CORRELATION OF MATERIAL GRADATION COEFFICIENT WITH DENSITY AND SOIL SHEAR STRENGTH

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ABSTRACT

Reclamation fill requires material to fulfil the particle gradation requirements as follow : gravel 30% max, sand 50% min, and silt-clay 20% max. Generally, field officer wants to know the density degree of material when it has arrived in the field immediately and easily by using sieve testing. Water content changing caused by rainy season and tidal, taking the largest part of affecting the density and strength of soil. This laboratory test research is using material taken from quarry river, shores and hills which have requirement as follows: silt-clay 20% max, sand 80% min, and gravel which has represented by sand. This material is tested using sieve and hydrometer to determine Cu (coefficient of uniformity) and Cc (coefficient of curvature). Next step is to dense using Modified Proctor and Direct Shear testing with saturated water value (on Zero Air Void line) and non-saturated (on w_{opt}). Research result shows the bigger the Cc/Cu value is (soil is more homogen), maximum dry density will become smaller, γ_{dmax} (γ_{dmax} = -0,808.Cc/Cu + 2,061) and also the optimal water content will become bigger, w_{opt} (w_{opt} = 7,512.Cc/Cu + 9,492). The bigger the Cc/Cu, cohesion effectiveness value(C') and effective internal angle friction (ϕ') will become smaller. Non-saturared condition is showing bigger value (C' = -0,088.Cc/Cu + 0,087 and ϕ' = -29,886.Cc/Cu + 53,309) than in saturated condition (C' = -0,057.Cc/Cu + 0,072 and ϕ' = -33,052.Cc/Cu + 48,761) for the same Cc/Cu value. Similarity between these parameters is only valid if reclamation fill material composition used are as follow: sand 80% min, silt-clay 20% ax, and Cu limit of 1≤Cu≤50.

KEYWORDS: *density; fill; gradation; soil shear strength.*

INTRODUCTION

High-rate of citizen growth causes decreasing living area which requires land development by reclamation.

Besides material gradation requirement of gravel 30% max, sand 50% min, and silt-clay 20% max[1], density requirement also need to be fulfilled. Generally, field officer wants to know the density degree of material immediately and easily when it has arrived in the field by using a sieve testing in order to know whether it has fulfilled the fill material requirement or not, based on required density.

Determination of soil gradation is very important because it will affect the grains size distribution, whether it is well graded, poorly graded or gap graded. These gradations are determined by coefficient of uniformity (Cu) and coefficient of curvature (Cc) value, which very affecting material density.

Several issues required to be solved on this paper are:

- What is the relationship between Cu, Cc, grains gradation with density (γ_d) and internal angle friction (ϕ) and cohesion (C), for initial condition: saturated and non-saturated.
- Also what is the effect of water content (w) against dry density (γ_d) and soil shear strength (ϕ and C).

Hopefully, this research would be able to solve decision issue among field practician in fillmaterial selection on shore reclamation to predict the desired density based on material grains composition.

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Note. The manuscript for this paper was submitted for review and possible publication on April 15, 2011. Discussion open until May 2012. This paper is part of the ITS Journal of Civil Engineering, Vol. 31, No. 1, May 2011. © ITS Journal of Civil Engineering, ISSN 2086-1206/2011.

REFERENCE OBSERVATION

Reclamation Material

Technical requirement of reclamation material shouldn't be 100% homogenous soft sand, and material shouldn't contains too much silt-clay (≥ 20%).

If fill material contains too much silt-clay, then it will create *instabilitas* (caused by large shrink, swell settlement or high density, moveable, low power of soil support) inside the fill reclamation itself.

Material for fill reclamation as SETRA and LCPC must fulfill the gravel requirement 30% max, sand 50% min, and silt-clay 20% max.

Material resources (*quarry*) of fill reclamation is available to be obtained from: ocean base, certain island, land (hill, mountain), river base and lake base.

Gradation

Grains size soil distribution is also known as gradation.[2] Gradation is known on coarse grains soil. Gradation indication can be numerically calculated using grains size curve, using *uniformity coefficient* which is defined as:

$$C_U = \frac{D_{60}}{D_{10}} \quad (1)$$

and curve shape defined as *coefficient of curvature*:

$$C_C = \frac{{D_{30}}^2}{D_{60} \cdot D_{10}}, \quad (2)$$

with :

D_{10} : grains diameter on 10% filter-passed
D_{30} : grains diameter on 30% filter-passed
D_{60} : grains diameter on 60% filter-passed

If Cu is become bigger (≥ 4) then grains soil size distribution will be more heterogeneous, which means soil gradation is *well graded*.

