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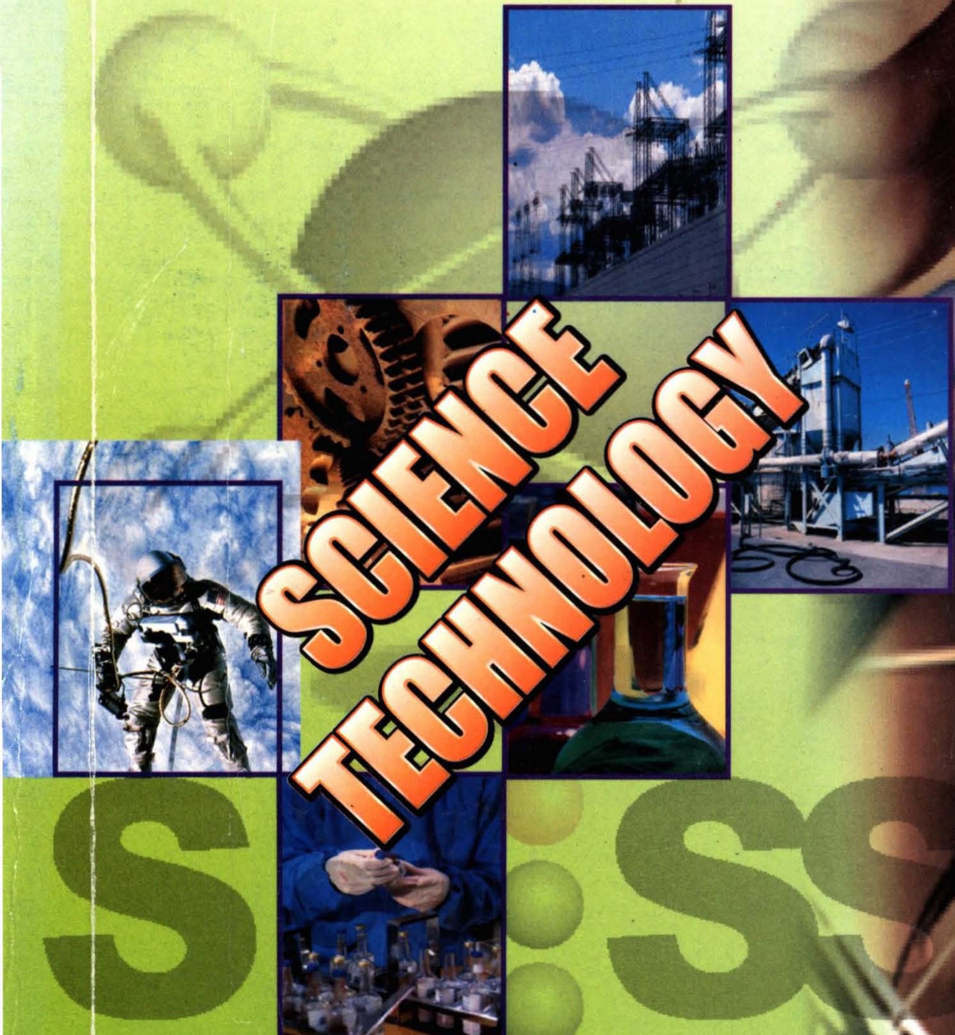

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Evaluation of Guidelines for Chemical Stabilization of Tropical Residual Soils

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ABSTRACT

Soil stabilization has been widely used based on the effectiveness and as an alternative to substitute the lacking of suitable material on site. Past research works on stabilizing residual soil have shown various results depending on the selection and application of various additives. Guidelines and standards have been developed to assist practitioners in designing road structure by means of chemical stabilization. TRL (1993), US Army (1994), and PWD (1985) are some of the authorities that endeavor with either extensive or acceptable guide for the process. However, precedent research works shows deficiency in applying these guidelines. Efforts were made in this paper to review these guidelines for chemical stabilization of residual soil. TRL (1993) was found to give a more simplified route in the selection of suitable binders for the soil stabilization process. TRL could also be readily adaptable to the practice in the country as the standards used (i.e. the British Standards) are commonly used for the testing of local soils.

