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Effect of use of quicklime mix on the slope surface and number of layers on embankment stability

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Abstract. Common problems that are often found on embankments are soil instability and low soil bearing capacity. To prevent landslides, consideration of the embankment stability and ways to improvement it is essential. This study investigates the use of quicklime as a stabilising material and a number of fill layers on the safety factor of the slope of the embankment in order to find the optimal combination. The type failure or deformation and extreme stresses that occurred in these soil embankments was also studied. Laboratory testing is used to determine soil properties. Three types of soil were analysed; subgrade, fill from original soil and fill from soil mixed with 15% quicklime. This quicklime mix was used as a 40 cm reinforcement layer on the slope surface of the embankment.

1 Introduction

Civil engineering structures are highly dependent on the soil as soil is used as a building material and as a foundation for buildings. The first step in any construction is to find out whether the soil at the construction site meets the planning requirements with regard to stability, deformation and density [1].

The construction of highways, airports and other large construction works especially in areas with uneven contours often requires excavation and construction of embankments to prepare the site

In constructing an embankment for a road fill material is usually sourced from a quarry and transported to the project site. The soil used as fill is usually excavated soil that consists of particles which enable it to exhibit sand-like properties and cannot provide structure [2].

The process of constructing an embankment takes considerable time for the transportation of the fill to the site and its compaction. This is impossible to achieve in one construction phase, so it needs to be done in stages.

The safety factor for the slope of the embankment needs to be determined. Landslides of soil slopes can be very dangerous even leading to the collapse of the road, making it unusable.

The soil used for embankment consists of grains of soil and pores that contain water and air. It consists of solid mineral aggregates which are not cemented (chemically bound) to each other and solid particles of decaying organic matter along with liquids and gases which fill the empty space between these solid particles [3]. Embankment soil contains clay which presents some problems that must be faced by a civil engineer when the location has poor soil characteristics needing some improvements and increase its bearing capacity [2].

Much research has been done on using fly ash as a stabilizer. Low calcium fly ash is a waste material that is widely used in Indonesia along with silica and alumina [4]. However, quicklime is also a suitable choice as a clay stabilizer and it is easily available at a reasonable cost. In this study, the stabilizer used was quicklime.

Compaction carried out in the laboratory is a way of modelling compaction carried out in the field. This study was conducted on a model embankment slope using empirical methods for analysis [5]. The test parameter was the safety factor of the slope. The number of layers in the construction of the embankment was varied and a stabilising layer of quicklime mixed soil applied to the outside of the slope to investigate their impacts on the safety factor.

2 Geological investigation

The research location was the road in the Faculty of Engineering, Andalas University, Padang. The tests were conducted at the Soil Mechanics Laboratory, Department of Civil Engineering, Faculty of Engineering, Andalas University.

2.1. Physical properties of subgrade and embankment

The results of the test of the physical properties of subgrade can be seen in Table 1. The properties of subgrade, from the sieve analysis results show that 87.2% of the soil passed through a No. 200 sieve. From the Atterbergh limits test the liquid limit value is obtained 50.6% and Plasticity Index 12.0%. Plot results

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showed that the soil could be classified in the MH (Elastic silt) group according to the Unified Soil Classification System (USCS). It was a mix of fine sandy and silty soils, elastic silts, organic silts, clay and silts clay [3]. From Table 1 the properties of embankment show that 14.8% of the fill soil passed through a No. 200 sieve or > 50% was retained in the No. 200 sieve and > 50% of this coarse fraction passed through a No. 4 sieve, the soil was classified as GC (Clayey Gravel) according to the USCS classification system [1].

