Seminar on Soil Sub-grade Stabilization
Public Works Department (JKR) of Malaysia & Road Engineering Association of Malaysia
15 July 2008, Legend Hotel, Kuala Lumpur, Malaysia

Chemilink Stabilization Technologies for Roads and Airfields

Dr Wu Dong Qing & Tan Poi Cheong

Chemilink Technologies Group, Singapore

www.chemilink.com.sg

Abstract

Chemilink Stabilization Technologies and Products have, based on the latest scientific results and construction technologies, been developed and produced in this region for past about 15 years. Being one of the leaders in soil stabilization industry, Chemilink products have been proven in various large-scale projects in South East Asia. Soil stabilization with chemical admixtures is a practical method for soil improvement and this chemical stabilization is also a most important and effective approach for soil recycling to reduce the destruction of natural environment due to construction works. This paper introduces the scope, advantages and benefits of the Chemilink soil/stone stabilization in civil engineering, especially in roads, airfields and other shallow base foundations. Various types of chemical stabilizing agents are summarised and the application conditions of the major frequently used agents are analysed. Furthermore the paper concentrates on the working principle, application scope and advantages of Chemilink Stabilization Technologies. The basic design requirements and criteria of chemical stabilizing agents have been presented, and then the general installation process of chemical stabilization has briefly been introduced. As the case studies, several typical projects with using Chemilink stabilization products in this region, such as airport runway and taxiway widening in both Singapore and Malaysia, highway and city road in Brunei, and shipyard platform in Indonesia, have been analysed and discussed in order to evaluate the performances and the benefits by using the chemical stabilization.

Key Words: **Chemilink**, **Technologies**, **Soil**, **Stabilization**, **Roads**, **Airfields**

1. Introduction

Most construction activities have been done on, in or with soils. Due to lack of suitable construction sites or limitations in selecting locations with good soil conditions, the demanding on utilizing poor soils has increased. In order to utilize these poor soils for engineering purposes, soil improvement, mainly including compaction, consolidation, grouting, chemical and thermal stabilizations, reinforcement and so on, has been developed and applied for hundreds or thousands years (Mitchell and Katti, 1981) and it remains valid and effective even in the new century.

The chemical stabilization is an oldest and most commonly and widely used method among the soil improvement family. By mixing chemical admixtures with soils, the chemical stabilization can improve the properties of soils in order to improve or control the volume stability, the strength and stress-strain properties, permeability and durability. Soil stabilization with chemical admixtures or chemical stabilizing agents has mainly been used for the improvement of sub-grade and base courses materials for construction of shallow foundations, such as roads and airfields. Various roads and airfields are the typical types of the shallow base foundations, which will be mainly discussed as the background in this paper.

In 1937, a cement-stabilized soil base course of a 3.2km long road was successfully built up in California of USA. Since then, more and more cement-stabilized soils has been used for roads and airfields in the world. For example, the equivalent length (with double lanes) of cement-stabilized base and sub-base courses in North American during the period of 1960s is about 80,000km. For past more than sixty years, soil stabilization with various chemical admixtures has widely been used for roads and airfields construction all over the world. It is interesting to notice that soil stabilization with cementitious chemicals was used in South East Asia such as Brunei Darussalam in 1950s for road construction. The chemical stabilized soils have become the major pavement materials for the base and sub-base courses of roads, especially for highways and runways.

Previously the in-situ or natural soils and some of construction waste materials can be recycled to be used with simple mechanical treatments (such as compaction) for civil engineering purposes. As the loading and traffic frequency become higher and higher at current modernized time, the simply recycled soils or construction wastes cannot meet the higher requirements for many civil projects. More and better quarry materials are required, which will increase the destruction of natural environment. And more unsuitable in-situ soils or construction wastes have to be disposed to some places, which will further impact and pollute the environment.

Chemical stabilization can be used to improve most of soils and construction wastes to achieve higher technical standards. With the chemical stabilization, limited fresh quarry materials and less waste disposals are required. For roads and airfields constructions or other shallow base foundations, the recycling of construction materials can be summarised as follows:

1) **For new pavement construction**, the in-situ soils can be maximized to be used with the chemical stabilization as the upper layers of the sub-grade, sub-base and base courses for high-grade pavements; and the stabilised soils can even be used as the surface layer for the low-grade pavements.

2) **For pavement maintenance**, the existing quarry materials of the base course can be recycled with the chemical stabilization to form a new base course with equivalent or higher engineering properties.

3) **For construction wastes**, the suitable wastes after simple mechanical treatment, such as wasted concrete after crushing, can directly be stabilized either through the central mixing plant or at site. These stabilized “waste materials” can directly be used as the base and sub-base courses for both constructions of new pavement and existing pavement repairing.

Generally soil stabilization and recycling with various chemical-stabilizing agents have the following major advantages:

1) The chemical stabilized materials have higher strengths and the strengths can be adjusted to meet different design requirements.

2) The stabilized materials have good volume stability such as lower compressibility under different water and temperature conditions. The higher the strengths, the higher stability they have. Furthermore they have lower permeability and much longer durability if comparing with those of un-stabilized materials. The stabilized materials can form a semi-rigid platform so as to deliver a lot of engineering benefits.

3) Most soils or construction wastes can be stabilized with suitable chemical stabilizing agents. It will be very economical for those areas where lack of good construction materials.

4) Construction of chemical stabilization is simple and fast. With proper construction equipment and procedures, the quality of stabilized materials is reliable.

5) It has been proven all over the world that the chemical stabilization with correct design and quality construction is technically effective.

2. Chemical Stabilizing Agents

Academically, the commonly used soils and gravels for civil constructions belong to the range of soils. Soil stabilization with or without admixtures is a practical approach of soil improvement and the chemical stabilization with numerous chemical-stabilizing agents is the most commonly used method of the soil stabilization. In this chemical stabilization, one or more chemical compounds are added into soils for treatment through chemical reactions between these chemical additives and soils. The common chemical reactions normally include cementation, hydration, ion exchange, flocculation, precipitation polymerisation, oxidation and carbonation (Fang, 1990). The chemical stabilization in which the cementation is the major or one of the major chemical reactions could be a cheapest and easiest method in engineering practice.

There are numerous chemicals or chemical stabilizing agents used for various soil stabilization purposes. The most widely used agents are cement, the modified cementitious chemicals, lime, bitumen, resin, the wastes like fly-ash from power plants and others, such as salts and acids. The selection and application of stabilizing agents may be subject to constraints with respect to local conditions such as economy, environment, soil conditions and engineering experience. Cement stabilization is the most common method while lime stabilization is the oldest known method of chemical stabilization in the world. However the stabilizations with modified cementitious or polymer bases chemical stabilizing agents, are sometimes more technically and commercially effective and durable in this region.

