Pore pressures and lateral stresses using in situ properties

Pressions interstitielles et contraintes latérales à partir des propriétés in-situ

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SYNOPSIS: Two examples of the prediction of pore pressures under static and dynamic conditions are presented. The first example deals with the prediction of pore pressures and lateral stresses in the foundation clay of the Kaubvik Caisson retained sand island in the Canadian Beaufort Sea. The second example deals with the prediction of pore pressure generation and dissipation during and after an earthquake at the Paper Mill Site, Ying Kou City, PRC. Input properties for the above analyses were obtained using the in situ electrical measurements. The total lateral stresses and pore pressures predicted by the finite element analysis in the static case compared favorably with the actual field measurements made by pore pressure transducers and total stress cells. The 100 percent excess pore pressure ratio predicted at various depths using a semi-empirical one-dimensional elastoplastic constitutive model and finite difference method to solve the governing differential equation in the second example due to earthquake loading is in conformation with the liquefaction behavior observed at Ying Kou City during the 1975 Haicheng earthquake.

1 INTRODUCTION

Finite element and finite difference method with elastoplastic constitutive models describing the soil behavior have been used in the analysis of boundary value problems in geotechnical engineering. The success of the predictions depends to a large extent on the accuracy of the input parameters used in the analysis. In this paper two examples of the prediction of pore pressure under static and dynamic conditions are presented. The first example deals with the predictions of pore pressures and lateral stresses in the foundation clay of the Kaubvik Caisson retained sand island in the Canadian Beaufort Sea (Shinde et al. 1988). The second example deals with the prediction of pore pressure generation and dissipation during and after an earthquake at the Paper Mill site, Ying Kou City, PRC, (Arulanandan, et al. 1986). The input properties used in the analyses were predicted from the nondestructive in situ testing using the electrical method (Arulanandan 1977). The predicted results are compared with the measured values in the first case and the observed behavior in the second example.

2 PREDICTION AT THE KAUBVIK I-43 SITE

At the Kaubvik 1-43 site in the Canadian Beaufort Sea during the summer of 1986, ESSO installed a steel Caisson Retained Island (CRI) with a comprehensive instrumentation system on the caisson and the foundation to continuously measure environmental forces (Shinde et al. 1988). An electrical probe was used in one type of in situ test (Arulanandan, 1977; Arulmoli et al. 1985). The results from the electrical soil probe tests (ESPT) were used to confirm the soil parameters selected during the design stage. They were also used to predict the response of the foundation under gravity loads using a numerical model.

2.1 Prediction of in situ state of the soil using the electrical probe

The electrical soil probe used in this study was a Geoelectronics Electrical Soil Probe Model GE100 developed at the University of California at Davis (Arulanandan, 1977).

Table 1 gives the values of horizontal (F_H), vertical (F_V), average (F) formation factors and electrical anisotropy index (A), probe measurements calculated from (Dafalias and Arulanandan, 1979).

Table 1

Depth of Testing (m) from caisson surface	F_V	F_H	$\bar{F} = \frac{(F_V+2F_H)}{3}$	$A = \sqrt{\frac{F_V}{F_H}}$
27.2 - 27.48	3.175	2.941	3.019	1.039
30.3 - 30.52	4.101	3.328	3.586	1.110
34.8 - 35.07	3.853	3.360	3.524	1.071
36.27 - 36.55	3.683	3.704	3.697	0.997
42.39 - 42.67	3.875	3.774	3.808	1.013

The relationship between average formation factor ($\bar{F}$) and porosity (n) determined by laboratory tests on a remolded soil sample from 14.8 m depth below seabed is shown in Figure 1. Using Figure 1 and the $\bar{F}$ given in Table 1, the in situ porosity can be obtained. The in situ Ko is obtained by using the relationship between log (A^4f) and Ko, given by Meegoda et al. (1986), "A" being obtained from Table 1 and "$\bar{f}$" from Figure 1. The predicted Ko is compared in Figure 2 with the predicted values by self boring pressuremeter tests and with the values measured by performance monitoring instruments.

The predicted in situ state of the Kaubvik soil in terms of void ratio, vertical (σ_V) and horizontal (σ_H) effective stresses, overconsolidation ratio and preconsolidation pressures (p_o) is given in (Shinde et al. 1988).

