RESPONSE OF PILES UNDER PASSIVE LATERAL LOADS A NUMERICAL APPROACH

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ABSTRACT: The paper describes a 3D finite element based numerical approach to investigate the response of piles under passive lateral loads induced due to an adjacent excavation. In the analysis, the pile is treated as linear elastic material and the soft clay has been idealized using Drucker-Prager constitutive model with non-associated flow rule. The effects of some of the key parameters like height of excavation and pile location from excavation face are studied. The numerical results are presented in terms of lateral deflections and maximum bending moments in piles. Simultaneously, the results of the analysis carried out on piles under active lateral loads (corresponding to pile deflections upto 5% of pile width) are also presented and discussed. The limiting values of the above parameters beyond which passive lateral loads really need to be given serious emphasis in the design of piles has also been brought out.

1. INTRODUCTION

The piles, in general are designed to support 'active loads', i.e. the loads that 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. The resulting stresses can be significant, particularly when soft soil deposits are present and the lateral soil displacements are large. 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. Hence, it is essential to enumerate the influence of these passive lateral loads on the response of piles.

Stewart et al. (1993), Chen (1994) 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 2-d FE analysis and studied the response of piles using boundary element approach. 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 the similar lines, the present paper describes a 3-d finite element study to evaluate the response of piles under passive ground movement due to an adjacent excavation. The ground movements with respect to different heights of excavation and at distances away from excavation face are initially predicted and the effect of these profiles on pile response is presented and discussed. Further, the limiting value of the above parameters upto which the pile designed for active loads is good enough to take care of the passive loads and beyond which serious emphasis need to be given, is also outlined.

2. PRESENT FINITE ELEMENT MODEL

In the present analysis, a three-dimensional finite element program has been developed. The pile is assumed to be linear elastic and the soil is treated as an elasto-plastic material, obeying Drucker-Prager yield criterion with non-associated flow rule. The finite element mesh 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 FE mesh details, analysis scheme using incremental finite element equations adopted etc. have been in general as brought out in Rajagopal et al. (2003). A typical problem with the schematic as shown in Fig.1 has been chosen and for the sake of analysis, the following parameters are considered:

Pile : *Diameter (D) = 0.6m ; Length (L) = 15m; Young's Modulus (Ep)= 25000MPa; x - pile location away from excavation face = 0 to*

50D; Soil : cohesive strength of clay (c_u) = 30kPa, unit weight of soil (γ) = 17kN/m^3, E_s - Young's modulus of soil = 12MPa.

Excavation : Unsupported type; Width (B) = 8m; Maximum height (h) from stability considerations = 7m.

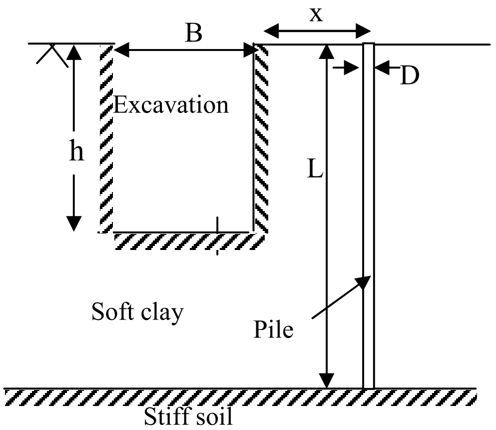
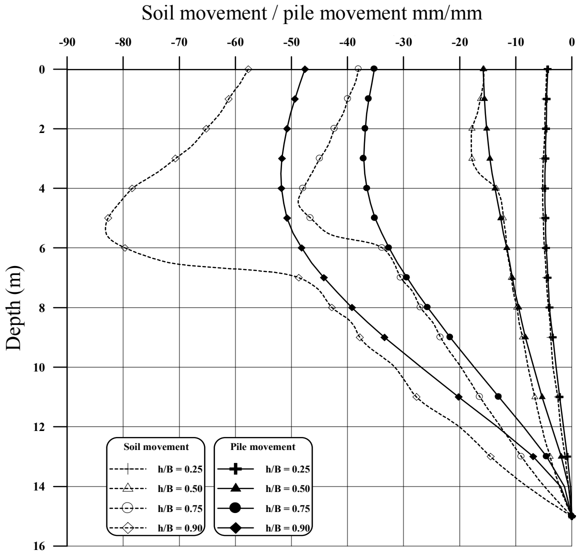


