Comparison of California Bearing Ratio (CBR) Value Based on Cone Penetration Test (CPT) and Dynamic Cone Penetrometer (DCP)

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Abstract: In civil engineering, land is important because as a place for building infrastructure to be built, so that the building infrastructure on it is stable, adequate carrying capacity is needed. The amount of soil bearing capacity can be determined in several ways, including the California Bearing Ratio (CBR) Field Test, Cone Penetration Test (CPT) and Dynamic Cone Penetrometer (DCP). The CBR and DCP tests are often used to determine the level of surface soil density on road structures, while CPT is usually used to determine the hard soil layer on the building structure. However, in certain situations CPT and DCP data are often used to predict the CBR value, because the test is quite practical and efficient compared to the CBR test. CBR testing requires heavy equipment which in most small-scale projects is not available. In this study, we compared the CBR value based on the data obtained from the CPT and DCP tests. Data collection was carried out in Surakarta and its surroundings. The location in question is on the UNS Campus, UTP Campus and In Mojosongo. The method used in this research is direct field testing. CPT and DCP tests were carried out at each location. The results of the CPT and DCP tests are then converted to CBR values using empirical equations. Based on the test results, the CBR value generated from the DCP test tends to be smaller than that from the CPT test with a ratio of 0.62: 1. This study resulted in the relationship between CBR values from the results of the CPT and DCP tests shown in the following equation: CBR $_{(DCP)}$ % = 0.2552 CBR$_{(CPT)}$ + 2.6306 and CBR $_{(DCP)}$ % = 0.617 CBR$_{(CPT)}$.

Keywords: *CBR; CPT; DCP; soil*

1. Introduction

1.1. Background

Soil is a material consisting of aggregates (grains) of solid minerals that are not cemented (chemically bonded) to each other and of decayed organic matter (which has solid particles) accompanied by liquids and gases that fill the spaces. empty between the solid particles, (Das, 1995). Soil has a very important role because almost all civil engineering structural work is always related to soil behavior, where the soil is used as construction material which is directly available in the field or as a place for placing structures (Arbianto, 2009,ex: [3]). In order for the building infrastructure above it to be stable, adequate carrying capacity is needed. The amount of soil bearing capacity can be determined in several ways, including the California Bearing Ratio (CBR) Field Test, Cone Penetration Test (CPT) and Dynamic Cone Penetrometer (DCP). CBR and DCP tests are often used to determine the level of surface soil density in road structures, while CPT (Sondir) is commonly used to determine hard soil layers in building structures. However, in

certain situations Sondir and DCP data are often used to predict CBR values, because the test is quite practical and efficient compared to the CBR test. This research was conducted in the Surakarta Residency, Central Java, because in this area there are many small-scale projects that require information on the carrying capacity of the land in a more practical and efficient way. These locations in the UTP Campus II Surakarta.

This research is expected to provide benefits, especially in the world of civil engineering to determine the carrying capacity of the land and to help business actors in the world of construction. If the comparison of CBR values from CPT and DCP results, it will be able to assist in determining design parameters. In other words we can predict the CBR value from one of the tests

Fig. 1. Research Location.

1.2. Literature Study

1.2.1. Soil Component

Based on the particle size (grain gradation), soil can be defined from its individual components such as: boulder, gravel, gravel, sand, silt and clay, as shown in Table 2.1.

Table 1. Soil component definition

Soil characteristic		Sieve standard		Size (mm)	
		Passing	Stopped	Maximum	Minimum
Boulder		-	-	-	-
Cobble		-	3 inch	-	75
Gravel		3 inch	No. 4	75	4.750
	Coarse	3 inch	¾ inch	75	19
	Fine	¾ inch	No. 4	19	4.750
Sand		No. 4	No. 200	4.750	0.075
	Coarse	No. 4	No. 10	4.750	2.000
	Medium	No. 10	No. 40	2.000	0.425
	Fine	No. 40	No. 200	0.425	0.075
Fines		No. 200	-	0.075	-
	Silt	-	-	0.075	0.005
	Clay	-	-	0.005	-

1.2.2. California Bearing Ratio (CBR)

Field CBR testing is intended to obtain in-place CBR values which are used for planning pavement thickness and pavement overlays. Field CBR testing is carried out with the help of trucks/heavy equipment as a barrier to penetration loads. This is based on the possibility of CBR testing in the field.

