

# For Which Soil Conditions Are Under-reamed Pile Foundations Superior to Other Foundation Systems ?

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**SYNOPSIS** A general consensus was arrived at the IGC-1986 that under-reamed piles are superior to other foundation systems for the following soil and loading conditions : (1) Black cotton soils; (2) surficial weak soils underlain by soils with adequate bearing capacity; (3) where advantage can be taken of an intermediate stratum with good end bearing characteristics (4) for light to moderately loaded structures (5) for structures subjected to uplift forces (6) for avoiding deep excavations and dewatering, and/or (7) where manual construction methods are advantageous. Bored compaction under-reamed piles are superior to conventional under-reamed piles with regard to load carrying capacities and foundation performance and should be used wherever possible. Under-reamed piles are not suitable if a consolidating clay layer occurs below the pile tip, in rocky strata and strata containing boulders. In soils where the borehole or the under-ream portion could collapse, under-reamed piles should be used with caution and a carefully prepared drilling fluid should be used.

## INTRODUCTION

The superiority of any foundation system over others mainly depends on its performance under structural loads, its ease of construction and economic factors. Thus, the superiority of under-reamed piles is considered not only from a technical view-point but also where they provide an engineering solution to problems either due to construction difficulties or comparatively high cost of other types of foundation systems.

Under-reamed piles have been used in India since 1955. These piles were developed by CBR1 in the fifties primarily for use in black cotton soils but have since found wide application in various soil conditions for a variety of structures. The use of these piles increased rapidly in India since the seventies.

Currently, guidelines for design and construction of under-reamed piles are available in a handbook by Sharma et al (1978) as well as in IS 2911 (Part III), 1960. Chummar (1986) and Sharma (1986) discuss the use of under-reamed piles in India, construction practices and situations where they are superior. This paper attempts to synthesize the various practices and applicability of these piles and highlights areas of future research on under-reamed piles.

## BEHAVIOUR OF UNDER-REAMED PILES

An under-reamed pile is a short bored pile with one or more bulbs formed by under-reaming. Usually, the bulb diameter is 2 to 2.5 times the stem diameter. In India, manual methods are usually used for construction. Under compression loads, the pile load transfer is achieved by the end bearing of the pile stem tip, the bearing offered by the bulb and the skin friction of the stem. Under tensile loads, uplift resistance is generated by passive resistance generated by the bulb. Fig.1 schematically depicts the load transfer mechanism.

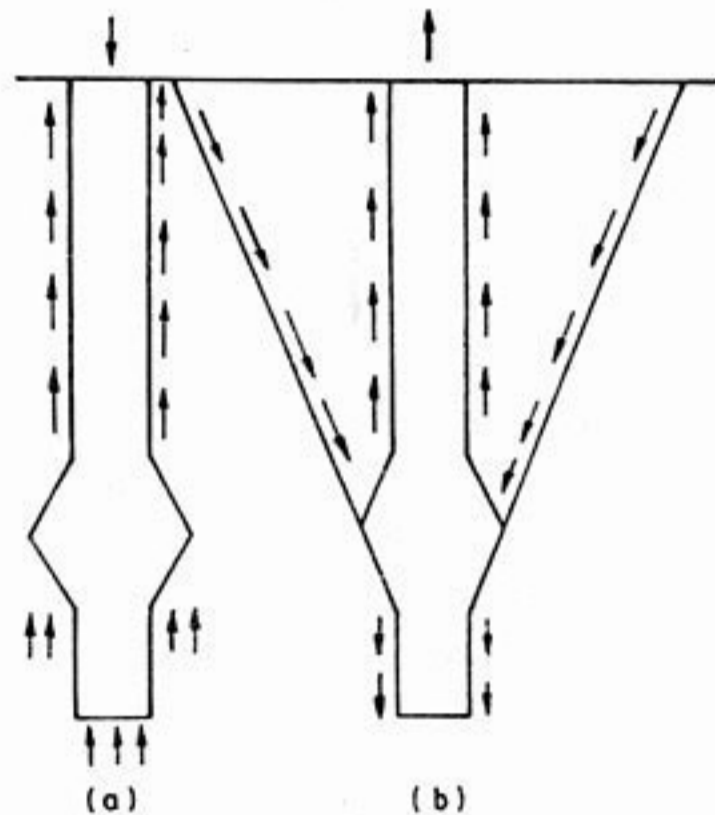


Fig. 1. Load transfer mechanism for under-reamed piles.  
a) - Compression load.  
b) - Tension load.

