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Effect of Compaction to Increase the Critical Height of a Slope without any Support

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Abstract. Embankment is a common way to raise ground level of any construction. Raising the ground level will also help structure from being flooded, flood especially in major city such as in Capital City of Indonesia, Jakarta, is a yearly problem. On the other hand, embankment will also be a problem if not handle carefully. Clay and sand can be used as materials. Properties of material that should be investigate before the materials being used are cohesion and angle of friction. Beside selection of high quality materials, compaction can also help embankment from failure. When the materials get well-compacted the chance of sliding should be lower. This study analyse the correlation whether well-compacted material can have higher critical height and the result can be imply on the construction site as not every embankment need retaining structure to be stable but only by compaction the embankment can withstand by it self

1. Introduction

Flood is a problem that happened in many cities in Indonesia, especially Jakarta. Many new constructions raise their ground floor level to accommodate this situation. Elevating the base of construction means construct embankment using fill material. Fill material according to Federal Highway Administration (FHWA) usually consist of soil but may also include aggregate, rock, or crushed paving material; with coarser material placed at the bottom (sand and gravel) followed by more fined material (silt and clay) and get compacted to provide better support for any structure on top. Beside material, gradation also is very important in the construction of embankment in order to provide a firm foundation to withstand any loading condition without deflection or undesirable movement. The properties of soil such as unit weight, water content and specific gravity also influence the capability of embankment.

A certain amount of water is mixed during compaction proctor test defined by ASTM standard (ASTM D698 and ASTM D1557) in laboratory. Using proctor test, optimum water content and maximum dry density can be achieved.

Beside water content, according to FHWA [4], a reference of testing procedures stated by ASTM standard has been established considering the condition of soil material (Table 1).

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Table 1. Embankment or fill material test procedures [4]

Property	Test Method	Reference
	Particle Size Analysis of Soils	ASTM D422
Gradation	Sieve Analysis of Fine and Coarse Aggregate	ASTM D135
	Unit Weight and Voids in Aggregate	ASTM D29
	Specific Gravity of Soils	ASTM D854
Unit Weight and	Relative Density of Cohesionless	ASTM D2049
Specific Gravity	Maximum Index Density of Soils Using a Vibratory Table	ASTM D4253
	Minimum Index Density of Soils and Calculation of Relative Density	ASTM D4254
Moisture of Density	Moisture-Density Relations of Soils and Soil-Aggregate Moistures Using 5.5 lb (2.49 kg)	ASTM D698
Characteristic	Rammer and 12 in (305 mm) Drop	(Standard)
	Moisture-Density Relations of Soils and Soil-Aggregate Moistures Using 10 lb (4.54 kg)	ASTM D1557
	Rammer and 18 in (457 mm) Drop	(Modified)
	Density of Soils in Place by the Sand Cone Method	ASTM D1558
Compacted Density	Density and Unit Weight of Soils in Place by the Rubber Baloon Method	ASTM D2167
(In-Place Density)	Density of Soils and Soils-Aggregate in Place by Nuclear Methods (Shallow-Depth)	ASTM D2922
	Density of Soils in Place by the Sleeve Method	ASTM D4564
	Unconsolidated Undrained Compressive Strength of Cohesive Soils in Triaxial Compression	ASTM D2950
	Direct Shear Toast of Soils Under Consolidated Drained Conditions	ASTM D3080
Shear Strength	Consolidated Undrained Triaxial Compression Test on Cohesive Soils	ASTM D4767
	One-Dimensional Consolidation Properties of Soils	ASTM D2435
Compressibility	One-Dimensional Consolidation Properties of Soils Using Controlled-Strain Loading	ASTM D4168
	One-Dimensional Swell on Settlement Potential of Cohesive Soils	ASTM D4546
	California Bearing Ratio (CBR) of Laboratory-Compacted Soils	ASTM D1883
Bearing Capacity >	Bearing Ratio of Soils in Place	ASTM D4429
Permeability	Permeability of Granular Soils by Constant Head	ASTM
	D2434 pH of Soils For Use in Corrosion Testing	ASTM G51
Corrosion	Field Measurement of Soils Resistivity by Using the Wenner Four-Electrode Method	ASTM G57
Resistance	Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer	ASTM D4542

Many main contractors regularly use fill material of clay to raise the level of ground floor. As seen in Figure 1, contractor used soil to raise about 2.5 meter from existing soil layer.

Figure 1. Construction site with clay as embankment material to raise ground level

To prevent failure from sliding, fill material should be well-compacted (Figure 2). At construction site, compaction equipment such as sheepsfoot compactor, smooth drum, vibratory, rubber tire, jumping jacks, plates and trench compactors can be applied.

