EFFECT OF LIQUIDITY INDEX ON THE STABILISED LATERITIC SOIL BY ACIDIC BASED STABILIZER

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Abstract

Soils stabilization can be performed using various chemical additives, in order to improve soil engineering properties. In many regions of the world where desirable soils for construction do not exist locally, it is often more economically viable to stabilize poor local soils than to excavate and replace undesirable soils with imported quality materials. In this study, 7% and 13% of an acidic based stabilizer in liquid form were used as a means of stabilizing the laterite soil at various water contents. Laboratory investigation included standard Proctor compaction and unconfined compressive strength (UCS) tests were carried out. The maximum UCS was found at 7% of the acidic based stabilizer at the maximum dry density (MDD) value of 1.54 Mg/m^3 and 25.47% of optimum moisture content (OMC). Based on the test results, the suggested improvement was 7% of the acidic based stabilizer at OMC.

Keywords: **Acidic stabiliser, laterite soil, Liquidity Index, Unconfined compressive strength**

Introduction

T Due to the lack of natural quality materials, the improvement of locally available soils to meet engineering properties (soil strength, compressibility and permeability) requirements for a given project is a challenging work for geotechnical and pavement engineers. Two widely used soil improvement methods are: (1) replacing with imported quality materials (ATJ 5/85, 2013), which is generally expensive and causes significant logistical and sustainability problems, and (2) stabilizing by traditional and non-traditional chemical (Latifi *et al.*, 2015, 2016; Phetchuay *et al.*, 2014, 2016, Hoy *et al.*, 2016 and Jongpradist et al., 2018).

Lateritic soils are generally found in tropical and sub- tropical countries such as Africa, India, Southeast Asia, Australia, Central and South America (Latifi et al., 2015 and Phummiphan et al., 2015 and Donrak et al., 2016). More than half of the area of Peninsular Malaysia is covered with residual sedimentary rock soil rich in iron and alumina content which give its lateritic nature (Eisazadeh et

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al., 2011). The lateritic soil is generally recognized as residually weathered soils created in regions of recent volcanic activity or continuous wet climates with an average rainfall generally above 1,500 mm (Osula, 1993).

The requirement strength of road subgrade is between 137 kPa to 372 kPa based on the resilient modulus, M_R at 2% of failure strain (Schaefer et al., 2008). However, a road which constructed on the lateritic soil as the base and subgrade is categorized by high natural moisture content and liquid limit, low natural density, and are friable and/ or have a crumbly structure (Omowumi, 2017). Therefore, the characteristics of lateritic soil are difficult to predict during construction. This problematic lateritic soil is not suitable for road construction as it is; thus, if the techniques of road design and construction are not in accordance with the soil conditions, then failure will prevail in the design. To ease the work on construction surfaces, stabilization works have been introduced to improve the engineering behaviour of the soil, such as its compressive strength, compressibility and permeability (Latifi et al., 2015, 2016; Raftari et al., 2014; Rashid et al., 2014). Chemical stabilization is a widely used method to improve the physical and engineering properties of the soil (Phetchuay et al., 2016).

It has been well established that a number of non-traditional soil additives, which are not calcium-based, are effective for soil stabilization *(*Latifi *et al.*, 2015*)*. Additionally, many studies have been carried out using stabilizer agents to improve the engineering properties of lateritic soils (Eberemu, 2011; Eisazadeh *et al.*, 2011; Latifi *et al.*, 2015; Phummiphan *et al.*, 2015 Phetchuay *et al.*, 2016 and Donrak *et al.*, 2016), On the other hand, Eisazaedeh *et al.* (2011) have used a phosphoric acid-based stabilizer to improve the engineering properties of lateritic soil. They found that the acidic stabilizer is more effective as compared to lime. However, fewer attempts have been made to study the effect of the Liquidity Index (LI) on the stabilized soil strength (Rashid *et al.*, 2014). Liquidity Index (LI) is a ratio between the different of soil moisture content with the soil plastic limit and the different of soil liquid limit with the soil plastic limit (Liu & Evett, 2014).

Rashid *et al.* (2014) have proposed a relationship between soil strength and LI treated by Ordinary Portland cement (OPC). They found that the strength was decreased with the increase of LI. LI is important because water is an influencing factor in the stabilization process and, in practice, the in situ water content keeps changing due to environmental effects (Ishak *et al.* 2012). In addition, the value is considered a dimensionless value and could be used under different ranges of PI and LL and moisture content values.

