

Road Maintenance Experience Using Polyurethane (PU) Foam Injection System and Geocrete Soil Stabilization as Ground Rehabilitation

A M M Fakhar¹ and A Asmaniza¹

¹ Maintenance Monitoring Department, PLUS Berhad, PLUS, 47301 Petaling Jaya, MALAYSIA

E-mail: fakhar@plus.uemnet.com

Abstract. There are many types of ground rehabilitation and improvement that can be consider and implement in engineering construction works for soil improvement in order to prevent road profile deformation in later stage. However, when comes to road maintenance especially on operated expressways, not all method can be apply directly as it must comply to opeation's working window and lane closure basis. Key factors that considering ideal proposal for ground rehabilitation are time, cost, quality and most importantly practicality. It should provide long lifespan structure in order to reduce continuous cycle of maintenance. Thus, this paper will present two approaches for ground rehabilitation, namely Polyurethane (PU) Foam Injection System and Geocrete Soil Stabilization. The first approach is an injection system which consists two-parts chemical grout of Isocynate and Polyol when mixed together within soil structure through injection will polymerized with volume expansion. The strong expansion of grouting causes significant compression and compacting of the surrounding soil and subsequently improve ground properties and uplift sunken structure. The later is a cold in-place recycling whereby mixture process that combines in-situ soil materials, cement, white powder (alkaline) additive and water to produce hard yet flexible and durable ground layer that act as solid foundation with improved bearing capacity. The improvement of the mechanical behaviour of soil through these two systems is investigated by an extensive testing programme which includes in-situ and laboratory test in determining properties such as strength, stiffness, compressibility, bearing capacity, differential settlement and etc.

Keywords: Polyurethane foam (pu), geocrete, soil stabilization.

1. Introduction

Expressways or high speed road corridors have been one of the most vital infrastructures in the overall socio-economic development in Malaysia and the asset maintenance is basically the key toward preservation to restore and maintain at specified level of services and prolong the life span by reducing its deterioration rate. By neglecting or delaying maintenance activities may indirectly incurred the overall repair cost thus increase vehicle operating costs. With the existing road infrastructure that been served towards public road users, there will be time where deterioration may occur especially on soft ground and weak road base area (e.g settlement, depression, faulting, undulation, sinkhole and etc.) due to loss materials (wash away effect), poor compaction during construction, sunken structure, high



traffic loadings, current global climate and many more which requires continuous round of maintenance thus increased the unnecessary budget spending.

In practice, conventional remedial method applied such as asphalt overlay and regulating, cementitious grout, sealing cracks only provide short-term solutions by addressing the symptoms, but not the underlying problem. These actually exacerbate the problem by placing additional weight on an already overstressed soil structure, thus will continuously require similar round of maintenance. Treatment reconstruction by full depth removal can be done however its time consuming, bigger space for closure and extremely costly. A practical of immediate measurement which able to sustain for some period of time, reduces frequency of remedial maintenance, shortening time of repairing is greatly needed [1]. The reparative pavement structure and soil improvement should have sufficient bearing strength and good flatness to ensure the vehicle's safety on the expressways [2]. A green, sustainable and cost-effective technology is hereby tabled to address the issues of insufficient bearing capacities and differential settlement for roads in soft grounds and weak base area. Soil stabilization can be defined as an approach or technique in improving the existing ground soil through modification properties of engineering characteristics behaviour such as bearing capacity, stiffness, strength, density, compressibility as well as hydraulic conductivity [3]. This is to address long term consolidation and settlement, stability and bearing capacities for the foundation. The following will describe further fundamental product for both soil stabilization systems.

