POTENTIAL OF USING CEMENT-RUBBER CHIPS AND CEMENT-SAND AS ADDITIVES IN STABILISED SOFT CLAY

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ABSTRACT

Soft clays fall short of the desired construction specifications due to their low yield stresses, high compressibility, low shear strength and low permeability. Such properties can be improved by incorporating a sustainable element in the existing variety of stabilisation techniques. Rubber chips derived from waste rubber tyres and sand were used as additives together with cement to stabilise clay. Unconfined compressive strength (UCS), bender element (BE), one-dimensional consolidation test; Scanning Electron Microscopy (SEM)) observations, Acid Neutralisation Capacity (ANC), Synthetic Precipitation Leaching Procedure (SPLP), X-Ray Fluorescence (XRF), X-ray Diffraction (XRD) and pH were done to examine the efficacy of rubber chips and sand stabilisation. Analysis was carried out to investigate the effects of 0, 2 and 4 % cement (for kaolin) while 0, 5 and 10 % cement (for soft clay) together with 0, 5, 10 and 15 % rubber chips or sand addition, as well as different curing periods up to two months. Furthermore, the stringently controlled laboratory tests were complemented with semi-controlled test and field tests on the optimum strength mixtures obtained from the laboratory test result (viz. for SC-10C-5R and SC-10C-15S). An analytical comparison was made of the philosophy of the three different environmental methods of the stabilised soil testing, i.e. laboratory-controlled, semi-controlled and field test. Overall, it was found that both rubber chips and sand improve the stiffness and unconfined compressive strength of the untreated soft clay. The waste tyre rubber chips used in the study developed only a slight increase (viz. 20 % for kaolin and 4 % for soft clay) in soil stiffness and therefore the economic potential of its use as a soil stabiliser is not so promising provided more cement, rubber chips and sand were added. ANC_9 of the stabilised clay were all lower than 1 meq/g, hence these stabilised clays do not necessarily be disposed at a segregated landfill. Also there was no leaching of heavy metals from the rubber chips was observed.

ABSTRAK

Tanah liat lembut menjadi kurang memuaskan untuk spesifikasi pembinaan yang dikehendaki disebabkan tekanan rintangan yang rendah, kebolehmampatan yang tinggi dan kebolehtelapan yang rendah. Kekurangan ini dapat diperbaiki dengan menggabungkan elemen lestari pada teknik-teknik penstabilan tanah yang sedia ada. Serpihan getah daripada tayar terpakai dan pasir digunapakai sebagai penambah bersama dengan simen untuk menstabilkan tanah liat lembut. Ujian kekuatan mampatan tak terkurung, elemen bender, ujian satu-dimensi pemadatan; pemerhatian pengimbasan elektron mikroskopi, ujian keupayaan peneutralan asid, prosedur pengurasan hujan tiruan, kaedah pendaflour sinar-X, kaedah pembelauan sinar-X dan ujian pH telah dijalankan untuk menguji keberkesanan penstabilan tanah dengan serpihan getah dan pasir. Analisis telah dijalankan untuk menyiasat kesan penambahan 0, 2 dan 4 % simen (untuk kaolin), manakala 0, 5 dan 10 % simen (untuk tanah liat lembut) bersama dengan 0, 5, 10 dan 15 % tambahan serpihan getah atau pasir; pada tempoh awet yang berbeza sehingga dua bulan. Tambahan pula, ujian makmal yang dikawal ketat, beserta dengan ujian separa terkawal dan ujian di tapak ke atas campuran yang mempunyai kekuatan optimum yang diperoleh daripada keputusan ujian makmal (yakni SC-10C-5R dan SC-10C-15S). Perbandingan analitikal dilakukan ke atas falsafah pengunaan tiga kaedah ujian penstabilan tanah yang berbeza dari segi persekitaran; iaitu ujian makmal-terkawal, ujian separa-terkawal dan ujian di tapak. Secara keseluruhan, ia dikenalpasti bahawa kedua-dua serpihan getah dan pasir dapat meningkatkan kekukuhan dan kekuatan mampatan tak terkurung pada tanah liat lembut. Serpihan getah dan pasir yang digunakan dalam kajian ini hanya memberi peningkatan yang kecil (yakni 20 % untuk kaolin dan 4 % untuk tanah liat lembut) ke atas sifat kekukuhan, dan oleh sebab itu, pengunaan bahan tersebut sebagai penambah kurang menjanjikan dari segi potensi ekonomi, hanya jikalau kandungan simen, serpihan getah dan pasir ditambah. ANC_9 bagi tanah yang distabilkan adalah lebih rendah daripada 1 meq/g. Oleh itu, tanah yang distabilkan ini tidak semestinya dibuang ke tapak pelupusan yang diasingkan. Tambahan pula, tidak terdapat kesan larut lesap logam berat daripada serpihan getah.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Project background

