean and Gribble, 1979). Note that the strongest soils (e.g. stiff clays) exhibit UCS value of less than 1 MPa (Clayton and Serratrice, 1997). Thus in terms of UCS, duricrusts are similar to rocks of moderate strength.
- In terms of Slake's durability index (after 2nd cycle), soils usually exhibit very low index of less than 30%. For materials with slaking index between 68 and 90 % (Table 2) can be classified as *Moderate* to *Moderately High* degree of slaking resistance (ISRM, 1981), which is typical of moderate strength rocks.
- Farmer (1983) classifies rock materials with Point-load index strength (I_s) between 0.3 and 1.0 MPa as rock of *Moderate Strength*.
- Surface hardness (R) indicates the compressive strength of sample surface. For unweathered sample, R is approximately equals to UCS. For duricrusts, UCS values between 17 and 22 MPa, they are equivalent to rocks of *High Strength* (Farmer, 1983).
- Despite of value less than 1 MPa, the tensile strength of duricrusts is still relatively high compared to soils (negligible tensile strength). This indicates some degree of cementation between mineral grains of duricrusts.
- The typical field P-wave velocity for hardpan is in the range of 1680 to 2440 m/s (Bickel and Kuesel, 1982). Although the P-wave propagation velocities in Table 2 were measured in laboratory, the value does indicate that duricrusts are of similar characteristics as hard clays and sandstone (Hunt, 1984).

It is due to the strength and hardness that cutting and trimming of samples of duricrusts would require machineries normally used for rock samples (Mohd For Mohd Amin and Muhd Zaimi Abd. Majid, 1993). Typical cores of duricrusts shown in Figure 3, were obtained using tungsten carbide coring bit.

Figure 3: Core sample of duricrusts

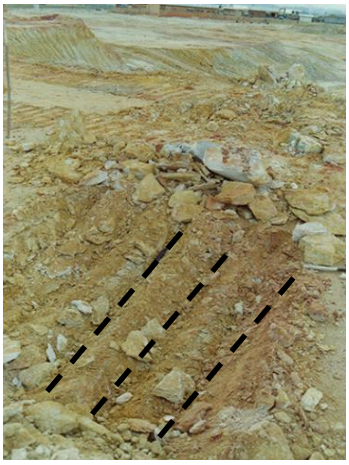

Figure 4: Multiple parallel cuts produced by ripper.

3.0 Excavation of hard materials

It is usually cheaper to break up rock masses by ripping rather than by drilling and blasting, but productivity may be low. Therefore, a successful excavation necessitates determination of relevant factors like nature of material, prevailing discontinuities and volume of material to be excavated. Of great importance is the nature of the material, which implies not just the general lithologic classification but also the relevant properties of the material (Legget and Hatheway, 1988). The value of general classification is by no means unimportant, indeed this is most essential, but each class of hard material can vary so considerably that for civil engineering purposes, it must be further described by some indications of its physical properties, both at large- and small-scale properties, as discussed below.

3.1 Mass and material properties related to excavatability

Excavatability assessments on rocks and other hard materials must include both their *material* and *mass* properties so that clear conception of the actual properties can be obtained (Pettifer and Fookes, 1994; Basarir and Karpuz, 2004).

Mass properties are those properties that rocks display in massive and actual form, and occasionally referred to as *in situ* state. The *in-situ* mass properties that influence excavatability include volume, mode of occurrence, weathering state and prevailing discontinuities/weakness planes (e.g. joints and bedding planes).

Material properties refer to the nature of rock in a relatively smaller scale (e.g. laboratory size specimens). In general, it implies gross properties of the minerals composition, together with small-scale weaknesses (e.g. micro-fractures, voids

and laminations). Materials strength is usually higher than mass strength for small size specimens are free from large-scale discontinuities. The relevant material properties that influence excavatability include strength, hardness, abrasiveness, and grain size.

