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Indian Standard

**CODE OF PRACTICE FOR DESIGN
AND CONSTRUCTION OF PILE FOUNDATION**

PART 1 CONCRETE PILES

Section 4 Bored Precast Concrete Piles

(Incorporating Amendment No. 1)

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Price Group 7

Indian Standard

CODE OF PRACTICE FOR DESIGN
AND CONSTRUCTION OF PILE FOUNDATION

PART 1 CONCRETE PILES

Section 4 Bored Precast Concrete Piles

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Indian Standard

CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION OF PILE FOUNDATION

PART 1 CONCRETE PILES

Section 4 Bored Precast Concrete Piles

0. FOREWORD

0.1 This Indian Standard (Part 1/Set 4) was adopted by the Indian Standards Institution on 27 February 1984, after the draft finalized by the Foundation Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Piles find application in foundation to transfer loads from a structure to competent subsurface strata having adequate load-bearing capacity. The load transfer mechanism from a pile to the surrounding ground is complicated and could not yet be fully determined, although application of piled foundations is in practice over many decades. Broadly, piles transfer axial loads either substantially by friction along its shaft and/or substantially by the end bearing. Piles are used where either of the above load transfer mechanism is possible, depending upon the subsoil stratification at a particular site. Construction of pile foundations requires a careful choice of piling system, depending upon the subsoil conditions, the load characteristics of a structure and the limitations of total settlement, differential settlement and any other special requirement of a project. The installation of piles demands careful control on position, alignment and depth and involve specialized skill and experience.

0.3 This standard (Part 1) was originally published in 1964 and included provisions regarding driven cast *in-situ* piles, precast concrete piles, bored (cast *in-situ*) and under-reamed piles, including load testing. Subsequently portions pertaining to under-reamed pile foundations were deleted and which are now covered in IS : 2911 (Part 3). At that time it was decided that the provisions regarding other types of piles should also be published separately for the ease of reference and to take into account the recent developments in this field. Consequently IS : 2911 (Part 1)-1964* has been revised in various sections. So far the following sections have been formulated.

*Code of practice for design and construction of pile foundation: Part 1 Load bearing concrete piles.

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Section 1 Driven cast *in-situ* concrete piles

Section 2 Bored cast *in-situ* piles

Section 3 Driven precast concrete piles

Section 4 Bored precast concrete piles

0.3.1 This section covers the bored precast concrete piles which have now come into use in recent times.

0.4 Bored precast concrete pile is a pile constructed in a casting yard and subsequently lowered into pre-bored holes and the space grouted. These piles find wide applications where safety against chemical aggressive subsoil and the ground water condition is needed. Such protection is possible with bored precast concrete piles, because these are made using vibrated dense, matured concrete, with low water cement ratio and are not subjected to driving stresses. These are also useful where artesian conditions exist or where local obstructions are encountered above the founding level or subsoil water flow exists. They also offer facility for applying protective coating on the pile surfaces. The provision in respect of segmental piles with properly designed joints are under consideration of the Committee and its provisions will be covered at a later stage.

0.5 The Sectional Committee responsible for the preparation of standard, while formulating this standard, gave due consideration to the available experience in this country in pile construction and also the limitations regarding the availability of piling plant and equipment.

0.5.1 The information furnished by the various construction agencies and specialist firms doing piling work in this country and technical discussions thereon considerably assisted the committee in formulation of this code.

0.6 This edition 1.1 incorporates Amendment No. 1 (October 1987). Side bar indicates modification of the text as the result of incorporation of the amendment.

0.7 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard (Part 1/Sec 4) covers the design and construction of load bearing bored precast concrete pile which transmit the load of the structure to the strata where resistance is adequate.

NOTE — This standard is based on assumption that strength of grout fill up in the space shall be at least equivalent to that of surrounding soil and the skin friction developed on the pile shall be determined by probative test.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Allowable Load — The load which may be applied to a pile after taking into account its ultimate load capacity, pile spacing, overall bearing capacity of the ground below the pile, the allowable settlement, negative skin friction and the loading conditions including reversal of loads, etc.

2.2 Batter Pile (Raker Pile) — The pile which is installed at an angle to the vertical.

2.3 Bearing Pile — A pile formed in the ground for transmitting the load of a structure to the soil by the resistance developed at its tip and/or along its surface. It may be formed either vertically or at an inclination (Batter Pile) and may be required to take uplift.

If the pile support the load primarily by resistance developed at the pile point or base it is referred to as 'End Bearing Pile', if primarily by friction along its surface then as 'Friction Pile'.

2.4 Bored Precast Pile — A pile constructed in reinforced concrete in a casting yard and subsequently lowered into prebored holes and space grouted.

2.5 Cut-off Level - It is the level where the installed pile is cut-off to support the pile caps or beams or any other structural components at that level.

2.6 Factor of Safety — The ratio of the ultimate load capacity of a pile, to the safe load of a pile.

2.7 Safe Load — The load derived by applying a factor of safety on the ultimate load capacity of the pile or as determined in the load test.

2.8 Ultimate Load Capacity — The maximum load which a pile or pile shaft can carry before failure of ground (when the soil fails by shear as evidence from the load settlement curves) or failure of pile materials.

