BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

SINGLE AND DOUBLE UNDER-REAMED PILES FOR FOUNDATIONS IN BLACK COTTON SOILS

Introduction

Structures built on expansive soils on normal strip and other types of traditional footings often tilt and crack due to the differential ground movements. This is caused by alternate swelling and shrinkage of the soil due to changes in its moisture content. In order to safeguard against this movement effectively, the best remedy is to anchor the structure at a depth where the volumetric change of the soil due to seasonal variations is negligible. This has been achieved by adopting under-reamed pile foundations. These may be single or double under-reamed. Single under-reamed piles have only one bulb at the bottom whereas in double under-reamed piles there is another bulb also. The latter provides 50 percent additional bearing.[1] Single under-reamed piles have been extensively used for single and two storey buildings, maximum being upto four storeys. Use of double under-reamed piles has made it possible to construct multistoreyed buildings and other heavy structures to rest on these piles.

Under-reamed piles are also being used for factory buildings including machine foundations. The additional anchorage provided by these piles also render them suitable for transmission lines and other tower footings. Under-reamed piles can be effectively used both for light and heavy structures, in shallow as well as in deep layers of expansive soils and also in other types of poor soils of shallow depths overlying firm soil strata.

Experience gained by the construction of over 4000 buildings and other structures on such piles has proved that under-reamed pile foundation is an almost fool-proof solution of the problem. It is also economical by 20 to 30 per cent over the traditional type of footings (about 4 to 6 ft. deep; 1.22 to 1.83 m) as reported from all the sites. The traditional footings, on which buildings are standing intact, when compared with the under-reamed pile foundations, have been found to be twice as costly.

This digest supersedes the previous digest No. 13 on under-reamed pile foundations in black cotton soils.

How to proceed

The construction of the foundation involves the following steps.

The design of piles and beams is first prepared. Boring guides are then fixed at proper positions and bore-holes of the required size are dug using a manually operated spiral earth auger. The bases of the bore-holes are enlarged by an under-reaming tool. The reinforcement is introduced and concrete poured in the bore-hole. The plinth beam, which is kept clear of the ground, is then provided to support the super-structure.

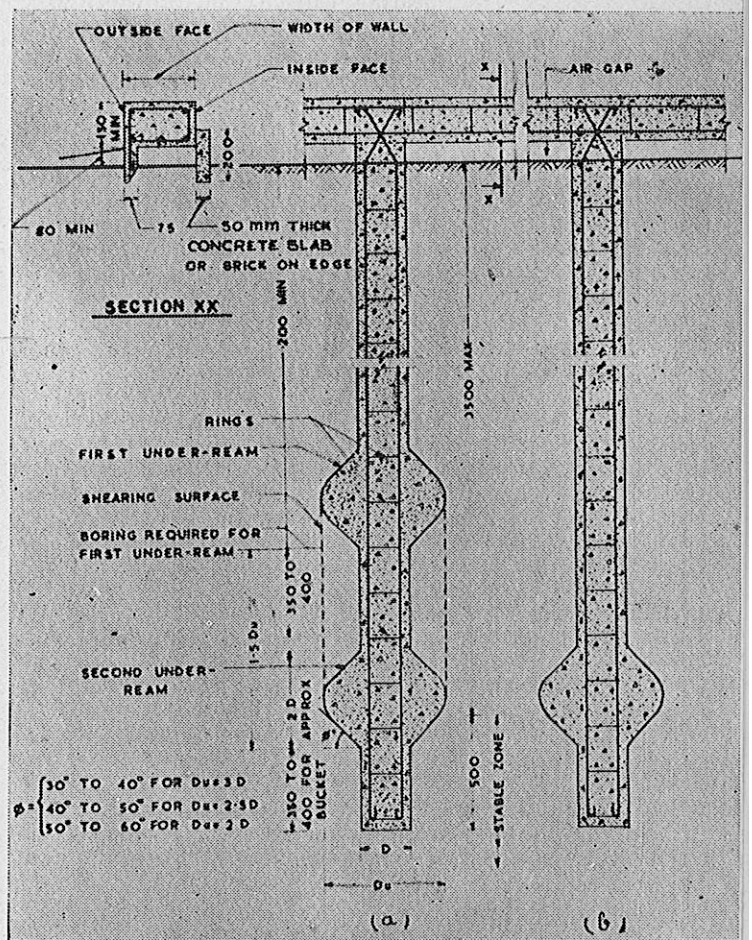

Fig. 1 : (a) Double under-reamed pile
(b) Single under-reamed pile

Design

Piles—Structural load at the plinth level is first worked out and it is marked on the plan in lbs per running foot (kg/cm). The position of piles is then fixed after selecting suitable sizes which in turn depends on the plan of the structure, loading conditions, availability of the equipment and the nature of the ground.