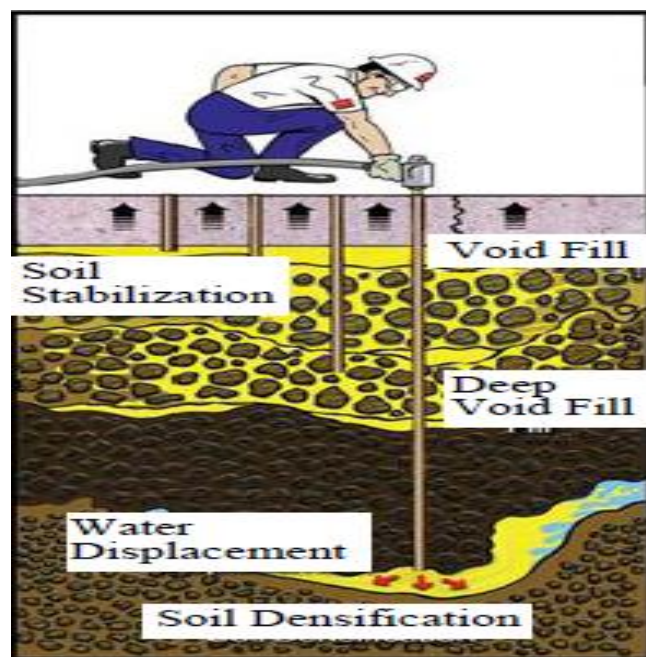
1.1 Polyurethane (PU) Foam Injection System

A patented process that uses chemical grout (isocyanate and polyol) combination product that able to uplift, realign, underseal, fill voids and strengthening ground soil structure which has been implemented with successful outcome at several States [4,5]. The injected resin within the soil will gain approximately 90% of its maximum compressive strength (minimum compressive strength of 0.276 N/mm²) within 15 minutes [6] and can be open to traffic the next day. Both chemicals are environmental friendly, non-toxic product and indefinite life span (refer Table 1 for chemical properties). The PU foam is based on three dimensional networked solid polymer with high strength that is produced with generation of heat and increase of volume when both liquid isocyanate and polyol (contains little amount of water) compound is mixed [7,8,9]. Rigid PU (referred as "hard bubble") has characteristics of light weight and expansion foam ability with high specific strength, strong in bonding stress with other substances, anti-aging properties and curing in a short time.

Method of PU grouting is basically identical to the conventional cement grouting whereby the chemical resin is injected into the ground by drilling the hole, install the packer with tube and filling up the voids between the ground soil (see Figure1). In addition, with the use of PU the bearing capacity of the soil is improved due to the expansion of voids between the soil particles [3]. Furthermore, the lightweight characteristics of PU allow a reduction of settlement rate and expansion characteristics of PU able to lift up the ground soil.

Table 1. Properties of Isocyanate and Polyol Component.

Property	Polyol	Isocyanate	
Density, 25°C	1.10 g/cm ³	1.23 g/cm ³	
Viscosity, 25°C	1500 mPa.s	220 mPa.s	
	Units	Test Method	Results
Density	kg/m ³	ASTM D-1622	160
Ultimate Compressive Strength at 20°C	kPa	ASTM D-1621	2,290
- Force parallel			
- Force perpendicular			
Thermal Conductivity at 20°C Fresh Foam	W/m.K	ASTM C-518	0.0379
Percentage of closed-cells	%	ISO 4590	91
Water Absorption at 20°C	% by volume	ASTM D-2842	0.33

**Figure 1.** PU injection illustration.

1.2 Geocrete Soil Stabilization

Stabilization on existing ground soils using cement has been widely used through recycling approach in improving the properties and enhanced the span life usage. However, applications of cement with cohesive soils are difficult as serious cracks render, less durability and requires minimum of 7 days of curing prior to road opening. Stabilizing the soils with cement quite an issue as humus acids especially fulvic and carbon acids within the organic mass blocks the cement hydration process almost completely. Lime also has been introduced in stabilizing poor soils, however it results low strength and durability of soil. Moreover, the usage of foamed bitumen as stabilizing agent to waterproof soils and aggregates, keeping moisture contents low and high bearing capacity, however extremely costly

with potential environment hazard [10]. Thus, Geocrete additive agent is introduced to countermeasures the issues highlighted especially curing process.

