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# Performance of embankments on Bombay marine clay

## Fonctionnement des remblais sur l'argile marine de Bombay

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**SYNOPSIS** According to Bjerrum (1972), the field vane shear strength values need correction depending on the plasticity of soft clays. Ladd and Foott (1974) suggested SHANSEP method to obtain true value of shear strength from undisturbed samples. There is a difference of opinions regarding applicability of stability analyses based on total or effective stresses. Two test embankments, with instrumentation, one at Wadala and another at Bassien bridge site are constructed upto failure and their stability is analysed to understand the mobilized shear strength characteristics of Bombay marine clay. A stable section of approach road embankment with instrumentation to Bassien bridge is also analysed for stability by both the methods. It is observed that for Bombay marine clay :

- i) Bjerrum's correction needs not be applied to the field vane shear strength values.
- ii) The difference in the shear strength of the undisturbed sample and that of true sample is negligible and hence SHANSEP method needs not be applied.
- iii) Both the methods of stability analysis correctly represent the performance of embankments constructed on Bombay marine clay.

### INTRODUCTION

Marine clays that form the mud flats around Bombay are geologically of recent origin and consist of two main strata. The upper stratum is overconsolidated weathered crust 1.5 m thick. Generally, the lowest tide level separates the two layers. Lower layer is a soft clay with thickness ranging from 4 to 16 m. The shear strength is least at a level just below the contact of these two layers and increases with depth. These are normally consolidated insensitive clays,  $\frac{C_u}{\sigma}$  ranging from 0.20 to 0.25 and are classified as silty clays.

Evaluation of stability of embankments on soft clay foundation is still empirical and of indeterminate accuracy as the shear strength mobilised at failure may not be represented by shear strength values determined by field vane shear tests. The full scale test embankments erected on soft normally consolidated clay deposits and brought to failure have indicated that insitu vane shear tests largely overestimate the shear strength of soil (Bjerrum 1972, Table I). Bjerrum (1972) has suggested correction to be applied to the field vane shear strength so as to account for effect of anisotropy and strain rate on undrained strength. Ladd and Foott (1974) proposed SHANSEP method for obtaining insitu undrained shear strength.

In view of the above limitations in applying total stress analysis for stability problems on soft clay foundation, Janbu (1977) proposed adoption of effective stress analysis. Ladd (1971) expressed the difficulties in correctly predicting the excess pore water pres-

ssures developed due to embankment stresses and evaluating effective cohesion ( $c'$ ) of the top overconsolidated dry crust for effective stress analysis.

To understand the shear strength characteristics of Bombay marine clays, two test embankments, one at Wadala reclamation and another at Bassien creek bridge site are constructed up to failure. Both the test embankments are instrumented for monitoring the development of pore water pressures, settlements and heave during their construction. The objectives of the study are :

- a) To assess the applicability of findings by Bjerrum (1972) and Ladd and Foott (1974) regarding the mobilised shear strength of Bombay marine clay.
- b) To check the suitability of the method of analysis which correctly represents the state of stability of embankment either by total stress ( $\phi = 0$ ) or by effective stress.

For this purpose, stability analyses of test embankments at failure as well as of stable sections of Wadala test embankment (2.44 m high) and of maximum height of approach road to Bassien creek bridge are carried out. All these embankments are instrumented in order to monitor their behaviour as regards pore pressure, settlement and heave.

