GREEN APPROACH TO RURAL ROADS CONSTRUCTION – STABILIZATION OF IN-SITU SOILS AND CONSTRUCTION WASTES

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ABSTRACT

A good network of roads links and transfer resources effectively and is vital for economic and social development. The number of paved roads in the world is 16 million kilometers. In Asia, China's 5 years plan to allocate resources to construct and rehabilitate 1.2 million kilometers, aiming to connect every village. At these numbers, the amount of quarry materials to be mined and transported is mind boggling; so is the cost – the cost to the treasury and the cost to the environment. However, building of roads in rural areas is always hindered by geographical limitation and often can be costly and energy inefficient, hence causing more adverse impact on the environment. In order not to increase burden on the mother earth, green approach is urgently required to fulfill the needs on rural roads, as well as preserve the environment. In this paper, CO_2 emission during rural roads construction by using conventional replacement method was estimated and compared with an alternative green approach – Chemilink Soil Stabilization method, to study the effectiveness of this new green approach in reducing the overall carbon footprint of rural roads construction, as well as other aspects in civil engineering. Chemilink Soil Stabilization was found to be able to reduce CO_2 by 16 times with providing better technical performances.

Keywords: Carbon Footprint, CO_2 Emission, Chemilink Soil Stabilization, In-situ Recycling

1. IMPORTANCE OF RURAL ROADS

1.1 Road to Development

Roads provide the platform and sustainability for economic activities and growth not only for urban areas but also rural areas. Quoting from the Asia Development Bank (ADB), in China Shaanxi province, "for every RMB 10,000 invested in roads, 3.2 poor people are lifted out of poverty and for every 1% increase in the length of roads per capita, household consumption increases by 0.08%. Besides, access creates higher land values, open up new entrepreneurial investment and stimulate the local industries enabling agricultural products to be efficiently moved to the market.

Roads are essential for development in rural areas. However difficult topography and unstable geology make the rural road constructions hard. Even though, due to the pressing needs to increase productivity and the lifestyles of all its inhabitants, the pressure is building up to build all these connections into the rural areas, in order open them up, to initiate and to kindle the economic activities. The demand is also mainly fueled by the expectations and wants created in these isolated rural areas which have all, but the most isolated been touched and connected by the internet and telecommunication – the mobile phone. It opens up a floodgate of sudden needs and wants, having connected wirelessly they now want to be connected physically – by roads.

1.2 Roads to Villages, and Resources

There is a total of 16 million kilometers of roads in the world, which can take us more than 20 times to the moon and back. It is still ever increasing especially in the developing countries; China in its latest 5 years plan includes building and renovating of 1.2 million kilometers of road, aiming for a road to every village.

Malaysia, in its last budget, allocated a substantial fund for soil stabilization, a green approach, for building of rural roads. It was mentioned to Prime Minister's budgetary speech 2009 that in 2010, a sum of RM2.3 billion will be allocated to construct and upgrade infrastructures in rural areas. Priority will be given to the use of soil stabilizers in the construction of rural roads, where appropriate. This is due to its lower cost of construction and maintenance. Under its NKRA (National Key Result Area) agenda and initiative, it focuses on its rural initiative in "Connecting roads" where the plan is to build 1500 km of rural roads in the next 3 years, to connect the villages as well as the resources.

1.3 Road to Economic and Environmental Considerations

As with the developed countries, the developing countries need to build its network of highways and roads to bring forth its productive resources. But the environment consequences cannot be neglected only foreseeing long term economic benefit. It must be noted that the traditional way of road building extracts a heavy price on the environment and this couple with the usually non-accessibility of rural roads make the task all that more difficult and expensive. The logistics of transporting road building materials hundreds of kilometers over often non-existent access road is enough to kill the project at the gestation and conception stage. Besides the many tons of aggregates, asphalt… etc mined from non-renewable sources and the many gallons of fuel needed to truck them and lay the roads, extracting a heavy cost on the environment with the consequential CO_2 emission.

