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Experimental Studies on Treated Sub-base Soil with Fly Ash and Cement for Sustainable Design Recommendations

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***Abstract*—**The pavement constructions on soft and expansive soils are not durable and unable to sustain heavy traffic loading. As a result, pavement failures and settlement problems will occur very often even under light traffic loading due to cyclic and rolling effects. Geotechnical engineers have dwelled deeply into this matter, and adopt various methods to improve the engineering characteristics of soft fine-grained soils and expansive soils. The problematic soils are either replaced by good and better quality material or treated by using chemical stabilization with various binding materials. Increased the strength and durability are also the part of the sustainability drive to reduce the environment footprint of the built environment by the efficient use of resources and waste recycle materials. This paper presents a series of laboratory tests and evaluates the effect of cement and fly ash on the strength and drainage characteristics of soil in Miri. The tests were performed at different percentages of cement and fly ash by dry weight of soil. Additional tests were also performed on soils treated with the combinations of fly ash with cement and lime. The results of this study indicate an increase in unconfined compression strength and a decrease in hydraulic conductivity of the treated soil.

***Keywords*—**Pavement failure; soft soil; sustainability; stabilization; fly ash; strength and permiability

I. Introduction

VARIOUS methods are adapted to improve the engineering characteristics of soft fine-grained soils and expansive soils. The problematic soils are either removed and replaced by good and better quality material or treated using chemical stabilization. The chemical stabilization of the problematic soils is very important for many of the geotechnical engineering applications such as pavement structures, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines, and sewer lines to avoid damage due to settle of soft soil or to the swelling action of expansive soil. Generally, the stabilization concept can be dated 5000 years ago. Treated earth roads were used in ancient Mesopotamia and Egypt, and that the Greek and Roman used soil-lime mixtures [1]. The first experiments on soil stabilization were achieved in the USA with sand/clay mixtures around 1906. In the 20th century, especially in the thirties, the soil stabilization relevant to road construction was applied in Europe [2]. In Malaysia, the soil stabilization techniques for road construction are not applied and there are no Malaysian recommendations and regulations for soil stabilization using fly ash and cement.

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Engineers in Malaysia often faced with problem of constructing roadbeds on problematic soils. These soils do not possess enough strength to support the wheel loads upon them either in construction or during the service life of the pavement. Thus, soil treatment must be conducted to provide a stable sub-base or a working platform for construction of pavement. One of the strategies to achieve this is soil stabilization. The soil stabilization includes both physical and chemical stabilization. Chemical stabilization involves mixing binding agents with natural soils to remove moisture and improve strength properties of the soil. Generally the role of stabilizing agent in the treatment process is either reinforcing of the bounds between the particles or filling of the pore spaces. There are two types of chemical stabilization depending to the depth of the problematic soil and the type of geotechnical application: surface or deep stabilization. The traditional surface stabilization begins by excavating and breaking up the clods of the soil followed by the addition of stabilizing agents. The known amount of water is mixed with the soil and additives and compacted. Approximately 150 to 250mm depth of soil can be strengthened by this surface method. Moreover, by using heavy equipment with appropriate modification, the depth of stabilized zone can be increased to 1m. These methods are used extensively to stabilized bases and sub-bases of highways and airfield pavements [3]. The pavement soil qualities will be improved by thoroughly mixing and compacting with additives include portland cement, fly ash, bitumen, and combinations of any of the additives [4]. The type of the additive and the amount required are dependent upon the soil classification and the degree of improvement desired [5]. The pavement structure consists of a relatively thin wearing surface constructed over a base course and a sub-base course that rests upon a sub-grade course. Asphalt/concrete is primarily used for the wearing surface. The properties of all the pavement layers are considered in the design of the flexible pavement system [6].

They suggested that construction of long-lasting, economical flexible pavement requires materials that exhibit good engineering properties. The sub-base should possess desirable properties to extend the service life of the roadway section and reduce thickness of the flexible pavement structure. Strength, drainage, and permanency of strength are the few desirable properties. The fly ash classified ‘F’ exhibits low self-cementing properties and however, with a addition of an activator such as lime the fly ash Class ‘F’ produces cementitious product [7]. Even for very expansive clayey soil, unconfined compressive strength increased by 106% when fly ash content was increased from 0 to 25% [8].

