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An Investigation of an Embankment Failure in Soft Clay

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AN INVESTIGATION OF AN EMBANKMENT FAILURE IN SOFT CLAY

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ABSTRACT

A number of embankment founded on soft clays have become unstable during construction of a major highway project in Malaysia. One of the embankment was back analysed based on its geometry before the failure. Measured in-situ vane shear strength was used in total stress analysis to determine the factor of safety at failure. Performance of the soft clay subsoil with regards to vertical and horizontal displacements, and piezometric response, when the failure was imminent is also described.

KEYWORDS

Embankment, failure, soft clay.

INTRODUCTION

Extensive deposits of low strength and compressible soils are found worldwide and the difficulties of supporting load on such foundations have been widely reported. In Malaysia, Quaternary erosion accentuated by climatic and sea level changes has produced widespread and thick deposit of soft clays in the coastal areas and major river valleys. Roads founded on the soft deposits often have to be raised on high embankments, giving rise to problem of instability during construction, and long term and persistent settlement subsequently.

This paper presents the finding of back analysis of an embankment failure on soft ground.

SITE AND HISTORY OF THE FAILED EMBANKMENT

The embankment was part of a recently constructed highway in north of Peninsular Malaysia.

Figure 1 shows plan, profile and instrumentation of the embankment. The instruments installed include settlement markers, piezometers and inclinometers.

The embankment was to be built to about 3.2 m high above original ground level, inclusive of a 1.5 m surcharge. Site clearing was commenced in early January 1992 followed by placement of geotextile separator layer with 400 mm thick sand blanket. Earth filling was commenced in early March 1992 and was completed to final level by midst July 1992 (i.e. on Day 140). Five days later the embankment collapse without prior sighting of any tension crack.

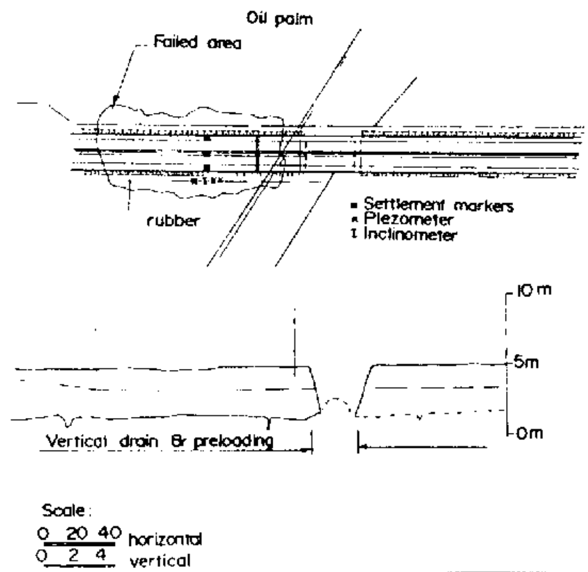

Fig. 1 Plan and profile of embankment

SOIL PROFILES AND PROPERTIES

Figure 2 show subsoil profile of the embankment as obtained from the site investigation carried out during the design stage. The subsoil comprised of soft silty clay layer of about 10 m thick, underlain by layer of loose to medium dense sand. The liquid limits of the soft clay vary from 90 % - 100 % with natural water content close to the liquid limit, and plasticity indeces in the range of 35 % - 70 %. Undrained strength obtained from the vane test showed a general trend of strength increase below a weathered upper crust, with Su/σ c ratio in the range of 0.3 - 0.4. The clays are shown to be moderately sensitive, with sensitivity ratios in the range of 3 - 9. Results obtained from the oedometer tests indicated that the clays are slightly over consolidated but highly compressible. The apparent over consolidation of the clay is believed to be due to that of the weathered crust. The values of Cv are typically low, ranging from 1 - 10 m^2/yr.

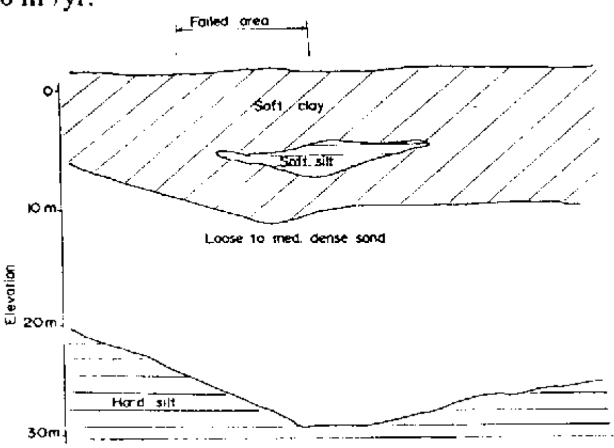

Fig. 2 Subsoil profile of the embankment

INVESTIGATION AND ANALYSIS OF THE FAILURE

Soon after the failure attempt was made to obtain sufficient geotechnical data of the distressed embankment to enable analysis of the failure to be carried out. These were in the form of detailed survey of the collapse section and additional soil strength measurements.
Figure 3 shows cross sections of the embankment surveyed soon after the failure. As shown the failure of the embankment was characterised by wide open crack through the embankment fill with a significant heave at the embankment toe. This indicated that the mode of the embankment failure has been that of a rotational slip.

