IS 2911-1-3 (2010): DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE, Part 1: CONCRETE PILES, Section 3: Driven Precast Concrete Piles [CED 43: Soil and Foundation Engineering]

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भारतीय मानक

पाइल नींव की डिजाइन और निर्माण — रीति संहिता

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(दूसरा पुनरीक्षण)

Indian Standard

DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE

PART 1 CONCRETE PILES

Section 3 Driven Precast Concrete Piles

(Second Revision)

ICS 91.100.30 : 93.020

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Soil and Foundation Engineering Sectional Committee, CED 43

FOREWORD

This Indian Standard (Part 1/Sec 3) (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 section. 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 this 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 2 Bored cast *in-situ* 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) 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.
c) 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.

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(*Continued from second cover*)

d) Provision has been made for use of any established dynamic pile driving formulae, instead of recommending any specific formula, to control the pile driving at site, giving due consideration to limitations of various formulae.

e) Minimum grade of concrete to be used in pile foundations has been revised to M 25. Minimum time of curing before handling of precast piles has been modified.

Driven precast concrete pile is a pile constructed in a casting yard and subsequently driven in the ground with or without jetting, or other technics like preboring (depending on the conditions of soil) when the pile has attained sufficient strength. By driving, the subsoil is displaced and remain in direct contact with the pile. These piles find wide application particularly for structures, such as, wharves, jetties, etc, to act as a free standing pile above the soil/water level or where conditions are unfavourable for use of cast *in-situ* piles.

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 the formulation of this standard is given in Annex F.

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 3 Driven Precast Concrete Piles

(Second Revision)

1 SCOPE

1.1 This standard (Part 1/Sec 3) covers the design and construction of driven precast concrete piles of solid section 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 driven precast 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 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.

3.5 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.

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

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

3.8 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.

3.9 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.

3.10 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'.

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

3.12 Pile Spacing — The spacing of piles means the centre-to-centre distance between adjacent piles.

3.13 Precast Driven Pile — A pile constructed in concrete in a casting yard and subsequently driven into the ground when it has attained sufficient strength.

3.14 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 not more than 1.5 times the safe load.

3.15 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.

3.16 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.

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

3.18 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 driven precast 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 chemical 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 and forces due to water current, etc, 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.

4.3 The design details of pile foundation shall give the information necessary for setting out, 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 precast driven piles, giving due consideration to the subsoil strata, ground-water conditions, types of founding material and the required penetration therein, wherever applicable.

5.2 Among the commonly used plants, tools and accessories, there exists a large variety; suitability of which depends on the subsoil condition, manner of operation, etc. Brief definitions of some commonly used equipment are given below.

5.2.1 *Dolly* — A cushion of hardwood or some suitable material placed on the top of the casing to receive the blows of the hammer.

5.2.2 *Drop Hammer (or Monkey)* — Hammer, ram or monkey raised by a winch and allowed to fall under gravity.

5.2.3 *Single or Double Acting Hammer* — A hammer operated by steam compressed air or internal combustion, the energy of its blows being derived mainly from the source of motive power and not from gravity alone.

5.2.4 *Hydraulic Hammer* — A hammer operated by a hydraulic fluid can be used with advantage for increasing the energy of blow.

5.2.5 *Kentledge* — Dead weight used for applying a test load on a pile.

5.2.6 *Pile Rig* — A movable steel structure for driving piles in the correct position and alignment by means of a hammer operating in the guides of the frame.

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 subsoil 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. Alternatively, piles may be installed in rake.

6.3.1 The ultimate load capacity of a pile may be estimated by means of static formula on the basis of soil test results, or by using a dynamic pile formula using data obtained during driving the pile. However, dynamic pile driving formula should be generally used as a measure to control the pile driving at site. 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 *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 parameters obtained from field tests. The two separate static formulae, commonly applicable for cohesive and non-cohesive soil respectively, 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**.

6.3.1.2 *Dynamic formula*

Any established dynamic formula can be used to control the pile driving at site giving due consideration to limitations of various formulae.

Whenever double acting diesel hammers or hydraulic hammers are used for driving of piles, manufacturer’s guidelines about energy and set criteria may be referred to. Dynamic formulae are not directly applicable to cohesive soil deposits, such as, saturated silts and clays as the resistance to impact of the tip of the casing will be exaggerated by their low permeability while the frictional resistance on the sides is reduced by lubrication.

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 driving 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. In case 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 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 restraint 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 pile 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, driven into progressively stiffer materials or in end-bearing piles. For driven piles in loose sandy soils the group capacity may even be higher due to the effect of compaction. In such cases a load test may be carried out on a pile in the group after all the piles in the group have been installed.