Improvement of soft soils using deep mixing technology goes way back to the mid 1960s in Sweden and Japan. This is now widely used in an increasing number of countries; i.e. in China (Shen, 1998; Ye *et al.*, 2006), United States (Croft, 1968; Andromolos *et al.*, 2000), Korea (Lee and Lee, 2002), Thailand (Miura *et al.*, 2001; Horpibulsuk *et al.*, 2005; Jaritngam and Swasdi, 2007; Jongpradist *et al.*, 2011), Malaysia (Kok and Kassim, 2001; Chan, 2006) and Singapore (Eriktius *et al.*, 2001; Tan *et al.*, 2002; Xiao and Low and Phoon, 2008). Today, soils are stabilised not only by using the traditional binders, namely cement and lime, but also increasing variety of binders including various industrial by-products. An important factor for the design of deep mixing is the effect of these binders on the strength achieved in the stabilised soils (Åhnberg, 2006). Thus, soil stabilisation by means of deep mixing is adopted to reduce compressibility and excessive settlement of weak soft soil (Larsson, 2005).

Soft clay occurs in places where the water contents are high, i.e. approaching that of liquid limit giving large potential for settlement with low shear strength. Thus, a stable state should be achieved to satisfy both the pre-construction and post-construction settlement to ensure stability in view of strength and deformations. Many ground improvement systems can be adopted to improve the soft clay conditions for example geo-drains to enhance the shear strength, embankment construction, pre-loading and surcharging to remove pore water over time, vibro-replacement stone columns improves the bearing capacity of soil and vacuum consolidation generates rapid consolidation and increased stability.

There are extensive deposits of very soft normally consolidated clay in both East and West Malaysia. Soft clay is found along the west coast of West Malaysia at Johor, Melaka, Port Klang, Penang and Alor Setar and the local depth may even exceed 40 m (Kok and Kassim, 2001). The Figures 1.1 and 1.2 below show the distribution of soft clays around South East Asia and West Malaysia.

