A Green and Effective Approach for Pavements in Tropical Region

Dong Qing Wu[1]

[1]Managing Director & CEO, Chemilink Technologies Group, 20 Kranji Road, Singapore 739462. Email: wu@chemilink.com

ABSTRACT: In tropical region, conventional methods engage a lager quantity of quarry materials but the resulted pavements are often not satisfactory in both technical performance and durability. Soil stabilization with proper designs, chemical binders and application methodologies can maximize the usage of in-situ and local soils as well as some construction wastes and has been proven to be effective in providing durable pavements with faster construction, higher performances and overall cost effectiveness in South East Asia. It is a green approach to construct various pavements together with significant reduction of CO_2 emission. This paper introduces a range of pavements constructed by a commonly used soil stabilization system in South East Asia over past 20 years for airport, seaport, highways and, various roads and shallow base foundations. This systematic solution is thus recommended for various pavements in tropical region while its technical advantages and environmental benefits are discussed together with comprehensive case studies. The proven system for pavement presents some premier and leading models of a "floating" semi-rigid platform over the swampy and soft ground; the non-cracking performance of pavement and an excellent workability under extremely limited time and space environments such as runway construction under exceptional heavy operational conditions.
Keywords: Soil Stabilization, Green Approach, Pavements, Airfields, Roads, CO_2 Emission, Geotechnical Improvement

东南亚热带雨林地区的路面建设是一个国际性的技术难题. 用土壤固化的绿色方式处理路面各结构层的设计理念, 环保型固化材料和工程实践能最大限度地利用和再循环现场或当地的土壤资源及建筑废料, 不仅提高了路面结构的各项技术指标, 而且也减低了工程的碳排放量, 对生态平衡和环境保护起到了积极和推进作用. 本文介绍了一种流行的土壤固化工程体系在东南亚机场, 海港, 高速公路等的应用, 结合其近 20 年来典型工程案例的讨论, 展现了该体系在诸如建设沼泽和软土地基上的半刚性浮平台; 高等级路面抗裂; 国际繁忙机场跑道等基础设施的快速修扩建等方面均有创新和突破.

INTRODUCTION

In tropical region like South East Asia, there are a lot of swampy, soft ground and low land areas together with reverse climatic conditions like rich rainfall, high water table, peaty and problematic soils and so on. Most pavement construction activities have to be done on, in or with local soils and thus the reverser natural environments and the poorer geotechnical properties of ground soils in the tropical region make pavement construction to be most difficult over the world. Due to lack of suitable construction sites or limitations in selecting locations with good soil conditions, the demanding on inventing and utilizing technologies, materials and application methodologies for various pavements over the very soft ground has increased.

Conventional methods engage a lager quantity of quarry materials but the resulted pavements are often not satisfactory in both technical performance and durability. More and better quarry materials are required, which has increased the destruction of natural environment. Meantime more unsuitable in-situ soils and construction wastes have to be disposed, which will further impact and pollute the environment.

Chemical stabilization method has been proven to be a most green and effective approach to pavement construction in tropical region especially in South East Asia for past 20 years. This method can maximize the in-situ and local soils as well as construction wastes and stabilize both physically and chemically these "waste materials" as called traditionally to achieve higher technical performances and cost effectiveness. With chemical stabilization, limited fresh quarry materials and less waste disposals are required and thus CO_2 emission can be reduced ten times more if comparing with that from conventional method (Lee et al, 2010).

SOIL STABILIZATION AGENT AND GREEN SOLUTION

By mixing proper chemical or bio-chemical admixtures or called Stabilizing Agents with soils or construction wastes, the geotechnical properties will significantly be improved mainly in aspects of volume stability, various strengths, the stress-strain properties, permeability, compressibility and durability. The stabilized pavement can achieve higher design performances as comparing with conventional pavement and thus generate more technical and commercial advantages and benefits for infrastructure construction. Most known soils and non-toxic & non-metallic solid construction wastes can be stabilized or recycled with proper stabilizing agents.