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 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.

6.7.3.1 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**.

6.7.4 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 cap effectively from lateral or rotational movement.

6.7.5 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 excessive 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 different 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 either static formula or dynamic 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 Design of Pile Section

6.11.1 Design of pile section shall be such as to ensure the strength and soundness of the pile against lifting from the casting bed, transporting, handling and driving stresses without damage.

6.11.2 Any shape having radial symmetry will be satisfactory for precast piles. The most commonly used cross-sections are square and octagonal.

6.11.3 Where exceptionally long lengths of piles are required, hollow sections can be used. If the final condition requires larger cross-sectional area, the hollow sections can be filled with concrete after driving in position.

6.11.4 Wherever final pile length is so large that a single length precast pile unit is either uneconomical or impracticable for installation, the segmental precast RCC piles with a number of segments using efficient mechanical jointing could be adopted.

Excessive whipping during handling precast pile may generally be avoided by limiting the length of pile to a maximum of 50 times the least width. As an alternative, segmental precast piling technique could be used.

The design of joints shall take care of corrosion by providing additional sacrificial thickness for the joint, wherever warranted.

6.11.5 *Lifting and Handling Stress*

Stresses induced by bending in the cross-section of precast pile during lifting and handling may be estimated as for any reinforced concrete section in accordance with relevant provisions of IS 456. The calculations for bending moment for different support conditions during handling are given in Table 1.

Table 1 Bending Moment for Different Support Conditions

Sl No.	Number of Points of Pick Up	Location of Support from End in Terms of Length of Pile for Minimum Moments	Bending Moment to be Allowed for Design kN-m
(1)	(2)	(3)	(4)
i)	One	0.293 *L*	4.3 *WL*
ii)	Two	0.207 *L*	2.2 *WL*
iii)	Three	0.145 *L*, the middle point will be at the centre	1.05 *WL*

NOTE — *W* = weight of pile, in kN.
L = length of pile, in m.

6.11.6 The driving stresses on a pile may be estimated by the following formula:

$$\frac{\text{Driving resistance}}{\text{Cross-sectional area of the pile}} \times \left[\frac{2}{\sqrt{n}} - 1\right]$$

where

n = efficiency of the blow (*see* Annex D for probable value of n).

NOTE — For the purpose of this formula, cross-sectional area of the pile shall be calculated as the overall sectional area of the pile including the equivalent area for reinforcement.

6.12 Reinforcement

6.12.1 The longitudinal reinforcement of any type or grade shall be provided in precast reinforced concrete piles for the entire length. All the main longitudinal bars shall be of the same length and should fit tightly into the pile shoe if there is one. Shorter rods to resist local bending moments may be added but the same should be carefully detailed to avoid any sudden discontinuity of the steel which may lead to cracks during heavy driving. The area of main longitudinal reinforcement shall not be less than the following percentages of the cross-sectional area of the piles:

a) For piles with a length less than 30 times the least width — 1.25 percent,

b) For piles with a length 30 to 40 times the least width — 1.5 percent, and

c) For piles with a length greater than 40 times the least width — 1.5 percent.

6.12.2 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.

6.12.3 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 to be provided along the 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.

6.13 Design of Pile Cap

6.13.1 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.

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

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

6.13.4 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.

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

6.13.6 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.

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

6.14 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 driven precast 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. The minimum grade of concrete to be used for piling shall be M 25.

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

8 WORKMANSHIP

8.1 Casting and Tolerance

8.1.1 The casting yard for all concrete piles should preferably be so arranged that the piles 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.

8.1.2 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 lubricated with oil on the inside face.

8.1.3 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 2.5 m apart. The reinforcement shall be checked for tightness and position immediately before concreting.

8.1.4 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. 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 affect the previously placed concrete for piles during the setting period.

8.1.5 *In-situ* extension of piles already pitched shall be avoided. If necessary, piles may be extended at the top and cured before pitching. Lifting positions shall be adjusted to suit the increased length of piles.

The reinforcement at the top of the pile will need to be exposed for a distance of 40 times the bar diameter and the new bars overlapped for the distance. The central duct will also have to be carefully extended. Where facilities at site are available, welding of reinforcement shall be as per the relevant Indian Standard referred for welding in the product specification standard for steel reinforcing bars.

Extension of piles length 150 mm or lesser should be avoided and instead pile cap depths increased suitably 150 mm all around the pile.

