LOCAL CORRELATION OF HAND CONE PENETROMETER TEST TO FIELD CALIFORNIA BEARING RATIO TEST FOR PEKANBARU SOILS

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ABSTRACT

Prior to the construction of a highway, inspection of base soil bearing capacity is required. Bearing capacity of base soil determines the design thickness of a highway pavement. Several field methods are available to determine the base soil bearing capacity such as Dynamic Cone Penetrometer (DCP) and Hand Cone Penetrometer (HCP) and field California Bearing Ratio (field CBR). In practice, the design of pavement is commonly based on the California Bearing Ratio test. Correlations between the results of DCP to CBR tests are available. However, as far as can be found in literature, correlation between HCP to CBR test results is hardly found. This research was performed to study local correlation between HCP tests, which is simple and fast to conduct, to the field CBR value. The local correlation is determined based on comparisons of HCP and CBR test results for the same density of soil taken from several locations in Pekanbaru city, Indonesia. It was found that there is an approximate linear relation between HCP test results to CBR values for a certain density of soil.

Key Words : Hand Cone Penetrometer, California Bearing Ratio and Soil Density.

1. INTRODUCTION

Base (sub-grade) soil bearing capacity plays very important role for the design of highway structure. It determines design thickness of the pavement. High bearing capacity of base soils reduces the required thickness of pavement. The bearing capacity base soil is mostly influenced by the type of soil, water content and its density. Several methods are available to determine base soil bearing capacity such as California Bearing Ratio (CBR) test, Plate Bearing test (to determine modulus of sub-grade reaction and modulus of resilient), Dynamic Cone Penetrometer (DCP) test, and Hand Cone Penetrometer (HCP) test, which is also known as Proving Ring Penetrometer (Farshad, 2003).

It is common in Indonesia that the base soil bearing capacity for highway pavement design is determined by CBR test measurement. This can be from the laboratory CBR test or directly from field CBR test. However, base soil bearing capacity can also be determined using field tests such as DCP and HCP. These tests are much simpler and faster to perform. Correlation between the result of DCP test and CBR value is available whereas the correlation between the result of HCP test and CBR value is hardly found. Moreover, this correlation should be determined locally based on common local experience.

This research is aimed to obtain a local correlation between the results of HCP test and CBR value. The correlation is based on the comparison HCP test results and CBR value which has the same soil density.

2. LITERATURE REVIEW

2.1 California Bearing Ratio (CBR) test

The equipment for determining CBR value is a piston having an area of three square-inches. The piston is moved in vertical direction on a soil sample with a speed of 0.05 inch/minute. A Proving ring with dial gauge is attached to the piston to measure the load at certain penetration. The CBR value is the comparison between applied piston loads on a soil sample and the standard loads, which value is expressed in percentage (ASTM D-1883, AASTHO T-193).

Basically, the CBR value describes the strength soil compared to the standard material. Indirectly, it also describes the relative density of the soil. Several correlations between CBR values and the results of other field measurements exist such as to results of Dynamic Cone Penetrometer (DCP) test (Van Vuuren, 1969, Klimochko, 1991, Smith and Pratt, 1983). This has been used in practice.

2.2 Hand Cone Penetrometer (Proving Ring Penetrometer)

Hand Cone Penetrometer test is relatively new. It was first developed in 1988 (Das, 2008). Hand Cone Penetrometer (HCP) testing is aimed to measure soil bearing capacity or durability of sub-grade. HCP equipment is simple to be used for soil investigation until a depth of 1 meter below ground surface. Compared to other field measurements, HCP test is relativity cheap and the test can be done quickly. Similar to other cone penetration tests such as Dutch cone penetration test, the results of HCP tests is in the form of cone resistance which is quasi-statically embedded into soil. The cone resistance value can be related to the density of the soil.