The interacting effects of both material and mass properties in excavatability of a material can only be realized when the actual excavation is being undertaken. For example, weaker sedimentary rocks (less than 15 MPa compressive strength) like mudstones are not as easily removed by blasting, as their low strength would suggest, since they pulverized easily when the blasting waves have dissipated. Ripping is more effective than blasting when excavating a thin layer (less than 1 m) of moderate strength sedimentary rocks, particularly if major discontinuities are running parallel to the surface. Strong and massive rock like granite may be found in such state of weathering as to be excavatable by hand-shovel.

3.2 Excavatability of duricrust

Excavatability assessments (based on material properties) on duricrusts by Jerry Chua Kuo Seng (2004) and Fauzilah Ismail (2002) show that they require mechanical methods to be broken up before removal. Excavation work on duricrust observed in Pasir Gudang (Mohd For, 1993) indicates that ripping (using Caterpillar D9N ripper) seems to be an effective method for these cemented sediments. However, there are several characteristics of duricrusts that need further verification before one can conclude that ripping is the best option. Hence, this study is geared towards refining and verifying the properties of duricrusts that are related to rippability, through field and laboratory assessments.

It is anticipated that mode of occurrence, in situ strengths and weathering state are among the mass properties of duricrusts that need further verification. Field observations show that duricrusts may also occur as individual boulder instead of bedding or layer. The material strength and hardness of duricrusts do indicate their resistance to ripping, but Slake's durability index implies that they slake relatively easy under soaking (see Table 2). This may reflect certain effect on the excavatability of duricrusts following a heavy rainfall on site. Besides minor laminations and fractures, duricrusts do not display any major weakness planes thus, in terms of mass they can be considered as massive.

3.3 Ripping assessment procedures

Comprehensive review on rippability of rock materials have been undertaken by many authors (e.g. MacGregor *et al*.1994; Pettifer and Fookes, 1994; Basarir and

Karpuz, 2004). Majority agrees upon the importance of both laboratory and field assessments in gathering data pertaining to the material and mass properties.

There are several methods for rippability assessments namely; *direct methods* and *indirect methods* (Basarir and Karpuz, 2004). Direct methods are costly for they involved undertaking direct excavation of material *in situ* using pre-selected dozers. In addition, certain parameters (e.g. operator efficiency) are prone to bias evaluation. Of interest is the direct methods termed as *volume by length*. The procedure is based on time required for ripping a material over a measured distance, and seems to be valuable for quick and reliable estimation on rippability. Average ripping length, width, distance, and penetration depth can be readily obtained by observing a cut produced by single ripper tine attached behind a dozer. The typical multiple cut produced by a ripper dozer is shown in Figure 4. These data give the volume per cycle run of dozer, and from which the production in bank cubic meters can be calculated. Indirect methods include *Seismic velocity based method* and *graphical method*. The latter (as discussed below) is the most popular among the indirect methods that accommodates parameters like strengths (UCS, Point-load) and spacing of discontinuities and weakness planes.

A revised version of graphical method has been proposed by Pettifer and Fookes (1994) who considers the mass and material properties in evaluating excavatability of rock. For a more realistic assessment, average block size, three-dimensional discontinuity spacing (volumetric joint count, J_v) is included in the method. In addition, to account for the effect of mode of occurrence (mass properties) on excavatability, descriptive terms on block size are accommodated into the system, such as very small block (fracture spacing between 0.02 to 0.06 m) up to very large block (fracture spacing between 2 to 6 m).

4.0 Rippability assessments on duricrusts.

Since duricrusts cannot be classified as rocks therefore, to emphasize its resistance against excavation, it is essential to show that they exhibit properties similar to rock or other equivalent hard materials. It is thought that the material properties (in addition to mass properties) listed in the Table 3, are directly related to the degree of resistance against ripping.

Table 3: Material properties and their relationhsip with ripping.

Material properties	Indication for rippability
Uniaxial compressive strength.	Indication on: strength and any pulverization during excavation, and resistance against loading and fracturing.
Point-load index strength.	Similar to UCS.
Slakes durability index.	Indication on: resistance against slaking and degree of bonding of cementing materials.
Surface hardness.	Indication on: resistance against impact and abrasion.
Tensile strength	Indication on: resistance against fracturing and degree of bonding of cementing materials.
P-wave velocity	Indication on: denseness and any pulverization during excavation.

