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मानक

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Mazdoor Kisan Shakti Sangathan

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“पुराने को छोड़ नये के तरफ”

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IS 14593 (1998): Design and construction of bored cast-in-situ piles founded on rocks - Guidelines [CED 48: Rock Mechanics]



“ज्ञान से एक नये भारत का निर्माण”

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“Invent a New India Using Knowledge”



“ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है”

Bhartrhari—Nitiśatakam

“Knowledge is such a treasure which cannot be stolen”

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भारतीय मानक

चट्टानों पर नींव रखने हेतु बोर करने के लिए
निर्माण स्थल पर ही निर्मित की जाने वाली सामग्री का
डिजाइन और विसंरचना — सिफारिशें

Indian Standard

**DESIGN AND CONSTRUCTION OF BORED
CAST-*IN-SITU* PILES FOUNDED ON ROCKS —
GUIDELINES**

ICS 93.020

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

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

Pile foundations provide an effective means of transmitting large concentrated loads through overburden soils to underlying rock or socketed into rock. Bored cast-*in-situ* piles has the advantages of increasing the load carrying capacity by socketing the pile into rock. However the load transfer mechanism or distribution of load support of socketed pile is still in the development stage and depends upon the substrata condition and the type of rock modulus of rock, strength and unfavourable condition of rock. The rock material can vary from hard, fresh bed rock stronger than concrete, to highly weathered rock with properties of hard clay. Rock socketed piles derive their load carrying capacity from two components' shearing resistance at the concrete-rock interface around the vertical cylindrical surface of the socket and end bearing resistance at the pile tip. There are several factors which control the load carrying capacity of rock socketed pile, like quality and strength of rock, efficiency of the load transfer mechanisms between the concrete pile and its rock socket.

Construction of such rock socketed piles requires careful choice of method of construction including effective cleaning of the socket portion. As the techniques for measurements of the rock mass properties of foliated/jointed rock are not well developed, the mechanisms for side resistance and base resistance in rocks exhibit complex differences from those relevant to soils. Therefore, a separate standard covering bored cast-*in-situ* piles socketed into rock has been formulated for design, construction, and interpretation of test results.

The information from various international practices, designers, executing agencies, construction agencies being practiced in this country and the technical discussions thereon, including the available literature and considerable assistance from National Thermal Power Corporation Ltd have assisted in the preparation of this standard. It has been decided to use the standard as guidelines initially, before adopting this standard as a code of practice.

Technical Committee responsible for the formulation of this standard is given in Annex A.

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

DESIGN AND CONSTRUCTION OF BORED CAST-IN-SITU PILES FOUNDED ON ROCKS — GUIDELINES

1 SCOPE

This standard covers the design of load bearing concrete bored cast-*in-situ* piles of diameter less than or equal to 1 500 mm which transmit the load of the structure to the rock through resistance developed either at the pile tip by end bearing or along the interface surface by pile rock adhesion or through both.

This standard does not cover well foundations.

2 REFERENCES

The Indian Standards given below contain provisions which through reference in this text, constitute provision 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 indicated below:

<i>IS No.</i>	<i>Title</i>
456 : 1978	Code of practice for plain and reinforced concrete (<i>third revision</i>)
1892 : 1979	Code of practice for subsurface investigation for foundation
2131 : 1981	Method of standard penetration test for soils (<i>first revision</i>)
2809 : 1972	Glossary of terms and symbols relating to soil engineering
2911	Code of practice for design and construction of pile foundations.
(Part 1/ Sec 1 to 3) : 1979	Concrete piles
(Part 4) : 1985	Load test on piles (<i>first revision</i>)
4651	Code of practice for planning and design of ports and harbours: Part 4
(Part 4) : 1989	General design consideration (<i>second revision</i>)
8009	Code of practice for calculation of settlement of foundations:
(Part 1) : 1976	Shallow foundations subjected to symmetrical static vertical loads
(Part 2) : 1980	Deep foundations subjected to symmetrical static vertical loading
11358 : 1987	Glossary of terms and symbols relating to rock mechanics

IS No.

Title

12070 : 1987	Code of practice for design and construction of shallow foundations on rocks
13063 : 1991	Code of practice for structural safety of buildings on shallow foundation in rocks

3 TERMINOLOGY

For the purpose of this standard, the definition of terms given in IS 2809 and IS 11358 shall be applicable in addition to the following.

3.1 Rock Socket

That portion of pile shaft which penetrates into a rock formation beneath the overburden.

4 NECESSARY INFORMATION

4.1 For the satisfactory design and construction of bored cast-*in-situ* piles in rock, the following information is necessary :

- a) Information as per IS 2911 (Part 1/Sec 2).
- b) Geotechnical investigation data as laid down as per IS 1892, IS 13063 or any other relevant IS code.
- c) The rock profile, contours, the geological data and the necessary information as listed in IS 13063 along with the engineering and physical properties of the rock strata/mass.
- d) Information of rock below the anticipated level of pile tip, generally not less than 5 m in bed-rock or more if otherwise.
- e) In case of bridge on pile foundations data on high flood level, maximum scouring depth, normal water level during working season, etc.
- f) In case of marine construction necessary information as per IS 4651 (Part 4).
- g) Results of chemical tests to ascertain the chemical constituents like chlorides, sulphates, alkali and/or any other deleterious chemical content of soil/rock and ground water.