In this study, an acidic based stabilizer (phosphoric acid and sulphuric acid) in liquid chemical form was used as the soil stabilizer. This stabilizer was mixed with lateritic soil, which normally used as a subgrade formation for the road construction. In that sense, the groundwater level is far below from the subgrade level and the soil is assumed under partially saturated condition. However, the changes in suction or in density are not been investigated in this study.

The main purpose of this research is to determine the optimum of the acidic based stabilizer content to be used in the stabilization of lateritic soil and to investigate the effect of water content on stabilized soil's compressive strength. Several basic tests were carried out to determine the physical properties and the classification of the lateritic soil according to BS 1377 including the Atterberg limits test and the particle size distribution test. Optimum moisture content (OMC) was determined by conducting the standard Proctor compaction test prior to conducting the unconfined compressive strength (UCS) test. The 0%, 7% and 13% of the acidic based stabilizer contents were selected for this study. The soil strength was evaluated at 7, 14 and 28 days of curing. The intention of the study is to provide strength information under a rapid subgrade construction. Therefore, the strength was evaluated within 28 days of curing.

Materials

The material used was a reddish lateritic soil, which was rich in iron and aluminium oxides. The lateritic soil was obtained from the hillside located in Universiti Teknologi Malaysia, Johor, Malaysia. The sample was air-dried under laboratory conditions and passed through a 2 mm sieve. Table 1 and Figure 1 show, respectively, the properties and particle size distribution of the laterite soil sample. The lateritic soil consists of 60% of fine contents (silt and clay). The oxides and chemical composition of lateritic soils contained SiO_2, Al_2O_3,

Table 1. Physical properties of natural laterite soil.

Engineering & Physical Properties (Laterite)	Values
Specific Gravity	2.70
Liquid Limit, LL (%)	82
Plastic Limit, PL (%)	49
Plasticity Index, PI	33
British Standard Classification	MH
Maximum Dry Density (Mg/m^3)	1.44
Optimum Moisture Content (%)	33.4

Fe_2O_3 and CO_2 detected from the X-ray fluorescence (XRF) test. The X-ray diffraction (XRD) result indicates that the main minerals in the lateritic soil were kaolinite, quartz, goethite and gibbsite (Latifi et al., 2015). To enhance the strength of the lateritic soil, an acidic chemical liquid was used in this study. Due to the solution is a corrosive and toxic fume liquid, a full protective clothing and self-contained breathing apparatus were used during the sample preparation. The exact chemical composition of the stabilizer has not been released since it is a commercially registered brand. Table 2 shows the general properties of this stabilizer given by the manufacturer.

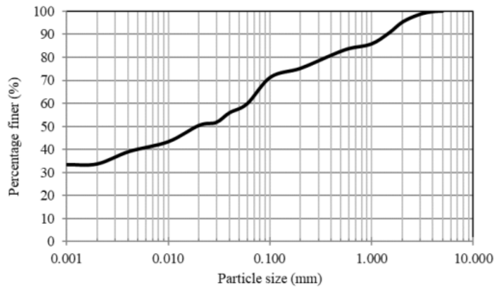

Figure 1. Particle size distribution of natural laterite soil.

Table 2. Description of the acidic based stabilizer.

Chemical Name	Acidic based stabilizer
Chemical Family	Corrosive liquid, N.O.S. (phosphoric acid, sulphuric acid) Class 8; UN 1760; PGII
Specific Gravity	1.136
pH	<2
Appearance	Dark brown liquid
Odour	Slightly pungent to acidic odour

Sample Preparation

The standard Proctor compaction test was conducted to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the sample according to BS 1377: 1990: Part 4 (Head, 1990). The acidic based stabilizer contents studied were 0%, 7% and 13% by weight of dry soil. This cement content range was recommended for Silty and Clayey soils by Walsh-Healey Public Contracts Act (PCA) (1936). The air-dried sample was mixed thoroughly with the stabilizer before conducting the compaction test. The obtained results from the MDD and OMC for different stabilizer contents were used in preparing UCS samples. The acidic based stabilizer contents studied are in accordance with those used in the previous study and practical applications in the field (Shahminan *et al.*, 2013).