Geocrete (whitish powder consisting of alkaline earth element compound) is an additive to cement that able to neutralize the humus acids. The hydration of cement in the soil stabilization or immobilization when mix with water (see Figure 2) [11]. The powder and cement mix allow an environmental friendly transition of the existing soil into a newly build concrete like structure or in other word semi-rigid formation with impermeability characteristics. Unlike concrete where short crystalline structures are form and easily cracks. Geocrete allows long crystalline structures to be build and produce higher bearing capacities of soil, strength, elastic modulus and water impermeable. This can be illustrated using electronic microscopic as shown in Figure 3 & Figure 4. Besides improving the mentioned, Geocrete promotes the immobilization of pollutants such as heavy metals and organic parameters which get permanently embedded to the newly crystallized soil structure. Determination of the mixture will depend on the properties for in-situ soil. The next section will describe further the material preparation and scope of works for both systems that have been successfully implemented.

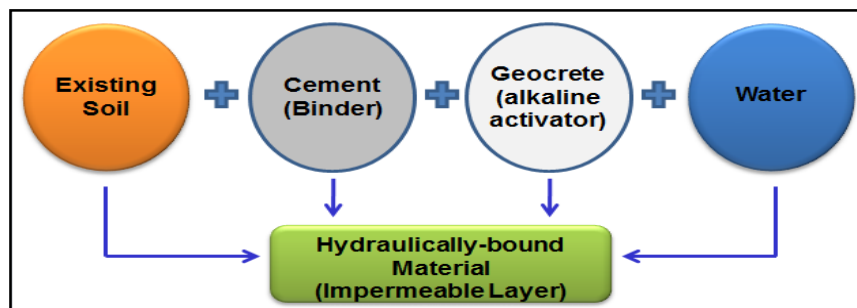


Figure 2. Mixing combination of Geocrete soil stabilization.

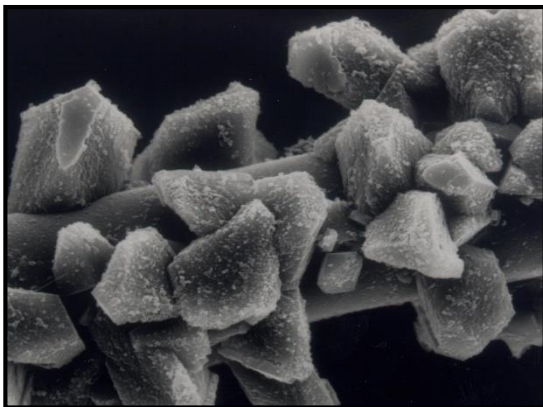


Figure 3. Cement soil stabilization – low crystal interlocking connectivity.

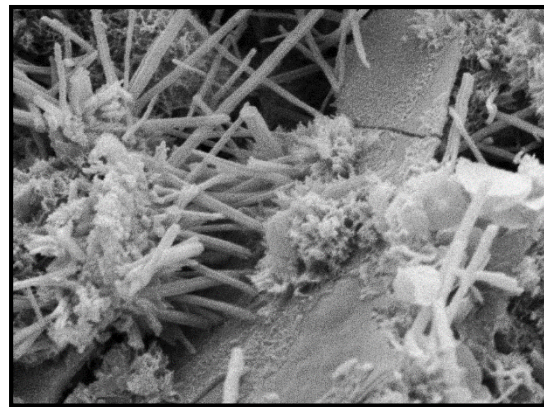


Figure 4. Cement-Geocrete soil stabilization - high crystal interlocking connectivity.

2. Materials and Methods

2.1 Material Preparation and Scope of Work for PU Foam Injection System

The case study presented herewith is at KLIA Toll Plaza, North-South Central Link of which experienced undulation road profile along concrete pavement. Thus, proposal of using 2 types of chemical polyurethane, namely *Rapid Polyurethane* (soil stabilization and ground compacting) and *Dense Polyurethane* (densification and uplifting of concrete structure). Also, materials used the combination of Isocyanate and Polyol mixture with mix ratio of 1.1 : 1.0 respectively. Blowing agent

has been incorporated into the resin, however additional agent (nitrogen based catalyst) will be added to improve foam's expansion.