On the other hand, if Cu is become smaller, then grains size will be more similar or *uniform*.

Coefficient of curvature (Cc) is used for a reference of the grains soil size distribution curve shape between D_{60} and D_{10}. Ideal curve shape of grains soil size distribution has Cc value between 1 and 3. If Cc < 1, thus curve shape of grains soil size distribution will show a curvature above of ideal curve, and if Cc > 3, then curve shape of grains soil size distribution will show a curvature below of ideal curve.

Compaction

In several civil works, soil is densed to increase tecnical characteristics. Day[3] said required factors to shrink *void ratio* (e) when densing are: well graded grains size distribution, high ratio between d_{100}/d_0 (ratio between biggest and smallest size of grains diameter), silt-clay particle (with low *activity*) to fill the smallest pore space and densing process to press soil particle to become more dense structure.

Lee and Suedkamp[4] had learnt densing curves from 35 soil types. They concluded that those soil densing curves can be determined into 4 common types. The result can be seen on Figure 1. Type A densing curve usually can be found on almost all clay soil with limit liquid value (LL) between 30 – 70. Type B densing curve peak on one and a half, usually can be found on sand with LL < 30. Type C curve has 2 peaks, can be found on soil with LL < 30 or LL > 70. Type D curve with odd shape, usually can be found on soil with LL > 70.

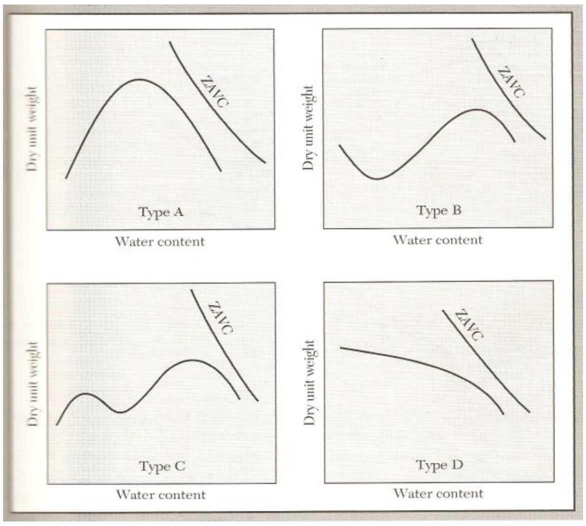


Figure 1. Common four curve types founded on soil[4]

Relationship between water content (ω) with dry density (γ_d) and unit weight of zero air void (γ_{ZAV}) can be formulated as follow:

$$\gamma_d = \frac{\gamma_{sat}}{1+\omega}$$

$$S_r = 100\% \rightarrow \gamma_{ZAV} = \frac{\gamma_W \cdot G_s}{1+G_s \cdot \omega} \qquad (3)$$

With:

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

Soil Shear Strength

Soil shear strength can be shown by cohesion (C) and internal angle friction (ϕ). From *direct shear* testing, will be retrieved 2 values: normal stress (σ) and shear stress (τ), which affected by normal force element (P), shear force (H) and *direct shear* ring surface area (A).

In this *direct shear* testing, sample is made on 2 conditions which are (Figure 2):

1. *unsaturated soil*
   This sample is made based on result of modified *proctor* testing, using optimal water value.
2. *saturated soil*
   This sample is made by water content retrieved from line intersection between maximum dry density (γ_{dmax}) and ZAV line.

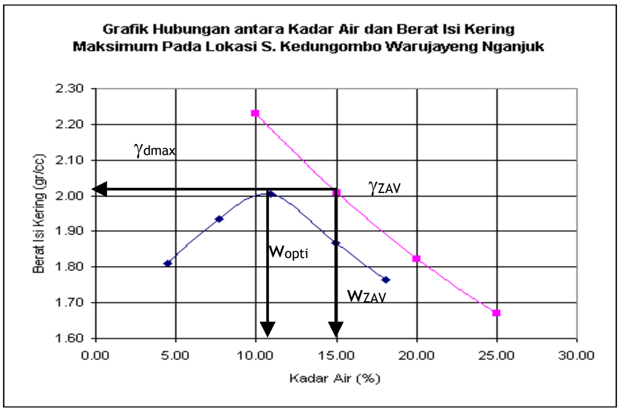


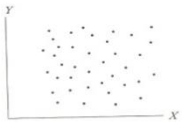
Figure 2. One example of *Proctor Modified* graphic to determine saturated and unsaturated water content

Regression Correlation Theory

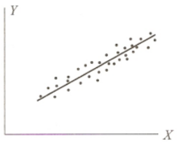
Correlation is a relationship degree among variables to know how good a linear equation or other equations are.

