UPLIFT CAPACITY OF PILE GROUPS

CAPACITE DE SOULEVEMENT DE PIEUX EN GROUPE

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SYNOPSIS : From the limited informations available for ultimate uplift capacity of pile groups embedded in different soils, it is seen that variables like group shape, size, spacing and length to diameter ratio of the piles, soil type and method of installation affect the efficiency of the pile group in uplift. In order to investigate the effects of such variables, uplift tests on group of 2,3 and 4 numbers of model pile groups for various spacing and length of embedment were conducted in dry sand and also in compacted cohesive soil. Group uplift efficiency varies with embedment, number of pile in the group and also spacing of the pile in groups upto certain value.

INTRODUCTION :

Piled foundations are generally used to support compressive loads from superstructures. However foundations of structures like transmission tower, tall chimneys, mooring systems for ocean surface or submerged platforms jetty structures etc. are constructed on pile foundations, which have toresist uplift loads. Straight shafted piles are being used increasingly to resist and sustain uplift loads and it is becoming necessary to evaluate accurately the uplift resistance of piles for economic and safe design. Theoretical and experimental investigations have been carried out in last few decades to study the behaviour of piles subjected to tensile axial inclined or lateral loads. Several theoretical methods to predict uplift capacity of single piles are now available. (Chattopadhyay and Pise 1985, 86a 86b, 87, 90, Chattopadhyay 90). Effects of different factors like diameter and length of embedment of pile, method of pile installation, inclination of pile axis or load application with vertical, presence of number of layers of soils within the depth of embedment, on the uplift capacity of the pile, have been investigated.

In many circumstances, however, piles are used in groups. Related published materials for the uplift capacity of pile groups are scarce. A limited number of experimental results for the ultimate uplift capacity of pile grous embedded in sand, are presently available in the works of investigators like Chaudhuri, Ghataora, and Symons (1982), Das et al. (1976),Meyerhof and Adams (1968). Some large scale field tests on the group capacity of screw piles in sands have been reported by TrofimenKov and Mariupolskii (1969). In contrast, published works relating to the ultimate uplift capacity of group piles embedded in clays are still lesser. Meyerhof and Adams (1968) presented results of few model tests on uplift capacity of pile groups in clay. Das and Azim (1985) reported results of some laboratory tests on group uplift capacity of piles in clay with embedment ratio varying between 10 to 18.

However, it appears that there are several variables such as the group shape, length and size of the piles, spacing, length to diameter ratio of the piles, soil type and method of installation of the pile, which will affect the efficiency of the uplift capacity of the piles. More theoretical and experimental studies are needed for proper understanding of the uplift capacity of pile groups. In order to investigate the effects of above variables, on uplift capacity of pile grous, a programme was undertaken to conduct uplift test on model pile groups with various shapes, sizes and spacings.

In this paper, results of uplift capacity test on model pile groups of various configurations, pile spacings and lengths of embedment, in dry sand and also compacted cohesive soil, are reported.

EXPERIMENTAL PROGRAMME

Laboratory model test were conducted on model aluminium piles of diameter 19 mm. For conducting test on group of piles at various centre to centre spacing to diameter ratio, the piles were attached to steel pile caps. The pile caps were made out of steel plates with proper attachments of fixing piles at desired spacing in a geometric pattern of group configuration.

The plans of the configuration of group piles tested are shown in Fig.1. Three pile groups comprising of 2 piles, 3 piles and 4 piles respectively alongwith a single pile, as shown in Fig.1 were tested for spacing, s, varying between 2.3d to 6.0d, where d = diameter of the pile. Uplift tests were conducted for length of embedment ranging from 30 cm to 60 cm. Model tests were conducted in a model test tank having dimensions of 145 cm x 90 cm high.