Table 1 summarises the properties of the fill material. The fill was of red sandy clay with greater than 60 % of the material in the silt-clay range. The plasticity indeces were low, about 17 %. Shear strength parameter were c' = 25 kPa, and ø' = 23°.

Post failure in situ vane shear tests were also carried for the subsoil beneath centre of the embankment.

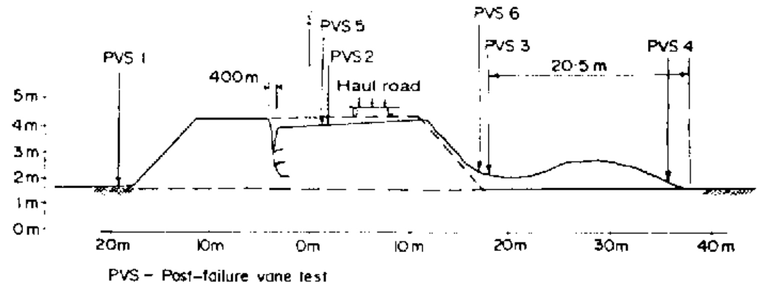

Fig. 3 Cross-section of the embankment

Table 1 : Description and Properties of Embankment Fill

Soil Description	:	Reddish sandy Clay
Atterberg's Limit	:	WL = 42 % WP = 25 % PI = 17 %
Sieve Analysis	:	Gravel 8 % Sand 23 % Silt and Clay 69 %
Max. Dry Density	:	2.07 Mg/m^3 OMC = 10.2 %
Strength Parameters (CIU)	:	c' = 25 kPa ø' = 23

It was found that there appears to be no significant gain in shear strength after the construction. It may therefore be concluded that the failure of the embankment occured essentially under undrained conditions. A total stress analysis can therefore be applied (Wolski et. al., 1989). In this case it is used for calculating the factor of safety of the embankment at failure. The properties of the fill are accounted for using values as summarised in Table 1. Neglect of the embankment strength as suggested by Bjerrum (1973) would be too conservative. For the subsoil, the average vane strengths were used as input parameter. These were corrected with Bjerrum's (1973) correction factors for the effect of anisotropy and shear rate. The corrected average vane strength was found to lie close to the lower bound of the field data.

The minimum factor of safety of the embankment at failure was found to equal to 1.03 (i.e. essentially unity). This indicated that given representative strength parameters have been obtained for both fill and subsoil, the total stress analysis is sufficient for prediction of short term failure of embankment on soft clays. It has been suggested that the total stress analysis offers an unambigous way of estimating stability (Pilot et. al. 1972; Brand, 1983; Wolski et. al. 1989).

OBSERVED BEHAVIOUR OF EMBANKMENT ON THE ONSET OF FAILURE

Figure 4 shows construction history and settlement of the embankment. As shown there has been a dramatic increase in settlement rate just prior to the failure.