Relationship between x and y is positive if x increasing (decreasing) is followed by y increasing (decreasing). On the other hand, x and y is negative if x increasing (decreasing) followed by y decreasing (increasing)

x and y relationship strength measured with a value called correlation coefficient (symbolized as r), can be seen at Figure 3. Correlation coefficient value is $-1 \le r \le 1$, means: If r = 1, x and y relationship is perfect and positive (closer to 1, which is a very strong and positive). If r = -1, x and y relationship is perfect and negative (closer to -1, which is a very strong relationship and negative). If r = 0, x and y relationship is very weak and no relation.



a. r = 0 (no correlation)



b. r = +1 (positive linear correlation)

c. r = -1 (negative linear correlation)

Figure 3. Correlation coefficient on spread-diagram

x is affecting y if x value changing will change y value; means every x increasing or decreasing will make y value increasing or decreasing as well, y value will have more variation for y-mean and linear line represent in spread-diagram. However, not all y value increasing or decreasing which make y value will have more variation is caused by x, because there are other factors which also affects y value. The x contribution value for y increasing or decreasing is retrieved from *coefficient of determination*, symbolized as R^2. For example ff r = 0.92, thus $R^2 = (0.92)^2 = 0.85$ (85%), means the amount of x contribution for y increasing or decreasing is 85%, and 15% because of other factors. Besides r and R^2, *standard of deviation* (s) is also required to know whether the data from spreading-data is valid or not. The smaller values of standard deviation, the analysis result will getting closer to the *mean* of *linear regression* curve, which means the existing data is more valid.

METHODOLOGY

An experiment was done to complete this research at Laboratorium Mekanika Tanah Teknik Sipil ITS Surabaya. The sample is a fill of soil taken from 10 different locations originating from Sungai Kedungombo Warujayeng Nganjuk, Sungai Brantas Kertosono Nganjuk, Sungai Lanang Ngrambe Ngawi, Sungai Lengkong Gulu-gulu Sumenep, Sungai Talambung Ganding Sumenep, Pantai Lombang Sumenep, Pesisir Pantai Camplong Sampang, Pantai Prigi Trenggalek, Pantai Kenjeran Surabaya and Bukit Ramania Samarinda. *Granulometri* (grains size dividing) testing applied to this material to get Cu and Cc value with reclamation material must meet the conditions determined by SETRA and LCPC (1976): gravel 30% max, sand 50% min and silt-clay 20% max.

On this research, *gravel* is not being used because implementation on the field requires 5 cm for gravel size and on the laboratory testing takes 1/10 of gravel maximum size which equal to 5 mm, closer to maximum sand size 4.75 mm. Sand is assumed able to be a representation of actual gravel

Sequences taken on this research is shown at Figure 4:

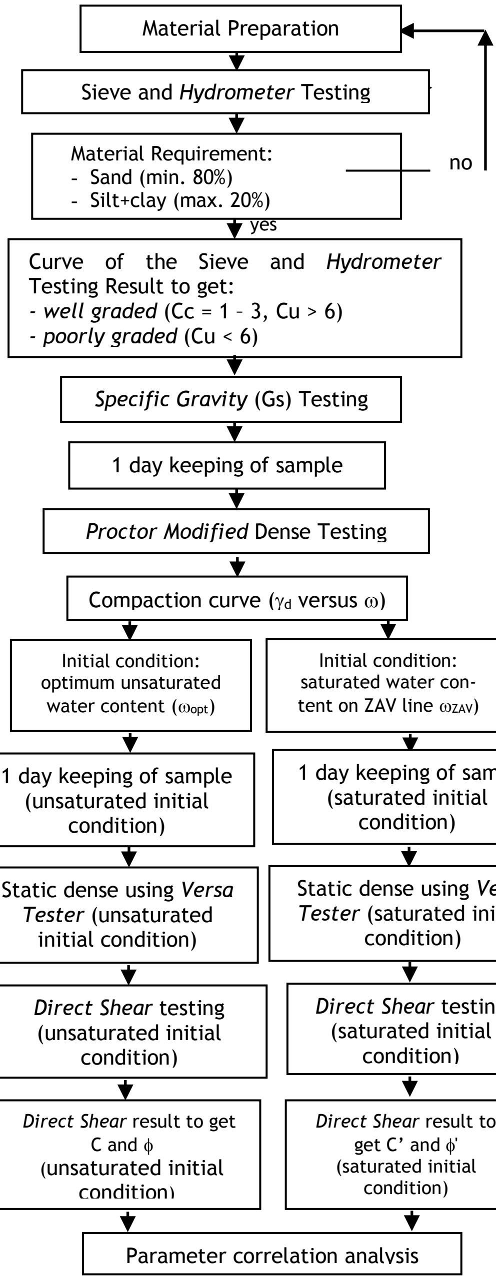


Figure 4. Flow diagram of sequence and testing type

RESULT AND ANALYSIS

Initial Condition of Sample

From sieve testing result and *hydrometer* (Table 1.), soil material obtained from river and hill has soft fraction content more than 2%, except on Sungai Lanang Ngrambe Ngawi location which only 0.18%.

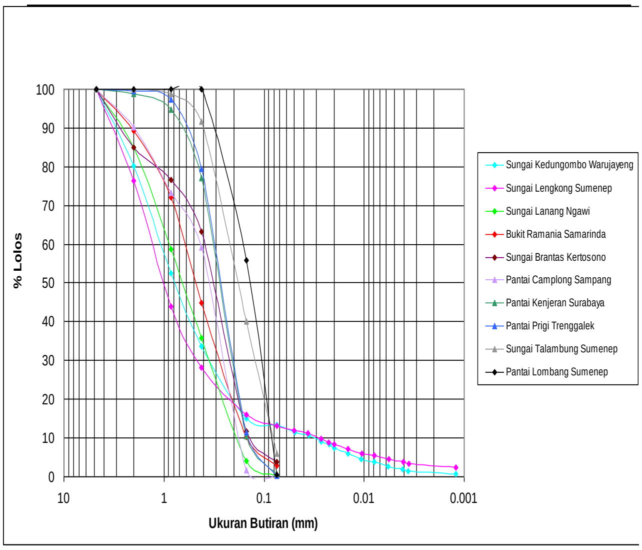


Figure 5. Grains size distribution from various locations: rivers, beaches and hills based on soil classification *USCS*

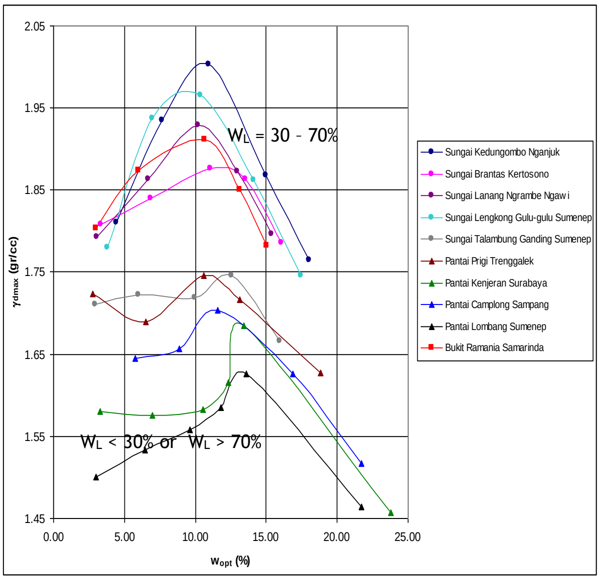


Figure 6. Density curves on 10 reclamation fill material location

Table 1. Soil Material Initial Condition

Location	**Gs**	Sieve-Hydrometer		**Cu**	**Cc**	**Cc/Cu**
		Sand fraction (%)	Silt-clay fraction (%)			
Sungai Kedungombo	2.87	86.57	13.43	43.67	2.94	0.07
Sungai Lengkong	2.67	86.8	13.20	50.00	5.56	0.11
Sungai Lanang	2.87	99.82	0.18	4.68	0.72	0.15
Bukit Ramania	2.56	97.04	2.96	4.13	0.90	0.22
Sungai Brantas	2.84	96.26	3.74	2.76	0.87	0.32
Pantai Camplong	2.68	99.79	0.21	2.36	0.82	0.35
Pantai Kenjeran	2.61	99.17	0.83	2.20	0.89	0.40
Pantai Prigi	2.92	99.87	0.13	2.07	0.90	0.44
Sungai Talambung	2.61	94.13	5.87	2.68	1.25	0.46
Pantai Lombang	2.63	99.46	0.54	1.90	0.90	0.47

