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PILES UNDER INDUCED LATERAL GROUND MOVEMENTS

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ABSTRACT - The paper discusses the 3D finite element based numerical analysis to predict the lateral ground movement and to investigate the response of piles under these induced ground movements. In the analysis, the source of ground movement has been due to an unsupported excavation in uniform clay medium. The pile is treated as linear elastic material and the soil is treated as elasto-plastic materials based on Drucker-Prager constitutive models with non-associated flow rule. The results obtained from the analyses are presented in terms of the ground movement profiles, lateral deflections and bending moment along the length of pile, which are of prime interest to designers. Numerical results indicate that the response of piles mainly depends on the parameters, viz., magnitude of soil movement, pile location etc. The results predicted from the present analysis are in fairly good agreement with those of published work of Poulos & Chen (1996).

INTRODUCTION

The majority of piles are designed to support 'active loads', i.e. the loads are applied directly to pile head by a structure. However, with the increased construction activity in the form of excavations, road embankments, tunnelling etc., piles are also subjected to 'indirect or passive loads' induced from the ground movements. Besides, there are situations where piles are used to stabilize the moving and liquefiable soils. In all these cases, the externally imposed soil movements will impart additional stresses, cause increase in lateral deflections and bending moments in piles, which may finally lead to distress of the structure. Hence it is essential to enumerate the influence of these induced ground movements on the response of piles. Although the movement is possible in both vertical and lateral directions, lateral movement is more critical as piles are not often designed to sustain significant lateral loads due to these movements.

Stewart et al. (1993), Chen (1994), Goh et al. (1997) studied the behaviour of piles in soils undergoing lateral movement by a 2-d plane strain finite element analysis assuming different soil displacement profiles. Poulos and Chen (1996) predicted ground movements using 2d FE analysis and studied the response of piles using boundary element approach. Bransby & Springman (1999) attempted to predict passive lateral stress due to the ground movement and then studied the pile-soil interaction behaviour by 2-dimensional finite element analysis for a single rigid pile and for closely spaced pile rows. Efforts have also been initiated by a few investigators Pan et al. (2002), Karthigeyan et al. (2004)] to analyse the response using 3-d finite element analysis assuming various soil movement profiles. In view of the above, the present paper discusses the 3-d finite element studies to predict the ground movement due to excavation, and to investigate the effect of parameters, viz., magnitude of ground movement and location of pile from source of movement on the response of piles.

PRESENT FINITE ELEMENT MODEL

In the present analysis, a three-dimensional finite element program has been developed to simulate the response of piles under excavation-induced ground movement. For modelling, the pile is assumed to be linear elastic and the soil is treated as an elasto-plastic

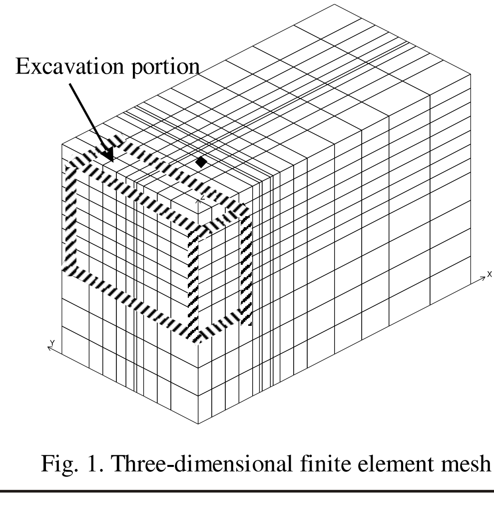
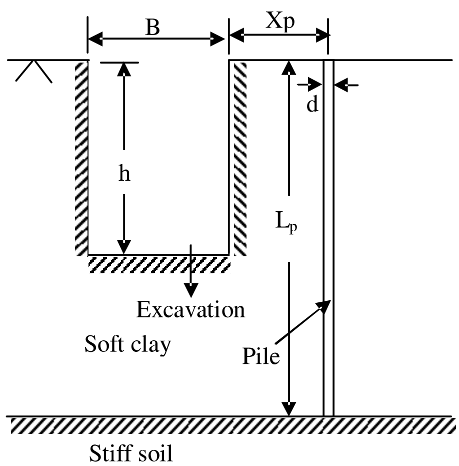


Fig. 1. Three-dimensional finite element mesh

material, obeying Drucker-Prager yield criterion with non-associated flow rule. The finite element mesh (Fig.1) consisting of both pile and soil continuum has been generated using 20-node isoparametric brick elements. All the nodes on the lateral boundaries are restrained from moving in the normal direction to the surface representing rigid, smooth lateral boundaries. All the nodes on the bottom surface are restrained in all the three directions. The numerical modelling details and incremental finite element procedure adopted etc. have been in general as brought out in Rajagopal et al. (2003).