Cement. Various types of cement have been used for the purpose of soil stabilization and the Portland cement, which is the finely powdered hydraulic cement, could be most widely used cement among the cement family. For granular soils, cement can increase strengths of the stabilized soils and decrease the permeability mainly through cementation. Practically, the cement stabilization is effective for most of granular soils but ineffective for cohesive soils because of high dosage, difficulties in construction especially when the soil is wet, and excessive shrinkage properties. Ideal application of cement stabilization is applied with a well-graded soil containing gravel, coarse sand and fine sand with or without small amounts of silt or clay.

Mainly based on the considerations of the cost effectiveness and construction workability of soil-cement stabilization, the applicable range of soils to be used for cement stabilization is limited in the relevant design codes of many countries. The limited applicable range of the soil is generally related to the following properties:

1) Liquid Limit: <40% - China, France and US (AASHTO); <45% - UK;

2) Plastic Index: <20% - China, France and US; <18% - UK;

3) Coefficient of Uniformity: >5~10 - China, France and UK; and

4) Grain Size Distribution. The typical recommended ranges of the applicable soils from some countries (Sai, 1998) are selected as examples in Table 1.

Table 1. Applicable Grain Size Range of the Soils to Be Stabilized by Cement

(% of mass passing the following sieve size in mm)

Country	**75**	**40**	**20**	**5**	**2.5**	**1**	**0.5**	**0.15**	**0.075**	**0.002**
Canada	100	-	-	> 50	-	-	> 15	-	< 50	< 30
France	-	100	75 ~ 100	30 ~ 50	-	10 ~ 40	-	0 ~ 10	-	-
Japan	100	95 ~ 100	50 ~ 100	-	20 ~ 60	-	-	-	0 ~ 15	-
US	100	-	-	> 50	-	-	> 15	-	< 50	-
Country	**50**	**40**	**37.5**	**20**	**5**	**4.75**	**0.6/0.5**	**0.15**	**0.075**	**0.002**
China	-	100	-	-		50 ~ 100	15 ~ 100	-	0 ~ 50	0 ~ 30
UK (CBM3)	100	-	95 ~ 100	45 ~ 80	25 ~ 50	-	8 ~ 30	0 ~ 8	-	-

It should be noted that the recommendations shown in Table 1 are almost for the base course in the higher grade roads and that the requirements on the soil properties as mentioned above might have a little bit differences between base and sub-base courses and between different grade roads or shallow base foundations.

Cement stabilization may be a cheapest and simplest method among the chemical stabilization. There are sufficient experience and established technical data for cement stabilization in the world. The major disadvantages of this method are the application range limited to the contain types of soils and the shrinkage cracking. The wet soils will also cause difficulties during the mixing and compaction.

Lime. It is another commonly used additive for soil stabilization or for improving soil properties. Lime stabilization is suitable to the clayey soils with advantages like reducing the plasticity index, decreasing the clay content substantially, accelerating the breaking up of clay clods during mixing, drying out the water from wet soils, reducing the shrinkage and swelling, and increasing strengths of the stabilized soils after curing. The increasing process and the increment of strengths of lime-soil are much lower by comparing with those of cement stabilization. The more important disadvantage is the durability of lime stabilization in this tropic region.

Thus the lime stabilization can independently be used for sub-grade and sub-base or other pavement layers with lower bearing capacity requirements. It is frequently used as a preparative measure for subsequent treatment with other chemical stabilization, where this measure looks very difficult in this region because of the local conditions such as frequent raining during the interval of lime and the other chemical stabilizations. The lime stabilization can also function as an additional improving measure in granular soil stabilization.

Other Agents. Bituminous stabilization with bituminous materials (organic type of materials) such as Bitumen incorporated with soils or soil-aggregate mixture can be used to construct base courses, sometimes to form surface courses. The key function of bitumen is to waterproof soils to be stabilized as a mean of maintaining them at low moisture contents and thus remaining the stabilized soils at high bearing capacities. This type of stabilization may be affected by the cost and environment requirements.

Fly-ash is a by-product of power plants fuelled by pulverized coal. About 70% of its chemical composition is alumina and silica. It reacts with Lime in the presence of water, setting and hardening similarly to hydraulic binder (Fang, 1990). Fly-ash is often used with Lime to stabilize the soils. Furthermore the soil stabilization with several stabilizing agents of Cement, Lime and Fly-ash has been proven to be effective and economical in many countries, especially for highway construction in China. For passed multi-ten years, the combination of chemical stabilizations with two or more different stabilizing agents has shown superior effectiveness and wider applicable range, if comparing with the soil stabilization only with one stabilizing agent.

It is the reasonable and appropriate criteria of selecting the suitable stabilizing agents that any good stabilizing agent must be able to overcome the both general engineering difficulties and localized construction troubles. The universal stabilizing agents do not exist. There are some specific difficult conditions for road construction in this region, such as rainy weather conditions, low-lying land, high water table, swampy areas, wet soils and poor or trouble soils. More attentions and efforts have to be paid to these localized difficulties.

As discussed above, the conventional stabilizing agents such as Cement, Lime, Fly-ash and Bitumen have their advantages, disadvantages and limitations in application. Especially and specifically for local conditions in this tropical region, the modified and/or combined chemical stabilizing agents are required in order to effectively overcome the local difficulties.

Chemilink Stabilizing Agents. In order to effectively overcome the construction difficulties in this tropical region and to enlarge the application ranges of chemical stabilization, Chemilink SS-108 Soil Stabilizing Agent and Chemilink SS-111 Stone Stabilizing Agent were especially invented and developed. The products have been tried, verified and widely applied in South East Countries and China Since 1994.

Chemilink stabilizing series products are one of few chemical stabilizing agents in powder form that were widely used in this region. Chemilink Stabilizing Agents were specially developed for tropical construction conditions and their effectiveness as well as durability especially for Chemilink SS-108 soil stabilization has been proven in this region mainly in public roads for passed about years.

Chemilink SS-108 is a polymer modified cementitious chemical agent in fine powder form and designed for soil stabilization especially for sandy and clayey soils under tropical conditions and environment. The basic functions of Chemilink Stabilizing Agents can be summarised as follows:

- To improve and maintain the soaking strengths of soils and thereby improve the bearing capacity of sub-grade or stabilized soils through binding particles of soils and immediate as well as long-term chemical reactions with soils;

- To form a semi-solid platform with a certain tensile strength and thereby reduce total settlements and minimise differential settlements;

- To decrease the compressibility and permeability of the stabilised soils and to provide anti-cracking effect, and thereby to reduce or eliminate the potential damages due to swelling, shrinkage and seepage; and

- To improve the long-term performance of soils.

From these basic functions, the advantages and the resulted benefits by using Chemilink Stabilization have been drawn and presented by Yong and Wu (1999).