Keywords: *cement stabilization, residual granite and sedimentary soils, PWD (1985), TRL (1993), US Army (1994) Plasticity Index, Compaction, Unconfined Compression Strength (UCS)*

Introduction

Studies of soil stabilization by using solid stabilizing agents such as cement, lime and fly ash have been conducted on soils in many regions around the world. The uses of chemical additives have been used to improve the handling and engineering characteristic of soils for civil engineering purposes. Stabilized soils offer a viable alternative for road structural layers especially in resource scarce area. In Malaysia, the practice of using chemically stabilized soil is still uncommon, attributed to its high cost compare to the production cost of bituminous mix and concrete (Noor 1994). However, more than half of the area in Peninsular Malaysia is covered with residual granite and sedimentary rock soil. Given the humid tropical climate that prevails in Malaysia which is characterized by high temperatures and heavy rainfalls, the formation of tropical residual soils is intense with a predominance of chemical weathering of rocks, thus resulting in deep weathering profiles and soil mantles often exceeding 30m (Tan 2004). This feature gives relatively abundant materials for engineering works such as highway cut slopes, urban developments, dam site excavation, road constructions and others.

As road construction benefited from the stabilization method, a number of guidelines based on soil stabilization have been developed throughout the globe. Examples are the US Army (1994) and TRL (1993). These guidelines are equipped with guide and mechanism in analyzing potential natural soils to be used in the soil stabilization process. There is also a local guideline concerning soil stabilization, which is the PWD (1985).

A review of the literatures indicates that there has been local and regional researches on the application of a number of binders including cement, lime, rice husk ash (RHA) as well as other chemical additive, such as Renolit (Faisal 1990; Faisal et. al. 1992; Lee & Faisal 2004; Mohamed and Hosani 2000; Noor 1994; Siswosoebrotho et. al 2003; and Wong 2003) for residual soil stabilization. However, it appears that none of these studies have referred to any guideline in their binder selection process. The degree of improvement of in-situ soil may differ within a particular method and also between the methods. The reason is that soil exists in a broad range of types and different soils react differently to different stabilizer. With the variety of residual soil composition, identifying suitable guideline in the process of soil stabilization will come in handy. With the abundant residual soil as the readily available and inexpensive construction material, especially for the construction for structural road layer, a suitable guideline would be systematic, useful for design works and construction practices. The potential of optimum usage for residual soil to be use in developing the rural road by using soil stabilization method can be done in comprehensive approach as alternative for conventional practiced. Simplified guidelines are necessary to direct the engineer to stabilization techniques that appear most suitable for a particular situation.

Evaluation of Guidelines

There are varieties of guidelines that have been produced by many researchers. Most of the guidelines proposed by these researchers were made without specified any restriction toward local condition or regional climates, of which assumption can be made that the guidelines can be used to suit any environment. However, the guidelines produced might be minimal in terms of the method of stabilization that suit to the types of soil without any explanation on the processes, the strength to be achieved and limitation to be considered. There are also a number of governments, state and private agencies which have produced guidelines concerning soil stabilization especially in the country where soil stabilization method is common to be used to developed local road. Some of the guidelines were purposely prepared to suit local environment. There are also guidelines concerning the condition for similar climate, for example, tropical climate, produced to assist developing country.