The working area is measured 51 m length x 45 m wide which covers 4 Smart Tag, 3 Touch n Go and 2 Cash lanes as shown in Fig. 5. About 621 points were identified for grouting injection with drilled hole size of 16 mm diameter for *Rapid Polyurethane* injection and 32 mm diameter drilled hole for *Dense Polyurethane* injection at each point respectively. Each point was injected in two (2) phases; Phase 1 injection of *Rapid Polyurethane* up to the depth of 2 m and Phase 2 injection of *Dense Polyurethane* up to the depth of 1 m) below concrete structure. Works are done on lane per lane basis to compensate the operational highway requirement. Pre- and post evaluation and performance test were also carried out through using in-situ JKR Probe test for strength parameter. Coring soil samples were before and after injection to determine improved strength, stiffness and compressibility by performing Unconfined Compression Test and One-Dimensional Consolidation Test.

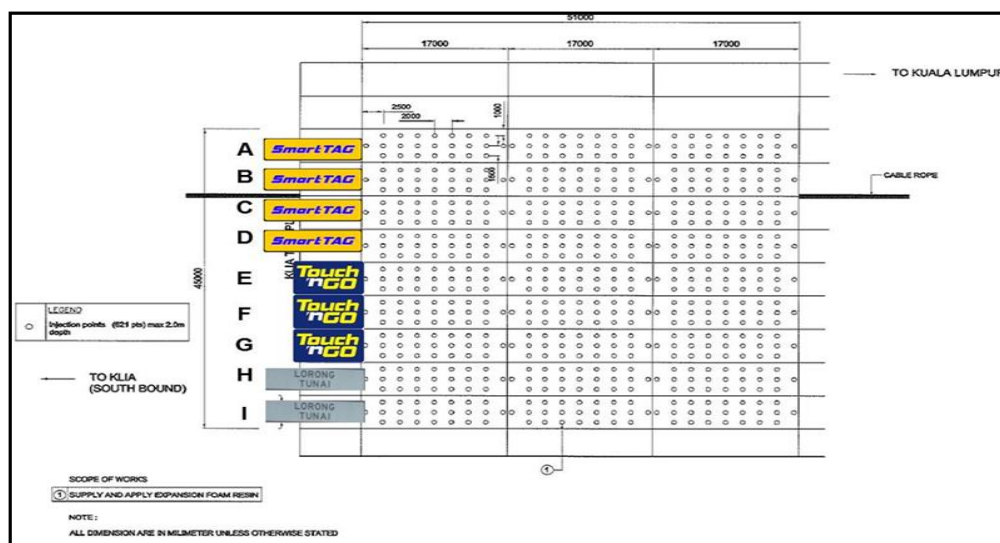


Figure 5. Points identified for PU injection.

2.2 Material Preparation and Scope of Work for Geocrete Soil Stabilization

Soil stabilization using Geocrete at KM 150.70 Southbound, Along Tangkak–Pagoh North South Expressway presented herewith. Initially, existing road experienced undulation with uneven surface, severe cracks and pumping effect at all lanes. Total area proposed for soil stabilization was 6215 m² (refer Figure 6). Prior to implementation, sample of existing road base was taken and conducted series of laboratory test through classification and pre-qualification test (e.g sieve analysis, proctor test, moisture content, density and unconfined compressive strength) in conforming Geocrete design mix. For this project, the proposed mix design was 8% of cement (Type 1), 2% of Geocrete powder (by weight of cement) and 10% of quarry dust (to improve the existing material nearer to an ideal particle size distribution curve). Proposed depth of soil stabilization is 300 mm which based on design traffic (e.g 10 to 30 x 10⁶ ESAL) and specification used for recycling work is *JKR Standard Specification for Road Works, Section 4: Flexible Pavement—Cold in Place Recycling* and *Specification for Soil: Cement Agent Mixture* respectively. Evaluation test were carried out by means of Light Falling Weight Deflection (LFWF) and Unconfined Compressive Strength (UCS) test during and post construction. On site, the stabilization works are done through lane per lane basis.