8.1.6 For precast piles, the following tolerances should be adhered:

a) *Cross-section* (Each direction) — *Tolerance*

1) Up to 500 mm — ± 6 mm
2) 500 to 750 mm — ± 10 mm
3) Additional for every subsequent 250 mm — ± 3 mm

b) *Straightness or bow* (Deviation from intended line) — *Tolerance* (maximum)

1) Up to 3 m — 6 mm
2) 3 to 6 m — 10 mm
3) 6 to 12 m — 12 mm
4) Additional for every subsequent 6 m — 6 mm

8.1.7 All precast piles shall be inspected for any defects/honeycombing, etc, and approved for installation as per structural requirements.

8.1.8 Piles shall be identified by marking in paint the number of the pile, length of the pile and its date of casting.

8.2 Curing

8.2.1 Though from consideration of speed and economy precast concrete piles will have to be in place 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 driven and proper schedule to take care of this shall be decided for 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.

8.2.2 Before the handling of the piles, the minimum periods counted from the time of casting shall be as given in Table 2.

Table 2 Time for Curing of Precast Piles
(*Clause* 8.2.2)

Type of Cement	Minimum Periods from the Time of Casting			
	Strike Side Shutters (h)	Roll Pile off Bottom Shutter (days)	End of Wet Curing (days)	Lift from Casting Yard (days)
(1)	(2)	(3)	(4)	(5)
Ordinary Portland cement/Sulphate resisting Portland cement	8	48	7	8 /21[1)]

[1)] When pile length is more than 15 m.

8.3 Storing and Handling

8.3.1 Piles shall be stored on firm ground free from chances of unequal subsidence or settlement under the weight of the piles.

8.3.2 Care shall be taken at all stages of transporting, lifting and pitching of the piles so that they are not damaged or do not crack. During transportation, the piles shall be properly secured and shall be lifted 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 or on firm level ground.

8.4 Control of Pile Driving

8.4.1 The hammer blow generates a stress wave which traverses the length of the pile, and failure, whether by compression or tension, may occur anywhere along the pile.

8.4.2 Failure due to excessive compressive stress most commonly occurs at the head. Head stresses depend upon the ground conditions, weight of the hammer, its drop and the stiffness of head cushion.

8.4.3 The maximum set for a given stress is obtained by using the heaviest hammer and the softest packing the hammer drop being adjusted to suit the allowable stress in the concrete.

8.4.4 Head-packing materials increase in stiffness with repeated use. Hence, optimum driving conditions can be maintained only by regular replacement of the packing.

8.4.5 Failure in the lower sections of a pile can only occur in exceptionally hard driving where in theory the compressive stress at tip can reach twice the head stresses. In practice, however, this rarely occurs and the maximum compressive stress tends to be fairly uniform over considerable length of the pile.

8.4.6 Longitudinal tension is caused by reflection of the compressive wave at the 'free' end. Tensile stresses, therefore, may arise when the ground resistance is low and/or when the head conditions result in hammer rebound, that is, with hard packing and light hammer.

8.4.7 In addition, a relatively long length of pile unsupported above a hard stratum may encourage transverse or flexural vibrations, which may be set up if the hammer below becomes non-axial or the pile is not restrained.

8.4.8 Pile may be driven with any type of hammer, provided the pile penetrate to the prescribed depth or attain the specified resistance without being damaged. The hammer, helmet, dolly and pile shall be coaxial and shall sit squarely one upon the other. It is always preferable to employ the heaviest hammer practicable and to limit the stroke/drop so as not to damage the pile. The stroke/drop of a single acting or drop hammer shall preferably be limited to 1.2 m. A shorter stroke/drop with particular care shall be used when there is a danger of damaging the pile. The following are examples of such conditions.

a) Where in the early stages of driving of a long pile, a hard layer near the ground surface has to be penetrated.

b) Where there is a very soft ground up to a considerable depth, so that a large penetration is achieved at each hammer blow.

c) Where the pile is expected suddenly to reach refusal on rock or other virtually impenetrable soil.

8.4.9 A satisfactory set with an appropriate hammer and drop for the last 10 blows shall be achieved. Repeat tests shall be carried out if necessary, with caution. Long-continued driving, after the pile has almost ceased to penetrate, shall be avoided.

8.4.10 Any sudden change in the rate of penetration which cannot be ascribed to normal changes in the nature of the ground shall be noted and the cause ascertained, if possible, before driving is continued.

8.4.11 When the acceptance of piling is determined by driving to a set, the driving conditions when taking the set shall be the same as those used when the sets of test piles were obtained.

8.4.12 The head of precast concrete pile shall be protected with packing of resilient material, care being taken to ensure that it is evenly spread and held securely in place. A helmet shall be placed over the packing and provided with a dolly of hardwood or other material not thicker than the width of the pile.