The chemical stabilization is an oldest and most commonly-used method among the soil improvement family. There are various stabilizing agents such as cement, lime, bituminous materials, coal fly-ash, and others in powder form, while those in liquid form are generally ineffective for pavements with bearing purposes (Liu et al., 2004). The conventional stabilizing agents have their advantages and disadvantages. However their applications have been limited very much in tropical region. For example, the surface cracking is an unresolved issue not only in tropical region but also in this field for pavements stabilized by inorganic or cementitious binders, and the cracking has seriously limited the durability especially in the region with rich rainfall. Therefore the modified and/or combined chemical stabilizing agents together with the whole systematic solutions are required to be invented especially in tropical region, in order to effectively overcome technical difficulties; strengthen green solution in both materials and applications; and increase cost effectiveness of infrastructure construction. In this paper, a well modified soil stabilizing agent family called Chemilink SS-108 sub-series products is introduced, while Chemilink also provides systematic green solutions from designs, materials and application methodologies. For past about 20 years, it has commonly used in this tropical region for full ranges of pavements from airport, seaport and highways to various roads, loading yards and shallow base foundations (Suhaimi & Wu, 2003, Wu & Tan, 2009).

A typical product among this family is a type of polymer and bio-material modified ceramic- or cementitious-base chemical binder. In view of rising awareness in environmental and ecological issues, a "Total Green" concept has been incorporated into this solution system in following approaches, in order to achieve a sustainable infrastructure development.

- Green Product: A substantial percentage of its raw materials include recycled waste materials such as agricultural bio-mass and mining wastes.
- Green Process: The application of the stabilizing agents is green because the process reuses in-situ soils and/or waste materials, and thus minimizes the demand on fresh quarry materials and also reduces the removal of the soil as a waste. Besides quality performances with faster construction speed and longer durability, disturbance to natural environment and public is lesser.
- Green Result: The stabilized soil is physically and chemically stable under the specified usage and therefore creates no environmental issues, which has been proven for past years too.

By integrating chemical-, biochemical- and physical- reactions, basic functions of this stabilizing agent family can be summarized as follows:

- To improve and maintain the soaking strengths of soils and thereby improve the bearing capacities of sub-grade or stabilized soils mainly through immediate and long-term chemical reactions with soils;
- To form a semi-rigid platform with a certain tensile strength and thereby to 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 performances of stabilized soils and materials.

Through continuous R&D studies and project applications internationally such as in China, India, Australia, Brazil, Middle East and South East Asia, under different environment and soil conditions with various operational requirements, Chemilink green solutions have been proven to be applicable from tropical region to cold zone; from extremely low latitude region to higher latitude area (e.g. Tibet); and from swampy areas to deserts (Liu et al., 2004).

DESIGN AND INSTALLATION OF SOIL STABILIZATION

In addition to pavement structural design and installation methodology, material mix design is an important part for soil stabilization, which may mainly include various strengths and mechanical parameters under wet-dry cycling and cold-hot cycling. For example in this green solution system, the following tests are crucial for bearing purposes, where a general range of achievable results of the system are also given as reference:

- CBR (California Bearing Ratio, %) : 30 ~ 200 (7-day)
- UCS (Unconfined Compressive Strength, MPa) : 0.75 ~ 6.00 (7-day)
- M_R (Resilient Modulus, MPa) : 1,000 ~ 10,000

Where, CBR and UCS are commonly used for roads, while M_R is often for airfields.

The installation of soil stabilization can be categorized into 2 types: in-situ mix and plant mix. A typical in-situ mixing process is shown in Photo. 1. For light-duty roads or under extremely soft ground conditions, spreading by manual and use of smaller mixing machines like Rotovator used in agricultures are workable.

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

Photo. 1. Typical In-Situ Mixing Process of Soil Stabilization
(Photos source: Singapore Changi Airport Runway Widening)

ADVANTAGES AND BENIFITS

Mainly based on the practice of this solution system for past years, the advantages by using soil stabilization method can be concluded as follows while numerous benefits can also be derived from these advantages:

Higher Technical Performances The stabilized soils and materials can provide the higher strengths and modules comparing with conventional ways to support heavier and more frequent loading; satisfactory waterproofing properties to prevent damages by water that is “No. 1 Killer” for roads especially in tropical region; anti-cracking properties to deliver a higher standard pavement; and semi-rigid “floating” platform effect to ensure a quality pavement over the swampy or very soft ground areas.

