IS 2911-1-2 (2010): DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE, Part 1: CONCRETE PILES, Section 2: Bored Cast In-situ Concrete Piles [CED 43: Soil and Foundation Engineering]

BLANK PAGE

भारतीय मानक

पाइल नींव की डिजाइन और निर्माण — रीति संहिता

भाग 1 कंक्रीट पाइल

अनुभाग 2 स्वस्थान ढलित कंक्रीट की वेधित पाइल

(दूसरा पुनरीक्षण)

Indian Standard

DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE

PART 1 CONCRETE PILES

Section 2 Bored Cast *In-situ* Concrete Piles

(Second Revision)

ICS 91.100.30 : 93.020

B U R E A U O F I N D I A N S T A N D A R D S
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

May 2011 **Price Group 9**

Soil and Foundation Engineering Sectional Committee, CED 43

FOREWORD

This Indian Standard (Part 1/Sec 2) (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Soil and Foundation Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

Piles find application in foundations 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 is not yet fully understood, 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 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 require 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.

This standard was originally published in 1964 and included provisions regarding driven cast *in-situ* piles, precast concrete piles, bored piles and under-reamed piles including load testing of piles. Subsequently the portion pertaining to under-reamed pile foundations was deleted and now covered in IS 2911 (Part 3) : 1980 'Code of practice for design and construction of pile foundations: Part 3 Under-reamed piles (*first revision*)'. At that time it was also decided that the provisions regarding other types of piles should also be published separately for ease of reference and to take into account the recent developments in this field. Consequently this standard was revised in 1979 into three sections. Later, in 1984, a new section as (Part 1/Sec 4) was introduced in this part of the standard to cover the provisions of bored precast concrete piles. The portion relating to load test on piles has been covered in a separate part, namely, IS 2911 (Part 4) : 1984 'Code of practice for design and construction of pile foundations: Part 4 Load test on piles'. Accordingly IS 2911 has been published in four parts. The other parts of the standard are:

Part 2 Timber piles

Part 3 Under-reamed piles

Part 4 Load test on piles

Other sections of Part 1 are:

Section 1 Driven cast *in-situ* concrete piles

Section 3 Driven precast concrete piles

Section 4 Precast concrete piles in prebored holes

It has been felt that the provisions regarding the different types of piles should be further revised to take into account the recent developments in this field. This revision has been brought out to incorporate these developments.

In the present revision following major modifications have been made:

a) Definitions of various terms have been modified as per the prevailing engineering practice.

b) Minimum diameter of pile has been specified.

c) Procedures for calculation of bearing capacity, structural capacity, factor of safety, lateral load capacity, overloading, etc, have also been modified to bring them at par with the present practices.

(*Continued on third cover*)

(*Continued from second cover*)

d) Design parameters with respect to adhesion factor, earth pressure coefficient, modulus of subgrade reaction, etc, have been revised to make them consistence with the outcome of modern research and construction practices.

e) Minimum grade of concrete to be used in pile foundations has been revised to M 25.

f) Provisions for special use of large diameter bored cast *in-situ* reinforced cement concrete piles in marine structures have been added.

Bored cast *in-situ* pile is formed within the ground by excavating or boring a hole within it, with or without the aid of a temporary casing (to keep the hole stabilized) and subsequently filling it with plain or reinforced concrete. These piles are particularly applicable in certain subsoil conditions where penetration to a pre-determined depth is essential.

The recommendations for detailing for earthquake-resistant construction given in IS 13920 : 1993 'Ductile detailing of reinforced concrete structures subjected to seismic forces — Code of practice' should be taken into consideration, where applicable (*see also* IS 4326 : 1993 'Earthquake resistant design and construction of buildings — Code of practice').

The composition of the Committee responsible for that formulation of this standard is given in Annex G.

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 or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE

PART 1 CONCRETE PILES

Section 2 Bored Cast *In-situ* Concrete Piles

(Second Revision)

1 SCOPE

1.1 This standard (Part 1/Sec 2) covers the design and construction of bored cast *in-situ* concrete piles which transmit the load to the soil by resistance developed either at the pile tip by end-bearing or along the surface of the shaft by friction or by both.

1.2 This standard is not applicable for use of bored cast *in-situ* concrete piles for any other purpose, for example, temporary or permanent retaining structure.

2 REFERENCES

The standards listed in Annex A contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed in Annex A.

3 TERMINOLOGY

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

3.1 Allowable Load — The load which may be applied to a pile after taking into account its ultimate load capacity, group effect, the allowable settlement, negative skin friction and other relevant loading conditions.

3.2 Anchor Pile — An anchor pile means a pile meant for resisting pull or uplift forces.

3.3 Batter Pile (Raker Pile) — The pile which is installed at an angle to the vertical using temporary casing or permanent liner.

3.4 Bored Cast *In-situ* Pile — A pile formed by boring a hole in the ground by percussive or rotary method with the use of temporary/permanent casing or drilling mud and subsequently filling the hole with reinforced concrete.

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

3.6 Diameter of Piles — Piles of 600 mm or less in diameter are commonly known as small diameter piles while piles greater than 600 m diameter are called large diameter piles. Minimum pile diameter shall be 450 mm.

3.7 Elastic Displacement — This is the magnitude of displacement of the pile head during rebound on removal of a given test load. This comprises two components:

a) Elastic displacement of the soil participating in the load transfer, and

b) Elastic displacement of the pile shaft.

3.8 Factor of Safety — It is the ratio of the ultimate load capacity of a pile to the safe load on the pile.

3.9 Gross Displacement — The total movement of the pile top under a given load.

3.10 Initial Load Test — A test pile is tested to determine the load-carrying capacity of the pile by loading either to its ultimate load or to twice the estimated safe load.

3.11 Initial Test Pile — One or more piles, which are not working piles, may be installed if required to assess the load-carrying capacity of a pile. These piles are tested either to their ultimate load capacity or to twice the estimated safe load.

3.12 Load 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 resist uplift forces.

If the pile supports the load primarily by resistance developed at the pile tip or base it is called 'End-bearing pile' and, if primarily by friction along its surface, then 'Friction pile'.

3.13 Net Displacement — The net vertical movement of the pile top after the pile has been subjected to a test load and subsequently released.

3.14 Pile Spacing — The spacing of the piles means the center-to-center distance between adjacent piles.

3.15 Routine Test Pile — A pile which is selected for load testing may form a working pile itself, if subjected to routine load test up to one and 1.5 times the safe load.

3.16 Safe Load — It is the load derived by applying a factor of safety on the ultimate load capacity of the pile or as determined from load test.

3.17 Ultimate Load Capacity — The maximum load which a pile can carry before failure, that is, when the founding strata fails by shear as evidenced from the load settlement curve or the pile fails as a structural member.

3.18 Working Load — The load assigned to a pile as per design.

3.19 Working Pile — A pile forming part of the foundation system of a given structure.

4 NECESSARY INFORMATION

4.1 For the satisfactory design and construction of bored cast *in-situ* piles the following information would be necessary:

a) Site investigation data as laid down under IS 1892. Sections of trial boring, supplemented, wherever appropriate, by penetration tests, should incorporate data/information down to depth sufficiently below the anticipated level of founding of piles but this should generally be not less than 10 m beyond the pile founding level. Adequacy of the bearing strata should be ensured by supplementary tests, if required.

b) 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 level and artesian conditions, if any, should also be recorded. Results of chemical tests to ascertain the sulphate, chloride and any other deleterious chemical content of soil and water should be indicated.

c) For piling work in water, as in the case of bridge foundation, data on high flood levels, water level during the working season, maximum depth of scour, etc, and in the case of marine construction, data on high and low tide level, corrosive action of chemicals present and data regarding flow of water should be provided.

d) The general layout of the structure showing estimated loads and moments at the top of pile caps but excluding the weight of the piles and caps should be provided. The top levels of finished pile caps shall also be indicated.

e) All transient loads due to seismic, wind, water current, etc, are to be indicated separately.

f) In soils susceptible to liquefaction during earthquake, appropriate analysis may be done to determine the depth of liquefaction and consider the pile depth accordingly.

4.2 As far as possible all informations given in **4.1** shall be made available to the agency responsible for the design and/or construction of piles and/or foundation work.

The design details of pile foundation shall give the information necessary for setting out and layout of piles, cut-off levels, finished cap level, layout and orientation of pile cap in the foundation plan and the safe capacity of each type of pile, etc.

5 EQUIPMENTS AND ACCESSORIES

5.1 The equipments and accessories would depend upon the type of bored cast *in-situ* piles chosen for a job after giving due considerations to the subsoil strata, ground water condition, types of founding material and the required penetration therein.

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

5.3 Boring operations are generally done by percussion type rigs or rotary rigs using direct mud circulation or reverse mud circulation methods to bring the cuttings out. In soft layers and loose sands, bailers and chisel method should be used with caution to avoid the effect of suction.

5.4 For percussion boring using bailer chisel and for rotary rigs, stabilization of bore holes may be done either by circulation or suspended mud.

5.5 Kentledge

Dead weight used for applying a test load on a pile.