Source: Testing result

Table 2. Density Parameter on Saturated and Unsaturated Initial Condition

No	Location	Saturated ($S_R = 1$)		Unsaturated ($S_R < 1$)		
		w (%)	$\gamma_b = \gamma_{ZAV}$ (g/cc)	w (%)	S_R (%)	γ_b (g/cc)
1	Sungai Kedungombo	15.25	2.00	10.92	72.43	2.22
2	Sungai Brantas Kertosono	18.00	1.88	11.04	61.05	2.08
3	Sungai Lanang	17.00	1.93	10.22	60.02	2.13
4	Sungai Lengkong	13.70	1.96	10.37	76.79	2.17
5	Sungai Talambung	18.75	1.75	12.54	66.11	1.96
6	Pantai Prigi	23.00	1.75	13.12	56.85	1.98
7	Pantai Kenjeran	21.30	1.68	13.41	63.82	1.91
8	Pantai Lombang	23.20	1.63	13.57	57.90	1.85
9	Pantai Camplong	21.50	1.70	11.57	54.03	1.90
10	Bukit Ramania Samarinda	13.20	1.91	10.65	80.29	2.12

Source: Testing result

Compared with material from beach which has soft fraction content only 0.13% – 0.83%.

Figure 5 shows the smaller the gradation coefficient ratio Cc/Cu, soil material is become more heterogeneous, vice versa, if Cc/Cu is getting bigger then soil material is become more homogenous or *uniform*. Table 1 is classifying the soil based on *USCS*: material gradation on Sungai Kedungombo Warujayeng is *well graded* because Cu > 6 and Cc is approximately between 1 – 3 with the smallest Cc/Cu ratio which is 0,067, comparing with the others which are *poorly graded*.

Figure 6 shows most of density curve on rivers and hills location has bell shape (type A), except on Sungai Talambung with 2 peaks (type C). However, reclamation material on beach location is dominated by type B because material on beach location contains more than 55% of soft sand, then γ_{dmax} is inclined to be lower with water content higher than material which located from river or hill.

Throughout testing result of *proctor modified* dense for saturated and unsaturated initial condition for each location can be seen at Table 2. From the result of material gradation and one of the density parameter which is maximum dry density, γ_{dmax} (Table 3 and Figure 7) shows the bigger Cc/Cu ratio then the dry unit weight maximum is inclined to decrease.

This is because of Cc/Cu which getting bigger then grains size is inclined to be same (*uniform*), hence there will be pore empty spaces between solid soil grains showing the density is lower than *well graded* soil. *Linear regression* equation on Figure 7 showing if r = -0,927 closer to -1 means x and y relationship is perfect and negative which make the equation to be valid.

Correlation between Cc/Cu and Water Content

Based on the result of materials gradation and one density parameter that is optimum water content (w_{opt}) at Table 3 and Figure8, its represent that the Cc/Cu ratio with an optimum water content trend to form a straight line (linear), which means the bigger Cc/Cu ratio will make optimum water content is tend to increase, or vice versa.

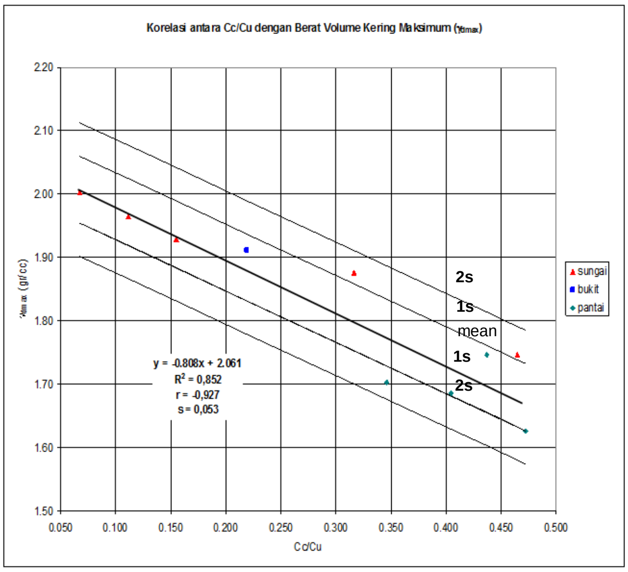


Figure 7. Effect of reclamation material gradation (Cc/Cu) against maximum dry unit weight (γ_{dmax})