The only available local manual of pavement design was developed by Public Works Department of Malaysia (PWD 1985) on the method of chemical soil stabilization. The guideline provides a minimal explanation to stabilized laterites soil which refers to local soil. The used of the term 'laterite' (as defined by the original description of Buchanan 1807) might bring some skepticism to the practitioners and engineers, as not all residual soils harden on exposure to form laterite (Northmore et. al. 1992). The local scientists and researches eventually correspond to the 'tropical residual soil' rather than the former used of laterites. This corresponding term of 'tropical residual soil' has been accepted by the Public Works Institute of Malaysia (1996). On the chemical soil stabilization process, the PWD (1985) recommends stabilization whenever CBR is less than 20% for natural (laterite) soil. However, the PWD (1985) stated that for cement stabilized soil, the stabilized soil must achieve CBR value of not less than 60%. The strength achievement should be three times stronger than the natural soil. No gradation is specified to maximize use of suitable local materials including sand and laterite (PWD 1985). Gradation is only required for crushed aggregates. Two major aspects considered in PWD (1985) are plasticity index and strength values, but the criteria are not explained explicitly for all condition (i.e. sub grade, sub base or base). PWD (1985) stated that minimum strength to be achieved by cement stabilized for base course is 2.9 MPa. Furthermore, only Portland cement suggested as the admixture to enhance the properties of local soil. The examples on the criteria of soil stabilization proposed by PWD (1985) with regard to specific road structural layer are given by the Tables 1 and 2.

Table 1: Standard Properties of Sub-base, PWD (1985)

Quality	Test Method	Crushed Aggregate	Sand Laterite, etc
CBR (%)	BS 1377: 75	Not less than 30	Not less than 20
Plasticity Index (PI)	BS 1377: 75	Not greater than 6	Not greater than 6
Cement Stabilized, CBR (%)	BS 1377: 75	-	Not less than 60

Table 2: Material Properties of Base course (PWD 1985)

Requirement	Cement Stabilized
Unconfined Compressive strength (7 days) kg/cm^2	30 to 40 (2.9 MPa)
Plasticity Index (PI)	Not greater than 8
Gradation for Base Course	Nominal size of material used shall not be greater than 1/3 of compacted layer thickness

TRL (1993) developed the Overseas Road Note 31 (ORN 31) as the result from various research and development programs. TRL (1993) recommends the used of cement, lime and fly ash as chemical binder for soil stabilization for the used in road base, sub-base, capping and selected fill layers of pavements. The selection of binder suggested by TRL (1993) mainly depends on the soil properties and plasticity index. Guide to select appropriate binder is as shown in Table 3. The selection of binder strongly depends on the particle size distribution and the plasticity index. Two categories which are soil properties with more than 25% grain passing 0.075 mm (#200 in ASTM standard) and less than 25% passing the #200 sieve. TRL (1993) specified the minimum acceptable strength of a stabilized material depends on its position in the pavement structure and the level of traffic. The material should be strong enough to resist traffic stresses but upper limits of strength are usually set to minimise the risk of reflection cracking. Minimum strengths to be achieved base on the position of road structural layer are summarized in Table 4. TRL (1993) suggested three types of stabilized layers strength requirement. CB1 is used in composite road base-unbound and cemented for traffic classes 6.0 to 30 x 10^6 ESA (equivalent standard axle). While CB2 and CS type of stabilized soil can be used for traffic classes as low as, 0.3 x 10^6 ESA for cemented road-base/ surface dressing type of road construction. The TRL (1993) pavement designs are based primarily on the results of full-scale experiments where all factors affecting performance have been accurately measured and their variability quantified and studies of the performance of as built existing road networks.

Table 3: Guide to the Type of Stabilization likely to be Effective (TRL 1993)

Type of Stabilization	**Soil properties**					
	More than 25% passing the 0.075 mm sieve			**Less than 25% passing the 0.075 mm sieve**		
	PI < 10	10 < PI < 20	PI > 20	PI < 6 PP** < 60	PI < 10	PI > 10
Portland cement	Yes	Yes	*	Yes	Yes	Yes
Lime	*	Yes	Yes	No	*	Yes
Lime- Pozzolan	Yes	*	No	Yes	Yes	*