6 DESIGN CONSIDERATIONS

6.1 General

Pile foundations shall be designed in such a way that the load from the structure can be transmitted to the sub-surface with adequate factor of safety against shear failure of sub-surface and without causing such settlement (differential or total), which may result in structural damage and/or functional distress under permanent/transient loading. 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.

6.2 Adjacent Structures

6.2.1 When working near existing structures care shall be taken to avoid damage to such structures. IS 2974 (Part 1) may be used as a guide for studying qualitatively the effect of vibration on persons and structures.

6.2.2 In case of deep excavations adjacent to piles, proper shoring or other suitable arrangement shall be made to guard against undesired lateral movement of soil.

6.3 Pile Capacity

The load-carrying capacity of a pile depends 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 soil primarily by horizontal subgrade reaction generated in the upper part of the shaft. Lateral load capacity of a single pile depends on the soil reaction developed and the structural capacity of the shaft under bending. It would be essential to investigate the lateral load capacity of the pile using appropriate values of horizontal subgrade modulus of the soil.

6.3.1 The ultimate load capacity of a pile should be estimated by means of static formula based on soil test results. Pile capacity should preferably be confirmed by initial load tests [*see* IS 2911 (Part 4)].

The settlement of pile obtained at safe load/working load from load-test results on a single pile shall not be directly used for estimating the settlement of a structure. The settlement may be determined on the basis of subsoil data and loading details of the structure as a whole using the principles of soil mechanics.

6.3.1.1 *Vertical load capacity (using static formula)*

The ultimate load capacity of a single pile may be obtained by using static analysis, the accuracy being dependent on the reliability of the soil properties for various strata. When computing capacity by static formula, the shear strength parameters obtained from a limited number of borehole data and laboratory tests should be supplemented, wherever possible, by *in-situ* shear strength obtained from field tests. The two separate static formulae, commonly applicable for cohesive and non-cohesive soil are indicated in Annex B. Other formula based on static cone penetration test [*see* IS 4968 (Parts 1, 2 and 3)] and standard penetration test (*see* IS 2131) are given in **B-3** and **B-4**.

6.3.2 *Uplift Capacity*

The uplift capacity of a pile is given by sum of the frictional resistance and the weight of the pile (buoyant or total as relevant). The recommended factor of safety is 3.0 in the absence of any pullout test results and 2.0 with pullout test results. Uplift capacity can be obtained from static formula (*see* Annex B) by ignoring end-bearing but adding weight of the pile (buoyant or total as relevant).

6.4 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 during installation 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. Existence of such a phenomenon shall be assessed and suitable correction shall be made to the allowable load where appropriate.

6.5 Structural Capacity

The piles shall have necessary structural strength to transmit the loads imposed on it, ultimately to the soil. Incase of uplift, the structural capacity of the pile, that is, under tension should also be considered.

6.5.1 *Axial Capacity*

Where a pile is wholely embedded in the soil (having an undrained shear strength not less than 0.01 N/mm^2), its axial load carrying capacity is not necessarily limited by its strength as a long column. Where piles are installed through very weak soils (having an undrained shear strength less than 0.01 N/mm^2), special considerations shall be made to determine whether the shaft would behave as a long column or not. If necessary, suitable reductions shall be made for its structural strength following the normal structural 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 the fixity 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. In good soil the lower point of contraflexure may be taken at a depth of 1 m below ground surface subject to a minimum of 3 times the diameter of the shaft. In weak soil (undrained shear strength less than 0.01 N/mm^2), such as, soft clay or soft silt, this point may be taken at about half the depth of penetration into such stratum but not more than 3 m or 10 times the diameter of the shaft whichever is more. The degree of fixity of the position and inclination of the pile top and the restraints provided by any bracing shall be estimated following accepted structural principles.

The permissible stress shall be reduced in accordance with similar provision for reinforced concrete columns as laid down in IS 456.

6.5.2 *Lateral Load Capacity*

A pile may be subjected to lateral force for 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 capacity of a single pile depends not only on the horizontal subgrade modulus of the surrounding soil but also on the structural strength of the pile shaft against bending, consequent upon application of a lateral load. While considering lateral load on piles, effect of other co-existent 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 pile analysis under lateral load is given in Annex C.

Because of limited information on horizontal subgrade modulus of soil, and pending refinements in the theoretical analysis, it is suggested that the adequacy of a design should be checked by an actual field load test. In the zone of soil susceptible to liquefaction the lateral resistance of the soil shall not be considered.

6.5.2.1 *Fixed and free head conditions*

A group of three or more pile connected by a rigid pile cap shall be considered to have fixed head condition. Caps for single piles must be interconnected by grade beams in two directions and for twin piles by grade beams in a line transverse to the common axis of the pair so that the pile head is fixed. In all other conditions the pile shall be taken as free headed.

6.5.3 *Raker Piles*

Raker piles are normally provided where vertical piles cannot resist the applied horizontal forces. Generally the rake will be limited to 1 horizontal to 6 vertical. 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 weight 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. In consolidating clay, special precautions, like provision of permanent casing, should be taken for raker piles.

6.6 Spacing of Piles

The minimum centre-to-centre spacing of piles is considered from three aspects, namely,

a) practical aspects of installing the piles,
b) diameter of the pile, and
c) nature of the load transfer to the soil and possible reduction in the load capacity of piles group.

NOTE — In the case of piles of non-circular cross-section, diameter of the circumscribing circle shall be adopted.

6.6.1 In case of piles founded on hard stratum and deriving their capacity mainly from end-bearing the minimum spacing shall be 2.5 times the diameter of the circumscribing circle corresponding to the cross-section of the pile shaft. In case of piles resting on rock, the spacing of two times the said diameter may be adopted.

6.6.2 Piles deriving their load-carrying capacity mainly from friction shall be spaced 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 3 times the diameter of the shaft.

6.7 Pile Groups

6.7.1 In order to determine the load-carrying capacity of a group of piles a number of efficiency equations are in use. However, it is difficult to establish the accuracy of these efficiency equations as the behaviour of pile group is dependent on many complex factors. It is desirable to consider each case separately on its own merits.

6.7.2 The load-carrying capacity of a pile group may be equal to or less than the load-carrying capacity of individual piles multiplied by the number of piles in the group. The former holds true in case of friction piles, cast into progressively stiffer materials or in end-bearing piles.

6.7.3 In case of piles deriving their support mainly from friction and connected by a rigid pile cap, the group may be visualized as a block with the piles embedded within the soil. The ultimate load capacity of the group may then be obtained by considering block failure taking into account the frictional capacity along the perimeter of the block and end-bearing at the bottom of the block using the accepted principles of soil mechanics.

6.7.4 When the cap of the pile group is cast directly on reasonably firm stratum which supports the piles, it may contribute to the load-carrying capacity of the group. This additional capacity along with the individual capacity of the piles multiplied by the number of piles in the group shall not be more than the capacity worked out according to **6.7.3**.

6.7.5 When a pile group is subjected to moment either from superstructure or as a consequence of 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 moment due to lateral loads or eccentric loading, beams may be provided to restrain the pile effectively from lateral or rotational movement.

6.7.6 In case of a structure supported on single piles/ group of piles resulting in large variation in the number of piles from column-to-column it may result in large differential settlement. Such differential settlement should be either catered for in the structural design or it may be suitably reduced by judicious choice of variations in the actual pile loading. For example, a single pile cap may be loaded to a level higher than that of the pile in a group in order to achieve reduced differential settlement between two adjacent pile caps supported on a number of piles.

6.8 Factor of Safety

6.8.1 Factor of safety should be chosen after considering,

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

6.8.2 When the ultimate load capacity is determined from static formula, the factor of safety would depend on the reliability of the formula and the reliability of the subsoil parameters used in the computation. The minimum factor of safety on static formula shall be 2.5. The final selection of a factor of safety shall take into consideration the load settlement characteristics of the structure as a whole at a given site.

6.8.3 Higher value of factor of safety for determining the safe load on piles may be adopted, where,

a) settlement is to be limited or unequal settlement avoided,
b) large impact or vibrating loads are expected, and
c) the properties of the soil may deteriorate with time.

6.9 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 safe load on a single pile may be limited to the provisions contained in IS 1893 (Part 1). For transient loading arising out of superimposed loads, no increase is allowed.

6.10 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 group should not, however, be more than 10 percent of the capacity of the group subject to the increase of the load on any pile being not more than 25 percent of the allowable load on a single pile.

6.11 Reinforcement

6.11.1 The design of the reinforcing cage varies depending upon the installation conditions, the nature of the subsoil and the nature of load to be transmitted by the shaft-axial, or otherwise. The minimum area of longitudinal reinforcement of any type or grade within the pile shaft shall be 0.4 percent of the cross-sectional area of the pile shaft. The minimum reinforcement shall be provided throughout the length of the shaft.

6.11.2 The curtailment of reinforcement along the depth of the pile, in general, depends on the type of loading and subsoil strata. In case of piles subject to compressive load only, the designed quantity of reinforcement may be curtailed at appropriate level according to the design requirements. For piles subjected to uplift load, lateral load and moments, separately or with compressive loads, it would be necessary to provide reinforcement for the full depth of pile. In soft clays or loose sands, or where there may be danger to green concrete due to installation of adjacent piles, the reinforcement should be provided up to the full pile depth, regardless of whether or not it is required from uplift and lateral load considerations. However, in all cases, the minimum reinforcement specified in **6.11.1** shall be provided throughout the length of the shaft.