2.9 Working Load — The load assigned to a pile according to design.

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3. NECESSARY INFORMATION

3.1 For the satisfactory design and construction of bored precast piles, the following information is necessary:

- a) Site investigation data as laid down in IS : 1892-1979*, and other relevant Codes. Sections of trial boring, supplemented, wherever appropriate, by penetration tests, should incorporate data/information sufficiently below the anticipated level of the pile tip; the boring below the pile tip should generally be not less than 10 m unless bed rock or firm strata has been encountered earlier. The nature of the soil both around and beneath the proposed pile should be indicated on the basis of appropriate tests of strength, compressibility, etc. Ground-water levels and conditions (such as artesian conditions) should be indicated. Results of chemical tests to ascertain the sulphate and chloride content and/or any other deleterious chemical content of soil and/or ground water should be indicated, particularly in areas where large piling work is envisaged or where such information is not generally available.
- b) In case of bridge foundations, data on high flood level, maximum scouring depth, normal water level during working season, etc, should be provided. In the case of marine construction, high and low tide level, flow of water and other necessary information, as listed in IS : 4651 (Part 1)-1974† should be provided.
- c) In case rock is encountered, adequate description of rock to convey its physical conditions as well as its strength characteristics should be indicated.
- d) General plan and cross section of the structure showing type of structural frame, including basement, if any, in relation to the proposed pile-cap top travels should be provided.
- e) The general layout of the structure showing estimated loads, vertical and horizontal, moments and torque at the top of pile caps, but excluding the mass of the piles and caps should be provided. The top levels of finished pile caps shall be clearly indicated.
- f) All transient loads due to seismic and wind conditions and load due to under water should be indicated separately.
- g) Sufficient information of structures existing nearby and the experience of piles in the area close to the proposed site and boring report thereof for assessing the founding level of piles should be provided.

*Code of practice for subsurface investigations for foundations (*first revision*).

†Code of practice for planning and design of ports and harbours: Part 1 Site investigation (*first revision*).

4. EQUIPMENT AND ACCESSORIES

4.1 The equipment and accessories will depend on the type of bored precast piles chosen in a job and would be selected giving due consideration to the subsoil strata, ground-water conditions, type and founding material and the required penetration therein wherever applicable.

4.2 Among the commonly used plants, tools and accessories, there exist a large variety; suitability of which depends on the subsoil conditions, manner of operation, etc.

Boring operations are generally done by any appropriate method with or without temporary casing. Boring may be carried out using mud stabilisation if required.

4.3 Handling Equipment for Lowering — Handling equipment such as crane, derricks, movable gantry, may be used for handling and lowering of the precast piles in the bore. The choice of equipment will depend upon length, mass, and other practical requirements.

4.4 Grouting Plant — The mixing of the grout can be carried out in any suitable high speed collidal mixer. For grouting a suitable grout pump with stirring/agitating arrangement may be used.

5. DESIGN CONSIDERATION

5.1 General — Pile foundations shall be designed in such a way that the load from the structure it supports, can be transmitted to the soil without causing any soil failure and without causing such settlement differential or total under permanent transient loading as may result in structural damage and/or functional distress. The pile shaft should have adequate structural capacity to withstand all loads (vertical, axial or otherwise) and moments which are to be transmitted to the subsoil and shall be designed according to IS : 456-1978*. The shaft of bored precast piles may be of circular or octagonal shape, and may be of solid section or with a central hollow core. The limiting size of the pile will depend mainly on available handling equipment and the mass of the pile shaft to be handled.

5.2 Adjacent Structures

5.2.1 When working near existing structures care shall be taken to avoid any damage to such structures. In the case of bored pile care shall be taken to avoid effect due to loss of ground; when boring is carried out using mud, the stability of the bore particularly adjacent to loaded foundations shall be examined.

5.2.2 In case of deep excavations adjacent to piles, proper shoring or other suitable arrangement shall be done to guard against the lateral movement of soil stratum or releasing the confining soil stress.

*Code of practice for plain and reinforced concrete (*third revision*).

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5.3 Soil Resistance — The bearing capacity of a pile is dependent on the properties of the soil in which it is embedded. Axial load from a pile is normally transmitted to the soil through skin friction along the shaft and end bearing at its tip. A horizontal load on a vertical pile is transmitted to the subsoil primarily by horizontal subgrade reaction generated in the upper part of the shaft. A single pile is normally designed to carry load along its axis. Transverse load bearing capacity of a single pile depends on the soil reaction developed and the structural capacity of the shaft under bending. In case the horizontal loads are of higher magnitude, it is essential to investigate the phenomenon using principles of horizontal subsoil reaction adopting appropriate values for horizontal modulus of the soil. Alternatively piles may be installed in rake.

5.3.1 The ultimate load capacity of a pile may be estimated using a suitable static formula. However, it should preferably be determined by an initial load test [see IS : 2911 (Part 4)-1984]*. The cross sectional area for the purpose of the calculation shall be the concrete section excluding the grout where chemical aggression is likely to inhibit setting of cement.

The settlement of pile obtained at safe load/working load from load test results on a single pile shall not be directly used in forecasting the settlement of structure [see IS : 8009 (Part 2)-1980†].

The average settlement may be assessed. It would be more appropriate to assess the average settlement on the basis of subsoil data and loading details of the structure as a whole using the principles of soil mechanics.

5.3.1.1 Static formula — By using static formula, the estimated value of ultimate load capacity of a typical pile is obtained, the accuracy being dependent on the reliability of the formula and the reliability of the available soil properties for various strata. The soil properties to be adopted in such formula may be assigned from the results of laboratory tests and field tests like standard penetration tests (see IS : 2131-1981‡). Results of cone penetration tests may also be utilized where necessary correlation with soil results data has been established [see IS : 4968 (Part 1)-1976§, IS : 4968 (Part 2)-1976§, IS : 4968 (Part 3)-1976§. Two separate static formula commonly applicable for cohesive and cohesionless soil respectively are indicated in Appendix A

*Code of practice for design and construction pile foundations: Part 4 Load test on piles (*first revision*).

†Code of practice for calculation of settlement of foundations: Part 2 Deep foundations subjected to symmetrical static vertical loading.

‡Method for standard penetration test for soils (*first revision*).

§Method for subsurface sounding for soils:

Part I Dynamic method using 50 mm cone without bentonite slurry (*first revision*).

Part II Dynamic method using cone and bentonite slurry (*first revision*).

Part III Static cone penetration test (*first revision*).

to serve only as a guide. Other alternative formula may also be applicable, depending on the subsoil characteristics and method of installation of piles.

