DESIGN AND CONSTRUCTION OF MULTI-UNDER-REAMED PILES

CONCEPTION ET CONSTRUCTION DE PIEUX MULTI-ELARGIS

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SYNOPSIS Under-reamed piles with single bulbs have now been extensively used in India for foundations of structures built on expansive soils. Recent studies carried out at the Central Building Research Institute have shown that these piles with single or multi-bulbs could find wider applications either as anchor or bearing piles in any type of soil. The economy effected by the multi-under-reamed over the uniform large diameter pile, for the same design load, is found to be very significant. Recent investigations on design and construction procedures of single and multi-under-reamed piles are presented in this paper.

INTRODUCTION

Under-reamed piles are becoming popular in India for foundations of structures built on expansive and other types of soils. They may serve as anchor or load bearing piles. The bulbs of the piles are usually placed in the zones of stable equilibrium for the purpose of anchorage in expansive soils. The general practice is to use a single bulb in a pile for anchorage and one or more bulbs for load bearing. Single under-reamed piles were first adopted in the Indian Sub-continent in the year 1955 (Dinesh Mohan and Jain) for light structures in expansive soils. A study in the field indicated that the average depth of stable zone did not exceed about 12 ft. in such soils and the lengths of under-reamed piles were, therefore, fixed at 12 ft. A subsequent study based on a series of load tests on full scale piles, indicated their usefulness as bearing piles for heavier structures upto three storeys. It was at this stage that two-bulb piles were thought of with the upper bulb lying in the zone of soil movement. It was found that these piles when left unloaded for a long time did not show any significant movement indicating thereby that the upthrust developed on the stem and the upper bulb due to the swelling of soil was not larger than the anchorage provided by the lower bulb. Laboratory investigations further indicated considerable increase in the bearing capacity which were later on substantiated by full scale tests in the field. It was found that by adding one more bulb, the bearing capacity could be increased by 50 per cent.

BEHAVIOUR OF PILES WITH TWO OR MORE BULBS

Two dimensional model tests on multi-under-reamed piles (Fig. 1) in clay show that failure occurs by shearing along the periphery of bulbs and by bearing at the bottom. Model load tests by Neumann and Peleg (1955) also indicated that the load carrying capacity would increase if two bulbs were provided. According to Mintskovkii (1964) all the bulbs in a pile would contribute for the increase in the bearing capacity.

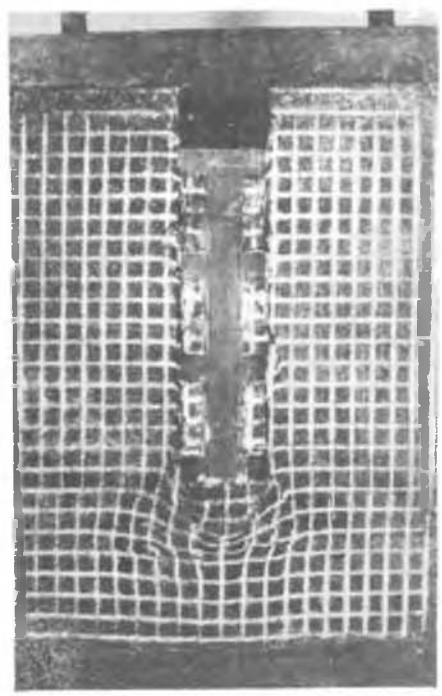

Fig. 1 Two Dimensional Model Test on a Multi-under-reamed pile.

Pull-out tests were carried out on full scale piles to study the effect of spacing of bulbs. The bulbs were spaced at 1.0, 1.25, 1.50, 1.75 and 2.0 times the bulb diameter. Results indicate that the optimum value lies between 1.25 and 1.5.

BEARING CAPACITIES OF UNIFORM DIAMETER AND MULTI-UNDER-REAMED PILES

The ultimate load bearing capacity of a uniform diameter pile in clayey soils may be determined from the expression

$$Q_u = A_p N_c c_p + f c_a A_s \quad \ldots \quad (1)$$

Where

A_p = cross-sectional area of the base
N_c = bearing capacity factor (usually 9 for clayey soils)
c_p = shear strength of the soil around the toe
f = reduction factor (usually 0.5 for Indian black cotton soils)
c_a = average undisturbed shearing strength of the soil along the pile stem
A_s = surface area of the stem.

The proportion of the load shared by friction and bearing depends on the shape of the pile and nature of the strata. Eq. (1) is based on the assumption that the two components of load act independently so that the principle of superposition is justified and suitable factors of safety may be applied to the components to give working loads on piles. Interdependence of stem friction and end-bearing is not ruled out (Hobbs, 1963; Meyerhof, 1951), but at the same time model tests by Cooke and Whitaker (1961) indicate the absence of mutual effects. Based on the present state of knowledge (1968), it can be concluded that the mutual effect is not large and Eq. (1) may be used for all practical purposes.

The ultimate bearing capacity of multi-under-reamed piles may be examined by the following two methods:-

(1) Mobilisation of frictional resistance along the upper shaft, shearing resistance of the soil developed on the surface of the cylinder circumscribing the bulbs and the bearing resistances of the bottom bulb and base.

(2) Mobilisation of frictional resistance along the upper shaft, and the bearing resistances of all the bulbs and the base.

According to method (1), the ultimate bearing capacity equation can be written as

$$Q_u = A_p N_c c_p + A_a N_c c'_a + c'_a A'_s + f c_a A_s \ldots (2)$$

Where

$A_a = \pi/4 (D_u^2 - D^2)$, in which D_u and D are the under-reamed and shaft diameters respectively
c'_a = average undisturbed shearing strength of soil around the under-reams and
A'_s = surface area of the cylinder circumscribing the under-reams.

