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Embankment Stabilisation Using Lime and Ash: An Option for Safer Slopes

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ABSTRACT

One of the low-cost techniques of preventing the slope failure is to stabilise the freshly built slope using lime piles or lime columns. This may involve some extra costs on the project but in the long run maintenance cost may be reduced significantly. A new technique of constructing a stable embankment is introduced using strips of stabilised layers. A combination of laboratory tests on control specimens and suitable design procedures allow the effectiveness of the stabilised embankment to be assessed.

INTRODUCTION

Embankment slips and slope failures form major problems on many highways and new housing schemes in Malaysia. The recent incident of slope failure in Johor at a housing estate in Tampoi revealed that the slope progressively lost its stability with time. Compacting soil in an embankment can create positive pore pressures but in some cases negative pore pressures are generated especially if a soil is overconsolidated. Failure often occurs because of the increase in water content due to suction pressures within the embankment. Perry [1] reported that a total of over 17 km of embankment slopes and 5.5 km of cut slopes in the UK have significant incidence of shallow slope failure. Besides that he had also estimated at least three times as many failures would occur in the future.

Several slope failure modes often exist and the common ones being rotational, translational and compound, with compound slips being a cross between the first two. If the local soil is unsuitable but must be used for economic reasons, a number of design options are proposed, namely:

a) re-grading the slope to a more suitable angle
b) strengthening the slope/embankment by stabilisation techniques

The first option requires more land area, which may not always be possible or could be costly, and more fill material would be consumed, as the total volume would be increased.

On the other hand the second option requires the utilisation of a stabilising agent that is mixed with the soil in place as columns of stabilised soil or strips of stabilised layers as shown in Figure 1. Stabilised columns are better suited for the stabilisation of an existing embankment since such embankment would require to be constructed unstabilised prior to the positioning of columns.

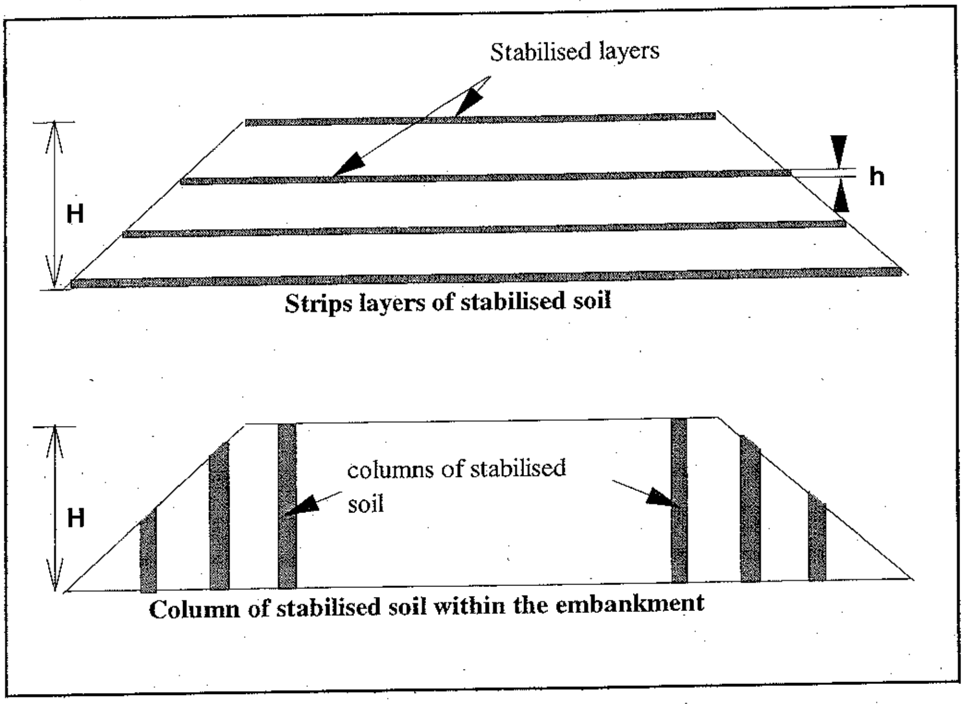


Figure 1 Types of soil stabilisations within the embankment.