This is happen due to the bigger Cc/Cu ratio, pile material grains is tend to have similar form (*uniform*) with its pore increasing, hence a lot of pore water is required to get its maximum density.

Figure 8 showing that Cc/Cu increasing ratio is being dominated by materials taken from beach location with optimum water content bigger than 11%. In order to reach its maximum density, pile materials on beach location require bigger optimum water value, because materials taken from beach location is dominated by *fine sand* with grains diameter smaller than 0,425 mm, which required more water to be more solid compared with pile materials taken from rivers or hills which contains fine sand approximately less than 40%.

Linear regression equations on Figure 8 represent that r value = 0,873 are getting closer to 1. It means x and y relationship is perfect and positive, thus the formula is *valid* to be used.

Table 3. Correlation between Cc/Cu and Dry Density (γ_{dmax} and w_{opt})

Location	Gradation	Soil Density	
	Cc/Cu	γ_{dmax} (gr/cc)	w_{opt} (%)
Sungai Kedungombo Warujayeng Nganjuk	0.067	2.00	10.92
Sungai Brantas Kertosono Nganjuk	0.316	1.88	11.04
Sungai Lanang Ngrambe Ngawi	0.155	1.93	10.22
Sungai Lengkong Gulu-gulu Sumenep	0.111	1.96	10.37
Sungai Talambung Ganding Sumenep	0.465	1.75	12.54
Pantai Prigi Trenggalek	0.437	1.75	13.12
Pantai Kenjeran Surabaya	0.405	1.68	13.41
Pantai Lombang Sumenep	0.473	1.63	13.57
Pesisir Pantai Selatan Selat Jawa Camplong Sampang	0.346	1.70	11.57
Bukit Ramania Samarinda	0.219	1.91	10.65

Source: Testing result

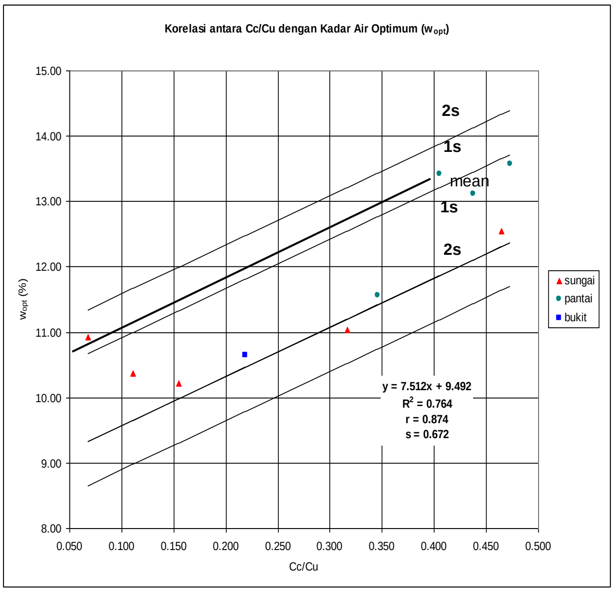


Figure 8. Effect of reclamation material gradation (Cc/Cu) against optimum water content (w_{opt})

Correlation between Cc/Cu and Cohesion

Table 4 and Figure 9 represent that the bigger Cc/Cu value, it will make the cohesion value is tend to decrease. The bigger Cc/Cu ratio value, then the grains gradation will be worse, which mean those grain are tend to be more *uniform* hence when its being mixed up there will be void exist between grains and there will be less cohesion in it.

Cohesion is also affected by the existence of water defined with saturated and unsaturated conditions. From Figure 9, it can be seen that with the same Cc/Cu value then cohesion value on unsaturated condition is bigger than cohesion on saturated condition. This is because water existence will separate bond between grains and cause cohesion between grains to become more less than before.