The length of under-reamed piles should not normally exceed four meters. This is the maximum required in deep layers of black cotton soils because ground movements are negligible below 12 ft. (3.6 m) depth. In shallower depths of black cotton soils, the length can be reduced and the piles should be taken only 20 in. (50 cm) into the stable zone. The lengths can be increased if higher loads are required.

The ultimate load which a pile can take may be determined from the following expression :

$$Q_u = A_p \, NC_p + \alpha \bar{C} \, A_s$$

where Q_u = ultimate bearing capacity of the pile

A_p = area of the pile base

N = bearing capacity factor which may be taken as 9.0 for expansive soils

C_p = undisturbed shear strength of the soil at the pile base. Its value may be taken as 1 ton/sq. ft. (1 kg/cm²) in the absence of actual tests.

α = reduction factor which may be taken as 0.5 (In double under-reamed piles, however, between the first and the second under-ream, shearing takes place along the surface of a cylinder of diameter equal to the under-reamed diameter and for this portion the value of α may be taken as 1.0).

$\bar{C}$ = the average undisturbed shearing strength of the soil along the pile. Its value may be taken as 1 ton/sq. ft. (1 kg/cm²) in the absence of actual tests.

A_s = The surface area of the pile shaft excluding the top 4 ft. (1.2 m) length of the shaft and another 20 in. (50 cm) for the under-reamed portion.

In double under-reamed piles, the shaft diameter between the two under-reamings may be taken equal to the under-reamed diameter.

Diameter of manually bored piles ranges from 8 to 12 in. (20 to 30 cm). In case a tripod with a pulley block is used, piles up to 18 in. (45 cm) in diameter can be made.

The under-reamed portion should normally be kept 2 to 2½ times the diameter of the shaft. For tower footings where piles could be subjected to additional pull also, it may be increased to 3 times.

In double under-reamed piles the spacing between the two under-reamings should be kept 1½ times the under-reamed diameter. It may be decreased to 1¼ times for 12 in. (30 cm) and larger diameter piles to avoid the upper bulb coming too close to the ground, the minimum desirable depth being 6.5 ft. (2 m).

Piles should first be provided under all the wall junctions in order to avoid point loads on beams. Intermediate piles are then provided, if necessary. The depth of the plinth beams should preferably be kept the same all over.

The minimum centre to centre spacing of piles should normally be twice the under-reamed diameter. The maximum spacing should not exceed 10 ft. (3 m). When piles are of two different diameters, an average value may be taken.

It is good practice not to adopt too many different sizes of piles in one structure and it should normally be limited to three.

The reinforcement may be worked out on the assumption that the piles could be subjected to tensile forces due to the heaving of soil around the shaft. The total tension can be worked out by multiplying the average unit friction (half of unit skin friction) by the total surface area of the embedded length of the pile shaft above the pile bulb. In the absence of actual soil test data an average shear strength of 1 ton/sq. ft. (1 kg/cm²) may be assumed and the average unit friction due to heaving may be taken equal to only 25 per cent of this value.

The safe load bearing capacity of 12 ft. (3.6 m) under-reamed piles along with the details of steel reinforcement under normal conditions in expansive soils having an average shear strength equal to 1 ton/sq. ft (1 kg/cm²) is given in Table 1. (In working out the average shearing strength, values from 4 ft. (1.2 m) depth to a foot below the pile base should be taken into account.) These are fairly conservative values with a factor of safety of 2.5 and the safe loads given are based on a large number of short and long term load tests carried out in different parts of the country. For other types of clayey soils also which may not be of expansive type the loads given in the table should apply unless the shearing strength of soil reduces considerably.