*Marginally effective
** Plasticity product

Table 4: Properties of Cement and Lime-stabilized Material (TRL 1993)

Code	**Description**	**Unconfined compressive strength (MPa)**
CB1	Stabilized road-base	3.0 – 6.0
CB2	Stabilized road-base	1.5 – 3.0
CS	Stabilized sub-base	0.75 – 1.5

The departments of the US Army and Air force established criteria for improving the engineering properties of soils. This guideline is also applicable for the design roads and airfields by means of stabilization. The manual was written to prescribe the appropriate type or type of additive to be used with different soil types, procedures for determining a design treatment level for each type of additive, and recommended construction practices for incorporating the additive into the soil. US Army (1994) describes the selection of stabilizers candidate by referring to Figure 1. The soil gradation triangle is based upon the soil grain size characteristics. The triangle is divided into areas of soils with similar grain size and therefore the pulverization characteristics. According to US Army (1994), stabilized base and sub-base course materials must meet certain requirements of gradation and strength to qualify for reduced layer thickness design. Unconfined compressive strength requirements for bases and sub-bases treated with cement, lime, lime-fly ash and lime cement fly-ash are indicated in Table 5. A higher value of strength is required for base course of flexible pavement design compare with rigid pavement design.

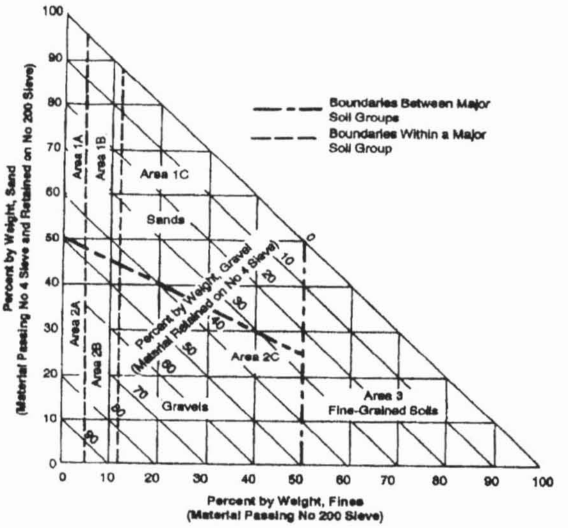

Fig. 1: Gradation Triangles for Aid in selecting Commercial Stabilizing Agents (after US Army 1994)

Table 5: Minimum Unconfined Compressive Strength for Cement, Lime, Lime-cement, and Lime-cement-Fly Ash Stabilized Soils (US Army 1994)

Stabilized Soil Layer	Minimum Unconfined Compressive Strength	
	Flexible pavement	Rigid pavement
Base course	750 psi (5.171MPa)	500 psi (3.447 MPa)
Sub base course or subgrade	250 psi (1.724 MPa)	200 psi (1.379)

* Unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime, lime fly ash, or lime-cement-fly ash stabilization

Both TRL (1993) and US Army (1994) further the guide for soil stabilization with method of preparing the samples, the curing processes depends on the types of binder selected, appropriate test to be conducted and other consideration as well. Table 6 shows a summary of the guidelines (PWD 1985; TRL 1993 and US Army 1994) highlighting the general information of the essential criteria and features of the guidelines. Based on the review of the literature indicates that all of the major guidelines (TRL (1993) and US Army (1994) insist on the importance of classifying the basic properties of soil, such as particle size distribution and plasticity index, for the selection of suitable binder. TRL (1993) specifies no limitation on soils PI. The US Army (1994) however limits all soils having PI more than 30% not to be used in soil stabilization process. US Army (1994) stated restriction on soil composition to be adapted in soil stabilization process. TRL (1993) limits soil gradation for use as base construction material for likely maximum strength achievement.