## SITUATIONS UNDER WHICH UNDER-REAMED PILES ARE SUPERIOR

A general consensus has been achieved on the soil conditions and loading conditions where under-reamed pile is considered a 'superior' foundation system. These are discussed below:-

1. Under-reamed piles are an effective solution to the problems of swelling/shrinkage in expansive soils and black cotton soils. In these soil conditions, the bulb acts as an anchor and resists

the heave and settlement due to swelling and shrinkage of the expansive soils.

2. Under-reamed piles are often a more economical and hence a superior foundation system in soil conditions where surficial loose soils and poorly compacted fills are underlain by soils with adequate bearing capacity. In this situation, the use of under-reamed piles eliminates the settlement of the surficial loose soils by transferring the loads to a deeper and more competent stratum.
3. In situations where advantage can be taken of an intermediate stratum with good end bearing characteristics, under-reamed piles may sometimes prove to be superior foundation system. Examples are a loose sand or soft clay stratum sandwiched between a surficial dense sand stratum and an underlying hard clay or dense sand stratum. For certain loading situations, an ordinary bored pile may have to be taken sufficiently deep below the underlying soft clay or loose sand. Use of under-reamed pile in this situation may shorten the length of the pile significantly because of the end bearing resistance of the bulb in the dense sand. This soil condition is schematically shown in Fig.2. However care should be taken to ensure that the pile tip is sufficiently above the underlying weak soils so that the loading of the pile does not induce significant settlement of the underlying stratum.
4. For light to moderately loaded structures bearing on soils which have low bearing capacity in the upper 1 to 3 m under-reamed piles may often be an economical as well as superior alternative to raft foundations placed on the strong soils underlying the weak soils.
5. Since the under-ream bulb generates a significant uplift resistance, an under-reamed pile is superior to other piles of the same length and diameter with regard to uplift capacity. These piles can be effectively used to resist hydrostatic uplift, and moments due to wind and seismic forces and have found wide applicability in structures where uplift forces and overturning moments are the governing factor in foundation design. Examples are transmission towers, television towers and antennae, overhead tanks, tall structures subjected to wind forces, under-ground tanks placed below groundwater table and hydraulic structures providing resistance against buoyancy forces.
6. At sites where the groundwater is very shallow, it may be required to provide foundations below the water table. If spread open foundations are planned, this would involve excavation below water table, dewatering, bracings and similar supporting systems. Under such situations, under-reamed piles may prove to be an economical as well as a quicker method of construction.
7. Under-reamed piles are normally constructed in India manually using light weight equipment. At sites where the surficial soils are of poor bearing capacity and cannot take the load from heavy construction equipment, the use of light weight equipment may be advantageous. Also, the construction of the piles does not depend on power and uses limited quantity of water which make it better foundation scheme for remote sites.

Discussions on various aspects of design and construction of under-reamed piles in different soil conditions highlighting the use of these piles as a 'superior foundation scheme' are presented below.

#### EXPANSIVE SOILS

In expansive clay and black cotton soils, seasonal variations in moisture content cause heave and shrinkage of the soils. These variation in moisture content are due to the capillary forces set up by evaporation and consequent suction forces created by thermal gradients (Ramaswamy, 1986). The zone of soil where such moisture variations occur is called the 'active zone'. Where the groundwater level is shallow, this zone is related to the maximum and minimum level of groundwater. Where groundwater is sufficiently deep, the active zone extends to some depth below the existing ground surface. Experience by various researches and practicing engineers indicates that the extent of this zone may vary from 1.5m to 3.5m below the ground surface.

It is therefore essential that the depth of the active zone be determined in order that the design may be more realistic. Ramaswamy (1986) recommends developing suction profiles to determine this active zone. The total heave or shrinkage is a function of the difference between the present suction and the expected equilibrium suction pressure under the structure. The zone of variation of the suction pressure defines the extent of the active zone. In the absence of such data, local experience may be used and a suitable depth of the active zone should be considered.

Ramaswamy (1986) states that pile load tests are unreliable in expansive clays because such tests do not correctly model the behaviour of the active zone. He provides a method for computing the pile capacities in the swelling clays taking into account the influence of the active zone. In this method, the capacity of the soils in the active zone is neglected. The uplift force on the pile is calculated and the depth of pile required below the active zone is calculated to resist the uplift force.

Poulos and Davis (1980), through elastic analysis of under-reamed piles in expansive clays, found that pile movements due to swelling are controlled, by using under-reamed piles founded just below the base of the active zone or by using uniform diameter piles of length about twice the depth of the active zone. However, the current consensus of experts in India seems to be that the pile design should ignore the capacity of the active zone. Further research is required on the behaviour of under-reamed piles in expansive clays.

