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Critical Review of Innovative Soil Road Stabilization Techniques

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Abstract*—New roads are vital socio-economic pathways to a better quality of life for the thirty-five per cent of the Malaysian living in rural areas. However, building of roads in rural areas is always hindered by geographic limitation and often can be costly and energy inefficient. Hence it causes more adverse impact on the environment. Roadways designed for low-volume traffic are constructed of local soils containing high percentages of fines and high indices of plasticity. These soils may not have characteristics appropriate for use in soil road construction, but can often be upgraded with soil stabilization technology to successfully recondition and strengthen existing road base and sub-base materials for extended life and heavier traffic duty. In this paper, an attempt is made to bring in together soil road stabilization technologies for the extremes of dry and wet condition and discuss their positive impacts so as to convince the field engineers to adopt such technologies effectively.

Index Terms*—California bearing ratio; enzyme; soil roads; soil stabilization.

I. INTRODUCTION

In some developing ASEAN countries, soil roads infrastructure has not yet been developed appropriately as vital transportation system unlike the main roads and highways because they carry lower volumes of motorized traffic. Soil roads help connect the nation and transport it towards its goals of reaching fully-developed nation status. Making inroads with the construction of soil roads has been challenging, the amount of quarry materials to be mined and transported is mind boggling [3]. Highlights of Budget 2012 tabled by Prime Minister Datuk Seri Najib Tun Razak in the Parliament on Friday, 7 October 2011, was that 5 billion Malaysian Ringgit will be allocated for developing rural infrastructure, including RM1.8 billion to be earmarked for Rural Road Programme & Village-Link Road Project [15]. The rural connectivity is expected to give positive impact on economy, agricultural, employment and social services to rural masses [2]. There is Standard Specification for Road Works published by the Malaysian Public Works Department (JKR). However, there are situations in many states where the prescribed standards are not available at normal leads resulting in longer haulage and higher costs.

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From the construction viewpoint of soil roads, conventional construction methods need a heavy demand of gravel, asphalt, that require large amounts of suitable quarry materials to be mined which will increase the carbon footprint emission to the environment [4]. Hence successful innovative soil stabilization techniques are necessary to fulfill the needs on rural roads, as well as preserve the environment. It is to assure adequate subgrade stability, especially for weaker or wetter soils [1].

II. OBJECTIVES

The Objectives of this Paper are:

- Critically overview the soil roads needing ground improvement through soil stabilization.
- Critically review such current stabilization techniques.
- Appraise the state of the art of new and innovative commercial stabilizers and their technology.

III. SOIL STABILIZATION TECHNIQUE

Soil stabilization is the alteration of one or more soil properties to create an improved soil material possessing the desired engineering properties. There are three purposes for soil stabilization. These include increasing the shear strength of an existing ground condition to enhance its load-bearing capacity, achieve a desired improved permeability and enhance the durability of the soil to resistance to the process of weathering, and traffic usage among others [8]. Some of the soil stabilization methods that are currently been used for improvement of highway sub-grade and sub-base can be grouped into three broad categories:
Authors should consider the following points:

1) Mechanical stabilization
2) Use of geosynthetics for soil stabilization
3) Chemical admixture stabilization

Fig. 1 illustrates such different stabilization methods and their appropriateness to the different soil types defined by its effective size). Mechanical stabilization is a process of mixing two or more soils with different particle size gradations to produce a new soil with desired engineering characteristics and then compacting the mixture to the required density using conventional methods. The particle size distribution and the mineralogical composition are the important factors governing the engineering behavior of a soil and significant changes in the properties can be made by addition or removal of suitable soil fractions. The soils may be mixed at the construction site, or at a central plant, or in a burrow area. Adequate mixing and compaction are required for successful mechanical stabilization.

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Compaction provides a significant effect on soil properties, such as strength and stress-strain characteristics, permeability, compression, swelling and water absorption.

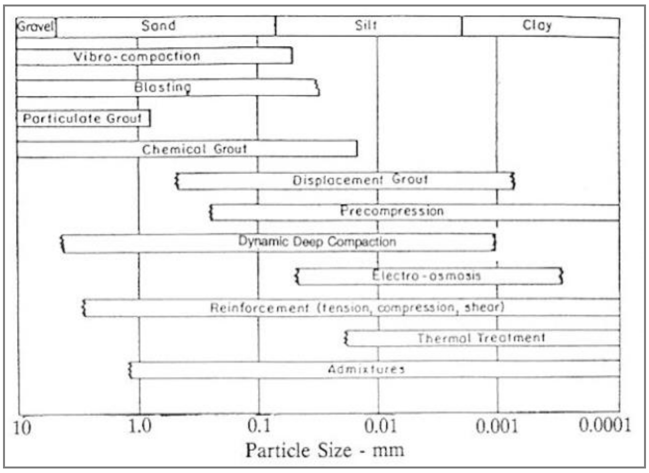

Figure 1: Soil stabilization technique with respect to soil type (Mitchell 1981)