CBR (California Bearing Ratio) is the ratio between the penetration load of a layer of soil or pavement against standard materials with the same depth and speed of penetration. The implementation of field CBR testing is regulated in SNI 1738-2011.

1.2.3. Cone Penetration Test (CPT)

"Sondir" testing or CPT (Cone Penetration Test) in Indonesia refers to SNI 2827:2008 or ASTM D 3441-86 on how to test field penetration with sondir. The main parameters resulting from the sondir test are qc end resistance and frictional resistance. In the sondiri test, the standard cone with a diameter of 35.7 mm + 0.4 mm with a conical angle of 60° + 5° and a sliding blanket surface area of 150 cm2 + 3 cm^2 is penetrated through the soil layer by being pressed both mechanically and hydraulically with a penetration speed of 10 mm/s – 20 mm /s + 5 mm which is read every 20 cm. Cone resistance is recorded from the reading of 2 pieces manometer with a capacity of 0 MPa - 2 MPa for and 0 MPa - 5 MPa for relatively soft soils, or 0 MPa - 5 MPa for and 0 MPa - 25 MPa for moderately hard soil layers. In this soil investigation work, the CPT test was carried out using a sondir machine with a capacity of 2.5 tons.

The empirical equation for the relationship between CBR and Sondir values (Hardiyatmo, 2002) is as follows:

$$CBR\ (\%) = 0.454\ q_c \tag{1}$$

where:
q_c = conus resistance (kg/cm^2)
CBR   = CBR value (%)

1.2.4. Dynamic Penetrometer Test (DCP)

The dynamic cone penetrometer (Dynamic Cone Penetrometer) was originally developed to determine the strength profile of flexible pavements, but has since been used to determine soil strength. The DCP test has been used to determine the strength of the subsurface material and can measure soil strength with a rough CBR value. The DCP test procedure is contained in ASTM D 6951 or SNI 1738:2011.

The DCP tool consists of a 60º angled cone and 20 mm in diameter attached to a 16 mm diameter steel support bar. The slipping of a bat weighing 8 kg (17.6 lb) and falling 57.5 cm (22.6 in) above the rod causes the cone to penetrate the ground. Two people are required to operate this tool, one operates the DCP and the other records the cone penetration. In performing the DCP test, the instrument is held vertically, the cone is placed on the ground until its bottom (flat side) is level with the ground and a zero penetration reading begins at this position.

The test begins by raising the bat to a height of 57.5 cm and releasing it until it strikes the steel retaining below. The depth of penetration and the number of strokes are recorded. This process is repeated until the penetration depth reaches the desired depth or 1000 mm, whichever comes first. For pavement design, the DCP index value is converted to the CBR value using the equation:

$$Log\ CBR = 2.46 – 1.12\ (log\ DCP) \tag{2}$$

Where:
DCP   = DCP index, penetration depth by one stroke (mm)
CBR   = CBR value (%)

The correlation was developed by the USAE Waterways Experiment Station. The relationship between CBR and DCP suggested by the FAA (1985) and NCHRP (2004) is shown in Fig. 1. The relationship between CBR and DCP suggested by Webster et al. (1994):

$$CBR = 292/(DCP^{1.12}) \quad \text{(for gavel, sand and silt)} \tag{3}$$

$$CBR = 1/(0.002871\ DCP) \quad \text{(for clay high plasticity)} \tag{4}$$

$$CBR = 1/(0.017\ DCP)^2 \quad \text{(for clay low plasticity)} \tag{5}$$

The DCP test is very easy to perform and is suitable for use on materials with CBR. Values 80%. This tool has advantages, including easy operation, practical, fast, and easy to carry. The weaknesses, among others, are the results obtained are relatively rough compared to the others.