Hence the green road approach is proving to be a sustainable way of constructing rural roads. Environment friendly construction techniques, participatory and decentralization approach, optimum utilization of local resources, simple technology, and self help efforts justified the Green road approach as a best way of constructing rural roads in developing countries.

In this paper, a green road approach – Chemilink Soil Stabilization method was studied and compared with conventional road building method, in terms of environmental impact as well as other civil engineering implications.

2. GREEN HOUSE GAS EMISSION AND CARBON FOOTPRINT

2.1 Outline of Estimation on CO_2 Emission

In this study, CO_2 emission from rural road constructions was analyzed in 2 different methodologies, Conventional Replacement method which use quarry material (or stone aggregate) and asphalt concrete as the major construction materials, and Chemilink Soil Stabilization method which use soil stabilization agent to improve the engineering properties of in-situ material to function as road base with chip seal layer for surface layer.

Generally, for both methods, construction work involved in rural roads construction is divided into 4 stages as shown on Figure 1. Energy consumed and CO_2 emitted in rural road construction were calculated based on following scope of work:

(i) Material Production: Total quantities of materials, including road base and surface layer, machines and disposal of any waste.
(ii) Transportation: Fuel consumption to deliver all materials and machineries to work site, and to dispose any construction waste generated away from site.
(iii) Construction: Fuel consumption for machineries that used for rural road paving construction.