2.2 Prediction of the response and performance of the foundation clay

A two-dimensional finite element computer program SAC2 (Herrmann and Mish 1988) was used for the prediction of

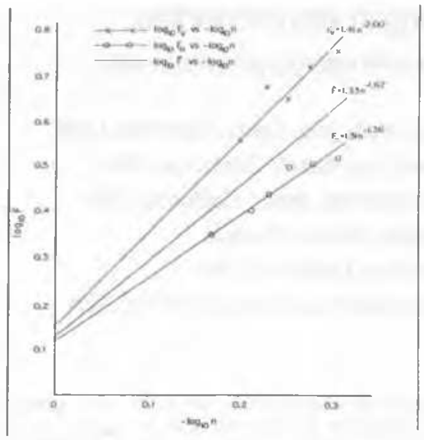

Figure 1. Formation factor vs porosity relationship for the foundation soil at Kaubvik I-43 site

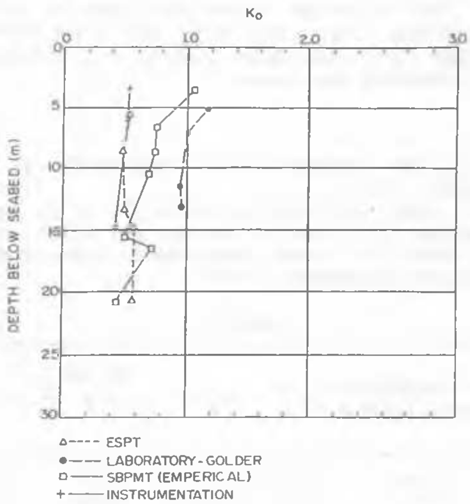

Figure 2. Comparison of predicted & measured in situ K_o

the response of the foundation clay under the loads imposed by the "construction" of the caisson retained island (Gravity load). This computer program uses the bounding surface plasticity model to describe the stress-strain behavior of the soil.

Input parameters for SAC2, in addition to loading conditions, are the initial conditions of the soil and bounding surface model parameters and is given in Shinde et al. 1981.

The geometry at Kaubvik was asymmetric due to the presence of an off-center glory hole (Figure 3). Due to the 2D nature of the computer program and since a plane strain approximation is not appropriate for this geometry, the problem is analyzed as two axisymmetric problems with loads properly scaled using the centerline of the glory hole as the axis of symmetry. This approximation results in a source of error for subsequent predictions. Predicted total horizontal stresses and total pore water pressure at various depths are given in Figure 4 and 5. Also given in these figures are the total horizontal stresses and total pore water pressures at various depths obtained by instrumentation as well as pressure meter. Assuming the Instrumentation to provide baseline in situ total horizontal stresses and pore water pressures due to their robust and pore water temperature insensitive nature, values predicted by SAC2 agrees reasonably well with the measured in situ values except in the top 5 m. This can be attributed to the nature of the very soft top clay layers and to the axisymmetric assumption made.

3 PREDICTION OF PORE PRESSURE GENERATION AND DISSIPATION

A method was developed and incorporated into a computer program (ELMA1) for level ground soil liquefaction analysis, which is treated as a boundary value problem (Arulanandan and Muraleetharan 1985). This method uses a semi-empirical, one-dimensional elastoplastic constitutive model and finite difference method to solve the governing differential equation for the prediction of pore pressure generation and dissipation during and after dynamic excitation. A compressibility function incorporating effects at low effective stresses is included in this method, which was verified by centrifuge model tests. This procedure utilizes input properties representative of field conditions determined by nondestructive electrical method.