The properties of a soil under compaction depend upon the water content, amount and type of compaction [8]. Since the early 1940s, stabilization of soil with admixtures, such as cement, lime, bitumen, fly ash, etc. have been successfully investigated and used extensively for road and airport foundations in many countries. Addition of inorganic chemical stabilizers like cement and lime has had a two-fold effect on soil namely; acceleration of flocculation and promotion of chemical bonding. Due to flocculation, the clay particles are electrically attracted and aggregated with each other. This results in an increase in the effective size of the clay aggregations [2].

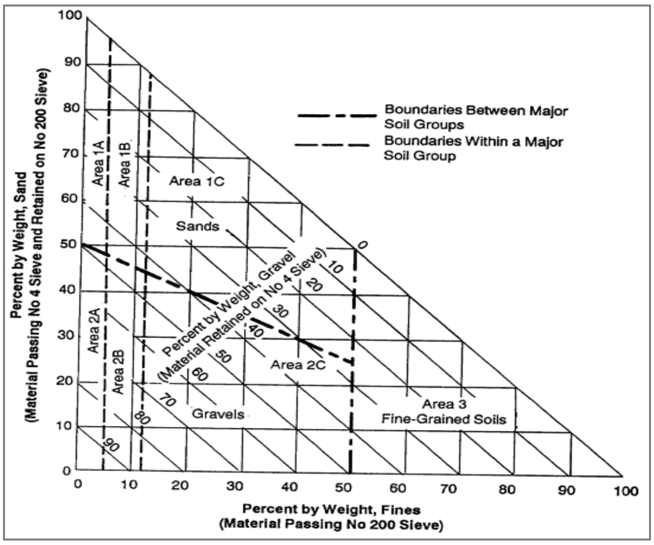

Figure 2: Gradation triangle for use in selecting suitable stabilizer (US Army 1997)

Purpose	Soil type	Method/Additive
Improves load-carrying and stress-distribution characteristics	Fine-grained	Mechanical, asphalt & cement
	Coarse-grained	Mechanical, asphalt & cement
	Clays of low PI	Asphalt, cement & lime
	Clays of high PI	Lime
Improves water-proofing and runoff	Clays of low PI	Asphalt, cement & lime
Controls shrinkage and soil	Clays of high PI	Lime

Figure 3: Subgrade stabilization method most suitable for specific applications (US Army 1997)

The main advantages of liquid chemical stabilization is that only a small volume of stabilizing agent is generally required and the cost of stabilization is lower than that of other methods of stabilization [4]. The authors overviews the advantages of using chemical stabilization for soil road stabilization in the later sections of this paper.

A. Fly Ash

Fly ash is a residue of coal combustion that occurs at power generation and incineration plants in many countries. Fly ash can be used to:

1) lower the water content of soils,
2) reduce shrink-swell potential,
3) increase workability, and
4) increase soil strength and stiffness.

Two types of fly ash can be used to stabilize soils: Class C and Class F. Both classes of fly ash contain pozzolans, but Class C fly ash is rich in calcium that allows it to be self-cementing. Class F fly ash requires an activation agent (e.g., lime or cement) for a pozzolanic reaction to occur and create cementitious bonds within the soil [4]. Fly ash stabilization is often used as a construction expedient when wet soil conditions are present and weather conditions or time constraints prevent the contractor from processing the soil to dry it out. The fly ash lowers the water content and plasticity of the soil and improves workability; This allows for construction of an adequate working platform for construction operations. Fly ash also used to reduce the shrink/swell potential of clay soils. Fly ash stabilization of clay soils can increase CBR values from 2 to 3 (untreated) to 25 to 35 (treated). Unconfined compressive strengths for fly ash-stabilized clay soils can be improved from 700 to 3,500kPa, depending on fly ash source and application rate and the material being stabilized [4]. Fly ash stabilized soils/aggregates are not used as a surfacing material. Fly ash stabilized subgrade and sub base materials can be used for very low to high traffic volume applications. The highway lanes need to be closed during construction. If possible, it is recommended that the lane remain closed until a wearing surface can be applied; however, the treated material can be opened to temporary traffic after 1 day. Fly ash application rates are in the range of 2,950 to 4,200m /day.