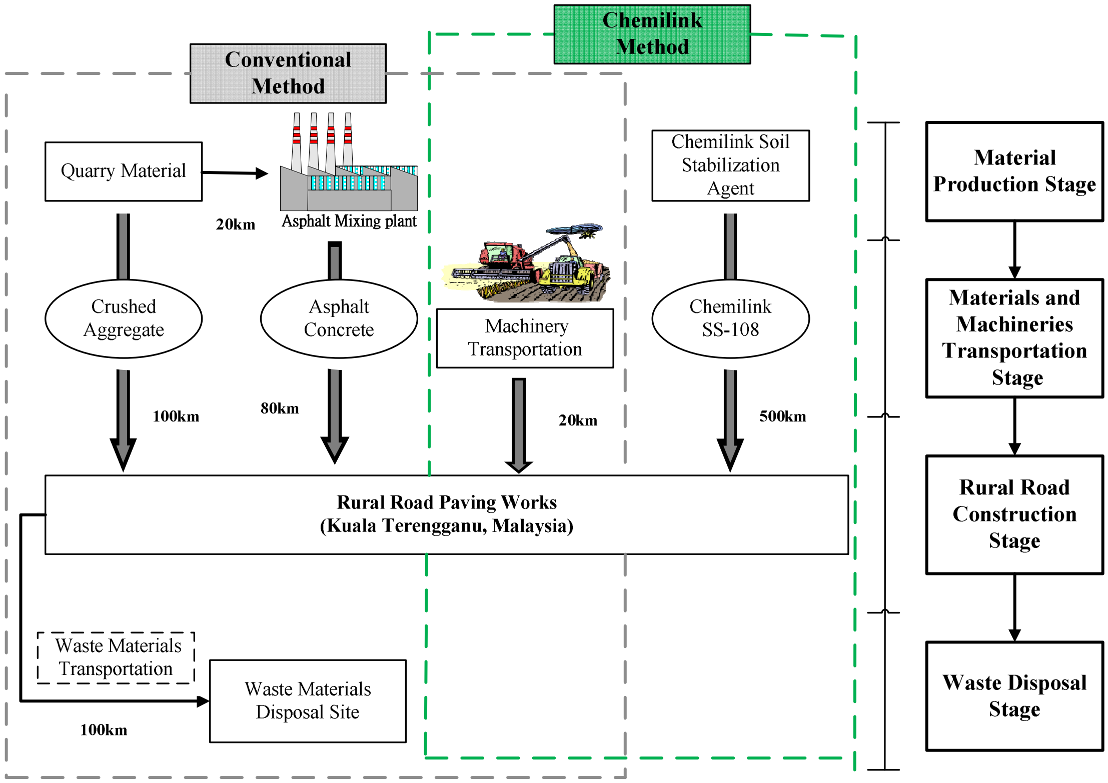


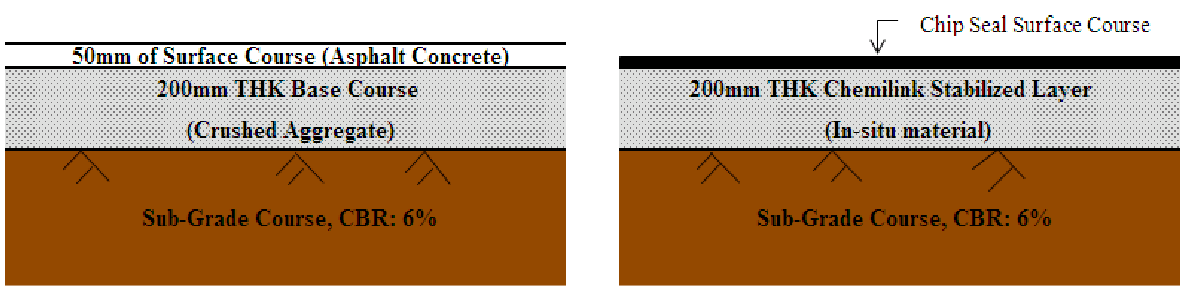
Figure 1: Range for Determine the Environmental Loads of Rural Road Construction

2.2 Case Study - Estimation and Comparison on CO_2 Emission

Two rural road construction projects in Terengganu, Malaysia were completed in December 2009, by using a green approach – Chemilink Soil Stabilization Method. Following project information were extracted and used for the estimation and comparison on CO_2 emission.

(i) Logistic Movement: Based on the completed project mentioned above, the distance of transporting for quarry materials to the paving works site were estimated to be 100km, 500km for Chemilink soil stabilization agent and 20km for road construction machineries.

(ii) Pavement Structural Design: Cross sectional drawing for pavement structural design for both conventional method and Chemilink method are shown in Figure 2. Conventional design was based on common practice of rural road construction in the region while Chemilink design was based on the design parameters and specifications adopted for these rural roads.



(a) Conventional Design (b) Chemilink Design

Figure 2: Different Schematic Cross Sectional Designs for Rural Roads

(iii) Dimension: Estimation based on rural road of 1km length and 4m width, with total area of 4000m^2

(iv) Calculation
Based on the pavement design, the quantities of materials and machines used for rural road paving construction, as well as the amounts of fuel consumption for both logistics and construction, can be estimated.

With references to various available sources (Atsushu et. al., 2009), fuel consumption for machineries as well as transportation can be estimated based on the rate of consumption as tabulated in Table 1. With quantity of resources known, including all construction materials and fuel consumed, the CO_2 emission can be calculated based on basic unit of environmental loads.

Table 1: Machineries Used and Respective Fuel Consumption

Equipment and machinery		Fuel consumption rate (Diesel)
A. Surface layer	Asphalt Paver	0.019-0.053 L/m^2
	Road roller	0.015-0.030 L/m^2
	Tire roller	0.018-0.036 L/m^2
	Vibratory roller	0.031 L/m^2
B. Base layer	Rotovator	0.019-0.053 L/m^2
	Motor grader	0.019-0.053 L/m^2
	Water tank	0.1114 L/m^2
C. Material transportation	Truck	4.90-19.72 L/hour

Suggested by Hiroyuki et. al. (2008), basic unit of environmental loads of materials used for rural road paving construction were as shown in Table 2. Based on these data, CO_2 emission for rural road construction by each stage can be determined.

Table 2: Basic Environmental Loads

Item	**Unit**	**CO_2 Emissions (kg-CO_2)**
Asphalt Concrete	Ton	26.2
Virgin aggregate	Ton	0.95
Bitumen	Kg	0.248
Diesel	L	2.69

2.3 Results of Estimation on CO_2 Emissions

Table 3 shows the estimation of the materials consumed by both Conventional method and Chemilink method for rural road construction. The CO_2 emission estimation was derived by multiplying the amount of material consumed by the basic units of environmental loads, the result of environmental loads for different rural road construction methods as shown at Table 4 and Figure 3.