Besides properties listed in Table 3, further refinement and variation on test methods and procedures will also be developed. This is mainly for detailed verification and confirmation on properties being evaluated. In particular are properties like surface hardness and abrasiveness that have significant effect on ripping. A device, namely surface impact apparatus, has been fabricated to test surface hardness of duricrusts. The apparatus is shown in Figure 5 and consists of ball bearing, vertical perspex tube and a base plate that equipped with sample clamping mechanism. The equipment essentially measures impact size (i.e. indentation diameter) produced on a sample. The impact is achieved by dropping the ball bearing (of known mass) from a known height (i.e. through the perspex tube). Energy to produce the impact can be readily calculated and consequently, can be correlated with surface hardness and UCS. The concept is that the stronger the surface of a material, the smaller is the impact indentation produces by the ball bearing.

Figure 5: Laboratory impact test apparatus

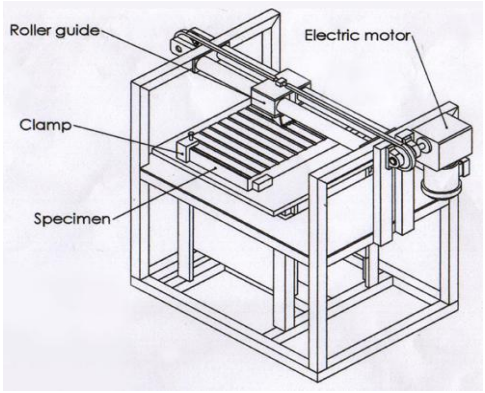

Figure 6: Laboratory ripping (drag tool) apparatus

Besides field/direct assessments using actual ripping machine, an apparatus is being fabricated to assess rippability of duricrusts under laboratory conditions. The proposed apparatus (Figure 6) comprises the following main components:

Main frame – A rigid frame to accommodate all the related movements and forces created by the drag cutting tool.
Sample holder – To hold cubic samples (500×350×300 mm) in rigid position during cutting process.
Cutting tool (tine) – An actual size shank (tungsten carbide with 10% cobalt). The shank is positioned to give rake angle of -5^0 and back clearance angle of 5^0. The cut groove produces is V-shaped.
Electric Motor – A continuous and constant torque motor to produce drag cutting mechanisms and capable of driving the cutting tool into sample at a constant speed of 150 mm/s. A dynamometer is accomodated in the motor to measure mean force required during cutting.

Laboratory direct ripping method represents excavation under *unconfined condition* therefore, a correction factor is required to cater for any confinement effect on site. The machine is designed to give a standard test parameters: depth of cut 5 mm, cutting speed 150 mm/s, and cutting width: 12 to 13 mm (see Basarir and Karpuz (2004); Fowell and Johnson (1982)).

Analysis of the test is relatively simple. The weight (gm) of cut material is measured using the material density and the volume of cut V (m^3). The cut length L (m) is equal to sample length . The mean cutting force F_c is measured using dynamometer. The specific energy (SE) in MJ/m^3 is calculated as:

$$SE = F_c L/V \quad (1)$$

Specific Energy (work done per unit volume of material excavated) is a good indicator for estimating the performance of surface excavation machinery such as ripper (Basarir and Karpuz, 2004). For laboratory ripping data to be a useful parameter in assessing ease of ripping, it must be correlated with direct assessments on site (i.e. production of ripping in m^3/hr) as listed in Table 4.

Table 4: The suggested production, specific energy and rippability class boundaries [Basarir and Karpuz, 2004]

Specific energy, MJ/m^3.	Direct ripping production, m^3/hr.	Descriptive terms
> 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

5.0 Conclusions

With regard to the indurated sediments being studied and their properties that are related to excavatability, the following conclusions can be derived:

1. Duricrusts can be classified according to their mode of formation and the types of cement matrix that are associated with their formation.
2. The origin duricrusts implies that they cannot be classified as rock, although they exhibit properties similar to clastic sedimentary rocks.
3. Excavation on duricrusts has been noted at several construction sites in Johore and Selangor. Due to the limited understanding on the classification and degree of excavatability of these indurated sediments, the associated earthworks at these sites have been subjected to costly and lengthy arbitration disputes between the contractors and project owners.
4. Series of laboratory and site assessments have been proposed for detailed verification on the degree of rippability of duricrusts particularly in terms of their material and mass properties. The proposed assessments include the determination of specific energy required to rip duricrusts using laboratory ripping machine.