Beams—Beams supporting masonry walls should be designed taking into account the panel action. For this, masonry with even inferior quality bricks made out of black cotton soils and constructed in lime or cement mortar is found adequate.

A maximum bending moment of $\frac{WL^2}{50}$, where W is the uniformly distributed load per ft. run (per cm) and L is the effective span in ft. (cms), should be taken if beams are supported during construction. It should be increased to $\frac{WL^2}{30}$ if beams are not supported[2]

In working out the uniformly distributed load W, a maximum load of two storeys only should be considered. The load of any additional storeys should be deemed to be transferred directly to the piles.

For concentrated and other loads such as suspended ground floors etc., which directly rest on such beams, full bending moments should be accounted for.

Beams should preferably be made continuous if they are *cast-in-situ.* For this, negative reinforcement in the beams equal to the main reinforcement, is provided to a distance ¼ span both ways on top of the piles. Two M. S. bars, normally ⅜ in. (10 mm) diameter should, however, be provided for the full length so as to support the stirrups and also to resist any unforeseen moments. The cranking of bottom bars upwards near supports is not considered necessary and nominal ¼in. (6mm) diameter stirrups should be provided at 12 in (30 cm) centres. Beams can also be precast. These should be properly bonded to the pile tops with due provision for the negative reinforcement. Bending moments should be taken as for beams which are not supported during construction.

Construction*

Layout—The site is first roughly levelled. The position of piles is marked by pegs and a boring guide (Indian Pat. No. 82303) is fixed on each in turn (Fig. 2).

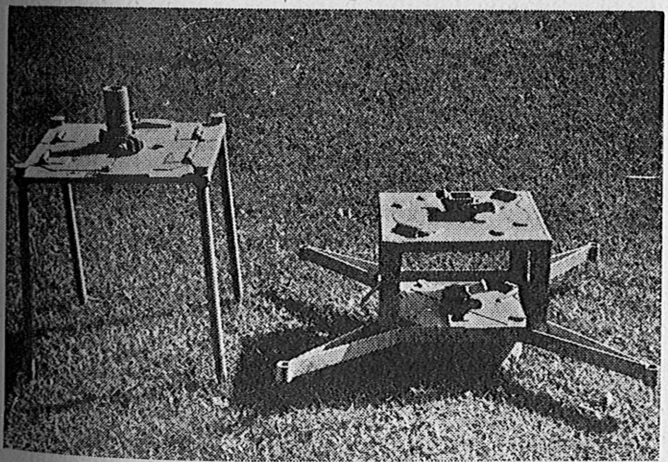

Fig. 2 Boring Guides

The guide is levelled by fixing into it a piece of extension pipe which should be kept to the desired inclination by hammering at the four pegs. The use of a boring guide is essential in order to keep the bore holes in position and also vertical. It also does not allow the mouth of the bore hole to widen due to frequent insertion and removal of the auger and other boring tools. In loose and filled-up soils, it may be necessary to fix the boring guide with longer pegs.

Boring and under-reaming—A manually operated spiral earth auger is used. If the soil is very dry and stiff, it can be first loosened by a cutting tool and then removed with the auger. In very dry weather, a little water may be added sometime before boring or better still it can be left overnight. Since fairly moist soil is generally met with below 4 ft. (1.2m), the addition of water should, preferably, be confined up to this depth only.

Care should be taken that the top few feet (about a meter) of the bore hole is made truly vertical.** The lids of the boring guide should be kept closed after the auger passes them.

The movement of the auger should be slow. With too rapid a movement, the soil cannot be cut properly and it tries to move up the spirals. Also, taking out too much soil at a time should be avoided because the soil may get compressed causing difficulty in removal of the auger.

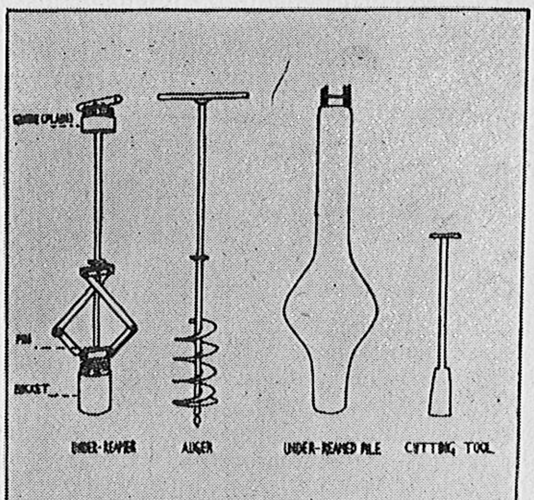

Fig. 3 Under-reamer and auger

For enlarging the base, the manually operated portable under-reaming tool may be used. Here too, the use of a boring guide will be useful but it is not essential except for piles which are bored to an inclination other than vertical. For vertical piles, a plain guide