8.4.13 Jetting may be used as a means of minimizing or eliminating the resistance at the tip; frictional resistance along the surface of the pile shaft may also be reduced. Very hard driving and vibration can be avoided and greater rates and depths of penetration can be achieved by reducing the tip resistance by jetting than by percussive methods. Jetting is effective in cohesionless soils, such as, sand, gravel and also in fine-grained soils provided the percentage of clay is small. Jetting is not effective in clay soils.

8.4.14 Jetting of piles shall be carried out only when it is desired and in such a manner as not to impair the bearing capacity of the piles already in place, the stability of the ground or the safety of any adjoining buildings.

8.4.15 The quantity of water required for effective jetting is directly related to the cross-sectional area of the piles (including external jet piles). Pile in dense cohesionless soils may require water up to 2 $l/min/cm^2$ of the pile cross-sectional area. Loosely compacted soils may require less water. The jetting pressure shall be from 0.5 to 1.0 N/mm^2 or more. If large quantities of water are used, it may be necessary to make provision for leading away the water that emerges at the ground surface so that the stability of the piling equipment is not endangered by the softening of the ground.

8.4.16 The arrangement of the jets shall be balanced to ensure that the pile penetrates vertically. Independent piles surged down or two pipes attached to the opposite sides of the pile may be used. To minimize the risk of blockages, the nozzles shall not be positioned at the point of the tip. Acceptable verticality may be achieved by the use of rigid leaders and allowing the pile to enter the ground gradually, after operating the water under weight of the pile and hammer, the rate of penetration being controlled by the pile winch. Once maximum apparent penetration is achieved by this method, further penetration may generally be obtained on cohesionless soils by light driving whilst the water jets are running.

Jetting shall be stopped before completing the driving, which shall always be finished by ordinary methods.

8.5 Control of Alignment

Piles shall be installed as accurately as possible as per 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, an angular deviation of 1.5 percent and, for raker piles, a deviation of 4 percent should not normally 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. 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 (100 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 a re-design of the pile cap or pile ties, the piles shall be replaced or supplemented by additional piles.

8.6 Sequence of Piling

8.6.1 In a pile group the sequence of installation of piles shall normally be from the centre to the periphery of the group or from one side to the other.

8.6.2 *Driving a Group of Friction Piles*

8.6.2.1 Driving piles in loose sand tends to compact the sand, which in turn, increases the skin friction. In case where stiff clay or dense sand layers have to be penetrated, similar precautions described in **8.2.1** need to be taken. However, in the case of very soft soils, the driving may have to proceed from outside to inside so that the soil is restricted from flowing out during operations.

8.6.2.2 In ground where there is a possibility of piles rising due to ground heave, levels of the tops of the piles should be measured at interval while nearby piles are being installed. Piles which have risen as a result of driving adjacent piles should be redriven to the original depth or resistance, unless redriving tests on neighbouring piles have shown this to be unnecessary.

8.7 Concreting

8.7.1 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 cut-off level. The reinforcing cages shall be left with adequate protruding length above cut-off level for proper embedment into the pile cap.

8.7.2 Where cut-off level is less than 1.50 m below working level, the concrete shall be cast to a minimum of 600 mm above the cut-off level. In case the cut-off is at deeper level, the empty bore shall be filled with lean concrete or suitable material, wherever the weight of fresh concrete in the casing pipe is found inadequate to counteract upward hydrostatic pressure at any level below the cut-off level.

8.8 Defective Piles

8.8.1 In case defective piles are formed, they shall be left in place and additional piles as necessary shall be provided.

8.8.2 If there is a major variation in the depths at which adjacent piles in a group meet refusal, a boring may be made nearby to ascertain the cause of such difference. If the boring shows that the strata contain pockets of highly compressive material below the level of shorter pile, it may be necessary to take such piles to a level below the bottom of the zone, which shows such pockets.

8.9 Deviations

Any deviation from the designed location, alignment or load-carrying capacity of any pile shall be noted and adequate measures taken to check the design well before the concreting of the pile cap and grade beams are done.

8.9.1 While removing excess concrete or laitance above cut-off level, manual chipping shall be permitted after three days of pile concreting. Pneumatic tools shall be permitted only after seven days after casting. Before chipping/breaking the pile top, a groove shall be formed all around the pile diameter at the required cut-off level.