According to method (2), the ultimate bearing capacity equation can be written as

$$Q_u = A_p N_c c_p + n A_a N_c c'_a + f c_a A_s \ldots\ldots (3)$$

Where

n = number of bulbs.

It has been found that equations (2) or (3) could be applied to piles with bulbs spaced at $1\frac{1}{2}$ times the under-reamed diameter, and possibly equation (3) is more appropriate for greater spacings. The application of the equations can be examined by citing an example. Consider a pile of $24\frac{1}{2}$ ft. long, shaft dia. 2 ft., and under-reamed diameter 5 ft. with 3 bulbs in London clay (Fig. 2). Assuming for London clay (Whitaker and Cooke, 1966) c_p = 1.2 T/sqft., $c_a = c'_a$ = 0.9 T/sqft., N_c = 9, a reduction factor of 0.8 on N_c, the ultimate bearing capacities of the pile according to equations (2) and (3) work out to be 366 and 368 tons respectively.

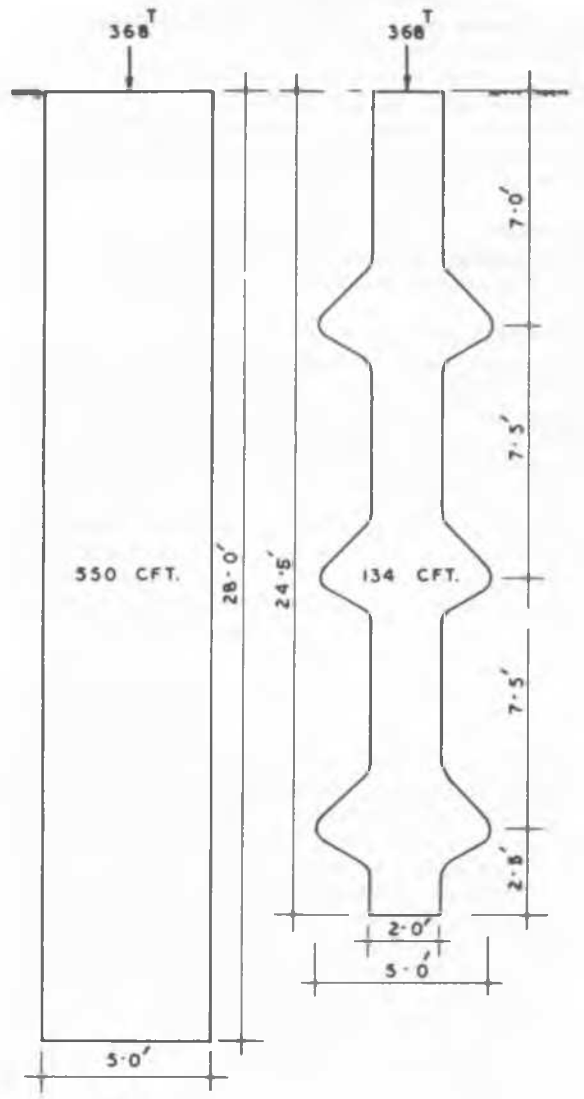

Fig. 2 Uniform Diameter And Multi-under-reamed Pile.

MULTI-UNDER-REAMED VERSUS UNIFORM DIAMETER PILE

A straight pile of 5 ft. uniform diameter and 28 ft. long would carry the same load as the multi-under-reamed pile cited earlier. However, the straight pile requires 550 cft. of concrete for construction as against 134 cft. for the multi-under-reamed with three bulbs, which is about 24.5 per cent of the former (Fig. 2). It is thus evident that multi-under-reamed piles are very economical and can successfully be used as high load bearing piles.

Since the load transferred along the shaft of a pile is quite high, the comparatively narrow stem of a multi-under-reamed pile should suitably be re-inforced, or alternatively the load be limited so as not to exceed the structural strength of the concrete.

Some recent investigations have shown that multi-under-reamed piles can effectively be used in sandy soils also (Jain & Gupta, 1968). The investigations have led to their adoption for the foundations of a 151 ft. high R.C.C. Tower where 15 in. dia., 30 ft. long piles with four bulbs were used resulting in a net saving of over 25 per cent in the cost of foundations apart from a considerable saving in time.

CONSTRUCTION

Simple equipments fabricated with indigenous materials and suitable for manual operation, are used for the construction of under-reamed piles. First an auger boring guide is fixed in position. It helps to keep the bore vertical or to the required batter. Boring is done either by a spiral or bucket auger and the bulbs are formed by a portable under-reaming tool. For piles of 15 in. or larger shaft diameters, and depths exceeding 12 ft., a portable tripod hoist with a winch is used. Two piles of 24 tons safe load capacity can be constructed in a day by using one set of equipment costing about £ 150.00 only with the help of three to four labourers. The over all cost of these piles does not normally exceed a quarter pound sterling per ton of safe load. Thus, a 100T safe load capacity pile hardly costs £ 25.00.

CONCLUSIONS

The following conclusions can be drawn on the basis of the study reported in this paper:-

(1) Under-reamed piles can provide one of the most economical foundations for both light and heavy structures.

(2) Multi-under-reamed piles can replace large diameter piles with an added economy.

(3) The optimum spacing of bulbs in a multi-under-reamed pile lies between 1.25 and 1.5 times the under-reamed diameter for maximum efficiency.

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