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Prediction and Observation of Pore Pressure Due to Pile Driving

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SYNOPSIS

In this study, pore pressure response due to pile driving has been observed in the field. Cavity Expansion theory using critical state parameters of the soil has been used to predict the trend of the pore pressure development and dissipation. Parametric study has been carried out to know the sensitivity of various parameters on the predicted results. A comparison has been made between the predicted and observed results.

INTRODUCTION

The behaviour of displacement piles in clay is an important and significant problem in geotechnical engineering. When displacement piles are driven into a cohesive soil, large excess pore pressures are generated close to the pile. The high pore pressures down the pile shaft reduce the active stresses and thus facilitate the process of driving the pile to the required depth of penetration. At te same time, this may create problem of large displacement of pile head. Pile driving operations are sometimes greatly interrupted or even stopped due to the development of excessive pore pressures may affect the stability of slopes into which the piles are driven. In order to explore these problems, a knowledge of the magnitude and distribution of the induced pore pressures with respect to both depth and distance from the pile axis is essential.

This study concentrates on the prediction of pore pressure response due to pile driving and compares it with the observations in the field. The use of the cavity expansion theory to predict the pore pressure is one of the methods tried in the past. Ladyani (1963) investigated analytically the expansion of a cavity in a saturated clay medium considering different cases of stress distribution around the cavity. General solutions to the problems of expansion of spherical and cylindrical cavities in an ideal perfectly plastic soil possessing both cohession and friction have been presented by Vesic (1972). These solutions can be used to evaluate the stress and pore pressure generated during the undrained cavity expansion.

Desai (1978) studied theoretically the changes in stress and pore water pressure due to pile driving on the basis of the cavity expansion approach and used finite element procedure. Randolph and Wroth (1979) presented an analytical solution for the consolidation of soil around a driven pile, based on the radial of pore water. They showed that the rate of dissipation of pore pressure depends on the coefficient of consolidation and maximum pore pressure developed during the pile driving and that the pore pressure close to the pile falls off very rapidly initially.

RANDOLPH et.al. (1979) showed that, by using the finite element method incoporated with the modified Cam-clay model, the rate of increase in shear strength of soil after pile driving can be predicted.

CARTER et.al. (1979) presented a more rigorous analysis ofthe dissipation of excess pore pressure the solution have been obtained using a finite element analysis incorporating the modified cam-clay model. It has been concluded that the dissipation of pore pressure with time is relatively unaffected by the choice of the soil model and a good estimate can be obtained by assuming a linear elastic soil with sensible choice of parameters.

The development and dissipation of pore pressure, in this study have been predicted by using the computer program CAMFE (finite element representation of undrained cylindrical cavity expansion with modified Cam-clay as model). The predicted values were compared with observed values and in general, the aggrement between the two was very encouraging.

FIELD INVESTIGATIONS

In order to check the validity of CAMFE program for Bangkok soil and to observe the influence of different soil parameters on the response of pore pressure during pile driving, field observations were made at Thammasat University, Rangsit campus, Bangkok. The depth of exploration was limited to 15 meters since the study was concerned mainly with the soft clay layer of Bangkok subsoil. Excess pore pressure was observed from eighteen piezometers surrounding the pile and observations were recorded from the time of pile installation

(October 28, 1986) until 15th February, 1987. In addition to this, 6 dutch cone penetration tests, 6 vane shear test and two boreholes upto 15 meters depth were carried out. The location of these tests and the arrangements of piezometers is shown in Fig. 1.