In the case of Tampoi slope failure, reported in Berita Harian 24th July 1998, it shows a clear indication of a progressive failure due to the increase in pore water pressure (Figure 2). The embankment was constructed from lateritic soil originated from decomposed granitic rock. This type of soil has been reported to exhibit a 'quasi preconsolidation pressure when loaded in the oedometer, in a manner similar to an overconsolidated soil [2]. Overconsolidated soils usually create suction, after compaction, hence provides sufficient stability only in the short term.

As water permeated into the embankment through cracks or diffusion, it will increase the water content within the embankment. The increase in the water content will reduce the suction pressures and eventually increases the pore water pressure. Such increment of pore water pressure led to the reduction of the effective stress, thus lower the factor of safety against shear failure.

As reported the slope has failed at almost half the width of the embankment. In addition to that, a suggestion was also tabled whereby the embankment was to be reconstructed using the existing materials. This can be done by stabilising the existing material with the addition of lime or lime-ash to increase the shear strength of the material. The embankment can then be reconstructed in a usual way but with inclusion of strips of stabilised layers as shown in Figure 5.

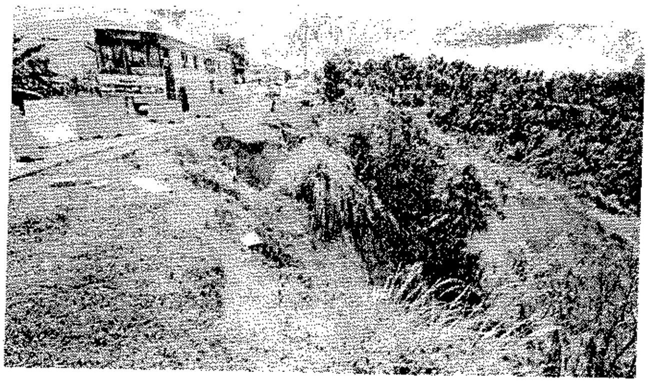
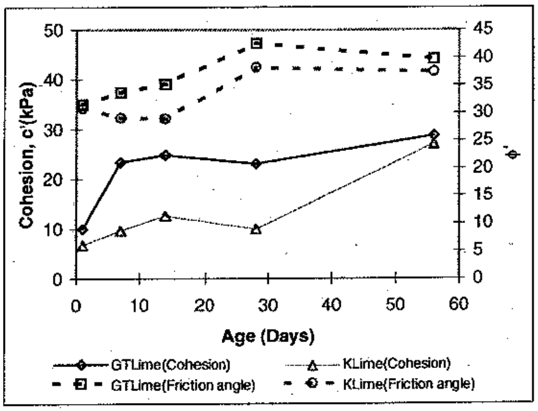


Figure 2a Initial stage of the slope failure in December 1997 (Berita Harian, Thursday, 23 July 1998).

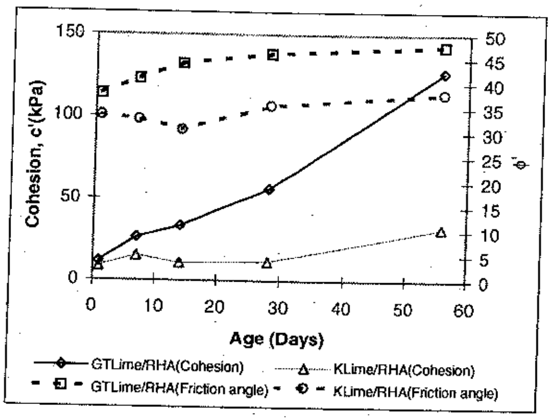
Figure 2b The condition of the slope after seven month (Berita Harian, Thursday,23 July 1998.