In order to study the effect of water content on the soil's UCS, the soil samples were prepared based on the dry density under different moisture contents of 0.9 OMC, OMC and 1.1 OMC (Shahminan *et al.*, 2013). The air-dried soil was mixed with the required amount of water and liquid chemical content until a uniform mixture was achieved. Finally, the mixtures were compressed in a 38 mm in diameter and 76 mm in height of cylindrical special fabricated mould with designed OMC and MDD obtained from the compaction test for each stabilizer content. A compression machine was used to compress the soil inside the fabricated mould in order to control the specimen quality (Latifi et al., 2016b). Then the soil samples were extruded from the mould and put in thin-walled PVC tubes, wrapped with thin plastic and sealed with tight rubber lids. The samples were stored for 7, 14 and 28 days in a controlled temperature (25ºC). To ensure the repeatability of the procedure, two samples for each soil mix under three different curing periods and three different concentrations of the stabilizer agent were prepared. Two concentrations of 7% and 13% of the acidic based stabilizer dilution were proposed for stabilization of the laterite soil and 0% of the acidic based stabilizer soil mixtures were used as the control samples. This made a total of 54 samples prepared and tested to determine the standard of the shear strength of the laterite soil with different curing periods and amounts of the acidic based stabilizer mixture. The UCS test procedures were carried out in accordance with BS 1377: 1990.

Results and Analysis

Standard Proctor Compaction Test

The results of the compaction tests of stabilized soil at different stabilizer contents are shown in Figure 2. The OMC and MDD range from 24.4% to 33.4% and 1.44 Mg/m^3 to 1.54 Mg/m^3, respectively. The OMC decreases with the increase in the stabilizer content, implying that the soil requires less water content to form soil structure. The MDD increases with stabilizer content up to the highest value at an optimum stabilizer content of 7%. The increase in the MDD associated with the decrease in the OMC is the typical for compacted stabilised cohesive soil (Latifi et al, 2016a). This is due to the flocculation and agglomeration effect caused by the rapid cation exchange in the soil–stabilised agent solution mixture (Latifi et al., 2016a). The highest MDD was recorded at around 1.52 Mg/m^3, which is 0.10 Mg/m^3 higher than that of the unstabilized sample.

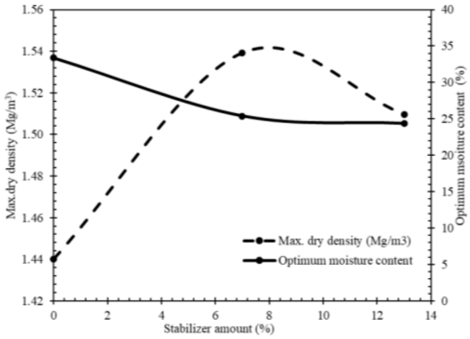

Figure 2. MDD and OMC versus percentage of acidic based stabilizer.

Unconfined Compressive Strength (UCS) Test

Figures 3 to 5 show the stress-strain curves under the UCS tests for 7, 14 and 28 days of curing and 0%, 7% and 13% stabilizer contents. **Figure 3** shows that the UCS and stiffness of unstabilized soil decrease with increasing water content. In other words, the compacted soil on the dry side of OMC exhibits higher UCS and stiffness that the compacted soil at the OMC and on the wet side of OMC. This is the typical characteristics of compacted fine-grained (Rashid et al., 2014) and coarse-grained soils (Horpibulsuk et al., 2006). The range of strain failure is between 1% and 8%. Generally, the strain failure is related with the influence of the OMC, stabilised agent amount and curing times. A less failure strain was found when the untreated soil in dry condition and the failure strain for the treated soil (7% and 13%) show similar trend when the curing period achieved 28 days. The higher stiffness is associated with higher strain failure.

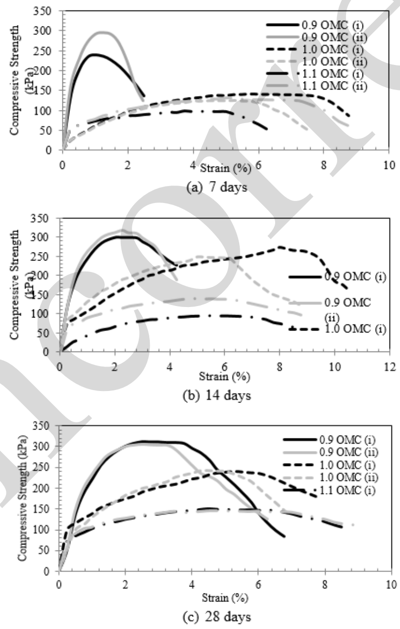

Figure 3. Compressive stress versus strain for 0% of the acidic based stabilizer (a) 7-day curing period, (b) 14-day curing period and (c) 28-day curing period.