5.4 Negative Skin Friction or Dragdown Force — When a soil stratum through which a pile shaft has penetrated into an underlying hard stratum, compresses as a result of either it being unconsolidated or it being under a newly placed fill or as a result of remoulding of the pile, a dragdown force is generated along the pile shaft up to a point in depth where the surrounding soil does not move downward relative to the pile shaft.

NOTE — Estimation of this dragdown force is still under research studies and considerations, although a few empirical approaches are in use for the same. The concept is constantly under revision and, therefore, no definite proposal is embodied in this standard.

5.5 Structural Capacity — The piles shall have necessary structural strength to transmit the loads imposed on it, ultimately to the soil.

5.5.1 Axial Capacity — Where a pile is wholly embedded in the soil (having a undrained shear strength not less than 0.1 kgf/cm^2) its axial carrying capacity is not limited by its strength as a long column. Where piles are installed through very weak soils (having an undrained shear strength less than 0.1 kgf/cm^2) special considerations shall be made to determine whether the shaft would behave as long column or not; if necessary suitable reductions shall be made for its structural strength following the normals tructural principles covering the buckling phenomenon. When the finished pile projects above ground level and is not secured against buckling by adequate bracing, the effective length will be governed by fixity conditions imposed on it by the structure it supports and by the nature of the soil into which it is installed. The depth below the ground surface to the lower point of contraflexure varies with the type of the soil. A stratum of liquid mud should be treated as if it was water. The degree of fixity of the position and inclination of the pile top and the restraint provided by any bracing shall be estimated following accepted structural principles. The permissible stress shall be reduced in accordance with similar provisions for reinforced concrete columns as laid down in IS : 456-1978*.

5.5.2 Lateral Load Capacity — A pile may be subjected to transverse force from a number of causes, such as wind, earthquake, water current, earth pressure effect of moving vehicles or ships, plant and equipment, etc. The lateral load carrying capacity of a single pile depends not only on the horizontal subgrade modulus of the surrounding soil but also on

*Code of practice for plain and reinforced concrete (*third revision*).

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the structural strength of the pile shaft against bending consequent upon application of a lateral load. While considering lateral load of piles, effect of other coexistent loads including the axial load on the pile, should be taken into consideration for checking the structural capacity of the shaft. A recommended method for the determination of depth of fixity, lateral deflection and maximum bending moment required for design is given in Appendix B for fully or partially embedded piles. Other accepted methods, such as the method of Reese and Matlock for fully embedded piles may also be used.

NOTE — Because of limited information on horizontal modulus of soil, and refinements in the theoretical analysis, it is suggested that adequacy of a design may be checked by an actual field load test.

5.5.3 Raker Piles — Raker piles are normally provided where vertical piles cannot resist the required applied horizontal forces. In the preliminary design the load on a raker pile is generally considered to be axial. The distribution of load between raker and vertical piles in a group may be determined by graphical or analytical methods. Where necessary, due consideration should be made for secondary bending induced as a result of the pile cap movement, particularly when the cap is rigid. Free-standing raker piles are subjected to bending moments due to their own mass, or external forces from other causes. Raker piles embedded in fill or consolidating deposits, may become laterally loaded owing to the settlement of the surrounding soil.

5.6 Spacing of Piles — The centre-to-centre spacing of piles should be considered from two aspects:

- a) practical aspects of installing the piles, and
- b) the nature of the load transfer to the soil and possible reduction in the bearing capacity of a group of piles thereby.

The choice of the spacing is normally made on semi-empirical approach.

5.6.1 In case of piles which are predominantly resting on hard stratum and deriving their capacity mainly from end bearing, the spacing will be governed by the competency of the end bearing strata. The minimum spacing in such cases, shall be 2.5 times the diameter of the pile. In case of piles resting on rock, the spacing of twice the diameter of the pile may be adopted.

5.6.2 Piles deriving their bearing capacity mainly from friction shall be sufficiently apart to ensure that the zones of soils from which the piles derive their support do not overlap to such an extent that their bearing values are reduced. Generally the spacing in such cases shall not be less than three times the diameter of the pile.

5.6.3 The spacing should not be so close as to cause direct contact between two adjacent piles in a group, the deviations at depths arising out of the tolerance allowed in the installation. This would mean the minimum spacing would, to some extent, depend on the length of piles installed.

5.7 Pile Grouping — In order to determine the bearing capacity of a group of piles, a number of efficiency equations are in use. However, it is very difficult to establish the accuracy of these efficiency equations as the behaviour of piles group is dependent on many complex factors. It is desirable to consider each case separately on its own merit.

5.7.1 The bearing capacity of a pile group may be either:

- a) equal to the bearing capacity of individual piles multiplied by the number of piles in the group, or
- b) it may be less.

5.7.2 In case of piles deriving their support mainly from friction and connected by a pile cap, the group may be visualized to transmit load to the soil, as if from a column of soil enclosed by the piles. The ultimate capacity of the group may be computed following this concept, taking into account the frictional capacity along the perimeter of the column of soil as above and the end bearing of the said column using the accepted principles of soil mechanics.

5.7.2.1 When the cap of the pile group is cast directly on reasonably firm stratum which supports the piles it may contribute to the bearing capacity of the group. The additional capacity along with the individual capacity of the piles multiplied by the number of piles in the group should not be more than the capacity worked out in **5.7.2**.

5.7.3 When a moment is applied on the pile group either from super structure or as a consequence of unavoidable inaccuracies of installation, the adequacy of the pile group in resisting the applied moment should be checked. In case of a single pile subjected to moments due to lateral forces or eccentric loading beams may be provided to restrain the pile cap effectively from lateral or rotational movement.

5.7.4 In case of structure supported on single pile/group of piles, resulting into large variation in the number of piles from column to column, it is likely, depending on the type of subsoil supporting the piles, to result in a high order of differential settlement. Such high order of differential settlement may be either catered for in the structural design or it may be suitably reduced by judicious choice of variations in the actual pile loadings. For example, a single piles cap may be loaded to a level higher than that of a pile in a group in order to achieve reduced differential settlement between two adjacent pile caps supported on different number of piles.

