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RELATING THE FIELD AND LABORATORY CALIFORNIA BEARING RATIO (CBR) OF STABILISED ROAD BASE

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ABSTRACT: Road base materials may not comply with the stipulated minimum load-bearing capacity, especially those of soft soil deposits with high clay and silt contents. An effective and potentially economical solution is the stabilization of the in situ poor soils instead of the conventional remove-and-replace approach, especially for low-cost subsidiary and private roads leading to agricultural land with heavy tonnage traffic. This paper examines the California Bearing Ratio (CBR) of stabilized soils for an existing site, with comparisons made between field and laboratory tests of the treated soil samples. With 3% stabilizer admixed per dry weight of the soil, rolled and pounded to at least 95% of compaction degree, 5 samples were tested in situ and the laboratory. The field measurements differed from laboratory results within the range of 30-60%, an observation attributed to the ideal compaction attained with the laboratory sample's preparation procedure and condition. Laboratory measurements recorded approximately 55-88 kPa for the bottom face (5.0 mm penetration), and 90-105 kPa for the top face penetration (2.5 mm penetration). The corresponding unconfined compressive strength of the 3% binder-treated sample was 3.2 MPa, with a distinct rather linear climb of the stress-strain plot before sudden rupture at the peak, typical of a hard and brittle material under compression. Summarily, the stabilized road base was found to sustain traffic loads of up to 5 tonnes while complying with the CBR requirement of at least 50%. Variations between laboratory and field measurements were mainly due to the controlled sample preparation method adopted in the former.

Keywords: CBR, Strength characteristics, Stabilised soils, Compaction, Clay, Silt

1. INTRODUCTION

Road transportation networks are vital assets for a nation to promote both social and economic activities. To Malaysia Road Statistic 2021 Edition, as of 31 December 2020, there were altogether 290,099.384 km lengths of roads in Malaysia, including federal and state roads [1]. Among these roads, 198,437.910 km were paved roads, 45,853.820 km were unpaved gravel roads, and 22,753.85 km were unpaved soil/laterite roads. Total road length has increased by approximately 21.5% over the last five years.

In road construction, from the bottommost sub-grade layer to the surface course, the characteristics of every component would significantly affect the overall performance of the road. According to [2], typical structural components of a major road consist of asphaltic concrete wearing course, binder course, bituminous mix road base, crushed aggregate or wet mix road base, sub-base, and subgrade.

Typically, raw granular materials, such as granular soils or granite stones, are used to construct subgrade, sub-base, or base courses. To harvest raw materials, the natural environment is adversely affected, and the process is costly [3]. Rocks are blasted to produce granite stones, and rivers are mined to produce sand. The natural environment is being destroyed while resources are being harvested. Therefore, the extraction of raw gravel materials is getting more challenging due to rising urbanization and environmental and commercial concerns [4]. Apart from environmental considerations with increased demand for urban development, suitable gravel materials may not always be available at reasonable monetary costs. Haulage and transportation also cause inevitable disturbances to the environment. Indeed, the disposal of unsuitable materials becomes difficult with more stringent environmental restrictions [5]. It is, therefore, imperative that harvested natural resources are put to maximum usage without wastage, such as prolonging the lifespan of the structural road layers and enhancing the properties of materials subpar to standard requirements.

In general, the performance of pavements is dependent on the mechanical characteristics of materials for each layer, climatic conditions, as well as construction technology, and quality [6]. For instance, exposure to extreme moisture could lead to a significant reduction in strength and premature failure [7]. In addition, poor compaction and subpar materials can result in fissuring and large, damaging deformations of pavements.

To this end, chemical stabilization could be a potentially viable solution. It is a method in the living mixing of soil with a chemical binder. Previous studies reported that the strength and stiffness of geomaterials could be improved through a chemical reaction between soil and binder [8]. By adding appropriate chemicals, in-situ materials can be strengthened to meet engineering requirements, thus reducing the demand, haulage, and usage of raw materials, consequently reducing the overall road construction costs, especially in rural areas [9].