6.11.3 Piles shall always be reinforced with a minimum amount of reinforcement as dowels keeping the minimum bond length into the pile shaft below its cut-off level and with adequate projection into the pile cap, irrespective of design requirements.

6.11.4 Clear cover to all main reinforcement in pile shaft shall be not less than 50 mm. The laterals of a reinforcing cage may be in the form of links or spirals. The diameter and spacing of the same is chosen to impart adequate rigidity of the reinforcing cage during its handling and installations. The minimum diameter of the links or spirals shall be 8 mm and the spacing of the links or spirals shall be not less than 150 mm. Stiffner rings preferably of 16 mm diameter at every 1.5 m centre-to-centre should be provided along length of the cage for providing rigidity to reinforcement cage. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. If required, the bars can be bundled to maintain such spacing.

6.12 Design of Pile Cap

6.12.1 The pile caps may be designed by assuming that the load from column is dispersed at 45º from the top of the cap 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 45º 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 method of analysis and allowable stresses should be in accordance with IS 456.

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

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

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

6.12.5 The clear overhang of the pile cap beyond the outermost pile in the group shall be a minimum of 150 mm.

6.12.6 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.

6.12.7 The embedment of pile into cap should be 75 mm.

6.12.8 The design of grade beam if used shall be as given in IS 2911 (Part 3).

7 MATERIALS AND STRESSES

7.1 Cement

The cement used shall be any of the following:

a) 33 Grade ordinary Portland cement conforming to IS 269,
b) 43 Grade ordinary Portland cement conforming to IS 8112,
c) 53 Grade ordinary Portland cement conforming to IS 12269,
d) Rapid hardening Portland cement conforming to IS 8041,
e) Portland slag cement conforming to IS 455,
f) Portland pozzolana cement (fly ash based) conforming to IS 1489 (Part 1),
g) Portland pozzolana cement (calcined clay based) conforming to IS 1489 (Part 2),
h) Hydrophobic cement conforming to IS 8043,
j) Low heat Portland cement conforming to IS 12600, and
k) Sulphate resisting Portland cement conforming to IS 12330.

7.2 Steel

Reinforcement steel shall be any of the following:

a) Mild steel and medium tensile steel bars conforming to IS 432 (Part 1),
b) High strength deformed steel bars conforming to IS 1786, and
c) Structural steel conforming to IS 2062.

7.3 Concrete

7.3.1 Consistency of concrete to be used for bored cast *in-situ* piles shall be consistent with the method of installation of piles. Concrete shall be so designed or chosen as to have a homogeneous mix having a slump/workability consistent with the method of concreting under the given conditions of pile installation.

7.3.2 The slump should be 150 to 180 mm at the time of pouring.

7.3.3 The minimum grade of concrete to be used for bored piling shall be M 25. For sub aqueous concrete, the requirements specified in IS 456 shall be followed. The minimum cement content shall be 400 kg/m^3. However, with proper mix design and use of proper admixture the cement content may be reduced but in no case the cement content shall be less than 350 kg/m^3.

7.3.4 For the concrete, water and aggregates specifications laid down in IS 456 shall be followed in general.

7.3.5 The average compressive stress under working load should not exceed 25 percent of the specified works cube strength at 28 days calculated on the total cross-sectional area of the pile. Where the casing of the pile is permanent, of adequate thickness and of suitable shape, the allowable compressive stress may be increased.

7.4 Drilling Mud (Bentonite)

The drilling mud to be used for stabilizing the borehole in bored piling work should conform to the requirements given in Annex D.

8 WORKMANSHIP

8.1 Control of Piling Installation

8.1.1 Bored cast *in-situ* piles should be installed by installation technique, covering,

a) the manner of borehole stabilization, that is, use of casing and/or use of drilling mud;

b) manner of concreting which shall be by use of tremie; and

c) choice of boring tools in order to permit satisfactory installation of a pile at a given site. Detailed information about the subsoil conditions is essential to determine the installation technique.

8.1.2 *Control of Alignment*

Piles shall be installed as accurately as possible according to the design and drawings either vertically or to the specified batter. Greater care should be exercised in respect of installation of single piles or piles in two-pile groups. As a guide, an angular deviation of 1.5 percent in alignment for vertical piles and a deviation of 4 percent for raker piles should not be exceeded. 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 single pile under a column the positional deviation should not be more than 50 mm or $D/6$ whichever is less (10 mm in case of piles having diameter more than 600 mm). Greater tolerance may be prescribed for piles cast over water and for raking piles. For piles to be cut-off at a substantial depth below the working level, the design shall provide for the worst combination of the above tolerances in position and inclination. In case of piles deviating beyond these limits and to such an extent that the resulting eccentricity can not be taken care of by redesign of the pile cap or pile ties, the piles shall be replaced or supplemented by additional piles. In case of piles, with non-circular cross-section '*D*' should be taken as the dimensions of 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.

8.1.3 A minimum length of two metres of temporary casing shall be provided for each bored pile. Additional length of temporary casing may be used depending on the condition of the strata, ground water level, etc.

8.1.4 In subsurfaces comprising of loose fill, soft marine clay, presence of aggressive ground water, tidal effect or in adverse subsoil conditions like loose bouldary zones/voids, etc, and in marine condition, piles may be formed using permanent liner upto the firm strata.

8.1.5 For marine piles, *see* Annex E .

8.2 Use of Drilling Mud

8.2.1 In case a borehole is stabilized by use of drilling mud, the specific gravity of the mud suspension should be determined at regular intervals by a suitable slurry sampler. Consistency of the drilling mud shall be controlled throughout the boring as well as concreting operations in order to keep the hole stabilized as well as to avoid concrete getting mixed up with the thicker suspension of the mud.

8.2.2 The concreting operations should not be taken up when the specific gravity of bottom slurry is more than 1.12. The slurry should be maintained at 1.5 m above the ground water level.

8.3 Cleaning of Borehole

8.3.1 If a borehole is stabilized by drilling mud, the bottom of the hole shall be cleaned of all loose and undesirable materials before commencement of concreting in the following manner:

a) *Boring done with normal bailor and chisel with temporary/permanent liner* — First heavier material to be removed with cleaning tools, such as, bailor and then reinforcement cage and tremie pipe to be lowered. Flushing then to be continued with water/drilling fluid under pressure through tremie pipe.

b) *Boring done with bentonite slurry* — Procedure given in (a) above to be followed. However, flushing shall be done with fresh bentonite slurry.

c) *Boring done by rotary drilling rigs* — Cleaning bucket attached to the kelly shall be used for cleaning the bore. Wherever bentonite slurry is used, after using cleaning bucket, the bore shall be flushed with fresh bentonite slurry.

In case of flushing with water or bentonite slurry, the pump capacity shall be suitably decided depending on depth and diameter of bore so that sufficient pressure is built to lift the material up along with the fluid. Flushing should be continued till coarse materials cease to come out with the overflowing fluid. The finer materials will normally remain suspended in the fluid but they do not pose any problem. Alternatively, air lift technique may be used for cleaning of bore hole, if required.

8.4 Tremie Concreting

Concreting for bored piles shall be done by tremie method. The following requirements are particularly to be followed for tremie concrete work:

a) The concrete should be coherent, rich in cement (not less than 400 kg/m^3) and of slump between 150-180 mm;

b) The tremie should be water-tight throughout its length and have a hopper attached to its head by a water-tight connection;

c) The tremie pipe should be large enough in relation to the size of the aggregate. For 25 mm down aggregate, the tremie pipe should have a diameter not less than 200 mm. For 20 mm down aggregate, tremie pipe should be of diameter not less than 150 mm. All piling above 600 mm diameter piles, should, however preferably be done with 200 mm diameter tremie pipe;

d) A steel plate or a ball is placed at the bottom of the hopper and the hopper is filled with concrete. The first charge of concrete is sent down the tremie by removal of this plate or ball. Additional concrete is then added into the hopper and by surging action is pushed down the tremie and into the pile bore to the bottom of the pile. Theoretically, a small part of the first charge which gets contaminated is supposed to be the top of the rising concrete within the bore;

e) The tremie pipe should always be kept full of concrete and should always remain at least one meter into the concrete in the bore hole with adequate margin against accidental withdrawal of tremie pipes;

f) The pile should be concreted wholly by tremie and the method of deposition should not be changed midway to prevent laitance from being entrapped within the pile;

g) All tremie pipes should be cleaned before and after use; and

h) A sliding plug of polystrene or similar material lighter than water and approved by the Engineer-in-charge or his representative shall be placed in the tremie pipe to prevent direct contact between the first charge of concrete in the tremie and the bentonite slurry.

8.4.1 Normally concreting of the piles should be uninterrupted. In exceptional cases of interruption of concreting, it shall be resumed within 1 or 2 h, but the tremie shall not be taken out of the concrete. Instead it shall be raised and lowered from time-to-time to prevent the concrete around the tremie from setting.