The soil used for the first series of the test was locally available brownish grey dry Mogra sand. The sand is coarse to medium, with D_{60}= 0.95 mm, D_{10}= 48mm and Cu =1.98. Different pile groups alongwith single

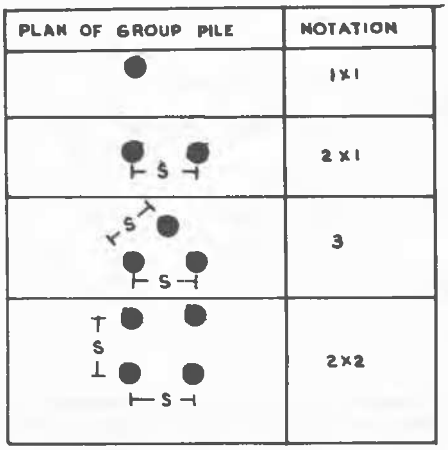


FIG.1 CONFIGURATION OF GROUP PILES TESTED IN SAND & COMPACTED COHESIVE SOIL.

pile were suitably positioned in the tank and sand was prosed by rainfall technique to embed the piles with to and from movement of steel hopper from a height of 30 cm. The placement density of sand ranged arround 1.70 g/cc.

The soil used for second series was locally available blackish grey clayeysilt having 8% clay and 92% silt. The effective size D was 0.005 mm and corresponding values of uniformity coefficient is 2.93. The liquid and plastic limits are 35.5% and 23.5% respectively.

Dried soil was pulverised and then seived through IS40. The soil was thoroughly mixed with water to make water content around 17.5%. For testing piles under uplift loads, the placement density of the foundation medium was around 1.70 gm/cc. at a moisture content of 17.5%. To achieve this density, 150 nos of blows per 10 cm thick layer with falling weight of 6.2 kg over a free fall of 30 cm was used. The piles with desired configuration were driven into the soil using guided free fall of hammer on the pile cap.

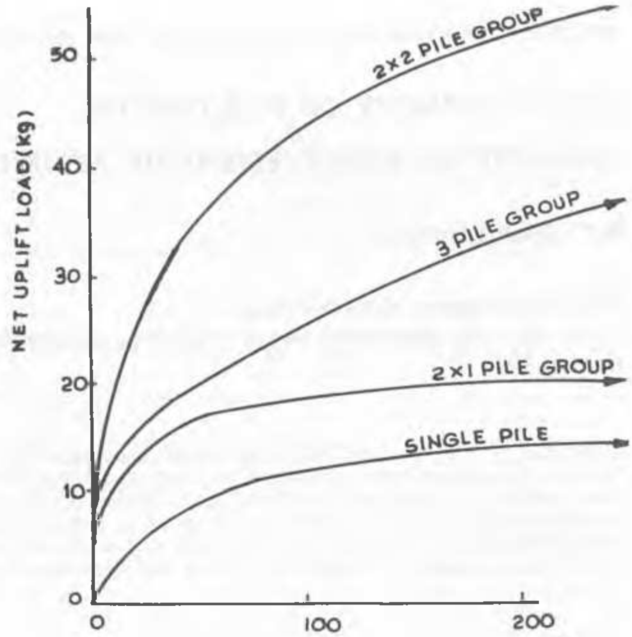
A cable was attached to the top of the pile cap, at its center of gravity and the cable was passed over two pulleys. Step loads were attached to the load hanger causing pull on the piles. The vertical displacement of the pile groups were measured by dial gauges.

MODEL TEST RESULTS

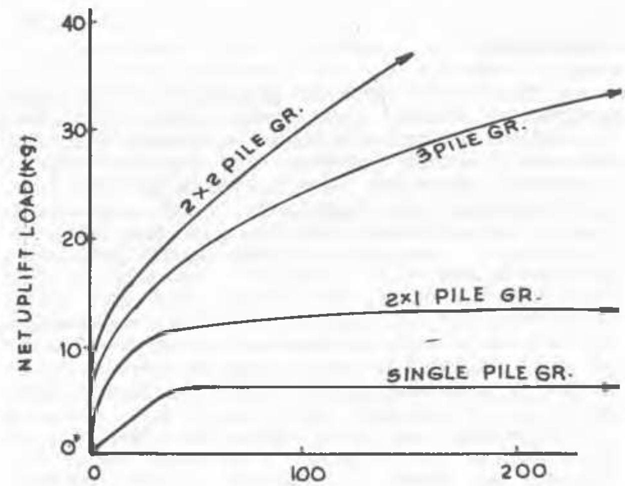
Three series of uplift tests were run for pile groups of 2 x 1, 3 and 2 x 2 piles shown in Fig.1, for embedment depth of 30 cm, 45 cm and 60 cm. In each set of experiment, along with these groups, a single pile was also embedded and tested for uplift. Thus single pile being tested with the groups in same density of soil of embedment, allowed the comparison of the capacity of the pile groups with respect to that of the individual one. The uplift capacity of each p;ile groups was evaluated from uplift load versus pile head cap displacement diagram.