Fig. 1 Schematic of pile adjacent to excavation

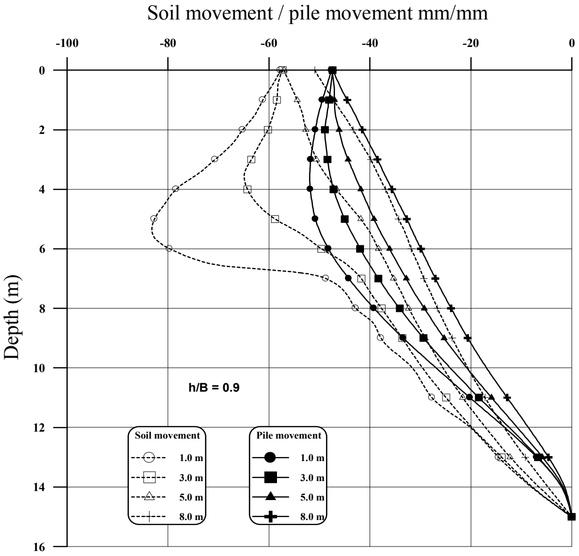
Prior to the actual analysis, the self-weight analysis (K_0 condition) has been carried out. The passive load analysis is carried out in two phases. In the first phase, the analysis for the excavation has been carried out from top to bottom in steps, with each step involving the removal of a clay layer of specified thickness to predict the free-field stresses / ground movements. While in the second phase, the predicted ground movement profiles are imposed onto the pile to study the response. The validation of the proposed numerical model against the popular work of Poulos and Chen (1996) has been discussed in Ramakrishna et al. (2005). Simultaneously, the pile is also analyzed for active lateral loads considering loads corresponding to different lateral deflection levels upto 5% width of pile.

3. RESULTS AND DISCUSSION

Fig. 2a represents the response of pile (located at 1m away from the excavation face) with respect to different heights of excavation. The dotted lines represent the lateral soil movement profiles initially predicted with respect to different stages (depths) of excavation without considering the presence of pile. It can be seen from the figure that the ground movement increases with increase in h/B ratio and the magnitude of lateral soil movement is much more high when the height of excavation becomes almost equal to the width of excavation (h/B = 0.9). It is also noted that magnitudes and variations in the pile deflection & soil movement profiles are almost same at shallow depths of excavation and varied significantly as the height of excavation increased. Besides, it is also observed that the ground movements are highest closer to the bottom of excavation and consequently, the pile deflections are also high towards the points of maximum soil movement. Fig. 2b shows the pile response at different locations away from the excavation face along with the initially predicted lateral soil movement profiles (without considering the presence of pile). The ground movements were considered at maximum depth of excavation. This figure indicates that the soil movements are large closer to the excavation face and reduce at distances. The pile response curves also showed similar trends, i.e., the deflections are more when the excavation takes place nearer to the pile and less at greater distances.