The DCP value used to determine the CBR value is done by converting the penetration that has been obtained from the number of collisions per depth

2. Research Method

This research is divided into three stages of work, namely: Field Data Collection including Sondir and DCP Tests, Initial Data Analysis, Analysis and Discussion. Soil data collection according to the implementation procedure was taken at three locations, including:

Table 2. Location Test

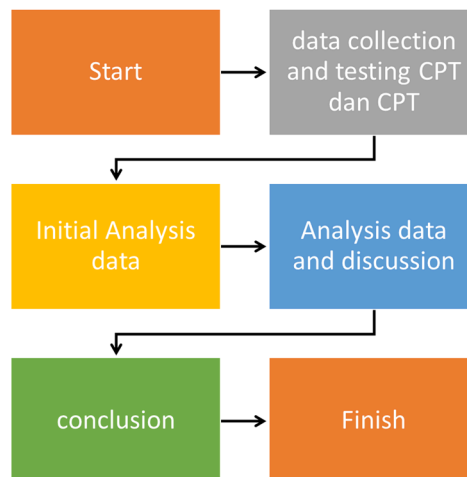| Location	Point value	Code
Mojosongo	3	A
UNS Campus	3	B
UTP Campus	3	C

Fig. 2. Research Flow

After obtaining the data in the field, an initial analysis is carried out so that the data obtained is representative and in accordance with the hypothesis. If there is still doubt, additional testing points will be carried out.

The tests that have been carried out will then be analyzed for data to calculate the CBR value of each test. Then the results obtained from the CBR values are compared between the data obtained from the CPT and the data obtained from the DCP data. Next, look for possible correlations between the parameters.

3. Result and Discussion

3.1. CPT Result

The results of the CPT test are taken at a maximum depth of 1 m, because it adjusts to the penetration length of the DCP tool. The results of the CPT test are presented in the following table.

Table 3. CPT Mojosongo

Depth (m)	Conus (q_c) (kg/cm^2)			CBR (%)			CBR (CPT) Average		
	S_{A1}	S_{A2}	S_{A3}	S_{A1}	S_{A2}	S_{A3}	S_{A1}	S_{A2}	S_{A3}
0.00	0.00	0.00	0.00	0.00	0.00	0.00			
0.20	6.00	8.00	5.00	2.72	3.63	2.27			
0.40	8.00	8.00	10.00	3.63	3.63	4.54			
0.60	12.00	15.00	15.00	5.45	6.81	6.81	6.17	5.99	6.99
0.80	20.00	15.00	22.00	9.08	6.81	9.99			
1.00	22.00	20.00	25.00	9.99	9.08	11.35			

Table 4. CPT UNS Campus

Depth (m)	Conus (q_c) (kg/cm^2)			CBR (%)			CBR (CPT) Average		
	S_{B1}	S_{B2}	S_{B3}	S_{B1}	S_{B2}	S_{B3}	S_{B1}	S_{B2}	S_{B3}
0.00	0.00	0.00	0.00	0.00	0.00	0.00			
0.20	10.00	15.00	10.00	4.54	6.81	4.54			
0.40	6.00	8.00	15.00	2.72	3.63	6.81			
0.60	5.00	8.00	10.00	2.27	3.63	4.54	3.18	4.45	4.63
0.80	6.00	8.00	8.00	2.72	3.63	3.63			
1.00	8.00	10.00	8.00	3.63	4.54	3.63			