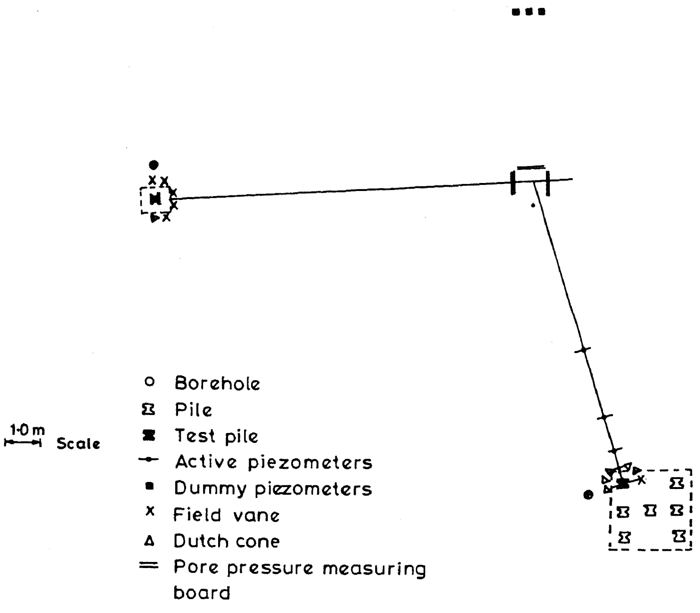

Fig. 1 Location of piles, Piezometers Boreholes, Field Van tests, and Dutch Cone Tests

The measurement of excess pore pressure was carried out by using AIT hydraulic type piezometers. Open stand pipes were used as 'Dummy' piezometers and a closed hydraulic system was used for the 'active' piezometers. As a large no of piles were driven earlier at the site, some excess porewater pressure was already exsisting at the site. As the dissipation of pore pressure of the earlier driven piles became very slow at that stage, it was therefore expected that the pore pressure measurements due to the test pile driving would not be effected much. Under this condition the pile driving operation of the test pile started. The excess pore pressure due to this was monitered continuously during the pile driving and was continued until the maximum value was reached. After that the readings were taken at certain intervals of time. The measurements were continued for 3 months and 15 days until most of the excess pore pressure dissipated.

LABORATORY TESTS : In the laboratory, triaxial tests were performed on soil samples from BH1 and BH2 at the depths 3.0, 6.0 and 9.0 m below ground level to get preconsolidation pressure, compression index swelling index coefficient of consolidation and coefficient of permeability. CIU tests were performed to get normalized stress-strain curves to evaluate the undrained Youngs Modulus and undrained shear modulus. The plot of mean effective stress (P) verses devioteric stress (q) was also made to get the stress ratio at the failure (M) and the earth pressure at rest (k).

INPUT DATA FOR THE PROGRAM

In order to run the program some soil propertie and initial state of stresses were needed. Thes parameters were obtained from the laborator tests on the samples of the site. The progra was run with the standard values and also wit the upperbound and lower bound values o different parameters for the Bangkok soil. Thes values are listed in Table I. The parameter were divided into following three categories t observe their influence in the prediction o excess pore pressure.

(i) critical state parameters (1, k, e, M
(ii) shear modulus (G)
(iii) permeability (K)

Table 1 Input parameters for CAMFE program

Para-meters	From lab	Past work	Lower bound	Upper bound
Depth 3·0 m				
Ko	---	0·60	---	---
σ_{vo}' kn/m^2	35·6	---	---	---
pc' kn/m^2	100·1	---	---	---
M	1·12	1·00	0·95	1·15
λ	0·456	0·51	0·40	0·55
K	0·081	0·091	0·075	0·10
ecs	2·75	2·16	2·5	3·0
kh x10E-8 m/min	8·90	10	0·89	89
G kn/m^2	3500	---	1500	3500

PILE GEOMETRY

The test pile which was used to observe the pore pressure response was 0.6 x 0.26 x 21.0 m I-section prestressed concrete pile. It was assumed that the soil in between the flanges were also active in expanding the cavity and the equivalent radius of pile was taken as 0.147 m. The initial radius of cylindrical cavity, therefore, was taken as 0.147 m. The phenomenon of cavity expansion was modelled by considering the expansions of a pre existing cavity of initial radius r = a to a new cavity of radius r = 2a .

Three node elements were used for the analysis. The nodes are so spaced that the radial coordinates of any two adjacent nodes are in fixed proportion. The only mesh data required as input for the program are the number of nodes, the initial radial coordinates of the interior node and the raidius ratio. The arrangement of the Nodes in an element is shown in Fig. 2 with maximum number of elements as 99.