Acknowledgement

The authors wish to express their gratitude to Construction Industrial Development Board (CIDB) for the financial support of this study and En. Abd. Rasid Jaapar of Soils and Foundations Sdn. Bhd., Kuala Lumpur, for his advice on the study sites.

References

Abd. Rasid Jaapar (2004) Personal communication, Soils and Foundations Sdn. Bhd., Taman Desa 58100 Kuala Lumpur.

Basarir, H. and Karpuz, C. (2004) A Rippability Classification System for Marls in Lignite Mines, *Quarterly Journal Engineering Geology* V. 74, pp. 303 – 318.

Burton, C.K. (1973) *Geology and Mineral Resources Johore Bahru – Kulai Area, South Johore*, Geological Survey of Malaysia, Jabatan Cetak Kerajaan, Ipoh, Malaysia, 72p.

Clayton, C.R.I and Serratrice, J.F. (1997) The Mechanical Properties and Behaviour of Hard Soil and Soft Rock. In Anagnostopoulos *et al*., *Geotechnical Engineering of Hard Soils and Soft Rocks,* Vol. 3, Balkema, Rotterdam, pp. 1839 - 1877.

Farmer, I. (1983) *Engineering Behaviour of Rocks*. 2nd edn. Chapman and Hall, London, 208 p.

Fauiran, A. and Jeje, L.K. (1983) *Humid Tropical Geomorphology*, London, Longman, 527p.

Fauzilah Ismail (2002) *Excavatability of Hard Materials Based on Laboratory and Field Assessments*. Disertasi Sarjana Muda Kej. Awam, Univ. Teknologi Malaysia, Skudai, Johor.

Fowell, R.J. and Johnson, S.T. (1982) Rock Classification and Assessment for Rapid Excavation, *Proceedings of the Symposium on Strata Mechanics*, Farmer I.W. (ed.), Newcastle upon Tyne, Elsevier, Amsterdam, pp. 241 – 244.

ISRM (1981) *Rock Characterisation Testing and Monitoring, ISRM Suggested Methods*. Commission on Testing Methods, International Society for Rock Mechanics. Brown E.T. (ed) Pergamon Press Ltd. Oxford, 211 p.

Jerry Chua Kuo Seng (2004) *Classification of Hard Materials for Contract Documentation*. Disertasi Sarjana Muda Kej. Awam, Univ. Teknologi Malaysia, Skudai, Johor.

JKR (1988) Specifications on Earthworks, Jabatan Kerja Raya, Malaysia.

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

Macias, F. and Chesworth, W. (1992), Weathering in humid regions, with emphasis on igneous rocks and their metamorphic equivalents, *Weathering, Soils and Paleosols*, Martini and Chesworth (eds.), Elsevier Science Publisher, Amsterdam, pp. 283 – 347.

Mohd For Mohd Amin and Muhd Zaimi Abd. Majid (1993) *Rippability assessment of hard material, a case study at Pasir Gudang*, Seminar Penyelidikan Kejuruteraan Awam (SEPKA 93), 23rd June, Johor.

Mohd For Mohd Amin (1993) *Classification of Excavated Material based on Laboratory Testings*, Annual Geological Conference ’93, Pulau Langkawi, 12 – 13 June.

Pettifer, G.S. and Fookes, P.G. (2004) A Revision of the Graphical Method for Assessing the Excavatability of Rock, *Quarterly Journal Engineering Geology* V. 27, pp. 145 – 164.

Wilson, R.C.L. (1983) *Residual Deposits: Surface Related Weathering Processes and Materials*, The Geological Society of London, Blackwell Scientific of London, 257 p.