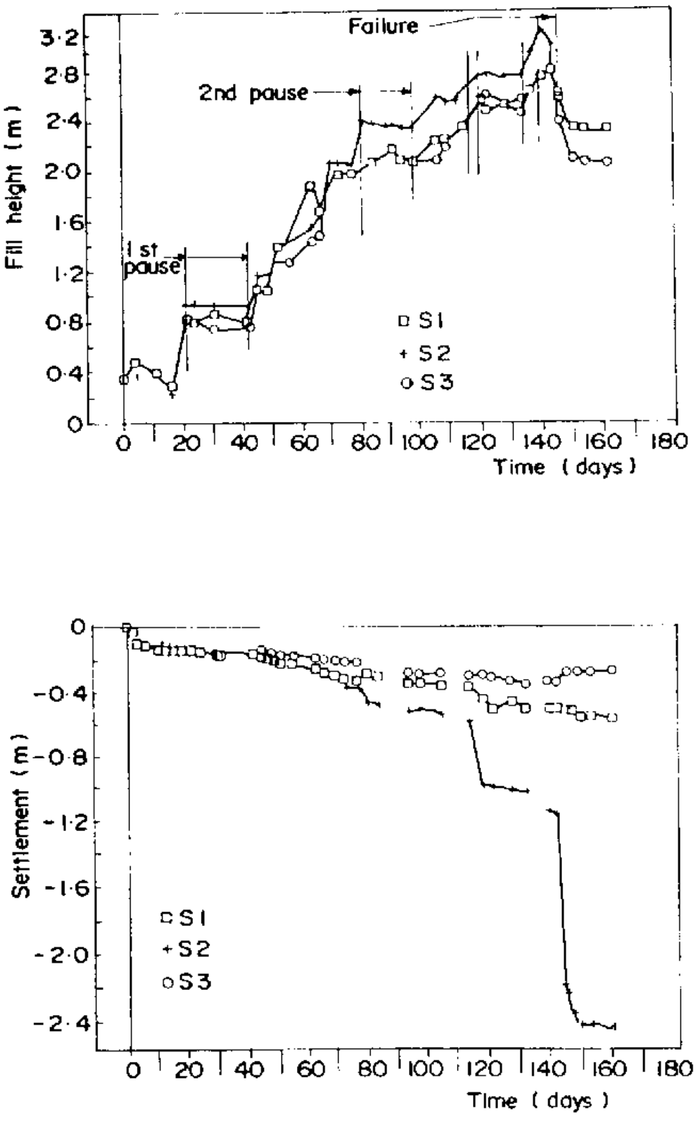

Fig. 4 Construction history and settlement of the embankment

Figure 5 shows plot of maximum lateral displacement (Δ y) versus centreline settlement (Δ S) of the embankment. It is of interest to note that when the fill was low, i.e. for fill thickness of less than 1 m, the Δ y / Δ S relation is small with Δ y ≅ 0.29 Δ S. But on the onset of the failure, Δ y increases significantly; from approximately equal to Δ S to almost 3 times Δ S.

The variation of excess pore water pressure (Δ u) with applied vertical stress, Δ σ_v is shown in Fig. 6.

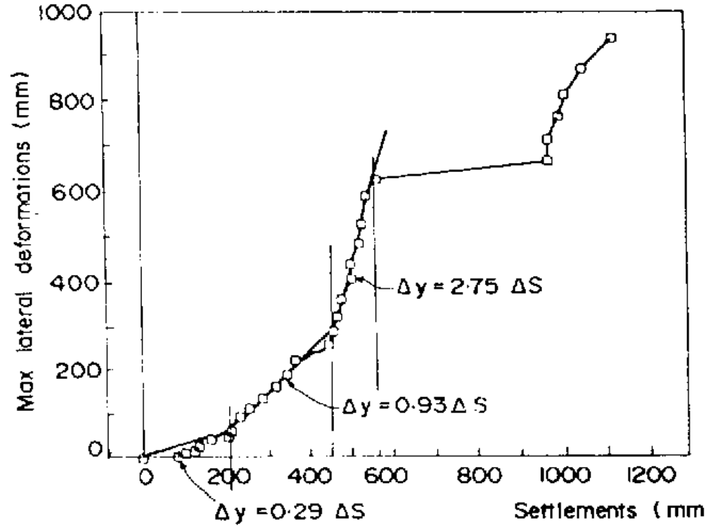

Fig. 5 Max lateral deformations - centreline settlements of the embankment

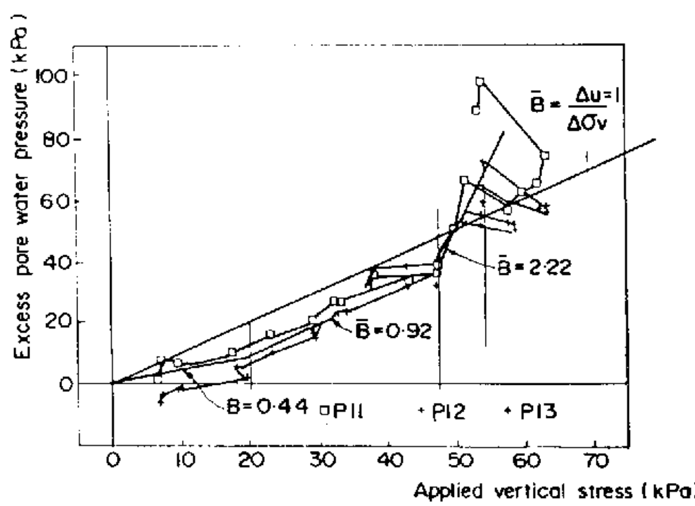

Fig. 6 Pore pressure ratio (B=Δu/dσv) of the embankment

For low fill of less than 1 m, the piezometric response of the clay foundation is low; Δ u = 0.44 Δ σ_v V. The increase in the pore water pressure then becomes approximately equals to the applied vertical stress. However on the onset of failure, the piezometric response is large; Δ u >> Δ σ_v. This is probably due to the following scenario. Prior to collapse of the embankment, local failures may have been initiated in the subsoil beneath the embankment. This results in strain softening hence an increase in total horizontal stresses and pore water pressures. Therefore prior to the failure, one should expect Δ u > Δ σ_v, and this is shown in the pore pressure plot in Fig. 6.

CONCLUSION

Provided adequate informations have been obtained on the strengths of both fill and soft clays, the total stress approach can be used for design of embankment on soft ground. Failure of the embankment occured essentially at factor of safety equals unity based on stability analysis with vane readings corrected with Bjerrum's factor.

For case of compacted cohesive fill, the strength properties of the fill should be accounted for in the stability analysis. The corrected average vane strengths of the soft clay generally lies close to the lower bound of the field data.

Failure of the embankment is preceeded by soft response of the foundation with regards to generation of excess pore water pressures, settlement and lateral deformations.

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