RECYCLING OF UNSUITABLE IN-SITU SOILS AND CONSTRUCTION WASTES BY CHEMICAL SOIL STABILIZATION

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Abstract

Environmental and ecological protection is the new focus in construction industry. Whenever in-situ soils are unable to achieve design specifications, it is termed as "unsuitable" and foundation improvement has to be done. The most common method is to replace unsuitable in-situ soils by using good backfilling materials, such as granite stones. In order to harvest these good raw materials, natural environment is adversely affected. Besides, disposals of those unsuitable materials are always disturbances to natural environment. To resolve these problems, alternatives were studied intensively and chemical (or bio-chemical) stabilization is a proven effective approach. By adding the appropriate stabilizing agent, unsuitable in-situ soils can be recycled and strengthened to meet different engineering requirements. Similarly, solid construction wastes, such as used aggregate and milling waste can also be recycled, thus reduce creation of waste. By doing so, both the environmental problems above are minimized. Therefore recycling of soil and construction waste is especially important to those countries which are lacking of natural resources, such as Singapore. Besides environmental friendly, chemical stabilization also provides other benefits like good performances, longer durability and cost effectiveness. Because of relatively faster and easier construction, chemical stabilization also reduces disturbances to public during the construction. Several types of commonly used chemical stabilizing agents are studied and compared in this paper. One proven stabilizing agent is specially highlighted in the paper and this green product is environmental friendly in the process of manufacturing, by reusing waste materials and agricultural by-products, which provides a total green solution from product, application and end-result. Several applications with this green solution including technology, product and methodology, such as Singapore Changi International Airport Runway Widening, various highways and city roads in Brunei swampy areas are reported in the paper with discussions on advantages and performances of chemical stabilization in different scenarios.

Key Words: **Recycling**, **Chemical Soil Stabilization**, **Construction Waste**, **Chemilink Green Solution**

1. INTRODUCTION

1.1 Background of Chemical Soil Stabilization

To build a durable road pavement, characteristics of every component, from bottommost sub-grade to surface are important. These characteristics include various strengths, stiffness, compressibility and permeability. Most untreated in-situ soils cannot generally meet the technical specifications to form satisfactory sub-base and base courses of roads, and foundation improvement has to be done. Conventionally, these unsuitable in-situ soils are replaced by quarry materials. However, the quarry materials are sometime difficult and expensive to procure in certain areas. Natural environment is adversely affected as well. Besides, removal and disposal of those unsuitable materials are always disturbances to public environment. In recently years, alternative solutions have been studied intensively to address these environmental issues, and fulfilling technical requirements at the same time. Among these alternatives, chemical stabilization is a proven solution especially in tropical regions.

Chemical stabilization can be used to strengthen sub-grade and week roads base. By mixing proper chemical or bio-chemical admixtures with soils, the chemical stabilization can improve the properties of soils in order to improve or control the volume stability, the strengths 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, sub-base and base courses materials for construction of shallow foundations, such as roads and airfields. With the chemical stabilization, limited fresh quarry materials and much less waste disposals are required. Advantages of Chemical Soil Stabilization will be discussed in details in this paper.

The chemical stabilized pavement can achieve higher design strengths as comparing to the conventional flexible pavement, which is because the stabilized pavement has lower compressibility and lower permeability under different water table and temperature conditions. Most soils or construction wastes can be stabilized with suitable stabilizing agents and the construction process of stabilization or recycling is simple and fast. It has been proven all over the world that chemical stabilization with correct design and quality construction is technically reliable and commercially effective.

1.2 Process of Chemical Stabilization Application

Generally, Chemical Stabilization can be done by two methods:

i. In-situ Mixing

A mechanical spreader is used to evenly spread the stabilizing agents onto the surface to be stabilized, followed by an advanced self-running mixer called Stabilizer or Recycler be used for in-situ mixing of local soil, solid construction waste the stabilizing agent. Finally the mixture is compacted by rollers with higher capacity (Figure. 1). With latest machinery, the stabilized depth could be up to 500mm and the mixing quality is close that handy mixing in laboratory. High construction speed is the advantage of in-situ mixing, where a construction speed up to 8,000~15,000m² per day is achievable according to previous project records.