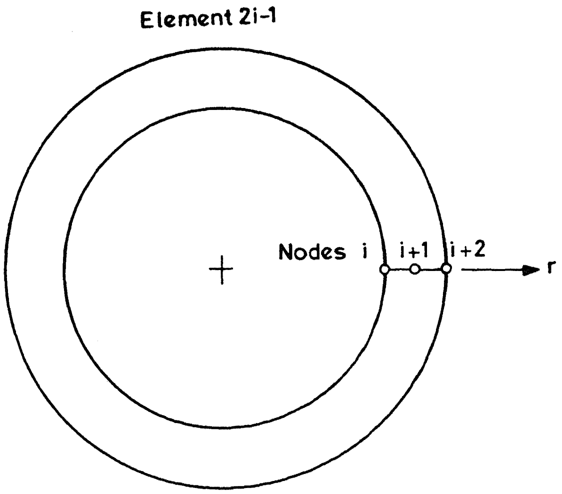

Fig. 2 A Typical finite element

TIME STEPS AND CAVITY EXPANSION

The expansion of the cavity has been analysed using 190 time steps and at each step the inner boundary of the soil is displaced outward by a specified amount. Small displacement steps are required during early part of the expansion when element of the soil adjacent to the cavity are yielding and approaching the failure (or critical state) conditions. The time step size is progressively enlarged as the cavity expands. If the rate of expansion is taken as 0.1 m/min., then it will take a total time of 0.847 min to double the cavity size. This time is considered small enough to adequatetly approximate an undrained expansion and yet large enough to avoid numerical problems with the solution routine. The reconsolidation of soil after the cavity expansion is assumed, in this case, to be achieved in 34 time steps of varying sizes.

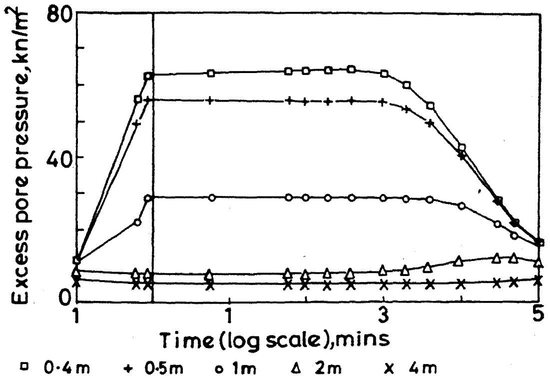

Fig. 3 Predicted time history of excess pore pressure at different radial distances from the pile axis at 3·0m depth

RESULTS AND DISCUSSIONS

The time history of excess pore pressure at different distances as predicted by the CAMFE program for depths of 3.0 m, 6.0 m and 9.0 m are shown in Figs.3 to 5 respectively. From these Figures it can be seen that the maximum pore pressure develops quite early (i.e. at the same time at which the cavity doubles) in all cases. It maintains the maximum value for a certain period (nearly 1000 minutes) and then starts dissipating. The effect is found negligible at 2.0 m and 4.0 m distances.

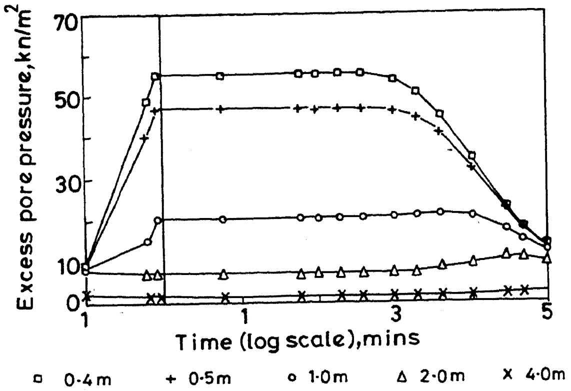

Fig. 4 Predicted time history of excess pore pressure at different radial distances from the pile axis at 6·0m depth

The comparision of observed and predicted pore pressures for different depths, viz. 3.0 m, 6.0 m and 9.0 m at different distances from the pile axis and for different parameters is discussed below :

