6.1 INTRODUCTION

In Chapter 4, presentation of the results of the analysis of the single piles and groups of piles of uniform diameter has been made along with discussion. In this chapter, results of studies on straight-shafted piles embedded in non-homogeneous expansive clays are presented and discussed.

6.2 DISTRIBUTION OF FORCES ALONG THE PILE LENGTH

6.2.1 SINGLE PILE

Fig.6.1 shows the depth-wise variation of \( \frac{P}{P_{IS}} \), the ratio of the cumulative load at any depth \( Z \) to the maximum load in a single isolated pile embedded in an expansive clay with varying Young's Modulus. The variation is given for different \( L/d \) ratios ranging from 10 to 50. As in the case of piles embedded in homogeneous clays, in this case also, the maximum value of \( \frac{P}{P_{IS}} \) occurs around the mid-depth of the pile. However, there is no negative load, which has occurred in case of piles in homogeneous soils, for \( L/d \)=10. Instead, small values on the positive side are seen. When \( L/d \) increases from 10 to 20, there is a substantial increase in the pile load ratio \( \frac{P}{P_{IS}} \) which is about 4.5 times that obtained for \( L/d \) is equal to 10. Beyond \( L/d \) equal
to 20, the pile load ratio once again drops and continues to decrease with increase in the 'L/d' ratio. A similar trend was observed in case of piles embedded in homogeneous soils. The reasons for this distribution are the same as those given for homogeneous soils.

As the length of the pile increases, the withholding force increases and, therefore, 'P/IS' increases. This causes the reduction in 'P/IS' with increase in 'L/d' ratio.

It can be seen that the absolute values of 'P/IS' for any 'L/d' are higher than the corresponding values of the piles embedded in homogeneous soils, presented in chapter 4 of this thesis.

6.2.2 PILE GROUPS
6.2.2.1 EFFECT OF NUMBER OF PILES IN A GROUP

The depth-wise variation of 'P/IS' for pile groups containing 2, 3 and 4 piles are presented in Figs. 6.2 to 6.4 respectively. Piles with 'L/d' equal to 10 have the least value. However, piles with 'L/d' equal to 20 have the maximum value of 'P/IS', as in the case of single piles. Beyond 'L/d' equal to 20, once again the pile load ratio drops. This trend is clearly discernible in all the pile groups. With increase in number of piles, the value of 'P/IS' decreases for any 'L/d', and at any depth, as in the case of piles in homogeneous soils, (Fig.6.5). This is due to the effect of the influence of the neighbouring piles on the load-carrying capacity on any pile whereas 'P/IS' remains constant. When compared with the values of a single isolated pile, for 'L/d' of 30 and 's/d' of 3.0, the percentage reduction in pile loads at about the mid-depth of the piles are 19.36 and 42.5 for 2-, 3- and 4- pile groups respectively.
6.2.2.2 EFFECT OF PILE SPACING

Figs. 6.6 to 6.8 show the depth-wise variation of the pile load ratio $P/P_{IS}$ in 2-, 3- and 4- pile group respectively. The spacing between the piles is varied from 2d to 4d. The effect of spacing can be clearly seen from the figures. At around the mid-depth of the pile where the maximum cumulative load occurs, cumulative pile load increases with increase in spacing. This trend is obvious because with increase in the pile spacing, interference from the neighbouring piles will be reduced and hence the pile load increases. However, the effect due to spacing at any depth, in respect of piles in non-homogeneous soils is less when compared with the effect of spacing of piles in homogeneous soils. Further, the absolute values of the pile load ratios $P/P_{IS}$, for any $s/d$, are also smaller for piles in non-homogeneous soils when compared with those in homogeneous soils.