For the sake of analysis, a typical problem with the parameters as shown in Fig.2 has been chosen. The analysis has been carried out in two stages. In the first stage, the ground movement due to excavation is predicted and in the second stage, the



[B - width of excavation = 8m, H - total thickness of clay = 15m, X_p - pile at a distance from excavation, h - depth of excavation = 7m, c_u - cohesive strength of clay = 30kPa, γ - unit weight of soil = 17kN/m^3, E_s - Young's modulus of soil = 12MPa, L_p - pile length = 15m, d - pile diameter = 0.6m and E_p - Young's modulus of pile = 25000MPa. For the sake of analysis, it is assumed that soil is excavated for an area of 8 × 10 m with maximum height up to 7m are considered].

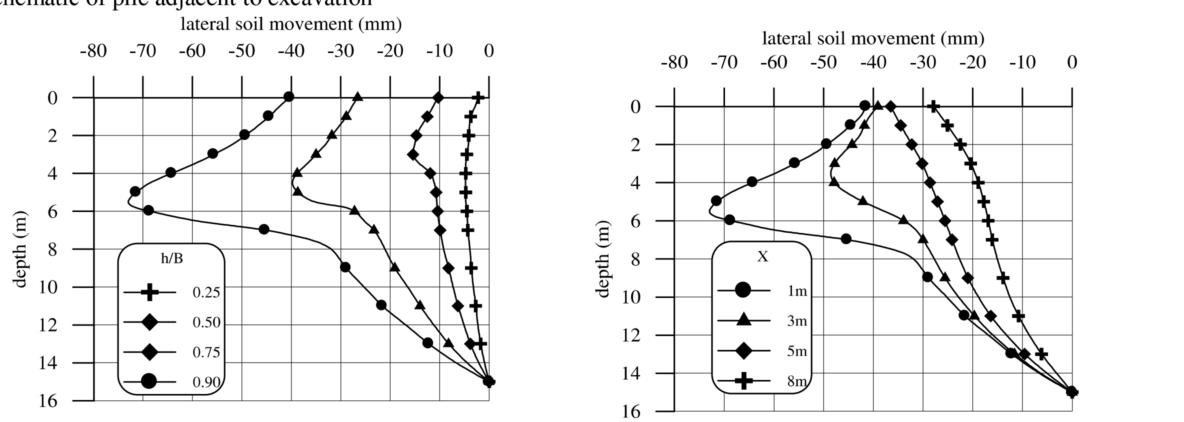
Fig. 2. Schematic of pile adjacent to excavation

response of adjacent piles under these induced ground movements has been analysed. Prior to the actual analysis, the self-weight analysis (K_0 condition) has been carried out. The analysis for the excavation has been carried out from top to bottom in 7 steps, with each step involving the removal of a 1m thick clay layer. During the next stage, the computed lateral soil movements were then used as input to study the pile response.

RESULTS AND DISCUSSION

Fig. 3a represents the lateral soil movements predicted at 1m away from the face of excavation with respect to different stages (depths) of excavation. It can be seen from the figure that the variation of the lateral soil movement along the depth is of parabolic nature, i.e., the ground movement increases with increase in h/B ratio and the rate of increase is more rapid for h/B value beyond 0.5, indicating that the magnitude of lateral soil movement is much more high when the depth of excavation becomes almost equal to the width of excavation (h/B = 0.9). Further, it is also noted that the ground movement is maximum towards the bottom of excavation. Fig. 3b shows the predicted lateral soil movements at maximum depth of excavation w.r.to different locations away from the face of excavation. It can be seen from the figure that the lateral soil movement decrease with increasing distance from excavation face and it is seen that the lateral soil movement increase rapidly near to excavation as seen from the case of 1m from excavation face. Further, it is also noted that the depth at which maximum ground movement occurs is moving towards the bottom of excavation particularly at closer distances from excavation face.