A comparative study of HCP and DCP tests has been performed by Indrawan (2004) on clayey sand and clays soil. The study was aimed to indirectly relate the value of HCP to CBR value through the comparison of the results of DCP to HCP tests. From the point of view of testing mechanism, DCP and HCP test procedures are different. DCP test uses dynamic penetration whereas HCP is a quasi-static penetration test. Compared to CBR test, which is also a quasi-static penetration test, HCP is a closer method. Hence, direct correlation between HCP test results to CBR value seems to be more relevant. This correlation can be based on the same soil density. This study aims to obtain direct local correlation between the two latest two tests.

3. METHODOLOGY

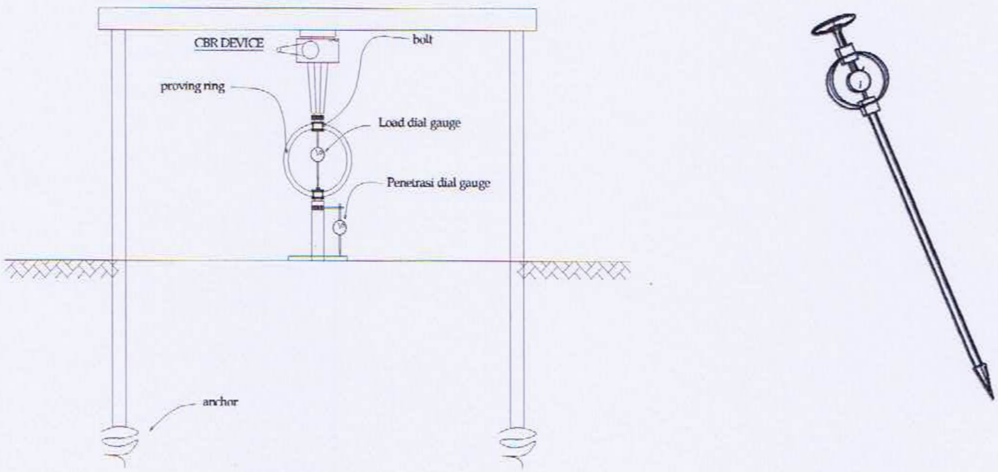
In order to obtain the correlation between HCP test results and CBR values, comparison of HCP with CBR tests results of several soil samples from Pekanbaru were performed. The HCP tests and CBR tests were performed for each soil sample from each location. Thus, the density of the soil for both tests is the same for each soil from each location. There were 40 HCP tests and 40 CBR tests performed at eight locations within the city of Pekanbaru (see Table 1).

Table 1: Number of Tests Samples

Locations	Moisture content	Plasticity index	Grain size	HCP	density	CBR
Kubang	5	5	5	5	5	5
Pandau	5	5	5	5	5	5
Rumbai	5	5	5	5	5	5
Tangkerang	5	5	5	5	5	5
Panam	5	5	5	5	5	5
Kulim	5	5	5	5	5	5
Palas	5	5	5	5	5	5
UNRI	5	5	5	5	5	5
Total Sample	40	40	40	40	40	40

3.1 Equipment

Equipments required for field tests are a set Hand Cone Penetrometer tools, field CBR tools and a CBR mould. The CBR mould was used to obtain undisturbed sample for determination of physical and mechanical properties of the soil in laboratory. Figure 1 shows the layout of field CBR test.



a. Field CBR Test b. Hand Cone Penetrometer Device

Figure 1 : Field Test Equipment

3.2 Testing Methods

The HCP tests were performed simply by pressing the hand penetrometer tools into the ground for the eight different locations. After that, the field CBR tools were installed very close to the HCP test locations and then the tests were performed. For the determination of the physical and mechanical properties of the soils, undisturbed samples were taken from each location and the tests were done in laboratory.

4. RESULTS AND DISCUSSION

The results of this research are presented in three parts. First, the results of the all performed tests are described. After that regression analysis between HCP test results and filed CBR values as well as regression of HCP tests results with the density of the soils are shown. In the final part, the correlation between HCP tests results and CBR value are put forward.

4.1 Physical and Mechanical Properties of Test Samples

The test results of physical and mechanical properties of the samples can be divided into four categories based on the type of soils as seen in Table 2.