6.3 MAXIMUM PILE LOAD

6.3.1 EFFECT OF $L/d$ RATIO

Figs. 6.9 to 6.11 show the effect of $L/d$ on the maximum pile load ratio $P_{max} / E_0 d S_0$ for $K=1000$, $v=0.30$ and $Z_d L = 0.2$, for 2-, 3- and 4- pile groups and for different pile spacings varying from 2d to 4d. It can be seen that, generally, as $L/d$ increases, the maximum pile load increases for any group. However, for a 2-pile group at $L/d$ equal 15, there is peak followed by a trough at $L/d$ equal to 20 for any pile spacing. Correspondingly, for the 3-pile group, the crest and trough occur at $L/d$ values of 20 and 25 respectively for all pile spacing. However, for a 4-pile group, the crest occurs at $L/d$ equal to 20 followed by trough at $L/d$ equal to 25 for pile spacing equal to 2d. As pile spacing is increased to 3d and 4d, the crest is shifted to $L/d$ equal to 25.
and the trough to $L/d$ equal to 30. Similar trends were observed in respect of piles in homogeneous soils also. But in the case of non-homogeneous soils, the positions of crests and troughs are shifted to larger $L/d$ ratios for each of the pile group considered.

Figs. 6.12 to 6.14 give the effect $L/d$ on the maximum pile load ratio for 2-, 3-, and 4- pile groups and for the same spacings as above, but for a $Z/g/l$ value of 0.6. The trends are exactly the same including the relative positions of crests and troughs. Only the absolute maximum values of $P_{\text{max}}/E_d d_S$ have increased from what were obtained for $Z/g/l = 0.2$. Similar increase with $Z/g/l$ was obtained for single incompressible piles with a constant Young's modulus up to $Z/g/l = 0.75$ (Poulos and Devis, 1980).

6.3.2 EFFECT OF NUMBER OF PILES AND PILES SPACING

Figs. 6.9 to 6.14 also depict the effect of the number of piles in a group. The values of the maximum pile load ratio increase with the increase in the number of piles. This is quite understandable. Also observed from the figures is the increase in the maximum pile load with increase in the spacing. This is also logical because, as the spacing between the piles increases, the piles to tend to behave more as single isolated piles and the influence of the other piles on any pile in the group reduces.
Fig. 6.1: Depth-wise variation of \( P/P_{1S} \) for a single straight-shafted pile (Variable 'E')
Fig. 6.2: Depth-wise variation of $P/P_{1s}$ for a 2-pile group of straight-shafted piles (Variable 'E')
Fig. 6.3: Depth-wise variation of \( P/P_{1s} \) for a 3-pile group of straight-shafted piles (Varying 'E')
Fig 6.4: Depth-wise variation of $P/P_{15}$ for 4-pile group of straight shafted piles (Variable 'E')
Fig. 6.5: Depth-wise variation of $P/P_{1s}$ for piles in different groups (Variable: 'E')

K = 1000
\( v = 0.30 \)
\( s/d = 3.0 \)
\( L/d = 30 \)
Fig. 6.6: Depth-wise variation of $P/P_{1s}$ for a 2-pile group of straight-shafted piles, for different $s/d$ ratios (Variable 'E')
Fig. 6.7: Depth-wise variation of $P/P_{1s}$ for a 3 pile group of straight-shafted piles, for different s/d ratios (Variable 'E')
Fig. 6.8: Depth-wise variation of $P/P_{1s}$ for a 4-pile group of straight-shafted piles, for different $s/d$ ratios (Variable 'E')
Fig 6.9: Variation of $P_{\text{max}}/E_dS_0$ for a group of 2 straight-shafted piles

$K=1000$
$v=0.30$
$Z_s/L=0.2$
Fig. 6.10: Variation of $P_{\text{max}}/E_d d_S_0$ for a group of 3 straight-shafted piles
Fig. 6.11: Variation of $P_{\text{max}}/E_d dS_0$ for a group of 4 straight-shafted piles.
Fig. 6.12 : Variation of $P_{\text{max}}/E_s d S_0$ for a group of 2 straight-shafted piles

$K=1000$
$v=0.30$
$Z_s/L=0.6$
Fig. 6.13: Variation of $P_{\text{max}}/E_s dS_0$ for a group of 3 straight-shafted piles.

- $K = 1000$
- $\gamma = 0.30$
- $Z_s/L = 0.6$

Graph showing the variation of $P_{\text{max}}/E_s dS_0$ with $L/d$ for different $s/db$ values.
Fig. 6.14: Variation of $P_{\max}/E_d dS_0$ for a group of 4 straight-shafted piles