II. PAVEMENT FAILURE IN SARAWAK

Most of the roads in Sarawak are facing the pavement distress problem which needed attention and proper treatment to ensure the satisfactory in the level of service. In order to ensure the risk of premature deterioration is minimized, it is necessary to use the best practice pavement technology in the planning, design, construction, maintenance, rehabilitation, and operation of the road system. Figure 1 shows the juncture of the paved and unpaved shoulder of the road section nearer to the security gate at the entrance of Curtin University, Miri. Even though the road section have the same pavement thickness, soil compositions and subjected to the same traffic loads, the road section with unpaved shoulder has more failure cracks and damages resulting from inadequate drainage system.

Fig. 1 The road section at Curtin entrance

A greater knowledge of what constitutes best practice pavement technology can be achieved by examining pavements that have failed prematurely, with the focus being on determining the causes of the failure so that it can be prevented in the future, and designing a rehabilitation treatment that minimizes any further deterioration. The study was conducted to assess the pavement condition along a few roads in Miri, Sarawak. The study focused on site assessment for flexible pavement through visual assessment based on the Pavement Assessment Guide, JKR [9]. Apart from that, a laboratory tests were conducted to assess the strength of sub-grade soil samples, collected from the depth of 0.5m to 0.8 m at 5 different locations.

A. Field Condition Survey

The assessment includes all related information, which will be used to determine the type of pavement distress as well its possible causes of the failure. The main parameters that were assessed during the field survey include pavement cracking, surface deformation, surface defects and drainage condition. The study area was recorded in dual way direction. The field survey was conducted along the study area segment by segment. The assessment were made and summarized for every 250meter stretch in each lane.

Assessment had also been conducted on the pavement drainage as these elements contribute significantly to the overall performance of the pavement structure. Surface drainage was judged by the ability of the pavement surface to drain water as well as not allowing water to pond either on the bituminous surfacing or on the shoulder verge. Observations had been made to identify whether the existing drainage system was sufficient and properly functioning to safeguard the pavement structure. The distress types and its distribution along the study area are presented at the table 1.

TABLE I
SUMMARY OF DISTRESS TYPE AND ITS DISTRIBUTION

Distress Type	***Road 1***	***Road 2***	***Road 3***	***Road 4***	***Road 5***
Length (km)	9	3	10	3	4
Cracking (segment)	51	15	44	16	22
Cracking %	70.83	62.50	55.00	66.67	68.75
Rutting (segment)	52	14	54	17	21
Rutting %	72.22	58.33	67.50	70.83	65.63
Pothole (segment)	7	5	6	3	4
Pothole %	9.72	20.83	7.50	12.50	12.50
Patching (segment)	12	6	24	6	6
Patching %	16.67	25.00	30.00	25.00	18.75

B. Laboratory Testing Result

The laboratory results of the investigation on the effect of moisture on the subgrade CBR *(California Bearing Ratio)* of soil sample 1 to soil sample 5 are plotted against the moisture content and shown in Figure 2.

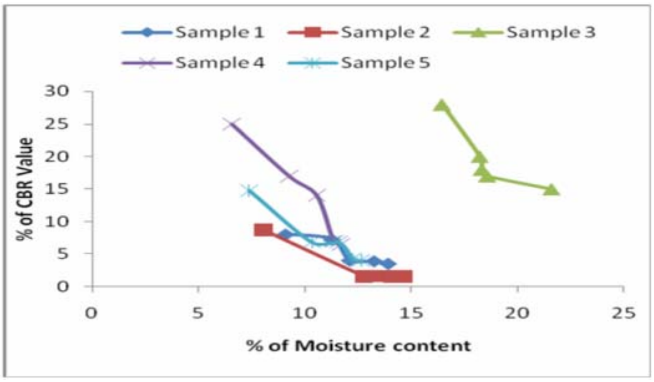

Fig. 2 CBR strength vs Moisture content

The mean dry density achieved in this soil samples range from 1.721Mg/m^3 to 2.196Mg/m^3 corresponding to 95% level of compaction based on the maximum dry density. The scatter in the dry density values may be due to the variation of water content during compaction. The rate of reduction in the CBR during wetting is noticed in a sudden drop during the initial soaking. The rate of reduction decreases after the initial sudden drop.

The result shows that on soaking from optimum moisture content condition, the CBR of the subgrade drop between 46% and 82% for dry density of 1.721Mg/m^3 to 2.196Mg/m^3.

III. SOIL STABILIZATION

A series of laboratory tests were conducted to evaluate the effect of cement and fly ash on the strength and drainage characteristics of soil in Miri. The tests were performed at different percentages of cement (2%, 4%, and 6%), and fly ash (6%) by dry weight of soil. An additional test was also performed on soils treated with mixture of 3% fly ash and 3% cement. The fly ash, Class 'F' acquired from the Sejingkat Thermal Power Plant in Kuching, Sarawak was used in this experimental studies. All the experiments performed in this study were in accordance with ASTM standard. For permeability test, the constant head method was adapted. For unconfined compression test, cylindrical samples of soil-cement, soil-fly ash and soil-cement/fly ash mixtures were prepared at their respective optimum moisture content and maximum dry density. The stabilized soil mixtures, 38mm diameter and 76mm in length were prepared by static compaction. The samples were cured in an enclosed water tank for a period of 3, 7 and 15 days.