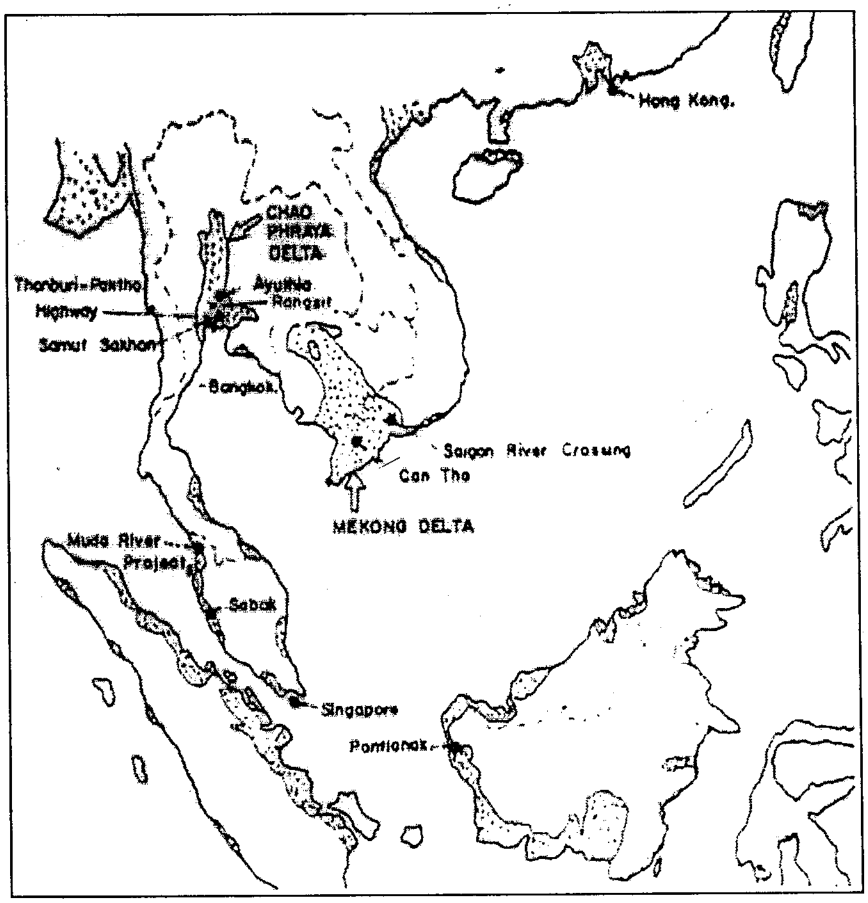

Figure 1.1: Marine clay in South East Asia (Malaysian Highway Authority, 1989).

As observed in Figures 1.1 and 1.2, the marine clay deposits occur near the coastal region. These marine clays were formed as estuarine deposits.

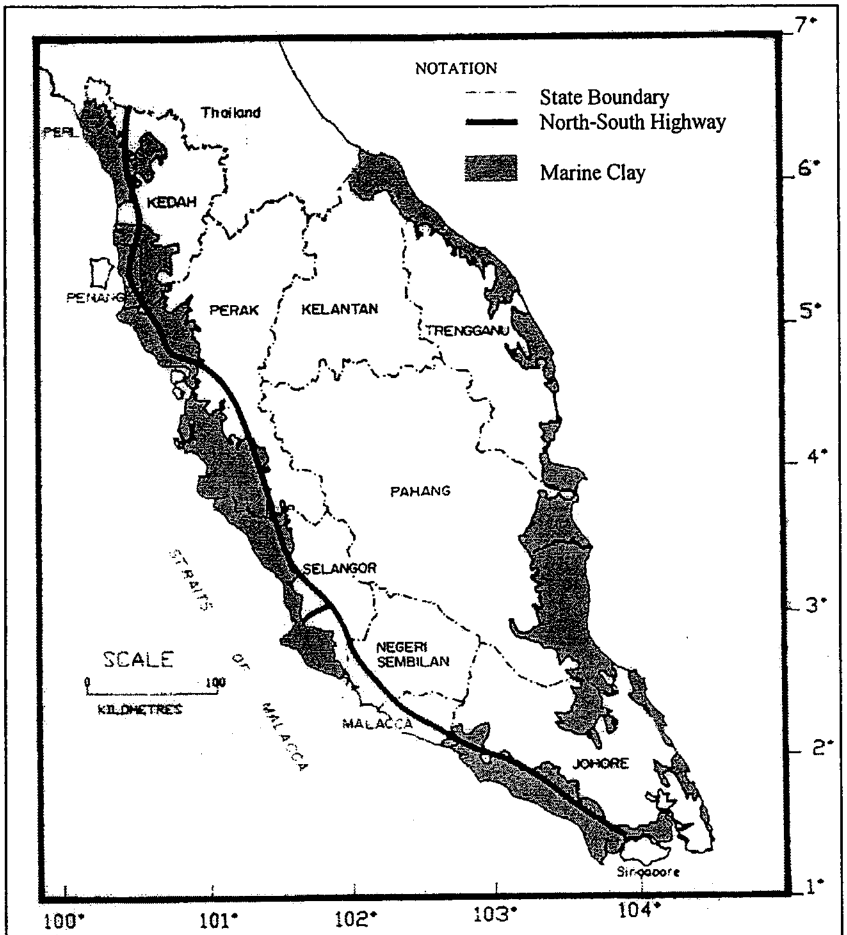

Figure 1.2: Marine clay in West Malaysia (Malaysia Highway Authority, 1989).

In this thesis, the word 'stabilisation' or 'stabilised' was used to refer to the addition of ordinary Portland cement, in dry or wet condition, into soft clay. Its purpose is to increase the strength and reduce the compressibility of the soft clay. Stabilisation is a process of fundamentally changing the physical properties of soft soils by adding binders or stabilisers, either in wet or dry conditions, to increase the strength and stiffness of the originally weak soils (Kyu and Song, 2002; Yilmaz and Degirmenci, 2009). The resistance to compression and consequently to strength development in such cemented state is a short term solution to the problem.

The principal mechanism of ground improvement is done by forming mechanical and chemical bonds between the soil particles. When the soil particles are bonded, it will be strengthened and become more stable physically and mechanically.