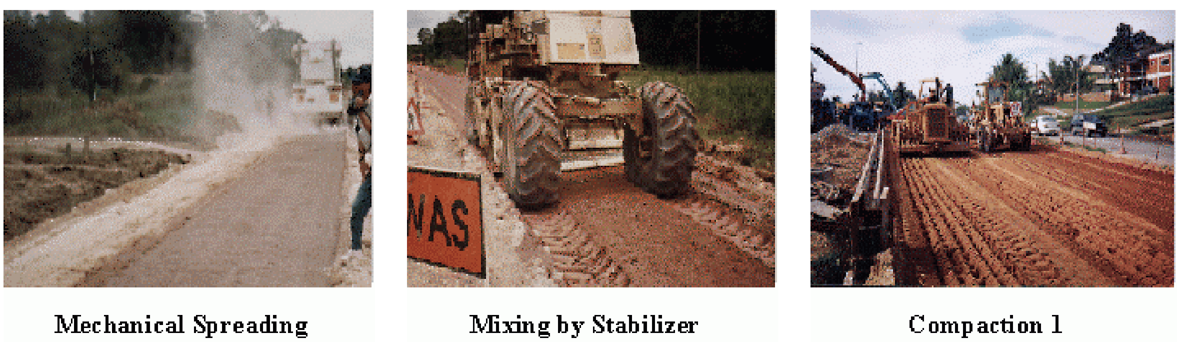

Photo. 1. In-situ Mixing

ii. 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. However it will have a double-handling issue in case of 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.

1.3 Commonly Used Chemical Stabilizing Agents

Cement stabilization is effective for most of granular soils to increase strengths and decrease permeability. However cement stabilization is 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:

- Liquid Limit: <40% - China, France and US (AASHTO); <45% - UK;
- Plastic Index: <20% - China, France and US; <18% - UK;
- Coefficient of Uniformity: >5~10 - China, France and UK; and
- Grain Size Distribution

Lime 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, of the stabilized soils after curing. However strength increment is not significant. Therefore lime stabilization is usually used independently for foundations with lower bearing capacity requirements, or used as a preparative measure for subsequent treatment with other chemical stabilization.

Bituminous stabilization with using 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.

Liquid form stabilizing agents are generally produced for non-bearing purposes such as dust control. 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 these agents, addition of the agents will always make the compaction more difficult when the soil is in high moisture content. Furthermore the durability of the soils stabilized by the agents in liquid form is not reliable in the tropic region. Therefore there are hardly liquid form agents that have been used to completely and independently stabilize the soils for load bearing purposes.

As discussed above, the conventional stabilizing agents such as Cement, Lime, and Bitumen have their advantages, disadvantages and limitations in applications. 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. A series of modified soil stabilizing agents, which were proven over past 15 years are discussed in Chapter 2.

2. CHEMILINK SOIL/STONE STABILIZATION – A GREEN SOLUTION

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.

Chemilink stabilizing series products are one of few chemical stabilizing agents in powder form that were widely used in this region. The products have been tried, verified and widely applied in South East

Countries and China Since 1994. Chemilink Stabilizing Agents were specially developed for tropical construction conditions and their effectiveness as well as durability.

Chemilink SS-108 is a polymer and bio-material modified cementitious based chemical agent in fine powder form and designed for soil stabilization especially for sandy and clayey soils under tropical conditions and environment. By integrating chemical-, biochemical- and physical- reactions, basic functions of Chemilink Stabilizing Agents can be summarized 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 minimize differential settlements;
- To decrease the compressibility and permeability of the stabilized 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 based 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.

In view of rising awareness in environmental and ecological issues, “Total Green” concept was incorporated into Chemilink Stabilization Technologies, in following approaches, to model a sustainable infrastructure development.

Green Product: Various materials are recycled and utilized, such as agricultural bio-mass, in the fabrication of the product.

Green Process: The application of the stabilizing agents is green as the process reuse in-situ soil, thus minimize the demand on raw granite materials and reduce the removal of the soil as a waste. Besides, with faster construction speed, disturbance to environment and public will be less.

Green End-Result: The stabilized soil is physically and chemically stable under the specified usage and therefore creates no environmental problem.

3. ADVANTAGES OF CHEMICAL SOIL STABILIZATION

3.1 Better Technical Performances

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

In AASHTO Guide For Design of Pavement Structures 1993, the concept of Structural Number (SN) was introduced for pavement structural design. Structural Number is an index that is indicative of the total pavement that is required, and structural layer coefficient is an expression of the relative ability of a material to function as a structural component of the pavement. With this coefficient, actual thickness of each layer can be converted to structural number, and vice versa.