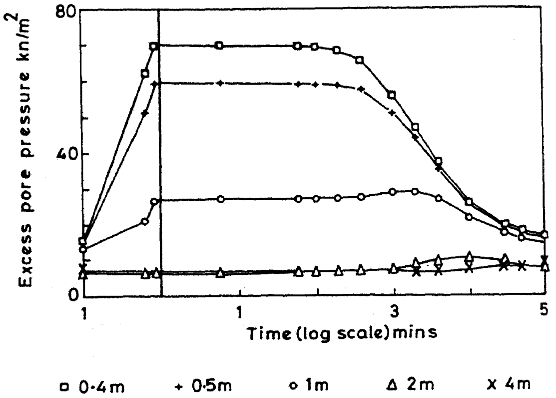

Fig. 5 Predicted time history of excess pore pressure at different radial distances from the pile axis at 9·0m depth

pressure. Though the dissipation started nearly at the same time in all cases, the developed peak excess pore pressure varied considerably with 'G' value. The higher the peak value of 'G', the higher the peak value of excess pore pressure at all depths.

Influence of Permeability (k) on Predicted Pore Pressure :

Fig. 8 shows the influence of permeability 'k' on the predicted pore pressure at 3.0 m depth. k is a sensitive parameter and it affects both the starting time of dissipation and rate of dissipation of excess pore pressure. The lower the value of 'k' the slower will be the dissipation rate. For a lower value of 'k' the dissipation starts after a long time. There is no influence of 'k' on the predicted maximum excess pore pressure.

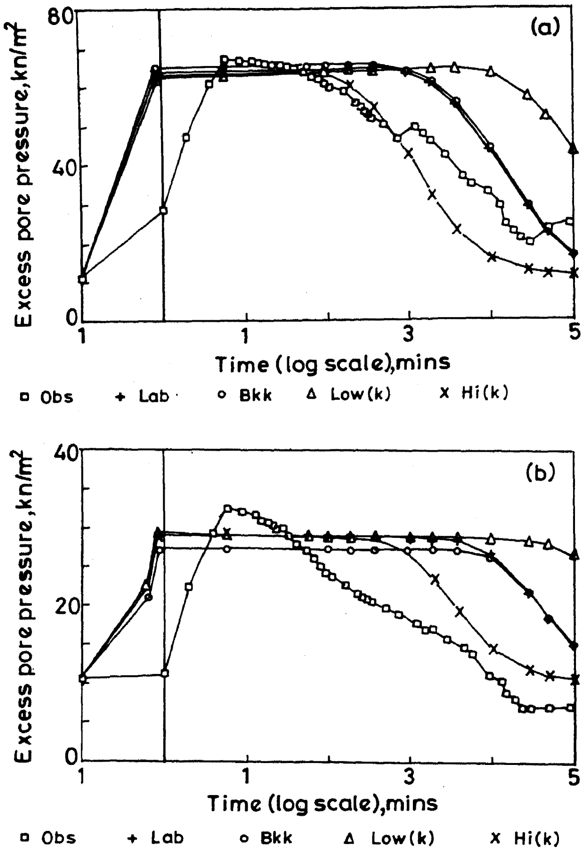

Fig 6 Influence of permeability (k) on the predicted pore pressure at 3·0m depth.(a) Radial distance from pile axis=0·4m;(b) Radial distance from pile axis=1·0m

Influence of Input Time Step on the Predicted Pore Pressure :

In the program the pore pressure generally attains its maximum value (specially to the nodes closer to pile) corresponding to the time to double the cavity. The field results d not agree with this condition. Therefore a attempt was made to run the program with th time at which the pore pressure in the field i the maximum. Fig. 9 shows the influence o shifting the time step to double the cavity o the predicted pore pressure at 6.0 m depth. Th time step which is representative of the fiel condition shows better agreement between th predicted and observed pore pressure on th development side though there is not much chang in the dissipation side.

