Proceeding *20th SEAGC - 3rd AGSSEA Conference in conjunction with 22nd Annual Indonesian National Conference on Geotechnical Engineering.* Jakarta - INDONESIA, 6 -7 November 2018. ISBN No. 978-602-17221-6-9

Correlations between Gradation, Physical and Mechanical Parameters for Material Embankments Reclamation

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ABSTRACT: A structural reclamation embankment material generally requires minimum sand content of 50%, maximum gravel of 30% and silt & clay of 20%. Related to quality control material in the field, it is desirable to only do sieve analysis with some gradation coefficient and water content test to know the correlation some parameters of soil density such as dry density, void ratio, effective cohesion, internal angle friction & CBR. Thus it can be determined at that time in the field whether the embankment of reclamation has been qualified or not. To study the correlation between gradation and CBR with physical and mechanical parameters of embankment material then performed laboratory tests, among others CBR, sieve analysis, volumetric gravimetric, proctor and direct shear tests. Research through laboratory tests to study the correlation between the CBR with the physical parameters of the soil embankment uses reclaimed embankment material consisting of sand (pass of sieve No.2) and clay-silt (pass of sieve No. 200). Samples are made of 5 types with composition sand and silt-clay as follows 100% : 0% , 95% : 5% , 90% : 10% , 85% : 15% , 80% : 20%. The next step is the compaction of modified proctor and CBR test with saturation-unsaturated condition and then volumetric-gravimetric and specific gravity test. Other tests such as sieve analysis and hydrometer test are performed to determine C_u (coefficient of uniformity) and C_c (coefficient of curvature). This test is done using reclamation embankment material from river, beach and hill quarry, while the material from the selected quarry is material containing maximum 20% clay and sand 80% minimum. The next step is compacted by Modified Proctor and Direct Shear testing with saturated water content (on Zero Air Void line) and unsaturated (on w_{opt}). The results of the tests indicate that the increasing value of C_c/C_u then the value of the maximum dry unit weight (γ_{dmax}), effective cohesion and effective internal friction angle decreases and increases the optimum water content. In addition the test results show that the increasing value of γ_d then the CBR value increase and the void ratio (e) and porosity (n) decrease. The correlation between sieve analysis and CBR with soil physical and mechanical parameters is applicable for reclamation material with minimum sand composition 80% and clay maximum 20% and the limit of C_u is $1<C_u<50$.

Keywords: embankment, reclamation, density, shear strength, CBR.

1. INTRODUCTION

Implementation of coastal reclamation requires very large embankment material. The general requirements of embankment material must be fulfil maximum 30% gravels, minimum 50% sand and maximum 20% clay and density must be comply with requirements. Generally the field practitioners want to know quickly and easily when the embankment material arrives in the field by only observe at the composition of sand and clay-silt. Based on the composition can be determined whether the material involves the requirements or not as a material embankment. Furthermore, the required density can be determined by performing one test only. The test can be a CBR test or a sieve analysis test.

Determination of the density level of a soil can be seen from three parameters: relative density (Dr), dry unit weight (γ_d) and void ratio (e). Relative density is only used for granular soil type, while dry unit weight (γ_d) and void ratio (e) for all types of fine and coarse-grained soils. Therefore the dry unit weight (γ_d) and void ratio are more suitable for use in reclamation work because the soil type of embankment consists of fine and coarse grained soils. The determination of grain size distribution is very important in order to determine including into well graded, poorly graded or gap graded. These gradations are determined from the value of uniformity coefficient (C_u) and the curvature coefficient (C_c), which greatly affects the density of the embankment. In addition, the density is also influenced by water content. Water content in the field is influenced by the rainy season and reclamation work is always associated with tidal conditions. This submerged and non-submerged condition affects the compaction. Such conditions affect the compaction process and the stability of embankment.

The existing problems based on above condition are as follows :

- How does the composition of sand and silt-clay affect the dry unit weight (γ_d), and the correlation of soil composition with the CBR value.
- How is the influence of water content and the relationship between void ratio and CBR value.
- How is the relation between C_u, C_c, gradation of grain size with dry unit weight (γ_d), internal friction angle (ϕ) and cohesion (C), for saturated and unsaturated initial conditions.
- What is the effect of water content (w) on dry density (γ_d) and soil shear strength (ϕ and C).

This research is expected to be a solution in the selection of reclamation material. The expected solution is related to the material composition and parameters based on the required CBR, in addition to estimate the required density based on the composition of embankment material grain size.