Table 5. CPT UTP Campus

Depth (m)	Conus (q_c) (kg/cm^2)			CBR (%)			CBR (CPT) Average		
	S_{c1}	S_{c2}	S_{c3}	S_{c1}	S_{c2}	S_{c3}	S_{c1}	S_{c2}	S_{c3}
0.00	0.00	0.00	0.00	0.00	0.00	0.00			
0.20	10.00	48.00	10.00	4.54	21.79	4.54			
0.40	8.00	50.00	8.00	3.63	22.70	3.63			
0.60	10.00	85.00	12.00	4.54	38.59	5.45	4.18	24.49	4.72
0.80	6.00	60.00	10.00	2.72	27.24	4.54			
1.00	12.00	30.00	12.00	5.45	13.62	5.45			

3.2. DCT Result

The DCP test is taken close to the CPT test point. The results are as follows:

Table 6. DCP Mojosongo

No.	Point Number	Layer (mm)	DCP (mm/blows)	CBR (%)	CBR Average (%)
1	T$_{1A}$	0 - 530	88.83	1.92	3.00
2		530 - 950	45.24	4.09	
3	T$_{2A}$	50 - 470	103.10	1.62	2.39
4		47- 950	56.93	3.16	
5	T$_{3A}$	80 - 620	91.60	1.85	2.63
6		620 - 980	53.3	3.40	

Table 7. DCP UNS Campus

No.	Point Number	Layer (mm)	DCP (mm/blows)	CBR (%)	CBR Average (%)
1	T$_{1B}$	120 - 950	59.29	3.02	3.02
2	T$_{2B}$	100 - 520	60.02	2.98	2.57
3		520 - 930	79.53	2.17	
4	T3$_B$	150 - 900	46.67	3.95	3.95

Table 8. DCP UTP Campus

No.	Point Number	Layer (mm)	DCP (mm/blows)	CBR (%)	CBR Average (%)
1	T$_{1C}$	30 - 165	27.00	7.28	5.06
2		165 - 613	41.64	4.48	
3		613 - 763	45.94	4.02	
4		765 - 950	41.82	4.46	
5	T$_{2C}$	55 - 272	15.50	13.56	9.35
6		271 - 940	36.88	5.14	
7	T$_{3C}$	110 - 237	15.88	13.20	
8		237 - 950	52.5	3.46	8.33

### 3.3. Recapitulation of CPT and DCT Test Result

CBR value of CPT and DCP test results for each point in the average. Then paired to find out the comparison value. The results of the comparison are as follows:

Table 9. Recapitulatian Test Result

No.	Point Number		CBR $_{(CPT)}$	CBR $_{(DCP)}$
	CPT Test	DCP Test	(%)	(%)
1	S$_{1A}$	T$_{1A}$	6.17	3.00
2	S$_{2A}$	T$_{2A}$	5.99	2.39
3	S$_{3A}$	T$_{3A}$	6.99	2.63
4	S$_{1B}$	T$_{1B}$	3.18	3.02
5	S$_{2B}$	T$_{2B}$	4.45	2.57
6	S$_{3B}$	T$_{3B}$	4.63	3.95
7	S$_{1C}$	T$_{1C}$	4.18	5.06
8	S$_{2C}$	T$_{2C}$	24.79	9.35
9	S$_{3C}$	T$_{3C}$	4.72	8.33
	Average		**7.23**	**4.48**
	Ratio		**1.62**	**1.00**