8.10 Recording of Data

8.10.1 A competent inspector shall be maintained at site to record necessary information during installation of piles and the data to be recorded shall essentially contain the following:

a) Sequence of installation of piles in a group,
b) Type and size of driving hammer and its stroke, or with double acting hammers, the number of blows per minute,
c) Type of the packing on the pile head and the dolly in the helmet,
d) Dimensions of the pile including the reinforcement details and mark of the pile,
e) Cut-off level and working level,
f) Depth driven,
g) Final set for the last ten blows or as may be specified,
h) Time taken for driving and for concreting recorded separately, and
j) Any other important observations, during driving, concreting and after withdrawal of casing tube.

8.10.2 Typical data sheet for recording piling data are shown in Annex E.

9 ADDITIONAL PROVISION FOR PRESTRESSED CONCRETE PILES

9.1 General

The stresses set up when handling prestressed piles of given length can be resisted by smaller cross-section and thus economy in materials may be achieved. The small cross-section may permit or necessitate greater penetration. The bearing capacity may govern the cross-section of a pile and could preclude the use of the smaller sizes that would be possible from strength considerations alone. The tensile stresses caused by the action of stress waves when driving can be reduced by the prestress. The reduction of tensile cracks may give greater durability to the pile, particularly if the pile is submerged. The piles are better able to resist, without cracking, any tensile forces set up by the working loads, whether direct or due to bending, or by accidental loads.

9.2 Concrete

9.2.1 The maximum axial stress that may be applied to a pile acting as a short strut should be 25 percent of the specified works cube strength at 28 days less the prestress after losses.

9.2.2 The static stresses produced during lifting and pitching should not exceed the values given in IS 1343, the values relating to loads of short duration. To allow for impact, the tensile stresses during transport, calculated as static stresses, should not exceed one-third of the values calculated as above.

9.3 Prestresses

9.3.1 The prestress after allowing for losses of prestress should satisfy the following conditions:

a) Prestress to cover handling, transporting and lifting conditions. For this purpose, it may be assumed that only 75 percent of the full loss of prestress will have occurred within two months of casting.

b) Prestress in N/mm^2 of not less than 0.07 times the ratio of the length of the pile to its least lateral dimensions.

c) Minimum prestress related to the ratio of effective weight of hammer to weight of pile to be as follows:

Ratio of hammer to pile weight not less than	0.9	0.8	0.7	0.6
Minimum prestress for normal driving, N/mm^2	2.0	3.5	5.0	6.0
Minimum prestress for easy driving, N/mm^2	3.5	4.0	5.0	6.0

9.3.1.1 For diesel hammers the minimum prestress should be 5 N/mm^2.

9.3.2 A considerably greater prestress may be required for raking piles, particularly if these are driven in ground which may tend to deflect the piles from their true alignments.

9.3.3 Loss of prestress should be calculated in accordance with IS 1343.

9.4 Prestressing Wires and Stirrups

9.4.1 The prestressing wires should be evenly spaced parallel to faces of the pile.

9.4.2 Mild steel stirrups of not less than 6 mm diameter should be placed at pitch of not more than the side dimension less 50 mm. At the top and bottom, for a length of three times the side dimensions, the stirrup volume should be not less than 0.6 percent of the pile volume. The concrete cover to reinforcement should be in accordance with **6.12.3**.

9.5 Materials and Stresses

9.5.1 *Reinforcement*

Where ordinary reinforcement is introduced into prestress piles, it should be in accordance with **7.2** of IS 1786.

9.5.2 *Prestressing Steel*

Prestressing steel should be in accordance with IS 2090.

9.5.3 *Concrete*

The materials should, in general, be in accordance with IS 1343.

9.6 Workmanship

9.6.1 *Manufacture, Curing and Transfer of Prestress*

Prestressed piles require high strength concrete and careful control during manufacture, usually this means casting in a factory where the curing conditions can be strictly regulated. Where piles have to be lengthened the procedure is more elaborate.

9.6.2 *Manufacture*

Prestressed concrete piles are normally cast by the 'long-line' method in a factory under conditions of close control. Where piles are cast other than in factory, casting should take place in an enclosed space at an air temperature of not less than 10ºC (50ºF).

Piles should not be removed from the place of casting until after the transfer of prestress.

The piles should be cast in one operation using internal and external vibrators to assist compaction of the concrete.

Care should be taken to ensure that vibration from adjoining work does not affect the placed concrete during the setting period. Care should be taken that the head of the piles is finished plane and normal to the axis of the pile. Each pile should be marked with a reference number and date of casting. Curing should be carried out as described in **8.2** or the piles may be steam cured.

9.6.3 *Transfer of Prestress*

Whenever a batch of piles if cast, four test cubes should be cast and stored in close proximity to and under the same conditions of temperature and humidity as the piles.