Figure 2. Soil compactor equipment to provide uniform compaction

Figure 3. Embankment with uniform compaction

As seen on Figure 3, compactor equipment is riding and milling on the top of fill material to compact the clay expecting a uniform density of the materials. In the pictures, it can be seen that ground floor will be risen as high as the fence or approximately 2.5 meters.

2. Slope Stability

Ground with uneven level is vulnerable to soil movement; the higher differences of level will risk the possibility of soil movement. The movement will be similar to water flows from higher level to lower elevation. According to Cruden and Varnes (1996) [3] there are five major categories of soil movement: Fall, Topple, Slide, Spread and Flow.

All those possibilities will not happen when the soil has high shear strength, compared to shear stress developed along the potential failure surface of the soil. Soil Shear strength is dependent to cohesion and internal friction angle. Higher shear strength can be achieved by:

1. Using high quality soil material
   - Clay: higher cohesion
   - Sand: higher angle of friction
2. Compaction will also increase the value of soil shear strength

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Figure 4. Example of fill material failure

Figure 4 showing an example of slope failure. Embankment on this case using a mixture of clay and sand, the percentage of sand is dominant. The density is a major factor that can cause the failure of the embankment. In this case the embankment seems did not get enough compaction. Although a retaining wall was constructed, however, the shear stress was risen higher and the wall could not withstand the pressure. After an investigation, it was found that the factor of rain water run-off causing the weakening of the soil density, the drainage system was not designed properly resulting in higher lateral pressure to the retaining wall. In this paper, the rain water problem will not be discussed widely.

3. Common Solution for Slope Protection

To prevent embankment from failure, typically around the perimeter a retaining wall construction can be installed. Types of retaining wall used depend on how high lateral pressure generated behind the wall, equipment and material availability, and fill material quality.

Gravity wall, piling wall, cantilever wall and anchored wall are some types of retaining wall used by engineer to prevent soil from sliding. When designing retaining wall structure, engineer should calculate the safety factor against overturning, sliding, foundation pressure and the possibility failure of overall stability.

In this paper, a recommendation is proposed to reduce the construction cost by eliminating the cost of constructing retaining wall, replacing it by well-constructed embankment by compacting the soil layer by layer with tight control.

4. Critical Height Correlation to Compaction

Culmann's Analysis [3] (Figure 5) assumes the failure of a slope occurs along a plane when the average shearing stresses tending to cause the slip rather than the shear strength of the soil. Also, the most critical plane is the one that has a minimum ratio of the average shearing stress that tends to cause the failure of shear strength of the soil. A simple approach to estimate the critical height of a slope can be calculated by using the equation (1) [3]

$$H_{cr}=\frac{4c'}{\gamma}\left[\frac{\sin\beta\cos\phi'}{1-\cos(\beta-\Phi')}\right] \tag{1}$$

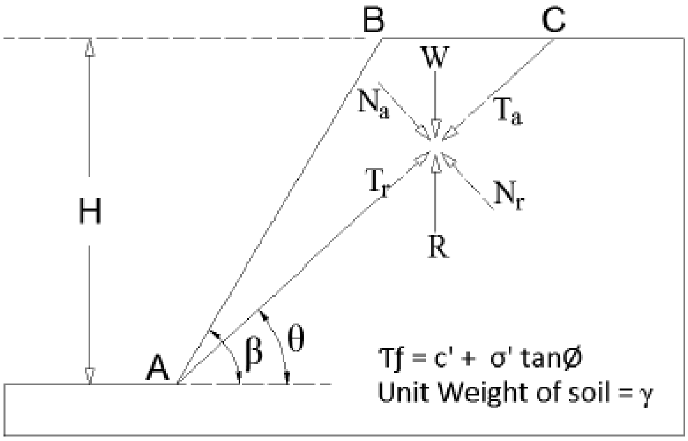

Figure 5. Finite slope

Where c' = Cohesion

Ø' = angle of internal friction

γ = Unit weight of soil

β = Slope angle with horizontal

H_{cr} = The maximum height of the slope for which equilibrium occurs

To use equation (1) properly, it is important to find parameters, unit weight, cohesion and angle of internal friction. Sometimes to find directly those parameters need costly effort. In this paper an alternative approach is proposed by using CBR (California Bearing Test) value, pocket vane shear value and empirical equation to estimate the approximately critical height.

The values of CBR and pocket vane shear can be found by testing soil samples in the laboratory. The ASTM standard (D1883) can be used to get CBR value. In order to get values of cohesion and angle of internal friction, the tested samples of CBR were cut in five layers and each layer was tested using pocket vane shear equipment. Average values from pocket vane shear test then can be defined.