Table 1. Physical properties of subgrade and embankment

Test	Result	
	Sub grade	Embankment
Water Content, w (%)	61.06	50,16
Specific gravity, G_s	2.61	2,672
Liquid Limit, LL (%)	50.56	44,407
Plastic Limit, PL (%)	38.35	30,738
Plasticity Index, PI (%)	12.03	13,669
Percent passing through the No. 200 sieve, (%)	87.23	14,8
Unit weight in the field, γ (g/cm^2)	1.24	1,709
Cohesion, c (gr/cm^2)	0.11	0,009
Angle of internal friction, ϕ (^{o})	17.53	29,31

2.2 Physical characteristics of embankment soil mixed with stabiliser

Table 2. Physical properties soil with stabilizer

Test	Result
Water Content, w (%)	37,805
Unit weight in the laboratory, γ (g/cm^2)	1,637
Cohesion, c (gr/cm^2)	0,234
Angle of internal friction, ϕ (^{o})	40,1

2.3 Mechanical properties test of subgrade

An Unconfined Compressive Strength Test (UCST), gave a q_u of 0.43 kg/cm^2 for a original sample, while the q_u of a remolded sample was 0.37 kg/cm^2. This gave a soil sensitivity value (ST) of 1.15 which means the soil tested is slightly sensitive [3].

2.4 Mechanical properties of embankment soil

Table 3. Vane shear test results data for embankment soil

Maximum torque reading (kg.m)	s
Vane diametres, d (m)	0.1
Vane height, h (m)	0.175
Undrained shear resistance (kg/m^2)	2444.62

Soil shear resistance was obtained using a Vane Shear Test and gave a shear stress of 2444.62 kg/m^2 for undisturbed soil.

Table 4. Compaction test data of embankment soil

Maximum torque reading (kg.m)	s
Optimum moisture content, w_{opt} (%)	37,805
Maximum dry unit weight, γ_{dry} (gr/cm^3)	1,231

Compaction test results indicated that the optimal water content was 37.8% at maximum dry unit weight with a dry content of 1.23 gr /cm^3. This optimal water content was used as a benchmark for water content for the direct shear test and the UCST. The results of the UCST were performed on each variation of the mixture, the q_u value was 0.31 kg/cm^2.

2.5 Mechanical properties of embankment soil mixed with stabilizer

q_u values were obtained on embankment soil mixed with 15% quick lime as a stabilizer using the UCST of the soil, After the soil was mixed it was cured for five days before testing. The q_u of the mixed fill was 0.77 kg / cm^2.

3 Results and discussion

3.1 Input Material

3.1.1 Subgrade soil

From the results of the sand cone test in the field, unsaturated soil unit weight (γ_{unsat}) of the subgrade was 1.24 gr/cm^3 or 12.17 kN/m^3. The soil unit weight below the phreatic level (γ_{sat}) or saturated unit weight was 14,17 kN/m^3 from a unit weight test. The horizontal permeability (k_x) and vertical permeability (k_y) was 0.001 m/day, indicating the soil was a silty clay type from the range of probability coefficient values. Young's Modulus (E_{ref}) was 350 kN/m^2 as obtained from a table of modulus values for soft elastic clays. Poison's Ratio (ν) was 0.35 (obtained from the Poison Ratio table) [7]. The value for cohesion from the Direct Shear test was 0.11 kg/cm^2 or 11.01 kN/m^2 and the friction angle (ϕ) was 17.53^o.

3.1.2 Embankment soil

From the results of the sand cone test in the field, γ_{unsat} of the subgrade was 1.64 gr/cm^3 or 16.1 kN/ m^3. The value for γ_{sat} was 20 kN/m^3. The horizontal permeability and vertical permeability was 0.001 m/day. The value of E_{ref} was 25000 kN/m^2 as obtained from a table of modulus values for medium sandy soils. Poison's Ratio (ν) was 0.3 as obtained from the Poison Ratio table for mediun sandy soil. The value for cohesion (c) from Direct Shear test was 0.009 kg /cm^2 or 0,918 kN/m^2 and internal friction angle (ϕ) was 29.31^o.

3.1.3 Embankment soil stabilised with quicklime

The value of γ_{unsat} from the field test was 1.747 gr/cm^3 or 17.133 kN/m^3 and the value of γ_{sat} was 20 kN/m^3. The value of k_x and k_y were 0.01 m/day respectively, indicating a solid sand soil type according to the range of values from the permeability coefficient. The value of E_{ref} for medium sandy soil modulus was 25000 kN/m^2. Poison's Ratio (ν) was around 0.3. The cohesion value

(c) was 0.234 kg/cm^2 or 22.941 kN/m^2 and internal friction angle (ϕ) was 40.1°.