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5.8 Factor of Safety and Safe Load

5.8.1 Factor of safety should be judiciously chosen after considering:

- a) the reliability of the value of ultimate load capacity of a pile,
- b) the type of superstructure and the type of loading, and
- c) allowable total/differential settlement of the structure.

5.8.2 The ultimate load capacity may be obtained whenever practicable, from a load test (initial) [see IS : 2911 (Part 4)-1984*].

5.8.3 When the ultimate load capacity is computed from static formula the factor of safety would depend on the reliability of the formula depending on a particular site and locality and the reliability of the subsoil parameters employed in such computation. The minimum factor of safety on static formula shall be 2.5. The final selection of factor of safety shall take into consideration the load settlement characteristics of the structure as a whole at a given site.

5.8.4 Factors of safety for assessing safe load on piles from load test data should be increased in unfavourable conditions where:

- a) settlement is to be limited or unequal settlement avoided as in the case of accurately aligned machinery or a superstructure with fragile finishings,
- b) large impact or vibrating loads are expected,
- c) the properties of the soil may be expected to deteriorate with time, and
- d) the live load on a structure carried by friction piles is a considerable portion of the total load and approximates to the dead load in its duration.

5.9 Transient Loading — The maximum permissible increase over the safe load of a pile as arising out of wind loading, is 25 percent. In case of loads and moments arising out of earthquake effects, the increase of safeload on a single pile may be limited to the provisions contained in IS : 1893-1975†. For transient loading arising out of superimposed loads no increase may be generally allowed.

5.10 Overloading — When a pile in a group, designed for a certain safe load is found, during or after execution, to fall just short of the load required to be carried by it, an overload up to 10 percent of the pile capacity may be allowed on each pile. The total overloading on the

*Code of practice for design and construction of pile foundations: Part 4 Load test on piles (*first revision*).

†Criteria for earthquake resistant design of structures (*third revision*).

group should not be more than 10 percent of the capacity of the group and not more than 40 percent of the allowable load on a single pile. This is subject to the increase of the load on any pile not exceeding 10 percent of its capacity.

5.11 Lifting and Handling Stresses — Stresses induced by bending in the cross section of a precast pile during lifting and handling may be estimated just as for any reinforced concrete section in accordance with relevant provisions of IS : 456-1978*. The calculations with regard to moments depending on the method of support during handling will be as given below. Excessive whippiness in handling precast pile may generally be avoided by limiting the length of pile to a maximum of 50 times the least width.

<i>Number of Points of Pick Up</i>	<i>Location of Point of Support from and in Terms of Length of Pile for Minimum Moments</i>	<i>Bending Moment to be Allowed for Design</i>
One	0.293 L	$\frac{WL}{23.3}$
Two	0.207 L	$\frac{WL}{46.6}$
Three	0.145 L, the middle point will be at the centre	$\frac{WL}{95}$

where

W = mass of pile in kg, and

L = length in metres.

During hoisting the pile will be suspended at one point near the head and the bending moment will be the least when it is pulled in a distance of 0.293 L , and the value of bending moment will be:

$$\frac{WL}{23.3}$$

5.12 Reinforcement — The longitudinal reinforcement shall be provided in for the entire length preferably of high yield strength to withstand the handling stresses to the extent to meet requirement as given in 5.11. All the main longitudinal bars shall be of the same length. The area of the main longitudinal reinforcement of any type and grade shall not be less than 0.4 percent of the cross section area of the piles or as required to cater for handling stresses whichever is greater. The lateral reinforcement shall be links or spirals preferably of not less than 6 mm diameter bars. The cover of concrete over all the reinforcement including bending wire should not be less than 40 mm, but where the piles are exposed to the sea water or water having other

*Code of practice for plain and reinforced concrete (*third revision*).

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corrosive contents the cover should be no where less than 50 mm. A thin gauge sheathing pipe of approximately 40 mm diameter may be attached to the reinforcement cage, in case of solid piles, to form the central duct for pumping grout to the bottom of the bore.

5.13 Design of Pile Cap

5.13.1 The pile caps may be designed by assuming that the load from column is dispersed at 45° from the top of the cap up to the mid-depth of the pile cap from the base of the column or pedestal. The reaction from piles may also be taken to be distributed at 45° from the edge of the pile, up to the mid-depth of the pile cap. On this basis the maximum bending moment and shear forces should be worked out at critical sections. The methods of analysis and allowable stresses should be in accordance with IS : 456-1978*.

5.13.2 Pile cap shall be deep enough to allow for necessary anchorage of the column and pile reinforcement.

5.13.3 The pile cap should normally be rigid enough so that the imposed load could be distributed on the piles in a group equitably.

5.13.4 In case of a large cap, where differential settlement may be imposed between piles under the same cap, due consideration for the consequential moments should be given.

5.13.5 The clear overhang of the pile cap beyond the outermost pile in the group shall normally be 100 to 150 mm depending upon the pile size.

5.13.6 The cap is generally cast over a 75 mm thick levelling course of concrete. The clear cover for main reinforcement in the cap slab shall not be less than 60 mm.

5.13.7 The pile should project 50 mm into the cap concrete.

5.14 The design of grade beams if used shall be as given in IS : 2911 (Part 3)-1980†.

6. MATERIALS

6.1 Cement — The cement used shall conform to the requirements of IS : 269-1976‡, IS : 455-1976§, IS : 8041-1978||, IS : 1489-1976¶, and IS : 6909-1973** as the case may be.

*Code of practice for plain and reinforced concrete (*third revision*).

†Code of practice for design and construction of pile foundations : Part 3 Under-reamed pile foundations (*first revision*).

‡Specification for ordinary and low heat Portland cement (*third revision*).

§Specification for Portland slag cement (*third revision*).

||Specification for rapid hardening Portland cement (*first revision*).

¶Specification for Portland-pozzolana cement (*second revision*).