The effect of pozzolanic reactions between lime and clay produces cementitious products binding the soil particles together and thus increasing the shear strength of the soil with time ([3], [4], and [5]). Either hydrated lime, $(Ca(OH)_2$ or quicklime, CaO can be used for stabilisation. Inactive additives, such as ash, act as a filler to increase the solids content, thereby, reducing the ratio of water to solids (i.e., the water content) thus modifying the soil. Ash can also be used as a replacement for soil that contains insufficient clay fraction to react with lime. Pulverised fuel ash(PFA) and rice husk ash(RHA) contains high percentage of silicate and aluminate, are example of pozzolanic material that can be used for such purpose. The range of types of soil that can be treated with lime can therefore be extended.

The effect of lime and lime-ash on the increase in strength of stabilised soil is time dependants. This phenomenon can be observed from Figure 3 and 4. Figure 3 shows the effect of stabilisation with lime and lime-RHA on the compressive strength of cohesive clay at various ages. The compressive strength increases with addition of lime-RHA due to modification of the soil characteristics and pozzolanic reactions between lime, clay and ash. The pozzolanic reaction also increases the strength of the stabilised soil with age. RHA, which acts as a clay replacement in Grey Till reacts effectively with lime to produce a secondary cementitious product thus, improved further its shear strength (Figure 3b). For soil with high clay fraction, such as Kaolin, addition of ash may only modify the soil by increasing the mass of solid, thus reducing the water content of the soil.



(a)



(b)

Figure 3 Variation in effective cohesion and angle of shearing resistance with time of soaked (a) lime and (b) lime-RHA stabilised Grey Till and Kaolin.

The rate of increase in strength also influenced by the surrounding temperature. Tropical countries with temperature above 30°C could benefit from lime stabilisation, as more than 200% increase in compressive strength was achieved in 28days, (Figure 4b).

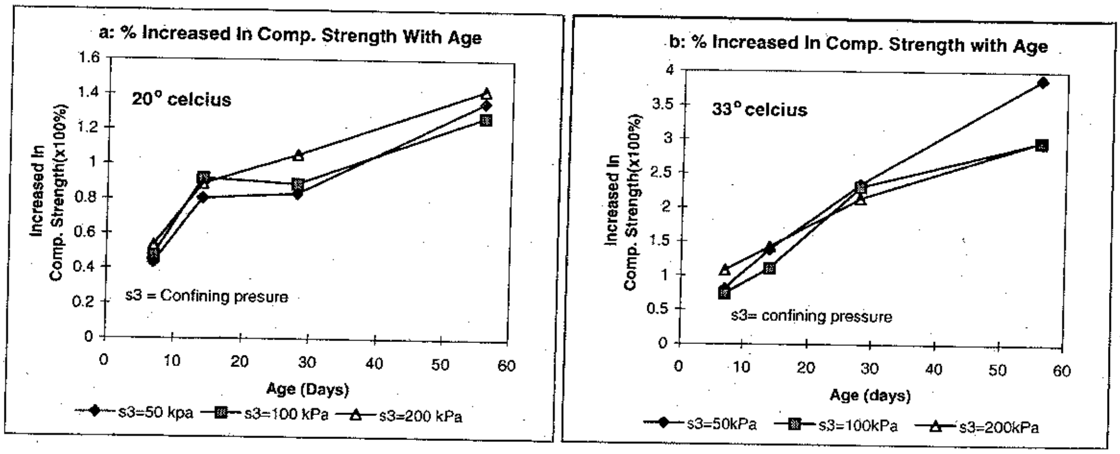


Figure 4 Effect of lime and age on the max ($\sigma_1 - \sigma_3$) of stabilised Kaolin Clay.