PWD (1985) specifies only cement. TRL (1993) specifies to three types of stabilizers, i.e. cement, lime, fly ash-lime. The US Army (1994) provides a wider selection of bituminous, Portland cement, lime and lime-cement-fly ash. All reviewed guidelines specify performance criteria to be attained by the stabilized soil either in term of PI, unconfined compression strength (UCS) or California bearing ratio (CBR). In addition the US Army (1994) also specifies performance in term of durability which consider the wet-dry cycle or freeze-thaw cycle, which is critical in the temperate climate region. The physical and engineering performance criteria depend on the types of structural road layer to be constructed, either as sub-grade, sub-base or base course.

PWD (1985) and TRL (1993) state the procedure of determination of percentage of stabilizer content by trial and error, of 2 to 8% of the weight of dry soil, for case of TRL (1993). The minimum percentage of stabilizer content that achieve the required strength will be used and adapted for the stabilization process. The US Army (1994) however provides of a minimum percentage of stabilizer content based on the soil classification, followed by ± 2%. Both the US Army (1994) and TRL (1993) describe the appropriate mixing procedure and test to be done in the laboratory, but not the PWD (1985). Both the TRL (1993) and US Army (1994) describe the methods of stabilized soil in detail for the ease of practitioners and engineers. Only TRL (1993) provides charts of catalogue for the design for road construction thickness. This simplicify the design process and provide ease of use for practitioners and engineers.

Table 6: Summary of Reviewed Guideline

Description	TRL (1993)	US Army (1994)	PWD (1985)
Choice of stabilizers	Yes	Yes	No
Stabilizers recommendation	Cement Lime	Bituminous Cement Lime Lime-cement-fly ash	Cement
Principle/method of stabilizers selection	Particle size distribution Plasticity Index Gradation (for base material only)	Particle size distribution Plasticity Index Gradation (restricted to passing #200 sieve)	Plasticity index
Suggestion of minimum percent-age of stabilizer	Trial and error (starting with 2 to 8%)	Yes Based on soil classification, ± 2%	No
Curing method	7 days moist curing 7 days soaking	7 days moist curing	Not mentioned
Experimental program	BS	ASTM	BS
Other requirement	-	Durability test	-
Specific region	Tropical and semi-tropical	General	Local (tropical)
Construction method	Yes	Yes	No
Other contents	□1 Description on control of shrinkage and reflection cracks for road construction. □2 Explanation on carbonation. □3 Quality control	Quality control	None

Selection of Guidelines

Based on the above information, it appears that TRL (1993) would be the best available guideline to be adopted for the Malaysian residual soils. In summary, this guideline is specially published to be adapted in tropical and semi-tropical climate region. Furthermore, the extensive guide and procedure in selecting the suitable binder for a given properties of soil is provided. The approach and simplicity of this guide makes it more applicable for local practice. Recommendations of chemical binders such as cement and lime, are abundant in the local market. For historical reasons, the TRL (1993) uses standards (i.e. British Standards) for the experimental program which is more readily applicable to local practice. The procedure preparing the stabilized soil samples is to include the requirement for the samples to be soaked for 7 days in water that indicated the minimum requirement. This would ideally suit the wet Malaysian climate. Additionally, TRL (1993) also provides with other requirement for soil stabilization such as the general guide for construction and quality control and equips with chart of catalogue for ease of design of the construction layer. The existing PWD (1985) guideline is too simplified and inadequate.

Conclusion

The main aim of this paper is to review and evaluate the suitability of the available guidelines for stabilizing residual soils of Malaysia to enable them to be used as structural layers (sub base and base) in road pavement design. Three available guidelines, namely the US Army (1994), TRL (1993) and PWD (1985) were examined with regard the prerequisite physical properties to select appropriate chemical stabilizers, the specific particle size distribution and gradation before soil stabilization process can be executed, curing method, and the minimum strength requirement for specified structural road layer (i.e. base or sub-base). Available local and regional researches on soil stabilization were also evaluated.