**Specification for super-sulphated cement.

6.2 Steel — Reinforcement steel shall conform to IS : 432 (Part 1)-1982*, IS : 1786-1985† or IS : 226-1975‡.

6.3 Concrete

6.3.1 Materials and method of manufacture for cement concrete shall in general be in accordance with the relevant requirements given in IS : 456-1978§. The stresses in concrete due to working load and during handling, pitching and driving of the pile should not exceed than those stipulated in IS : 456-1978§ according to the grade of concrete used and having due regard to the age of piles at the time of handling.

6.3.2 The grade of concrete should be preferably not less than M25.

6.3.3 For the concrete, water and aggregates specifications laid down in IS : 456-1978§ shall be followed in general. Natural rounded shingle of appropriate size may also be used as coarse aggregate. It helps to give high slump with less water-cement ratio. For tremie concreting aggregates having nominal size more than 20 mm should not be used.

7. WORKMANSHIP

7.1 As far as possible *in-situ* extensions shall be avoided. The casting yard for all concrete piles should preferably be so arranged that they can be lifted directly from their beds and transported to the piling frame with a minimum of handling. The casting yard should have a well-drained surface to prevent excessive or uneven settlement due to softening during manufacture and curing.

7.2 As far as practicable each longitudinal reinforcement shall be in one length. In cases where joints in reinforcing bars cannot be avoided, the joints in bars shall be staggered. The hoops and links for reinforcement shall fit tightly against longitudinal bars and be bound to them by welding or by tying with mild steel wire, the free ends of which should be turned into the interior of the pile. The longitudinal bars may be held apart by temporary or permanent spreader forks not more than 1.5 m apart. The reinforcement shall be checked for tightness and position immediately before concreting.

7.3 Casting and Curing

7.3.1 The piles should be cast in a continuous operation from end to end of each pile. The concrete should be thoroughly compacted against the forms and around the reinforcement by means of immersion and/or shutter vibrators. The faces of the pile including those exposed at the

*Specification for mild steel and medium tensile steel bars and hard drawn steel wires for concrete reinforcement: Part 1 Mild steel and medium tensile steel bars (*third revision*).

†Specification for high strength deformed steel bars and wires for concrete reinforcement (*third revision*).

‡Specification for structural steel (standard quality) (*fifth revision*).

§Code of practice for plain and reinforced concrete (*third revision*).

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top of pile should be dense as far as possible. Immediately on completion of the casting the top surface should be finished level without excessive trowelling. Care should be taken to ensure that vibration from adjoining works does not effect the previously placed concrete for piles during the setting period.

7.3.1.1 All shuttering shall be placed on firm supports capable of withstanding the loads of shuttering, wet concrete and incidental load of workmen, so that cast piles are straight and free from deformations. The shuttering shall be coated with oil on the inside face.

7.3.2 Though from consideration of speed and economy precast concrete piles will have to be placed with the least possible delay after casting, it shall be kept in mind that a thorough curing and hardening is necessary before the piles are placed and proper schedule to take care of this shall be decided for the operations of casting, stacking and placing. The most important factors effecting the time of curing are the method of curing, weather during hardening, probable hardness of placing and the method of lifting and pitching.

7.3.4 Before the operation of handling the piles, the minimum periods counted from the time of casting as given in IS : 456-1978* shall be followed.

7.4 Sorting and Handling

7.4.1 Piles shall be stored on firm ground free from liability to unequal subsidence or settlement under the mass of the stack of piles. The piles shall be placed on timber supports which are truly level and spaced so as to avoid undue bending in the piles. The support shall be vertically one above the other. Spaces shall be left round the piles to enable them to be lifted without difficulty. The order of stacking shall be such that the older piles can be withdrawn for placing without disturbing the newer piles. Separate stacks shall be provided for different lengths of piles. Wherever curing is needed during storage, arrangements shall be made to enable the piles to be watered if weather conditions so require. For detailed precautions with regard to curing operations reference may be made to IS : 456-1978*.

7.4.2 Care shall be taken at all stages of transporting, lifting and handling of the piles that they are not damaged or cracked. During transportation, the piles shall be supported at the appropriate lifting holes provided for the purposes. If the piles are put down temporarily after being lifted, they shall be placed on trestles of blocks located at the lifting points.

*Code of practice for plain and reinforced concrete (*third revision*).

7.5 Control of Pile Installation

7.5.1 Bored precast piles shall be constructed by suitable choice of boring and installation techniques; covering the manner of soil stabilization, that is, use of casing and/or use of drilling mud and choice of boring tools in order to permit a satisfactory installation of a pile at a given site. Sufficient detailed information about the subsoil conditions is essential to predetermine the details of the installation technique. The bottom end of the pile shall have proper arrangements for cleaning and grouting.

7.5.2 Control of Alignment — Piles shall be installed as accurately as possible according to the designs and drawings either vertically or to the specified batter. Greater care should be exercised in respect of installation of single pile or piles in two pile groups. As a guide, for vertical piles a deviation of 1.5 percent and for raker piles a deviation of 4 percent should not be normally exceeded although in special cases a closer tolerance may be necessary. Piles should not deviate more than 75 mm or $D/6$ whichever is less (75 mm or $D/10$ whichever is more in case of piles having diameter more than 600 mm) from their designed positions at the working level. In the case of a single pile in a column the positional tolerance should not be more than 50 mm or $D/6$ whichever is less (100 mm in case of piles having diameter more than 600 mm). Greater tolerance may be prescribed for piles driven over water and for raking piles. For piles to be cut off at a substantial depth (below ground level) or height (above ground level), the design should provide for the worst combination of the above tolerance in position and inclination. In case of piles deviating beyond these limits and to such an extent that the resulting eccentricity cannot be taken care of by a redesign of the pile cap or pile ties, the piles should be replaced or supplemented by one or more additional piles. In case of piles, with non-circular cross section ' D ' should be taken as the dimensions of the pile, along which the deviation is computed. In such cases the permissible deviation in each direction should be different depending upon the dimension of the pile along that direction.

7.6 Flushing — The central duct/hole shall be connected to a suitable pump and water drilling fluid allowed to flow through the bottom of the pile removing loose material.