Table 2: Physical and Mechanical Properties of Test Samples

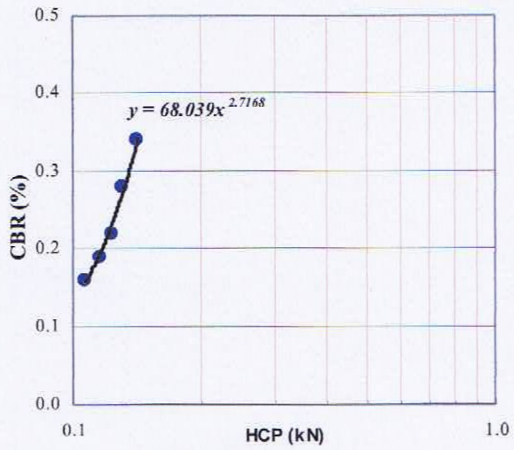
Soil type	Location	USCS classif.	Water content, w_n [%]	Unit Weight, γ [gr./cm^3]	HCP value [kN]	CBR value [%]
Peat	Kubang	Fibrous peat	180,2-225,3	1,06-1,10	0,1070–0,1423	0,16–0,34
Clay	Pandau, rumbai, tangkerang	Lean Clay (CL)	10,13-56,19	1,36-2,12	0,2762–0,6889	2,52–22,43
Sandy clay	Panam, kulim, palas	Sandy clay (SC)	10,13-56,19	1,13-2,12	0,1923–0,6889	1,01–22,43
Sand	UNRI	Poorly sand (SP)	10,38-43,01	1,13-1,72	0,1923–0,4987	1,01–10,94

For the soils which are considered as in-organic soils (Sand, Clay, Sand-Clay mixture), in general, they have water content, w_n between 10,13 – 56,19%, unit weight, γ between 1,13– 2,12 gr./cm^3. Furthermore, It was recorded that the values of HCP tests on those soils are between 0,1923 – 0,6889 kN and field CBR values between 1,01- 22,43% (see Table 2). It is shown that the range of the physical and mechanical properties the soils varies considerably.

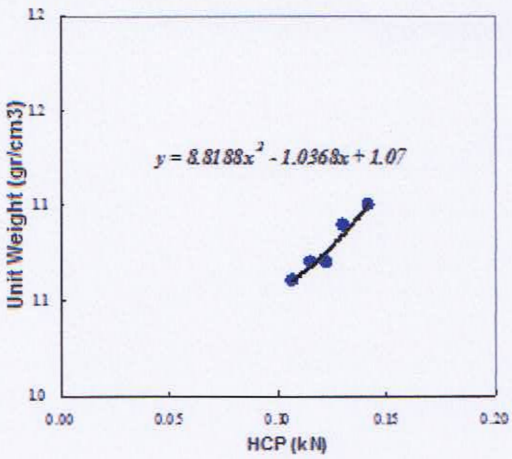
As also can be seen in Table 2, for the peat soils (organic soil), its properties are significantly different compared to other soils showing that it has a significant characteristic compared to the other soils. The minimum water content of peat is far above the maximum water content of all an-organic soils. On the other hand, the maximum values of its density, HCP, and field CBR are far below the minimum values of the an-organic soils.

4.2 Regression Analysis of HCP-CBR and HCP-Density (Unit Weight)

Figure 2 to Figure 5 show the results of regression analyses between HCP and CBR tests results as well as regression results between HCP and Density test results. The regression analyses are made for each type of soils which are peat, sand, clay and sand and clay mixture.
It can be seen that regression using power rule suits the relation between HCP and CBR relatively accurately whereas for the relation between HCP and soil density, second order polynomial function shows relatively accurate approximation. The two regression analyses will be combined later using Pearson's correlation method to find the correlation between HCP test results and field CBR values.