Uplift Capacity of Pile Groups in Sand

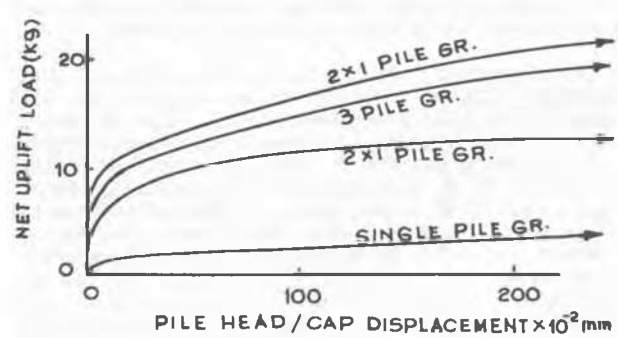
A typical load displacement diagram of a single



(c) PILE LENGTH = 60 cm. d= 1·90 cm.



(b) PILE LENGTH = 45 cm, d= 1·90 cm.



(a) PILE LENGTH = 30 cm · d= 1·90 cm

FIG.2. UPLIFT LOAD VERSUS PILE HEAD/ CAP DISPLACEMENT DIAGRAMS FOR PILE GROUPS= 2·3 d.

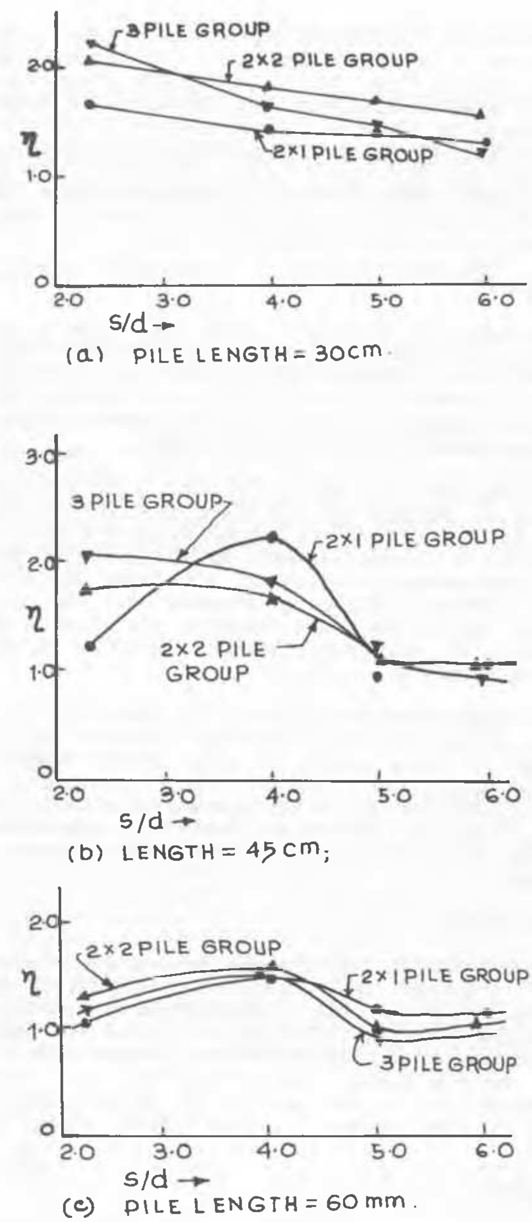


FIG. 3. EFFICIENCY OF PILE GROUPS VERSUS SPACING OF PILES IN SAND.

pile 2x1, 3 and 2x2 pile groups with spacing S = 2.3d, is shown in Fig.2 for lengths of pile embedment of 30 cm, 45 cm and 60 cm. For lesser depth of embedment, but with same spacing it is seen that much lesser pile head/caps movement caused uplift failure. The general nature of these diagrams was similar for different spacings and lengths tested.

