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KEYWORDS:

Soil-cement Stabilization; Soft Ground Treatment; Roadbase.

ABSTRACT:

The North South Expressway section in Kedah was partly built on an overlying soft clay formation. The ground stabilization technique, namely stone column piles, was implemented to construct denser roadbase layer. However, consolidation and creeping processes had resulted in uneven settlement on treated layer thus undulating the pavement surface or creating an effect known as "mushroom". The common pavement treatment of regulating, mill and pave to the undulated surface proves to be short term measures. In this paper, an innovative treatment method using alkaline compound was introduced to alleviate these issues at the Alor Setar Selatan Interchange ramps. Utilizing mostly alkaline earth elements, this technique recycles existing roadbase material by mixing it with cement additive to stimulate direct hydration processes to form a stiffer roadbase foundation. After curing it with adequate moisture content, upper layers of binder and wearing course are then applied. This treatment has effectively improvised roadbase compressive strength and bearing capacity.

Asset Management to Highway: Soil-Cement Stabilization Technique

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1. INTRODUCTION

The northern part of North-South Expressway that traverses the state of Kedah is mostly rested on the paddy field plain. Since its construction back in 1986, several locations have experienced uneven ground settlement and caused undulation, depression and cracks on the pavement surface. This condition may endanger the highway users during heavy rain due to hydroplaning effects as a result of water lying stagnant within the settlement area.

Undulation and uneven ground settlement on the highway surface is significantly influenced by soft ground condition with low compression and stiffness characteristics. Conventionally, for the ground stabilization technique, stone column piles were applied to construct denser road base layer. However, consolidation and creeping processes had resulted in uneven settlement on treated layer thus undulating the pavement surface or creating an effect known as "mushroom". The highway pavement rehabilitation by applying the Cement-Bound Material (CBM) was introduced to extend the life span of the pavement structure by recycling the existing roadbase material (Chai et al., 2005). From this stabilization technique, the cement effect significantly improves the stiffness properties of unbound layer, thus providing better load transfer to the pavement foundation.

The factors that influence the physicochemical reactions of soil-cement hydration and the interactions of peat soil-cementation process are the amount of solid particles, the water-soil ratio, the quantity of binder, the presence of humic and/or fulvic acids, the soil pH and the amount of organic matter in the peat (Zulkifley et al., 2014). According to Wu et al. (2016), the applicability and the effectiveness of soil-cement stabilization technique in soft ground improvement are mainly evaluated by the compactability and strength performance.

2. DESIGN CRITERION

2.1 Existing Roadbase Identification

Prior to the determination of the design mix, samples of the existing roadbase was taken for identification and laboratory identification tests. The respective tests being conducted were Particle Size Distribution (PSD) for coarse and fine grained soils (BS 1377: Part 2: 1990: 9), moisture content determination (BS 1377: Part 2: 1990: 3) and Proctor test (BS 1377: Part 4: 1990) to determine the maximum dry density and optimum moisture content.

From the PSD qualification result, the existing roadbase material had mixed with subgrade material whereby a significant amount of silt and sand had been identified with the percentage of fine material (i.e. less than 0.8mm) not exceeding 10% (Figure 1), conforming to Arahan Teknik Jalan 5/85 (2013). While, the result for proctor test on the same existing roadbase was recorded 2.08 Mg/m^3 of maximum dry density (Figure 2) which surpassed the minimum requirement of 1.3 Mg/m^3 thus showing a very good material as a soil-cement stabilization medium. Hence, the preliminary stage for existing roadbase condition had found that additional fine material (i.e. quarry dust) shall be combined to improve the PSD curve grading. Furthermore, a minimum of 8% cement and 2% alkaline compound as the stabilizing agent shall act as a basis for the proposed mix design to display higher stiffness and strength properties.