On initial, Cc/Cu values shows cohesion value on saturated and unsaturated condition have very significant differences. But when Cc/Cu ratio is getting bigger, the cohesion value on saturated and unsaturated condition will closer each other. It happen when Cc/Cu values reach = 0.47 with cohesion value 0.46 kg/cm^2. This indicates the bigger Cc/Cu values, the cohesion content will getting smaller (dominated by fine sand 99%) hence cohesion will not depend on water (*Van Der Waal* force).

Figure 9 shows r value on unsaturated initial condition = -0,963 and r value on saturated initial condition = -0,920 which both of them are getting closer to -1. It means x and y relationship is perfect and negative, thus formula above is valid to be used.

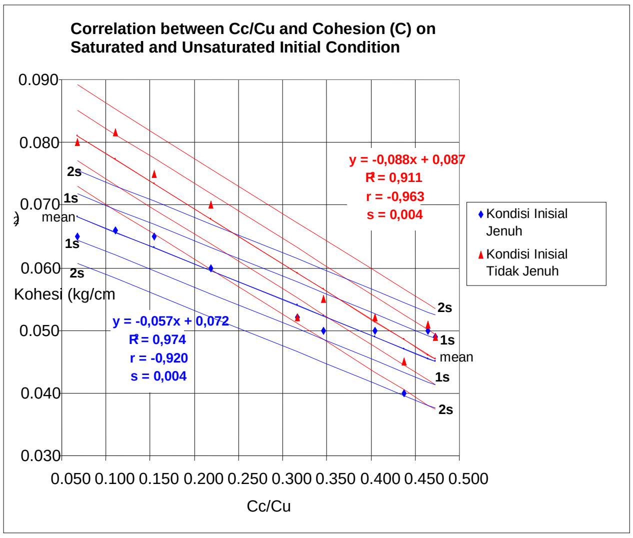


Figure 9. Effect of reclamation material gradation (Cc/Cu) against cohesion (C') at saturated and unsaturated initial conditions.

Correlation between Cc/Cu and Internal Angle Friction (ϕ)

Table 4 and Figure 10 represent that the smaller Cc/Cu value then the internal angle friction value is tend to increase. The smaller Cc/Cu value, the better its grains

Table 4. Correlation between Cc/Cu with soil shear strength (C' and ϕ') on saturated and unsaturated initial conditions

Location	Cc/Cu	Soil Movement Strength			
		Saturated Initial Condition		Unsaturated Initial Condition	
		C' (kg/cm^2)	ϕ' (°)	C' (kg/cm^2)	ϕ' (°)
Sungai Kedungombo	0.067	0.065	40.65	0.080	49.74
Sungai Lengkong	0.111	0.066	48.41	0.082	52.45
Sungai Lanang	0.155	0.065	48.77	0.075	50.48
Bukit Ramania	0.219	0.060	42.07	0.070	50.77
Sungai Brantas Kertosono	0.316	0.052	35.72	0.052	35.32
Pantai Camplong	0.346	0.050	36.84	0.055	39.92
Pantai Kenjeran	0.405	0.050	34.28	0.052	40.97
Pantai Prigi	0.437	0.040	32.55	0.045	36.24
Sungai Talambung	0.465	0.050	38.12	0.051	45.14
Pantai Lombang	0.473	0.049	31.25	0.049	42.59