DESIGN OF STABILISED SOIL EMBANKMENT

As a preliminary example let us consider an embankment for a dual two lanes motorway. In accordance with the Department of Transport [6] specification for a *Dual 2 Lane Motorway (type D2M),* the overall top width is 28.2 m which takes into account the verge, hard shoulder, carriageway and central reservation dimensions. A surcharge pressure of 15 kPa is added to account for traffic and road surfacing. The required height of the embankment is assumed to be 5 m.

Stabilised embankment

The strip of stabilised layer is uniformly spread over the whole embankment in 250 mm thick layers. The unstabilised soil is compacted to a uniform 1m to 1.5 m thick per layer requiring three to four placements depending on the number of stabilised layers for the required height of embankment of 5 m. Three stabilised embankments were analysed (Figure 5).

The first (type 1) had four layers of unstabilised soil and four layers of stabilised soil above ground level. The bottom of the lower layer of stabilised soil is at ground level to reduce the ingress of ground water and to strengthen the toe of the slope. The second (type 2), has three layers of unstabilised soil and two layers of stabilised soil with 500 mm stabilised capping to improve the bearing capacity of the foundation. The third design is the same as the type 2 but with an extra layer within the embankment. The stabilised embankments are illustrated in Figure 5.

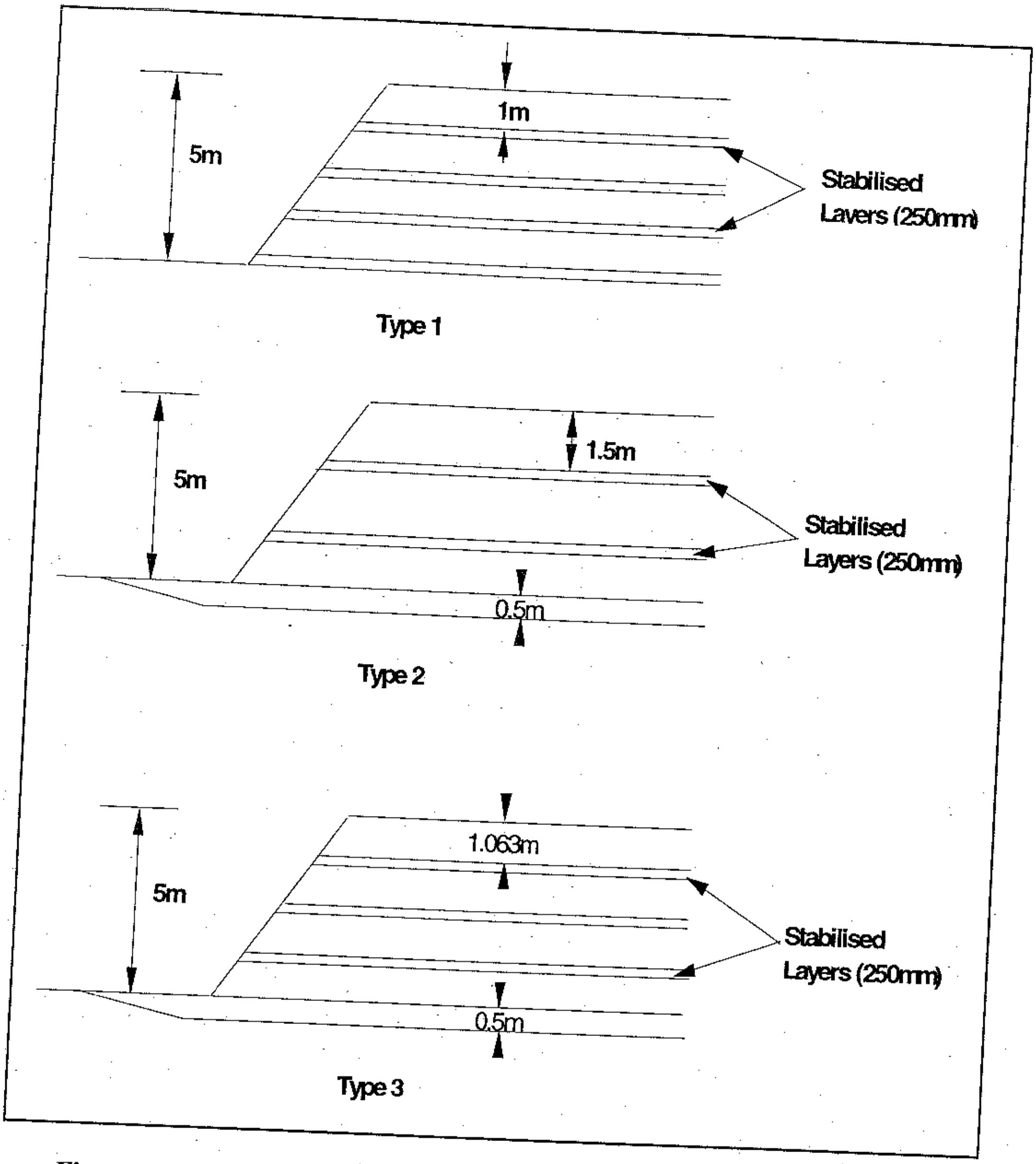


Figure 5 Design of stabilised embankment with strips of stabilised soil.