The minimum cube strength of the concrete at transfer of prestress should be 2.5 times the stress in the concrete at transfer, or 28 N/mm^2 for strand or crimped wire or 35 N/mm^2 for plain or indented wire, whichever is the greater. The attainment of this strength may be checked either by testing the relevant test cubes or by allowing sufficient times to elapse after casting, provided this period can be shown to be adequate on the basis of previous test cube results and strictly controlled curing conditions. After transfer of prestress, the prestressing wires should be cut-off flush with the face of the concrete or pile shoe.

9.6.4 *Stacking and Storing*

For stacking and storing, **8.3** may be referred to.

9.7 Driving

There is some evidence to suggest that a larger ratio of hammer weight to pile weight is required to avoid damaging the pile. Driving of prestressed concrete piles should follow the recommendations for reinforced concrete piles as in **8.4, 8.5** and **8.9**. Although the effect of prestressing is to reduce tension cracks induced by stress waves, such cracking may still occur, particularly when driving is ‘light’, or if too light a hammer is used. A careful check for tension cracks should be made during the driving of the first pile and, if these occur, the hammer drop should be reduced. If the cracks persist or recur when the full drop has to be used, then a heavier hammer should be substituted.

9.8 Embedment of Pile Head into Pile Cap

The concrete of the pile may be stripped to expose the prestressing wires. The concrete should be stripped to such a level that the remaining concrete projects 75 mm into the pile cap. Where tension has to be developed between the cap and pile, the exposed prestressing wires should extend at least 600 mm into the cap. An alternative method is to incorporate mild steel reinforcement in the upper part of the pile. After stripping the concrete this reinforcement should be bonded into the cap.

9.9 Where piles have to be lengthened during driving, this may be done by one of the following methods:

a) Where mild steel reinforcement is incorporated in the head of the pile, lengthening may be as described in **8.1.5**.

b) By using a mild steel splicing sleeve together with a precast extension piece. The sleeve should be bedded on to the top of the pile with an earth-dry sand/cement mortar or other compound, and the extension piece similarly bedded on to the sleeve.

   It should be noted that piles lengthened in this way have a limited resistance to bending at the splice.

c) By means of dowel bars inserted into drilled holes the connection being made with grout or epoxy resin.

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*)
1343 : 1980	Code of practice for prestressed concrete (*first 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*)
2090 : 1983	Specification for high tensile steel bars used in presetressed concrete (*first revision*)
2131:1981	Method for standard penetration test for soils (*first revision*)
2911	Code of practice for design and construction of pile foundations:
(Part 3) : 1980	Under-reamed piles (*first revision*)
(Part 4) : 1984	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*)
4968	Method for sub-surface sounding for soils:
(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:

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

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 m²;

D = diameter of pile shaft, in m;

γ = effective unit weight of the soil at pile tip, in kN/m³;

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/m² (*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 *i*th layer (*see* Note 3);

P_{Di} = effective overburden pressure for the *i*th layer, in kN/m²;

δ_i = angle of wall friction between pile and soil for the *i*th layer; and

A_{si} = surface area of pile shaft in the *i*th layer, in m².

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 driven 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 2 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.

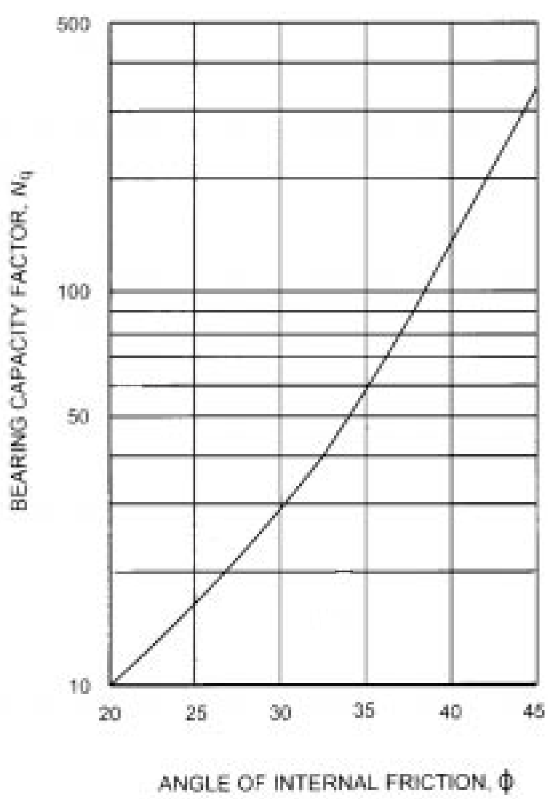


FIG. 1 BEARING CAPACITY FACTOR, N_q FOR DRIVEN PILES

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 m²;

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

c_p = average cohesion at pile tip, in kN/m²;

$\sum_{i=1}^{n}$ = 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/m²; and

A_{si} = surface area of pile shaft in the ith layer, in m².