According to the relevant highway specifications in some countries that are experienced in chemical stabilization (Sai, 1998), road base course shall exhibit California Bearing Ratio (CBR) ⩾90% or Unconfined Compressive Strength (UCS) ⩾2MPa. Refer to AAHTO Guide for Design of Pavement Structures 1993 Chapter 2 Design Requirements, structure layer coefficients are obtained as following:

Granular Base Layer Coefficient (CBR⩾90%) = 0.135
Chemical-Treated Base Layer Coefficient (7d-UCS⩾2MPa) = 0.153

With greater value of Layer Coefficient for Chemical-Treated Base suggested that its strength is higher than those of granular base course.

Equivalency factor is another idea to compare the technical performances of different materials applied by United State. Equivalency factor indicate the substitution thickness ratios applicable to higher quality layer. The lesser thickness is computed by dividing the required thickness of layer, by the appropriate equivalency factor of the substituting material.

Based on the advisory circulation from United State Federal Aviation Administration (FAA AC 150/5320-6D), the recommended equivalency factor converting aggregate base (P-209) to chemical treated base (P-304), is in the range of 1.2 to 1.6, which literally suggest chemical treated base is generally 1.2 to 1.6 times stronger than aggregate base course.

Besides indices from various design codes, numerically indicate higher performances, chemical stabilized soil as bound material, provides better technical performances in following aspects when comparing unbound material (granite stone or granular soil) conventionally used in road pavement foundation, 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. After stabilization, permeability is decreased and therefore minimizes mechanical loosening caused by water penetration. As a result stabilized soil provides much longer durability if comparing with those of un-stabilized materials.

Furthermore, the stabilized materials form a semi-rigid platform so as to deliver a lot of engineering benefits. After stabilization, this semi-rigid platform is effective in distributing load and prevents localized loading. Therefore differential settlement problem can be minimized or eliminated and total settlement can also be reduced. Effectiveness of this floating platform characteristic in solving settlement problem was proven in several highway projects in the swampy areas of Brunei, which will be further discussed in the case study later.

3.2 Reduce Demands on Raw Backfilling Materials

By applying chemical soil stabilization, physical and mechanical properties of in-situ soil can be improved to meet the requirements. By doing so, less raw backfilling materials, such as granite aggregates and granular soils, would be required. Reducing of demands on natural resources is not only environmental and ecological friendly, but also commercially efficient for development of urban cities lacking of natural quarry materials, such as Singapore. Besides, reduced usage of raw backfilling materials implies energy conservation arises from much less materials transportation and less mechanical crushing of granite aggregate.

3.3 Minimize Creation of Construction Waste

During conventional pavement construction, unsuitable soil is removed as construction waste, thus requires proper dumpsite for disposal. Due to high dumping cost, illegal dumping of the soil waste occurs frequently and thus creates environmental issues. With chemical soil stabilization, unsuitable in-situ soil can be reused, instead of removed as a construction waste. For example, widening of 2 runways in

Singapore Changi Airport (total 16km), the recycling of in-situ soils as construction material is environmentally friendly and avoided the need to dispose up to 21,000tons of, which translated to an immediate saving of nearly S$200,000 in disposal cost for the airport authority.

3.4 Faster Construction and Less Disturbance to Environment and Public

By stabilizing in-situ soil, the procedures of excavation of in-situ soil and replacement of backfilling material are eliminated. Therefore, the construction speed of chemical soil stabilization is generally three to five times faster than conventional replacement method, which enables early completion and reduces disruption to public, especially for the construction of road rehabilitation.

With less heavy vehicular movement involved, environmental pollution such as air, noise and dirt deposit can be greatly reduced.

3.5 Overall Cost Effectiveness

i. Short Term Direct Cost Saving

By recycling in-situ soil, usage of raw granite aggregate is greatly reduced. For countries lacking of natural quarry materials, such as Singapore and Brunei, reduction of raw granite usage can generally contribute to more than 10% direct saving in total construction cost. Besides, easier and faster construction requires less manpower and machineries, contributes to saving in terms of man-hour cost and rental for machineries.

ii. Long Term In-direct Cost Effectiveness

A road with better quality requires much less maintenances. Besides, better performances of stabilized soil can lengthen the life span of the pavement.