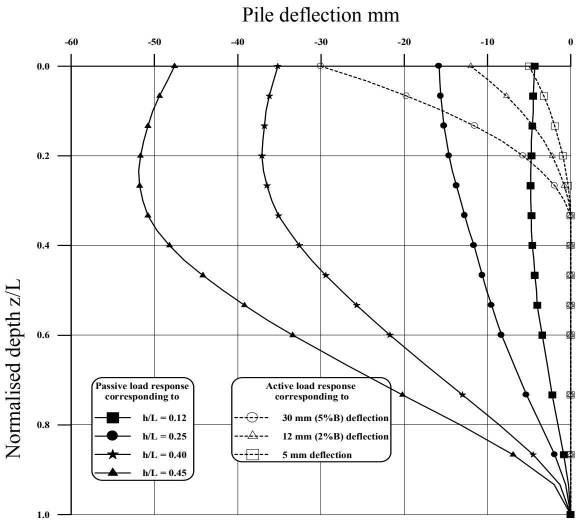
(a) Effect of height of excavation



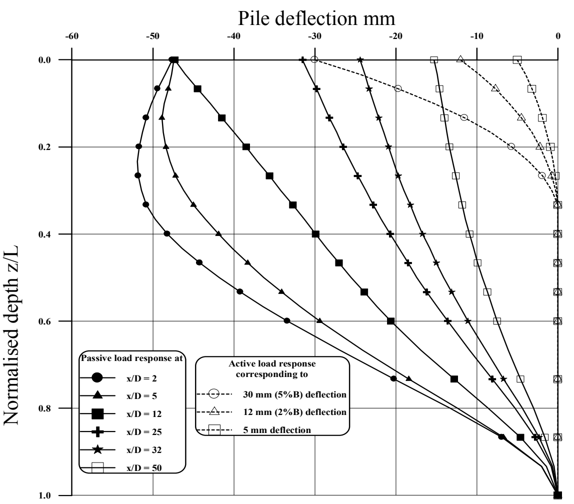
(b) Effect of pile location from excavation face

Fig. 2 Pile Response under Passive Loads due to Adjacent Excavation

Fig. 3a shows the pile deflection response along the depth (normalized, z/L) corresponding to different depths of excavation (normalized, h/L) ranging from 0.12 to 0.45. The dotted curves in this figure represent the pile behaviour initially designed for active loads corresponding to 30mm (5%B), 12mm (2%B) and 5mm (0.8%B) deflections. It is brought to the notice of the readers that the analyses for active loads and passive loads are done independently and thus the results are to be seen separately and not to be interpreted as a combined behaviour. From this figure, it can be interpreted that the behaviour of the piles in the portion above the intersection of solid and dotted curves is governed by the active loads and below, is governed by the passive loads. i.e., the active loads are slightly dominant in the top portion of pile for shallow depths of excavation, and once the excavation depth increases, the influence of passive loads initiates and aggravates.



(a) Effect of height of excavation



(b) Effect of pile location from excavation face

Fig.3 Pile Response along depth under Passive and Active Loads

Similarly, the variations with respect to different pile locations away from excavation face (and corresponding to maximum depth of excavation) as presented in Fig. 3b also reveal that except at a few locations beyond x/D = 32, mostly the passive loads govern the behaviour. For further understanding, the maximum pile deflections corresponding to different depths of excavation, which are of interest to designers, are plotted against the pile locations as shown in Fig. 4. In this figure, the intersection of the passive load response curves at 30mm, 12mm and 5mm deflections demarcates the criterion between active and passive loads to govern the design of piles. These limiting values are summarized in Table 1.