A. Standard Proctor Test

The compaction test results of treated and untreated soil samples are shown in Figure 3. Without any stabilizing agents, the optimum moisture content was 14.80% with corresponding maximum dry density of 1.548Mg/m^3. When the soil was treated with 2% cement, the compaction curve showed 1.592 Mg/m^3 at 14.40% OMC *(Optimum Moisture Content).* Further increase of cement content also showed higher value of MDD *(Maximum Dry Density)* obtained with lower OMC. Improvement in MDD was more obvious when 4% and 6% cement was reacting with the soil. At 4% cement content, the MDD was 1.605 Mg/m^3 with OMC of 14.10%. Besides that, 1.614 Mg/m^3 with OMC of 13.90% was gained when soil was treated with 6% cement. The density of the soil sample was developed as well when fly ash, acting as stabilizing agent was mixed with the soil. The MDD for 6% fly ash combined with soil was 1.607 Mg/m^3 with 14.00% OMC. Moreover, treatment with 3% cement/fly ash demonstrated enhancement in the MDD as compared to non-treated soil. The achieved MDD was 1.621 Mg/m^3 at 13.80% OMC.

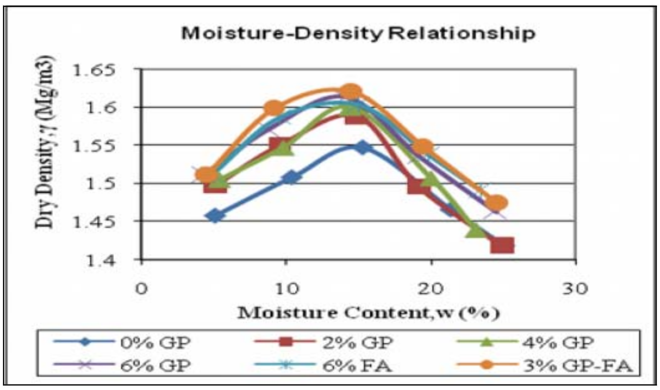

Fig. 3 Compaction curve of treated and untreated soil

B. California Bearing Ratio Test

The CBR test results are indicated in Figure 4. The soil mixtures were prepared at 96% of optimum moisture content. The soil mixture that was not added with additives illustrated lowest CBR values of 6.82%. The soil treated with 6% cement has the highest CBR value of 11.49%, whereas the stabilization with 2% cement has the lowest value of 8.02%. The hydration of cement forms calcium silicate hydrate gel. More cement dosages form more hydrate gel that enhance continuous increment in CBR. On the other hand, the soil-fly ash bearing capacity improvement is not as significant as cement due to lack of self-cementing ability of class 'F' fly ash. The CBR value of 9.16% was obtained when 6% fly ash was blended in the experiment. Addition of cement to fly ash mixed soil exhibited higher CBR value which recorded 10.41% as the improvement in fly ash was achieved by hydration of cement.

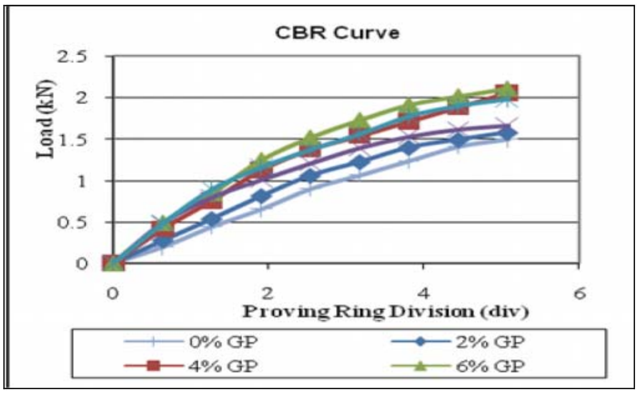

Fig. 4 CBR of treated and untreated soil

C. Hydraulic Conductivity

The effect of cement content on the water permeability is shown in Figure 5. As expected, the addition of cement reduces water permeability. The K-value decreases from 8.36x10^{-5}cms^{-1} to 3.02x10^{-5}cms^{-1} when the cement content increased from 0% to 6%. Furthermore, permeability of soil-fly ash and soil-cement/fly ash also indicated decrease in K-value. The hydraulic conductivity constant was recorded to be 3.33x10^{-5} cm/sec and 3.45x10^{-5} cm/sec, respectively. The K-value showed minor differences when the soil was treated with fly ash and cement/fly ash. This shows that stabilization of soil with cement and fly ash could lead to better strength and lower permeability thus better durability.