Works commenced by initially scrapping off the existing asphalt layer of 150 mm thickness. The Light Falling Weight Deflection (LFWF) are then carried out to determine the existing strength before stabilization. For Geocrete stabilization works, the existing road base material will be mixed with the designated cement (Type 1) + Geocrete powder mixture based on the approved mix design. The

required quarry dust are spread uniformly over the existing base area prior spreading cement (Type 1) + Geocrete which are laid equally per unit area. Once complete, the CAT RM500 machine is then commenced and stabilized the soil with the required depth and ensure uniform blend of stabilization material. Water are spread over the soil-cement-quarry dust-Geocrete mix to start chemical reaction for stabilization process with an extra of 2% from Optimum Moisture Content (OMC). After stabilization, the area is compacted with 10 tones drum roller vibration for 2 passes and subsequently grading uniformly to the required profile depth. Final compactions are performed for another 3 passes with speed of not more than 3 km/hr. Once completed, curing process are carried out by using water tank sprinkler on the stabilized soil periodically for every 3 to 4 hours within 24 hours. This is to ensure to avoid any formation of premature cracks by controlling hydration of the stabilization process and risk of quick evaporation. After 24 hours curing, paving work commenced by laying 60 mm Asphaltic Concrete Base Coarse (ACBC 28), 60 mm Asphaltic Concrete Wearing Coarse (ACWC – 50 mm) and regulating layer as final surface.

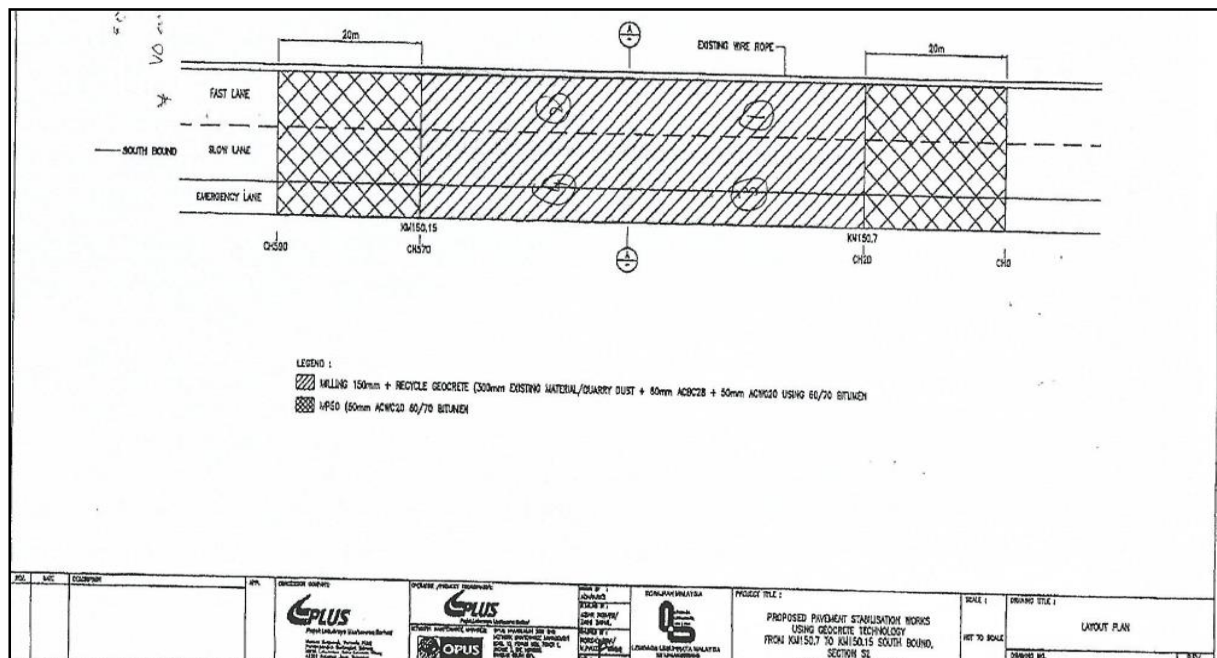


Figure 6. Layout plan for Geocrete stabilization work.