From the review, the TRL (1993) guideline had been found to be most suitable for tropical residual soils of Malaysia. TRL could also be readily adaptable to the local practice as the standards used (i.e. the British Standards) are commonly used for the testing of local soils.

References

BSI 1377. (1990). *Methods of Test for Soils for Civil Engineering Purposes*. London.: BSI.

BSI 1924. (1990). *Methods of Test for Soils for Civil Engineering Purposes*. London: BSI.

Faisal, A. (1990, April 16-20). Improvement of a Residual Soil. *Proceedings of the Tenth Souteast Asian Geotechnical Conference*. Taipei, Republic of China: pp. 1-8.

Faisal, A., Aminuddin, A. & Chew, K.C. (1992). Use of Rice Husk Ash to Enhance Lime Treatment of Soil. *Canadian Geotechnical Journal*, Vol 29, No 5: pp 843-852.

Huat, B.B.K., & Muhammad, M.M. (1997). *Effect of Lime Admixture on Geotechnical Properties of Tropical Residual Soil*. International Conference on Ground Improvement Technique, Macau.

Lee, S.T & Faisal, A. (2004). *Behaviour of Clayey Soils with Cement Additive*. Proceeding of the Malaysia Geotechnical Conference 2004. The Institution of Engineers Malaysia. Subang, Malaysia.

Mohamed, A.M.O. & Hosani, K.I. (2000). *Effects of Added Lime on the Soil Engineering Properties*. Geoengineering in Arid Lands. Balkema. Rotterdam, ISBN 90 5809 1600.

Noor, M.J.M.L. (1994). Durability and Strength Characteristic of Cement Stabilized Modified Melaka Series .*Journal of Islamic Academy of Science*.

Northmore, K.J., Culshaw, M.G., & Hobbs, P.R.N. (1992). *Engineering Geology of Tropical Red Clay soils. Project Background, Study Area and Sampling Sites*. British Geological Survey. Keyworth, Nottingham.

Public Works Institute Malaysia (IKRAM). (1996). *GEOGUIDES 1-5*. Tropical Weathered In-situ Materials.

Singh, H., & Huat, B.B.K. 2004. *Origin, Formation and Occurrence of Tropical Residual Soils*. In Huat et.al (ed). Tropical Residual Soil Engineering. Netherlands: Balkema.

Siswosoebrotho, B.I., Hossain, M., Asmidar Alias, & Huat, B.B.K. (2004). *Stabilization of Tropical Residual Soils*. In Huat et.al (ed) Tropical Residual Soil Engineering. Netherlands: Balkema.

Siswosoebrotho, B. I., Notodisuryo, P.W. & Moerdika O.V. (2003). Stabilisation of Lateritic Soil as Road Base Material. *2nd International Conference on Advances in Soft Soil Engineering and Technology*. Putrajaya, Malaysia.

Tan, B.K. 2004. *Country Case Study: Engineering Geology of Tropical Residual Soils in Malaysia*. In Huat et.al (ed) Tropical Residual Soil Engineering. Netherlands: Balkema.

Tappeiner, W.J. (2002). Foundation Materials for Flexible and Rigid Pavements. *Fifth Malaysian Road Conference*.

TRL (1993). *A Guide to the Design of Bitumen-Surfaced Roads in Tropical and Sub-Tropical Countries*. Overseas road note 31. 4th ed. Transport Road Research Laboratory, Crowthorne, London, United Kingdom.

US Army. (1994). *Soil Stabilization for Pavements*. Washington, DC: Joint Departments of the Army and Air Force, USA, TM 5-822-14/AFMAN 32-8010, Soil Stabilization for Pavements.

Vasudevan, J. & Muniandy, R. (2000). Overview of Subgrade Stabilizer for Road and Airport Pavements. *Proceedings of Research Seminar (GEGEU)*: pp. 67-73.

Wong, K.H. (2003). *Assessment of an Acrylic Polymer on the Properties of Soil-Cement*. Dissertation. UPM. Unpublished.

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