In this research, waste tyre chips and sand were used as additives in stabilising soft clay. This is to study the potential of using waste tyre chips and sand in a more beneficial way to recycle and reuse scrap wastes. Waste tyres pose a significant disposal problem because their composition makes them non-biodegradable, bulky and compaction-resistant (Cecich *et al.*, 1996). Civil engineering applications for scrap tyres include light-weight fill, retaining wall and bridge abutment, insulation layer and drainage applications (Moo-Young *et al.*, 2003). Anagnostopoulos (2006) have demonstrated the improvement in the engineering bahaviour of soft clay by mixing it with sand, treated with cement-acrylic resin, while Park (2008) used clean Nakdong river sand in fiber-reinforced cemented sand.

Since the early 1980s, research projects have been done to reuse tyres in different applications. McGown *et al.* (1987) suggested the use of lightweight compressible material behind the wall can reduce the wall stiffness and lateral earth pressure on the wall. Other researchers using compressible material for backfill (Ahmad, 1989; Cecich *et al.*, 1996; Tweedie *et al.*, 1998; Humprey and Tweedie, 2002) demonstrated the reduction in earth pressure exerted on walls and to control wall movement. While other past researches done using waste tyres, i.e. rubberised asphalt (Khosla and Trogdon, 1990; Khatib and Bayomy, 1999), as drainage material in landfill cover systems (Reddy and Marella, 2001), reuse of whole tyres as bank protection in port, coastal and river structure was done by Simm *et al.*, (2005), rubberised concrete (Siddique and Naik, 2004), sealing material in coastal waste disposal site (Mitarai *et al.*, 2006), scrap-tyre-rubber replacement for aggregate and filler in concrete (Ganjian *et al.*, 2008), light-weight composite rubberised bricks (Turgut and Yesilata, 2008).

In recent decades, the growth of automobile industry and the use of car as the main means of transport have increased the tyre production. This generates a massive stockpile of used tyres. Below is the recent estimation of tyres stockpiled (in million per year) in different countries:-

(a) United States

- 266 million in 1998 (Scrap Tire Management Council, 1998; U.S. Environmental Protection Agency, 1999)
- 300 million in 2000 (Rubber Manufacturers Association, 2000)
- 271.3 million in 2003 (Rubber Manufacturers Association, 2003)

- 128 million in 2007 (a reduction of 87 % since 1990) (Rubber Manufacturers Association, 2011)

(b) Canada

- 20 million in 1996 (European Tyre Recycling Association, 2003)
- 25 million in 1997 (European Tyre Recycling Association, 2003).
- 20 million in 2002 (Canadian Association of Tyre Recycling Agencies, 2002)

(c) Japan

- 102 million in 1996 (Scrap Tyre Management Council, 1996)
- 95 million in 1999 (European Tyre Recycling Association, 2003)
- 100 million in 2003 (Japan Automobile Tyre Manufacturers Association, 2003)

(d) France

- 55 million in 1996 (European Tyre Recycling Association, 2003)
- 10 million (Rubber Manufacturers Association, 2000)
- 30.4 million in 2004 (European Tyre Recycling Association, 2004)

(e) Germany

- 74 million in 1996 (European Tyre Recycling Association, 2003)
- 68.7 million in 2003 (European Tyre Recycling Association, 2003)

(f) England and Wales (UK)

- 23.4 million in 1996 (European Tyre Recycling Association, 2003)
- 14 million (Hird *et al.*, 2002)
- 30 million in 2003 (European Tyre Recycling Association, 2003)

(g) Italy

- 41 million in 1996 (European Tyre Recycling Association, 2003)
- 44.7 million in 2003 (European Tyre Recycling Association, 2003)

(h) Spain

- 12.6 million in 1996 (European Tyre Recycling Association, 2003)
- 34 million in 2003 (European Tyre Recycling Association, 2003)

(i) Australia – 17 million in 1996 (Scrap Tyre Management Council, 1996)

(j) Iran - 10 million (Ganjian *et al.*, 2008)

(k) Turkey - 9 million (Unlu, 2006)

(l) Malaysia - 5 million (Ghani *et al.*, 2003)

The United States was the biggest recycler in 2003 with about 3.3 million tonnes of tyres, followed by Japan with 855,000 tonnes of tyres. Germany is the largest recycler in Europe. For most countries, the major end-market of tyres is tyre-derived fuel, while civil engineering applications are growing faster. In countries such as Japan and Germany, tyre-derived fuel is the predominant application (European Tyre Recycling Association, 2003).