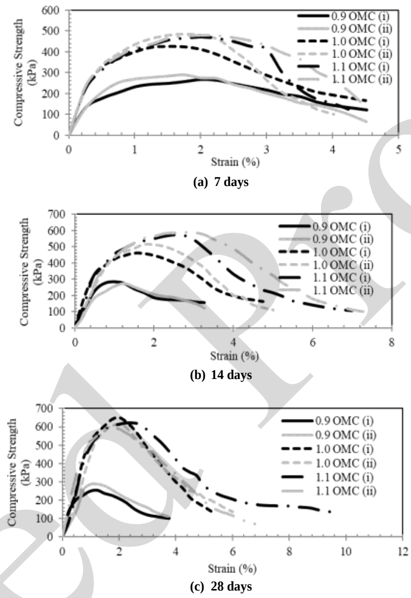

Figure 4. Compressive stress versus strain for 7% of the acidic based stabilizer (a) 7-day curing period, (b) 14-day curing period and (c) 28-day curing period.

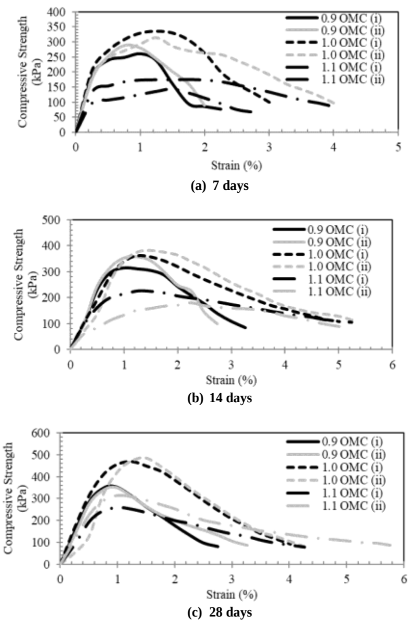

Figure 5. Compressive stress versus strain for 13% of the acidic based stabilizer s (a) 7-day curing period, (b) 14-day curing period and (c) 28-day curing period.

Unlike the unstabilized soil, the highest UCS of stabilized soil was found at OMC while the lowest UCS was found on the dry side of OMC for both 7% and 13% stabilizer contents (Figures 4 and 5). The higher UCS is associated with higher failure strain. The UCS at OMC is slightly higher than on the wet side of OMC but is approximately twice higher than on the dry side of OMC. With curing time, the UCS at all water contents increases. At 28 days of curing, the stiffness is more or less the same for all water contents tested. Similar to the compaction results, the highest UCS is associated with the highest MDD, which is at 7% stabilizer. It was found that, the water content corresponding to the maximum strength was the OMC of the compacted stabilises soil. This situation most probably contributed from the hydration process of the stabilised soil and the compaction effort from the compaction test (Horpibulsuk et al., 2006). In addition, the stabilised soil strength is greater than the required strength for the road subgrade construction.

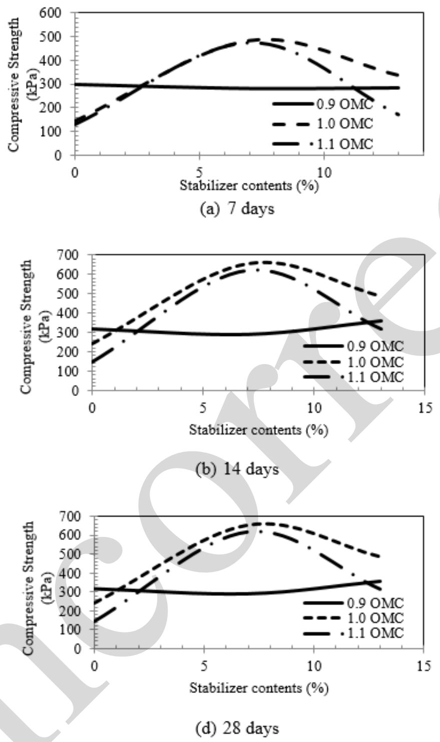

Figure 6. Graphs of failure stress versus the acidic based stabilizer (a) 7-day curing period (b) 14-day curing period (c) 28-day curing period.

Figure 6 shows the plots of UCS versus stabilizer content for various curing periods. (Figure 6(a)) shows that by adding 7% and 13% stabilizer content, the soil strength increases 2.44 and 1.38 times, respectively, compared to that of the unstabilized soil. (Figure 6(b)) shows that the UCS for the sample with OMC increases 3.24 times and 2.42 times for the soil mixture with 7% and 13% stabilizer, respectively. At 28 days of curing (Figure 6(c)) and for OMC, the UCS increases 3.15 times for 7% stabilizer content and 2.42 times for 13% stabilizer content, as compared to untreated soil. This result indicates that the 7% selected stabilizer is the most suitable in stabilization. For 0.9 OMC, the stabilizer does not cause much beneficial change in the soil strength.