This approach is taken from Wongkar (2018) study which correlated the value friction angle with CBR value. From pocket vane shear, value of soil strength (Su) can be found. Using equation 2 (Sowers, 1979) to get N-SPT value and using correlation of friction angle and N-SPT value from Meyerhoff (1956) as seen in table 2, friction angle can be predicted.

$$Su = (0.102 \text{ to } 0.179)\ N \tag{2}$$

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Table 2. Correlation between N-SPT value with friction angle

SPT N (Blows/0,3m)	Soil Packing	Relative Density (%)	Friction Angle (°)
< 4	Very Loose	< 20	< 30
4 to 10	Loose	20 to 40	30 to 35
10 to 30	Compact	40 to 60	35 to 40
30 to 50	Dense	60 to 80	40 to 45
> 50	Very Dense	> 80	> 45

5. Case Study

One example to use this approach is taken from an embankment construction located at Tangkil, Citeureup, Bogor, West Java, Indonesia. An amount of soil sample for embankment construction was taken from the field and tested in the laboratory. The parameters result of laboratory testing was used for design embankment height by using equation (1). The basic important parameters are ɤ (unit weight) = 16 kN/m^3.

In the laboratory some soil samples were also tested to find CBR values with several defined values (CBR = 2.5, 5.0, 7.5, and 10). Table 3 shows the result of laboratory study to correlate the CBR values with angle of internal friction (Ø') values. The Ø' values are calculated using the empirical equation (2) and Table 2 after getting the values from pocket vane shear tested in the laboratory. Those values are shown in Table 3, column (4). The critical height, H_{cr}, shown in column (6) was calculated using equation (1). By using those soil parameters and assuming slope angle with horizontal, β = 90 degrees, then critical height can be determined and being compared.

To show how the equation works, below is sample calculation for CBR value =2.5:

Safety Factor = 3 (Assumption)

Assume β = 90°

c/SF = 30.64/3

= 10.212 kN/m^2

Ø/SF = 39.40°/3

= 13.13°

$$H_{cr} = \frac{4 \times 10.212}{16}\left[\frac{\sin(90°)\cos(13.13°)}{1-\cos(90°-13.13°)}\right]$$

= 3.22 m

Tabel 3. The Correlation of CBR values with Angle of Internal Friction (Wongkar (2018) and result of critical height for each CBR values

CBR value	Position of point samples tested using pocket vane shear		Cohesion C (kN/m^2)	Ø' average (degree)	γ (kN/m^3)	H_{cr} (m)
(1)	(2)		(3)	(4)	(5)	(6)
2.50	TOP		30.64	39.4	16.00	3.22
	SIDE	TOP				
		MIDDLE				
		BOTTOM				
	BOTTOM					
5.00	TOP		36.04	43.12	16.00	3.87
	SIDE	TOP				
		MIDDLE				
		BOTTOM				
	BOTTOM					
7.50	TOP		40.15	45.19	16.00	4.37
	SIDE	TOP				
		MIDDLE				
		BOTTOM				
	BOTTOM					
10.00	TOP		48.00	50.00	16.00	5.37
	SIDE	TOP				
		MIDDLE				
		BOTTOM				
	BOTTOM					

The graph correlation between CBR values and critical height is shown in Figure 6

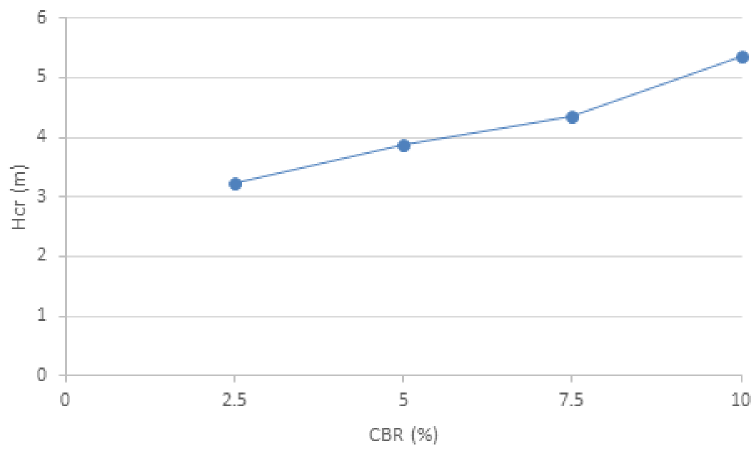

Figure 6. Correlation of CBR value versus Critical height

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6. Conclusion

Based on calculation above shown that critical height increase corresponding with the increase of CBR value. The recommendation from this result is density of embankment play a significant role in slope stability failure. When soil material is not well compacted protection using retaining wall might be inevitable and vice versa.

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