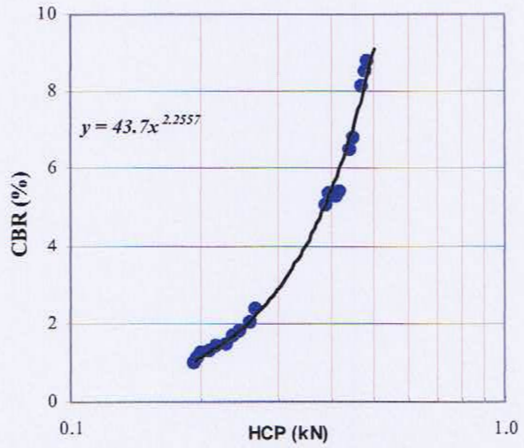


a. Relations Between HCP and CBR

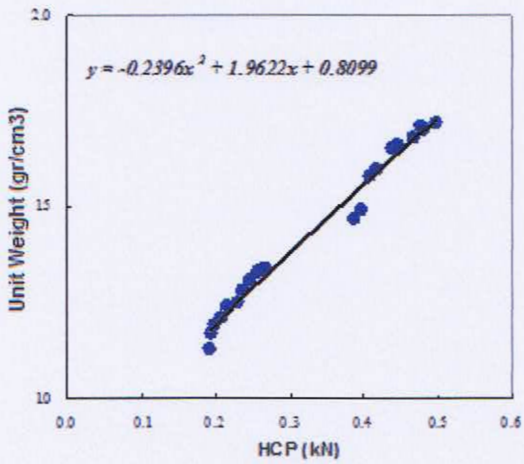


b. Relations Between HCP and Density

Figure 2: Regression Results for Peat

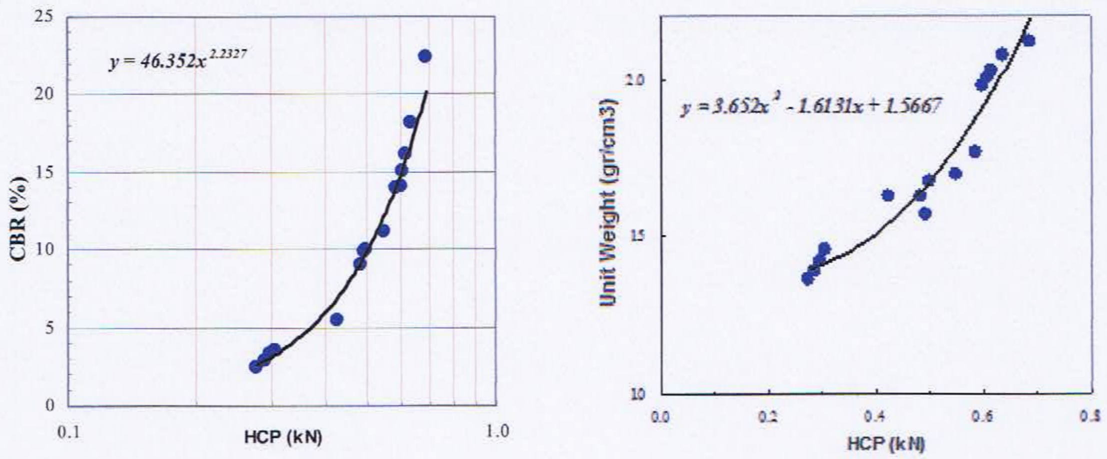


a. Relation between HCP and CBR



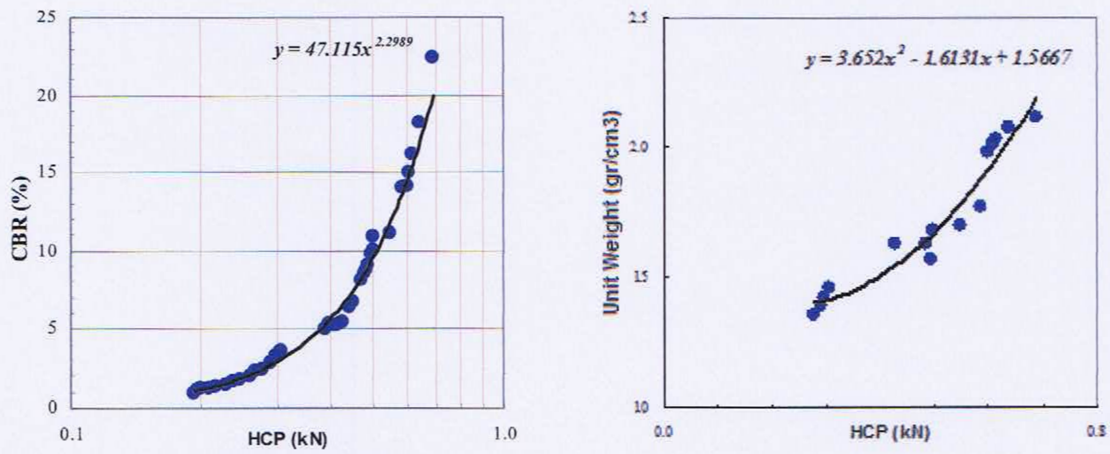
b. Relation between HCP and Density

Figure 3: Regression Results for Sand



a. Relation between HCP and CBR b. Relation between HCP and Density

Figure 4: Regression Results for Clay



a. Relation between HCP and CBR b. Relation between HCP and Density

Figure 5: Regression Results for Sand-Clay Mixture

4.3 Local Correlation between HCP Test Results and Field CBR Values

In the previous section, relations between HCP and CBR as well as between HCP and soil density have been obtained. In order to correlate the HCP test results to field CBR value, Pearson's correlation method is applied to both obtained power and polynomial functions for each type of soils.

On using soil density (unit weight) and the value of HCP test as variables, the following linear equation can be applied to find simple correlation between HCP and CBR on the basis of the same soil density value of (Supranto, 2000)

$$Y = a_0 + a_1 X_1 + a_2 X_2 \tag{1}$$

With
a_0, a_1, a_2 : constants
Y : value of field CBR (%)
X1 : bulk density ($gr./cm^3$)
X2 : value of Hand Cone Penetrometer (kN)