Basing on the classification of the environmental loads into CO_2 emission stage for rural road construction into material production, transportation, construction (paving works) and waste disposal stages, it showed that the CO_2 emission in the stage of material transportation was the greatest, followed by waste disposal transportation. Conventional method needs a large of import quarry material for replacing the existing materials, hence the logistics of material to construction paving work and disposal of the waste material resulted in the high fuel consumption.

Table 3: Amounts of Material Consumption

Emission stage		**Quantity of materials**	
		Conventional Method	**Chemilink Method**
I. Material Production			
Surface layer	Bitumen	29.7 t	2.5 t
	Imported virgin aggregate	510.8 t	46.0 t
Base layer	Imported virgin aggregate	2208.0 t	NIL
	Soil stabilization agent	NIL	49 t
Total Quantity of materials		2721.7 t	97.5 t
II. Materials and Machineries Transportation			
Diesel consumption (L) (Materials)		22584.0	2013.1
Diesel consumption (L) (Machineries)		92.0	52.6
III. Rural road construction			
Paving Work	Diesel consumption (L)	1063.2	587.3
IV. Waste Disposal			
Diesel consumption (L)		18142.0	0.0

Table 4: CO_2 Emission Estimation

Emission Stage	**Conventional Method**	**Chemilink Method**
I. Material production	16.30	0.71
II. Material and Machineries Transportation	60.95	5.56
III. Rural road construction	2.90	1.58
IV. Waste Disposal	48.80	NIL
Total stage emissions (ton-CO_2)	**128.95 ton**	**7.85 ton**

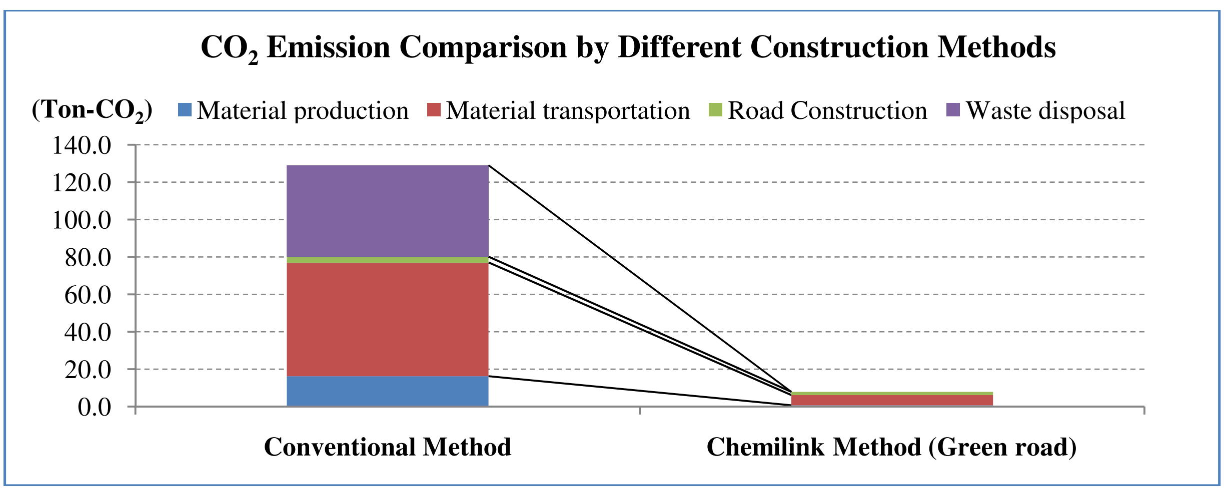


Figure 3: CO_2 Emissions Estimation Result

As shown in Table 4 and Figure 3, the CO_2 emitted to build 1km of rural road by using conventional method was estimated to be 128.95 ton and for Chemilink method 7.85 tons, which showed that by a green approach such as Chemilink Soil Stabilization method, the CO_2 emitted can be effectively reduced by up to 16 times.

3. CHEMICAL SOIL STABILIZATION

3.1 Background of Chemical Soil Stabilization

Conventionally in road construction, the unsuitable in-situ soils are replaced by imported quarry materials. However, the quarry materials are sometime difficult and expensive to procure in certain areas and Natural environment is adversely affected as well. 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 weak 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.