8.4.2 In case of withdrawal of tremie out of the concrete, either accidentally or to remove a choke in the tremie, the tremie may be introduced 60 cm to 100 cm in the old concrete and concreting resumed as mentioned in **8.4.1**. The fresh concrete will emerge out of the tremie displacing the laitance and scum and prevent impregnation or laitance of scum in the fresh concrete.

8.4.3 The top of concrete in a pile shall be brought above the cut-off level to permit removal of all laitance and weak concrete before capping and to ensure good concrete at the cut-off level. The reinforcing cages shall be left with adequate protruding length above cut-off level for proper embedment into the pile cap.

8.4.4 Where cut-off level is less than 2.5 m below the ground level, concrete shall be cast to a minimum of 600 mm above cut-off level. For each additional 0.3 m increase in cut-off level below the working level, additional coverage of minimum 50 mm shall be allowed. Higher allowance may be necessary depending on the length of the pile. When concrete is placed by tremie method, concrete shall be cast up to the ground level to permit overflow of concrete for visual inspection or to a minimum of one metre above cut-off level. In the circumstances where cut-off level is below ground water level, the need to maintain a pressure on the unset concrete equal to or greater than water pressure should be observed and accordingly length of extra concrete above cut-off level shall be determined.

8.5 Defective Pile

8.5.1 In case, defective piles are formed, they shall be left in place. Additional piles as necessary shall be provided.

8.5.2 Any deviation from the designed location, alignment or load capacity of a pile shall be noted and adequate measures taken well before the concreting of the pile cap and plinth beams.

8.5.3 While removing excess concrete or laitance above the cut-off level chipping by manual or pneumatic tools shall be permitted seven days after pile casting. Before, chipping/breaking the pile top, a 40 mm deep groove shall be made manually all round the pile at the required cut-off level.

8.5.4 After concreting the actual quantity of concrete shall be compared with the average obtained from observations made in the case of a few piles already cast. If the actual quantity is found to be considerably less, the matter should be investigated and appropriate measures taken.

8.6 Recording of Data

8.6.1 A daily site record shall be maintained for the installation of piles and shall essentially contain the following information:

a) Sequence of installation of piles in a group;
b) Number and dimension of the pile, including the reinforcement details and mark of the pile;
c) Depth bored (including depth in soft/hard rock);
d) Time taken for boring, concreting and empty boring, chiseling and whether the pile is wet or dry;
e) Cut-off level/ working level;
f) Sample bore log in the initial stage or when major variation occur;
g) When drilling mud is used, specific gravity of the fresh supply and contaminated mud in the bore hole before concreting shall be recorded regularly; and
h) Any other important observation.

8.6.2 Typical data sheet for facility of recording pilling data is shown in Annex F.

ANNEX A

(*Clause* 2)

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
269 : 1989	Ordinary Portland cement, 33 grade — Specification (*fourth revision*)
432 (Part 1) : 1982	Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part 1 Mild steel and medium tensile steel bars (*third revision*)
455 : 1989	Portland slag cement — Specification (*fourth revision*)
456 : 2000	Plain and reinforced concrete— Code of practice (*fourth revision*)
1489	Portland-pozzolana cement — Specification:
(Part 1) : 1991	Fly ash based (*third revision*)
(Part 2) : 1991	Calcined clay based (*third revision*)
1786 : 1985	Specification for high strength deformed steel bars and wires for concrete reinforcement (*third revision*)
1892 : 1979	Code of practice for sub-surface investigations for foundations (*first revision*)
1893 (Part 1) : 2002	Criteria for earthquake resistant design of structures: Part 1 General provisions and buildings (*fifth revision*)
2062 : 2006	Hot rolled low, medium and high tensile structural steel (*sixth revision*)
2131 : 1981	Method for standard penetration test for soils (*first revision*)
2720 (Part 5) : 1985	Method of test for soils: Part 5 Determination of liquid and plastic limit (*second revision*)
2911	Code of practice for design and construction of pile foundations:
(Part 3) : 1980	Under-reamed piles (*first revision*)
(Part 4) : 1985	Load test on piles (*first revision*)
2974 (Part 1) : 1982	Code of practice for design and construction of machine foundations: Part 1 Foundation for reciprocating type machines (*second revision*)
4651	Code of practice for planning and design of ports and harbours:
(Part 1) : 1974	Site investigation (*first revision*)
(Part 2) : 1989	Earth pressures (*first revision*)
(Part 3) : 1974	Loading (*first revision*)
(Part 4) : 1989	General design requirements (*second revision*)
(Part 5) : 1980	Layout and functional requirements
4968	Method for sub-surface sounding for soils:

IS No.	*Title*
(Part 1) : 1976	Dynamic method using 50 mm cone without bentonite slurry (*first revision*)
(Part 2) : 1976	Dynamic method using cone and bentonite slurry (*first revision*)
(Part 3) : 1976	Static cone penetration test (*first revision*)
6403 : 1981	Code of practice for determination of bearing capacity of shallow foundations (*first revision*)
8041 : 1990	Rapid hardening Portland cement — Specification (*second revision*)
8043 : 1991	Hydrophobic Portland cement— Specification (*second revision*)
8112 : 1989	43 grade ordinary Portland cement — Specification (*first revision*)
12269 : 1987	Specification for 53 grade ordinary Portland cement
12330 : 1988	Specification for sulphate resisting Portland cement
12600 : 1989	Portland cement, low heat — Specification

ANNEX B

(*Clauses* 6.3.1.1 *and* 6.3.2)

LOAD-CARRYING CAPACITY OF PILES — STATIC ANALYSIS

B-1 PILES IN GRANULAR SOILS

The ultimate load capacity (Q_u) of piles, in kN, in granular soils is given by the following formula:

$$Q_u = A_p(½ D\gamma N_\gamma + P_D N_q) + \sum_{i=1}^{n} K_i P_{Di} \tan\delta_i A_{si} \quad \ldots (1)$$

The first term gives end-bearing resistance and the second term gives skin friction resistance.

where

A_p = cross-sectional area of pile tip, in m^2;

D = diameter of pile shaft, in m;

γ = effective unit weight of the soil at pile tip, in kN/m^3;

N_γ and N_q = bearing capacity factors depending upon the angle of internal friction, ϕ at pile tip;

P_D = effective overburden pressure at pile tip, in kN/m^2 (*see* Note 5);

$\sum_{i=1}^{n}$ = summation for layers 1 to n in which pile is installed and which contribute to positive skin friction;

K_i = coefficient of earth pressure applicable for the ith layer (*see* Note 3);

P_{Di} = effective overburden pressure for the ith layer, in kN/m^2;

δ_i = angle of wall friction between pile and soil for the ith layer; and

A_{si} = surface area of pile shaft in the ith layer, in m^2.

NOTES

1 N_γ factor can be taken for general shear failure according to IS 6403.

2 N_q factor will depend on the nature of soil, type of pile, the *L*/*B* ratio and its method of construction. The values applicable for bored piles are given in Fig. 1.

3 K_i, the earth pressure coefficient depends on the nature of soil strata, type of pile, spacing of pile and its method of construction. For driven piles in loose to dense sand with ϕ varying between 30° and 40°, K_i values in the range of 1 to 1.5 may be used.

4 δ, the angle of wall friction may be taken equal to the friction angle of the soil around the pile stem.

5 In working out pile capacity by static formula, the maximum effective overburden at the pile tip should correspond to the critical depth, which may be taken as 15 times the diameter of the pile shaft for $\phi \leq 30°$ and increasing to 20 times for $\phi \geq 40°$.

6 For piles passing through cohesive strata and terminating in a granular stratum, a penetration of at least twice the diameter of the pile shaft should be given into the granular stratum.

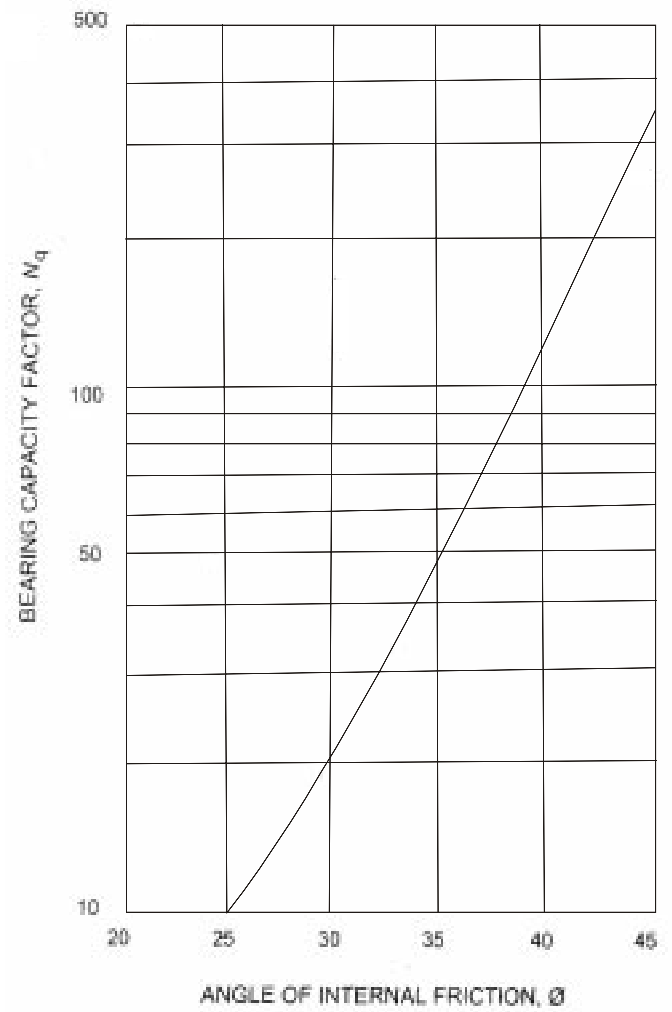


FIG. 1 BEARING CAPACITY FACTOR, N_q FOR BORED PILES

B-2 PILES IN COHESIVE SOILS

The ultimate load capacity (Q_u) of piles, in kN, in cohesive soils is given by the following formula:

$$Q_u = A_p\, N_c\, c_p + \sum_{i=1}^{n} \alpha_i c_i A_{si} \qquad \ldots(2)$$

The first term gives the end-bearing resistance and the second term gives the skin friction resistance.

