BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

# UNDER-REAMED PILE FOUNDATION IN BLACK COTTON SOILS

## Introduction

Structures built on expansive clays often crack because of differential movement caused by alternate swelling and shrinkage of the soil. The design of inexpensive and safe foundations in such soils has always been a troublesome problem for engineers. The under-reamed pile foundations described in this Digest have proved satisfactory and economical for buildings in black cotton soil areas.

## How to proceed

The construction of the foundation involves the following steps.

The design of piles and beams is first prepared; bore holes of the required size are dug to the required depth using a hand-operated earth auger; the bases of the holes are enlarged by under-reaming and the piles are then cast in situ and a plinth beam, clear of the ground, is constructed to support the super-structure.

## Design of piles

The length of an under-reamed pile should be 12 ft. for deep black cotton soils. The spacing of the piles depends on the plan of the structure, its loading and the safe bearing capacity of the piles. It may vary from 5 ft to 10 ft.; the diameter of piles may be varied from 8 in. to 12 in. the ratio of the diameter of the enlarged base to that of the stem of a pile may be varied from 2 to 3.

The steel reinforcement should be sufficient to take the maximum net tension induced in the pile due to up-lift forces. This may be calculated by multiplying the frictional resistance which is half the shear strength of the soil, by the total surface area of the embedded length of the pile in the shrinkage zone. In the absence of any soil test data, the shear strength of the soil, for this purpose, may be assumed as 0.75 tons/sq. ft.

The load-bearing capacity of under-reamed piles together with the details of steel reinforcement under normal conditions is given in table 1. The load bearing capacities have been based on a large number of short and long term load tests carried out in different parts of the country.

## Design of beams

The plinth beam should be at least 3 ins. clear of the ground. It is cast in situ and is continuous. Beams supporting masonry walls should be designed for a maximum bending moment of $\frac{wl^2}{50}$ when openings are near supports and of $\frac{wl^2}{100}$ for a blank wall or when openings are in the centre, where w is the uniformly distributed load on the beam per foot run and l is the effective span.[1] The reduced bending moment is permissible because of the composite action of the beam and masonry wall supported by it, the reinforced concrete beam itself serving as reinforcement for the composite beam. With the reduced bending moments the permissible stress in steel should be taken as 7 tons/in² if the beams are supported during construction and 5 tons/in² if the beams are not supported. For a practical range of loading design details of a plinth beam are given in table 2.

The loads given in the first column of table 2 include the self-weight of the beam. For a given span between 5 ft. and 10 ft. the overall depth of beam and details of bottom steel reinforcement can readily be obtained from the table. The reinforcement provided at the top of the beam should be equal to that at the

TABLE 1

**Load-bearing capacity of under-reamed piles**

| *Diameter of pile* (in) | *Under-reamed diameter* (in) | *Reinforcement* — *Vertical bars* | *Reinforcement* — *Spacing of ¼-in diameter rings* (in) | *Ultimate load-bearing capacity* (tons) | *Safe load-bearing capacity* (tons) |
|---|---|---|---|---|---|
| 8 | 20 | 3 ϕ ⅜ in dia† | 7 | 25 | 6 |
| 8 | 24 | 3 ϕ ⅜ in dia† | 7 | 33 | 8 |
| 10 | 25 | 4 ϕ ⅜ in dia | 9 | 38 | 10 |
| 10 | 30 | 4 ϕ ⅜ in dia | 9 | 50 | 12 |
| 12 | 24 | 4 ϕ ⅜ in dia | 10 | 37 | 10 |
| 12 | 30 | 4 ϕ ⅜ in dia | 10 | 52 | 12 |
| 12 | 36 | 4 ϕ ⅜ in dia | 10 | 70 | 15 |

†For perimeter walls four bars of ⅜ in dia should be provided.

bottom over the top of the piles only and for a length extending up to quarter span both ways. Two of these bars should be continuous to hold up the stirrups. The cranking of bottom bars upwards near supports is not considered necessary. No extra reinforcement is required for bond or shear stresses in the beam, except for nominal stirrups consisting of $\frac{1}{4}$ in. diameter bars at 12 in.-centres.

The design details given in table 2 are based on a maximum bending moment of $\frac{wl^2}{50}$ when the openings are near the supports, this being the worst condition. When openings are absent or are in the centre, the depth of the beam and steel reinforcement should be read in the table against a load equal to half the actual load per foot run coming on the beam. The design details have been given for loads in increments of 500 lb. For intermediate loading and spans the values may, if desired, be extrapolated.