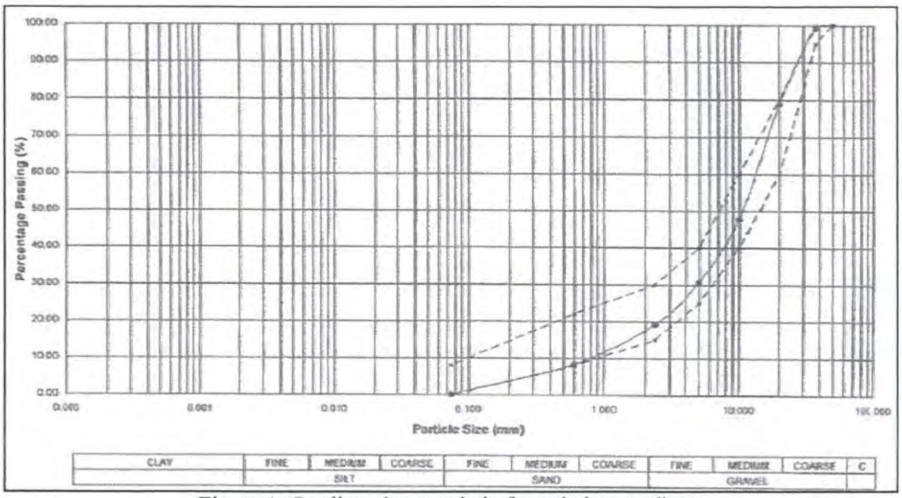

Figure 1. Grading characteristic for existing roadbase

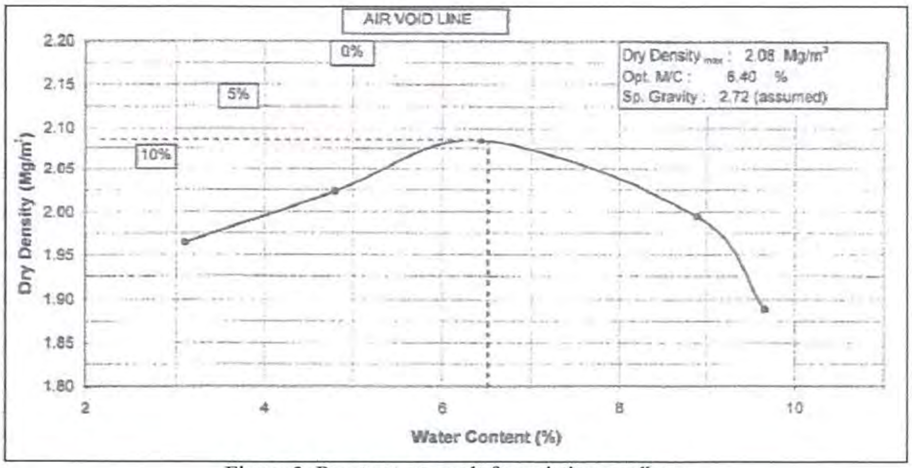

Figure 2. Proctor test result for existing roadbase

2.2 Design Application

The thickness of the layer to be treated by soil-cement stabilization is determined by the traffic category and equivalent standard axles as tabulated in Table 1. The stabilization thickness of 300 mm is determined in accordance with T4 traffic category. The recommended mix design then refers to Qualification test as per Soil Cement Specification, i.e. relationship between mix design and soil classification. This relationship then introduces the composition of Ordinary Portland Cement (OPC) mixed with alkaline compound that promotes cement hydration process, thus inhibiting the actions of fulvic acids and carbonic acids. Technically, this compound result in roadbase structural changes and the formation of minerals occurring during cement hydration greatly increases the compressive strength, the static and dynamic stiffness modulus, the tensile bending strength, besides stabilizing humus-rich soils (Suddath and Thompson, 1975; Wu et al., 2016).

Table 1. Relationship table between traffic categories with roadbase stabilization thickness (Arahan Teknik Jalan 5/85, 2013)

Traffic Category	Design Traffic (ESAL X 10^6)	Depth Stabilization Thickness
T1	≤1.0	200 mm
T2	1.1 to 2.0	250 mm
T3	2.1 to 10.0	275 mm
T4	10.1 to 30.0	300 mm
T5	>30.0	≥300 mm

The amount of OPC and alkaline compound to be added to the mixture for stabilization was decided based on soil matrix classification (Table 2) that leads to the design of initial water content and amount of OPC and alkaline compound. This amount highly influences the rate of pozzolanic reaction that progressively depends on mineralogy of the soil and pH level. According to Little et al. (2009), sufficient high pH is maintained to solubilize silicates and aluminates from the clay matrix or fine silt soil. This reaction then forms calcium-silicate-hydrates and calcium aluminate-hydrates, a similar compound produced during the strength development in the hydration of Portland cement.