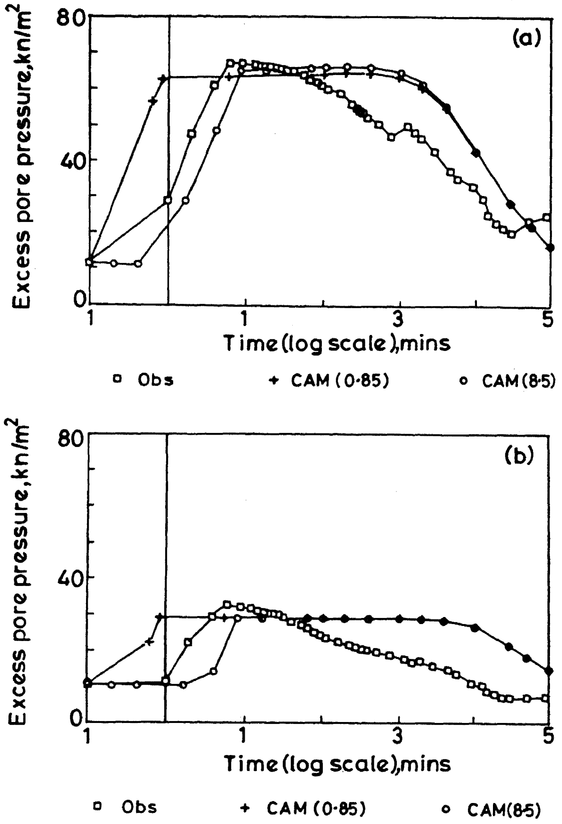

Fig 7 Influence of selection of time steps on the predicted pore pressure at 3·0m depth.(a) Radial distance from pile axis=0·4m;(b) Radial distance from pile axis=1·0m

CONCLUSIONS

Based on the comparison of observed and predicted results, and from the parametric study, the following conclusions can be drawn :

1. The program underestimates the peak of the excess pore pressure in most of the cases and the maximum difference observed is of the order of 20%. The peak excess pore pressure and the rate of dissipation of excess pore pressure at closer distances can be predicted better than that at farther points.

2. The rate of dissipation can be predicted by the program, but the time corresponding to a certain percentage of dissipation is

DEVELOPMENT AND DISSIPATION TREND OF EXCESS PORE PRESSURE WITH TIME :

Figs. 6(a) and 6(b) show the pore pressure response at 3.0 m depth as observed in the field and as predicted by the program at 0.4 m and 1.0 m distances from the pile axsis respectively. From the Fig. it is clear that the program is more or less capable of predicting thee peak of the excess pore pressure. The predicted excess pore pressure develops at 0.847 mins. after the pile driving.

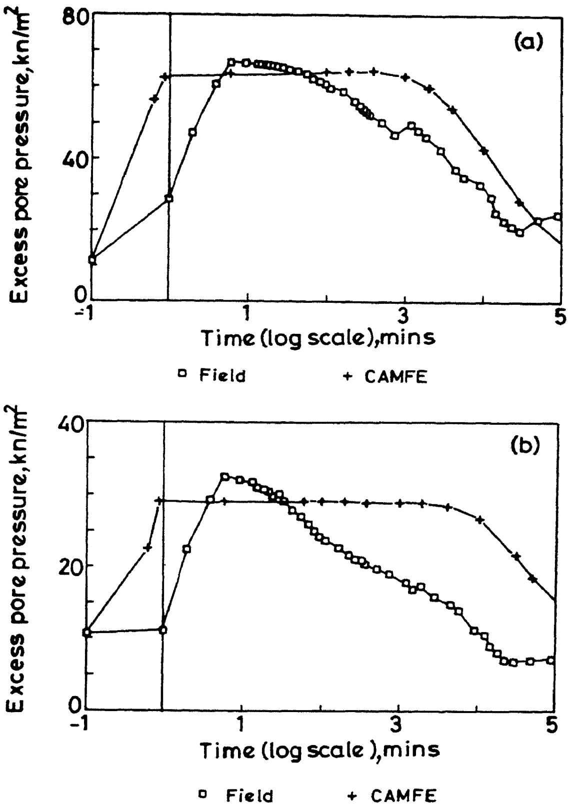

Fig. 8 Comparison of observed and predicted excess pore pressure at 3·0 m depth.
(a) Radial distance from pile axis=0·4 m;
(b) Radial distance from pile axis=1·0 m

The figure shows a big difference in observed values and predicted values along the development side of the curve. But there is a better agreement along the dissipation side. Further it can be observed that as the distance of the piezometers from the pile axis increases the accuracy in predicting the pore pressure by CAMFE program decreases. Therefore the prediction at 1.0 m distance is quite poor.