4. CASE STUDIES

4.1 Brunei Jalan Tutong Widening (Phase II and III)

Jalan Tutong is a heavy usage highway in Brunei, located at a poor sub-soils foundation. In order to meet the increasing traffic volume, widening of Jalan Tutong was started in early 90s, divided into 3 phases. In the design of Phase I, 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 as shown in Fig. 1. In order to minimize the changes in the original design (since this project construction had been started), a layer of 150mm thick imported crusher run stone was proposed to act as the base course and the provide anti-cracking function from the cement stabilization layer (which formed upper layer of sub-base), while 300mm thick chemical stabilized soil layer was used as the lower layer of sub-base 100mm thick asphalt concrete was designed as the road surface. The cost of the modified design is cheaper than that of the original design.

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. 2). 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.

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/m^3)	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. 1. Typical Cross Section of Widening of Jalan Tutong, Phase II

Photo. 2. Jalan Tutong Widening, Phase II (4 years later)

Jalan Tutong Widening, Phase III . Comparing with the previous widening projects, Phase I and Phase II, the soil conditions are worse and the water table is higher. Besides thick layer of soil replacement and geotextile, a dense pilling foundation was also proposed in the original design. However, similar design concept was applied in another road project several years ago and then proven ineffective. 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. 225mm thick crusher run stabilized by 1.5% of PR-1, where PR-1 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.

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 1 and 2 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. 3). Based on these testing results and direct observations, the stabilized layers were solid and had no deformation.

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.

Table. 1. 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% PR-1 with crusher 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. 2. 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% PR-1 with crusher run	501	623	508	544

a) Opened Road Cross Section after 2 Years

b) Road after 10-Year Completion

Photo. 3. Jalan Tutong Widening, Phase III

4.2 Brunei City Road Maintenance

With satisfactory technical performances in low lying and swampy areas in Brunei, Chemilink Soil Stabilization method was specified in Brunei General Specification for Pavement Stabilization (GS 7:1999), for both new road construction and road maintenance.

Construction efficiency is especially important for existing road maintenance. With simpler in-situ rehabilitation of the existing base materials by chemical soil stabilization, less heavy vehicular movement is involved and less working space is needed in addition to that no new or fresh materials are required. The road to be rehabilitated was closed lane by lane in the mid-night and re-opened in the early morning of the following day. High initial strength of Chemilink Soil Stabilization further allows the road to be re-opened immediately and makes traffic in day time unaffected and therefore much less disruption to public is created because of the rapid construction speed.

a) Road Partially Closed for Maintenance | *b) Road Opened for Use On the Next Day* | *c) Cored Samples stabilized Recycled Materials*

Photo. 4. City Road Quick Maintenance

4.3 Singapore Changi International Airport Runway Widening

Singapore Changi International Airport runways were widened in 2005 and became one of the first international airports 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. Ability to meet airport operational restrictions is the key concern. To reduce the impact of the construction works to airport operations, the runway closure was limited to 6 hours daily from midnight. Therefore construction methodology had to be simple and the speed had to be fast in order to shorten project duration and thus minimize runway closure and disturbance to airport operation. Chemilink Soil Stabilization Technology was finally chosen for various merits.

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

Photo. 5. Stabilization Work in Singapore Changi International Airport

A total of about 16km of runway widening was completed in 95 calendar days (used 60 working days), 3 months ahead of schedule. Refer to Fig. 2, both in-situ UCS and CBR test results met the requirements of ≥1.5MPa and ≥90% respectively. Average UCS and CBR values were 3.1MPa and 219% (Koh et. al., 2005). After more than 4 years since completion, no any form of defects, such as total settlement, differential settlement or cracking, was detected.