Figure 4: Fly ash

B. Rice Husk Ash

Rice husk ash is a waste material, if left un-used, may affect the surroundings and also create problem for their disposal.

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Use of these materials in road construction can alleviate the problem of their disposal to great extent. Studies results indicated that the usage has great impact on the improvement of soil properties and they are very useful for stabilizing clayey soils. The results indicate that unconfined compressive strength of soil and CBR value has increases by using rice husk ash for stabilization of soil [4].

Figure 5: Rice husk ash

C. Lime

Lime can be obtained in the form of quicklime or hydrated lime. Quicklime is manufactured by calcinations of limestone at high temperatures, which chemically transforms calcium carbonate into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water. Lime can be used to stabilize clay soils and submarginal base materials (i.e., clay-gravel, caliche, etc.). When added to clay soils, lime reacts with water in the soil and reduces the soil's water content. The lime also causes ion exchange within the clay, resulting in flocculation of the clay particles. This reaction changes the soil structure and reduces the plasticity of the soil. These changes will increase soil workability and can increase the soil strength and stiffness. In the long term, calcium hydroxide in the water reacts with the silicates and aluminates (pozzolans) in the clay to form cementations bonds that further increase the soil strength [4]. Lime works best for clayey soils, especially those with moderate to high plasticity (plasticity index greater than 15). Lime does not work well with silts and granular materials because the pozzolanic reaction does not occur due to a lack of suficient aluminates and silicates in these materials. For effective lime stabilizations of silts or granular materials, pozzolanic admixtures (i.e., fly ash) should be used in addition to lime.
Lime stabilization is often used as a construction expedient when wet soil conditions are present and weather conditions or time constraints prevent the contractor from processing the soil to dry it out. The lime lowers the water content and plasticity of the soil and improves workability; this allows for construction of an adequate working platform for construction operations. Lime is also used to reduce the shrink/swell potential of clay soils [4]. Lime-stabilized subgrade and subbase materials can be used for very low to high traffic volume applications. Lime application rates are in the range of 2,950 to 4,200m2/day. The roadway lane should be closed during construction. If possible, it is recommended that the lane remain closed until a wearing surface can be applied; otherwise, the treated material can be opened to traffic after 1 day for temporary use.

D. Portland Cement

Portland cement can be used to stabilize any soil except highly organic soils. Portland cement increases soil strength, decreases compressibility, reduces swell potential, and increases durability. Cement stabilization creates a hard, bound, impermeable layer. Cement-stabilized materials are rarely used as a surfacing material because they can become brittle and crack under traffic loads; cement-treated soils are most frequently used as a stabilized subgrade or road base.
Cement-stabilized materials are rarely used as a surfacing material. Cement-stabilized subgrade and base materials can be used in roads for very low to high traffic volume applications. Portland cement application rates are on the order of 2,950 to 4,200m2/day. The roadway lane should be closed during construction, but can be opened to light traffic once construction is complete [4].

E. Chloride

Chlorides are the most commonly used products for dust suppression in unbound road surfacing. These compounds, which contain chloride salts, can be mixed with other ingredients and are applied either in a liquid or solid state lakes or pellets. Chlorides draw moisture from the air to keep the road surface moist (i.e., hydroscopic) and help resist evaporation of road surface moisture (i.e., deliquescent). By keeping the road surface moist, chlorides reduce the amount of dust generated. Chlorides also facilitate compaction and promote soil stabilization [4]. Chlorides can be used on unbound road surfacing with higher traffic volumes, but more frequent applications are necessarily required. Chloride application rates can typically be about 3,300 to 5,000 m /hr. If the roadway surface is scarified prior to treatment, the roadway lane(s) being treated are closed during construction, so adequate traffic control is needed. The roadway can be opened to traffic as soon as the construction equipment is cleared from the roadway. If the chloride is applied to the surface without scarifying the surface, lane closures are not required.

F. Clay Additives

Clay additives are naturally occurring soils composed of the mineral montmorillonite. Montmorillonite is a highly plastic clay mineral with a high affinity for water. Clay additives are typically used to stabilize nonplastic crushed aggregates; the cohesive properties of the clay additive help to bind the aggregate particles and prevent raveling and wash boarding. The clay additive will also attach to fines in the aggregate mix to reduce fugitive dust. Some dust is still to be expected with clay-stabilized aggregates, so additional dust suppressants are also used in conjunction with the clay additive when dust is an important concern [4]. Traffic range: Very low to low (AADT < 250). Above this traffic range, the surface will require more frequent product mixing and surface grading.