Longer Pavement Lifespan The overall technical outcomes are also presented in the long-term satisfactory performances so as to tremendously reduce maintenances and increase the lifespan of pavements.

Green Approach By adopting the green concepts in stabilization product, installation process and resulted outcome, the most significant contribution of the soil stabilization is to reduce CO_2 emission during the entire infrastructural construction.

Faster Construction Because of utilization of in-situ soils with few percentages of stabilizing agent (based on the maximum dry density of soil), stabilization construction speed can be 5 to 10 times more than those with conventional methods, which maximizes the efficiency of investment.

Overall Cost Effectiveness The method has strengthened and maximized the investment effectiveness not only in short-term direct cost saving but also in long-term direct and indirect costs.

CASE STUDIES

1) Airfields

Singapore Changi International Airport Runways Widening (2005)

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 to 75m wide with an additional shoulder of 4.5m each side 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 (Photo. 1). Chemilink Soil Stabilization was finally chosen with various merits (Koh et al., 2005).

A total of about 16km of runway widening was completed in 95 calendar days (60 working days), 3 months ahead of schedule (Photo. 2). Because the airport was built on the reclaimed land, various in-situ soils including marine clay, beach sand and crushed stone were stabilized as the base of new shoulder for the two runways. As shown in Fig. 1, the both UCS and CBR test results met the requirements of $\geq$1.5MPa and $\geq$90% respectively, and the average UCS and CBR values are 3.1MPa and 219% (Koh et al., 2005). After 6 years operations, no any forms of defects, such as total settlement, differential settlement or cracking, are detected.

The stabilization system used in this pioneer and iconic project presented an excellent workability and quality performances under the extremely limited time and space environments in a running international airport with exceptional heavy operational activities as well as highest requirements especially in safety and security. No defects, especially settlements and cracking, also prove the excellent overall technical performances. Thus the project was recommended by the relevant government authorities and featured by the Discovery Channel in its TV program of "Man Made Marvels", which has been broadcasted worldwide since 2008.

a) Completion of Runway I Widening b) Runway II after Years

Photo. 2. Runways Widening in Singapore Airport

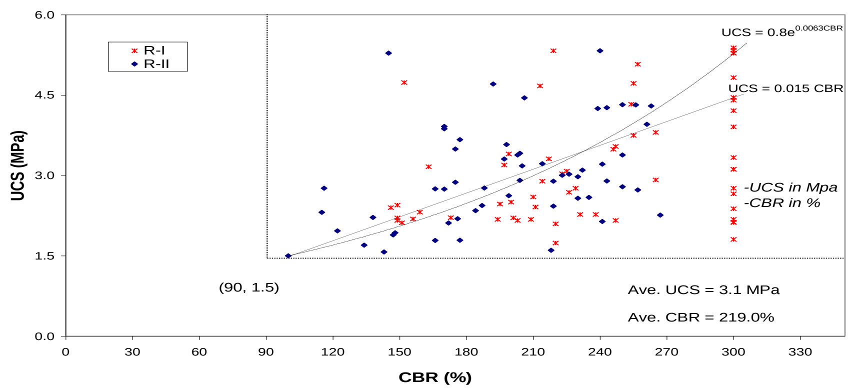


Fig. 1. UCS and CBR Results in Singapore Airport Runways Widening Project

<u>Malaysia Senai Airport Runway & Taxiway Widening (2007 & 2008)</u>

Malaysia Sultan Ismail International Airport (or called Senai Airport) runway widening was completed in 2007 and taxiway widening was completed in 2008, for new airport developments and services such as training centre for SIA Airbus A380. Being able to overcome operational limitation and technical challenges, Chemilink stabilization system was again invited for these two projects.