3. Results and Discussions

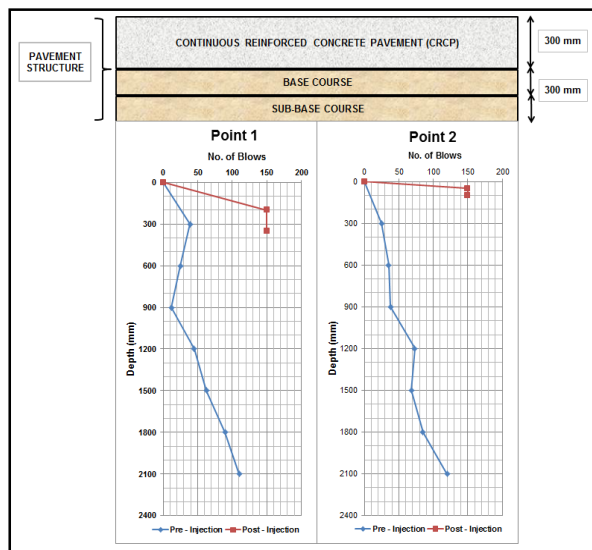
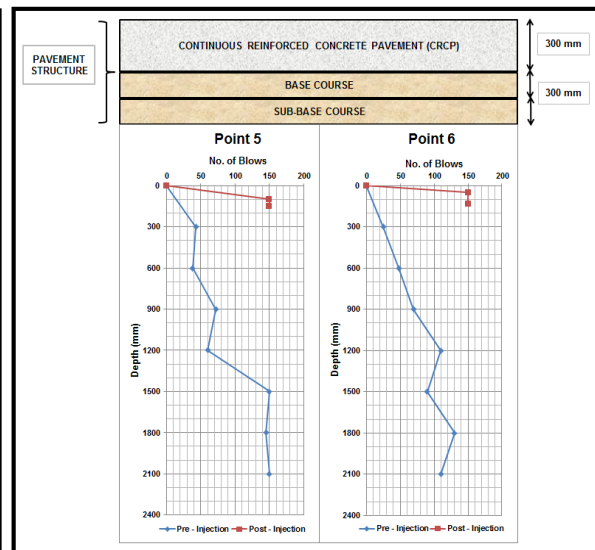
3.1 (PU Foam Injection System)

JKR Probe test measures soil resistance to penetration / stiffness by number of blows obtained per 300 mm penetration (150 blows per 300 mm for shallow foundation). Soil strength parameters correlated to JKR Probe is shown in Table 2.

Results blow count number per penetration depth for both natural (pre-injection) and modified (post-injection) soil displayed only for 2 lanes as shown in Figure 7 and Figure 8 as other area presents similar output. Observed that natural soil resulted low numbers of blows (less than 150 blows – blue line) and consistent with soil consistency ranging Very Soft to Stiff which suggests that the soil having loose soil formation with the presence of voids and cavities. As for modified soil (red line), it recorded 150 number of blows with maximum penetration depth up to only 350 mm and classified as Hard with strength value of 600 kPa. The injection foam successfully filled all existing voids, cavities and throughout the capillaries within the soil by expansion force thus improving the bearing capacity and strength of soil.

Table 2. Correlation for number of blows against strength of soil.