Since waste rubber is not easily biodegradable even after a long period of landfill treatment, material and energy recovery are alternatives to means of disposal (Segre and Joekes, 2000). On the other hand, a wide variety of waste materials have been suggested as additives to cement-based materials (Naik and Singh, 1991; Siddique and Naik, 2004). Innovative solutions to meet the challenge of tyre disposal problem have long been in development. The promising options are: (1) use of tyre in asphaltic concrete mixtures; (2) incineration of tyres for the production of steam and (3) reuse of ground tyre rubber in a number of plastic and rubber products (Paul, 1985). Recent research indicated that shredded tyres do not show any likelihood of being a hazardous waste material or of having adverse effects on groundwater quality (Edil and Bosscher, 1992).

The government in Malaysia encourages more research on various sustainable methods of handling the growing problem of wastes such as rubber waste through various funding and grants. For example, the Sustainable Urban Development Project in Kuching was funded by Danish Cooperation on Environment and Development (DANCED) to carry out a feasibility study to recommend a viable method of treating used tyres using economic instruments as part of the collection and recycling system (Danish International Development Assistance (Danida)-Malaysia Government, 2002).

Researchers studying the physical properties of sand mixed with shredded tyre mixes have concluded that this mix can be used in many engineering projects. Ahmed (1993) and Masad *et al.* (1996) used the triaxial test to study the shear strength properties of tyre chips and granulated rubber. Ahmed (1993) reported that adding tyre chips increases the shear strength of sand, with an increased angle of friction of up to 65° obtained for dense sand with 30 % tyre chips. He also found that rubber-sand with chip/mix ratios of 38% or less possesses excellent engineering properties, viz. easy to compact, low dry density, low compressibility, high strength and excellent drainage characteristics.

Masad *et al.* (1996) studied the effect of the addition of shredded tyres on Ottawa sand. It was concluded that the shredded tyres/ Ottawa sand mixes could be used as a lightweight fill material in highway embankments over weak or compressible soils.

Hence, this research focuses on testing stabilised clay addition with rubber chips, a kind of waste tyre, or sand for improved properties, namely strength and compressibility.

1.2 Problem statement

Soft clays are well known for their low strength, exhibit high compressibility including secondary consolidation, reduced strength, and low permeability and thus possesses characteristic of poor quality construction material. Due to its sedimentary process, both physical and engineering properties such as void ratio, water content, grain size distribution, compressibility, permeability and strength show significant variation. Thus in this study, cement stabilisation by addition of rubber chips or sand is used to improve the strength and deformation characteristics of these soft clays.

Since the last decades, some limitation have been imposed on construction, i.e. limits on space occupied, construction time frame, safety, growing environmental concerns and shortage of conventional natural materials. Soft clay deposits are problematic and challenging soils for construction and that is why it has been ignored for a long time in contrast with soils with higher quality with reduced technical difficulties and lower construction cost to improve the soil conditions. Alternative areas for construction also become more crucial as better quality soil is becoming difficult to obtain. Hence, it can be overcome by introducing and exploring the feasibility of an innovative mixing material, such as cement-rubber chips or cement-sand as a new construction technique. Consequently, this solves the problem of soft clay and recycling of the waste tyres that are stockpiled increasing by every year. Simultaneously reducing the amount of cement inclusion and reducing the usage of conventional materials for construction. The combined additives were intended to both reduce cost as well as promote a more environmental-friendly and sustainable stabilising agent.

Several minimum requirements are needed to adequately improve the engineering properties of the soft clays. Factors such as compressive strength, porosity (i.e. water or waste leakage through the particle grains), compression index (i.e. consolidation-settlement of foundations) should be taken into consideration (Bell, 1976; Kawasaki *et al.*, 1981).

Furthermore, considering the possible negative environmental effects of chemical addition to soils (i.e. cement and rubber chips), this study was conducted to explore the possibilities or capabilities of using cement-rubber chips or cement-sand as a stabilising agent to stabilised soft clays. Thus, study on the environmental effect was done by checking the leachability of cement and rubber chips to the surrounding clays. A comprehensive laboratory testing program was carried out in order to study the effect of inclusion of cement and/or sand on the physical, chemical and engineering behavior of soft clay.