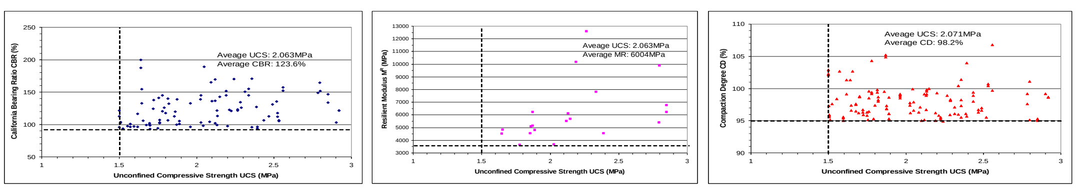
One of the key challenges in these projects is the extremely bad soil conditions (Table 1). Local soil was nearly 100% clayey soil with very high liquid limit (up to 88%), plastic index (up to 46%), and in-situ moisture content (up to 42%, which is about twice of the optimum moisture content). According to the local specifications, the in-situ soils are unsuitable materials and thus have to be replaced with fresh qualified quarry materials. After the soil stabilization (Photo. 3), such "unsuitable" materials as well as some asphalt milling wastes were strengthened and the achieved results met all the technical requirements. Referring to Fig. 2, the average values of UCS, CBR, M_R and Compaction Degree (CD) are 2.1MPa, 120%, 6,000MPa and 98% respectively (Wu et al., 2008).

Table. 1. Typical Soil Investigation for Senai Airport Widening

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. 3. Soil Stabilization in Senai Airport



a) UCS & CBR b) UCS & M_R c) USC and CD

Fig. 2. Testing Results in Senai Airport Widening Projects

2) Seaport Facilities

Indonesia Batanmas Shipyard (1997)

a) Manually Spreading b) In-Situ Mixing and Compaction

Photo. 4. Soil Stabilization in Progress in Shipyard

The existing ground was stabilized to form the sub-base for the upper layer of reinforced concrete. The spreading was done by manual and average daily construction rate is about 8,000m^2 (Photo. 4).

Malaysia Port Klang Container Yard Upgrading (2010)

Due to very soft ground conditions and ultra high loading, facilities in most seaports in the region experience serious different settlement issue. Maintenance and upgrading of the container stacking yard in Northport of Port Klang (the biggest port in Malaysia) was conducted in 2010 to mainly rectify differential settlement issue (Photo. 5). The in-situ mixtures of crushed aggregates and soils from existing pavement were stabilized to form a semi-rigid platform as the sub-base of the yard in order to improve the loading bearing capacities and to eliminate differential settlements. After the maintenance and upgrading, the loading bearing capacity increased three times from 2 tiers to 6 tiers of laden containers.

a) Before Upgrading b) Before and after Stabilization c) Upgraded Yard in Operations

Photo. 5. Upgrading of Port Klang Container Yard

3) Highways and Roads

Brunei Jalan Tutong, Phase III (1999)

It is a typical highway construction over the swampy areas. In original pavement design, a dense pilling foundation was proposed and the similar design adopted in another nearby highway was proven ineffective several years ago while the cost by using this full pilling system is too high to accept. Therefore after intensive technical studies and re-designs, the soil stabilization method was carried out for both base and sub-base courses on the top of backfilling soils after shallow excavation. A lower layer of 100mm thick well-compacted sandy fill with a layer of geotextile on the bottom was formed before the sub-base with 350mm thick stabilized soil and the base with 225mm thick stabilized weak stone to be constructed. The design of the surface layer remained the same (Fig. 3). Friction-pile was used incorporated with the soil stabilization system to provide a small portion as non-settlement zone for underground services while a gradual pile system was carefully incorporated in order to obtain a smooth road surface from non-settlement zone to free-settlement zone.

Fig. 3. Typical Cross Sections at Free- and Non-Settlement Zones

Furthermore several cross sections were cut and opened in order to directly observe and check the quality and performances of the chemical stabilized layers after 2 years from completion (Photo. 6-a). The road has been used with heavier public traffic for 12 years and there are no any signs of major defects and structural failures so that no major maintenances have been done (Photo. 6-b). The excellent performances during so many years have firmly proven the validity and durability of the Semi-Rigid "Floating" Platform generated from the soil stabilization system over the swampy areas, in additional to the huge cost savings for short- and long-terms.