In addition to the basic functions as mentioned above, Chemilink SS-108 Soil Stabilizing Sub-Series Products have some special functions, such as quick chemical reaction for increasing the initial strengths of soil-chemical mixture; breaking up of clay clods during the mixing for enlarging their application range to soils; quickly drying out the water from wet soils for better compaction of wet soils and pre-expansion for preventing the shrinkage cracking.

Chemilink SS-111 Stone Stabilizing Agent is a modified polymer-cementitious base chemical in powder form for chemical stabilization of crusher run stones and gravel. With the most of technical functions of Chemilink SS-108, Chemilink SS-111 was specially designed to have three additional functions: to improve the flexibility, to increase strengths to a moderate level and to have anti-shrinkage cracking capacity. The polymer compounds inside of the chemical not only improve the elastic property substantially but also prevent the water in the mixture from losing.

Stabilizing Agents in Liquid Form There are too many soil-stabilizing agents in liquid form with various chemical bases in the markets. In addition to some special cases at specific environmental conditions, the agents in liquid form are generally produced for non-bearing purposes such as dust control and assistance in improving compaction degree. A chemical-base agent is often for a specific soil type. Due to the limited solid content in these agents in liquid form, none of them has good effects in increasing the soaking compressive strength of stabilized soils. Because there is a very high percentage of water inside of the said agent, to add the agent will always make the compaction more difficult when the soils to be stabilized are not dry enough. Furthermore the durability of the soils stabilized by the agents in liquid form is not reliable in the tropic region. Based on the practical experience from this tropic region and China, it could hardly find a successful engineering example in which an agent in liquid form has been used to completely and independently stabilize the soils for bearing loading purposes.

3. Designs and Applications of Chemical Stabilization

The design of roads generally includes architectural design, pavement structural design, the thickness design and the materials design. The later three designs are normally called as the pavement design based on three design models: empirical design (such as AASHTO, US), theoretical-empirical design (such as Shell code) and theoretical (mechanical) computation (such as China code). The material properties of each pavement layer will be directly or indirectly used in the pavement design and computation.

The dosage design is the major design content of the materials design for those layers with chemical stabilization. A series of laboratory tests with or without site trails are conducted to verify and confirm the dosage design. It should be noted that there are some reductions between the testing results in laboratory and from site. According to Chemilink soil stabilization for sandy and silty soils for past years, the reduced coefficient for UCS (unconfined compressive strength) as well as CBR at site (4-7 days) comparing with laboratory results is about 0.7 with the in-situ method and about 0.9 with the central mixing method. The difference will be significantly reduced while time passes but this difference will existing especially for UCS values mainly due to the disturbances of sampling at site.

Conventionally, one of the key dosage design criteria of stabilized soils is the achieved compressive strength in terms of CBR value and/or UCS. Normally for fine-grained soils, both CBR and UCS are used and CBR is more frequently used, while for coarse-grained soils CBR testing data may not be accurate. In this region, a simple and conventional principle, i.e. that CBR is not less than 30% for sub-base courses and 80% to 90% for base courses, is often applied for soil stabilization. In the General Specification for Pavement Stabilization issued by Brunei government (CPRU, 1999), the design requirements on UCS together with CBR values were specified (Table 2).

Currently in the world, the most commonly used design criteria for the chemical stabilization basically include two parts. One is the requirement on strengths, where UCS (7 days) is frequently used as the index. Another is the requirement on durability, where the durability indexes can be determined in the both tests of dry-wet recycling and cold-hot recycling. Most frequently, if the UCS of the chemical stabilized soils is higher (such as more than 1.7 to 4.5 MPa), the durability requirement can automatically be meet.

According to the relevant highway specifications in some countries that are experienced in chemical stabilization (Sai, 1998), the design requirements on UCS for cement-stabilized soils were summarized in Table 2. It should be noted that many types of chemical stabilization are often categorized into the cement stabilization, if the cement content is more than about 30% in these chemical stabilizing agents.

Table 2. Design Requirements on UCS for Cement Stabilized Soils

Country	Curing Time (day)	Curing Condition	UCS (MPa)	Road Grade / Function	Remarks
Australia	7	-	3.0	-	
Brunei	7	Wet-air: 6d Soaking: 1d	2.0 0.7 ~ 1.5	All/Base All/Sub-base	Or per design
Canada	7	Soaking	2.1	-	
China	7	Wet-air: 6d Soaking: 1d	3.0 ~4.0 2.0 ~ 3.0 2.0 1.5	High/Base Low/Base High/Sub-base Low/Sub-base	UCS=5~6 for high road grade with more or very heavy loading
Ex-SU	28	Soaking	7.5 6.0 4.0 2.0	Highest/Base High/Base Low/Base All/Sub-base	
France	7	-	4.0 ~5.0 1.5	M./Base M./Sub-base	M. – Medium
Germany	-	-	3.0 ~ 10.0	-	
Japan	7	Wet-air: 6d Soaking: 1d	3.0 ~ 4.0 2.5 1.5 ~ 2.0 0.7 ~ 1.3	Highest/Base High/base Low/base All/Sub-base	
New Zealand	7	-	1.72	-	
Spain	7	-	6.0 2.5	All/Base All/Sub-base	
UK	7	-	4.5 ~ 15.5	-	
California Washington - US	7	Wet-air -	5.2 5.8	- -	

It can generally be summarized that the more commonly used design requirement on the UCS value (7 days, cylinder sample testing) is 1 to 2 MPa for sub-base courses and 2 to 4 MPa for base courses, where for lower grade or rural roads, the smaller values should be selected. Furthermore, based on the author's experience and numerous in-situ and in-house testing data about Chemilink (a series of modified cementitious and/or polymer stabilizing agents) soil stabilization for past 15 years in this region, the CBR values are always much higher than 30% for the sub-base and 90% for the base when the UCS values meet these international design requirements.

The resilient modulus of the stabilized materials is another important design parameter especially for airfield runway and taxiways as well as some of the higher grade road base course. It is a comprehensive testing data related to the strengths, rigidity, and capacities of dynamic rebound. The resilient modulus is currently used to determine the thickness of the pavement layers, if various elastic theoretical computation models are used rather than the empirical models. It will be very useful as a higher design requirement for chemical stabilization and for its quality control. It is very interesting to notice that the concept of requirement on resilient modulus has been proposed in Brunei stabilization specification (CPRU, 1999), where the resilient modulus is required to be not lower than 5,000MPa for the cement plus bitumen stabilization.

It should be noted that the over-design in chemical dosage of stabilizing agent will commercially cause cost ineffective and could technically cause the reversed effects. For examples, if the dosage of Cement is too high (e.g. more than 6% to 10%) in normal conditions, more and more shrinkage cracks will occur over a quite long period, while the higher usage of Chemilink SS-111 in stone/crusher run stabilization may cause the pre-expansion too high so that the gravel may have a going-up effect because the compressibility of the well-compacted gravel is lower. Furthermore more attentions should be paid on the issues caused by the construction joints of chemical stabilization.