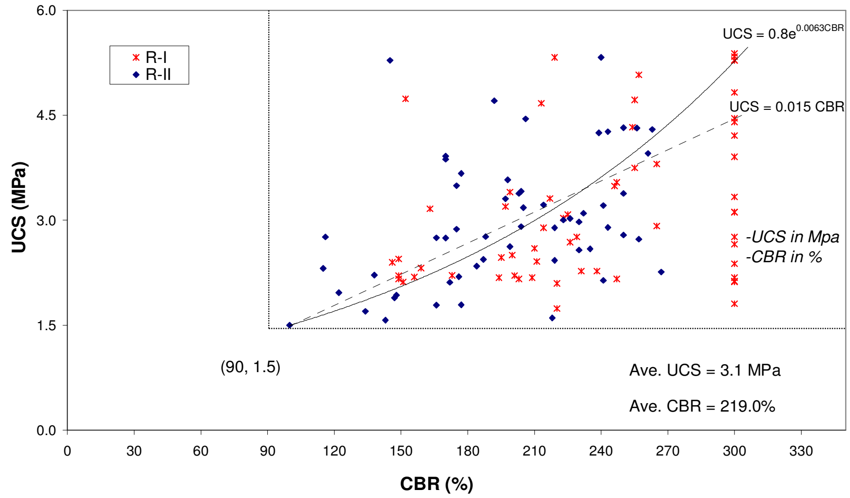

Fig. 2. UCS and CBR Testing Results

Photo. 6. Completion of Runway Widening in Changi Airport

4.4 Malaysia Sultan Ismail International Airport Runway and Taxiway Widening

Malaysia Sultan Ismail International Airport (a.k.a. Johor Bahru Senai Airport) runway widening was completed in 2007 and taxiway fillet widening was completed in 2008, 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-situ moisture content (up to 42%, which is about twice of the optimum moisture content). According to specification from Public Work Department (Malaysia JKR), for any soil with liquid limit exceeded 80% is termed as unsuitable material and has to be replaced with suitable materials. (refer to Table. 3.)

Nevertheless, after Chemilink Soil Stabilization, such “unsuitable” materials were strengthened and the achieved results met all the technical requirements. Refer to Fig. 3 to Fig.5, 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).

There was a section beside the fire engine access, asphalt milling waste was stabilized as the base course. The comparable testing results proved that chemical stabilization is also effective in binding construction waste materials.

Table. 3. Soil Investigation For Sultan Ismail International Airport Runway Widening

SENAI AIRPORT RUNWAY SHOULDER WIDENING
Soil Investigation Summary

NO	LOCATION	DEPTH (mm)	INSITU MC (%)	OMC (%)	MDD (Mg/m3)	LL (%)	PI (%)	CLAY&SILT (%)	SAND (%)	GRAVEL (%)
		150~450 mm	depth at 350mm							
6	P6	350	23.59	15.00	1.74	73	36	54.80	32.40	12.80
7	P7	350	30.08	22.00	1.49	88	37	78.80	19.20	2.00
8	P8	350	41.63	18.00	1.54	76	31	70.40	2.60	27.00
11	P11	350	27.38	19.00	1.68	62	33	66.80	33.20	0.00
12	P12	350	38.74	19.00	1.55	79	46	82.70	17.20	0.10
13	P13	350	21.37	17.00	1.71	56	23	62.20	30.60	7.20

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

Photo. 7. Stabilization work in Malaysia Sultan Ismail International Airport

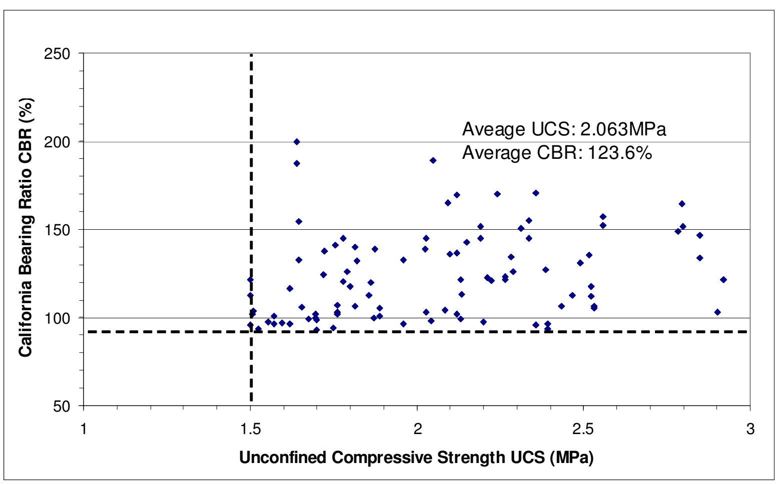

Fig. 3. UCS and CBR Testing Results for Sultan Ismail International Airport Runway Widening