To clarify the relationship between CBR values from CPT and DCP tests, it is shown in the Fig. 3 below.
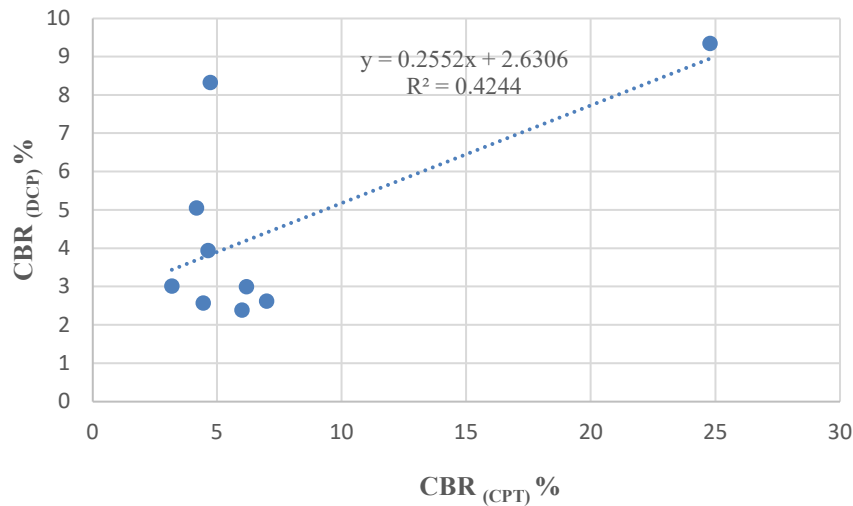
Fig. 3. Graph of the relationship between CBR$_{(CPT)}$ and CBR $_{(DCP)}$

Fig. 3. shows the relationship between the CBR value from the CPT test and the CBR from the DCP test which results in the degree of relationship between variables (R2) of 0.4244. Based on the graph in Fig. 3., the relationship equation can be made as follows:

$$\text{CBR }_{(DCP)}\% = 0.2552\,\text{CBR}_{(CPT)} + 2.6306 \tag{6}$$

With:
CBR$_{(DCP)}$ = CBR value from DCP test results (%)
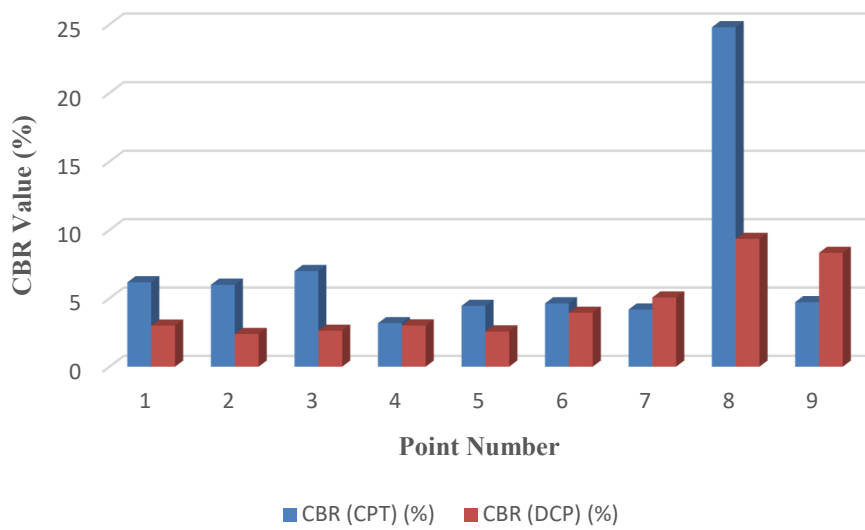CBR$_{(CPT)}$ = CBR value from CPT test results (%)

Fig. 4. Graph of Ratio between CBR$_{(CPT)}$ and CBR $_{(DCP)}$

Fig. 4. shows the comparison of CBR values from the results of the DCP and CPT tests. Based on the picture above, the ratio ratio can be made as follows:

$$CBR_{(DCP)}\% = 0.617\ CBR_{(CPT)} \tag{7}$$

equation 7 explains that the CBR value from the DCP test results can be found by multiplying the constant 0.617 against the CBR value from the CPT results.

4. Conclusion

1. Based on the test results, the CBR value generated from the DCP test tends to be smaller than that from the CPT test with a ratio of 0.617 : 1.
2. This study resulted in the relationship between CBR values from the results of the CPT and DCP tests shown in the following equation: CBR $_{(DCP)}\% = 0.2552\ CBR_{(CPT)} + 2.6306$ and CBR $_{(DCP)}\% = 0.617\ CBR_{(CPT)}$.

5. Recommendation

1. Validation required by field CBR testing
2. More sample testing is needed to get a more consistent correlation

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