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Clay additive construction rates are in the range of 2,000 to 5,000 m2/day for a mixing depth of 100 mm (4 in). The roadway lane should be closed during construction, but can be opened to traffic once construction is complete [4].

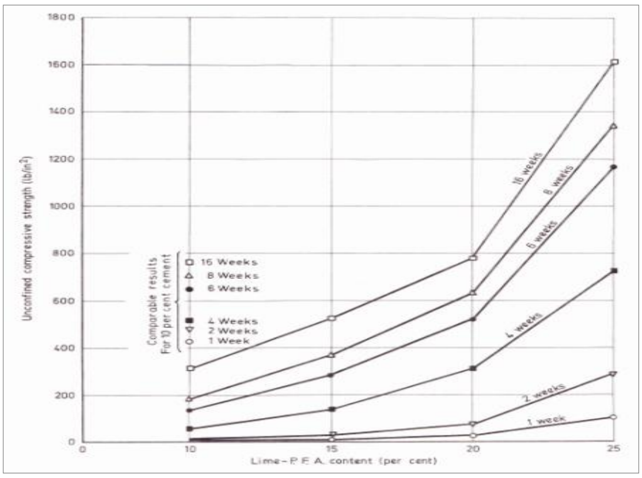
G. Electrolyte Emulsions

Many of the emulsions for dust suppression and/or soil stabilization are proprietary in nature and the exact composition and stabilization mechanisms are not publicly available; therefore, it is often difficult to group or classify the various emulsions accurately. Electrolyte emulsions contain chemicals that affect the electro-chemical bonding characteristics of soils and replace water molecules within the soil structure. The treated soil loses its affinity for water. When applied at low application rates to the surface of the unbound road surface, electrolyte emulsions perform well for dust suppression [4]. They bond soil particles together and so reduce dust generation. At higher application rates, electrolyte emulsions can be used to stabilize soils. When applied and compacted properly, the treated soil can be stabilized to form a firm to hard bound layer that can be used as a road surfacing. Most of the information available on electrolyte emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of electrolyte emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product specific testing and/or performance verification is recommended when selecting an electrolyte emulsion. Required application frequency will increase with increased truck traffic or increased vehicle speed. Additional traffic loading restrictions may be required depending on the material being treated (e.g., the load-carrying capacity of a clay soil is typically much less than that of a granular material). Electrolyte emulsion application rates are in the range of 2,000 to 5,000 m2/day [4]. The roadway lane should be closed during construction, but can be opened to traffic once construction is complete.

H. Pulverized Fuel Ash

Pulverised fuel ash (p.f.a.) is a waste product of coal burning power stations; 8 million tons are produced at the present time and its disposal presents considerable problems to the electricity industry. Only a small proportion of the amount produces is utilized and the majority is dumped in disused clay-pits, gravel pits, and low-lying areas. The construction of roads necessitates the quarrying of natural materials which also involves the dereliction of a large amount of land. Thus when p.f.a. is used in road construction a two-fold saving is achieved and it is obviously in the national interest that p.f.a. should be used as widely as possible [8]. Considerable quantities of p.f.a. are already used in road construction mainly as a fill material and to a very much lesser extent for sub-base and base construction when stabilized with cement. A possible obstacle to the more widespread use of p.f.a. in the construction of road payments is the variability of the material arising from different methods of operation at different power stations and from changes in the coal supply.

Figure 6: Between strength and stabilizer content for specimens of sand stabilized with 1:5 Lime-P.F.A. mixture (Sherwood and Ryley 1966)



I. Enzymatic Emulsions

Enzymatic emulsions contain enzymes (protein molecules) that react with soil molecules to form a cementing bond that stabilizes the soil structure and reduces the soil's affinity for water. Categorically speaking, enzymatic emulsions work on a variety of soils as long as a minimum amount of clay particles are present. When applied at low application rates to the surface of the unbound road surface, enzymatic emulsions perform well for dust suppression. They bond soil particles together and so reduce dust generation. At higher application rates, enzymatic emulsions can be used to stabilize soils. When applied and compacted properly, the treated soil can be stabilized to form a dense, firm to hard, water-resistant bound layer that can be used as a road surfacing. Most of the information available on enzymatic emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of enzymatic emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product specific testing and/or performance verification is recommended when selecting an enzymatic emulsion [4].

Traffic range: Very low to low (AADT < 250). Construction Rate: Enzymatic emulsion construction rates are in the range of 2,000 to 5,000 m2/day. Lane Closure Requirements: The roadway lane should be closed during construction, but can be opened to light traffic once construction is complete. The stabilized material should be allowed to cure for 2 to 3 days before normal traffic, including heavy loads, are allowed onto the surface.