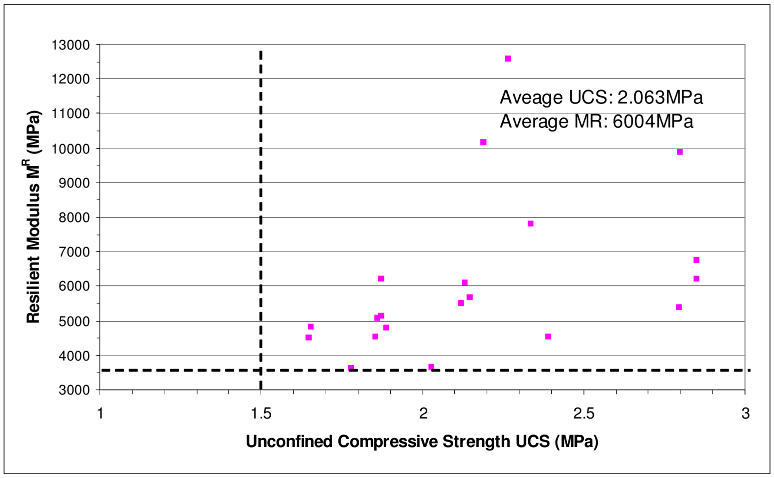

Fig. 4. UCS and M_R Testing Results for Sultan Ismail International Airport Runway Widening

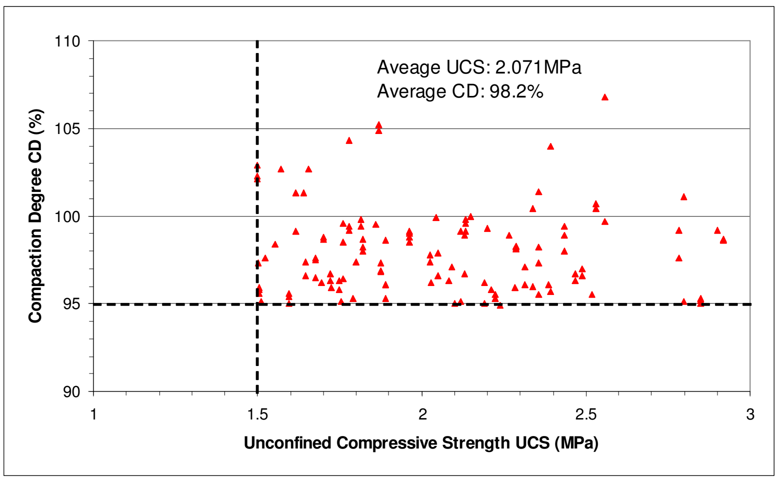

Fig. 5. UCS and CD Testing Results for Sultan Ismail International Airport Runway Widening

This runway widening project completed in 2.5 calendar months, 1.5 months ahead of the schedule. Till date, after nearly 2 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 fillet widening (full-strength case).

Photo. 8. Completion of Runway Widening in Senai Airport

5. CONCLUSION

Soil stabilization and recycling with chemical (or bio-chemical) admixtures is an effective approach for civil engineering. Not only technical performances are delivered, but also chemical soil stabilization provides a more environmental and ecological friendly approach, as compared with conventional replacement method. With proper stabilizing agents, advanced construction machinery and systematic application methodology, chemical soil stabilization could be one of the most satisfactory construction methods for roads and shallow base foundations, for sustainable urban development.

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 concerns. Recent years, more attention has been paid on the modified cementitious base and/or polymer base stabilizing agents because of the effectiveness and durability. As a good example of green solution incorporated with technology, product and methodology, Chemilink Soil/Stone Stabilization has technically and commercially been proven to be the effective and durable method especially for road and airfield construction internationally. 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 field internationally.

With the 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, not only from technical aspect, but also commercially cost efficient.

Besides better technical performances, Chemical Soil Stabilization is a “green” approach to infrastructure construction. Chemical Soil Stabilization reduces demand on raw granite materials and reduces disposal of unsuitable in-situ soil as a waste. Both of these factors contribute to conservation of natural resources and reduce disturbance to environment. Furthermore, due to construction efficiency the construction duration can be shortened.

In short, Chemical Soil stabilization provides a sustainable solution to urban development, which is technically effective as well as time- and cost- efficient.

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