Correlation between California bearing ratio (CBR) with plasticity index of marine stabilizes soil with cockle shell powder

M M Nujid¹, J Idrus², N A Azam³, D A Tholibon⁴ and D Jamaluddin⁵

¹,²,³,⁵Faculty of Civil Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, Jalan Permatang Pauh, 13500 Permatang Pauh, Penang, Malaysia.
⁴Faculty of Civil Engineering, Universiti Teknologi MARA, Cawangan Jengka, 26400 Bandar Tun Razak, Pahang, Malaysia.

*masyitahmn@uitm.edu.my

Abstract. Subgrade soil is important for design purpose of both flexible and rigid pavement structures; flexible and rigid. The quality of flexible and rigid pavement structures is correlated on the strength and stabilization of subgrade layers. The main function of subgrade is to act as a foundation for pavement layers and supporting the load which is transmitted from the overlying layers. The marine soil is a problematic soil which low in strength and do not suitable for road embankment for highway construction. Therefore, the soil strength can be improved by adding stabilizer or admixture to increase its strength. Soil stabilization change its physical and mechanical properties from its original soil. Thus, the physical properties of marine stabilized with cockle shell powder were determined and the potential of Cockle Shell Powder (CSP) as soil stabilizer based on percentage added in CBR test was investigated. Based on previous research, the performance of soil mixed with CSP in the proportion of constant 2.5%, 5%, 7.5% and 10% was examined with CSP properties and California Bearing Ratio (CBR) tests. The results obtained indicates an increment in specific gravity and decreasing in the plastic index (PI) with the addition of 2.5% of CSP. The CBR and PI show a good correlation and thus inclusion of CSP in marine soil could be used as alternative material for subgrade layer in increasing soil strength.

1. Introduction

Road constructions are divided into two types which are flexible pavement and rigid pavement. Subgrade soil is important for design purpose of both; flexible and rigid pavement structures. The quality of flexible and rigid pavement structures is correlated on the strength and stabilization of subgrade layer. Subgrade is the layer of soils that cater and receive the most traffic loading. Subgrade is the lowest layer in the structure of pavement and it may consist of existing soil layers which cut to form the foundation of the road structure [5].

Failures in pavement are often noticed in flexible pavement that is constructed over clay subgrades regardless the thickness of clay. During raining season, the heavy traffic roads are affected by the shear failures or excessive settlements in the edge regions due to soften subgrade. The marine soil is a problematic soil which low in strength and do not suitable for road embankment for highway. However the marine clay has to be treated with stabilization methods available such as by using natural stabilizers
(rice husk ash, cockle shell powder (CSP) and egg shell) or additive agents (chemical, physical and biochemical) before constructing the road. The use of natural stabilizer materials is getting attention in research interest worldwide due to the ability to increase the strength, reduce environmental impact and reduce cost of material. The use of CSP as natural stabilizer is due to cockle shell contains calcium carbonate (CaCO3) and Calcium oxide (CaO) which similar to cement additives [5,6,7,9,10]. Furthermore, CSP will be added in the subgrade layer to boost the strength of soil and it will reduce the overall environmental impact of the stabilization process. Therefore this type of soil strength can be improved by adding stabilizer or admixture to increase its strength. Soil stabilization changes its physical and mechanical properties from its original soil.

For road pavement design, among elements are considered are; i) configuration of vehicle wheels or tracks, ii) vehicle wheel load or axle load, strength of soil, iii) flexural strength for concrete pavements and iv) the volume of traffic during the design life of pavement are needed to estimate the desired load carrying capacity.

The procedure to design the flexible pavements is by referring to the California Bearing Ratio (CBR) design procedure. This procedure requires that each layer be thick enough to convey the stresses initiated by traffic to ensure the underlying layer are not overstress and produce excessive shear deformation. The value of California Bearing Ratio will present the strength of the soil. Therefore, the objectives of present study are to determine physical properties of marine stabilized with cockle shell powder and correlation between CBR and plasticity index of stabilized soil.

2. California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) is an empirical test for estimating the bearing value or to evaluate the strength of highway sub-base and subgrades for design of pavement thickness. In the CBR test is conducted by pushing a standard plunger onto the soil at a fixed rate of penetration and measuring the force required to maintain that rate.

The CBR value is defined as percentage between the measured force and standard force for a certain penetration and same penetration as given in Eq. 1. The ratio is usually determined for penetration of 2.5 mm and 5.0 mm. The standard forces corresponding to penetrations for 2.5 mm and 5.0 mm are 13.24 kN and 19.96 kN.

\[
CBR = \frac{\text{Measured force}}{\text{Standard force}} \times 100\% 
\]  

(1)

The CBR test is applied to coarse and fine grains on undisturbed or recompacted soils which can be performed in the field and laboratory. It is also applicable in design stage for various road construction types (flexible and rigid pavements). The CBR test is quick and simple to operate and can acquire fast result.