Series of three-dimensional finite element analysis have been carried out for the response of pile located at different distances from the excavation face by incorporating the lateral soil movement profiles predicted at respective locations from the excavation face. The



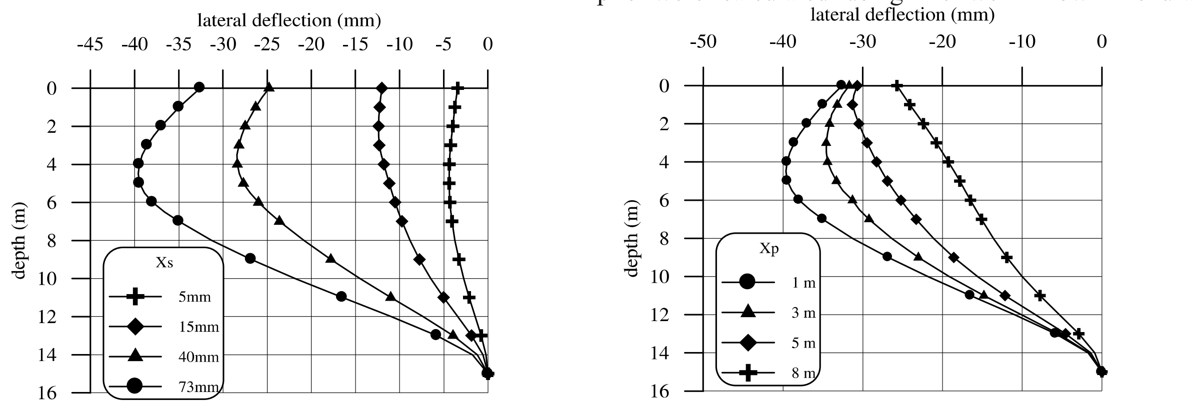
(a) At 1m from face of excavation (b) At maximum depth of excavation

Fig. 3. Predicted lateral ground movement due to excavation

lateral deflection profile along the depth of pile with respect to different soil movement profiles as predicted above is presented in Fig.4a. The maximum soil movement in each case is shown in the legend. It can be seen from the figure that the trend of pile deflection profiles is almost in line with the ground movement profiles as seen in Fig. 3(a). Also, it is noticed that at smaller ground movements, the maximum lateral deflection of pile is almost equal to the induced ground movement, which indicate that the pile is relatively flexible in nature. On the other hand, at larger ground movements, the lateral deflection of piles are relatively less compared to the induced ground movements, thus indicating that the relative stiffness of the piles even depend upon the induced ground movement.

Fig. 4b shows the lateral deflection profile of pile with respect to induced movements at different locations (X_p) away from the face of excavation. The ground movements were considered at maximum depth of excavation. It is seen from the figure that the response of pile at a larger distance (i.e. 8m away from the ground movements were considered at maximum depth of excavation) almost represent the trend of a pile subjected to direct (active) lateral loads (where there is no effect of induced movement) and the trends have changed significantly when the movements are induced closer to the pile.