With appropriate stabilizing agent, 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.

3.2 Process of In-situ Chemical Stabilization Application

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 (Photo. 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.

Mechanical Spreading

In-situ Mixing

Compaction

Photo. 1. In-situ Mixing

For rural road construction, in view of possible unavailability and inaccessibility of the sophisticated machineries, the construction methodology of in-situ soil stabilization was modified, to cater for the working condition in rural areas, as well as using machines available as an alternative. Spreading of stabilizing agent can be done manually, which can effectively lower the construction cost, this provides more job opportunities to the local residents. Besides, the widely available agricultural rotorvator can replace the specialize stabilizer. Construction procedures of such simple method were shown in Photo 2.

Manual Spreading

Mixing by Rotorvator

Compaction 2

Photo 2. Simplified Method of In-situ Soil Stabilization

3.3 Highlight of Projects Adopted Chemical Stabilizing Agents

3.3.1 Rural Roads Construction (2009), Terengganu Malaysia: The rural roads were completed by using Chemilink Stabilization Technologies, with the pavement design shown in Figure 2b above. With simple construction method, the projects were completed without closing the roads and disrupting the daily economic activities of the villagers.

3.3.2 Plantation Access Road Construction, Felda Sahabat 7 (2009), Malaysia: This palm oil plantation access road located in low lying area which was originally prone to flood. Previously this road is always damaged during flood and required frequent maintenance every few months. However, after Chemilink Soil Stabilization treatment on the road base course, without any surface course, the road was proven to be fully functional and operational even during and after each flood.

3.3.3 Sultan Ismail International Airport Runway/Taxiway Widening (2007-2008), Malaysia: Having been successfully applied in runway widening projects in both Changi Airport and Sultan Ismail International Airport (a.k.a. Johor Bahru Senai Airport), Chemilink Soil Stabilization Technologies was adopted in Taxiway Widening project of Sultan Ismail International Airport. By replacing graded granite aggregate sub-base course with Chemilink stabilized soil layer, daily construction was about three times faster, with the specified quality delivered (Wu et. al., 2008a).

3.3.4 Changi International Airport Runway Widening (2004-2005), Singapore: This runway-widening project is an example of how Chemilink stabilization can achieve cost and time savings and also reduces disruptions on the airport operations. Widening of both runways was completed in 60 working days while the schedule was 6 months. Changi Airport was one of first airports to meet operational requirements for Airbus A380, and was featured in Discovery Channel - “Man Made Marvels” programme (Koh et.al., 2005).

3.3.5 Oil Field Road Construction for Caltex (2003), Sumatra Indonesia: A temporary access road over swampy and peaty foundation was required, in order to mobilize heavy machineries, such as oil rigs, into the oil field. Instead of conventional deep replacement method, it was proposed to import 200mm of earth materials as embankment and chemically stabilize the earth materials. The proposal was adopted and proven for its technical effectiveness and cost efficiency (Wu et. al., 2008b).

3.3.6 Jalan Tutong Widening Phase II & III (1997-1999), Brunei: Jalan Tutong is a major city with heavy traffic, located in swampy area with high water table. From previous experiences of local Public Work Department, it was known that various methods such as geogrid system or piling system were not effective and not suitable for such ground condition. Chemilink Stabilization Technologies was adopted in both phases of the project, acting as sub-base course and road base course. After being succeed in road construction in soft ground and swampy foundation, Chemilink Soil Stabilization Technologies was specified in general Specification of Brunei Public Works Department (Suhaimi et. al., 2003).

3.3.7 Batamas Shipyard Construction (1997), Batam Indonesia: The foundation was weak with wet sandy silty soils, and some stone chips. Therefore the shipyard required the existing ground be strengthened. Instead of using lean concrete as the sub-base, it was proposed to stabilize up to 300mm deep, in order to form higher quality sub-base course to support the upper layer of reinforced concrete slabs. Previously, cement, lime and other chemical stabilizing agents were used to stabilize the soils but the results were unable to meet the design requirement of CBR ⩾ 60%. However, by using Chemilink Soil Stabilization, average CBR of 75% was achieved. By combining manual spreading and mechanical mixing, average daily production was 8,000m^2 (Wu et. al., 2008b).