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

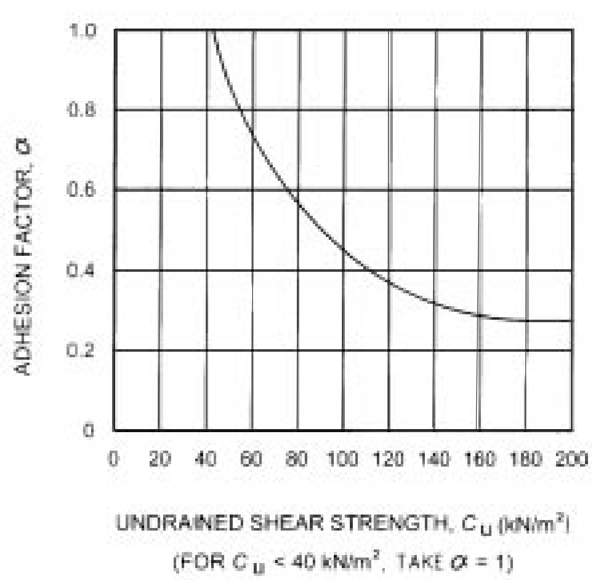


FIG. 2 VARIATION OF α WITH C_u

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:

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

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 3.

Table 3 Side Friction for Different Types of Soils

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 4 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 4 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 driven pile is given below. The ultimate load capacity of pile (Q_u), in kN, is given as:

$$Q_u = 40N \frac{L_b}{D} A_p + \frac{\overline{N} A_s}{0.50} \qquad \ldots(3)$$

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

where

N = average N value at pile tip;

L_b = length of penetration of pile in the bearing strata, in m;

D = diameter or minimum width of pile shaft, in m;

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

$\overline{N}$ = average N along the pile shaft; and

A_S = surface area of pile shaft, in m^2.

NOTE — The end-bearing resistance should not exceed 400 NA_p.

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

$$Q_u = 30N \frac{L_b}{D} A_p + \frac{\overline{N} A_s}{0.60} \qquad \ldots(4)$$

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 end-bearing and skin friction in different strata by using appropriate expressions given in **B-1** and **B-2**.

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 5.

Table 5 Modulus of Subgrade Reaction for Granular Soils, η_h, in kN/m^3

(*Clauses* C-2.1 *and* C-2.3.1)

Sl No.	Soil Type	N (Blows/30 cm)	Range of η_h kN/m^3 × 10^3	
			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 6.

Table 6 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/m²;

I = moment of inertia of the pile cross-section, in m⁴; and

η_h = modulus of subgrade reaction, in MN/m³ (*see* Table 5).

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/m²;

I = moment of inertia of the pile cross-section, in m⁴;

$K = \frac{k_1}{1.5} \times \frac{0.3}{B}$ (*see* Table 6 for values of k_1, in MN/m³); 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 7.

Table 7 Criteria for Behaviour of Pile Based on its Embedded Length

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. 3. 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.

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

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

…for free head pile

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

…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/m²;

I = moment of inertia of the pile cross-section, in m⁴;

z_f = depth to point of fixity, in m; and

e = cantilever length above ground/bed to the point of load application, in m.