1.3 Hypothesis and aim of study

The Author ***hypothesises*** the feasibility of reducing the environmental concern of the waste tyre stockpiles by using a product of it for the soft soil stabilisation. The potential of such rubber chips produced from waste tyres will marginally increase the desired strength and compressibility properties of soft soil with no adverse environmental effects.

The Author set out on this research with the ***aim*** of investigating and comparing the benefits of using cement-rubber chips and cement-sand for soft soil stabilisation.

1.4 Research objectives

In order to achieve the above aim, the following research objectives have to be carried out:

1. To establish the optimum proportion that gives the best strength characteristic for cement-rubber chips and cement-sand for kaolin and RECESS soft clay.
2. To establish a correlation of maximum shear modulus (G_o) and undrained shear strength (c_u); and further investigate the correlation of stiffness modulus (E_{50}) and maximum shear modulus (G_o) for stabilised clay.

3. To critically examine any possible relationship between the geotechnical and geo-environmental properties of stabilised clay.
4. To pragmatically compare the philosophy behind the stabilised soil testing in three different environments, viz. laboratory-controlled, semi-controlled and field test.

1.5 Scope of study

In this study, two different kinds of soft clays were used, namely a commercially processed Kaolin clay from Kaolin Malaysia Sdn. Bhd., Selangor, Malaysia and an in-situ soft clay obtained from the site of Research Centre for Soft Soils (RECESS) which is located in the Universiti Tun Hussein Onn Malaysia (UTHM) campus in Parit Raja, Batu Pahat, Johor, Malaysia. Figure 1.3 shows the location of the site and the university.

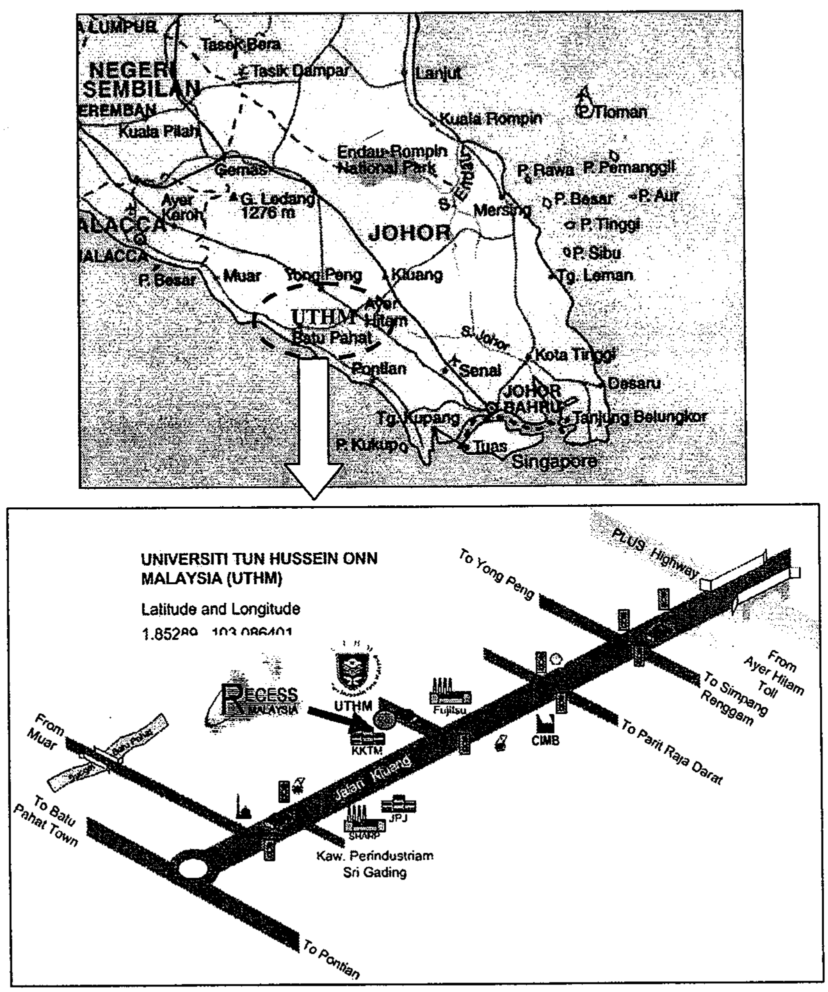

Figure 1.3: Location map of soil sampling site, RECESS and UTHM.