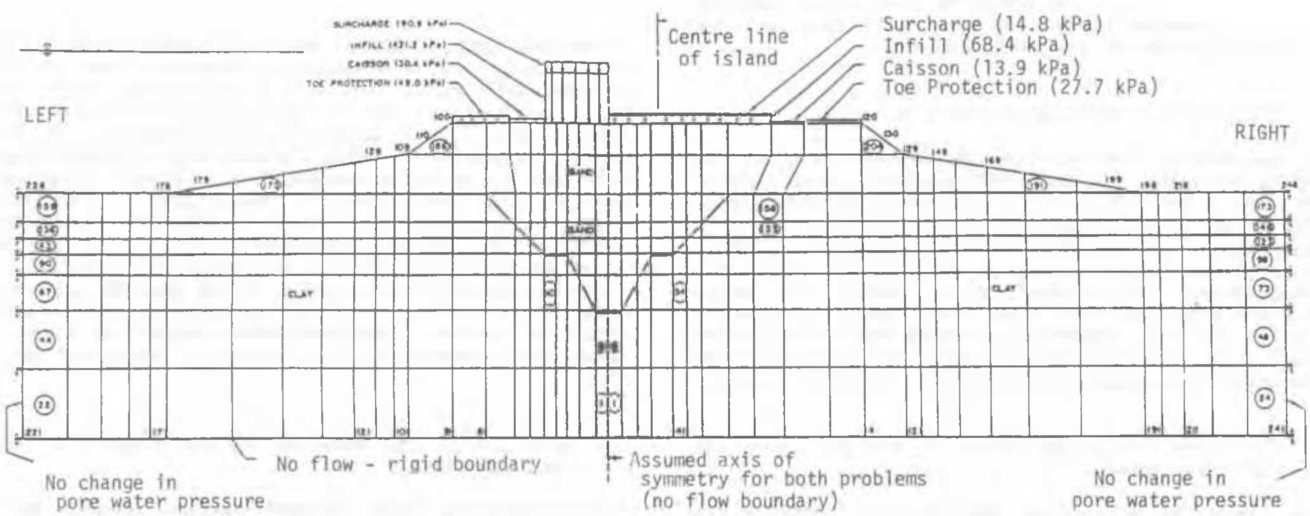

Figure 3. Finite element discretization of the Kaubvik site

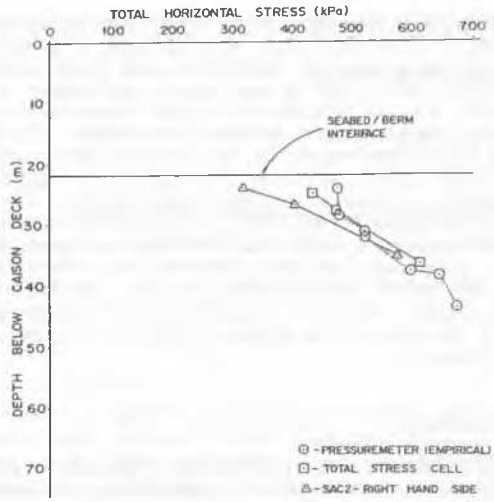

Figure 4. Comparison of predicted and measured horizontal stress

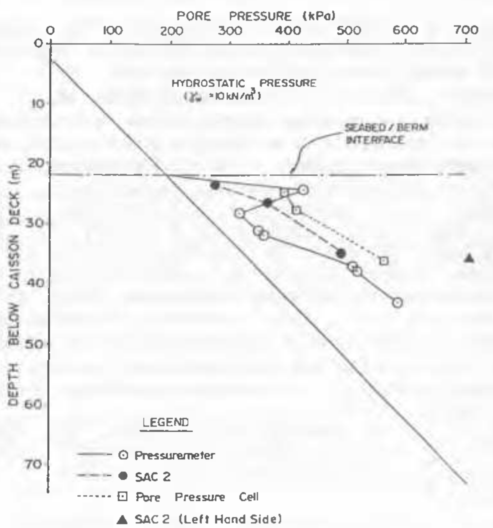

Figure 5. Comparison of predicted and measured pore pressures

Computer program ELMA1 together with input properties obtained by in situ electrical measurements (Arulanandan et al. 1986) is used in this study to predict pore pressure generation and dissipation after a particular earthquake at the paper mill site.

Soil profile at the paper mill site based on CPT results (Arulanandan et al. 1986) and bore hole data (provided by Institute of Engineering Mechanics, Harbin, PRC) together with the location of the pore pressure transducers which were installed recently (indicated by the arrows) are given in Figure 6. Electrical measurements were made up to a depth of 9.4 m. Below this depth electrical properties were deduced based on the electrical properties of similar soils above 9.4 m. The electrical properties (see Table 2) were used to obtain the necessary input parameters for the program ELMA1, using the available correlations (Arulanandan et al. 1988). During the 1975 Haicheng earthquake the maximum ground surface acceleration at Ying Kou City was estimated to to vary between 0.1 to 0.15 g (Arulanandan et al. 1986). Since no acceleration-time histories were measured at Ying Kou City during this earthquake, the paper mill site was analyzed using an earthquake having a surface acceleration of 0.0813 g (= 0.65x(0.1 + 0.15)/2. Equivalent number of uniform cycles and the duraction of the earthquake were obtained as 20 cycles and 40 sec., respectively.