3.3 Technical Justification of Alternative Chemilink Method

Refer to Figure 2, the Chemilink design concept is to replace the stone aggregate road base course with Chemilink Stabilized Soil Layer of same thickness. Instead of conventional requirement of California Bearing Ratio (CBR) ⩾ 80%, design criteria for Chemilink Stabilized Soil Layer is set to be CBR (7-d) ⩾ 90%, to provide technical performances in terms of stress bearing capacity and vertical stress reduction.

With the base course replaced by a stronger Chemilink Stabilized Soil Layer, the asphaltic concrete surface, acting as a structural component of the pavement, is no more required. Chemilink Stabilized Layer as a bound material layer with extremely high impermeability is effective in protecting the sub-grade from surface water. Therefore, the surface wearing course is replaced by a chip seal surface.

To verify Chemilink design is sufficient and at least having equivalent strength compared with conventional design, the program KENLAYER was used. By using "Pavement Design and Analysis by Yang H. Huang, Second Edition, 2003 in conjunction with KENLAYER", vertical stress of different structural component of the pavement can be analyzed. And so, the effectiveness in load bearing, distribution and reduction in each layer can estimated and the maximum vertical stress impose on existing sub-grade layer can be anticipated.

Following assumptions were made for calculation:

- Load configuration: Standard Axle Load: **80kN**, Single Axle with dual tires.
- Contact pressure: **700KPa.**
- Pavement thickness (structural) of conventional design = 250mm (50mm ACWC + 200mm base)
- Pavement thickness (structural) of Chemilink design = 200mm (200 of stabilized soil base)

From the KENLAYER analysis, for the Standard Axle Load of 80kN with 700kPa of contact pressure, in proposed alternative pavement design, the vertical stress imposed on top of sub-grade layer can be effectively reduce to **33.482kPa**, which is lower than conventional pavement design **(68.712kPa)**.

4 OTHER ADVANTAGES OF CHEMICAL SOIL STABILIZATION

4.1 Better Technical Performances

The chemical stabilized materials have higher strengths and these can always be adjusted to meet different design requirements, such as Unconfined Compressive Strength and California Bearing Ratio.

The stabilized materials have good volume stability such as lower compressibility under different water and temperature conditions. The higher the strength, 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 when compared to those of un-stabilized materials.

Furthermore, the stabilized materials form a semi-rigid platform that delivers 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.

4.2 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 urban cities and rural areas lacking of natural quarry materials. Besides, reduced usage of raw backfilling materials implies energy conservation arises from much less materials transportation and less mechanical crushing of granite aggregate. For rural areas and farming region the transportation of quarry materials is often far and can be done in small transport vehicles.

4.3 Minimize Creation of Construction Wastes

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 creating environmental issues. With chemical soil stabilization, unsuitable in-situ soil can be reused, instead of being 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 soil, which translated to an immediate saving of nearly S$200,000 in disposal cost for the airport authority.

4.4 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 allows early completion and early usage of the roads. With less heavy vehicular movement involved, environmental pollution such as air, noise and dirt deposit can be greatly reduced. Besides, Chemilink method contributes less to the traffic congestion.

4.5 Overall Cost Effectiveness

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

5. CONCLUSION

129 tons of CO_2 is emitted when every kilometer of rural road is constructed by using conventional method. It is now understood that conventional road paving method, especially for rural roads, poses serious environmental impact. Ironically we often ignore and pay little attention to the harmful contributions from the highly unfriendly traditional method of building roads with numerous virgin resources. Therefore, greener approach for road building, especially for rural road is to be implemented and executed. Chemical Soil Stabilization method was studied as an alternative with green approach to rural roads construction. By adopting this green approach, carbon footprint for rural roads construction can be reduced by more than 10 times. Among the common agents, Chemilink Soil Stabilizing agent is one of the widely used and proven in the region.

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