2.1 Correlation of California Bearing Ratio (CBR) and Index Soil Properties

Field and laboratory CBR testing somehow may not give an accurate result due to time-consuming operation, skill operator, sample disturbance and poor quality of the laboratory testing conditions. Therefore a prediction model is proposed to overcome all such problems raised in conducting a CBR testing. The prediction model is used as a reference for the opinion of the validity of the CBR values.

Previous studies show some correlation of CBR between optimum moisture content, Atterberg limit (liquid limit and plastic limit), plasticity index and soil classification. All of the CBR correlation studies were among index soil properties [8,13]. Nevertheless, the CBR correlation between compaction characteristics [1] also can be achieved. The CBR correlation studies with index soil properties is analysed by single and multiple regression analysis which show a satisfactory empirical correlation. It is also useful for pavement design of road base in characterising the strength of subgrade soils. The sample for soil CBR testing can be a natural soil or a stabilised soil with soaked or unsoaked sample.
3. Methods
In this study, marine soil samples were collected at the location of sampling from along the coastal area of Kuala Muda, Kedah (Figure 1a). The soil samples were collected using hand auger at the jetty area. Next, the cockle shell waste was handpicked from Kuala Kedah, Kedah (Figure 1b) and Pulau Aman, Pulau Pinang jetty area. The shells were washed thoroughly to remove the dirt from its surface and dried in an oven for 24 hours at 25°C - 30°C. Then the cockle shells were ground using an abrasion machine (ASTM C131) into powder form. The powder which was sieved using a 0.063 mm sieve was then used for testing. The cockle shell powder was mixed at different percentages, 2.5%, 5.0%, 7.5% and 10.0%, to the dry weight of soil. Table 1 provides the details of the mix proportion of cockle shell powders and soils.

![Figure 1. (a) Location of soil sampling, (b) Cockle shell waste collected at Kuala Kedah, Kedah.](image)

| Sample | Marine soil (%) | Cockle shell powder, CSP content (%) | Remark |
|--------|----------------|-------------------------------------|--------|
| 1      | 100            | 0                                   | Untreated Soil |
| 2      | 97.5           | 2.5                                 | Treated Soil  |
| 3      | 95.0           | 5.0                                 | Treated Soil  |
| 4      | 92.5           | 7.5                                 | Treated Soil  |
| 5      | 90.0           | 10.0                                | Treated Soil  |

The Atterberg’s limit test was applied according to BS 1377: Part 2:1990 in order to determine the moisture content and particle size distribution. The specific gravity of the marine clay samples was determined by establishing the pycnometer bottle technique. The technique adopted to determine the particle size distribution was the dry-sieving, where, if the soil percentage in the last pan was greater than 10%, the experiment will then be continued with the hydrometer test. The consistency index tests conducted consisted of liquid limit and plastic limit. The liquid limit was determined using the cone penetration test at 20 mm penetration. While the plastic limit was determined by rolling the soil thread into a 3 mm diameter without crumbling. In addition, the plasticity of soil can be determined using the Plasticity Chart. The unsoaked of CBR testing which is to determine bearing of the subgrade in accordance to BS 1377: Part 4: 1990. The mould that was used in this testing was a metallic cylinder of 152 mm diameter and height provided with a detachable metal extension collar at 50 mm in height and 4.5 kg of the rammer. Table 3 represents the CBR tested for soil alone and a combination of soil and cockle shell.
4. Results and Discussion
Table 2 summarizes the index geotechnical properties of the tropical marine soil from Kuala Muda, Kedah. The Gs value for the marine soil deposits was 2.27, which is lower than the range produced by in range of 2.55-2.67 [2] and 2.4-2.6 [11]. The marine soil was classified as SILT of high plasticity (MH) according to the BS 1377: Part 2:1990. From Table 2, it shows that the marine soil samples are dominated by silt fraction (50.37%) followed by a sand fraction (41.05%). The clay fraction in the marine soil sample was 8.44%. Shell fragments were also commonly found in the marine soil samples.

It was reported that the presence of higher silt and clay is a characteristic of the typical muddy coastal beach of peninsular Malaysia [2,11]. However, the present results indicate the clay fraction was a small percentage compared to silt and sand. The samples were collected near to the sandy/sediments beach area using a hand auger technique which led to sand particles to appear in the sampling process. The values of the liquid limit, LL and plastic limit, PL are shown in Table 2. The LL values were 68% while PL values were 32%. The values of the plastic index, PI was 36% and the Atterberg limits from the soil samples typically reflect marine clay from Asia countries mostly [2,11,12].