Analysis of stabilised embankment

Analysis for case of $\phi_u = 0$

The critical factor in the stability of an embankment is the shear strength of the soil in both the short and long term conditions. Analysis in terms of total stress covers the case of a fully saturated soil under undrained conditions. The destabilising moment will not change for a given failure mechanism, if part of the embankment is stabilised since it is a function of the weight of the failed mass and the geometry of the slope. The stabilised soil will have similar density to that of the unstabilised soil. The stabilising moment will increase by a factor related to the increase in shear strength along the failure surface.

The ratio of the improved factor of safety to that for the unstabilised soil, F, is given by

$$F = [c_u(L_a - T_s) + c_{us} T_s] / c_u L_a \quad (1)$$

where c_u is the undrained shear strength of the unstabilised soil, c_{us} the strength of the stabilised soil, L_a the length of the failure arc and T_s the length of the failure arc passing through the stabilised soil.

Equation 1 can be rewritten as

$$F = [1 + (c_{us} / c_u - 1)(T_s / L_a)] \quad (2)$$

(T_s / L_a) is approximately equal to the number of layers of stabilised soil times the thickness of one layer divided by the height of the embankment. Note that the failure surface is within the embankment and outcrops on the surface of the embankment.

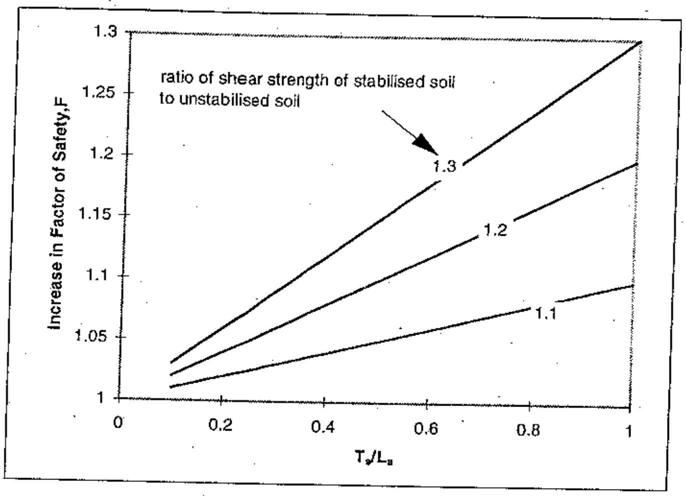


Figure 6 The increase in factor of safety of the side slopes of an embankment if using horizontal stabilised layers of soil within the embankment.