2. LITERATURE STUDY

2.1 Compaction

Lee and Suedkamp (1972) concluded that the soil compaction curve can be divided into four types. Type A compaction curve has bell-shaped. Type A is generally present in most clay soils with a liquid limit value (LL) between 30 - 70. Type B curve is one-half peak, generally present in the sand with LL<30 (type B curve is a more suitable result with condition of our predominant sand test sample). Type C has double peak curve, found on soil with LL<30 or LL>70. The D-type curve is odd-shaped, generally present in soils having LL>70.

The relationship between moisture content (w) and dry unit weight (γ_d) and weight of zero air void volume (γ_{ZAV}) can be formulated as follows:

$$\gamma_d = \frac{\gamma_{sat}}{1+\mu} \quad (1)$$

$$S_r = 100\% \rightarrow \gamma_{ZAV} = \frac{\gamma_W \cdot G_s}{1 + G_s \cdot \mu} \quad (2)$$

where :

γ_{sat} = saturated unit weight of soil
γ_w = unit weight of water
S_r = degree of saturated (%)
G_s = spesific gravity
w = water content

Day (1997) says that the requirement factors decrease of void ratio (e) at the compaction are the distribution of grain size, the ratio between d_{100}/d_0 (ratio between the largest and smallest diameter) clay (with low activity) to fill the smallest void and compaction process, to compress soil particles into more dense arrangement.

2.2 Swelling

Swelling calculation used the equation below:

$$\varepsilon_1 = \frac{\Delta H}{H_0} \times 100\% \qquad (3)$$

where :
ε_1 = axial strain (%)
ΔH = change of sample height (mm)
Ho = initial of sample height (mm)

Previous studies have been conducted to predict the magnitude of swelling. One of which is the research conducted by Seed et al. 1962, it discuses the correlation between plasticity index (IP) with swelling potential (Table 1).

Table 1 Correlation between swelling (ε1) and Plasticity Index (IP) (Seed et al., 1962)

IP (%)	ε_s (%)	Swelling potential
0 – 10	0 – 1.5	Low
10 – 20	1.5 – 5	Mean
20 – 30	5 – 25	High
>35	>25	Very high

2.3 Gradation

The distribution of soil grain size is known as gradation (Bowles, J.E. Hainim, Johan K, 1984). Gradation is usually known on coarse grained soils. The gradient indication can be calculated numerically from the grain size curve by using the uniformity coefficient (C_u) defined as :

$$C_u = \frac{D_{60}}{D_{10}} \qquad (4)$$

The shape of the curve defined as the coefficient of curvature (Cc),

$$C_c = \frac{(D_{30})^2}{D_{60}D_{10}} \qquad (5)$$

where :
D_{10} = grain diameter at 10% through sieve
D_{30} = grain diameter at 30% through sieve
D_{60} = grain diameter at 60% through sieve

When the C_u value gets larger (≥4), the soil grain size distribution becomes heterogeneous, indicating that the gradation of the soil is well graded. And the other hand, if the value of C_u is getting smaller then the grain size is getting the same (uniform).

The curvature coefficient (C_c) is used as a reference of the grain size distribution curve shape between D_{60} and D_{10}. The ideal grain size distribution curve shape of the C_c value lies between 1 and 3. If the value of C_c <1 then the shape of the grain size distribution curve shows the curved shape above the ideal curve and if C_c >3 then the shape of the soil grain size distribution curve shows the curved shape below the ideal curve.

2.4 Regression Correlation Theory

Correlation is the relationship degree between several variables that aim to know how well a linear equation or other equations.

Relationships x and y are said to be positive if the increase (decrease) x is generally followed by an increase (decrease) y. On the contrary it is said to be negative if the increase (decrease) x is generally followed by a decrease (increase) y.

The strength of the relationship between x and y is measured by the correlation coefficient (denoted r). The correlation coefficient value is $-1 \le r \le 1$, which means:
If r = 1, the relationship of x and y is perfect and positive (close to 1, ie very strong and positive relationship).
R = -1, the relationship of x and y is perfect and negative (close to -1, ie very strong and negative relationship).
R = 0, the relationship of x and y is very weak and there is no relationship.

It says x affects y if the change in value of x will cause a change in the value of y; that means the rise and fall of x will make the y value also up and down, so the y value will vary, either to the y average or to the linear line representing the scatter diagram. However, the rise and fall of y is such that the y value varies, not only due to x, because there are other factors that cause it.

The magnitude of the contribution of x to the rise and fall of the y value is obtained from the coefficient of determination, denoted by R^2. If r = 0.92 for example, then the value of $R^2 = (0.92)^2 = 0.85$ (85%), ie the amount of factor x contribution to the rise and fall of y is 85%, while 15% by the other factor. In addition to the value of r and R^2 is also required standard deviation value (s) to determine whether valid or not valid data from the distribution of data obtained. The smaller standard deviation value, the result of the existing analysis is closer to mean of linear regression curve, which means the existing data is more valid. Correlation regression theory is used to prove that the relationship between parameters sought is valid.