Table 2. Index properties of marine soil used in this study

| Soil properties                  | Values       |
|----------------------------------|--------------|
| Natural moisture content (%)     | 88-125.17    |
| Specific Gravity (Gs)            | 2.27         |
| Sand (%)                         | 41.05        |
| Silt (%)                         | 50.37        |
| Clay (%)                         | 8.44         |
| Liquid Limit, LL (%)             | 68           |
| Plastic Limit, PL (%)            | 32           |
| Plasticity Index, PI (%)         | 36           |
| Maximum Dry Density, $\rho_{d_{\text{max}}}$ (Mg/mm³) | 1.64         |
| Optimum Moisture Content (%)     | 16.34        |

The index properties of stabilized marine clay soil as shown in Figure 2 where results obtained indicates an increase in specific gravity and decrease in the plastic index (PI) with the addition of 2.5% of CSP. The specific gravity increase gradually as the number of stabilizer increases. The present study of Gs for untreated soil is low because the organic matter was found in the soil composition. It also true for untreated soil shows liquid limit is higher compare to treated soil with cockle shell powder. The liquid limit is the water content at which soil changes from the liquid state to a plastic state. Thus by adding cockle shell powder it cause to soil less in liquidity.
Figure 2. Relationship between (a) the specific gravity and (b) the percentage of CSP content (0, 2.5, 5, 7.5, and 10%).

The correlation between CBR value and plasticity index show that the CBR value is decreasing as the plasticity index (PI) increase. The current correlation CBR with plasticity index is differ with other previous studies is due to sample tested for stabilized soil with different percentage of stabilizer added into soil (during sample preparation) as shown in Figure 3. The summary of regression analysis equations from current and previous studies show in the Figure 3 and in Table 3.
5. Conclusion
The present study objectives are to determine physical properties of marine stabilized with cockle shell powder and correlation between CBR and plasticity index of stabilized soil. The performance of soil mixed with CSP in the proportion of constant 2.5%, 5%, 7.5% and 10% of CSP correspondingly was examined with respect to physical properties test and California Bearing Ratio (CBR) tests. The results obtained indicate an increment in specific gravity and decreasing in the plastic index (PI) with the addition of 2.5% of CSP. The CBR and PI shows a good correlation and thus inclusion of CSP in marine soil could be used as alternative material for subgrade layer in increasing soil strength.

6. Acknowledgment
The authors would like to acknowledge Universiti Teknologi MARA (UiTM), Cawangan Pulau Pinang, for financial support in this research work.

References
[1] Aderinola O S and Quadri A I 2017 Correlation of california bearing ratio value of clays with soil index and compaction characteristics International Journal of Scientific Research and Innovative Technology 4, 4 p. 12-22.
[2] Anggraini V Asadi A Syamsir A and Huat B B K 2017 Three point bending flexural strength of cement treated tropical marine soil reinforced by lime treated natural fiber. Measurement 111, p. 158–166.
[3] ASTM C131/C131M. 2006 Standard test method for resistance to degradation of small-size coarse aggregate by abrasion and .impact in the Los Angeles Machine. (West Conshohocken, PA, USA: ASTM International).
[4] British Standards Institution 1990 *British Standard Methods of Test for Soils for Civil Engineering Purposes, Part 2, Classification Tests* (London: BSI).

[5] Harun I M 2013 *Jalan oh Jalan Kenapa Engkau Rosak* (Kuala Lumpur: JKR Malaysia).

[6] Mohamed M Yusup S & Maitra S 2012 Decomposition study of calcium carbonate in cockle shell *J. Eng. Sci. Tech.* 7, 1 p1-10.

[7] Nor Hazurina, O., Hisham, B. A. B., Mashitah, M. D. and Azmi, M. M. J. 2013 Cockle shell ash replacement for cement and filler in concrete. *Malays. J. Civ. Eng.* 25, 2 p. 201-211.

[8] Nguyen B T and Mohajerani A 2015 Prediction of california bearing ratio from physical properties of fine-grained soils *Int. J. Civ. Environ. Eng.* 9, 2 p. 119-124.

[9] Olivia M Arifandita A and Darmayanti L 2015. Mechanical properties of seashell concrete *Procedia Eng.* 125, p. 760–764.

[10] Otoko G R and Cynthia E I 2014 Mechanical stabilization of a deltaic clayey soil using crushed waste periwinkle shells *International Journal of Engineering and Technology Research*, 2, 5 p.1-7.

[11] Rahman Z A Yaacob W Z W Rahim S A Lihan T Idris W M R and M.Sani W N F 2013 Geotechnical characterisation of marine clay as potential liner material. *Sains Malaysia*, 42, 8 p.1081–1089.

[12] Tanaka H Locat J Shibuya S Soon T T and Shiwakoti D R 2001 Characterization of Singapore , Bangkok , and Ariake clays. *Can. Geotech. J.* 400, p. 378–400.

[13] Katte V Y V Mfoyet S M Manefouet B Manefouet B Wouatong A S L and Bezeng L A 2018 Correlation of california bearing ratio (CBR) value with soil properties of road subgrade soil. *Geotech. Geol. Eng.*