Source: Testing result

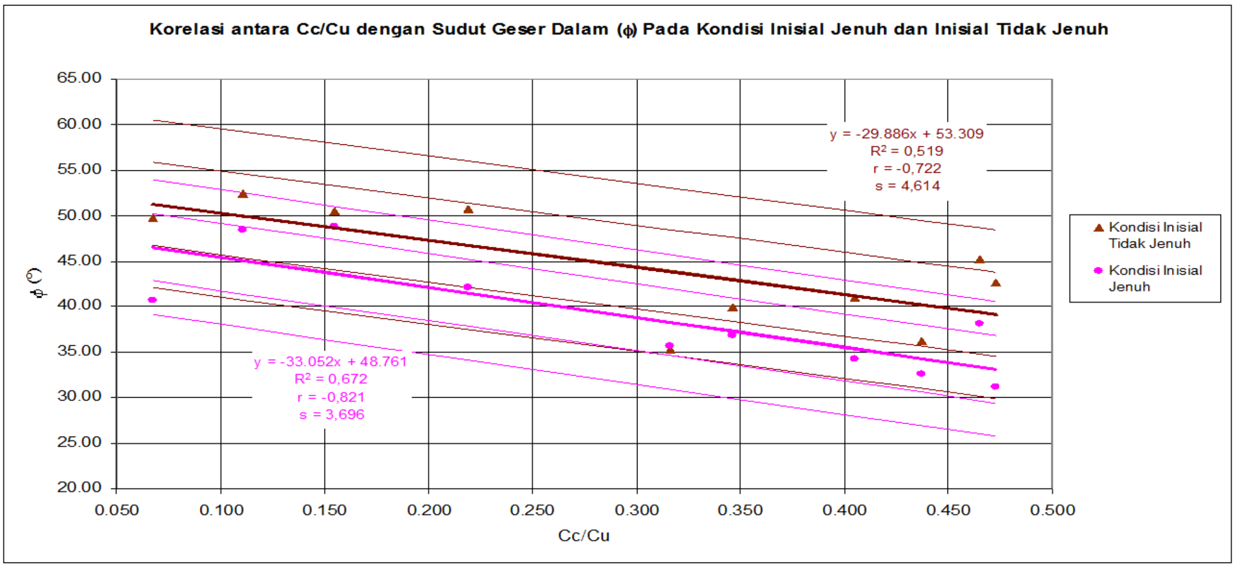


Figure 10. Effect of reclamation pile material gradation (Cc/Cu) against internal angle friction (ϕ') on saturated and unsaturated initial condition.

gradation. Because soil has various of grains shapes. Where soil has various sizes of grains, then it will be denser than soil which contains the same grains size (high Cc/Cu). This resulting whenever *interlocking* aspect increase so the friction between soil grains will also getting bigger. This *interlocking* and friction between soil grains will cause the soil internal angle friction (ϕ) also increasing.

Besides above matters, saturated and unsaturated condition is also affecting the soil internal angle friction. Figure 10 shows with the same Cc/Cu value then internal angle friction on unsaturated condition is bigger compared with on saturated condition. This is caused by the water existence on saturated condition will separate sand grains hence will prevent the *interlocking* and friction between grains.

Based on *linear regression* equation on Figure 10, it is showed that r value on unsaturated initial condition = -0,722 and r value on saturated initial condition = -0,821 which both of them are closer to -1 hence x and y relationship is perfect, negative, and *valid*.

CONCLUSION

This research with its title: "Effect of material gradation coefficient (curvature coefficient, Cc and uniformity coefficient, Cu) with density parameter and soil shear strength are only prevail for soil with composition of sand 80% min, and silt-clay 20% max, and Cu value limit is $1 \leq Cu \leq 50$.

Conclusion items:

1. The bigger Cc/Cu ratio will decrease the soil dry density maximum (γ_{dmax}), soil shear strength (effective cohesion, C' and effective internal angle friction, ϕ') and optimum water content (w_{opt}) will increase. This is caused by the bigger Cc/Cu ratio is, materials are tend to become similar form (*uniform*) and soil grains diameter will decrease, hence pore space will appear and it will causing the density, bond and interlocking between grains will also decrease. At the same Cc/Cu value, soil shear strength (effective cohesion and effective internal angle friction) on unsaturated initial condition is bigger than saturated initial condition. Saturated water condition will make bond between grains become separated hence cohesion capacity is decreased and it will also prevent *interlocking* and friction between grains.
2. Material from sea is tend to be have more optimum water content to meet its density compared with material from river, because fill materials on beach location is dominated by fine sand with grains diameter is smaller than 0.425 mm, which required more water to get more dense compared with pile materials from river that contains fine sand approximately less than 40%.
3. Correlation between Cc/Cu with dry unit weight maximum (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
4. Correlation between Cc/Cu with cohesion, C' and internal angle friction, ϕ' saturated initial condition (saturated degree, $S_R = 1$) and unsaturated ($S_R < 1$) :
   a. Effective cohession (C')
   - $S_R < 1$ (unsaturated) → C' = 0,087 – 0,088.Cc/Cu with r = -0,963
   - $S_R = 1$ (saturated) → C' = 0.072– 0.057.Cc/Cu with r = -0.920

   b. Effective internal angle friction (ϕ')
   - $S_R < 1$ (unsaturated) → ϕ' = 53,309 – 29,886.Cc/Cu with r = -0,722
   - $S_R = 1$ (saturated) → ϕ' = 48,761– 33,052.Cc/Cu with r = -0,821

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