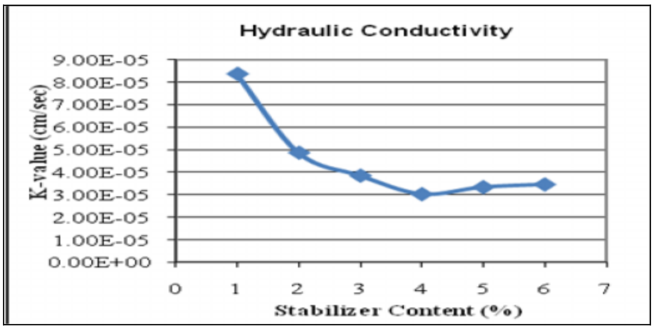

Fig. 5 Permeability of treated and untreated soil.

D.Unconfined Compression Strength

The variation of curing time with unconfined compressive strength is shown in Figure 6. The result shows that 6% soil-cement mix acquires the highest unconfined compressive strength at 3, 7 and 15 days curing period. The unconfined compressive strength at 3, 7 and 15 days are 125.7MPa, 165.9MPA and 223.2MPa. The strength improved 44% within 12 days of curing period. The results of strength improvement displayed by 6% soil-fly ash treatment are lowest as compared to soil-cement stabilization. The unconfined compressive strength at 3, 7 and 15 days are 6.9MPa, 11.1MPA and 14.7MPa. The class F fly ash shows very little self hardening property without the presence of cement [10]. For the soil treated with of 3% cement and 3% fly ash, the unconfined compressive strength at 3, 7 and 15 days are 47.0MPa, 64.8MPA and 82.3MPa. Significant strength enhancement is clearly visible.

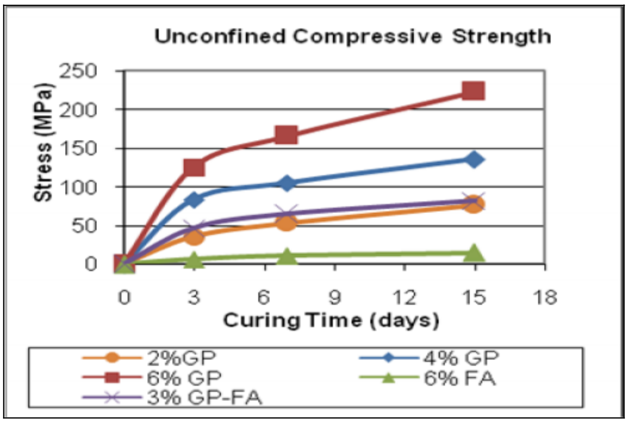

Fig. 6. UCS of treated and untreated soil

IV. Recommendations

Pavement surface drainage had been recognised as an important factor in the roadway design. Effective surface water drainage is essential to minimise the intrusion of moisture into the pavement structure. On the other hand, it will help to maintain the desirable level of service and traffic safety. Regular inspection on the drainage shall be made in order to ensure its function. Adequate cross-fall should be provided for the unpaved shoulder sections and maintained to drain the precipitated rain water effectively to the storm water drains as quick as possible for entire design life.

The subgrade or sub-base stabilization is one of the cost effective way to improve the soil performance compare with the conventional soil replacement method. According to research, the use of mixture of low calcium fly ash and cement or lime in soil stabilization can increase both the unconfined compressive strength and the CBR values substantially.

Stabilization with mixture of fly ash and cement or lime provides an economical method of recycling flexible pavements that have granular base. Existing pavement of this type may be pulverized in-place, sufficient quantities of stabilizing mixture and water added and compacted to function as a base or sub-base have a greater structural capacity than original pavement section. The recycling processes can be applicable for the existing pavement consisting of asphaltic concrete underlain by a granular base section of variable composition.

V. Conclusions

The redesigned flexible pavement consisting of modified *sub-base layer* of recycled existing asphalt and base course materials stabilized with fly ash and cement or lime mix and open graded bitumen stabilized *base layer*, will be the viable economical and sustainable solution to the pavement failure for most of the existing roads in Sarawak.

The new pavement design should ensure the adequate surface and sub-surface drainage system to meet the design requirement for local rainfall of that regions.

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