There are two major construction methods of the chemical stabilization for roads. One is the in-situ mixing/recycling and another is the central plant mixing.

<u>In-Situ Mixing/Recycling</u> The construction procedure of this method normally includes three main steps:

* **Spreading** (of the chemical agent on the soil layer to be stabilized);
* **Mixing** (the agent with soils to be stabilized); and
* **Compaction** (of the mixture).

With the different construction machines, the in-situ mixing methods can be classified into two ways:

* **Simple Way**. It includes Manual Spreading, Mixing with Simple Machines (such as Rotorvator or other agricultural mixing machines) and compaction (Photo. 1). With this simple way, the stabilized depth is only up to about 200mm and the construction speed is lower. The mixing efficiency and quality are lower, and a higher dosage of the stabilizing agent is required. Currently this way is still widely used for small or rural roads in this region such as in Malaysia and Indonesia.

* **Advanced Way**. A mechanical spreading is done by the Spreader specially made with or without computer control, an advanced self-running mixer called Stabilizer or Recycler be used for the mixing, and the compaction is conducted by rollers with higher capacity (Photo. 1). The advanced way is much better the simple way almost in all respects. The stabilized depth could be up to 400mm or more and the mixing quality is close that handy mixing in laboratory. The higher construction speed is another advantage, where a construction speed up to 8,000m^2 per day is achievable according previous experiences.

Central Plant Mixing. The materials to be stabilized are mixed together with the agents in the central mixing plant and then the well-mixed mixture is transported to the site for laying and compaction. By using this method, the mixing quality and efficiency are very good and it also enables the construction speed much higher and potential. The available capacity of the compaction machinery often controls the thickness of the stabilized layer. The transportation distance, transported volume and the chemical setting time may affect the construction speed, quality of the mixture and the cost too. Furthermore it will have a double-handling issue if recycling the in-situ soils. If the application conditions are not suitable, this method may be costly and its impact to public traffic could be significant. For the information, a local contractor may try this method for some portion of a newly awarded road project soon.

Mechanical Spreading

Mixing by Stabilizer

Compaction 1

a. Advanced Way

Manual Spreading

Mixing by Rotorvator

Compaction 2

b. Simple Way

Photo. 1. In-Situ Mixing/Recycling Method

4. Case Studies of Chemilink Stabilization/Recycling

Since 1994, Chemilink stabilization has gradually been applied and currently it has become a popular and conventional method for public roads, airfield runways and taxiways as well as some shallow base foundations in Asia especially in South East Asia (Wu et. al, 2008).

Only several typical projects of Chemilink stabilization are selected and introduced here due to the limited length of the paper. Furthermore their performances and benefits by using Chemilink stabilization have also been presented and discussed as follows.

Brunei First Trial Project of chemical stabilization with Cement, Polyroad and Chemilink SS-108 was carry out in 1995. The crusher runs layers were stabilized by Cement and Polyroad as the base course. The Chemilink SS-108 soil stabilization for the sub-base and base courses is situated at a widened section of swampy and low-rural road in Tutong District (Yong & Wu, 1999). The CBR value of the in-situ soils before Chemilink stabilization is less than 2%. The in-situ sandy clay was stabilized with 3% (by dry weight of the soil) of Chemilink SS-108 Soil Stabilizing Agent to form a 200mm thick sub-base course. In order to increase the elevation of the road surface, the surrounding sandy silt was backfilled on the stabilized sub-base course. The backfilled silty soils with a thickness of 200mm was stabilized by Chemilink SS-108 as the base course. The average in-situ CBR value after four soaking/wet days is about 100%. For monitoring the performance and behaviour of the stabilised pavement, no asphalt concrete surface layer was applied and the base course functioning as a road surface was opened to public traffic.

Four months later the in-situ and laboratory tests were conducted and a set of testing data is given in Table 2 (Yong & Wu, 1999). Some stabilized samples are shown in Photo. 2-a.

Table 3. Average Testing Data for Chemilink Trial Project

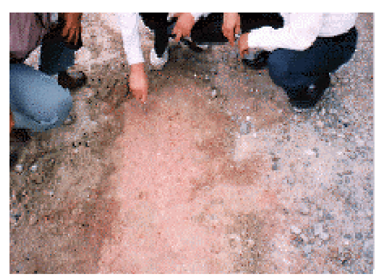
M/P Test		Plate Loading Test			In-Situ CBR Test (%)	UCS Test (MPa)
No. of Blows	Depth of Penetration (mm)	Peak Pressure (MPa)	Settlement Recorded (mm)	Modulus Of S/R, K (MPa/m)		
300	6.3	1.72	7.44	522.62 (Max. 812.48)	100 (Max. 129)	2.04 (Max. 2.67)

1) M/P Test - Dynamic Mackintosh Probe Test
2) Modulus of S/R - The Modulus of Sub-grade Reaction
3) UCS Test - Unconfined Compressive Strength Test

From the completion of this trial, the following-up site visit was conducted at least once a year. Based on the site observations for past 7 years, the conclusions on the performances of chemical stabilization look very encouraging and attractive. The structure of the stabilized pavement is still sound even after 7 years. Comparing with the multi-ten years old road on one side, neither significant total settlements nor obvious differential settlements can be observed (Photo. 2-b) for the new stabilized road on another side. And the stabilized surface is solid and has no cracks after so many years (Photo. 2-c).

a) Stabilized Samples

b) Stabilized Road (on the left) vs. Old Road



c) Stabilized Surface after Years

Photo. 2. The 1st Chemilink Trial Project in Brunei

Malaysia Trial Project is located at Alor Gajah of Melaka and was organised by the federal Public Works Department (PWD) and its research institute (IKRAM). The lower layer of the in-situ clayey soils were stabilized as the sub-base by 3% of Chemilink SS-108 after removing the upper layer of the in-situ clayey soils. Immediately after completion of the sub-base, the removed soils were filled back and stabilized as the base course by 5.5% of Chemilink SS-108. The higher dosages of the chemical stabilizing agent for the both sub-base and base courses were used because the clayey content of the in-situ soils was around 50% to 75% and the Simple Way of In-Situ Mixing Method was used for this project.

The completed road without surface layer was kept in soaking or wet conditions continuously for 4 days and then CBR tests were conducted. The CBR tests were also conducted at the 3rd and 9th months respectively after the completion of the stabilized road. The original in-situ soil without chemical treatment was about 15% and the 4-d soaking CBR after Chemilink stabilization was 110% and above. The followed tests showed that CBR value were consistent with a little bit increments as time passing. Photo. 3 show the road stabilized by Chemilink SS-108 after 1 year.

a) Road Surface

b) Stabilized Road

Photo. 3. Malaysia Trial Project

Shipyard Project in Indonesia required stabilizing the existing ground up to 300mm deep in order to form the sub-base course for the upper layer of reinforced concrete slabs. The in-situ soils were the wet sandy and silty soils with some gravels and stone chips. Before Chemilink stabilization, the contractor did try to use cement, lime and other chemical stabilizing agents to stabilize the soils but the results were not satisfactory to meet the design requirement of CBR not less than 60%.