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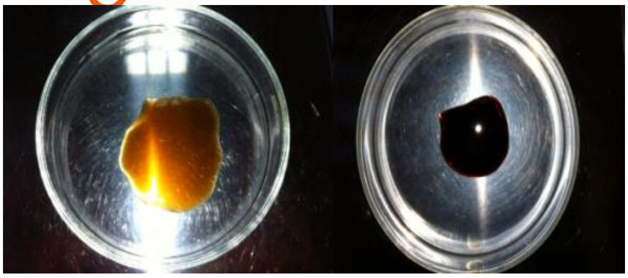

Figure 7: Enzymes in the market

1) Type of Enzyme

1) Lingo Sulphonate (By-product streams from pulping plants:

Lignin - a natural polymer, is a major component of wood. It imparts rigidity to the cell walls and acts as a binder between the wood cells creating a composite material. They are made from the waste liquor byproducts of the wood processing industries such as paper mills. Lignins are derived from basic units belonging to the C6H5CCC family. The lignosulphonates show higher strength in finer materials. Since lignosulphonates are by-products of other processes, they are relatively inexpensive. However, the major drawback is the toxicity of the dichromate salt, as well as the health hazards of the bezene type molecule present in all lignosulfonate grouts and the hexavalent chromium is highly toxic. It is reduced to the nontoxic trivalent form during the reaction, but the reduction is not necessarily complete especially at the higher range of pH and when using long gel times.

2) Terrazyme

Terrazyme is a surfactant (an ionic surface active agent) which changes the hydrophilic nature of lime material and clay to hydrophobic. Its application not only assists in the expulsion of water from the soils, but it also helps the lubrication of soil particles and increases the compatibility of many soils. The reaction of Terrazyme on these materials is effective due to the ion-exchange capacity of clay minerals. Terrazyme also changes the plastic characteristics of these materials due to a reduction in its water absorbing capacity. The effect of Terrazyme on these materials is permanent [1]. Terrazyme is a natural, non-toxic liquid, formulated using vegetable extracts. Apart from being a concept accepted the world over as a sound and resourceful road building practice, which completely replaces the conventional granular base and the granular sub base, it emphasizes on strength, performance and higher resistance towards deformation. Organic enzymes come in:

1) Liquid form
2) Soluble in water
3) Color: brown
4) Smell of molasses
5) Specific weight = water
6) pH: between 4.3 and 4.6

Their aroma has no effect. Neither gloves nor masks are required during handling but it can cause irritation to the eyes. If they are to be stored for long periods of time without losing any of their properties, it is necessary to maintain a temperature of 550°C. There is no risk of decay. The enzymes react with oxidizing agents. Terrazyme is specially formulated to modify the engineering properties of soil. They require dilution in water before application. Terrazyme acts to reduce the voids between soil particles and minimize absorbed water in the soil for maximum compaction. This decreases the swelling capacity of the soil particle and reduces permeability. The application of Terrazyme enhances weather resistance and increases load bearing capacity of soils. These features are particularly evident in fine-grained soils such as clay in which the formulation affects the swelling and shrinking behavior. This formulation has the ability to change the matrix of the soil so that after compaction the soil loses its ability to reabsorb water and the mechanical benefit of compaction are not lost even after water is reapplied to the compacted soil. Once the enzyme reacts with the soil, the change is permanent and the product is bio-degradable. Soil treated with Terrazyme renders improved density values by reducing the void ratios to a large extent which results in an overall improvement in the California Bearing Ration about 800% [1].

Type of suitable soil	Fine-grained soil (clay)	
Cost reduction (%)	Total cost of construction	Maintenance cost
	15 – 40	50 – 70

Avijeet Agencies

3) Endurazyme

Endurazyme functions in the soil chemistry as ion exchanger to improve the engineering characteristics of clay soil. It is a unique multi-enzyme product specifically developed as an effective aid to the workability, mixibility, binding and compaction of soil. It significantly improves stability in the construction of roads. It stabilized clay and increases the strength, CBR and reduces permeability of soil and thus binding the soils into lasting pavement. The main function of endurazyme is to reduce the amount of water held in soil to form voids for optimum compaction and to decrease the swelling capacity of the individual soil particles. One litre of endurazyme can treat about 30m3 compacted soils.