a) Opened Cross Section after 2 Years

b) Road after 12 Years

Photo. 6. Jalan Tutong, Phase III

<u>City Road Maintenance, Brunei (2000)</u>

a) Road Partially Closed during Night for Maintenance

b) Road Opened for Use in Next Morning

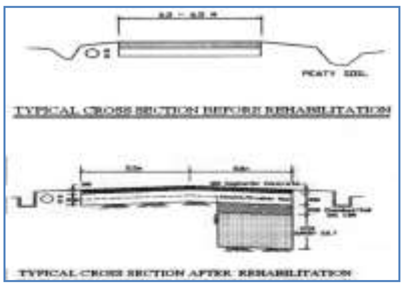
c) Cored Samples with Recycled In-Situ Materials

Photo. 7. City Road Quick Maintenance

With satisfactory technical performances in low lying and swampy areas in Brunei, Chemilink method was specified in the national General Specification for Pavement Stabilization in 1999 (GS 7:1999), for both new road construction and road maintenance. A road maintenance work in Jalan Tutong (Phase I) is a typical example of city road quick maintenance with in-situ rehabilitation of the existing base materials by the stabilization method (Photo. 7). The road was closed lane by lane in the mid-night and re-opened in the early morning of the following day. High initial strengths of stabilization allow the road to be re-opened immediately after laying the new asphalt concrete surface in the next morning to minimize impacts to the public.

<u>Widening of Junjungang Road, Brunei (1998)</u>

The key challenge in design to widen this road is how to prevent differential settlements between the existing pavement (30 years old) and the widening portion sitting on a fresh foundation with peaty sub-soils (Yong & Wu, 1999).



a) Typical Road Cross Section

b) Road after Years

Photo. 8. Widening of Junjungang Road

In the widening portion, the sandy silt with 1.5m thick was backfilled as the sub-grad and then the stabilization method was used in both sub-base and base courses (Photo. 8-a). The road with tens of kilometers has been opened to the public with excellent running conditions for years and no major defects, including differential settlement between new and old pavement, have been detected (Photo. 8-b).

<u>Examples of Roads in Swampy Areas, South East Asia (Since 1994)</u>

Several stabilized roads in the swampy areas under some interesting conditions are selected in this paper (Yong & Wu, 1999, Suhaimi & Wu, 2003). A 10-year monitored road section with stabilized soil sub-base and base courses is shown in Photo. 9, and the stabilized base surface after 10 years firmly indicated the good performances and durability of the stabilized road.

a) Stabilized Soil Samples *b) Stabilized Road (L) vs. Old Road* *c) Stabilized Surface after 10 Yeas*

Photo. 9. A 10-Year Monitored Road Section (1995-2004)

An interesting stabilized road at low-lying zone has lower embankment in order to reduce the total settlements. Though the water table is generally around the top of the base course so that the stabilized base and sub-base are soaked in the water as per normal in swampy area, the stabilized road performed well for years (Photo. 10).

Photo. 10. A Stabilized Road at Low-Lying Area (2004)

A stabilized access road in a Caltex oil field over the swampy area is shown in Photo. 11. The road was quickly built to support oil field operations under heavier loadings like the 120t equipment and its steel pipes stocks.

a) Sub-Grade Conditions b) Oil Field Road in Use

Photo. 11. A Stabilized Oil Road Access under Heavier Loads (2002)

CONCLUSIONS

Soil stabilization with appropriate stabilizing agents of chemical or bio-chemical admixtures, incorporated with proper designs and applicable methodologies, is a green and effective approach for pavement construction in tropical region with reverse environments and poor ground conditions for past about 20 years.

The stabilization with green product, green process and green result, can maximize the usage of in-situ or local soils and some construction wastes so as to obviously minimize the impacts to natural environment and significantly reduce the CO_2 emission.

Based the comprehensive case studies of various pavements, the systematic solution of soil stabilization introduced in the paper has been proven to deliver higher technical parameters and performances with fast construction and thus to provide longer pavement lifespan and overall cost effectiveness.

This well-proven system has presented premier, innovative and leading models especially in the "floating" semi-rigid platform over swampy or soft ground; the anti-cracking quality for high-grade pavement; and the excellent application workability and performances under exceptional heavily operational airport activities.

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