The stabilizer was used but the spreading was done by manual. The construction approach looks between the Simple Way and the Advanced Way of the In-Situ Mixing Method. Due to no many disturbances to this sizable construction site, the construction rate was up to 8,000m² per day per team. Additional 0.5% of Chemilink SS-108 was added to the original dosage design of 2.0% with consideration of manually spreading. The construction process with manually spreading, mechanically mixing by the Stabilizer and compaction is shown in Photo. 4.

a) Manually Spreading and Mechanically Mixing b) Compaction

Photo. 4. Chemilink Stabilization in Progress for a Shipyard in Indonesia

The average CBR value of 75% was achieved few days later after the construction completion and there have been no complains to the chemical stabilized sub-base for past 5 years.

<u>**Junjungan Road Project**</u> is the first rehabilitation project using in-situ chemical stabilization and pavement recycling method in Brunei (Yong & Hussien, 2001). This road was constructed in the early 1970s, which is sitting on the low and swampy land with the poor sub-soils including peat and organic clay, and with high water table during the rainy season. During the past about 30 years, the pavement was deteriorating rapidly and certain sections were prone to flooding due to the settlements caused by the

poor sub-soils. In addition to rehabilitation of the 6m wide existing pavement with the cement stabilized base course and new asphalt concrete, the road was widen to one side with 5m width, where 3m is carriageway and 2m is the paved road shoulder (Fig. 1).

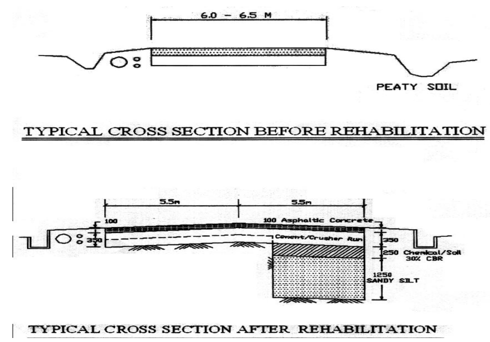


Fig. 1. Typical Cross Sections before and after Stabilization
(after Yong & Hussien, 2001)

The key challenge in design and construction of this road is how to prevent differential settlements between the existing pavement and the widening portion sitting on a fresh foundation with peaty sub-soils. In the widening portion, the sandy silt with 1.5m thick was backfilled and 2.5% of Chemilink SS-108 was used to stabilize the top layer (250mm) of the backfilled sandy silt. Furthermore 4.0% of cement was used to stabilize the crusher run stone base layer with 350mm thick. According to the report (Yong & Hussien, 2001), the designed parameters are CBR >30% and UCS (7 days) >1.0MPa for Chemilink stabilized sub-base and UCS (7 days) >4.0MPa for cement stabilized base respectively.

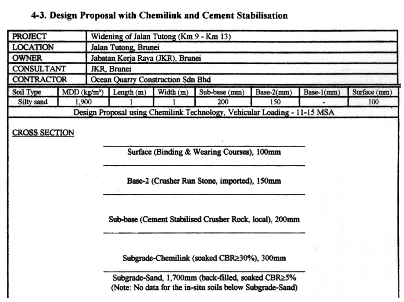
The costs of the chemical stabilization with cement and Chemilink SS-108 have been analysed in details and compared with those of conventional methods (Yong & Hussien, 2001). The conclusions were that the cost of Chemilink stabilised sub-base was almost equivalent to that of the conventional unbound sub-base and that the cost of cement stabilized base was much lower than that of conventional method if the existing stones can be recycled. However the benefits and advantages derived from the chemical stabilized soils/stones are far more superior to those of conventional methods, which will be discussed later in this paper.

The project was started in December 1996 and completed in June 1998. The road has been opened to the public with excellent running conditions for more than 4 years and no major defects or pavement failure been detected (Photo. 5). It is very interesting to notice that though there are a lot of surface cracks along the cement stabilization construction joints that are about 1m away from the boundary between the both new and old pavement; there are no any signs to indicate the differential settlements between the new pavement and old one. Furthermore the total settlement of the new road looks quite limited.

Photo. 5. Junjungan Road (after more than 4 years)

Widening of Jalan Tutong, Phase II in Brunei is a project located at a poor sub-soils foundation connecting to the road of the same project of Phase I, where the environment and soils conditions for both project at different phases are very similar. The original pavement design is the same as that of the Phase I. In the design, 2m thick of sandy soils was backfilled to replace the weak soils of the existing sub-grade. The sub-base and base courses were constructed with 3 layers of a Geogrid system with 300mm thick of local crusher rock and with a layer of 250mm thick imported crusher run stone. 100mm of asphalt concrete in 2 layers was finally laid as the binding and wearing courses. However within a relative short time from the completion of the Project - Phase I, a lot of differential settlements gradually occurred and became more significant. The functions of the geogrid system were suspected.

A modified pavement design for the Phase II was thus proposed after this project was started. In the modified design, the geogrid system was removed and the chemical stabilization was introduced, where the top layer (300mm) of the sub-grade was stabilised by 2.5% of Chemilink SS-108 and the 300mm thick sub-base was stabilized by cement. A layer of 150mm thick imported crusher run stone was proposed to be the base course and the anti-cracking function from the cement stabilization is an additional advantage of this base layer. 100mm thick asphalt concrete was designed as the road surface (Fig. 2). The cost of the modified design is cheaper than that the original design.



4-3. Design Proposal with Chemilink and Cement Stabilisation

PROJECT	Widening of Jalan Tutong (Km 9 - Km 13)
LOCATION	Jalan Tutong, Brunei
OWNER	Jabatan Kerja Raya (JKR), Brunei
CONSULTANT	JKR, Brunei
CONTRACTOR	Ocean Quarry Construction Sdn Bhd

Soil Type	MDD (kg/m³)	Length (m)	Width (m)	Sub-base (mm)	Base-2(mm)	Base-1(mm)	Surface (mm)
Silty sand	1,900	1	1	200	150	-	100

Design Proposal using Chemilink Technology, Vehicular Loading - 11-15 MSA

CROSS SECTION

Surface (Binding & Wearing Courses), 100mm

Base-2 (Crusher Run Stone, imported), 150mm

Sub-base (Cement Stabilised Crusher Rock, local), 200mm

Subgrade-Chemilink (soaked CBR≥30%), 300mm

Subgrade-Sand, 1,700mm (back-filled, soaked CBR≥5%
(Note: No data for the in-situ soils below Subgrade-Sand)

Fig. 2. Typical Cross Section of Widening of Jalan Tutong, Phase II

The road using chemical stabilization has been opened to the public since 1998 and no any major defects and failures are found so far (Photo. 6). Comparing with the performances of the Project – Phase I with the geogrid system, there are no observable differential settlements occurring in the Project – Phase II constructed with chemical stabilization.