4) Bio grouting (Bacteria and Reactants flushed to promote calcium carbonate precipitation)

Biogrout is a new soil reinforcement method based on microbial induced carbonate precipitation. Bacteria and reactants are flushed through the soil, resulting in calcium carbonate precipitation and consequent soil reinforcement. The Biogrout process consists of two parts, the microbial induced production of carbonate and the precipitation of calcium carbonate (CaCO3). First, bacteria are injected into the subsoil. Subsequently, urea (CO(NH2)2) is injected into the subsoil. The bacteria provide the hydrolysis of urea, which results in the formation of carbonate and ammonium. The reaction is given by: CO(NH2)2 (aq) + 2H2O (L) bacteria 2N(aq) + C (aq). Ammonium is an environmentally undesired side-product from this reaction.

5) Lignosulfonates

Lignosulfonates are derived from the lignin that naturally binds cellulose fibers together to give trees firmness. They have cementitious properties that bind the road surface particles together.

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Lignosulfonates also draw moisture from the air to keep the road surface moist (i.e., hydroscopic). When applied at low application rates to the top 25 mm (1 in) of an unbound road surfacing, lignosulfonates are well suited for dust suppression because they bond soil particles together and help to maintain a moist road surface, and so reduce dust generation. At higher application rates and deep mixing, typically 100 to 200 mm (4 to 8 in), lignosulfonates can be used to stabilize subgrade or base materials containing fines. Lignosulfonates increase the compressive strength and load bearing capacity of the treated material, bind materials to reduce particle loss, and provide a firm to hard dust-free surface [4]. Traffic range: very low to low (AADT < 250). Lignosulfonate application rates are in the range of 3,300 to 5,000 m2/hr for spray-on applications. For spray-on applications, the road may remain open during application, although it is preferable to allow some time for the lignosulfonate to infiltrate into the surface material. For mixed-in applications, the lane should be closed during construction, but can be opened to traffic once construction is complete [4].

6) Synthetic Polymer Emulsions

Many of the emulsions for dust suppression and/or soil stabilization are proprietary in nature and the exact composition and stabilization mechanisms are not publicly available; therefore, it is often difficult to group or classify the various emulsions accurately. Synthetic polymer emulsions primarily consist of acrylic or acetate polymers that are specifically produced for dust control or soil stabilization, or are by-products from the adhesive or paint industries. The polymers cause a chemical bond to form between soil particles, creating a dense and water resistant road surface. In general, polymer emulsions can be used on most soils; however, certain products are more effective on specific soil types. When applied at low application rates (sprayed-on or mixed-in) to the surface of the unbound road surface, synthetic polymer emulsions perform well for dust suppression. They bond soil particles together and so reduce dust generation. At higher application rates (mixed-in), synthetic polymer emulsions can be used to stabilize soils. Graded aggregates can be stabilized to form a very hard bound layer that can be used as a road surfacing. Most of the information available on synthetic polymer emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of synthetic polymer emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product specific testing and/or performance verification is recommended when selecting a synthetic polymer emulsion. Traffic range is very low to low (AADT < 250). Synthetic polymer emulsion application rates are in the range of 2,000 to 2 25,000 m /day (2,400 to 6,000 yd /day). For sprayed-on applications, the roadway can remain open, although emulsion splash/spray on vehicles can be a problem. For mixed-in applications, the roadway lane should be closed during construction, but can be opened to traffic once the stabilized material has dried, typically after less than 1 or 2 hours (warm, sunny weather) to 1 day (cool, cloudy weather). Synthetic polymer emulsions will take approximately 30 days to cure completely and develop their full strength [4].

7) Tree Resin Emulsions

Tree resin emulsions are derived from tree resins (mainly pine, fir, and spruce) combined with other additives to produce an emulsion that can be used for dust suppression or soil stabilization. When applied at low application rates to the top 25 mm (1 in) of an unbound road surfacing, tree resin emulsions are well suited for dust suppression because they bond soil particles together and so reduce dust generation. At higher application rates and deep mixing, typically 100 to 200 mm (4 to 8 in), tree resin emulsions can be used to stabilize subgrade or base materials containing fines. Graded aggregates (typical maximum particle size less than 10 mm [3/8 in]) can be stabilized to form a relatively hard surface layer that can be used as a road surfacing; the stabilized aggregate is purported to be up to three times stronger than asphalt concrete. The bound aggregate surfacing is usually 50 mm (2 in) thick. Most of the information available on tree resin emulsions comes from brochures and literature provided by the manufacturer. Therefore, it may be difficult to find independent test information for a particular product. The performance and applicability of tree resin emulsions can vary from one product to the next. In addition, products are frequently reformulated; so, historical case studies may no longer be representative of a current product. As a result, product specific testing and/or performance verification is recommended when selecting a tree resin emulsion [4]. Traffic range is very low to low (AADT < 250); above this traffic range, the surface will require more frequent product applications and surface grading. Tree resin emulsion application rates are in the range of 2,000 to 5,000 m2/day. For sprayed-on applications, the roadway can remain open, although emulsion splash/spray on vehicles can be a problem. For mixed-in applications, the roadway lane should be closed during construction, but can be opened to traffic once the stabilized material has dried, typically after 1 to 4 days. Tree resin emulsions will take approximately 30 days to cure completely and develop their full strength.