7.7 Grouting — Sand and cement grout mixed with water in a high speed collidal mixer is to be fed into the pile with a grout pump of suitable capacity connected to the central duct through a manifold. A grout of sand and cement with additives as necessary, of strength not less than 1 : 2 cement and sand (*see also* Note under **1.1**) suitable for pumping into the annulus, may also be used. The temporary casing here used shall be removed in stages with the rise of the level of grout. After final removal of the temporary casing, the grout level shall be brought up to the top by pouring in additional grout as required.

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7.8 Defective Pile — In case, defective piles are formed, they shall be removed or left in place whichever is convenient without affecting performance of the adjacent piles or the cap as a whole. Additional piles shall be provided to replace them.

7.9 Any deviation from the designed location alignment or load capacity of any pile shall be noted and adequate measures taken well before the concreting of the pile cap and plinth beam if the deviations are beyond the permissible limit.

7.10 Recording of Data

7.10.1 A competent inspector shall be present to record the necessary information during installation of piles and the data to be recorded shall include:

- a) the sequence of installation of piles in a group;
- b) the dimensions of the pile including the reinforcement details and mark of the pile;
- c) the depth placed;
- d) cut off level/working level; and
- e) any other important observation.

7.10.2 Typical data sheet for facility of recording piling data are shown in Appendix C.

7.11 Stripping Pile Heads

7.11.1 The concrete should be stripped to a level such that the remaining concrete of a pile will project minimum 50 mm into the pile cap. The effect of this projection on the position of any reinforcement in the pile cap should be considered in design. The pile reinforcement should be left with adequate projecting length above the cut off level for proper embedment into the pile cap. Exposing such length should be done carefully to avoid shattering or otherwise damaging the rest of the pile. Any cracked or defective concrete should be cut away and made good with new concrete properly bonded to the old.

7.12 Lengthening Piles — Where a pile is to have another length cast on to it before or during placing the longitudinal reinforcement should preferably be jointed by full penetration butt welding. The concrete at the top of the original pile should be cut down to expose not less than 200 mm of the bars. The bars should be held accurately and rigidly in position during welding. Where facilities at site are insufficient to make good butt welding practicable the joint may be made by lapping. The reinforcement at the head of the pile will need to be exposed for a distance of 40 times the bar diameter and the new bars overlapped for this distance. If the bonds are lapped, spot welding shall be done. As an alternative special bolt and nut joints may be provided.

APPENDIX A

(Clause 5.3.1.1)

LOAD CARRYING CAPACITY — STATIC FORMULA

A-1. PILES IN GRANULAR SOILS

A-1.1 The ultimate bearing capacity (Q_u) of piles in granular soils is given by the following formula:

$$Q_u = A_p \left(\frac{1}{2} D \gamma N_r + P_D N_q \right) + \sum_{i=1}^n K P_{Di} \tan \delta A_{Si}$$

where

A_p = cross-sectional area of pile toe in cm^2 ;

D = stem diameter in cm;

γ = effective unit weight of soil at pile toe in kgf/cm^3 ;

P_D = effective overburden pressure at pile toe in kgf/cm^2 ;

N_r and N_q = bearing capacity factors depending upon the angle of internal friction ϕ at toe;

$\sum_{i=1}^n$ summation for n layers in which pile is installed;

K = coefficient of earth pressure;

P_{Di} = effective overburden pressure in kg/cm^2 for the i^{th} layer where i varies from 1 to n ;

δ = angle of wall friction between pile and soil, in degrees (may be taken equal to ϕ); and

A_{Si} = surface area of pile stem in cm^2 in the i^{th} layer where i varies from 1 to n .

NOTE 1 — N_r factor can be taken for general shear failure as per IS : 6403-1981*

NOTE 2 — N_q factor will depend, apart from nature of soil on the type of pile and its method of construction, for bored piles, the value of N_q corresponding to angle of shearing resistance ϕ are given in Fig. 1. This is based on Berezantsev's curve for D/B of 20 up to $\phi = 35^\circ$ and Vesic's curves beyond $\phi = 35^\circ$.

NOTE 3 — The earth pressure coefficient K depends on the nature of soil strata, type of pile and its method of construction. For bored piles in loose medium sands, K values between 1 and 2 should be used.

*Code of practice for determination of bearing capacity of shallow foundations (*first revision*) .

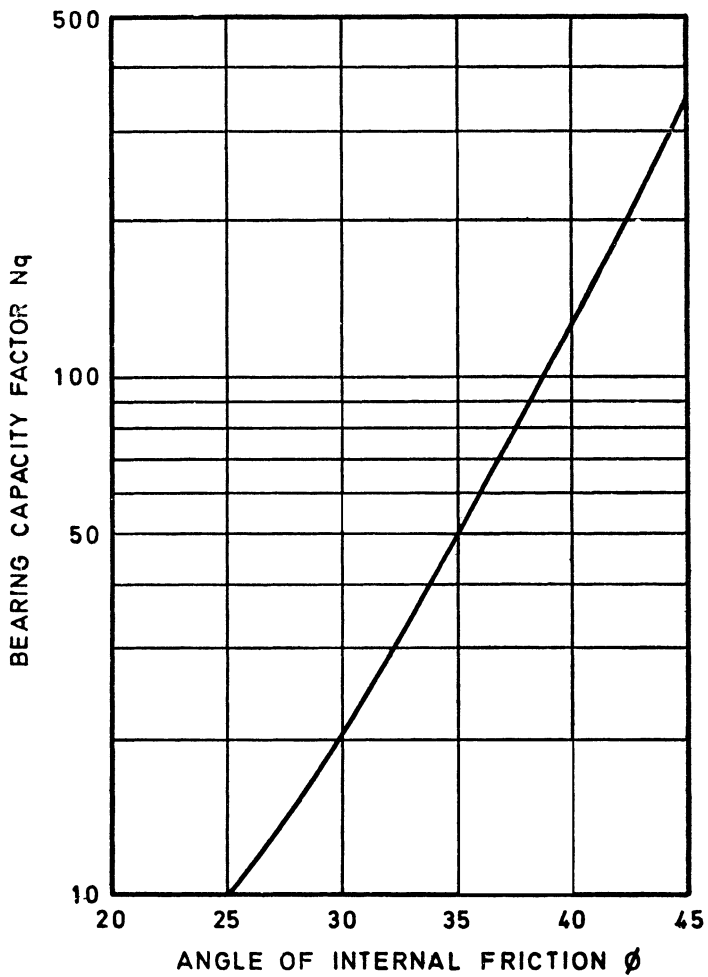


FIG 1 BEARING CAPACITY FACTOR N_q FOR BORED PILES

NOTE 4 — The angle of wall friction may be taken equal to angle of shear resistance of soil.