Lime is arguably the oldest traditional chemical used in soil stabilization [10]. Lime comes in the form of either 'quicklime' (calcium oxide - CaO) or 'hydrated lime' (calcium hydroxide - $Ca(OH)_2$). 'Quicklime' is the product of the calcination of limestone (calcium carbonate – $Ca(CO_3)_2$), where calcination is the thermal treatment below the melting point to drive out carbon dioxide. 'Hydrated lime' is the product of water addition to quicklime, which can be either in powder form or in slurry form. Upon reaction, hydrated lime ionizes and turns into calcium ions and hydroxide ions, which are major constituents in lime stabilization. Nonetheless, since hydrated lime can be obtained by mixing quicklime with water, quicklime is more readily usable as a stabilizer. Excessive moisture can also be removed from the geomaterial to be treated with quicklime. Being more reactive, at the same unit mass, quicklime provides more calcium ions, which are responsible for further chemical reactions, as elaborated by these studies [11,12]. This serves as the basis for proprietary binders being formulated with Ca-based compounds like quicklime.

With the addition of the binders, the strength and stiffness, and hence the CBR (California Bearing Ratio) values, an indicator of the strength of pavement component layers, can be improved. Laboratory and field CBR tests are commonly performed to gauge the load-bearing capacity of the stabilized pavement layers, such as road bases. Such QA/QC works are crucial to ensure the long-term stability and performance of the roads [13,14]. The engineering judgment very much depends on the compatibility between the CBR results of the design mix at the formulation stage and post-construction measurements on-site.

This paper describes the CBR values of a road base stabilized with a Ca-based binder, with emphasis on the comparison between laboratory and field measurements. Discussions are presented on the observations made and plausible explanations for the seeming incompatibility of the test results.

2. MATERIALS AND METHODS

2.1 Materials and Sample Preparation

The crusher run sample had a percentage passing 0.075mm of only 0.35%, which met the requirement of <10%, in accordance with [2]. The standard compaction test showed the maximum dry density (MDD) and optimum moisture content (OMC) to be 2.183 g/cm^3 and 6.53%, respectively. The proprietary lime-based binder was essentially a mixture of ionic compounds and poly-fibers. These fibers are reportedly expedient for plastic shrinkage and non-structural temperature shrinkage control in composites [15], an advantage for the stabilized road base in a tropical climate like that experienced in Malaysia.

2.2 Strength Measurements: CBR and UCS Tests

California Bearing Ratio (CBR) is defined as the ratio of strength required to penetrate a cylindrical plunger to a certain depth of the tested material as compared to the standard materials. According to the standard [16], the stabilized samples were molded into a CBR mold of 152 ± 0.5mm inner diameter and 127±1mm effective internal height. Compaction was carried out in 5 equal layers, using a 4.5 kg modified rammer, compacted in 62 blows per layer. The samples were then soaked in water for 24 hours before the tests. A standard plunger of a diameter of 50 mm was next pushed into the geomaterial at the rate of 1.25 mm/min, where the CBR is derived as a percentage of the load, causing penetration of 2.5 mm or 5.0 mm to the standard loads on crushed stone, with corresponding standard loads of 13.2 kN and 20.0 kN respectively. Readings of the penetrating force were recorded at penetration intervals of 0.25 mm, and the test was stopped at maximum penetration of 7.5 mm. The sample was then inverted for the test to be repeated on the bottom surface of the sample. These readings were compared with the standard penetration forces for 100% CBR, where the highest value was reported as the CBR value.

Unconfined compressive strength (UCS) is the measurement of a material's ability to resist compressive deformation in unconfined conditions. 100 mm x 100 mm x 100 mm cube samples were tested according to standard [16]. The mixed samples were compacted in 3 equal layers with 35 strokes of a tamping rod per layer. Upon demolding, the samples were cured in a moisture room for 7 days before the tests. Note that cylindrical strength is generally accepted to be about 80% of that of the cube sample, primarily due to the higher height-to-diameter ratio in cylinders and the plane friction between the sample ends and the loading platens [17].

3. MEASUREMENTS & RESULTS

3.1 Laboratory CBR Test Results

Fig.1 shows the comparison of water contents before (WC_i) and after 24-hour soaking (WC_f). A 1:1 equality line is included in the plot to illustrate the changes in the water content due to the immersion process. Clearly, there is a 60% increment in WC as the stabilized samples absorbed water into the voids. With an optimum water content of 6.5% for the crusher run, the higher WC recorded suggests ≈4% water being entrapped in the composite, where the remaining 2% was likely to be commonly inherent in the crusher run. This rather small water absorption is favorable for the stabilized material in situ, with minimal moisture intrusion to be expected, avoiding a negative impact on the engineering properties and performance of the road base.

A comparison of the CBR values acquired for the top and bottom of the samples, respectively, is shown in Fig. 2. With reference to the 1:1 unity line, CBR_{top} fell in the range of 65-90% of CBR_{bottom}. Considering the compaction energy deployed with compaction by layers, the bottom layers would arguably undergo more significant physical strengthening than the upper layers. Nonetheless, as all the CBR_{top} values fulfilled the JKR requirement of ≥50% for a bound road base layer, the ≤35% difference between top-bottom strength can be ignored for all practical purposes.