IV. COMMERCIAL SOIL STABILIZATION

A. Probase

TX-85 liquid soil stabilizer is produced by Probase Manufacturing Sdn. Bhd. in Johor Malaysia. It is 100% organic and is derived from combined organic sulphur and buffered acids that are combined as bi-sulphates. It is also water-soluble soil stabilizer chemical used in construction and non-toxic and poses no threat to groundwater supplies or flora and fauna. Use of this chemical stabilizer reduces the PI of soil and improves its CBR ratings. It is an economical construction methods especially for rural and estate roads.

Figure 8: Probase TX-85 Soil stabilizer

TABLE: SUMMARY OF IN-SITU CBR TEST FOR CLAYEY SAND SOIL

	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	CBR in % (before treatment)	CBR in % (after treatment)	CBR interment in %
Pt. 1	2	59	19	20	36.6	66.2	29.6
Pt. 2	7	55	20	18	38.9	78.0	39.1
Pt. 3	2	61	17	20	46.1	96.8	50.7
Pt. 4	7	53	23	18	30.2	61.7	31.5
Pt. 5	0	46	22	32	60.3	102.4	42.1
					Average in %	38.6	93.10

Figure 9: Before soil stabilization

Figure 10: After soil stabilization (9 months after construction)

Company: Probase Manufacturing Sdn. Bhd. (Johor, Malaysia)
Contact no.: +607 3556122
Website:www.probase.com.my

B. Termite Saliva (Eko Soil Enzyme)

The Eko-Soil Enzyme is a synthetic replication of enzymes contained in that effective natural building material, termite saliva. It reacts with clay particles in soil to accelerate a standard compacting process to create a surface with concrete-like strength. A typical road will require one litre of Eko Soil to stabilize 30m3 of road material and standard road-making equipment is sufficient to complete a road containing the enzyme. The use of Eko-Soil adds marginally to the cost of upgrading a road; dramatically increase the stability of the road base, significant long-term maintenance cost savings accrue. The application requires no special plant or equipment and follows standard gravel road construction protocols. Samples of the existing material are analysed for PI, Gradation and Moisture. This data provides the basis for geotechnical design. The enzyme is applied through the water truck, and based on geotechnical design requirements in a typical road analysis one litre of enzyme will stabilize 30m3 of road material. Standard road-making equipment is all that is required – a grader with ripper, water truck and vibrating steel drum roller. Use of a roto-mill will dramatically reduce mixing time – one pass with a roto-mill will substitute for seven or eight passes with a grader. 1 km x 6m wide x 150mm deep road can be laid in a day. The road can be opened to light traffic the next day, although full curing takes three days.

Norwood Hall (Asia) Pty Ltd (Australia)
Contact no.: 0419 340 593

C. Renolith

Renolith is polymer based chemical, which is environmentally friendly and which facilitates the bonding of soil particles (a phenomenon which is known a micro-rubber bonds). Soil-cement with Renolith has a high modulus of elasticity and can disperse the wheel loads very effectively. It is a semi-rigid material. A noteworthy feature of this technology is that it require very little amount of aggregate, which is useful at places where the material haulage is more. The use of Renolith, when used in soil stabilization with cement, gives strong and durable base. This type of construction does not require surfacing for low volume roads, since the base course is stabilized. It is expected to give good performance with longevity and reduces maintenance costs in almost dust free environment.

Renolith Technology Corporation (Thailand)
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D. Perma-Zyme

Perma-Zyme is a proprietary concentrated liquid multi-enzymatic formulation. It alters the properties of earth material to produce superior road base stabilization.

Perma-Zyme lowers the surface tension of water which promotes fast and through penetration and dispersal of moisture. This action causes hydrated clay particles to be pressed into and to fill the voids throughout the soil, thus forming a tight, dense permanent stratum. It reduces as much as 25% amount of water required to reach the optimum moisture level of the soil. Perma-Zyme creates a highly compacted permanent base which will resist water penetration, rutting and washboarding, weathering and wear. The process typically takes two days, with a full cure over a 72 hour period. One gallon of Perma-Zyme will stabilize 165 cubic yards of base material and 15 gallons Perma-Zyme can treat 1.61km, 7.62m wide, 152.4mm deep soil road. Developed and proven through years of field testing, Perma-Zyme provides additional advantages to road builders, communities and the ecology by being non-toxic, non-corrosive and environmentally safe.