The values of the constants a_0, a_1, a_2 can be solved using SPSS software which is based on the solution of the following matrix

$$\begin{bmatrix} 2 & \sum X_1 & \sum X_2 \\ \sum X_1 & \sum (X_1)^2 & \sum (X_1 X_2) \\ \sum X_2 & \sum (X_1 X_2) & \sum (X_2)^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_3 \end{bmatrix} = \begin{bmatrix} \sum y \\ \sum (X_1 Y) \\ \sum (X_2 Y) \end{bmatrix} \tag{2}$$

It was found that value for a_0 and a1 are 0,002 and 36,03 respectively for all soils. However, for the value of a_3, there is no unique solution for all soils. It is found that the value of a_3 of -5,3 suits for sand, clay and sand-clay mixture (in-organic soils) whereas for clay the solution of a_3 is -5,6.

The final local correlation formula obtained from the correlation analyses can be written as follow:

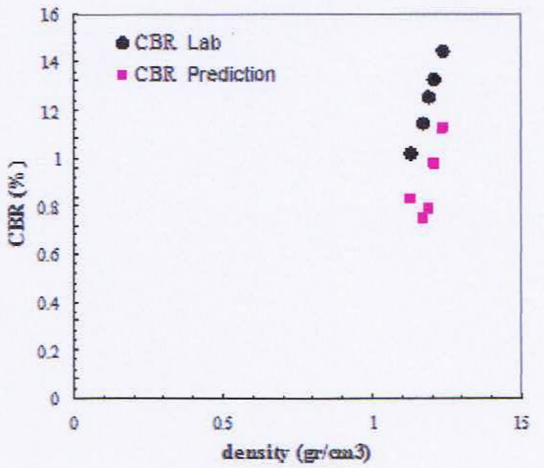
$$\text{Field CBR}_{\text{prediction}} = C_1 + 36{,}03 \cdot \text{HCP} - C_2\,\gamma \tag{3}$$

Where C_1 and C_2 is 0,002 and 5,3 for sand, clay and sand-clay mixture (in-organic soils). HCP is the value of HCP test. For peat soils, the value of C_1 need to be further tested and the C_2 value is 5,6. It was difficult to find a proper value for C_1 which might be due to the influence of fiber content of the peat. Hence, the local correlation formula as stated in Equation (3) is valid for in-organic soils only and can be rewritten as below:

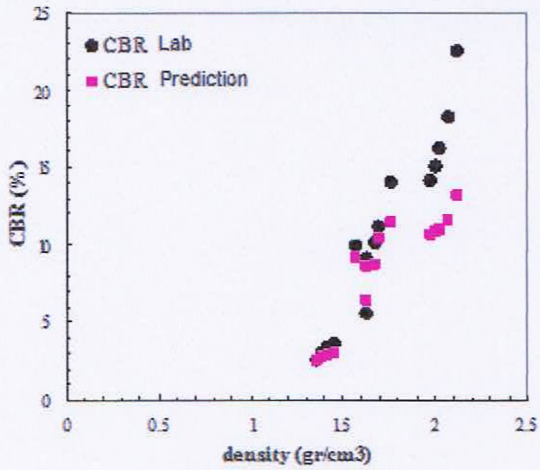
$$\text{Field CBR}_{\text{prediction}} = 0{,}002 + 36{,}03 \cdot \text{HCP} - 5{,}3\,\gamma \tag{4}$$

4.4 Validation of the Local Correlation Formula

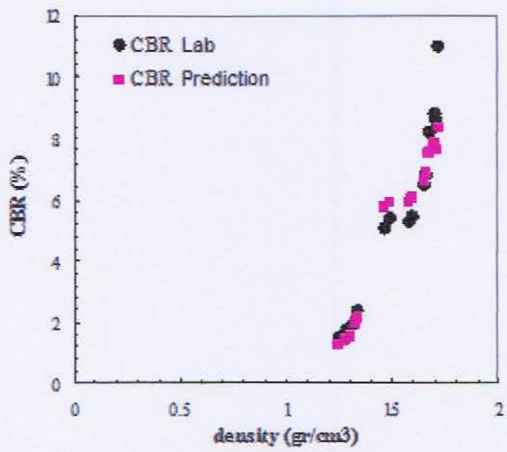
For the validation of Equation (4), several prediction tests have been performed. Figure 6a to figure 6d show the comparison between predicted values of field CBR and measured field CBR values for different soil types and soil densities.



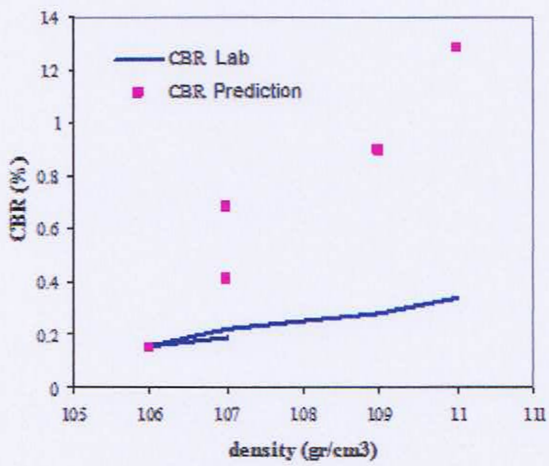
a. Predicted and Measured field CBR for Sand



b. Predicted and Measured field CBR for Clay



c. Predicted and Measured field CBR for Sand-Clay Mixture



d. Predicted and Measured field CBR for Peat

Figure 6: Comparison between Predicted Field CBR with Measured Field CBR for Different Soil Types and Soil Densities

It can be seen from Figure 6a to figure 6c, the predicted field CBR values give significant agreements with the measured field CBR from the tests for in-organic soils. On the other hand, very poor agreements were found for peat soils. Hence, the local correlation formula is only valid for in-organic soils. For peat soils further tests and verification needs to be done.

5. CONCLUSIONS

This research has been performed to find local correlation between HCP test results and field CBR values. A linear correlation has been put forward for the local correlation between the two values. Verification of the formula shows that the correlation can be used relatively accurately for predicting the field CBR values from the HCP test for in-organic soils (sand, clay and sand-clay mixture). The formula needs to be modified and further research need to be done for peat soils.

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