Photo. 6. Jalan Tutong Widening, Phase II (4 years later)

Jalan Tutong Widening, Phase III is one of the biggest road projects in Brunei with a project turnover of B$66.5 millions. Comparing with the previous widening projects, Phase I and Phase II, the soil conditions are worse and the water table is higher. In the original design proposal, the sub-base contained a layer of geotextile and a layer of 225mm thick crusher rock. A layer of 170mm thick dense bitumen macadam formed the base course. The surface was 100mm asphalt concrete. Furthermore in the original design a lot of efforts had been contributed to the improvement of the sub-grade. As least 1m thick backfills including 300mm thick crusher run with a geogrid system on the top of pilling foundation. The similar design system was applied in another road project several years ago from the time that the original was proposed and its performances were not very satisfactory. Furthermore the cost by using this system with the pilling foundation all over the road is too high to accept.

Further intensive technical studies and discussions were conducted and a comprehensive design was finally concluded. For the road pavement, the sub-base included a lower layer of 100mm thick well-compacted sandy fill with a layer of geotextile on the bottom and a layer of 350mm thick sandy soils stabilized by 2.5% of Chemilink SS-108. 220mm thick crusher run stabilized by 1.5% of Polyroad, where Polyroad has a good water resistant but has limited binding effect, formed the base. The design of the surface layer remained the same. For the improvement of the sub-grade, only about 30% of the pilling foundation was used for those important areas such as road junctions and the places where no settlements are allowed. To link the bearing-piling areas to the none-pilling areas, a transaction piling system was introduced in order to form a smooth surface slope corresponding to the gradually changed settlements (Fig. 3).

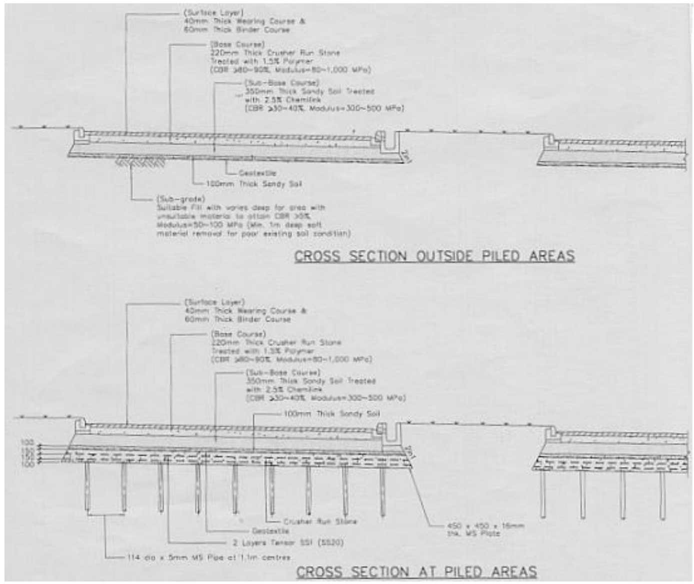


Fig. 3. Typical Cross Sections at Piled and Non-Piled Areas

During the construction, a lot of laboratory and in-situ tests as well as site observations were conducted to ensure the installation qualities. The average results of UCS (unconfined compressive strength) tests, in-situ CBR tests and degree of compaction tests, and some data of the modulus of sub-grade reaction from the in-situ plate loading tests are given in Tables 5 and 6 respectively for both chemical stabilized sub-base and base courses. Furthermore several cross sections were cut and opened in order to directly observe and check the quality and performance of the chemical stabilized layers (Photo. 7). Based on these testing results and direct observations, the stabilized layers were solid and had no deformation.

Table 4. Average Testing Results for Jalan Tutong Widening, Phase III

Products	Sample No.	UCS Test (MPa)		In-Situ CBR Test (%)	DOC Test (%)	Remarks
		4-day soaked	Unsoaked			
2.5% Chemilink SS-108 with sandy soils	129~163	1.3	1.62	81.25	> 97	Sub-base
1.5% Polyroad with crasher run	63~121	1.19	1.52	184.26	> 99	Base

Notes: 1) The samples used for UCS tests were made in Lab using the mixtures from site.
2) In-site CBR tests were normally conducted after 2-4 curing days.
3) DOC means the Degree of Compaction

Table 5. Plate Loading Test Data for Jalan Tutong Widening, Phase III

Products	Location-1 CH 2870~71 K (MPa/m)	Location-2 CH 2960~61 K (MPa/m)	Location-3 CH 3391 K (MPa/m)	Average Modulus of Sub-grade Reaction K, (MPa/m)
2.5% Chemilink SS-108 with sandy soils	895	564	894	784
1.5% Polyroad with crasher run	501	623	508	544

a) Opened Road Cross Section

b) Road after 2-Year Completion

Photo. 7. Jalan Tutong Widening, Phase III

The road has been used for public traffic for about 10 years and there are no any signs of major defects and structural failures. Because of using chemical stabilization design, the immediate cost saving is very significant. A further cost saving in maintenance is expected based on the experience from other chemical stabilization projects.

Singapore Changi International Airport runways were widened in 2005 and became the first international airport ready for Airbus A380 operation. The runways were widened by an additional 4.5m on each side to achieve overall shoulder width of 7.5m in order to (a) provide a safe area that can withstand occasional runway excursion by aircraft; (b) support ground emergency response vehicles and (c) resist jet wash and prevent Foreign Object Damage (FOD) hazard. Various technical proposals were evaluated not only in technical performances but also in cost effectiveness and operational aspects. Construction speed has to be fast in order to shorten project duration and thus minimise runway closure and disturbance to airport operation. Chemilink Soil Stabilization Technology was chosen for various merits.

a) Spreading b) In-situ Mixing c) Compaction

Photo 8. Stabilization Work in Singapore International Airport

A total of about 16km of runway widening was completed in 95 days, 3 months ahead of schedule. Refer to Fig. 4, both in-situ UCS and CBR test results met the requirement of ≥1.5MPa and ≥90% respectively. Average UCS and CBR values were 3.1MPa and 219% (Koh et. al., 2005). After more than 3 years since completion, no any form of defects, such as total settlement, differential settlement or cracking, was detected.