2.5 Correlation of CBR with Physical Parameter of Soil

Several studies related to CBR correlation and other soil physical parameters have also been performed by several researchers. Shirur et al. (2014) with submerged soil having LL between 20 - 70 gives CBR relationship and parameters as follows:

CBR = 5.09477-0.09323 (LL) + 0.10939 (SL) + 0.022566 (SI)
CBR = 5.813 – 0.007826 (LL) + 0.12097 (PL)
CBR = -4,8353 – 1,56856(OCMC) + 4.6351 (MDD)
CBR = -3.2353 – 0.06939 (PI) +2.8(MDD)
CBR = 6.5452 – 0.07703(OMC) – 0.10395(PI)

where :
CBR = california bearing ratio
LL = liquid limit
PL = plastic limit
SL = shrinkage limit
PI = plasticity index
OMC = optimum moisture content
MDD = maximum dry density

Zohib et al. (2016) with soil type SW-SM (well graded sand containing silt) submerged condition has the following relation:
CBR = 0.142 (%fines) + 0.0262 (LL) +0.0283 (OMC) + 1.043 (MDD) -17.029
The parameter relation has been valid since it has R^2 = 0,7 - 0,836

3. RESULTS

Based on previous research, the authors conducted laboratory experiments on two types of soil samples i.e soil samples made so as to have the composition of sand and clay 100%: 0%, 95%: 5%, 90%: 10%, 85%: 15%, 80%: 20% and soil samples taken from various locations as in Table 1. In all the compositions of sand and clay, the greater the moisture content (wc) the greater the dry density (γ_d) as shown in Figure 1. At certain water content γ_d will decrease, because the percentage of water that fills the pores between the grains enlarged. Therefore the percentage of incoming solid granules is not maximal. The greater the percentage of clay-silt in the mixture, the optimum water content will be greater, because the content of large clay (SiO_2) can absorb water (H_2O). In terms of density (γ_{dmax}), more greater the percentage of clay-silt then more greater γ_{dmax} will be but in the mixture clay-silt greater than 10%, the γ_{dmax} decreases. It can cause instability such as low bearing capacity and large settlement.

Table 2 Initial Condition of Soil Embankment Material

Location	Gs	Sieve-Hydrometer Analysis		C_u	C_c	C_c/C_u
		Sand (%)	Silt-clay (%)			
Kedungombo River	2.87	86.57	13.43	43.67	2.94	0.07
Lengkong River	2.67	86.80	13.20	50.00	5.56	0.11
Lanang River	2.87	99.82	0.18	4.68	0.72	0.15
Ramania Hill	2.56	97.04	2.96	4.13	0.90	0.22
Brantas River	2.84	96.26	3.74	2.76	0.87	0.32
Complong Beach	2.68	99.79	0.21	2.36	0.82	0.35
Kenjeran Beach	2.61	99.17	0.83	2.20	0.89	0.40
Prigi Beach	2.92	99.87	0.13	2.07	0.90	0.44
Talambung River	2.61	94.13	5.87	2.68	1.25	0.46
Lombang Beach	2.63	99.46	0.54	1.90	0.90	0.47

From the sieve and hydrometer test results (Table 1) shows that the embankment material from rivers and hills content of the fine fraction (silt-clay) is greater than 2%, except in Lanang River Ngrambe Ngawi containing only the fine fraction 0.18%. When compared with the location of embankment material from the beach fine fraction has ranged between 0.13% - 0.83%.

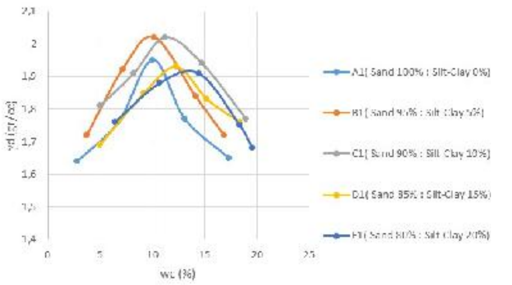

Figure 1 Relationship dry unit weight (γ_d-gr/cc) vs water content (Wc-%)

The correlation between γ_d, e, n with CBR for unsoaked condition for sample type 1.