#### WEAK SOILS UNDERLAIN BY STRONG SOILS

In areas where the surficial 1 to 3m of soils are loose/soft in conditions and are underlain by medium dense soils with adequate bearing capacity, under-reamed piles may prove to be an effective and superior solution. These piles are usually more economical than raft foundations or spread footings placed on the strong soils in several cases, particularly on large projects. Gupta and Sundaram (1986) discuss situations where under-reamed piles have been advantageously used in such soil conditions, in the Delhi area. Examples are light to moderately loaded structures such as housing projects, overhead tanks etc.

In such cases, the under-ream bulb should be formed in the under-lying strong soils so that adequate end bearing capacity can be achieved. Also, the soil conditions

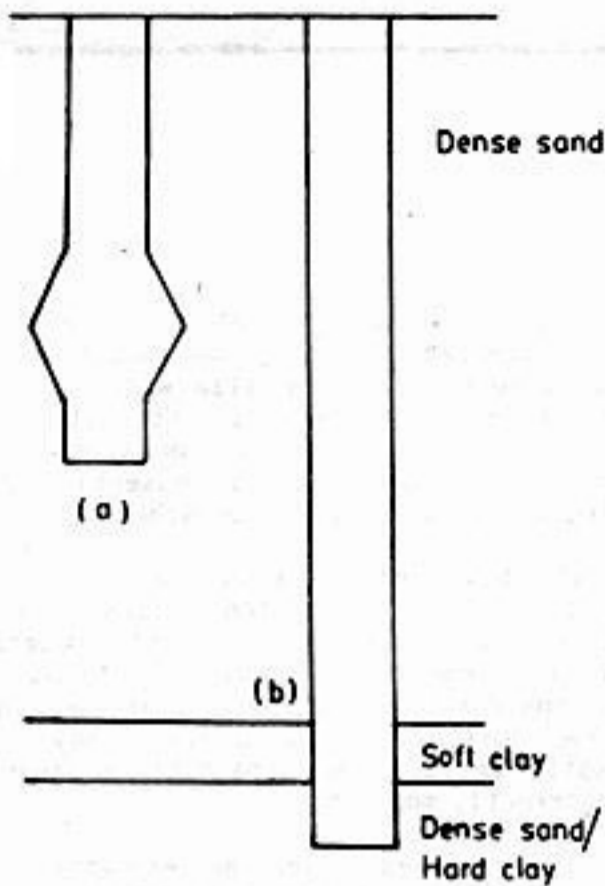


Fig. 2. Example of a soil stratigraphy where advantage can be taken and soil with good end bearing. (a) Under reamed pile. (b) Conventional bored pile.

should be evaluated to determine whether bored compaction piles would be advantageous and superior to conventional under-reamed piles. Bored compaction under-reamed piles are discussed in the next section.

**BORED COMPACTION UNDER-REAMED PILES**

Bored compaction under-reamed piles, a variation of conventional under-reamed piles has been widely used in India for the last 15 years. Sharma (1986) discusses the construction procedure for these piles and states that the advantage of compaction is more in sandy soils, bored compaction under-reamed piles yield significantly higher capacities than conventional under-reamed piles. It may, however, be stated here that bored compaction under-reamed piles do not yield any advantage in expansive soils.

The increase in capacity of bored compaction piles is primarily due to the compaction of the surrounding loose soils. Also, the compaction process tends to expand the hole and thus results in a higher co-efficient of lateral earth pressure.

The IS 2911 (Part III) recommends an increase in capacity of 50 percent over conventional under-reamed piles if the compaction process is used to install the piles. However, loads tests have shown that the increase in capacity, which is a function of the sand content of the soils, could be upto 100 percent. It is recommended that the increase in the skin friction capacity due to the compaction process be considered for a more realistic estimation of the pile capacity. Data from load tests in various soils should be analysed for this purpose to avoid the arbitrary prevalent practice of increasing the capacity of conventional under-reamed pile by a percentage factor.

Pile load tests are a valuable tool in determining the pile capacity in the field and confirming the design parameters adopted. The tests are useful for planning purposes and to ensure that the pile behaves as designed and to evaluate the superiority of the foundation system.

In the design and installation of under-reamed piles, care should be taken to identify situations where load tests may not correctly model the soil behaviour or where load test results may be less than the values computed from IS 2911 (Part III). Also, where load test results yield higher capacity than design, there should be an allowance in the planning process to redesign the piles for the higher capacities as indicated by the load tests.

Ramaswamy (1986) states that conventional pile load tests do not correctly model the pile behaviour in expansive soils because of the behaviour of the active zone. During the dry season, the active zone is likely to crack because of the shrinkage effect and may not contribute significantly to pile capacity. Also during the wet season, the tensile forces caused by heave are not modelled by the test. In such situations, pile capacity computations taking into consideration the behaviour of the active zone should be used rather than pile load tests.