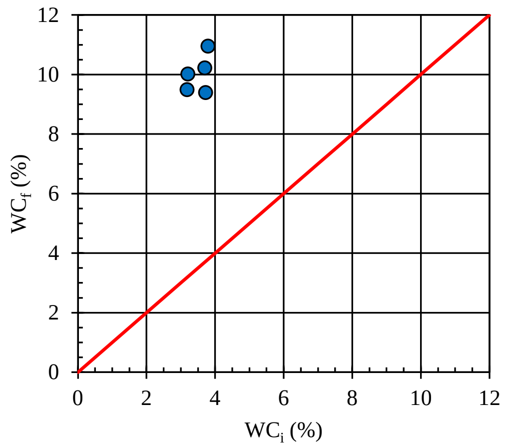

Fig. 1 Changes in water content post-soaking of samples

Further analysis by relating the CBR_{top}/CBR_{bottom} ratio with bulk density (ρ_b) and water content revealed some interesting insights (Fig. 3). Firstly, the water contents recorded varied by about 14%, indicating a relatively uniform and homogeneous compacted sample produced via good compaction and bonding of the crusher run. Secondly, a difference in the top and bottom CBR values of up to 35% could occur within the seemingly small water content range of no more than 15%. Thirdly, bulk density (ρ_b) of the stabilized samples appeared to be insensitive to the variations in water content, recording a negligible range of 2.8%. Fourthly, note that ρ_b dipped at approximately 0.8 CBR_{top}/CBR_{bottom} ratio, where water content has remained largely unchanged, pointing towards the water absorption of the stabilized samples, though with no adverse effect on the resulting strength. Water absorption was highest in this CBR_{top}/CBR_{bottom} range, i.e., 10.2%.

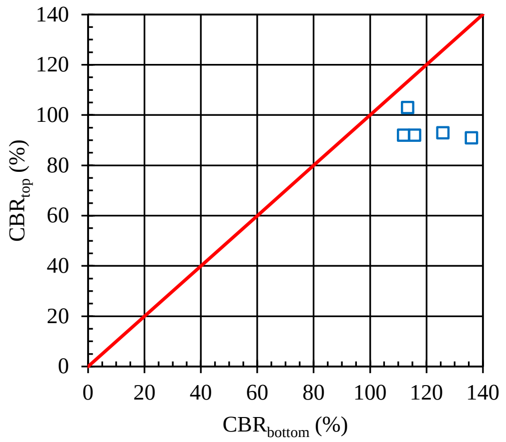

Fig. 2 Top and bottom values of laboratory CBR samples

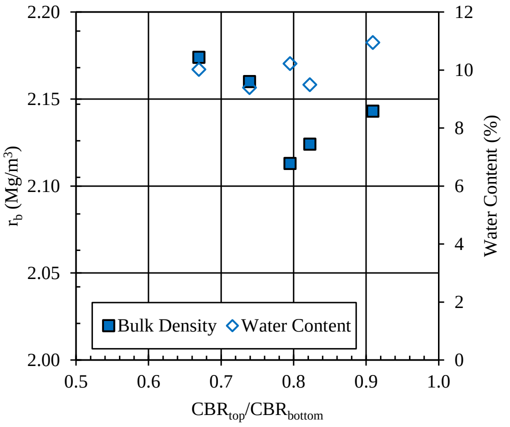

Fig. 3 Correlation between CBR_{top}/CBR_{bottom} ratio with bulk density (ρ_b) and water content

This could be attributed to several probabilities, such as the presence of voids in the stabilized material, water penetrating the more previous crusher run, and under the compacted top layer of the sample. All these factors would have enabled water to impregnate the sample more effectively but not significantly affect the resulting CBR values.

3.2 Correlating Laboratory and Field Measurements

Fig. 4 depicts the comparison between laboratory and field measurements of the corresponding stabilized samples, CBR_{lab} and CBR_{field}, respectively. Referring to the unity line in the same plot, CBR_{lab} is consistently greater than CBR_{field}, within the range of 1.5 to 2.5 times. Some obvious, probable explanations include the more controlled compaction effort in the laboratory than on-site and the constant conditions of the laboratory samples compared to field condition irregularities. Nonetheless, the soaking effect in the laboratory is not to be ignored, where the stabilized samples were given free access to water for complete chemical bonding reactions brought on by the stabilizer.