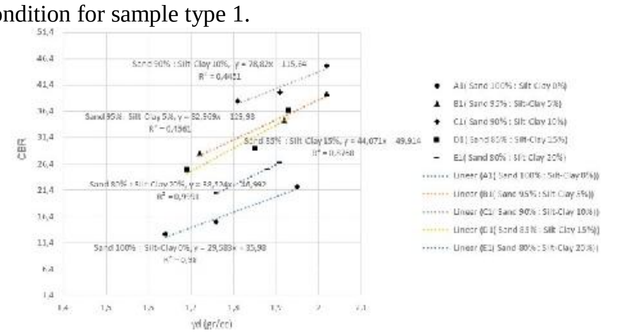

Figure 2 Relationship CBR vs unit weight (γ_d-gr/cc) for unsoaked condition

Figure 2 shows for all the composition of sand and clay tend to greater the dry unit weight (γ_d) the greater the CBR value. This is due to the greater unit weight of soil thus the more dense soil and the soil bearing capacity increase, which is seen with the value of CBR increase.

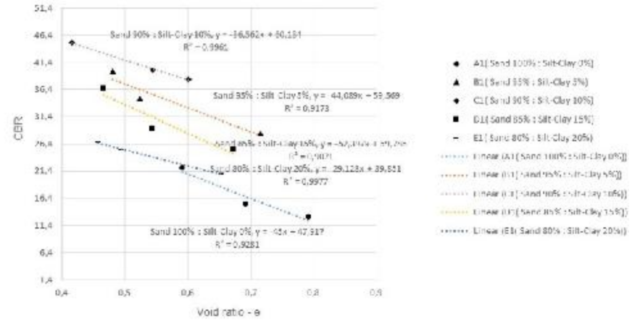

Figure 3 Relationship CBR vs void ratio (e) for unsoaked condition

Figure 3 shows that the CBR value increases hence the void ratio (e) decreases. This is due to the increasing value of CBR thus the soil occur granules reposition. Therefore, the void ratio is smaller.

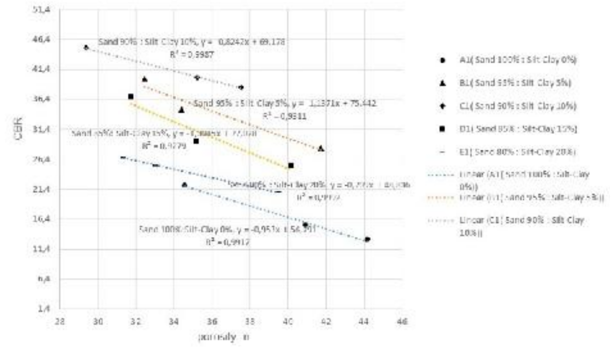

Figure 4 Relationship CBR vs porosity (n) for unsoaked condition

Figure 4 shows that the CBR value increases hence the porosity (n) decreases. This is due to the increasing value of CBR thus the soil occur granules reposition. Therefore, the porosity is smaller.

Based on Figure 2 to 4 can be obtained the relationship between CBR with γ_d, e, n for unsoaked condition as shown in the following equation :

a. Sand 100% dan Silt-Clay 0%

CBR = 29.583(γ_d) – 35.98 (R^2 = 0.9800)
CBR = -34.871(e) + 40.175 (R^2 = 0.9821)
CBR = -0.953(n) + 54.791 (R^2 = 0.9917)

b. Sand 95% dan Silt-Clay 5%

CBR = 37.386(γ_d) – 36.258 (R^2 = 0,9829)
CBR = - 44.089(e) + 59.569 (R^2 = 0,9173)
CBR = -1.1371(n) + 75.442 (R^2 = 0,9311)

c. Sand 90% dan Silt-Clay 10%

CBR = 31.989(γ_d) - 20.096 (R^2 = 0,9373)
CBR = -36.562(e) + 60.134 (R^2 = 0,9961)
CBR = -0,8238(n) + 69.165 (R^2 = 0,9986)

d. Sand 85% dan Silt-Clay 15%

CBR = 44.071(γ_d) – 49.913 (R^2 = 0,8760)
CBR = -52.397(e) + 59.786 (R^2 = 0,9072)
CBR = -1.3045(n) + 77.028 (R^2 = 0,9279)

e. Sand 80% dan Silt-Clay 20%

CBR = 38.524(γ_d) – 46.992 (R^2 = 0.9991)
CBR = -29.128(e) + 39.851 (R^2 = 0.9977)
CBR = -0.709(n) + 48.836 (R^2 = 0.9992)