Gupta and Sundaram (1986) state that in silty and clayey soils, where the natural moisture content in the vicinity of the under-ream is close to the liquid limit, pile load tests indicate that the failure load for conventional under-reamed piles is significantly less than that computed using IS 2911. This is because the shear strength of soils with water content close to the liquid limit is low and hence the end bearing capacity of the under-ream will be significantly impaired.

Kachroo and Kakroo (1986) have also reported load tests in Srinagar where the observed failure load was less than values computed from the IS Code. It is likely that laboratory determination of undrained shear strength of weak clays may not be representative because of sampling disturbances. Also standard penetration test (SPT) values may show higher resistance in clay. Static cone penetration tests and pressuremeter tests may give more realistic values in such cases. Care should be taken to identify such situations and modify the pile design accordingly. Pile design parameters should be judiciously selected so as to avoid a situation where field capacities are lower than computed values.

**CONSTRUCTION CONSIDERATIONS**

Careful monitoring of construction methods by engineers experienced in bored pile construction is an essential prerequisite for successful execution of all piling works. In particular, in weak soils where the borehole or the under-ream portion could collapse and in areas with high groundwater table, extreme caution should be used. Since the construction method is primarily manual, the caving problem needs more precaution than other bored piles. Construction problems with regard to hole stability in bored pile construction in collapsible soils are discussed by Tomlinson (1977) and Bhandari et al (1982).

Guidelines given by Sharma et al (1978) should be followed during construction. Where caving is a problem, the use of drilling mud of proper consistency should be used for boring and under-reaming. In such soils, the borehole should be cleaned by circulating drilling mud for about 15 minutes just before concreting. Also a tremie pipe with a flap valve for concreting may be used. As a

precautionary measure, the use of multiunder-reamed piles is not recommended in very unstable soils. All these do add to the cost of installing the pile and should be evaluated carefully in determining the superiority of the piles.

#### SITUATIONS WHERE UNDER-REAMED PILES ARE NOT SUITABLE OR SHOULD BE USED WITH CAUTION

Three situations have been identified where under-reamed piles are not a suitable foundation system or should be used with caution. These are identified below :

1. Where a consolidating soft clay layer or a loose sand layer occurs below the pile tip, the loading on the pile can cause settlement of underlying weak soils. An example of such a soil condition is schematically shown in Fig.3. In such soil conditions either piles should not be used or the pile tip should be extended below the compressible stratum, or kept significantly above the compressive stratum.
2. Due to the manual methods of construction prevalent in India, under-reamed piles present construction difficulties in strata containing boulders and where shallow rock is present. Additional costs of chiselling or rotary drilling and problems of under-reaming in such strata make this foundation scheme an expensive and unsuitable system.
3. Problems of construction in collapsible soils are discussed in a previous section of this paper. Although the problem of caving is usually not insurmountable, careful planning is required to complete the construction successfully. Also, the additional cost factor involved needs to be evaluated in determining the superiority of the pile over other foundation systems.



Fig. 3. Consolidating soil below pile-tip.

#### CONCLUDING REMARKS

The superiority of under-reamed piles as a foundation scheme is evaluated not only on technical superiority of foundation performance but also where economic factors and construction considerations and site factors make it a better and economical foundation scheme. A carefully planned site investigation is an essential pre-requisite in selecting a superior foundation scheme.

In expansive clays and black cotton soils, under-reamed piles are a superior foundation system. The under-ream bulb acts as an anchor against soil movements due to heave and shrinkage. The behaviour of the active zone should be considered in the design of under-reamed piles in expansive soils. Pile load tests may be unreliable in such soils because the behaviour of the active zone cannot be correctly modelled.

Under-reamed piles are often an economical alternative in light to moderately loaded structures bearing on soils which are weak to about 1 to 3m below ground surface and are underlain by soils with adequate bearing capacity.

For structure subjected to uplift forces more than the normal compressive load, under-reamed piles are usually a superior foundation system because of the higher uplift resistance developed due to the presence of the under-ream.

Where problems of dewatering associated with shallow foundation construction exists, provision of under-reamed piles may be economical. For remote sites and sites with problems of access, the light-weight equipment for manual construction of under-reamed piles may be advantageous.

Individual bored compaction under-reamed piles provide higher axial capacities than conventional under-reamed piles and are a superior foundation scheme. It is recommended that, where soil conditions permit, bored compaction under-reamed piles be used as a preferred alternative to conventional under-reamed piles.

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