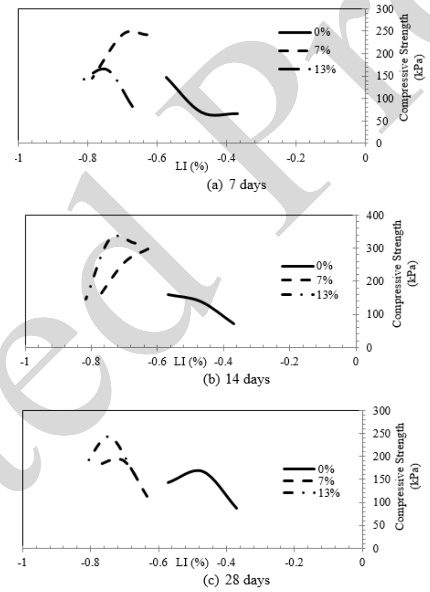

Figure 7. Graph of the undrained shear strength versus LI (a) 7-day curing period (b) 14-day curing period (c) 28-day curing period.

Discussion

Figure 7 shows the relationship between the LI and compressive strength of stabilized lateritic soil. This relationship determines the percentage of used stabilizer required to stabilize lateritic soil. For unstabilized soil, the LI is in the range of -0.3 to -0.6 for all curing periods. For 7% and 13% selected stabilizer, the range of the LI is - 0.6 to -0.9. For 0% stabilizer content, at 7 days and 14 days, the strength decreases with the increases in the LI value, while at 28 days, the strength of lateritic soil first increases with the decrease in the LI to -0.47, and then decreases with further decrease in the LI. For 7% and 13% used stabilizer, the strength of the lateritic soil increases first with an decrease in LI, and then decreases further with an decrease in LI for all curing periods except that at 14 days for 7% selected stabilizer whose the strength decreases with decreasing LI values to -0.79.

Conclusion

This study was carried out to investigate the strength performance on the stabilized lateritic using an acidic based stabilizer. The effect of the water content on the strength development of stabilized lateritic soil was also investigated. Conclusions can be made from this study as follows:

a) The result from the compaction test showed that the highest maximum dry density (MDD) was obtained from 7% of cement content.

b) By adding 7% and 13% of stabilizer to the soil, the soil strength increased by 2.44 to 3.24 and 1.38 to 2.42 times, respectively, compared to that of the untreated soil. The 7% stabilizer was found to be the suitable content exhibiting the highest strength and maximum dry density.

c) The optimum water content was suggested for the soil stabilization by the acidic based stabilizer while the stabilization on the dry side of OMC should be avoided.

References

ATJ 5/85 (2013). Manual for the structural design of flexible pavement. Public Work Department of Malaysia.

Aun. O.T. (1982). Malaysian Soils and Associated Problems, Geotechnical Engineering Course, Universiti Malaya.

British Standard Institution (1990). BS 1377, Method of tests for soils. British Standard Institution, London, UK.

Donrak, J., Rachan, R., Horpibulsuk, S., Arulrajah, A. and Du, Y.J. (2016). Improvement of marginal lateritic soil using melamine debris replacement for sustainable engineering fill materials. Journal of Cleaner Production, 134: 515-522.

Eberemu AO (2011) Consolidation properties of compacted lateritic soil treated with rice husk ash. Geomat (GM) 1(3):70–78.

Eisazadeh A, Kassim KA, Nur H (2011). Characterization of phosphoric acid-and lime-stabilized tropical lateritic clay. Environ Earth Science, 63(5):1057–1066.

Head, K.H. (1980). Manual of Soil Laboratory Testing, Volume 1: Soil Classification and Compaction Test. ELE International Limited; London.

Head, K.H. (1980). Manual of Soil Laboratory Testing, Volume 2: Permeability, Shear Strength and Compressibility Tests. ELE International Limited; London.

Hoy, M., Horpibulsuk, S., and Arulrajah, A. (2016). Strength development of recycled asphalt pavement- fly ash geopolymer as a road pavement material. Construction and Building Materials, 117: 209-219.

Horpibulsuk, S., Katkan, W., Sirilerdwattana, W., and Rachan, R. (2006). Strength development in cement stabilized low plasticity and coarse grained soils: Laboratory and field study. Soils and Foundations, 46(3): 351-366.