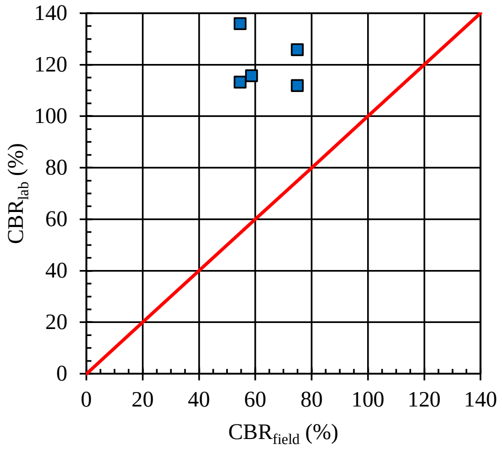

Fig. 4 Comparing laboratory and field CBR values

This is corroborated by the water content records of both field and laboratory samples, as shown in Fig. 5. Note the significantly higher CBR_{lab} values with corresponding higher water contents of 9.4 to 11.0%. In comparison, the field samples recorded no more than 4% water content, with CBR_{field} values ranging between 55 and 75%. Taking into account the optimum water content for the crusher run to be 6.53%, and that a certain amount of water is necessary to enable the chemical reactions between binder and water, as well as a small 'loss' due to water absorption, the average 10% water content in the laboratory samples would have fallen slightly to the wet side of optimum of the compaction curve for crusher run alone. It follows that the water consumption requirement of the stabilizer was fulfilled by the excess water provided by soaking the laboratory samples.

The implication of this observation on field application of the stabilization technique is twofold, i.e., (1) in situ mixing and compaction of the crusher run can only be optimized with the adequate provision of water for the chemical reactions, and (2) the less than satisfactory chemical reactions due to insufficient water availability can result in 50% reduction in strength, as evidenced by the CBR values of samples with the same material and mix ratio but different water contents.

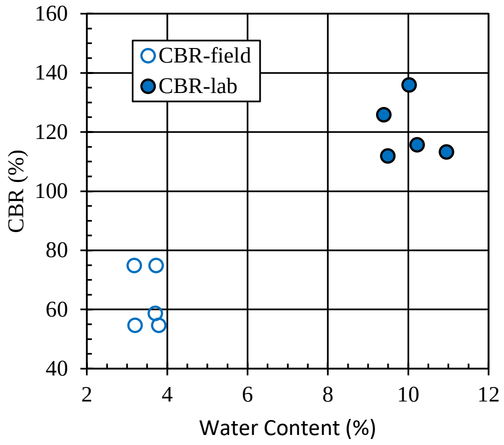

Fig. 5 Relating CBR values with water content

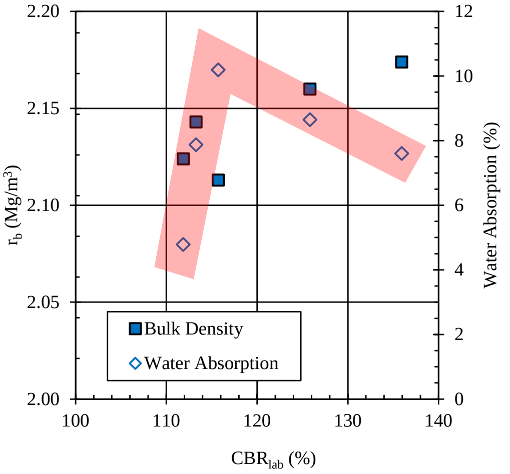

Fig. 6 Relating CBR values with water content

The remarkable relationship and effect of bulk density (ρ_b) and water absorption on CBR values are captured in Fig. 6. For the range of CBR_{lab} values between 112 and 136%, ρ_b appeared to vary marginally up to 3%. Nevertheless, a closer examination revealed changes between 5 - 10% of water absorption, corresponding to the range of ρ_b recorded. While the magnitudes are small, the relationship is suggestive of the dependency of ρ_b on the amount of water absorbed in the soaking stage, i.e., higher CBR values, as of greater strength in the stabilized material, are achievable in samples of denser nature. The increased density is in turn, inversely related to the water absorption, as depicted by the declining plot of the parameter in Fig. 6. Summarily, high water absorption points to greater porosity of the material, which could result in a weaker bound material even post-stabilization. On the other hand, adequate water must be available for effective reactions of the stabilizer to form cementitious bonds of the crusher run, which in other words, means an optimized mix ratio of the raw materials.