Figure 11: Perma-Zyme Soil Stabilizer and soil road using Perma-Zyme

Global Zyme (ASIA) Thailand
http://www.globalzyme.com

E. Con-Aid

Con-Aid is a water soluble anionic compound with surface-active properties. It was developed in South Africa from a blend of locally produced synthetic chemical products. It is designed for stabilizing poor quality soils containing clayey material in order to improve their properties as road construction materials. Con-Aid anionic soil stabilizer, originated from petrolcum, is viscous, deep red colour liquid with no smell or taste. The manufacturers claim that the chemical is totally water solube, non-hazardous, non-flammable, non-corrosive, non-toxic, environmentally safe and user friendly.

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Con-Aid can be used to stabilize various types of soils, i.e. silty sand, clay material, gravel, etc. under condition that the above-mentioned materials have PI>11 and clay content of 15% or more in order to facilitate densification and to provide the desired properties- permanent stability and increased workability of the soil.

Con-Aid chemical stabilizer has considerable potentials in modifying properties of black cotton soil and calcrete. The rate of application varies from 100ml/m3 for gravelly materials to 200ml/m3 for fine clays such as black cotton soils [7].

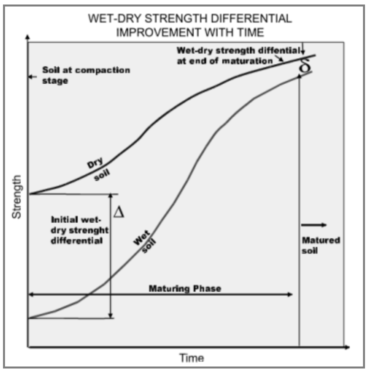

Figure 12: Phases of strength build-up in Con-Aid treated layers

Figure 13: Before and after soil stabilization

Figure 14: Con-Aid soil stabilization

CON-AID ASIA CO., LTD. (THAILAND)
Tel: 66-2260-8713
http://www.Conaidasia.Com

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REFERENCES

[1] A. U. Ravi Shankar, H. K. Rai, and R. Mithanthaya, "Bio-enzyme stabilized lateritic soil as a highway material," Indian Road Congress, in press.

[2] B. I. Siswosoebrotho, M. Hossain, A. Alias, and B. K. Huat, "Stabilization of tropical residual soils," Taylor and Francis Group, 2004, pp145-167.

[3] D. Daud, P. C. Tan, M. Lee, and D. Q. Wu, "Green and quality rural roads in Malaysia," unpublished.

[4] M. A. Kestler, "Stabilization selection guide for aggregate and native-surfaces low volume roads," U.S. Department of Agriculture, 2009.

[5] M. Lee, P. C. Tan, Daud, and D. Q. Wu, "Green approach to rural roads construction – Stabilization of in-situ soils and construction wastes," Asia Pacific, in press.

[6] M. Terashi, and I. Juran, "Ground Improvement – State of the art," GeoEng, Sydney Ullah, 2000.

[7] M. Vedula, P. Nath G, and B. P. Chandrashekar, "A critical review of innovative rural road construction techniques and their impacts," unpublished.

[8] P.T. Sherwood, and M.D. Ryley, "The use of stabilized pulverized fuel ash in road construction," Road Research Laboratory, RRL Report No. 49, Crowthorne, 1966.

[9] T. Abadjieva, "Chemical stabilization for low cost roads in Botswana," unpublished.

[10] T. E. Kowalski, and D. W. Starry, "Modern soil stabilization techniques," Annual Conference of Transportation Association of Canada: Saskatoon, 2007, pp 1-16.

[11] T. T. Abood, A. B. Kasa, and Z. B. Chik, "Stabilization of silty clay soil using chloride compounds," Journal of Engineering Science and Technology, Vol. 2, No.1, 2007, pp. 102-110.

[12] US Army, "Field mannual-410: Military soils engineering- Chapter 9: Soil Stabilization for roads and airfields, Department of the Army, Washington, D. C. June, 1997.

[13] W. H. Bushman, T. E. Freeman, and E.J. Hoppe, "Stabilization techniques for unpaved roads," Virginia Transportation Research Council, June 2004.

[14] Y. Yilmaz, A.G. Gungor, and C. Avsar, "Stabilization of clays using liquid enzymes," Taylor & Francis Group: London, 2009, pp.65–69.

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