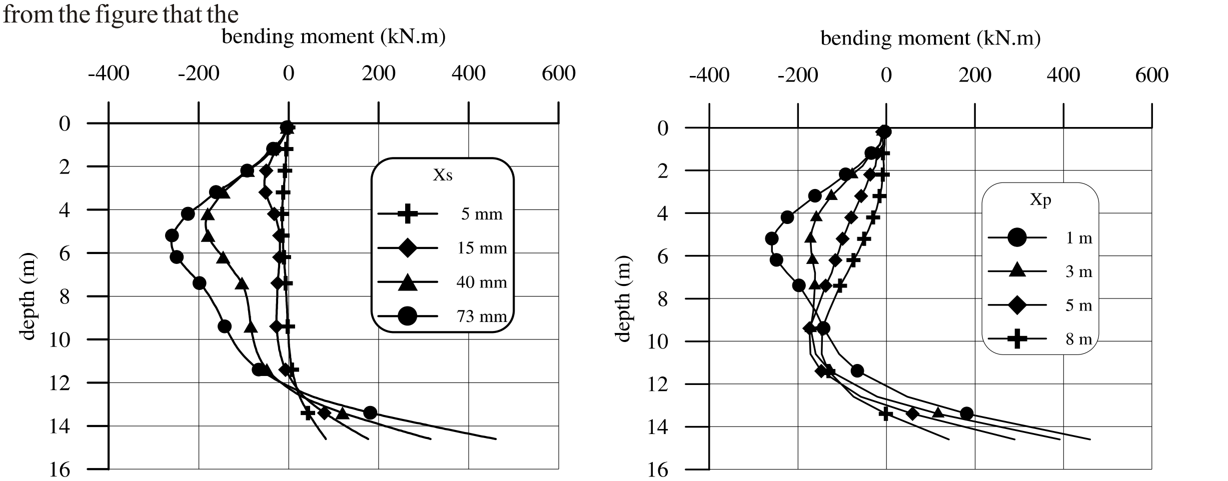
The bending moments along the depth of the pile were calculated using the well known flexural equation 'f' = (M/I)y in which 'f' is the flexural stress and y is the distance from the neutral axis. The normal stress in the 'z' direction is used for this calculation. Fig.5a shows the variation in bending moments along the depth of piles with respect to different soil movement profiles. It can be noted from the figure that the bending moment in pile section increases with the increase in magnitudes of ground movement. Further, the increased values of bending moment towards the pile tip may be due to resting of the pile on a relatively stiff soil layer. Fig. 5b shows the bending moment response of pile while located at different distances



(a) Effect of ground movements at X = 1m

(b) Effect of location of pile

Fig. 4. Response of pile under excavation induced lateral soil movement



(a) effect of ground movement at X=1m

(b) effect of location of pile

Fig. 5. Bending moment variations along the length of pile due to excavation adjacent to pile

(X_p) away from the face of excavation. It is seen from the figure that the pile located nearer (X_p=1m) to the excavation face exhibited higher bending moments than the pile located away from the excavation face.

COMPARISON OF PRESENT FE MODEL AGAINST PUBLISHED WORK

The lateral deflection response of pile predicted from the present 3-D numerical model has been compared against that predicted by Poulos & Chen (1996) for a case of excavation-induced ground movements. The excavation was carried out from top to bottom in 10 steps, with each step involving the removal of a 1m thick layer. The pile was 0.5m diameter and 22m deep and the soil was uniform clay layer (γ = 20kN/m^3 ; c_u = 50kN/m^2). In the Poulos analysis, the excavation-induced ground movements were predicted using 2-d plane strain finite element analysis and the pile response was studied using boundary element approach, whereas the present analysis the 3D finite element analysis has been used in both the stages. The height of excavation was expressed in terms of stability number $N_c = \gamma h/c_u$. The predicted lateral deflection response of pile located at 1m from the face of excavation against that of Poulos analysis as shown in Fig.6 reveals reasonably good agreement.

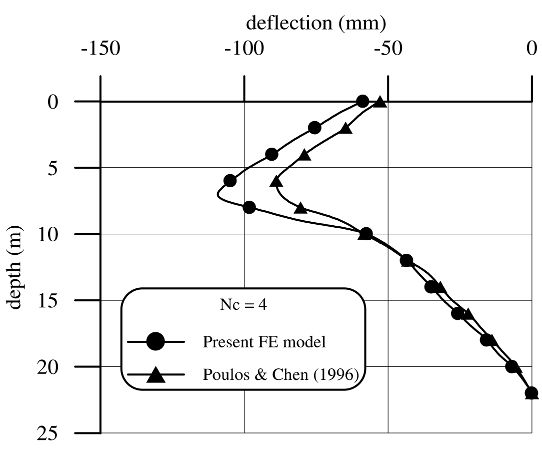


Fig. 6. Comparison of present FE model against Poulos & Chen model.

CONCLUSIONS

Based on the study, the following conclusions can be drawn;

A 3-D finite element analysis can be resorted to investigate the effect of various parameters on the response of pile under induced lateral ground movements.

The response of pile under excavation-induced lateral ground movements are more sensitive to the magnitude of soil movements, pile location from the excavation, stiffness of pile etc.

The lateral deflections and bending moments in piles are significant when piles are located nearer to the excavation face and hence proper care shall be taken while taking up the excavations nearer to pile-supported structures and/or the piles should be designed with additional factor of safety if such situation is likely in the near future.

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