Table 5. Soil parameters data

Paramaters	Sub grade	Embank ment	Using Stabili ser
Soil unit weight above phreatic level, γ_{unsat}, (kN/m^3)	12.17	16.06	17.13
Soil unit weight below phreatic level, γ_{sat} (kN/m^3)	14.17	20	20
Permebilitas horizontal, k_x (m/day)	0.001	0.001	0.01
Vertical permeability, k_v (m/day)	0.001	0.001	0.01
Young's Modulus, E_{ref} (kN/m^2)	350	25	25
Poisson's ratio, ν	0.35	0.3	0.3
Cohesion, c (kN/m^2)	11.01	0.92	22.94
Friction angle, ϕ' (°)	17.53	29.31	40.1
Dilatancy angle, ψ (°)	0	0	0

The slope cross-section of the model was based on data obtained from field measurements using the cartesian coordinate system having a height of 2.4 m and width 2.8 m

3.2 Analysis

3.2.1 Safety factor

The stability of the slope of the embankment is indicated by the safety factor. Comparing safety factors allows us to determine the relative stability of each embankment slope and the influence of the quicklime mix layer. From this, a comparison table of safety factor Fig.s for each layer of embankment could be constructed.

Table 6. Comparison safety factor of each embankment stage

Number of layer	SF days, 5 days construction		SF cha nge	Percentage of SF Change (%)
	Origi nal	Stabili zation		
1	1.15	1.9	0.75	65
2	0.99	1.82	0.82	83
3	1.01	1.84	0.83	82
4	0.99	1.85	0.86	86

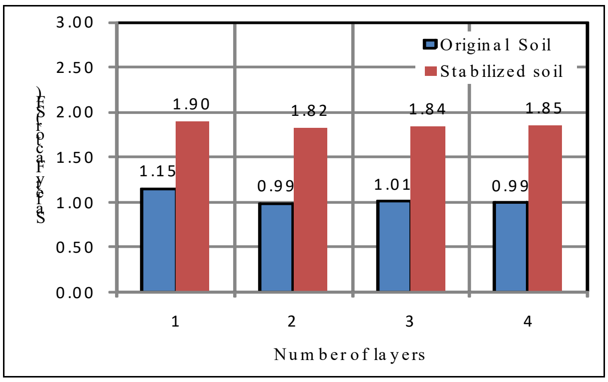

Fig. 1. Cmparison Safety Factor for each layer of embankment

From the Fig. and table above it can be seen that the largest safety factor for natural soil fill was for an embankment consisting of a single layer at 1.15. When a 15% quicklime mix was applied to the embankment slope surface the largest safety factor was also for a single layer and was 1.90. The lowest safety factor for natural soil fill was 0.99 for two layers and when using the quicklime mix 1.82 for two layers.

The safety factors using original soil without the quicklime mix were all below the standard 1.25 indicating that an embankment constructed from this material could be at risk of instability. However, when an embankment was covered with a 40 cm layer of quicklime mix the safety factor increased to above the standard indicating a reduced risk. The increase in safety factor from this quicklime mix layer was more marked when more than one layer of fill was used.

3.2.2 Analysis of extreme displacement

Table 7. Comparison of extreme displacement values for each embankment stage

Number of layer	Extreme displacement		Displac ement change	Percentage of Change (%)
	Origi nal	Stabili zation		
1	4.2	0.26	-3.94	-94
2	1.4	0.33	-1.06	-76
3	2.06	0.46	-1.06	-78
4	2.29	1.45	-.0.84	-37