The gross ultimate uplift capacity of each pile group was evaluated from the uplift load versus pile head/cap displacement diagram. Variation of the uplift capacity of the pile group is generaly expressed by group efficiency, η , where

$$\eta = Q_{ug} / nQ_u \qquad \ldots \quad (1)$$

where n = No. of piles in a group.

Q_u = Net ultimate uplift capacity of single pile.

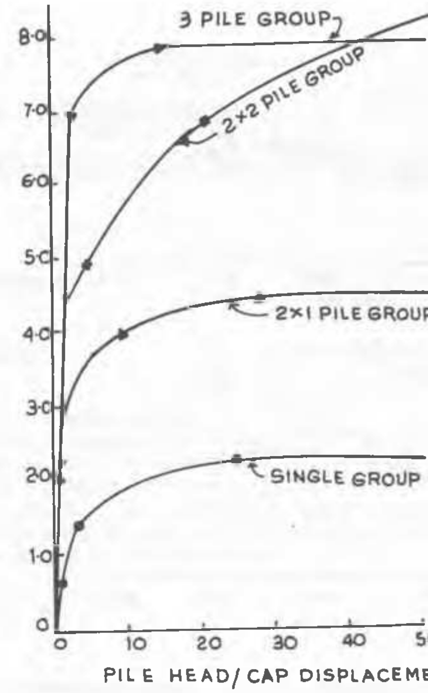


FIG. 4. UPLIFT LOAD Vs PILE HEAD/CAP MOVEMENT PLOT FOR PILES COHESIVE SOIL. L = 30 cm, d = 1.90 cm, S = 2.5d

Using the evaluated values of Q_{ug} from experimental test results and that of Q_u of single pile tested together with the group, the variation of group efficiency, η, have been calculated for all groups. They are shown in Fig.3.

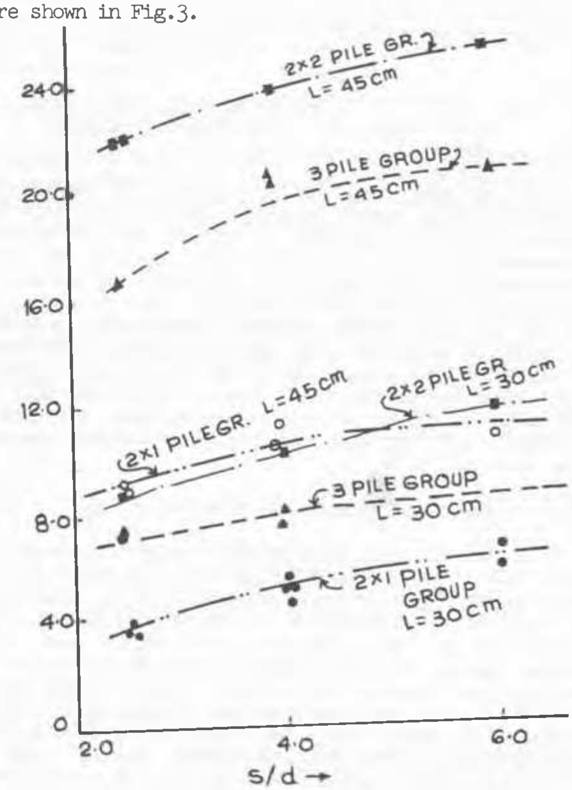


FIG. 5. VARIATION OF NET UPLIFT CAPACITY OF PILE GROUP IN COHESIVE SOIL WITH SPACING.