## Curtain walls

Curtain walls, 3 in. thick, should be provided on the outer side of the beam. They should extend about 6 in into the ground and should be cast monolithically with the beam. They should have nominal reinforcement consisting of one 3/8 in. diameter bar at the bottom and $\frac{1}{4}$ in. diameter stirrups at 12 in. centres. The inner edge of the beams should be protected by bricks laid on edge against the beam.

## Construction

*Boring and under-reaming for piles* : The site is first roughly levelled and the location of piles marked accurately by means of a theodolite or otherwise. Holes are then bored by means of hand operated earth augers (fig. 1). Care should be taken that the hole is vertical and to this purpose, the CBRI has developed a suitable guide for straight auger boring (2) (fig. 2). After the hole is dug to the required depth, the under-reamer (fig. 1) is lowered into the hole for enlarging the base. It is pressed and rotated. The blades widen with pressure and while rotating, cut the soil from the sides. When the bucket is full, the under-reamer is pulled out and the soil removed. The tool is again lowered into the hole and the process repeated. Care should be taken that no loose soil is left at the bottom of the hole. To get the required under-reamed diameter, the handle of the tool has to be progressively pressed down to a pre-determined distance. When the under-reaming is complete, the handle will rest on a pin inserted in the central rod of the tool at the required distance and the tool will rotate freely without cutting any more soil.

Correct under-reaming is an important requirement in the construction of under-reamed piles, and it is essential to ensure that the base has been enlarged to the required diameter.

## Concreting

The reinforcement cage for the pile should be held vertical and in the centre of the hole while the concrete is placed. Thorough rodding is very important. The pile caps should be cast monolithically with the pile and for this purpose a portable steel or wooden form-work is advisable.

For casting beams, steel or wooden form-work is ideal. Brick in mud mortar with a layer of sand over it, may be used for the bottom. The pile reinforcement should be properly anchored with the beam reinforcement.

## Construction in ground with high water table

When the ground water table is high, as during the monsoon, the normal method of boring and placing concrete for under-reamed piles is unsuitable as the sides of the bore tend to cave in. In such circumstances the bore hole may be kept true using a drilling mud and concreting may be done by a displacement method involving the use of a bailor or of a pipe with a close fitting lid at the lower end. (3)

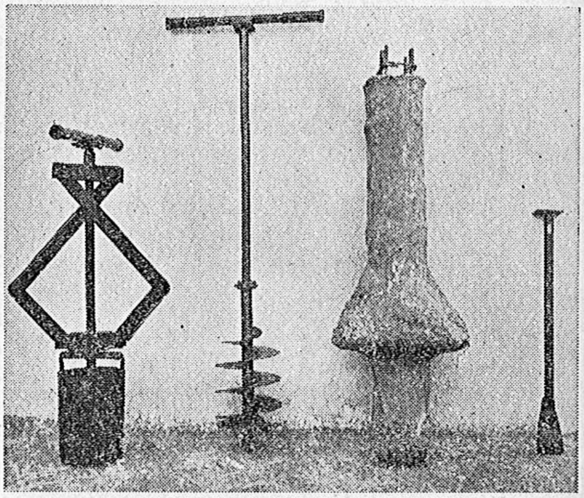

*Fig. 1 Assembly of Under-reamer, Auger, Under-reamed pile and Crowbar (from left to right)*