The prediction of excess pore pressure is not good due to the special characteristics of the weathered crust at 3.0 m depth. The accurate determination of different parameters are difficult and the values obtained may not be representative values particularly that of the permeability.

Variation of Excess Pore Pressure with Distance:

Fig. 7 shows the plots of excess pore pressure with normalised distances on a log scale. Both the observed and predicted pore pressures are plotted at four instants of time at the depth of 6.0 m. From the figures, it can be observed that the predicted pore pressure soon after driving are in good agreement with the observed ones whereas the difference between two values increase as the time passes by.

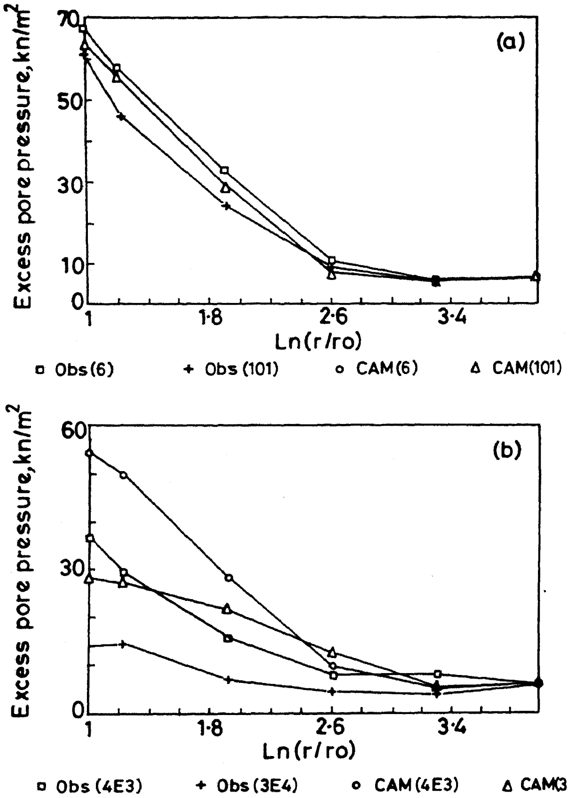

Fig. 9 Observed and predicted excess pore pressure with distance at different times (at 3·0 m depth) (a) 6 mins. & 101 mins. (b) 4000 mins. & 30000 mins.

Influence of Critical State Parameters on Predicted Pore Pressure

The study on the influence of critical state parameters on the predicted pore pressure at different distances from the pile at various depths indicated that the parameters have negligible influence as the nature of dissipation of the excess pore pressure and have small effect on the development of excess pore pressure.

Influence of Shear Modulus (G) on Predicted Pore Pressure :

The influence of 'G' on the predicted pore pressure at various depths was studied. It was observed that 'G' has significant influence on the development and dissipation of excess pore overpredicted. The time to develop the maximum pore pressure can not be predicted by the program.

3. The critical state parameters of soil have some effect on the prediction of peak value of excess pore pressure and no effect on the dissipation.

4. The shear modulus of soil is a sensitive parameter. It affects the predicted peak excess pore pressure considerably; but the time to start the dissipation as well as the rate of dissipation do not change much.

5. The permeability of soil affects both the rate of dissipation of excess pore pressure as well as the starting time of dissipation. It does not, however, affect the peak value of excess pore pressure predicted by the program.

6. The program needs the time to double the cavity size as an input parameter and an appropriate value of it improves the predictions on the development side of excess pore pressure. However, the maximum pore pressure, the rate of dissipation, and the time of starting the dissipation do not get affected by the time selected.

7. The influence of excess pore pressure development due to pile driving is very small after 1.0m distance and neglegiable after 2.0 m distance from the pile axis. This fact has been proved in the field as well as from the CAMFE program. The prediction is better for those piezometers which are closer to the pile. The prediction becomes poorer and poorer as the distance from the pile axis increases.

8. At the site the dissipation of excess pore pressure starts as soon as it reaches to the maximum value; but the program maintains a constant peak value for a certain period and then starts dissipation. This behavior is quite prominent in almost all the comparisons shown here. The rate of dissipation is also faster in the field than that predicted by the program.

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