where

A_p = cross-sectional area of pile tip, in m^2;

N_c = bearing capacity factor, may be taken as 9;

c_p = average cohesion at pile tip, in kN/m^2;

$\sum_{i=1}^{n}$ = summation for layers 1 to n in which the pile is installed and which contribute to positive skin friction;

α_i = adhesion factor for the ith layer depending on the consistency of soil, (*see* Note);

c_i = average cohesion for the ith layer, in kN/m^2; and

A_{si} = surface area of pile shaft in the ith layer, in m^2.

NOTE — The value of adhesion factor, α_i depends on the undrained shear strength of the clay and may be obtained from Fig. 2.

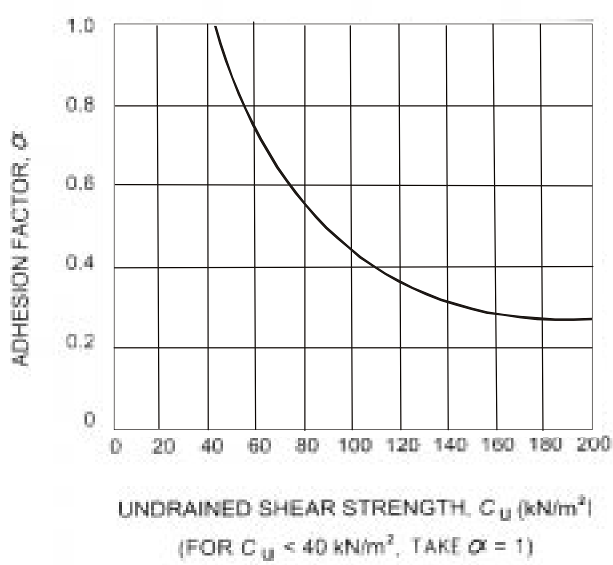


FIG. 2 VARIATION OF α WITH C_u

B-3 USE OF STATIC CONE PENETRATION DATA

B-3.1 When full static cone penetration data are available for the entire depth, the following correlation may be used as a guide for the determination of ultimate load capacity of a pile.

B-3.2 Ultimate end bearing resistance (q_u), in kN/m², may be obtained as:

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

where

- q_{c0} = average static cone resistance over a depth of 2D below the pile tip, in kN/m²;
- q_{c1} = minimum static cone resistance over the same 2D below the pile tip, in kN/m²;
- q_{c2} = average of the envelope of minimum static cone resistance values over the length of pile of 8D above the pile tip, in kN/m²; and
- D = diameter of pile shaft.

B-3.3 Ultimate skin friction resistance can be approximated to local side friction (f_s), in kN/m², obtained from static cone resistance as given in Table 1.

Table 1 Side Friction for Different Types of Soil

Sl No.	Type of Soil	Local Side Friction, f_s kN/m²
(1)	(2)	(3)
i)	q_c less than 1 000 kN/m²	$q_c/30 < f_s < q_c/10$
ii)	Clay	$q_c/25 < f_s < 2q_c/25$
iii)	Silty clay and silty sand	$q_c/100 < f_s < q_c/25$
iv)	Sand	$q_c/100 < f_s < q_c/50$
v)	Coarse sand and gravel	$q_c/100 < f_s < q_c/150$

q_c = cone resistance, in kN/m².

B-3.4 The correlation between standard penetration resistance, N (blows/30 cm) and static cone resistance, q_c, in kN/m² as given in Table 2 may be used for working out the end-bearing resistance and skin friction resistance of piles. This correlation should only be taken as a guide and should preferably be established for a given site as they can substantially vary with the grain size, Atterberg limits, water table, etc.

Table 2 Co-relation Between N and q_c for Different Types of Soil

Sl No.	Type of Soil	q_c/N
(1)	(2)	(3)
i)	Clay	150-200
ii)	Silts, sandy silts and slightly cohesive silt-sand mixtures	200-250
iii)	Clean fine to medium sand and slightly silty sand	300-400
iv)	Coarse sand and sands with little gravel	500-600
v)	Sandy gravel and gravel	800-1 000

B-4 USE OF STANDARD PENETRATION TEST DATA FOR COHESIONLESS SOIL

B-4.1 The correlation suggested by Meyerhof using standard penetration resistance, N in saturated cohesionless soil to estimate the ultimate load capacity of bored pile is given below. The ultimate load capacity of pile (Q_u), in kN, is given as:

$$Q_u = 13N\frac{L}{B}A_p + \frac{\overline{N}A_s}{0.50} \qquad \ldots(3)$$

The first term gives end-bearing resistance and the second term gives frictional resistance.

where

- N = average N value at pile tip;
- L = length of penetration of pile in the bearing strata, in m;
- B = diameter or minimum width of pile in m;
- A_p = cross-sectional area of pile tip, in m²;
- $\overline{N}$ = average N along the pile shaft; and
- A_s = surface area of pile shaft, in m².

NOTE — The end-bearing resistance should not exceed 130 NA_p.

B-4.2 For non-plastic silt or very fine sand the equation has been modified as:

$$Q_u = 10N\frac{L}{B}A_p + \frac{\overline{N}A_s}{0.60} \qquad \ldots(4)$$

The meaning of all terms is same as for equation 3.

B-5 FACTOR OF SAFETY

The minimum factor of safety for arriving at the safe pile capacity from the ultimate load capacity obtained by using static formulae shall be 2.5.

B-6 PILES IN STRATIFIED SOIL

In stratified soil/C-ϕ soil, the ultimate load capacity of piles should be determined by calculating the skin friction and end-bearing in different strata by using appropriate expressions given in **B-1** and **B-2**.

B-7 PILES IN HARD ROCK

When the crushing strength of the rock is more than characteristic strength of pile concrete, the rock should be deemed as hard rock. Piles resting directly on hard rock may be loaded to their safe structural capacity.

B-8 PILES IN WEATHERED/SOFT ROCK

For pile founded in weathered/soft rock different empirical approaches are used to arrive at the socket length necessary for utilizing the full structural capacity of the pile.

Since it is difficult to collect cores in weathered/soft rocks, the method suggested by Cole and Stroud using 'N' values is more widely used. The allowable load on the pile, Q_a, in kN, by this approach, is given by:

$$Q_a = c_{u1} N_c \cdot \frac{\pi B^2}{4F_s} + \alpha\, c_{u2} \cdot \frac{\pi BL}{F_s}$$

where

c_{u1} = shear strength of rock below the base of the pile, in kN/m^2 (*see* Fig. 3);

N_c = bearing capacity factor taken as 9;

F_s = factor of safety usually taken as 3;