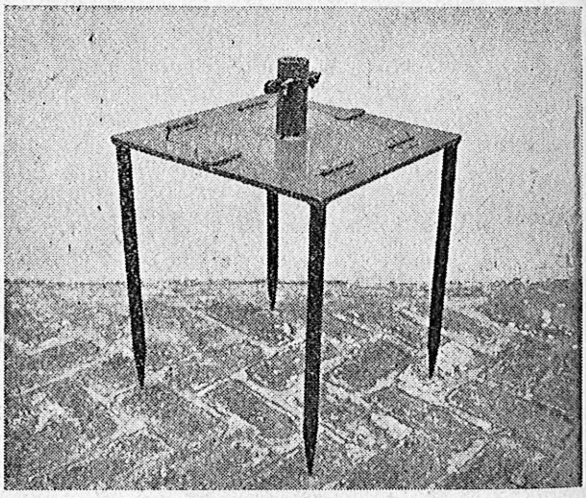

*Fig. 2 Auger boring guide*

TABLE 2

## STRUCTURAL DETAILS OF PLINTH BEAMS OF SPANS BETWEEN 5 FT. AND 10 FT.

| Load on beam | *For effective span of 5 ft.* | | *For effective span of 6 ft.* | | *For effective span of 7 ft.* | | *For effective span of 8 ft.* | | *For effective span of 9 ft.* | | *For effective span of 10 ft.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *(lb/ft.)* | *Depth (in)* | *Bottom reinforce-ment* | *Depth (in)* | *Bottom reinforce-ment* | *Depth (in)* | *Bottom reinforce-ment* | *Depth (in)* | *Bottom reinforce-ment* | *Depth (in)* | *Bottom reinforce-ment* | *Depth (in)* | *Bottom reinforce-ment* |
| 500 | 6 | 2Ø $\frac{3}{8}$ in | 6 | 2Ø $\frac{3}{8}$ in | 6 | 3Ø $\frac{3}{8}$ in | 6 | 3Ø $\frac{3}{8}$ in | 6 | 3Ø $\frac{3}{8}$ in | 6 | 2Ø $\frac{1}{2}$ in |
| 1,000 | 6 | 3Ø $\frac{3}{8}$ in | 6 | 3Ø $\frac{3}{8}$ in | 6 | 4Ø $\frac{3}{8}$ in | 6 | 4Ø $\frac{3}{8}$ in | 6 | 4Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in |
| 1,500 | 6 | 3Ø $\frac{3}{8}$ in | 6 | 4Ø $\frac{3}{8}$ in | 6 | 4Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in |
| 2,000 | 6 | 3Ø $\frac{3}{8}$ in | 6 | 4Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 6 | 3Ø $\frac{1}{2}$ in | 7 | 6Ø $\frac{3}{8}$ in | 7 | 4Ø $\frac{1}{2}$ in |
| 2,500 | 6 | 4Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 7 | 4Ø $\frac{1}{2}$ in | 8 | 4Ø $\frac{1}{2}$ in |
| 3,000 | 6 | 4Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 7 | 2Ø $\frac{1}{2}$ in plus 3Ø $\frac{3}{8}$ in | 8 | 4Ø $\frac{1}{2}$ in | 8 | 3Ø $\frac{1}{2}$ in plus 3Ø $\frac{3}{8}$ in |
| 3,500 | 6 | 5Ø $\frac{3}{8}$ in | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 8 | 4Ø $\frac{1}{2}$ in | 8 | 3Ø $\frac{1}{2}$ in plus 3Ø $\frac{3}{8}$ in | 9 | 5Ø $\frac{1}{2}$ in |
| 4,000 | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 7 | 2Ø $\frac{1}{2}$ in plus 3Ø $\frac{3}{8}$ in | 8 | 3Ø $\frac{1}{2}$ in plus 2Ø $\frac{3}{8}$ in | 9 | 3Ø $\frac{1}{2}$ in plus 3Ø $\frac{3}{8}$ in | 9 | 5Ø $\frac{1}{2}$ in |
| 4,500 | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 8 | 4Ø $\frac{1}{2}$ in | 8 | 3Ø $\frac{1}{2}$ in plus 3Ø $\frac{3}{8}$ in | 9 | 5Ø $\frac{1}{2}$ in | 10 | 6Ø $\frac{1}{2}$ in |
| 5,000 | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 8 | 4Ø $\frac{1}{2}$ in | — | — | — | — | — | — |
| 5,500 | 6 | 5Ø $\frac{3}{8}$ in | 7 | 6Ø $\frac{3}{8}$ in | 8 | 3Ø $\frac{1}{2}$ in plus 2Ø $\frac{3}{8}$ in | — | — | — | — | — | — |

## Precautions

The following general precautions should be taken:-

(a) There should not be a considerable timelag between the construction of the bore hole and that of the concrete pile.

(b) Before concreting, check that no loose soil is left at the bottom of the hole. The depth of the hole and the under-reamed diameter should also be checked carefully.

(c) Shuttering from below the beams should be removed only after the superstructure has reached lintel level.

(d) If bricks have been used for the shuttering of plinth beams, they must be removed at the proper time. The bottom of plinth beams should be at least 3 in. clear of ground.

## Cost and performance

Houses on under-reamed piles, single as well as double storeyed, have been constructed at a number of places in the country and an economy of 20 to 30 per cent in cost as compared to the traditional strip footings dug to about 6 ft. depth has been reported from all the sites.

## References


1. Wood, R.H. "Studies in composite construction—The composite action of brick panel walls supported on reinforced concrete beams" Research Paper No. 13 part I, Building Research Station, Watford.

2. Subhash Chandra and A.K. Deb, "Guide for straight-auger boring" Indian Concrete Journal, June 1962

3. Subhash Chandra, "Boring and placing concrete for under-reamed piles in grounds with high water table"; Indian Concrete Journal, June 1961.


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*There is a demand for short notes, summarising available information on selected building topics for the use of Engineers and Architects in India. To meet the need this Institute is bringing out a series of Building Digests from time to time and the present one is the thirteenth in the series.*


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