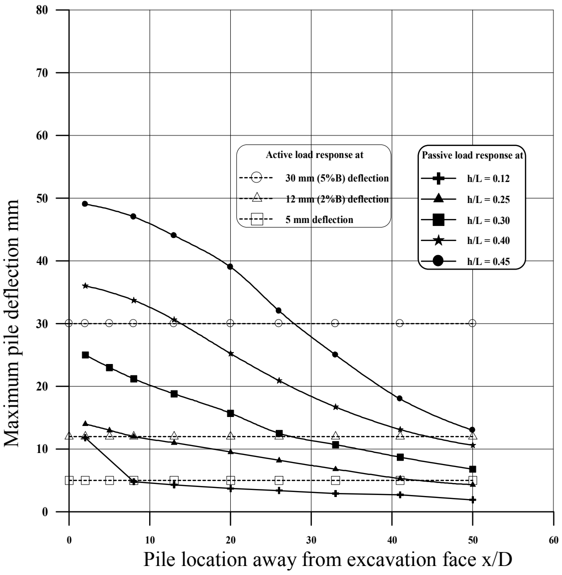


Fig. 4 Maximum deflection response of pile under Passive / Active loads

Table 1. Quantitative demarcation for active/passive loads to govern the design

Normalized depth of Excavation (h/L)	Normalized Pile location (x/D) beyond which pile design is safe		
	30 mm	12 mm	5 mm
0.12	0	3	8
0.25	0	8	41
0.30	0	26	> 50
0.42	13	43	> 50
0.45	28	50	> 50

From the table, it is understood that if a pile is designed for an allowable deflection of 30mm (5%B), the design is safe even if an excavation takes place upto depth of 0.3 times the pile length and even at a very close vicinity (zero distance). However, if the depth of excavation increases and if it is within the vicinity of less than 13 D distance, the influence of passive load initiates. Similarly, if the pile is designed only for an allowable deflection of 12mm, the passive load influence starts right from a depth of excavation of h/L = 0.12, however, the design is safe if the pile is located beyond a distance of x/D equal to 3. The influence is severe as the depth of excavation increases and extend even to large distances of 50D at h/L = 0.45. For normal residential structures, where piles are allowed to deflect not more than 5 mm as per Indian practice, it is clear that the passive loads have predominant effect right from the surface and extend to depths and for piles located even at distances beyond 50D or so. Thus, it is essential to take some precautionary measures to avoid such situations or if inevitable, the piles should be designed accordingly incorporating the effects due to possible passive loads.

The bending moments along the depth of the pile were also 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. For the present discussion, the maximum bending moments in the pile are also plotted with respect to different depths of excavation and distances away from the excavation face as shown in Fig. 5. The points of intersection of the curves demarcating the pile locations and depths of excavation between passive and active response that could be noted from this figure also substantiate the results observed from Fig. 4 and Table 1.

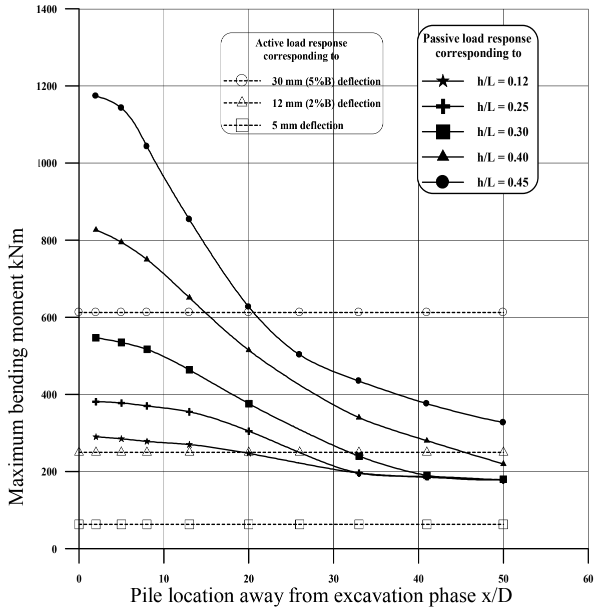


Fig. 5 Maximum bending moment response of pile under Passive / Active loads

4. 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 passive loads in detail and to distinguish from the active response of the piles. The effect of passive loads on the response of piles is more sensitive to the magnitude and variation of ground movements, pile location from the source of movement. Thus it is no doubt a serious concern, but the intensity of the influence of passive loads depends also on the (active) loads and displacements for which piles are initially designed. In view of the increasing construction activity, particularly in the urban areas, it is time to look into the current design practices, and it is desirable to design the piles for greater allowable deflections, so that effect of passive loads can be counteracted to the possible extent.

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