This non-binding material type of soil requires the amount of OPC and alkaline compound in the range of 140 kg/m^3 to 180 kg/m^3. For confirmation, the proposed mix design will be assessed by the seventh day Unconfined Compressive Strength (UCS) test (BS 1377: Part 7:1990) for bearing capacity.

Table 2. Soil matrix classification relation to mix design

	Soil Class		Initial Water Content	Normal Amount of OPC + Alkaline Compound
Non-Binding	GW	Well Graded gravels and gravel-sand mixture, little or no fine	From 0 to 15-20%	From 140 kg/m^3 to 180 kg/m^3
	SW	Well Graded sand and gravelly sand, little or no fine		
	GP	Poorly Graded gravels and gravel-sand mixtures, little or no fine		
	GM	Silty Gravels, gravel-sand-silt mixtures		
	GC	Clayey Gravels, gravel-sand-clay mixtures		
	SW	Well Graded Sand and gravelly sands, little or no fine		
Mixed Grains	SP	Poorly Graded Sand and gravelly sands, little or no fine	From 0 to 30-35%	From 160 kg/m^3 to 190 kg/m^3
	SM	Silty Sands, sand-silt mixtures		
	SC	Clayey Sands, sand clay mixtures		
Binding	ML	In organic silts, very fine sands, rocks, silty or clayey fine sand	From 0 to 15-30%	From 170 kg/m^3 to 220 kg/m^3
	CL	Inorganic clays of low to medium plasticity, gravelly/ sandy/ silty/ lean clays		
	OL	Organic silts and organic silty clays of low plasticity		
	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts		
	CH	Inorganic clays or high plasticity, fat clays		
	OH	Organic clays of medium to high plasticity		
Organic	Pt	Peat, muck and other highly organic soils	Import material recommended to be installed before stabilization	

2.3 Seventh Day Unconfined Compressive Strength (UCS) Test

This test was carried out to estimate and certify the bearing capacity of the proposed mix design and to choose the final mix design. The intended sample was prepared by mixing the existing material based on the ratio predetermined with 8% OPC and 2% alkaline compound. Cylinder of this mix of materials was prepared and cured for 7 days prior to the execution of the UCS test. Based on the results obtained (Table 3), the proposed mix design had surpassed the minimum strength of 2.5 MPa that has been set by JKR/SPJ/2008-S4, hence the ratio proportion for OPC and alkaline compound is satisfied.

Table 3. Summary results of UCS test after 7 days of curing

Sample No.	Age (days)	Maximum Load (kN)	Compressive Strength (MPa)
1	7	70.80	3.15
2	7	77.00	3.42
3	7	66.30	2.95

3. CONSTRUCTION APPLICATION

The pavement roadbase rehabilitation construction works by applying soil-cement stabilization technique was successfully completed at the respective ramp from Alor Setar Utara to Alor Star Selatan toll plaza. In this project works, the rehabilitation phases started from milling-off the existing pavement surface not exceeding 150 mm of thickness (Figure 3). Prior to stabilization works by mixing the existing roadbase material with OPC and alkaline compound (i.e. Geocrete), quarry dust was spread equally over the stabilized area (Figure 4). The mixing work was done by special rotary mixer machine, CAT RM500 that has the capability of ensuring a uniform blend of stabilization material with the set of 300 mm depth. Water was then spread uniformly over the mixed soil-cement-alkaline compound to start the chemical reaction for this stabilization process (Figure 5). Then, the mixture was compacted with 10 tonnes drum roller without vibration for two passes, followed by another compaction using three passes of vibration roller with the speed of not more than 3 km per hour (Figure 6).

Finally, before laying the bituminous layers, the curing process was performed by spraying water uniformly on the stabilized soil periodically for every three to four hours in three days. This is a process to ensure that no premature cracking is formed by controlling hydration during the stabilization process.

Figure 3. Milling process to scrape-off the existing asphalt layers

(a) (b)

Figure 4. (a) Spread layer of quarry dust; and (b) positioning of cement and alkaline compound packaging to ensure an evenly distribution over the stabilized area

Figure 5. Mixing process of mixed soil-OPC-alkaline compound by special rotary mixer machine, CAT RM500

Figure 6. Compaction process by a 10 tonnes drum roller without and with vibration

4. POST-CONSTRUCTION RESULTS

Two types of monitoring test procedures were conducted after the completion of construction works, i.e. UCS test after 28 days and Light Falling Weight Deflectometer (LFWD) test. As tabulated in Table 4, results confirmed that the application of soil-cement stabilization technique has achieved the expected strength and the project objective by complying with the requirement greater than 2.5 MPa.