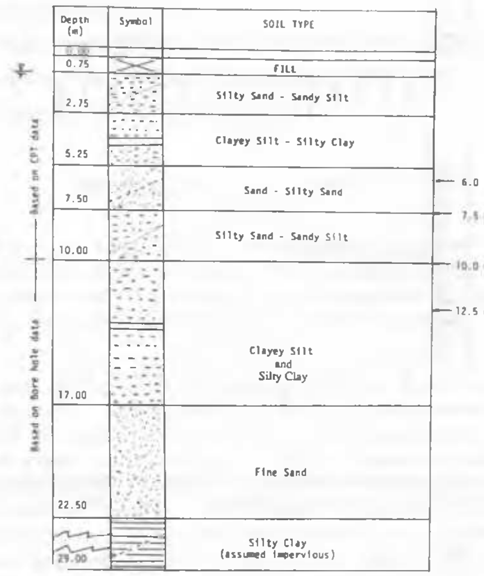

Figure 6. Soil profile at the Paper Mill site

Table 2

Main layer #	Thickness (m)	(1) Porosity	$\bar{F}$	$\bar{f}$	A
1	2.00	0.358	2.430	1.000	1.04
2	1.25	0.468	2.140	1.002	1.07
3	1.25	0.551	2.430	1.490	1.10
4	1.25	0.399	3.920	1.487	1.07
5	2.50	0.358	2.801	1.000	1.10
7	2.00	0.446	2.637	1.002	1.09
8	3.50	0.399	2.246	1.002	1.09
9	5.50	0.355	2.511	1.002	1.09

Excess pore pressure ratio ($\Delta u/\sigma'_{v_0}$) time histories predicted by ELMA1 at various depths are given in Figures 7 and 8, where Δu = excess pore water pressure and σ'_{v_0} = initial effective vertical stress. Observed liquefaction at this site validates the predicted liquefaction (100% excess pore pressure ratio at depths 10.0 m and 12.5 m).

4 SUMMARY AND CONCLUSIONS

The Kaubvik study has shown that a combination of instrumentation, in situ testing and analytical methods can be used to enhance confidence in currently used design methods. The following conclusions can be drawn:

1) Electrical soil probe testing is a viable tool for determining in situ properties especially if these properties are to be used in numerical models to predict foundation performance.

2) Finite element analysis using the bounding surface plasticity model to describe the stress-strain behavior of the soil, with input parameters obtained using in situ electrical probe testing, provides good predictions of foundation response.

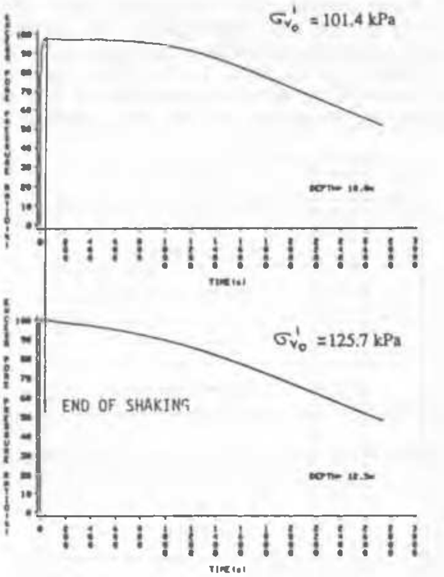

Figure 7. Excess pore-pressure ratio-time histories predicted by ELMA1 at various depths of the Paper Mill site

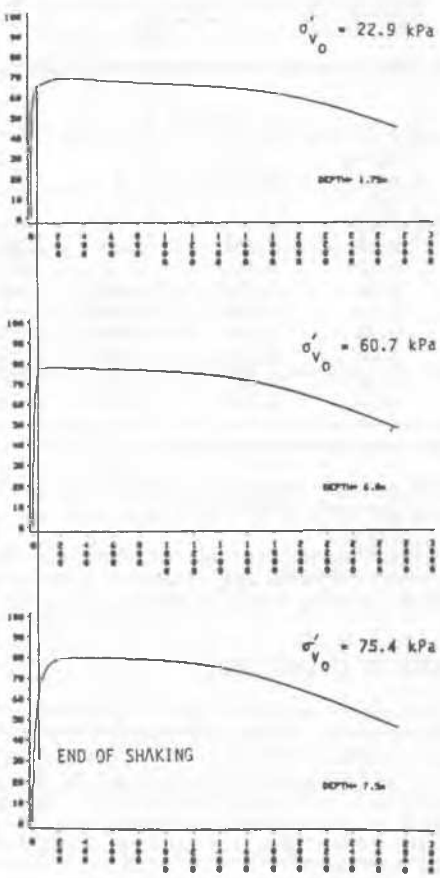

Figure 8. Excess pore-pressure ratio-time histories predicted by ELMA1, indicating liquefaction at the Paper Mill site

Treating soil liquefaction as a boundary value problem and using in situ electrical measurements, a priori prediction of pore pressure generation and dissipation are made during and after a particular earthquake at the Paper Mill site in Ying Kou City, PRC. Measurements made using the installed pore pressure transducers during and after a future earthquake can be used to verify the predicted pore pressure values for this future earthquake. Liquefaction observed at the site during the 1975 Haicheng earthquake validates the predicted excess pore pressures at depths 10.0 12.5 m that are equal to the initial effective vertical stresses at these depths (i.e., 100% excess pore pressure ratios). The method used in this paper predicts liquefaction of level ground sites, a boundary value problem based on the results of in situ testing.

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