JKR Probe (Blows/300mm)	Consistency of soil	Unconfined Compressive Strength	
		kPa	ton/ft ²
0 - 10	Very soft	0.0 - 25	0.00 - 0.25
10 - 20	Soft	25 - 50	0.25 - 0.50
20 - 40	Medium (firm)	50 - 100	0.50 - 1.00
40 - 70	Stiff	100 - 200	1.00 - 2.00
70 - 100	Very stiff	200 - 400	2.00 - 4.00
100	Hard	400	4.00

**Figure 7.** JKR Probe Test results.**Figure 8.** JKR Probe Test results.

As for strength and stiffness, results data are shown in Table 3. For reference purposes, natural soil specimens are labelled as KLIAud (undisturbed soil) and modified soils as KLIAMs. The maximum compressive stress values for modified soil recorded between 190.30 to 199.30 kPa respectively, 1 to 3 times higher than the natural soil (62.10 to 145.00 kPa) and stiffness increased up around 5 to 6 times greater. This can suggest that the modified soil able to withstand bearing foundation of more than 150 kPa as specified for shallow foundation.

Table 3. Shear strength and stiffness for natural and modified soil specimens.

Soil sample	Maximum deviator stress (kPa)	Young's modulus (kPa)	Undrained shear strength (kPa)
KLIAud01	68.70	1,400	34.30
KLIAud02	145.00	6,000	72.50
KLIAud03	62.10	1,400	31.10
KLIAMs01	198.30	5,000	99.15
KLIAMs02	199.30	8,000	99.65
KLIAMs03	190.30	7,000	95.15

For compressibility, both soil specimens (natural and modified) were analyzed to demonstrate the compressibility characteristics in terms of void ratio, pre-consolidate pressure, compression index and swelling index. Based on the results obtained (see Table 4), modified soil recorded 0.435 of initial void ratio (e_0), reduced about 31.5% than natural soil (0.635) and suggest that the PU foam has filled most of the void spaces and causing water or moisture entrapped within the soil to push out since it

has water repellent ability. Furthermore, the swelling index also reduced by 60.9% (0.009) for modified soil than that of natural soil (0.023) which indicates that volume change, settlement rate and also plastic of permanent deformation are minimal.

Table 4. Compressibility characteristics between natural and modified soils.

Soil	Initial void ratio, e_0	Compression index, c_c	Swelling index, c_s	Preconsolidated pressure, p_c (kPa)
KLIAud04	0.635	0.076	0.023	52
KLIAms04	0.435	0.075	0.009	56

3.2 Geocrete Soil Stabilization

For unconfined compressive strength (UCS) test, specimens of 3 numbers were taken on site by means of coring for day 1, day 7 and day 28 respectively to determine the strength through average value. Based on specification, the minimum USC value is 2.5 N/mm² and results of the stabilized soil are displayed in Table 5. Observed that from day 1 to day 28, soil stabilization with Geocrete significantly improve the strength properties and increased its bearing capacity thus, surpass the minimum requirement.

This can be suggest due to its high crystal interlocking connectivity, crystalline during hydration process of cement, water and Geocrete powder (alkaline) whereby it increased the rate of strength exponentially and faster curing process. However it maintains avoidance of premature cracks compared to normal cement stabilization. The final product provides hydraulically-bound mixtures of hard yet flexible, durable and impermeable (waterproofing).

For light falling weight deflection (LFWD) test, it is used to monitor and measure the bearing capacity and behavior of strength and stiffness of stabilized soil with time. It is a quick method to evaluate the dynamic deflection modulus, E_{vd} in MN/m² which calculated from measured settlements. For comparison purpose, readings are taken before and after stabilize. Readings are taken at day 1, day 3 and day 7 respectively. Based on specification, the minimum value to surpass is 25 N/mm². Results for both untreated and treated soil are shown in Figure 9. From the results obtained, the dynamic deflection modulus E_{vd} for existing road base recorded an average value of 72.46 MN/m² up to 7 days. As for the stabilized soil, at 1 day age after stabilization, an average reading of 146.37 MN/m², 202% increase when compared to untreated road base. Similar trend at 3 days and 7 days age, the value continues improved significantly to 173.17 MN/m² (239%) and 221.95 MN/m² (306%) respectively. These suggest that the chemical reaction of geocrete (alkaline) and cement with correct amount of water and curing process improves the hydration through high interlocking connectivity, thus enhance the strength and stiffness characteristics prominently.