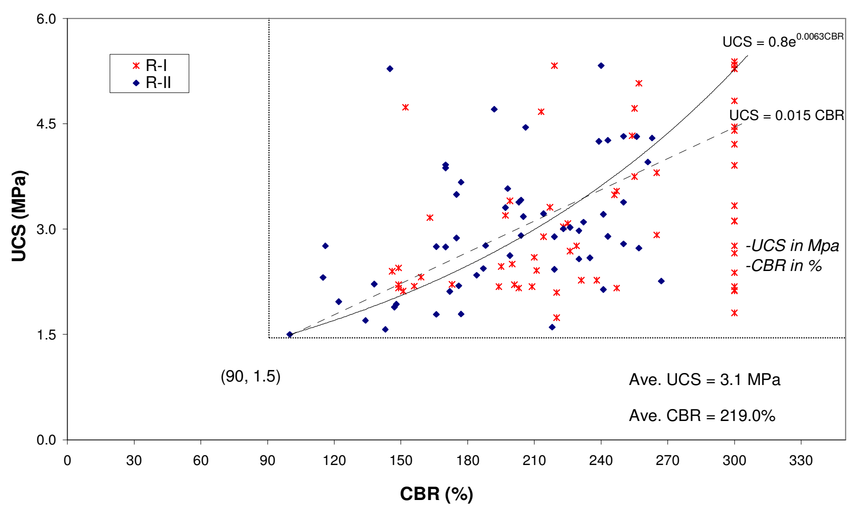


Fig. 4. UCS and CBR Testing Results

Photo 9. Completion of Runway Widening in Singapore Airport

<u>Malaysia Sultan Ismail International Airport (a.k.a. Johor Senai Airport)</u> runway widening was completed in 2007 and taxiway widening is still on going, for airport new development and services, such as training centre for SIA Airbus A380. Being able to overcome operational limitation and technical challenges, Chemilink Stabilization Technology was again invited for these two projects.

The key challenge was extremely bad soil condition. Local soil was nearly 100% clayey soil with very high liquid limit (up to 88%), plastic index (up to 46%), and in-sit moisture content (up to 42%, which is about twice of the optimum moisture content). Nevertheless, after Chemilink Soil Stabilization, such “unsuitable” materials (based on the standard of JKR, Malaysia) were strengthened and the achieved results meet all the technical requirements. Refer to Fig. 5 to Fig.7, average values of UCS, CBR, Resilient Modulus and Compaction Degree were found to be 2.1MPa, 120%, 6,000MPa and 98% respectively (Wu et. al., 2008).

a) Spreading b) In-sit Mixing c)Compaction

Photo 10. Stabilization work in Sultan Ismail International Airport

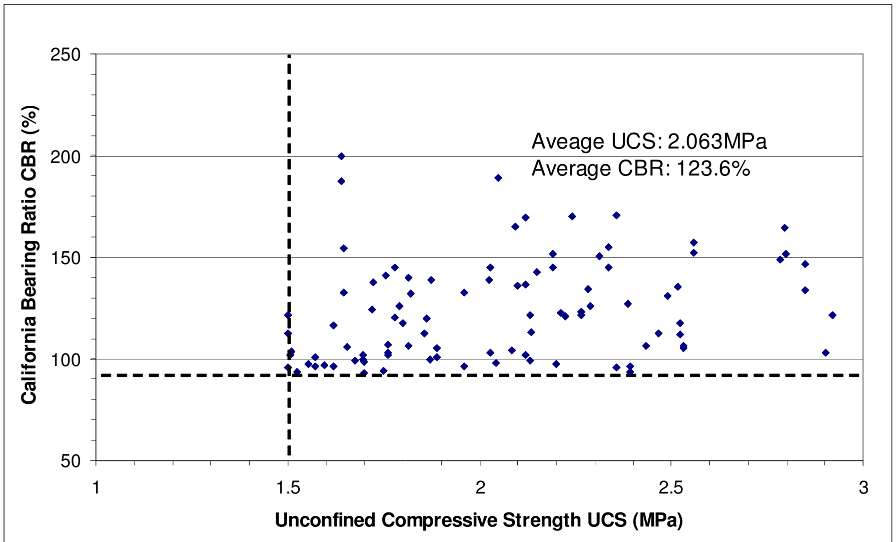


Fig.5. UCS and CBR Testing Results

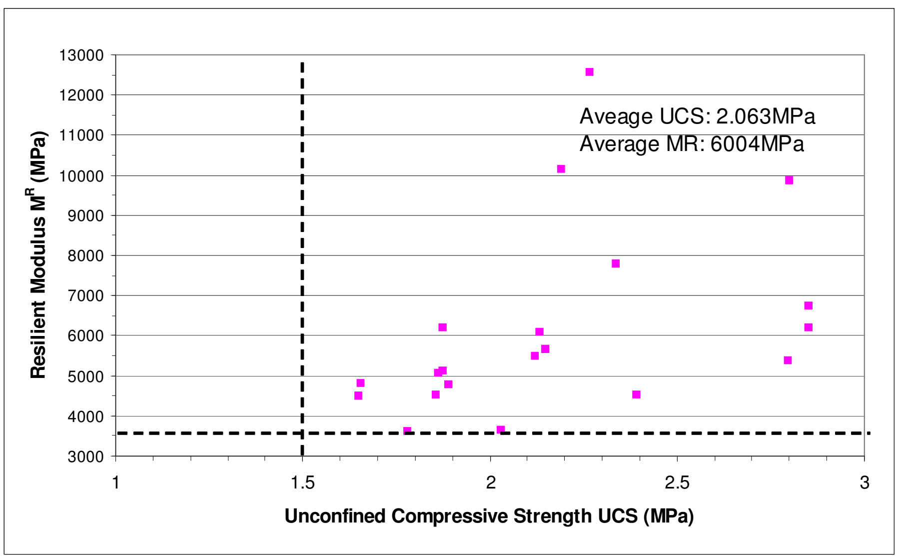


Fig.6. UCS and M_R Testing Results

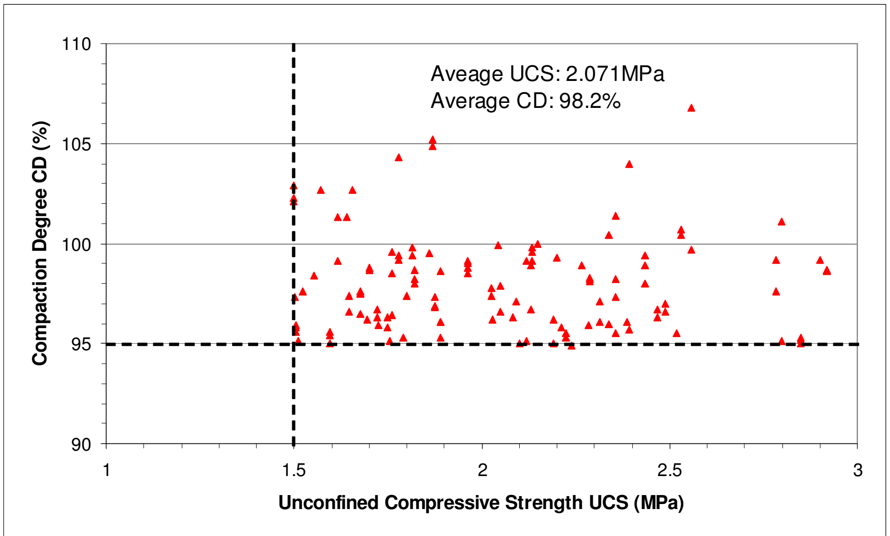


Fig.7. UCS and Compaction Degree Testing Results

This runway widening project completed in 2.5 months, 1.5 months ahead of the schedule. Till date, after nearly 1 year, no defect of any forms was detected. Considering technical and commercial benefits that Chemilink Stabilization Technology can provide, this method was also selected for taxiway widening (full-strength case).