The correlation between γ_d, e, n with CBR for soaked condition can be seen in the following equation :

a. Sand 100% dan Silt-Clay 0%

CBR = 134.95(γ_d) – 214.94 (R^2 = 0.9956)
CBR = -75.451(e) + 67.337 (R^2 = 0.9788)
CBR = -2.2052(n) + 105 (R^2 = 0.9699)

b. Sand 95% dan Silt-Clay 5%

CBR = 55.967(γ_d) – 90.89 (R^2 = 0.9453)
CBR = - 66.287(e) + 51.681 (R^2 = 0.9699)
CBR = -1.6763(n) + 74.39 (R^2 = 0.9829)

c. Sand 90% dan Silt-Clay 10%
CBR = 58.014(γ_d) – 92.613 (R^2 = 0.9969)
CBR = -70.884(e) + 56.679 (R^2 = 0.9998)
CBR = -1.7141(n) + 78.045 (R^2 = 0.9991)

d. Sand 85% dan Silt-Clay 15%

CBR = 37.995(γ_d) – 54.207 (R^2 = 0.9685)
CBR = -42.771(e) + 40.517 (R^2 = 0.9884)
CBR = -1.1253(n) + 56.692 (R^2 = 0.9760)

e. Sand 80% dan Silt-Clay 20%

CBR = 61.895(γ_d) – 102.47 (R^2 = 0.9995)
CBR = -88.835(e) + 61.256 (R^2 = 0.9994)
CBR = -2.2069(n) + 90.511 (R^2 = 1)

The experimental results are described by the relationship between γ_d and CBR, where the linear regression for unsaturated soil is γ_d = 0.0293(CBR) + 0.7088 and for saturated soils is represented by γ_d = 0.0171(CBR) + 1.6356. The equation between these parameters is only valid for reclamation materials with a minimum of 80% sand composition and 20% maximum clays.

Based on the results of Proctor, CBR and volumetric & gravimetric tests conducted on samples type 2 with different sand and clay compositions are obtained correlation relationship between C_u/C_c and soil parameters such as dry unit weight and water content. The results of the research obtained as follows.
Correation between Cc/Cu with maximum dry unit weight (γ_{dmax}) and optimum water content (w_{opt}) :

a. γ_{dmax} = 2,061 – 0,808.Cc/Cu with r = 0,927
b. w_{opt} = 9,492 + 7,512.Cc/Cu with r = 0,874

Correlation between C_c/C_u with effective cohesion (C’) and internal friction angle (ϕ’) at saturated initial condition (degree of saturation, S_R = 1) dan unsaturated initial condition (S_R < 1) :

a. Effective Cohesion (C’)
   - S_R < 1 (unsaturated) → C’ = 0.087 – 0.088(C_c/C_u) with r = -0.963
   - S_R = 1 (saturated) → C’ = 0.072 – 0.057(C_c/C_u) with r = -0.920

b. Effective internal friction angle (ϕ’)
   - S_R < 1 (unsaturated) → ϕ’ = 53.309 – 29.886(C_c/C_u) with r = -0.722
   - S_R = 1 (saturated) → ϕ’ = 48.761 – 33.052(C_c/C_u) with r = -0.821

4. CONCLUSION

1. From the results of this study concluded that optimal composition of reclamation embankment material to density is 80% sand and 20% clay. If the content of clay is multiplied (> 10%) or increases slightly (<10%), resulting in decreased density.
2. The results of this study indicate that the value of CBR, physical parameters and material density in unsaturated conditions is more optimal than with saturated conditions.
3. The most dominant soil parameter of the effect on the CBR value is the dry unit weight parameter (γ_d), this is because the CBR value increase if the soil density increases.
4. The larger the C_c/C_u ratio the smaller dry unit weight maximum (γ_{dmax}), the shear strength of the soil (effective cohesion, C' and effective shear angle, ϕ') while the larger optimum water content (wopt). This is due to the greater C_c/C_u ratio, the embankment material tends to be uniform and the smaller the grain diameter of the soil. Therefore, there is void resulting in density, bonding and interlocking between granules getting lower. At the same C_c /C_u value, the shear strength of the soil (effective cohesion and shear angle in effective) in the unsaturated initial state is greater than in the saturation initial state. The presence of water-saturated conditions will make the distance between the bonding granules getting away and consequently reduced cohesion and can block interlocking or friction between grains.
5. Materials from the ocean tend to have greater optimum water content to reach their density compared to materials from rivers because the embankment material on the coastal site is dominated by fine sand with a grain diameter smaller than 0.425 mm, requiring larger water to be solid compared with the embankment material of the river with an average content of fine sand is less than 40%.

5. ACKNOWLEDGMENT

Thanks to Kukuh and Baurada for the help of research on Correlation Between Gradation, Physical And Mechanical Parameters For Material Embankments Reclamation.

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