3.3 Analysis of Load - Displacement Characteristics

Load – displacement analysis was carried out on the data acquired from both CBR and UCS tests. A typical set of CBR test data, as of sample CH500, is compiled and presented in Fig. 7. The field data can be seen to lie consistently below those of the laboratory results. In line with earlier discourse, this can be attributed to the more favorable and controlled conditions in the laboratory compared to the site, though an optimum water content is still necessary to facilitate a sound chemical bonding outcome. Also, for the pair of laboratory data, load resistance was greater on the bottom side of the sample, most probably a direct result of excessive wetting of the upper layer of the sample during soaking, coupled with the lower compaction energy sustained by the layers placed later during sample preparation.

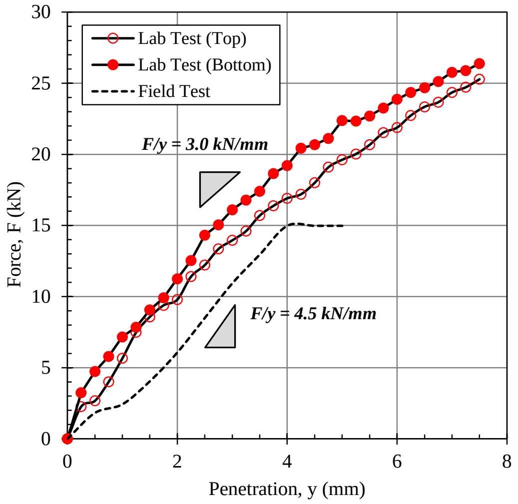

Fig. 7 Laboratory and field CBR test plots for sample CH500

Taking an approximate tangential gradient assessment of the plots in Fig. 7, the field-stabilized road base does seem to be stiffer than that of the laboratory samples by about 30%. Nonetheless, the actual field CBR value was found to be lower (see 3.2 and Fig. 4), which is indeed in agreement with the rise of the plots in Fig. 7, i.e., the laboratory plots were in the lead right from the initial loading stage. Therefore, the subsequent decline of the F/y ratio did not affect the final readout at all, even with a higher F/y ratio of the field plots.

Fig. 8 shows the stress-strain plots for the duplicate 7-day-old samples tested for UCS. Both plots fell admirably close to each other, proof of consistency in the sample preparation procedure and preservation. The UCS or qu can be derived as 3.2 MPa, corresponding with a failure strain, □f of 5.3% (computation based on initial sample height of 100 mm). This would give a corresponding Young’s modulus of 125 MPa. The negligible displacement at failure and the dramatic downturn of the plots are clear indicators of a stiff, brittle material. Notwithstanding agreement with the high CBR values of laboratory samples, in situ CBR measurements do indicate the probability of up to 50% loss in strength due to actual field conditions. Caution in QC & QA works on site are therefore rudimentary in assuring the long-term performance of the stabilized road base.

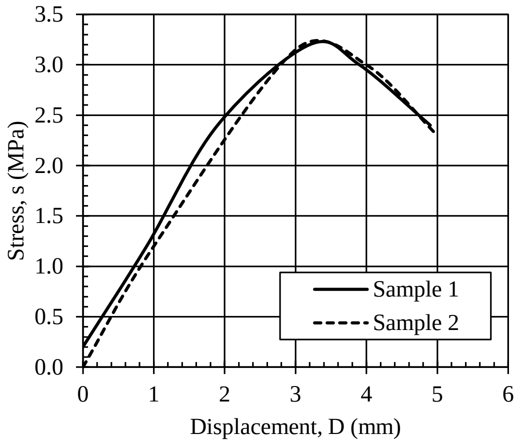

Fig. 8 Stress-strain plots for UCS test results

4. CONCLUSIONS

Following are the primary findings from the study, which can be potentially explored further:

- The stabilized crusher run can be effectively compacted to form a uniform, homogeneous composite for load-bearing, i.e., CBR >50%.
- Slight variation in the bulk density may occur due to inherent properties of the materials, though with no notable impact on the CBR values.
- CBR values could drop by half if insufficient water is available for the chemical reactions of the stabilizer, leading to compromised strength gain of the bound material.
- The force (F) – penetration (y) CBR plots could provide insights into the discrepancy between laboratory and field test results, where interpretation of the F/y ratio alone may be misleading at best.
- Unconfined compressive strength of 3.2 MPa with negligible failure strain of barely 6%

verifies the stabilized crusher run to be a stiff, brittle composite expedient for traffic load-bearing.

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