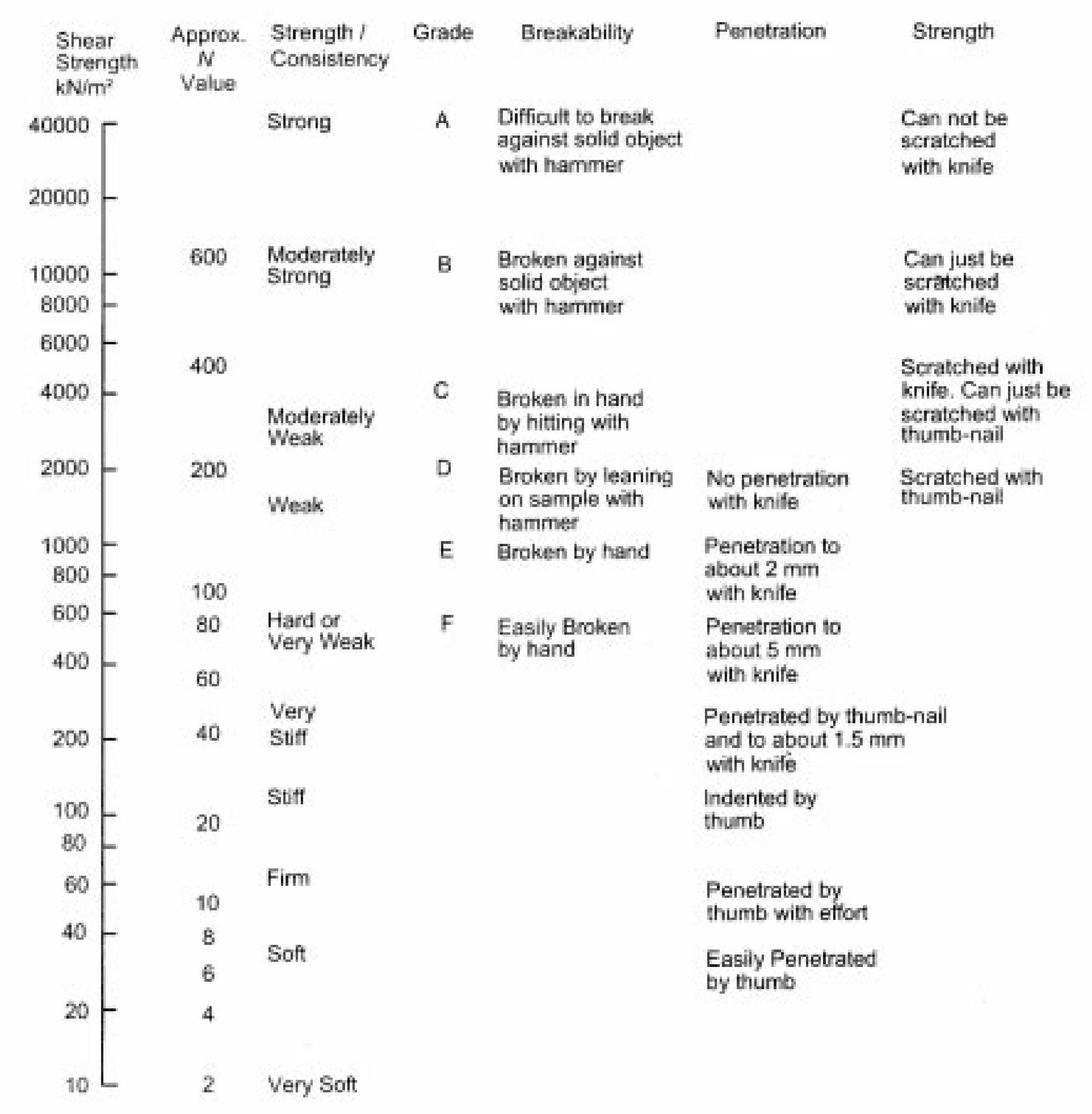
α = 0.9 (recommended value);

c_{u2} = average shear strength of rock in the socketed length of pile, in kN/m^2 (*see* Fig 3);

B = minimum width of pile shaft (diameter in case of circular piles), in m; and

L = socket length of pile, in m.

NOTE — For $N \geq 60$, the stratum is to be treated as weathered rock rather than soil.



NOTE — Standard penetration test may not be practicable for N values greater than 200. In such cases, design may be done on the basis of shear strength of rock.

FIG. 3 CONSISTENCY AND SHEAR STRENGTH OF WEATHERED ROCK

ANNEX C

(*Clause* 6.5.2)

ANALYSIS OF LATERALLY LOADED PILES

C-1 GENERAL

C-1.1 The ultimate resistance of a vertical pile to a lateral load and the deflection of the pile as the load builds up to its ultimate value are complex matters involving the interaction between a semi-rigid structural element and soil which deforms partly elastically and partly plastically. The failure mechanisms of an infinitely long pile and that of a short rigid pile are different. The failure mechanisms also differ for a restrained and unrestrained pile head conditions.

Because of the complexity of the problem only a procedure for an approximate solution, that is, adequate in most of the cases is presented here. Situations that need a rigorous analysis shall be dealt with accordingly.

C-1.2 The first step is to determine, if the pile will behave as a short rigid unit or as an infinitely long flexible member. This is done by calculating the stiffness factor *R* or *T* for the particular combination of pile and soil.

Having calculated the stiffness factor, the criteria for behaviour as a short rigid pile or as a long elastic pile are related to the embedded length *L* of the pile. The depth from the ground surface to the point of virtual fixity is then calculated and used in the conventional elastic analysis for estimating the lateral deflection and bending moment.

C-2 STIFFNESS FACTORS

C-2.1 The lateral soil resistance for granular soils and normally consolidated clays which have varying soil modulus is modelled according to the equation:

$$\frac{p}{y} = \eta_h z$$

where

p = lateral soil reaction per unit length of pile at depth z below ground level;

y = lateral pile deflection; and

η_h = modulus of subgrade reaction for which the recommended values are given in Table 3.

Table 3 Modulus of Subgrade Reaction for Granular Soils, η_h, in kN/m³

(*Clause* C-2.1)

Sl No.	Soil Type	*N* (Blows/30 cm)	Range of η_h kN/m³ × 10³	
			Dry	Submerged
(1)	(2)	(3)	(4)	(5)
i)	Very loose sand	0-4	< 0.4	< 0.2
ii)	Loose sand	4-10	0.4-2.5	0.2-1.4
iii)	Medium sand	10-35	2.5-7.5	1.4-5.0
iv)	Dense sand	> 35	7.5-20.0	5.0-12.0

NOTE — The η_h values may be interpolated for intermediate standard penetration values, *N*.

C-2.2 The lateral soil resistance for preloaded clays with constant soil modulus is modelled according to the equation:

$$\frac{p}{y} = K$$

where

$$K = \frac{k_1}{1.5} \times \frac{0.3}{B}$$

where k_1 is Terzaghi's modulus of subgrade reaction as determined from load deflection measurements on a 30 cm square plate and *B* is the width of the pile (diameter in case of circular piles). The recommended values of k_1 are given in Table 4.

Table 4 Modulus of Subgrade Reaction for Cohesive Soil, k_1, in kN/m³

Sl No.	Soil Consistency	Unconfined Compression Strength, q_u kN/m²	Range of k_1 kN/m³ × 10³
(1)	(2)	(3)	(4)
i)	Soft	25-50	4.5-9.0
ii)	Medium stiff	50-100	9.0-18.0
iii)	Stiff	100-200	18.0-36.0
iv)	Very stiff	200-400	36.0-72.0
v)	Hard	> 400	>72.0

NOTE — For q_u less than 25, k_1 may be taken as zero, which implies that there is no lateral resistance.

C-2.3 Stiffness Factors

C-2.3.1 *For Piles in Sand and Normally Loaded Clays*

$$\text{Stiffness factor } T\text{, in m} = \sqrt[5]{\frac{EI}{\eta_h}}$$

where

E = Young's modulus of pile material, in MN/m^2;

I = moment of inertia of the pile cross-section, in m^4; and

η_h = modulus of subgrade reaction, in MN/m^3 (*see* Table 3).

C-2.3.2 *For Piles in Preloaded Clays*

$$\text{Stiffness factor } R, \text{ in m} = \sqrt[4]{\frac{EI}{KB}}$$

where

E = Young's modulus of pile material, in MN/m^2;

I = moment of inertia of the pile cross-section, in m^4;

K = $\frac{k_1}{1.5} \times \frac{0.3}{B}$ (*see* Table 4 for values of k_1, in MN/m^3); and

B = width of pile shaft (diameter in case of circular piles), in m.

C-3 CRITERIA FOR SHORT RIGID PILES AND LONG ELASTIC PILES

Having calculated the stiffness factor T or R, the criteria for behaviour as a short rigid pile or as a long elastic pile are related to the embedded length L as given in Table 5.

Table 5 Criteria for Behaviour of Pile Based on its Embedded Length
(*Clause* C-3)

Sl No.	Type of Pile Behaviour	Relation of Embedded Length with Stiffness Factor	
		Linearly Increasing	Constant
(1)	(2)	(3)	(4)
i)	Short (rigid) pile	$L \leq 2T$	$L \leq 2R$
ii)	Long (elastic) pile	$L \geq 4T$	$L \geq 3.5R$

NOTE — The intermediate L shall indicate a case between rigid pile behaviour and elastic pile behaviour.

C-4 DEFLECTION AND MOMENTS IN LONG ELASTIC PILES

C-4.1 Equivalent cantilever approach gives a simple procedure for obtaining the deflections and moments due to relatively small lateral loads. This requires the determination of depth of virtual fixity, z_f.

The depth to the point of fixity may be read from the plots given in Fig. 4. e is the effective eccentricity of the point of load application obtained either by converting the moment to an equivalent horizontal load or by actual position of the horizontal load application. R and T are the stiffness factors described earlier.