NOTE 5 — In working out pile capacities using static formula, for piles longer than 15 to 20 pile diameter, maximum effective overburden at the pile tip should correspond to pile length equal to 15 to 20 diameters.

A-2. PILES IN COHESIVE SOILS

A-2.1 The ultimate bearing capacity of piles (Q_u) in cohesive soil is given by the following:

$$Q_u = A_p \cdot N_c \cdot C_p + \alpha \cdot \bar{C} \cdot A_s$$

where

A_p = cross sectional area of pile toe in cm^2 ,

N_c = bearing capacity factor usually taken as 9,

C_p = average cohesion at pile tip in kg/cm^2 ,

α = reduction factor,

\bar{C} = average cohesion throughout the length of pile in kg/cm^2 , and

A_s = surface area of pile shaft in cm^2 .

NOTE 1 — The following values of α may be taken depending upon the consistency of the soils:

<i>Consistency</i>	<i>N Value</i>	<i>Value of α</i>
Soft to very soft	< 4	0.7
Medium	4 to 8	0.5
Stiff	8 to 15	0.4
Stiff to hard	> 15	0.3

NOTE 2 — (a) Static formula may be used as a guide only for bearing capacity estimate. Better reliance may be put on load test on piles.

(b) For working out safe load a minimum factor of safety 2.5 should be used on the ultimate bearing capacity estimated by static formulae.

NOTE 3 — α may be taken to vary from 0.5 to 0.3 depending upon the consistency of the soil. Higher values of up to one may be used for softer soils, provided the soil is not sensitive.

A-2.2 When full static penetration data is available for the entire depth, the following correlations may be used as a guide for the determination of shaft resistance of a pile.

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<i>Type of Soil</i>	<i>Local Side Friction,</i> f_s		
Clays and peats where $qc < 10$	$\frac{qc}{30}$	$< f_s$	$< \frac{qc}{10}$
Clays	$\frac{qc}{25}$	$< f_s$	$< \frac{2qc}{25}$
Silty clays and silty sands	$\frac{qc}{100}$	$< f_s$	$< \frac{qc}{25}$
Sands	$\frac{qc}{100}$	$< f_s$	$< \frac{2qc}{100}$
Coarse sands and gravels		f_s	$< \frac{qc}{150}$

where

q_c = static point resistance, and

f_s = local side friction.

For non-homogeneous soils the ultimate point bearing capacity may be calculated using the following relationships:

$$q_u = \frac{\frac{q_{c0} + q_{c1}}{2} + q_{c2}}{2}$$

where

q_u = ultimate point bearing capacity,

q_{c0} = average static cone resistance over a depth of $2d$ below the base level of the pile,

q_{c1} = minimum static cone resistance over the same $2d$ below the pile tip,

q_{c2} = average of the minimum cone resistance values in the diagram over a height of $8d$ above the base level of the pile, and

d = diameter of the pile base or the equivalent diameter for a non-circular cross section.

A-2.3 The correlation between standard penetration test value N and static point resistance q_c given below may be used for working the shaft resistance and skin friction of piles.

<i>Soil Type</i>	q_c/N
Clays	2.0
Silts, sandy silts and slightly cohesive silt sand mixtures	2.0
Clean fine to medium sands and slightly silty sands	3-4
Course sands and sands with little gravel	5-6
Sandy gravels and gravel	8-10

APPENDIX B

(Clause 5.5.2)

DETERMINATION OF DEPTH OF FIXITY, LATERAL DEFLECTION AND MAXIMUM MOMENT OF Laterally LOADED PILES

B-1. DETERMINATION OF LATERAL DEFLECTION AT THE PILE HEAD AND DEPTH OF FIXITY

B-1.1 The long flexible pile, fully or partially embedded, is treated as a cantilever fixed at some depth below the ground level (see Fig. 2).

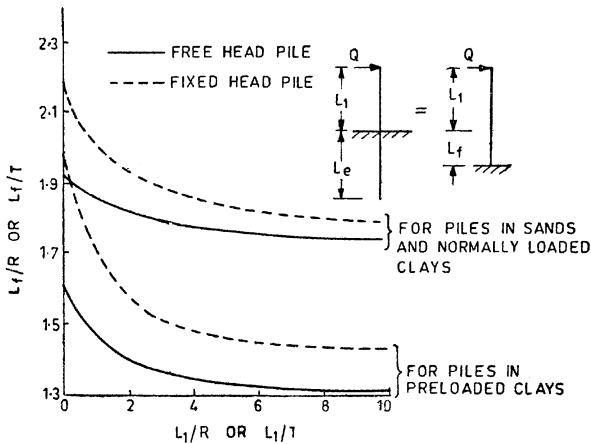


FIG. 2 DETERMINATION OF DEPTH FIXITY

B-1.2 Determine the depth of fixity and hence the equivalent length of the cantilever using the plots given in Fig. 2.

where

$$T = 5 \sqrt{\frac{EI}{K_1}} \text{ and } R = 4 \sqrt{\frac{EI}{K_2}} \text{ (} K_1 \text{ and } K_2 \text{ are constants given in$$

Tables 1 and 2 below, E is the Young's modulus of the pile material in kg/cm^2 and I is the moment of inertia of the pile cross-section in cm^4).