Photo 11. Completion of Runway Widening in Senai Airport

5. Quality Assurance and Quality Control

A proper and practical quality control of chemical stabilization is necessary and sometime vital to comply with the design requirements and to achieve the targeted results. It can also set up a common guideline for consultants and contractors to assure construction qualities before, during and after stabilization process.

Based on the established international practice and local engineering experience, an authorized specification called "General Specification for Pavement Stabilization" was published by Brunei PWD in 1999 (CPRU, 1999). In the published specification, the detailed regulations and requirements on quality assurance and quality control for the chemical stabilizations with Cement, Cement/Bitumen, and Polymer-base and the modified cementitious products have been specified for road pavement construction. The quality control requirements with testing methods, targets and tolerances, minimum checking frequencies and recording manners for each type of chemical stabilizations have mainly included the following aspects and elements:

Preparations that require the determinations of the properties of the in-situ or imported materials to be stabilized; and of the chemical stabilizing agents to be used;

Construction that requires the inspections of spreading quality with the mechanical spreader; mixing depths and widths; overlapping widths and lengths; timing limits from mixing to compaction; moisture controls; and compaction controls;

Finishing that includes level controls; surface finishing tolerances; and curing process; and

Technical Results that provide the testing requirements during and after construction in order to determine the relevant strengths; resilient modulus and other necessary technical data.

The quality control requirements for chemical stabilization of sub-grade in the specification (CPRU, 1999) are selected and illustrated in Table 7 as an example. Furthermore some requirements of quality assurance are also recommended (Instek, 1995), which is to ensure soil stabilization under qualified site personnel and with proper construction machinery.

Table 6. Quality Control Requirements for Chemical Stabilisation of Sub-Grade

Element	Test Method	Target	Minimum Frequency	Record
Suitability of using existing material	CBR tests to BS 1377	5%	As required with change in soil conditions	Test Report
Depth of stabilisation	Measurement	1.4 times designated thickness	Every 50 meters.	Daily Report
Dosage and spreading	Weighing and visual inspection	Not less than specified value	Every 40 meters.	Daily Report
Overlapping – Minimum Lengths	Measurement	Long : 0.3m Lateral : 1.0m	Every 50 meters.	Daily Report
Resultant strength	CBR, UCS and Resilient Modulus tests according to BS 1377	As per design requirement	Every 50 meters or a determined by RE.	Test Report

7. Conclusions

1) Soil stabilization and recycling with chemical admixtures is an effective approach for civil engineering. Chemical stabilization, with proper stabilizing agents and with advanced construction machinery and method, could be one of the best satisfactory construction methods for roads and shallow base foundations under tropical conditions in this region.

2) Many projects with chemical stabilization have been carried out in this region and the performances of the completed projects are generally satisfactory. With chemical stabilization method, many technical difficulties, especially the total and differential settlements, at clayey, swampy or low-lying land areas with peaty soils have successfully been resolved. The benefits and advantages derived from chemical stabilized roads are far more superior to those of roads constructed by conventional methods.

3) The commonly used chemical stabilizing agents are reviewed and discussed in the paper. The major criterion of selecting the agents has been proposed that the right agent must be able to overcome the both general engineering difficulties and localized construction troubles. It is recommended to pay more attention on the modified cementitious base and/or polymer base stabilizing agents because of the effectiveness and durability.

4) Chemilink Soil Stabilization has technically and commercially been proven to be the effective and durable method especially for road and airfield construction in this region, based on the performance and durability of numerous projects with Chemilink Technologies and Products. Since Chemilink has successfully been applied a lot of high-difficulty projects for both roads and airfield for past many years, it has been recognized to be a leading technology in soil stabilization industry internationally.

5) It is necessary and vital to comply with the quality control requirements in order to achieve successful stabilization works.

8. References

CPRU. (1999). General Specification for Pavement Stabilization, Construction Planning and Research Unit, Ministry of Development, 1st Edition, Brunei Darussalam, xxpp

Fang, H.Y. (1990). Foundation Engineering Handbook, 2nd Edition, New York, USA.

Suhaimi H.G. and Wu D.Q. (2002). Review of Chemical Stabilization Technologies and Applications for Public Roads in Brunei Darussalam, the Regional Seminar on Quality Roads – the Way Forwards, in conjunction with the Launching of REAAA (Brunei Chapter), Oct. 2-4, 2002, Bandar Seri Begawan, Brunei Darussalam.

Instek (1995). Quality Control Guideline for Chemilink™ Application on Roads, 1st Edition, Instek Holding Pte Ltd, Singapore

Mitchell, J.K. and Katti, R.K. (1981). Soil Improvement – State-of-the-Art-Report, Proc. of the 10th Inter. Conf. On SMFE, Vol. 1, pp. 261-317

Sai, Q.L. (1998). Asphalt Pavement on Semi-Rigid Roadbase for High-class Highways, 1st Edition, CIP (97) No. 23311, Beijing, PR China, 1,025pp. (in Chinese)

Yong T.C. and Wu D.Q. (1999). Chemical Stabilization for Road Construction in Brunei Darussalam, The First International Conference on Transportation for Developing Countries on Threshold of the 21st Century, Nov. 18-19, 1999, Hanoi, Vietnam, pp. I.26-I.32.

Yong T.C. and Hussien R. (2001). Rehabilitation of Jalan Junjungan by Using In-situ Stabilization and Recycling Method, the 19th Conference of Asean Federation of Engineering Organizations, Brunei Darussalam

Wu D.Q. (2002). Soil Stabilization/Recycling with Chemical Admixtures for Civil Engineering, Regional Seminar on Recycling Technologies for Civil Engineering, CPG (formerly Singapore PWD) Training Centre, Singapore, Nov. 19-20, 2002

Koh M.S., Lim B.C. and Wu D.Q. (2005). Chemical –Soil Stabilization for Runway Shoulders Widening at Singapore Changi Airport, 4th Asia Pacific Conference on Transportation and Environment (4th APTE Conference), Nov 8-10, 2005, Xi'an, PR China

Wu D.Q., Shaun Kumar and Tan P.C. (2008). Chemical-Clay Stabilization for Runway Widening at Sultan Ismail International Airport, Malaysia, 13th Singapore Symposium on Pavement Technology (SPT 2008), May 23, 2008, National University of Singapore, Singapore