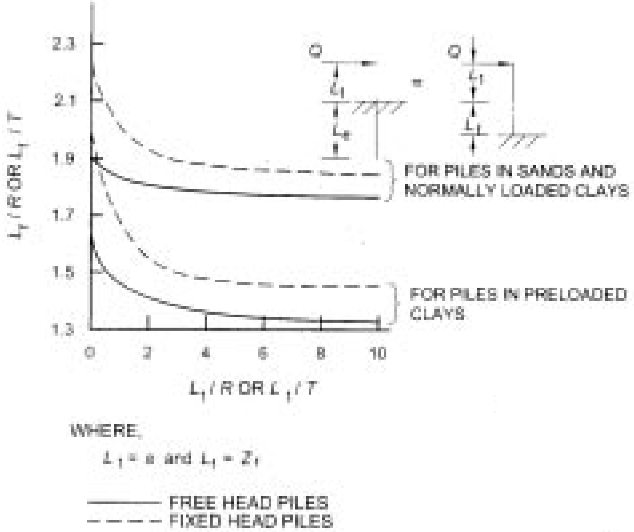


FIG. 3 DEPTH OF FIXITY

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

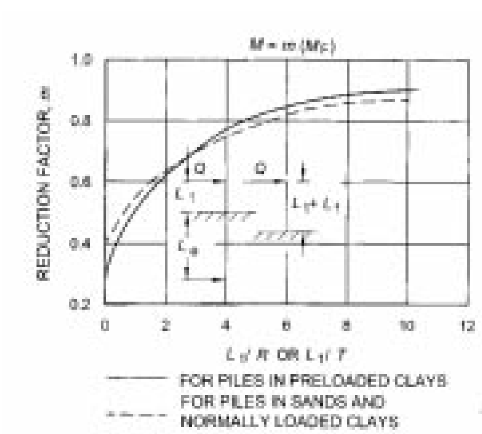
Fixed end moment, $M_F = H(e + z_f)$

…for free head pile

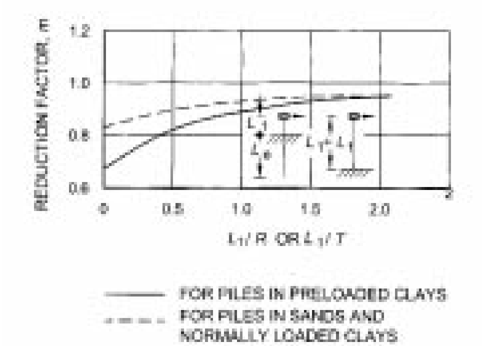
Fixed end moment, $M_F = \dfrac{H(e + z_f)}{2}$

…for fixed head pile

The fixed end 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. 4.



4A For Free Head Pile



4B For Fixed Head Pile

FIG. 4 DETERMINATION OF REDUCTION FACTORS FOR COMPUTATION OF MAXIMUM MOMENT IN PILE

ANNEX D

(*Clause* 6.11.6)

PROBABLE VALUES OF *n*, EFFICIENCY OF THE BLOW

D-1 The formula for efficiency of the blow, representing the ratio of energy after impact to striking energy of ram, *n*, is:

Where *W* is greater than *P.e* and the pile is driven into penetrable ground,

$$n = \frac{W + \left(P \cdot e^2\right)}{W + P}$$

Where *W* is less than *P.e* and the pile is driven into penetrable ground,

$$n = \left[\frac{W + \left(P \cdot e^2\right)}{W + P}\right] - \left[\frac{W - \left(P \cdot e\right)}{W + P}\right]^2$$

The following are the values of *n* in relation to *e* and to the ratio of *P*/*W*:

Ratio of *P*/*W*	*e* = 0.5	*e* = 0.4	*e* = 0.32	*e* = 0.25	*e* = 0
½	0.75	0.72	0.70	0.69	0.67
1	0.63	0.58	0.55	0.53	0.50
1½	0.55	0.50	0.47	0.44	0.40
2	0.50	0.44	0.40	0.37	0.33
2½	0.45	0.40	0.36	0.33	0.28
3	0.42	0.36	0.33	0.30	0.25
3½	0.39	0.33	0.30	0.27	0.22
4	0.36	0.31	0.28	0.25	0.20
5	0.31	0.27	0.24	0.21	0.16
6	0.27	0.24	0.21	0.19	0.14
7	0.24	0.21	0.19	0.17	0.12
8	0.22	0.20	0.17	0.15	0.11

NOTES

1 *W* = mass of the ram, in tonne and *P* = weight of the pile, anvil, helmet, and follower (if any) in tonne.

2 Where the pile finds refusal in rock, 0.5*P* should be substituted for *P* in the above expressions for *n*.

3 *e* is the coefficient of restitution of the materials under impact as tabulated below:

a) For steel ram of double-acting hammer striking on steel anvil and driving reinforced concrete pile, *e* = 0.5.
b) For cast-iron ram of single-acting or drop hammer striking on head of reinforced concrete pile, *e* = 0.4.
c) Single-acting or drop hammer striking a well-conditioned driving cap and helmet with hard wood dolly in driving reinforced concrete piles or directly on head of timber pile, *e* = 0.25.
d) For a deteriorated condition of the head of pile or of dolly, *e* = 0.

ANNEX E
(*Clause* 8.10.2)

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: From centre towards the periphery or from periphery towards the centre
(for groups)

Concrete : Mix ratio 1: .... by volume/weight
or strength after ……………days .... N/mm^2

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

Extra cement added, if any: ....

Weight of hammer .... Type of hammer ....
(Specify rated energy, if any)

Fall of hammer .... Length finally driven ....

No. of blows during last 25 mm of driving ....

Dynamic formula used, if any ....

Calculated value of working load ....
(Calculations may be included)

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 piling 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 F

(*Foreword*)

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