Kaolin was used due to its controlled properties and has been widely used by many previous researchers. Whereas the soft clay is a natural in-situ problematic clay chosen to study and apply practical methods to stabilise the soft soil condition in RECESS.

The whole laboratory research study was carried out at RECESS and in the UTHM environmental laboratory. The soil samples were collected from excavations at a depth of 1.5 to 2 m below the ground. The disturbed soil samples were brought to RECESS, UTHM for geotechnical properties testing. These soft clays were then added with cement-rubber chips or cement-sand.

Rubber chip is a waste product from used tyre and was obtained from Yong Fong Rubber Industries Sdn. Bhd., Klang, Malaysia. While sand was purchased from a local construction material distributor. Table 1.1 shows some description of materials used for the research.

Table 1.1: List of research materials, suppliers, location obtained and cost

Materials	**Suppliers**	**Location obtained**	**Cost**
Kaolin Grade: FM	Kaolin Malaysia Sdn. Bhd., Puchong, Selangor, Malaysia	Tapah, Perak	RM 50 (for 1 bag of 25 kg)
Soft clay	In-situ	RECESS site, Batu Pahat, Johor	-
Ordinary Portland cement Grade: Cem II/ B-M 32.5 N	Holcim Cement Malaysia Sdn. Bhd, Johor Bahru	Pasir Gudang, Johor Bahru	RM 18 (for 1 bag of 50 kg)
Rubber chips	Yong Fong Rubber Industries Sdn. Bhd., Port Klang, Selangor, Malaysia	Discarded used truck tyres	RM 0.90 per kg (for 1 bag of 25 kg)
Sand	Building material distributor in Batu Pahat, Johor	Minyak Beku, Batu Pahat, Johor	RM 46 (1 backhoe scoop)

All the laboratory tests were performed in accordance with the standard procedures described in BS 1377: 1990. The flow chart shown in Figure 1.4 describes how this study was conducted.