### INVESTIGATIONS

Figures 1 and 2 illustrate the test embank-

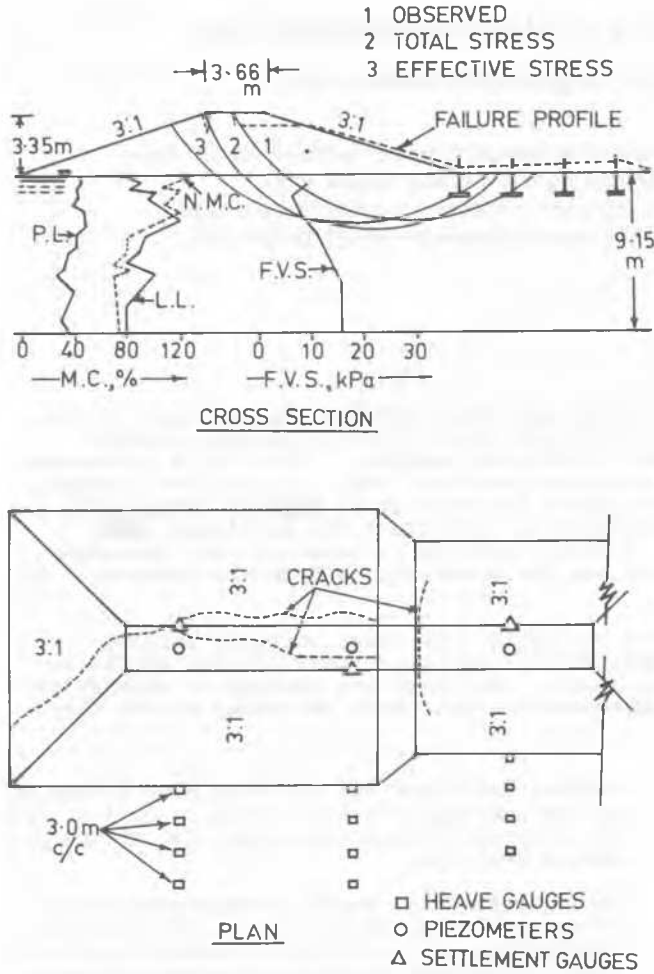


Fig 1 : Test Embankment at Wadala Site

ments, instrumentation and the profiles of index properties and field vane shear strength values for marine clays at Wadala and Bassien creek bridge sites respectively. The field vane shear tests are carried out at a rate of 0.1° per second by employing elaborate worm and gear arrangement. The general set up of the apparatus is as given by Gibbs (1957).

**CONSTRUCTION OF TEST LOAD EMBANKMENTS**

**Wadala Reclamation Site**

A test embankment as shown in fig. 1 is constructed. When the height of first 30.5 m length is increased to 3.35m, a small crack about 25 mm wide and 3.6 m long appeared in the murum cover between chainages 15 and 30.6 m. In the evening of the next day, the crack widened to about 80 mm and slip towards sea side took place. A transverse crack about 6 mm wide running across the top width appeared a week later at the junction of high and low height bunds.

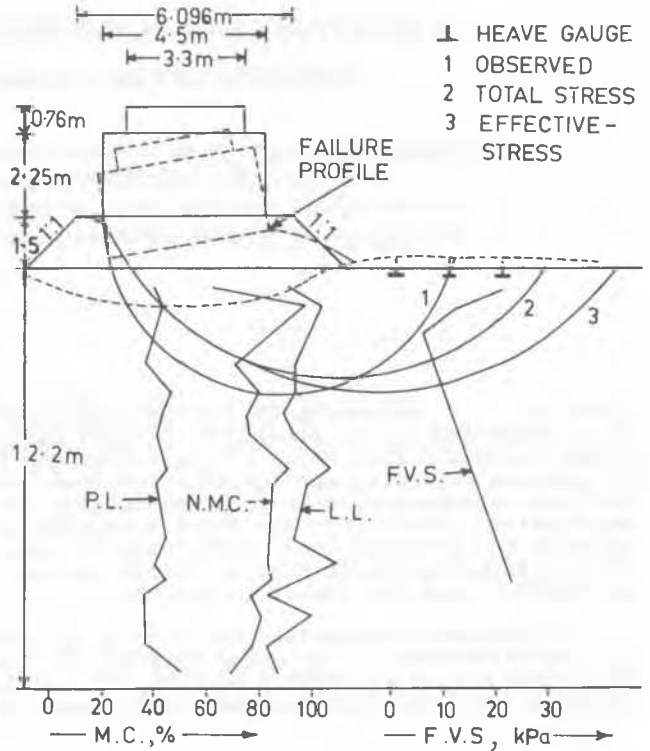


Fig 2 : Test Platform at Bassien Bridge Site

**BASSIEN CREEK BRIDGE SITE**

**Test Load Platform**

The test load platform as shown in fig.2 is constructed. When the height was 4.51 m, failure took place as the platform tilted to the extent of 1 in 10.

**Approach Road Embankment**

Fig. 3 illustrates the cross-section and instrumentation of the approach road embankment to Bassien creek bridge.

**SELECTION OF PARAMETERS FOR STABILITY ANALYSES**

**Wadala Test Embankment**

For total stress analyses average of field vane shear strength values is taken from the profile as shown in fig.1 without applying any correction (Bjerrum, 1972).

In the effective stress analysis, a grid of pore water pressures with grid points at smaller distance in comparison with that of piezometers is used. The distribution of stresses beneath the embankments (2.44 m and 3.35 m high) and beyond their toes is determined according to the theory of elasticity. Skempton's 'A' factor is computed from the observed pore water pressures and the calculated stresses at respective locations of