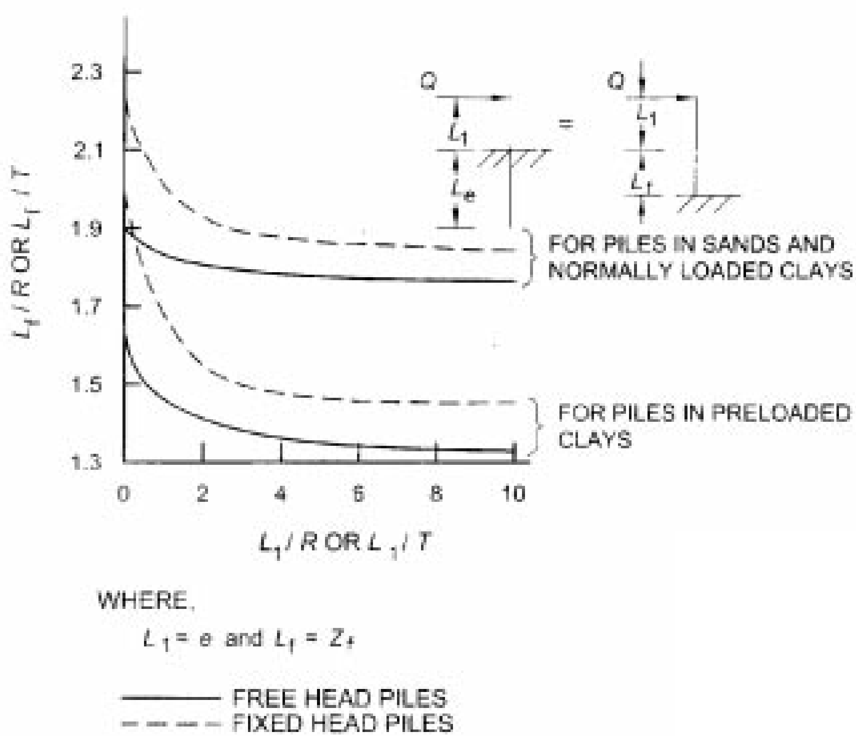


FIG. 4 DEPTH OF FIXITY

C-4.2 The pile head deflection, y shall be computed using the following equations:

$$\text{Deflection, } y = \frac{H(e+z_f)^3}{3EI} \times 10^3$$

...for free head pile

$$\text{Deflection, } y = \frac{H(e+z_f)^3}{12EI} \times 10^3$$

...for fixed head pile

where

H = lateral load, in kN;
y = deflection of pile head, in mm;
E = Young's modulus of pile material, in kN/m^2;
I = moment of inertia of the pile cross-section, in m^4;
z_f = depth to point of fixity, in m; and
e = cantilever length above ground/bed to the point of load application, in m.

C-4.3 The fixed end moment of the pile for the equivalent cantilever may be determined from the following expressions:

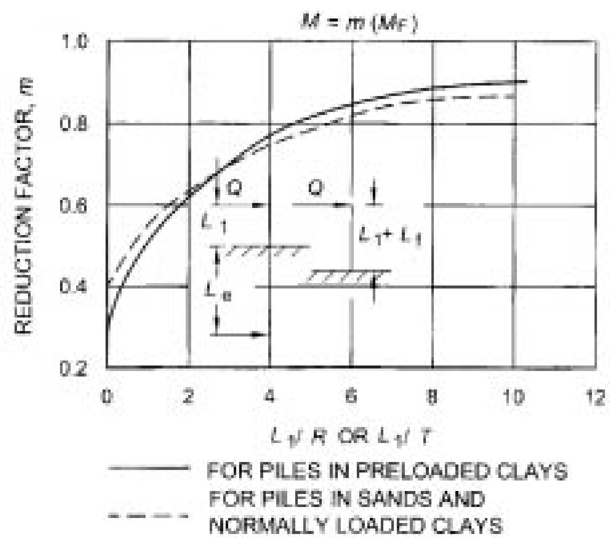
$$\text{Fixed end moment, } M_F = H(e+z_f)$$

...for free head pile

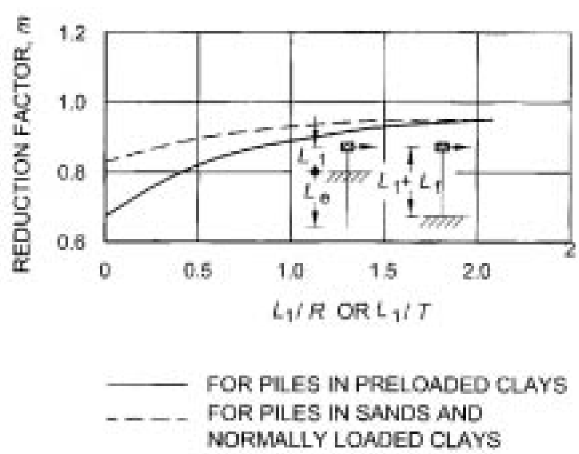
$$\text{Fixed end moment, } M_F = \frac{H(e+z_f)}{2}$$

...for fixed head pile

The fixed head moment, M_F of the equivalent cantilever is higher than the actual maximum moment M in the pile. The actual maximum moment may be obtained by multiplying the fixed end moment of the equivalent cantilever by a reduction factor, m, given in Fig. 5.



5A For Free Head Pile



5B For Fixed Head Pile

FIG. 5 DETERMINATION OF REDUCTION FACTORS FOR COMPUTATION OF MAXIMUM MOMENT IN PILE

ANNEX D

(*Clause* 7.4)

REQUIREMENTS OF DRILLING MUD (BENTONITE)

D-1 PROPERTIES

The bentonite suspension used in bore holes is basically a clay of montmorillonite group having exchangeable sodium cations. Because of the presence of sodium cations, bentonite on dispersion will break down into small plate like particles having a negative charge on the surfaces and positive charge on the edges. When the dispersion is left to stand undisturbed, the particles become oriented building up a mechanical structure of its own. This mechanical structure held by electrical bonds is observed as a thin jelly like mass or membrane. When the jelly is agitated, the weak electrical bonds are broken and the suspension becomes fluid again.

D-2 FUNCTIONS

D-2.1 The action of bentonite in stabilizing the sides of bore holes is primarily due to thixotropic property of bentonite. The thixotropic property of bentonite suspension permits the material to have the consistency of a fluid when introduced into a trench or hole. When left undisturbed it forms a jelly like membrane on the borehole wall and when agitated it becomes a fluid again.

D-2.2 In the case of a granular soil, the bentonite suspension penetrations into sides under positive pressure and after a while forms a jelly. The bentonite suspension then gets deposited on the sides of the hole and makes the surface impervious and imparts a plastering effect. In impervious clay, the bentonite does not penetrate into the soil, but deposits only as thin film on the surface of hole. Under such condition, stability is derived from the hydrostatic head of the suspension.

D-3 REQUIREMENTS

The bentonite powder and bentonite suspension used for piling work shall satisfy the following requirements:

a) The liquid limit of bentonite when tested in accordance with IS 2720 (Part 5) shall be 400 percent or more.

b) The bentonite suspension shall be made by mixing it with fresh water using a pump for circulation. The density of the freshly prepared bentonite suspension shall be between 1.03 and 1.10 g/ml depending upon the pile dimensions and the type of soil in which the pile is to be bored. The density of bentonite after contamination with deleterious material in the bore hole may rise up to 1.25 g/ml. This should be brought down to at least 1.12 g/ml by flushing before concreting.

c) The marsh viscosity of bentonite suspension when tested by a marsh cone shall be between 30 to 60 stoke; in special cases it may be allowed up to 90 s.

d) The *p*H value of the bentonite suspension shall be between 9 and 11.5.

ANNEX E

(*Clause* 8.1.5)

SPECIAL USE OF LARGE DIAMETER BORED CAST *IN-SITU* RCC PILES IN MARINE STRUCTURES

E-1 Because of the economy and availability of easy technology, large diameter bore cast *in-situ* piles are widely used in marine structures in India. In similar conditions, steel piles are generally preferred in western countries. This cast *in-situ* piles require certain special attention which are needed to be considered in design and construction.

E-2 CONSTRUCTION ASPECT

E-2.1 Generally, permanent mild steel liner is provided for the pile cut-off level to certain depth below bed level. This liner shall be of sufficient rigidity. This should be ensured by selecting suitable thickness of plate.

E-2.2 Piles installed using movable or fixed platform or jack up barge are generally within acceptable tolerance. Special care shall be taken when piles are installed from floating barge subjected to tide, water current or wave forces.

E-2.3 As per present practice, pile holes are bored with bailer and chisel operated by a winch or using rotary rigs. Since bentonite mud solution is used for the unlined bored depth for stability, utmost care shall be taken about the quality of bentonite (or other stabilization) slurry. Bentonite should be of approved quality and to be mixed with potable water. Mechanical mixing system shall be used.

E-2.4 After completion of boring in a pile hole, flushing with bentonite fluid or air flushing shall be done. Time for reinforcement cage lowering shall be kept to minimum and early start of concreting shall be ensured.

E-2.5 High grade concrete (minimum M 30 but preferably higher grades) shall be adopted. Cement content, workability and setting time of concrete shall be maintained as per IS 456 to ensure good health of concrete during construction and also during its serviceability period. Pumped concrete, transported from automatic batching plant using transit mixture are preferred in concreting work.

E-3 DESIGN ASPECT

E-3.1 Marine piles are subjected to large horizontal forces generated from wave, seismic wind, water current, berthing of ship, mooring pull, etc. Pile members are to be designed for axial force with moments and shear. Adequate cover to reinforcement (75 mm generally provided) shall be ensured.

E-3.2 Long-term serviceability condition shall be checked as per provision of IS 4651 (Part 4). Calculated crack width to be kept as per the provision of IS 4651 (Part 4). For splash zone subjected to tidal variation special care is to be taken and relevant provision of IS 456 shall be adopted. Generally large deflection is allowed for such long cantilever marine piles and relevant provision of IS 456 and IS 4651 (Parts 1 to 5) are to be followed.