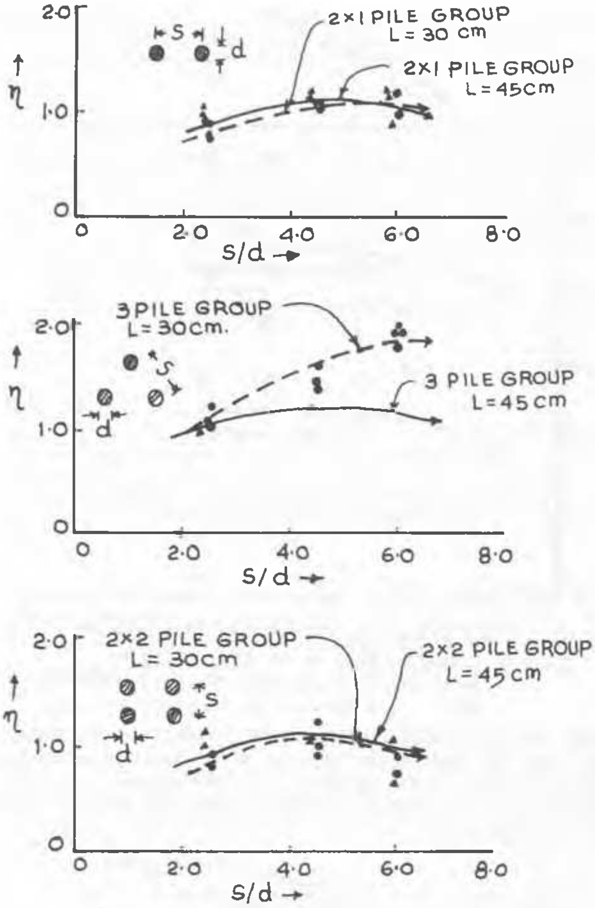


FIG. 6. VARIATION OF GROUP EFFICIENCY WITH S/d FOR PILE GROUPS IN COHESIVE SOIL.

It is seen that for all lengths of embedment, efficiency of all the pile groups is more than 100% for certain range of spacing of piles, and efficiency decreases gradually to 100% when spacing of piles approaches 6d. For 30 cm of embedment of piles,the efficiency is maximum when spacing of pile is around 2d for all the pile groups tested. However with increase of length of embedment, the peak efficiency is attained at higher values of spacing around 4d. It seems groups shape also influences this. However with increase of embedment of pile, the value of maximum efficiency attained, also decrease and isolation effects becomes prominent at S = 6d.

Uplift Capacity of Pile Group in Cohesive Soil

A typical load displacement diagram of a single pile, 2x1, 3 and 2x2 pile groups with spacing S = 2.5d is shown in Fig.4 for pile length of 30 cm. Variation of load with deformation is practically linear and sudden failure took place near ultimate load. The general nature of these diagrams was similar for other spacings and length. Net ultimate uplift capacity of each pile group was evaluated and is plotted in Fig.5 against S/d ratio. Using the experimental values, the group efficiency has been calculated from Eq.1 and is plotted in Fig.6 against the spacing of piles. From this plot it is observed that behaviour of 3 pile group in triangular configuration is different from those of 2x1 and 2x2 pile groups. Particularly for pile length of 30 cm, group efficiency of 3 pile group increases from 100% to nearly 200% with s/d increasing from 2.5 to 6.0. However this effect decreases with increase in length of pile to 45 cm. For 2x1 or 2x2 pile groups, the group efficiency is less than 100% when s/d ratio is 2.5 and increases to 100% when s/d ratio approaches a value of 6.0d. This has been also observed for steel piles embeded in clay for L/d ratio with a range of 12 to 15 (Das and Azim, 1985). Further the group efficiency for 2x1 or 2x2 pile groups, is seen not be too much affected by variation of length of embedment of piles.

CONCLUSION :

A number of laboratory model test results for ultimate uplift capacity of pile groups embedded in dry sand and also in cohesive soil have been presented for different geometry of pile groups, pile spacings and length of embedments. Based on the present tests, following general conclusions can be drawn.

1. In dry sand, in uplift, for 2x1, 3 or 2x2 pile groups it is observed that for close spacing of piles, the group efficiency attains a p eak value greater than 100% and the efficiency decreases to 100% gradually with spacing approaching a value of six times the pile diameter. Maximum efficiency attained and the pile spacing at which this occurs depend on the group shape and length of embedment. However, isolation effect becomes prominent at s = 6d.

2. In compacted cohesive soils, for driven 2x1, 3 or 2x2 pile groups, the group efficiency is seen to be less than 100% for close spacing of piles in the range of twice the pile diameter. The efficiency increases to a value of 100% when s/d ratio approach a value of 6. However triangular pile groups behave differently than the other pile groups particularly in shallow depth of embedments.

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