Table 5. Unconfined Compressive Strength results for stabilized soil.

Age of Soil Stabilized	Average Value of 3 samples	
	UCS, N/mm ²	Density, Mg/m ³
Day 1	4.27	2.17
Day 7	7.60	2.16
Day 28	11.00	2.16

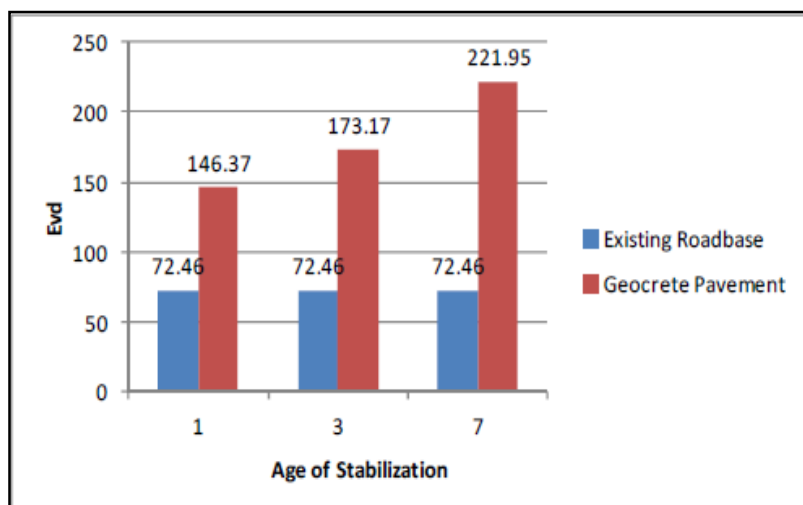


Figure 9. Dynamic deflection modulus (treated vs untreated soil).

4. Conclusion

This paper has presented 2 types of ground rehabilitation for maintenance that successfully comply the operational requirement (working window and duration) and yet maintained its quality to the upmost that met the requirements.

The use of both Rapid and Dense PU foam material with 1.1: 1.0 ratio (isocyanate : polyol) for grouting injection can be concluded has significantly improved the characteristics soil such as stiffness and shear strength which makes the soil almost rigid yet flexible. In terms of compressibility, injection with PU foam impressively reduced the void and swelling index by filling up the voids throughout capillaries within the soil by expansion and increased strength through densification and potential uplift of the structure as well. A good technique and experience are essential in determining volume of voids within the soil thus able to estimate the right composition of PU and amount needed for stabilization and uplifting which will last longer period.

As for Geocrete soil stabilization, by assessing the test results obtained, it can be concluded that the mixture combination of cement (Type 1) of 8% and Geocrete additive of 2% (by weight of cement) with quarry dust in stabilization of the existing road base has resulted high values of strength, bearing capacity and resilient modulus at early age, also more effective approach than that of conventional method. It also offers low risk of premature cracks due to the control process of hydration. The use of Geocrete in soil stabilization also surpasses the specification requirement for roads and considered to be practical engineering solution for maintenance due fast construction and curing process which able to open for traffic within short period of time. In tandem with Geocrete design approach to provide tailor made pavement solution, the amount of material required are flexible which will be based on soil condition basis and suit the requirement. Other benefit is that savings from removal of existing weak soil and import new material with transportation. This, undeniably creates eco-green construction and towards to sustainability. By stabilizing the soil with correct mix design, the soil can withstand the direct load for longer life span and durable, thus less cycle of maintenance required in the near future.

In conclusion, both approach considered suitable and practical for ground rehabilitation when comes to maintenance on the operated infrastructure as it contribute less effect to operational. Work can be done fast, less curing time needed and significantly reduces operational hazards and costs of lane closure when compared to conventional method. Thus, it provides beneficial to the owner as it acquires lesser cost of future maintenance.

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