Table 4. Summary for UCS test results after 28 days

Sample No.	Diameter (mm)	Length (mm)	Sample Mass (g)	Density (kg/m3)	Maximum Force (kN)	UCS (MPa)
1	94.0	323	1338.9	2113	73.0	10.5
2	94.0	318	1378.9	2094	105.0	15.1
3	94.0	334	1346.4	2098	106.0	15.3

LFWD tests were performed according to ASTM E2835 - 11(2015) to monitor the bearing capacity and the strength behaviour of unbound pavement material by using Light Drop Weight Tester ZFG2000 (Figure 7). This quick and cost effective method is to evaluate the dynamic deflection modulus, E_{vd} in MN/m^2. This modulus is an index for the bearing capacity of roadbase layer, and calculated from the measured settlement(s) which equivalent to the results obtained from static plate bearing test (BS 1377 Part 9: 1990) recorded for existing pavement; i.e. 46.03 MN/m^2.

Figure 8 shows an illustration for the summary average results of LFWD up to 28 days after the construction had been completed. For comparison purposes, the data of the 1st, 3rd, 7th and 28th days after stabilization were compared again with the result of existing roadbase surface. The readings recorded after stabilization on the 1st, 3rd, 7th and 28th days age were 109.08 MN/m^2, 140.45 MN/m^2, 159.46 MN/m^2 and 182.39 MN/m^2 respectively. It evidently shows an increase of 237% from the 1st day up to 396% on the 28th day, a significant improvement in roadbase bearing capacity index which was achieved in the post construction.

Figure 7. In-situ practical of Light Falling Weight Deflectometer (LFWD) test

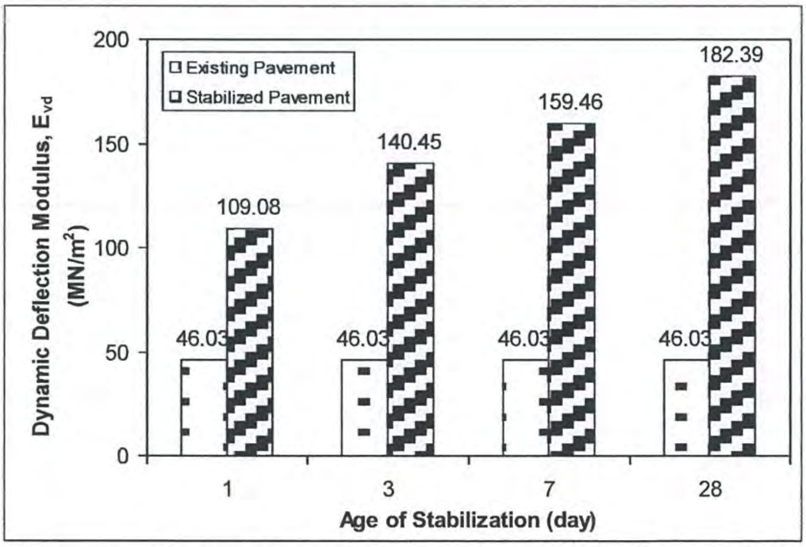

Figure 8. Summary of result for dynamic deflection modulus with respect to age of stabilization

5. CONCLUSIONS

The application of soil-cement stabilization technique with the incorporation of quarry dust and alkaline compound (e.g. Geocrete) with designated proportion has resulted in high value bearing capacity and is more effective than the conventional regulating during the mill and pave of the undulated surface of highway pavement. In tandem with soil-cement-alkaline stabilization design approach, a high performance of roadbase in term of compressive strength and high resilient modulus can be expected as a solution for unstable pavement.

From the mix design of 8% and 2% for OPC and alkaline compound respectively, the average results of 13.63 MPa for compressive strength and 396% increment in bearing capacity as compared to existing roadbase reading of LFWD for after 28 days were achieved. Subsequently, this stabilization technique can lessen the frequency of maintenance cycles, which makes it an effective and practical engineering solution especially for highway maintenance.

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