Ishak, F., Ali, N. and Kassim, A. (2012). Tree induce suction for sustainability slope, in: Proc. 3rd International Conference on Soil Bio- and Ecoeng., The Use of Vegetation to Improve Slope Stability.

Jongpradist, P., Homtragoon, W., Sukkarak, R., Kongkitkul, W. and Jamsawang, P. (2018). Efficiency of Rice Husk Ash as Cementitious Material in High- Strength Cement-Admixed Clay. Advances in Civil Engineering 2018(4):1-11.

Latifi, N., Marto, A., Rashid, A.S.A. and Yii, J.L.J. (2015). Strength and Physico- chemical Characteristics of Fly Ash–Bottom Ash Mixture. Arabian Journal for Science and Engineering. 40 (9):2447-2455.

Latifi, N., Rashid, A. S. A., Ecemis, N., Tahir, M. M. & Marto, A. (2016a). Time- dependent physicochemical characteristics of Malaysian residual soil stabilized with magnesium chloride solution. Arabian Journal of Geosciences. 9(1): 1-12.

Latifi, N., Rashid, A. S. A., Siddiqua, S., & Majid, M.Z.A. (2016b). Strength measurement and textural characteristics of tropical residual soil stabilised with liquid polymer. Measurement, 91:46-54.

Liu. C., and Evett. J. (2014). Soils and Foundations, 8th Edition. Pearson, London.

Mahalinga-Iyer, U. and Willams, D.J. (1991). Engineering properties of a lateritic soil profile. Eng. Geol., 31: 45-58.

Marto, A., Latifi, N., and Sohaei, H. 2013. Stabilization of laterite soil using GKS soil stabilizer. Electronic Journal of Geotechnical Engineering (EJGE), 18: 521-532.

Omowumi, A. (2017). Engineering Evaluation of Lateritic Soils of Failed Highway Sections in Southwestern Nigeria. Geosciences Research, 2(3): 210-218.

Osula, D.O.A. (1993). Laboratory Trial of Soil-Sodium Chloride-Cement Stabilization for Problem Laterite. Journal of Transportation Engineering 119(1).

Phetchuay, C., Horpibulsuk. S., Arulrajah, A., Suksiripattanapong, C., Udomchai, A. (2016). Strength development in soft marine clay stabilized by fly ash and calcium carbide residue based geopolymer. Applied Clay Science, 127-128: 134-142.

Phetchuay, C., Horpibulsuk, S., Suksiripattanpong, C., Chinkulkijniwat, A., Arulrajah, A. and Disfani, M.M. (2014). Calcium carbide residue: Alkaline activator for clay- fly ash geopolymer. Construction and Building Materials, 69: 285-294.

Phummiphan, I., Horpibulsuk, S., Sukmak, P., Chinkulkijniwat, A., Arulrajah, A., and Shen S.L. (2015). Stabilisation of marginal lateritic soil using high calcium fly ash based geopolymer. Road Materials and Pavement Design, 17(4):877-891.

Powrie, W. (2002). Soil Mechanics. Spon Press. Taylor and Francis Group, London and New York.

Public Work Department of Malaysia (2012) Design guide for alternative pavement structures Low- Volume Roads, Department of Road Engineering and Geotechnic.

Raftari, M., Rashid, A.S.A, Kassim, K.A. and Moayedi, H. (2014). Evaluation of kaolin slurry properties treated with cement.Measurement, 50(1):222-228.

Rashid, A.S.A, Kalatehjari, R., Noor, N.M., Yaacob, H., Moayedi, H., Sing, L.K. (2014). Relationship between liquidity index and stabilized strength of local subgrade materials in a tropical area. Measurement, 55:231-237.

Schaefer, Vernon. R., Stevens L., White, D. and Ceylan Halil. (2008). Design guide for subgrades and subbases. Tech. Transfer Summaries, 60.

Shahminan, D.N.I.A.A., Rashid, A.S.A., Bunawan, A.R., Yaacob, H. and Noor, N.M. (2014). Relationship between strength and liquidity index of cement stabilized laterite for subgrade application. International Journal of Soil Science, 9(1):16-21.

Walsh- Healey Public Contracts Act (PCA) (1936). US Department of Labour.

Xiang, W., Cui, D., Liu, Q., Lu, X., and Cao, L. (2010). Theory and practice of ionic soil stabilizer reinforcing special clay. Journal of earth science, 21:882-887.