Case studies of highway embankments constructed on soft clay soils

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Abstract: Limited case studies reported in the literatures were reviewed and summarized to better understand the behavior of highway embankments on soft clay soils. Total of 8 cases studies are presented to characterized the embankments, review the construction methods and identified the potential failure modes along with the design methods.

1. Introduction

Soft clay deposits cover many coastal regions of the world. The construction of embankments and retaining walls on these soft soils has always been associated with stability and settlement problems. Consequently, number of case studies on the behavior of embankments on soft clays has been documented in the literatures. In order to better understand the issues related to embankments on soft soils, it was critical to synthesize the reported behavior and the failures observed in various case studies. Hence, in this study, the embankments are investigated based on their dimensions and strength of soft clay layers (S_u =1.81psi - 3.65 psi for soft clay and S_u < 1.81 for very soft clay; after Terzaghi & Peck 1967), the methods of design and analysis and their failure mode.

In the case of Pacific Highway embankment in Australia constructed on alluvial soft clay, a new constitutive model accounting for the structure nature of the soft clay was developed to predict the settlement of the embankment since the Modified Cam-Clay model failed (Rouainia et al 2001). On the other hand, in the case of Boston trial embankment, the concern was the choice of the right model based on the soft soil parameters. Based on our documentation of case studies, soft soil constitutive model development and then implemented using a finite element method and a finite difference method are extensively used in the analysis of embankments.

2. Objectives

The overall objective was to develop a characterization method and to identify the common features and differences observed in the embankment performance on soft clay soils.

3. Case studies

Total of 8 case studies were reviewed and analyzed. (Ref. Table No. 2)

a. Geometrical classification (H: height in meter; W: width in meter)

In the eight cases documented $\frac{H}{W}$ ratio varied from 0.05 to 0.38, and the height of the embankment (H) to the soft clay layer thickness varied from 0.1 to 0.38

b. Type of clay: The embankments have been constructed on soft marine clay, soft alluvial clay and combined organic clay combined with soft clay layers.

c. Shear strength: In the eight documented case studies presented, the shear strength of the soft clay layer varied from 1 to 58 kPa.

Table 1: Classification of Embankments

H \ W	0–20	20–40	40–60
5	1 SMALL	1	1
10		2 MEDIUM	1
15			1 LARGE

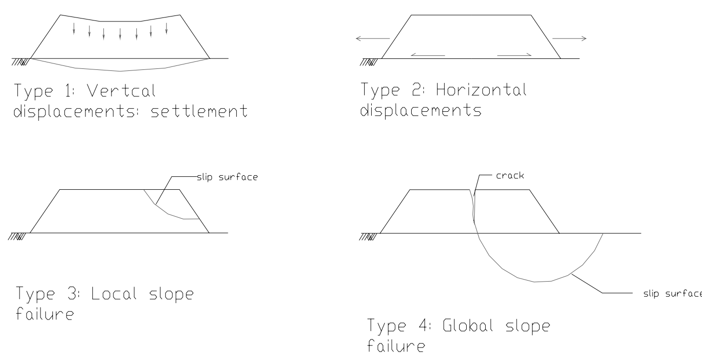

Figure 1: Different modes of failure

d. Methods of construction: stage construction is the most popular method used combined with preloading, sand drains and vacuum consolidation to accelerate the rate of consolidation.

e. Analysis/Models: Cam-clay model, soft soil model, soft soil creep model, isotropic and kinematics hardening soil model, coupled Biot consolidation model and also phenomenological model based on field and lab tests correlation have been used. In short constitutive models along with numerical analysis are extensively used to predict the behavior of embankments on soft soils.

f. Mode of failure: Five basic modes of embankments failures are as follow:
Type 1: Vertical settlement: excessive settlement causing damage to the highway;
Type 2: Horizontal displacement: can occur during construction and /or service;
Type 3: Local slope failure; the use of poor quality of embankment material and no slope protection;
Type 4: Global slope failure; result of shear failure in the soft clay layer and/or embankment;
Type 5: Combination of two or more of the above mentioned types of failures.

4. Conclusion

Predicting the vertical settlement, horizontal displacement and pore water pressure distribution within the soft clay layers are the main issues in assessing the behavior of an embankment on soft soil.

Determining the soft clay parameters (OCR, compressibility and permeability) and the choice of the constitutive model are the crucial steps in modeling the behavior of embankment on soft clays soils.

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6. References

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Table 1: **SUMMARY OF CASE STUDIES**

No	Location	Size HxW (m)	Soft clay layer thickness (m)	Type of clay	Su (kPa)	Method of constructrion	Issues	Analysis/Model	Failure Mode	Reference
1	Boston , USA	11 x 48	41	Marine	1	NA	Assessment of constitutive models	FE-code PLAXIS: Soft Soil model prediction	No failure	Neher , Wehnert and Bonnier (2001)
2	Sha Edeby, SWEDEN	1.5 x 4	15	NA	1	NA	Assessment of constitutive models	FE-code PLAXIS: Soft Soil Creep model prediction	No failure	Neher, Wehnert and Bonnier (2001)
3	Pusan Airport road, SOUTH KOREA	2 x 28	10 to 20	NA	31	Stage const. + geogrid	reducing diff. settlement by using geogrid	FE-code PLAXIS: hardening soil model	No failure	Cancelli, Recalcati, and Doh (1999)
4	Queensland, AUSTRALIA	NA	20	Marine & organic	13.5	Stage const.	Trial embankment Performance of vertical drains	FDA-code FLAC: coupled Biot consolidation mode	No failure	Rankine, Sivakugan and Wijeyakulasuriya (2003)
5	Guiche, FRANCE	4-8.75 x 35.8	3-7org	NA	NA	Stage const. with geogrid	Trial embankment .use to predict settlement	2-D FEM: elasto plastic model (Biot theory and critical state condition)	Vertical displaceme nt	Borges., Cardoso and Lopes (1995)
6	JAPAN	7.7 x 23	NA	Alluviu m	10 to 20	Stage const. + Preload	Development of a new design methods: normal-time and seismic cases	2-D FE-code parametric study : Cam -Clay model	No failure	Watanabe, Koichi Nishikawa et al. (1999)
7	Paradip, INDIA	5-8 x 44	NA	Marine and alluvial	NA	Stage const.	Development of a new settlement method prediction	FE-code implementing the new developed model	No failure	Simmons (1995)
8	Pacific Highway, AUSTRALIA	3-5x54	8	Alluvial	22 to 58	NA	Settlement prediction (MCC model failure)	New constitutive model accounting for clay structure	No failure	Rouainia, Sheng and Zhao (2001)

NB: NA= Not Available; FE = Finite Element; FD = Finite difference