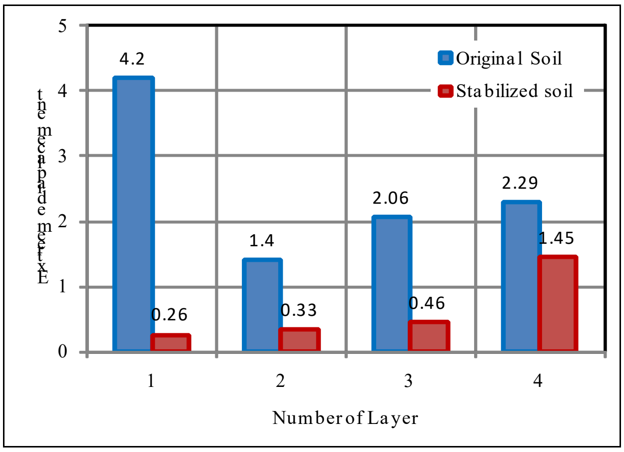

Fig. 2. Extreme displacement for layer variations

From the table and graph above, it was found that the highest extreme displacement value for the natural embankment was for one layer at 4.2 m and the largest extreme displacement value for embankments protected by the quicklime mix was for four layers at 1.45 m.

The lowest extreme displacement value for the natural soil embankment was for two layers of fill at 1.4 m and the smallest for those using quicklime mix was for one layer at 0.26 m. The addition of a 40 cm quicklime-mix layer on the embankment slope decreased the extreme displacement by 37% - 94%.

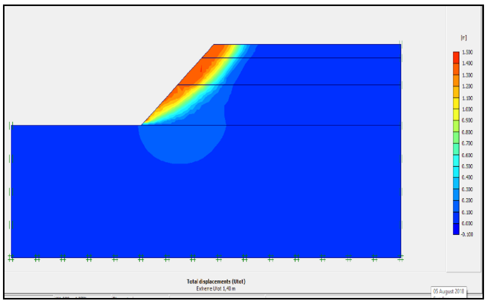

Fig. 3. Extreem displacement for two-layer embankment

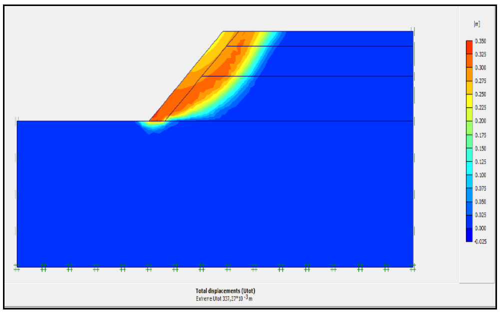

Fig. 4. Extreem displacement for two-layer embankment using quicklime stabilizer

3.2.3 Effective stress analysis

Table 8. Comparison of effective stress value for each embankment stage

Number of layer	Effective stresses displacement		Eff. Stress Change	Percentage of Change in Eff. Stress (%)
	Origi nal	Stabili zation		
1	-33.28	-33.08	0.2	-0.6
2	-33.05	-32.92	0.13	-0.39
3	-33.08	-32.96	0.12	-0.36
4	-33.09	-32.92	0.17	-0.51

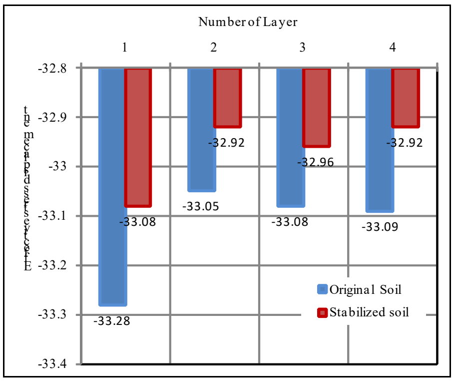

Fig. 5. Effective Stress values for embankments consisting of different numbers of layers with and without a quicklime-mix stabilising layer.

4 Conclusions

1. The safety factor for the initial conditions at the location was below the standard (1.25) so that the slope can be said to be unstable.
2. The largest safety factor value for layered fill of natural soil was 1.15 for a single layer.
3. The largest safety factor for layered fill with lime mix was 1.9 for a single layer
4. A 40 cm layer of 15% quicklime mixed with original soil on the slope of the embankment increases the stability of the slope as shown by the increase in the safety factor. This increase is most marked in embankments than were constructed of several layers where the safety factor increased by > 85%.
5. The embankment with the lowest extreme displacement value was the one layered embankment with the slope stabilised with a 40 cm layer quicklime mix. The extreme displacement value for this embankment was 0.26.
6. Addition of a 40 cm layer made from 15% quicklime mixed with original soil is effective in reducing extreme displacement and increasing the stability factor to above the standard value for slope stability.

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