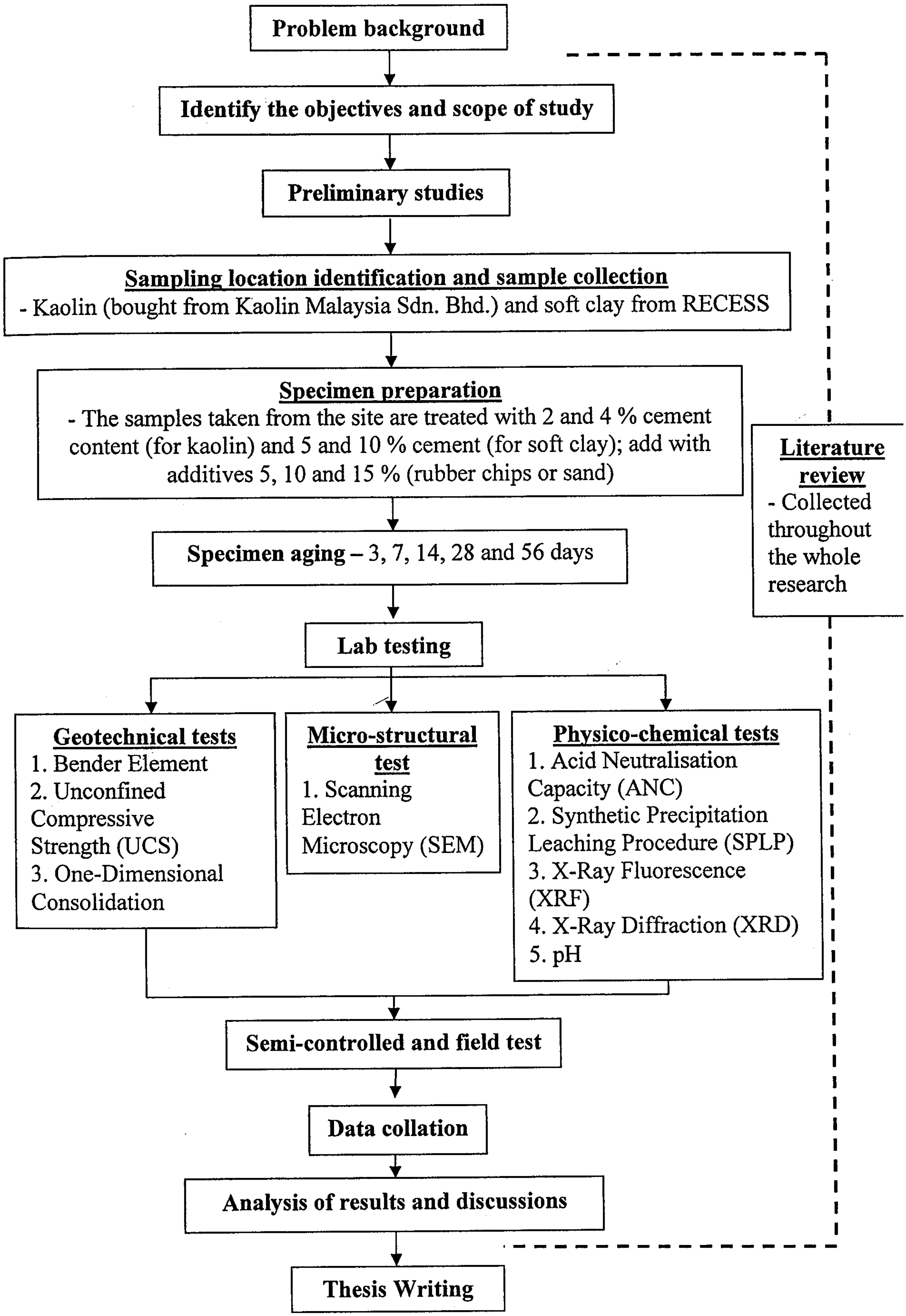

Figure 1.4: Methodology chart of the study.

1.6 Contributions to knowledge from the research

From this research, there are three main area of contribution, viz. the engineering application, the environmental impact and knowledge to researchers and engineers.

- Firstly, the engineering application by using this innovative method of stabilisation to reuse, recycle and reproduce a new kind of mixture to stabilise soft clay in Malaysia will not only help to innovate conventional method in construction and also to investigate the feasibility of rubber chips and sand being used as additives. As mentioned earlier, soft clay is a known problematic and weak soil that needs to be improved before any construction work can be proceed.
- Secondly, the geotechnical properties of compressibility and stiffness of the cement-rubber chips and cement-sand stabilised clay can be related to the chemical properties which are the pH, leachability and micro-structure of the stabilised clays. These three properties can inter-relate with one another and hence, the impact on the environment can be monitored. This new correlation and theory produced could be used in the preliminary design of structure on soft clay i.e. the relationship of yield stress and the stiffness of the stabilised clay can help to design a structure in the early stage of a construction site with consideration of the effect to the environment due to addition of cement, rubber chips and sand.
- Thirdly, this study is also an important guide and primary knowledge for many researchers, engineers (geotechnical and environmental) or to government agency such as Department of Environment Malaysia (under the Ministry of Natural Resources and Environment) and Public Works Department Malaysia. This is further explained in Chapter 6.

1.7 Outline of the thesis

There are a total of six chapters in this thesis. Chapter 1 gives a brief overall introduction of the entire research work done, the objectives, scope of study and the contributions to knowledge from the research.

Chapter 2 reviews critically the current knowledge relating to the research, which includes literature on theoretical and methodological contributions, stabilisation methods, laboratory testing, geotechnical and chemical properties of stabilised samples and the mixture as a composite.

Chapter 3 gives a step-by-step description of the experimental work in terms of sample preparation, test equipments, procedures, tools used and guidelines or standard used. Each technique is also carefully defined in this chapter to enable better communication of practical experience and knowledge.

In Chapter 4, the observations and results from a series of test are analysed, compared with the information from the past literature and discussed in detail. Correlations using different graph plots between the various parameters were established in the research are also presented and compared with that of other researchers on related work.

Chapter 5 gives a further critical discussion of the research findings and correlation. This will include critical summary of laboratory, semi-controlled and field test findings and some research outcomes.

Chapter 6 lists the main conclusions from this research work and emphasises the objectives of the study. Critical self evaluation and lessons learned throughout the research is presented. It also lays several recommendations for future work based on the Author's experience, in hope that further work will yield beneficial results.

Lastly, a complete list of References and Appendices are included. The references are listed in alphabetically order while the Appendices are in order of Chapters discussed.

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