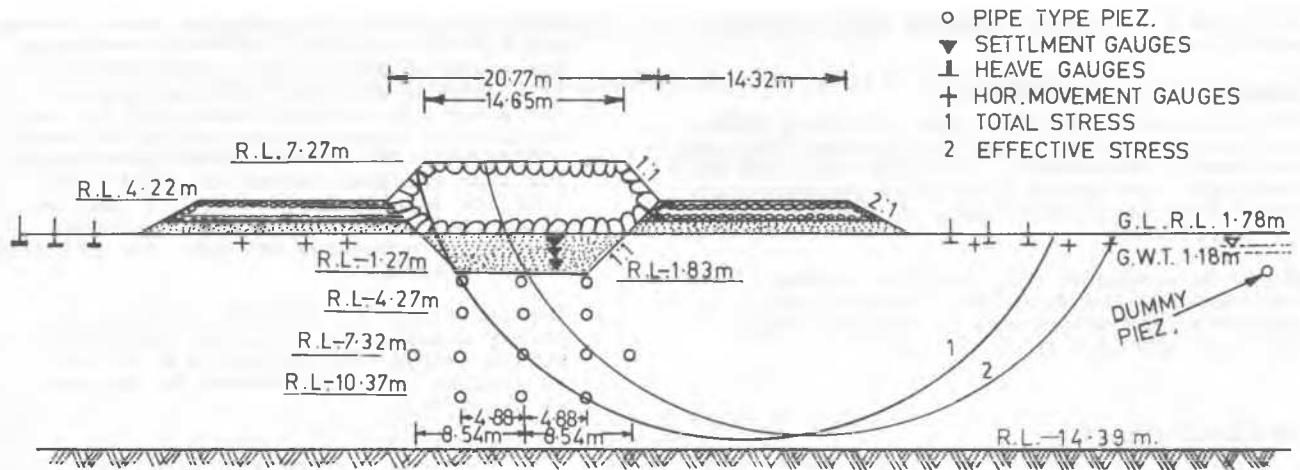


Fig 3 : Approach Road Embankment at Bassien Bridge Site

TABLE I

Shear Strength Parameters Adopted for Effective Stress Analysis

Site	Marine Clay		Clay Core	Murum	Rubble	Sand	Sand bags *
	Above G.W.T.	Below G.W.T.					
<b>Wadala Reclamation</b>							
i) $\rho$ $\text{kg/m}^3$	1601.0	1576.4	1440.9	1762.2	-	-	-
ii) $c'$ kPa	5.0	0.0	0.0	0.0	-	-	-
iii) $\tan \phi'$	0.2388	0.2388	0.2388	0.5773	-	-	-
<b>Bassien creek Bridge</b>							
<b>a) Test load Platform</b>							
i) $\rho$ $\text{kg/m}^3$	1440.0	1416.0	-	1470.0	-	-	1970.0
ii) $c'$ kPa	5.0	0.0	-	17.6	-	-	50.0
iii) $\tan \phi'$	0.2984	0.2984	-	0.53	-	-	1.0
<b>b) Approach road embankment</b>							
i) $\rho$ $\text{kg/m}^3$	1440.0	1416.0	-	1505.9	1521.9	1762.2	-
ii) $c'$ kPa	5.0	0.0	-	14.1	0.0	0.0	-
iii) $\tan \phi'$	0.2984	0.2984	-	0.5317	1.0	0.6494	-

\* Note :- As a failure plane passing through sand bags is unlikely, high values of shear parameters are adopted so as to eliminate the critical slip circle passing through that zone.

piezometers. A relationship between factor 'A' and deviator stresses is developed and used for determination of the pore water pressures at different grid points, thus refining the distribution of pore water pressures. The value of angle of shearing resistance was obtained from the following equation :

$$\sin \phi' = \frac{\frac{C_u}{\sigma}}{\frac{C_u}{\sigma} + K_o - A_f \left( 2 \frac{C_u}{\sigma} - 1 + K_o \right)}$$

The value of cohesion intercept ( $c'$ ) for stratum above ground water table is taken

as 5 kPa and zero for stratum below ground water table.

#### Bassien Creek Embankments

The parameters for total and effective stress analyses are obtained on the similar lines as for Wadala embankment. For approach road embankment the excess pore water pressures are taken from the observations at maximum height of embankment.

Parameters adopted for effective stress analyses for the test load platform and approach road embankment at Bassien creek site are given in table I.

#### STABILITY ANALYSES

In the total stress analysis for calculating driving and resisting forces above water table, moist densities of the material are considered; whereas, for material below water table submerged densities are used. In the effective stress analysis observed excess pore water pressures are taken into account alongwith saturated densities below water table. The results of stability analysis are shown in table II.

TABLE II  
Critical Factors of Safety

Method of stability analysis	Bassien		Wadala Embankment	
	Test load platform	Road section	2.44m high	3.35m high
Total stress	0.80	1.16	1.52	1.04
Effective stress	0.89	1.49	1.92	0.98

#### CONCLUSIONS

The conclusions regarding the shear strength and stability of embankments for Bombay marine clay are as under :

- 1) Stability analysis based on total stress, adopting field vane shear test values correctly represents the performance of embankments. The correction ( i.e. 0.87 to 0.65 for corresponding values of plasticity index ranging from 35 to 96) as suggested by Bjerrum (1972) is not required.
- 2) A study ( Kulkarni,1983) , indicated that difference in values of shear strength as obtained on undisturbed samples and those of perfect samples( Ladd and Lambe, 1963) is negligible. The SHANSEP method (Ladd and Foott, 1974) need not be applied.

- 3) Both the methods of analysis (total stress and effective stress) correctly evaluate the state of stability of embankments. Total stress analysis represents more correctly the state of stability for un-failed sections whereas for failed sections both the methods yield practically the same critical factor of safety and thus are equally applicable. It may be noted that observed and not predicated pore water pressures are used for effective stress analysis.
- 4) The difference in critical factors of safety obtained by total and effective stress methods at failure is 6 to 12% as against 20 to 30% stated by Hanzawa et al (1982).

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