* The required set of tools (Indian Pat. Nos. 82303 and 54907) as developed at this Institute are available with the licensee M/s. M. S. Jain, Engineers & Builders, Khanjarpur, Roorkee.

** Permissible positional deviation is D/4 or 3 in. whichever is less. Permissible inclination is 2%. The latter may, however, be permitted upto 5% with additional reinforcement. Beyond these limits, the stem should be so increased that it accommodates the above extremes.

can serve the purpose and the boring guide can be moved to the next position.

The under-reaming tool (Indian Pat. No.54907) consists of two sets of collapsible blades and a bucket at the bottom for collecting the soil (Fig. 3). This tool is attached to the extension pipes and lowered into the bore hole. As it is pressed and rotated the blades try to widen out and cut the soil from the sides. When the bucket is full, the under-reamer is pulled out of the bore hole and the soil removed by opening the bottom lid of the bucket. The under-reaming tool is again lowered and the process is repeated. When under-reaming is complete, a pin inserted into the shaft rests on the lower end of the tool and the blades cannot widen any more.

Correct under-reaming is an important requirement in the construction of under-reamed piles and it should be ensured that the base has been enlarged to the correct diameter.

The depth of the pile should also be carefully checked at the time of under-reaming and any loose soil from the bucket portion should be removed by an auger.

For double under-reamed piles, boring should first be made to the depth of the first under-reaming. After making the first under-reaming, the bore should be further extended by augering to the full depth and then the second under-reaming should be completed.

For boring deeper than 12 ft. (3.6 m) and also for bore holes larger than 12 in. (30 cm) in diameter, a light derrick or tripod with a pulley block may be used with advantage.

Boring and under-reaming under adverse conditions of weather also does not provide any special difficulties and the piles can be put down all round the year. In very dry weather, the soil in some localities may become fairly stiff and the progress will be slow. In heavy rains, temporary sheds have been used with advantage though they are not essential.

Boring and under-reaming under water table, specially in clayey soils, does not normally provide any special problem. An attempt should, however, be made that the process of boring, under-reaming and concreting is continuous so that, the amount of water collected in the bore hole does not come up beyond the space provided for the bucket. In case it does, a reduced bearing capacity of the pile should be adopted.

In soils where the sides of the bore holes are likely to cave in, the holes may be kept full by a drilling mud (a solution of fat clay in water) with advantage. Concreting may be done by displacement method involving the use of a tremie or a pipe with a detachable lid at the bottom end.

For a rapid progress on major projects, a team work is necessary. The first team should provide the layout and fix the guides. The second should make bore holes upto 3 ft. (0.91 m) depth. This should be followed by teams having longer extension pipes for 6, 9 and 12 ft. depths. Finally, under-reaming and concreting should be done.

Concreting—A concreting funnel is first placed on the bore hole. The reinforcement cage is next lowered carefully so that it does not scratch the sides and cement concrete is poured in. The concreting operation should preferably be done under the supervision of a responsible person.

For piles, a concrete of 5 in. (12.5 cm) slump is desirable. The limits including tolerences should be 3 in. (7.5 cm) minimum and 6 in. (15 cm) maximum. For compaction, thorough rodding is normally sufficient but care should be taken that it does not scratch the sides of the bore hole. Use of immersion type vibrators is not advisable unless the soil is fairly compact and the vibrator is handled by an experienced person with extreme care, otherwise loose soil from sides may get mixed up with the concrete.

The piles should normally be cast soon after the bore hole is ready. The casting of plinth beams should follow. If plinth beams are also cast simultaneously, it will have certain advantages of a monolithic structure but care should be exercised in concreting of the piles through all the reinforcement. Provision of shuttering etc. for the beams may also delay the concreting of the piles which is not quite desirable.