NOTE — Fig. 2 is valid for long flexible piles where the embedded length L_e is $\geq 4R$ or $4T$.

TABLE 1 VALUES OF CONSTANT K_1 (kg/cm³)

(Clause B-1.2)

	VALUE	
	Dry	Submerged
Loose sand	0.260	0.146
Medium sand	0.775	0.525
Dense sand	2.075	1.245
Very loose sand under repeated loading or normally loading clays	—	0.040

TABLE 2 VALUES OF CONSTANT K_2 (kg/cm²)

(Clause B-1.2)

UNCONFINED COMPRESSIVE STRENGTH IN kg/cm ²	VALUE
0.2 to 0.4	7.75
1 to 2	48.80
2 to 4	97.75
More than 4	195.50

B-1.3 Knowing the length of the equivalent cantilever the pile head deflection (Y) shall be computed using the following equations:

$$Y = \frac{Q(L_1 + L_F)^3}{3EI} \quad \dots\text{for free head pile}$$

(cm)

$$= \frac{Q(L_1 + L_F)^3}{12EI} \quad \dots\text{for fixed head pile}$$

where Q is the lateral load in kg.

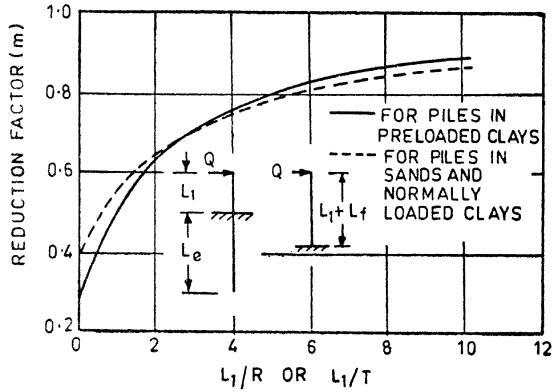
B-2. DETERMINATION OF MAXIMUM MOMENT IN THE PILE

B-2.1 The fixed end moment (M_F) of the equivalent cantilever is higher than the actual maximum moment (M) of the pile. The actual maximum moment is obtained by multiplying the fixed end moment of the equivalent cantilever by a reduction factor, m given in Fig. 3. The fixed end moment of the equivalent cantilever is given by:

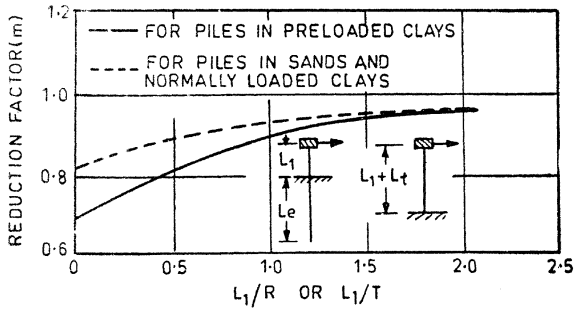
$$M_F = Q (L_1 + L_f) \quad \dots\text{for free head pile}$$

$$= \frac{Q (L_1 + L_f)}{2} \quad \dots\text{for fixed head pile}$$

The actual maximum moment (M) = $m (M_F)$.



3A FOR FREE HEAD PILE



3B FOR FIXED HEAD PILE

FIG. 3 DETERMINATION OF REDUCTION FACTORS FOR COMPUTATION OF MAXIMUM MOMENT IN PILE

APPENDIX C

(Clause 7.10.2)

DATA SHEETS

Site.....
Title.....
Date of enquiry.....
Date piling commenced.....
Actual or anticipated date for completion of piling work.....
Number of pile.....

TEST PILE DATA

Pile: Pile test commenced.....
Pile test completed.....

Pile type:
(Mention proprietary system, if any).....

Pile specification: { Shape.....
Size — Shaft.....toe.....
Reinforcement.....No.....dia for.....(depth)
.....)

Sequence of piling (for Groups): From centre towards the periphery or from periphery towards the centre

Concrete: Mix ratio 1:.....:by volume/mass or strength after.....dayskgf/cm²
Quantity of cement per m³:
Extra cement added if any:

Details of drilling mud if used:

Time taken for concreting:

Quantity of concrete — Actual:

— Theoretical:

Test loading:

.....

Capacity of jack.....

If anchor piles used, give.....No., Length.....

Distance of test pile from nearest anchor pile.....

Test pile and anchor piles were/were not working piles.

Method of taking observations:

Dial gauges/Engineers level.....

Reduced level of pile toe.....

General Remarks:

.....

.....

.....

.....

Special difficulties encountered:

.....

.....

.....

Results:

Working load specified for the test pile.....

Settlement specified for the test pile.....

Settlement specified for the structure.....

Working load accepted for a single pile as a result of the test.....

.....

.....

Working load in a group of piles accepted as a result of the test....

.....

.....

General description of the structure to be founded on piles.....

.....

.....

.....

.....

.....

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Name of the constructing agency.....

Name of person conducting the test.....

Name of the party for whom the test was conducted.....

BORE-HOLE LOG

1. Site of bore hole relative to test pile position.....

2. NOTE — If no bore hole, give best available ground conditions.....

<i>Soil Properties</i>	<i>Soil Description</i>	<i>Reduced Level</i>	<i>Soil Legend</i>	<i>Depth Below G.L.</i>	<i>Thickness of Strata</i>
------------------------	-------------------------	----------------------	--------------------	-------------------------	----------------------------

Position of the toe of pile to be indicted thus→

Standing ground water level indicated thus√

METHOD OF SITE INVESTIGATION

Trial pit/post-hole auger/shell and auger boring/percussion/probing/wash borings/mud-rotary drilling/core-drilling/shot drilling/subsurface sounding by cones or standard sampler.....

NOTE — Graphs, showing the following relations, shall be prepared and added to the report:

- 1) Load vs Time
- 2) Settlement vs Load

(Continued from page 2)

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