E-3.3 When piles are subjected to extremely large horizontal force due to wave and current forces special design incorporating analysis of pile, model analysis, etc, may be adopted.

E-3.4 When very soft marine clay or loose sand exists at bed level, it should be checked for potential liquefaction during earthquake.

ANNEX F

(*Clause* 8.6.2)

DATA SHEET

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 — Round/Square
- Size — Shaft .... Tip ....
- 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/weight or strength after .... days .... N/mm^2

Quantity of cement/m^3: ....

Extra cement added, if any: ....

Details of drilling mud used: ....

Time taken for concreting: ....

Quantity of concrete — Actual: ....

Theoretical: ....

Test loading:

Maintained load/Cyclic loading/C.R.P ....

....

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 tip ....

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 ....

....

....

....

....

....

....

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. If no bore hole, give best available ground conditions ....

   ....

   ....

Soil Properties	*Soil Description*	*Reduced Level*	*Soil Legend*	*Depth Below Ground Level*	*Thickness of Strata*
	Position of the tip of pile to be indicated 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/Sub-surface sounding by cones or Standard sampler

....

....

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

a) Load *vs* Time, and

b) Settlement *vs* Load.

ANNEX G
(*Foreword*)

COMMITTEE COMPOSITION

Soil and Foundation Engineering Sectional Committee, CED 43

Organization	*Representative(s)*
In personal capacity (*188/90, Prince Anwar Shah Road, Kolkatta 700045*)	Dr N. Som (***Chairman***)
A.P. Engineering Research Laboratories, Hyderabad	Shri P. Sivakantham Shri P. John Victor (*Alternate*)
AFCONS Infrastructure Limited, Mumbai	Shri A. D. Londhe Shri V. S. Kulkarni (*Alternate*)
Central Board of Irrigation & Power, New Delhi	Director
Central Building Research Institute, Roorkee	Shri Y. Pandey Shri R. Dharmraju (*Alternate*)
Central Electricity Authority, New Delhi	Director (TCD) Deputy Director (TCD) (*Alternate*)
Central Public Works Department, New Delhi	Superintending Engineer (Design) Executive Engineer (Design-V) (*Alternate*)
Central Road Research Institute, New Delhi	Shri Sudhir Mathur Shri Vasant G. Havangi (*Alternate*)
Central Soil & Materials Research Station, New Delhi	Shri S. K. Babbar Shri D. N. Bera (*Alternate*)
Engineer-in-Chief's Branch, New Delhi	Shri J. B. Sharma Shri N. K. Jain (*Alternate*)
Engineers India Limited, New Delhi	Shri T. Balraj Shri S. Debnath (*Alternate*)
F. S. Engineers Pvt Limited, Chennai	Dr A. Verghese Chummar
Gammon India Limited, Mumbai	Dr N. V. Nayak Shri S. Pattiwar (*Alternate*)
Ground Engineering Limited, New Delhi	Shri Ashok Kumar Jain Shri Neeraj Kumar Jain (*Alternate*)
Gujarat Engineering Research Institute, Vadodara	Director Shri J. K. Patel (*Alternate*)
Indian Geotechnical Society, New Delhi	Secretary
Indian Institute of Science, Bangalore	Prof A. Sridharan
Indian Institute of Technology, Chennai	Prof S. R. Ghandi
Indian Institute of Technology, New Delhi	Dr A. Varadarajan Dr R. Kaniraj (*Alternate*)
Indian Institute of Technology, Mumbai	Shri G. Venkatachalam
Indian Institute of Technology, Roorkee	Prof M. N. Viladkar Dr Mahendra Singh (*Alternate*)
Indian Society of Earthquake Technology, Uttaranchal	Representative
ITD Cementation India Ltd, Kolkata	Shri P. S. Sengupta Shri Manish Kumar (*Alternate*)
M.N. Dastur & Company (P) Ltd, Kolkata	Director-Civil Structural Shri S. N. Pal (*Alternate*)
M/s Cengrs Geotechnical Pvt Limited, New Delhi	Shri Sanjay Gupta Shri Ravi Sundaram (*Alternate*)
Ministry of Surface Transport, New Delhi	Shri A. K. Banerjee Shri Satish Kumar (*Alternate*)
Mumbai Port Trust, Mumbai	Shrimati R. S. Hardikar Shri A. J. Lokhande (*Alternate*)
Nagadi Consultants Pvt Limited, New Delhi	Dr V. V. S. Rao Shri N. Santosh Rao (*Alternate*)
National Thermal Power Corporation Limited, Noida	Dr D. N. Naresh Shri B. V. R. Sharma (*Alternate*)

Organization	*Representative(s)*
Pile Foundation Constructions Co (I) Pvt Limited, Kolkata	Shri B. P. Guha Niyogi Shri S. Bhowmik (*Alternate*)
Safe Enterprises, Mumbai	Shri Vikram Singh Rao Shri Suryaveer Singh Rao (*Alternate*)
School of Planning and Architecture, New Delhi	Prof V. Thirivengadam
Simplex Infrastructures Limited, Chennai	Shri Shankar Guha Shri S. Ray (*Alternate*)
The Pressure Piling Co (I) Pvt Limited, Mumbai	Shri V. C. Deshpande Shri Pushkar V. Deshpande (*Alternate*)
University of Jodhpur, Jodhpur	Shri G. R. Chowdhary
BIS Directorate General	Shri A. K. Saini, Scientist 'F' & Head (CED) [Representing Director General (*Ex-officio*)]

Member Secretary
Shrimati Madhurima Madhav
Scientist 'B' (CED), BIS

Pile and Deep Foundations Subcommittee, CED 43 : 5

In personal capacity (*Satya Avenue, 2nd Cross Street, Janganatha Puram, Velachery, Chennai 600042*)	Shri Murli Iyengar (***Convener***)
AFCONS Infrastructure Ltd, Mumbai	Shri A. N. Jangle
Association of Piling Specialists (India), Mumbai	Shri V. T. Ganpule Shri Madhukar Lodhavia (*Alternate*)
Central Building Research Institute, Roorkee	Shri R. Dharamraju Shri A. K. Sharma (*Alternate*)
Central Public Works Department, New Delhi	Superintending Engineer (Design) Executive Engineer (Design Division V) (*Alternate*)
Engineer-in-Chief's Branch, New Delhi	Director General of Works
Engineers India Limited, New Delhi	Dr Atul Nanda Shri Sanjay Kumar (*Alternate*)
Gammon India Limited, Mumbai	Dr N. V. Nayak Shri R. K. Malhotra (*Alternate*)
Ground Engineering Limited, New Delhi	Shri Ashok Kumar Jain Shri Neeraj Kumar Jain (*Alternate*)
Indian Geotechnical Society, New Delhi	Dr Satyendra Mittal Dr K. Rajagopal (*Alternate*)
Indian Institute of Technology, Chennai	Dr S. R. Gandhi Dr A. Bhoominathan (*Alternate*)
Indian Institute of Technology, Roorkee	Dr G. Ramasamy
Indian Roads Congress, New Delhi	Shri A. K. Banerjee Shri I. K. Pandey (*Alternate*)
ITD Cementation India Limited, Kolkata	Shri Manish Kumar Shri Partho S. Sengupta (*Alternate*)
M/s Cengrs Geotechnical Pvt Limited, New Delhi	Shri Sanjay Gupta Shri Ravi Sunduram (*Alternate*)
Ministry of Shipping, Road Transport and Highways, New Delhi	Shri V. K. Sinha
National Thermal Power Corporation, Noida	Shri R. R. Maurya Shri V. V. S. Ramdas (*Alternate*)
Pile Foundation Constructions Co (I) Pvt Limited, Kolkata	Shri B. P. Guha Niyogi Shri S. Bhowmik (*Alternate*)
Research, Designs & Standards Organization, Lucknow	Director (B&S) Director GE (*Alternate*)
Simplex Infrastructures Limited, Chennai	Shri Shankar Guha Shri S. Ray (*Alternate*)
Structural Engineering Research Centre, Chennai	Shri N. Gopalakrishnan Dr K. Ramanjaneyulu (*Alternate*)
TCE Consulting Engineers Limited, Mumbai	Shri C. K. Ravindranathan Shri S. M. Palerkar (*Alternate*)
Victoria-Jubilee Technical Institute, Mumbai	Representative

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 1986 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards : Monthly Additions'.

This Indian Standard has been developed from Doc No.: CED 43 (7283).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.org.in

Regional Offices:		*Telephones*
Central :	Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	2323 7617 2323 3841
Eastern :	1/14 C. I. T. Scheme VI M, V. I. P. Road, Kankurgachi KOLKATA 700054	2337 4899, 2337 8561 2337 8626, 2337 9120
Northern :	SCO 335-336, Sector 34-A, CHANDIGARH 160022	260 3843 260 9285
Southern :	C. I. T. Campus, IV Cross Road, CHENNAI 600113	2254 1216, 2254 1442 2254 2519, 2254 2315
Western :	Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	2832 9295, 2832 7858 2832 7891, 2832 7892

Branches: AHMEDABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. DEHRADUN. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. NAGPUR. PARWANOO. PATNA. PUNE. RAJKOT. THIRUVANANTHAPURAM. VISAKHAPATNAM.

Typeset by : S.S. Computers, Delhi