When the concrete in the piles becomes fairly hard (normally after 7 days), the top reinforcement should be bent as shown in Fig. 1 and the plinth beams provided.

Superstructure—In the case of beams which are not adequately supported and also for precast beams, proper panel action should be ensured by constructing the superstructure in stages, that is, first upto the window sill level, then to door lintel level and finally upto the roof level. In buildings where R.C.C. columns are provided over the piles the columns should also be cast in stages and should follow the masonry work in order to develop sufficient bond between the two materials.

All shuttering and other supports etc. are finally removed from under the beams. It should leave a clear gap of at least 3 in. (7.5 cm) so that the soil may not heave against the beam. This should preferably be done after the construction has reached lintel level.

Curtain Walls

Curtain walls 3 in. (7.5 cm) thick should be provided on the outer side of the perimeter plinth beams. They should extend a minimum of 3 in. (7.5 cm) into the ground and should be cast monolithic with the beam. A nominal reinforcement of one 3/8 in. (10 mm)

TABLE I

SAFE LOADS FOR UNDER-REAMED PILES

Diameter of pile	Under-reamed diameter	Reinforcement			SAFE LOADS									
		Vertical bars			Bearing resistance				Uplift resistance				Lateral	Thrust
		Single under-reamed	Double under-reamed	Spacing of ¼ in. (6 mm) diameter rings	Single under-reamed	Double under-reamed	Increase per ft./30 cm	Decrease per ft/ 30 cm	Single under-reamed	Double under-reamed	Increase per ft./30 cm	Decrease per ft./ 30 cm	Single under-reamed	Double under-reamed
in./(cm)	in./(cm)	Nos. diameter in./(mm)	Nos. diameter in./(mm)	in./(cm)	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes	tons or tonnes
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
8/(20)	20/(50)	*3,3/8(10)	4,3/8(10)	7/(18)	6	10	¾	½	4	6	½	⅓	0.6	0.8
10/(25)	25/(62.5)	4,3/8(10)	4,1/2(12)	9/(23)	9	15	1	¾	6	9	¾	½	0.9	1.1
12/(30)	30/(75)	4,3/8(10)	4,5/8(16)	10/(25)	12	20	1¼	1	8	12	1	⅔	1.2	1.4

*For perimeter walls it is desirable to provide 4 nos.

Vertical bars should be provided uniformly for the full length of the pile and with a clear cover of 1½ in. (4 cm). For inclinations exceeding 2% and upto 3½%, 1 extra bar should be provided and beyond this upto 5% inclination, 2 extra bars are to be provided.

For under-reamed piles subjected to a pull and/or a lateral thrust, steel as in col. (4) should be provided (except in double under-reamed piles subjected to a pull when one more bar is to be provided).

Values given in columns (14 & 15) for lateral thrusts may not be reduced for changes in pile lengths and are fairly conservative. Higher values may be adopted after conducting lateral load tests on single or group of piles.

When a pile designed for a certain safe load is found to be just short of the load required to be carried by it, then an over load of 10% should be allowed on it.

For working out the safe load for a group of piles, the safe load of individual piles is multiplied with the number of piles in the group. This would be applicable for piles taking lateral thrusts also.

Only 75% of the above safe loads should be taken for piles in which the bore holes are full of sub-soil water during concreting. When water is confined to the bucket portion only, no such reduction need be made.

diameter bar at the bottom and 1/4 in. (6 mm) dia. stirrups at 12 in. (30 cm) centres may be provided. On the inner edge of the beams and also on both sides of interior beams, a concrete slab 2 in. (5 cm) in thickness or brick-on-edge may be provided in order to check the soil entering under the beams.

Floors

It would be ideal to provide suspended floors but they are costly. Providing as coarse a material as possible in thc base course would normally be adequate.

References

1. Subhash Chandra and S. D. Khepar "Double under-reamed piles for foundations in black cotton soils", Ind. Conc. J., 38 (2), 1964, 50-52.

2. IS : 2911 (Part I)—1964 Code of Practice for Design and Construction of Pile Foundations, Part I—Load Bearing Concrete Piles—Appendix on short-bored under-reamed piles.

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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 37th in the series. Readers are requested to send to the Institute their experience of adopting the suggestions given in this Digest.

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