Figure 6 shows the increase in factor of safety in terms of the number of stabilised layers, the thickness of each layer, the height of the embankment and the ratio of the shear strength of the stabilised soil to that of the unstabilised soil. The factor of safety of an embankment built with unstabilised soil could be found from either Taylor's chart or a slope stability analysis.

Effective stress analysis

The effective stress analysis of slope stability is normally solved using the method of slices. The OASYS geotechnical package 'Slope' was used to analyse the minimum factor of safety for an embankment.

There are a number of solutions of calculating the stability, in this design the Fellenius (Swedish) method using effective shear strength parameters was used, where

$$FOS = \frac{c' L_a + \tan\phi' \, \Sigma(W\cos\alpha - ul)}{\Sigma W \sin\alpha} \qquad (3)$$

where L_a is the length of slip arc, W is the weight of slice, u is the pore pressure, l is the length of the slice base and α is the angle of inclination of the base to the horizontal for any slice. c' and ϕ' were based on the effective shear strength parameters of soaked samples.

RESULTS OF SLOPE STABILITY ANALYSIS

This analysis was based on the assumption that the underlying soils were sufficiently strong to support the embankment. If such cases were non-prevalent, then, the foundation soils would have to be improved by deep mixing in a similar manner to that used to strengthen the soil for shallow foundation. Results from the total stress and effective stress analysis (Fellenius method) using OASYS slope stability program are discussed.

Based on the total stress analysis, as the ratio of stabilised and unstabilised area within a slope increases, the improvement in the factor of safe increases. On the other hand as the ratio of shear strength between the stabilised and unstabilised soil increases, the improvement in the factor of safety also increases. This means that double improvement can be achieved by having larger stabilised area and allowing enough time for the stabilised soil to gain sufficient strength.

Based on OASYS slope stability programme and the shear strength of the stabilised and unstabilised soils, strengthening of the embankment material with the addition of lime and PFA increases the factor of safety of the slope. The factor of safety also increases as the stabilised soil increases in strength with age. From the three designs of stabilised embankments, it can be observed that the factor of safety can be significantly improved with stabilised layers within the embankment. The results of the slope stability are presented in Table 1.

Table 1 Results of slope stability based on drained analyses using OASYS Program.

Soil Description	Embankment Types	Slope Angle (vert : horiz.)	Minimum F.O.S	Weight Of Soil Mobilised (kN)	Radius Of Slip (m)	Coordinates x (m)	Coordinates y (m)
Unstabilised Grey Till		3 : 1	1.115	160	8	6	2
		1 : 1	1.717	277	10	9	5
Grey Till with Lime/PFA, (7 days)	1	3 : 1	1.184	159	8	6	2
	1	1 : 1	1.833	275	10	9	5
	2	3 : 1	1.153	160	8	6	2
	2	1 : 1	1.767	275	10	9	5
	3	3 : 1	1.175	159	8	6	2
Grey Till with Lime/PFA, (14 days)	1	3 : 1	1.585	223	7	8	2
	1	1 : 1	2.235	548	7	11	1
	2	3 : 1	1.361	160	8	6	2
	2	1 : 1	1.997	275	10	9	5
	3	3 : 1	1.492	159	8	6	2

Stabilisation of unsuitable soils for an embankment is an effective and simple measure that could easily be applied to save land, money and raw materials in modern construction. However, where the natural soil is of low strength the foundations must also be treated, possibly by deep stabilisation with column of stabilised soil.

CONCLUSIONS

Embankment constructed from compacted overconsolidated soils can cause slope failure with ingress of water. Inclusion of lime stabilised layers within the embankment provides reinforcement to the slope against shear failure. The lime stabilised layers increases in shear strength with time due to pozzolanic reactions. The cementing agent produced also provides additional stability to the embankment under long term effects. This technique encourages the use of readily available materials simply by modification and improving its strength characteristics, which reduces the need for imported aggregates. As the number of stabilised layers within the embankment and the age increases the factor of safety of the slope increases.

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