5 EQUIPMENT AND ACCESSORIES

The equipment and accessories would depend upon the type of subsoil strata, ground water conditions, the

type of rock/founding material and the required depth of embedment therein whichever applicable. Among the commonly used plants, tools and accessories, there exists a large variety of suitability on the subsoil and rock type conditions and manner of operations, etc.

5.1 Boring

Boring operations are generally done by rotary or percussion type drilling rigs using direct mud circulation or reverse mud circulation methods to bring the cuttings out. Bailer and Chisel method if employed should be used with caution to avoid the effect of suction. Over cutting especially at the change of strata should be done with caution.

5.2 Chiseling

Chiseling may be resorted to in rock strata to penetrate up to required depth.

5.3 Cutting Tool

The size of the cutting tool should not be less than the diameter of the pile by more than 75 mm.

5.4 Drilling Mud

Use of drilling mud in stabilizing sides of boreholes is also made where appropriate or necessary. Drilling mud should satisfy the basic properties as defined in IS 2911 (Part 1/Sec 2).

5.5 Cleaning

Proper cleaning of piles after boring, after lowering the reinforcement and before concreting shall be done. On completion of pile bore up to required depth, the bottom of pile bore shall be cleaned to remove rock debris, pile bore soil, etc. Rope operated grabbing or kelly mounted hydraulically operated grab can be used. Use of air lift technique is also effective in removing the rock debris.

5.6 Liner

Permanent liner may be used to avoid the aggressive action of ground water or otherwise. In case, liner is used and the pile bore is filled with water or drilling mud, the bottom part may be concreted using tremie so that the liner is effectively sealed against ingress of ground water, the upper part may be concreted in dry condition after inspection of the top surface of the concrete already placed.

6 DESIGN CONSIDERATIONS

6.1 General

Pile foundations socketed in rock strata shall be designed in such a way that the load from the structure it supports, is transmitted to the rock without causing any rock failure and/or without causing such settlement (differential or total) under permanent/transient loading as may result in structural damage

and/or functional distress. The pile shaft should have adequate structural capacity to withstand all loads (vertical, compression or uplift and moments which are transmitted to the rock mass).

6.2 The various factors to be considered during design are as per IS 12070.

6.3 Loading on Piles

6.3.1 Depending on the nature of the superstructure, the loads can form any combination of axial forces (either compressive or tensile), lateral forces and moments. The various load combinations of dead load, live load, wind load, earthquake load and uplift load to be considered should satisfy the requirements of IS 456.

6.3.2 The overburden soil may exert negative skin friction on pile shaft resting on rock. This should be accounted for in design of piles.

6.4 The load carrying capacity of a pile is dependent on the properties of the rock in which it is embedded/ socketed. Axial load from a pile is normally transmitted to the rock through adhesion at the interface of pile and rock and end bearing at the pile tip.

6.4.1 A single pile is normally designed to carry load along its axis. The horizontal load on a vertical pile is transmitted to the subsoil primarily by horizontal subgrade reaction generated in the upper part of the shaft. Transverse load bearing capacity of a single pile depends on the soil reaction developed and the structural capacity of the shaft under bending.

6.4.2 The permissible load carrying capacity of pile may be estimated using the proposed methods. However, it should be confirmed by an initial load test on trial pile IS 2911 (Part 4).

6.4.3 The settlement of pile obtained at safe load from load test results on a single pile shall not be directly used in forecasting the settlement of a structure unless experience from similar foundations on its settlement behaviour is available.

6.4.4 The average settlement may be assessed on the basis of properties of subsoil/rock and loading details of the structure as a whole using the principle of rock mechanics or as given in 6.6.

6.5 Estimation of Load Carrying Capacity

6.5.1 Compression

Rock socketed piles can be designed to carry compressive loads in side wall shear only or end bearing only, or a combination of both. The most important factors that influence the design procedure are the strength, degree of fracturing and modulus of deformation of rock mass, the condition of the walls and base of the socket and the geometry of the socket.

Depending upon the type of rock, any one of the following methods shall be used for computing compression capacity:

- a) Based on uniaxial compressive strength of rock,
- b) Based on limit pressure of rock,
- c) Based on shear strength of rock, and
- d) Structural strength of pile.

NOTES

1 Minimum length of socket for preliminary design may be taken from Table 1, although it should be estimated from static computations given in this standard and preferably verified by load test.

2 The rock up to depth of at least one diameter below the base of the socket is either intact or tightly jointed (no compressible or gougefilled scores).

3 There are no solution cavities or voids below the base of the pile.

Table 1 Suggested Minimum Length of Socket
(Clause 6.5.1, Note 1)

Rock Type (1)	l_s (2)
Sound relatively homogeneous rock including granite, gneiss	1 to 2 D
Moderately weathered, closely jointed including schist, slate	2 to 3 D
Soft rocks, sedimentary rocks including hard shale, sandstones, siltstone, mudstone	3 to 4 D

NOTE — D is the diameter of pile.

6.5.1.1 Based on uniaxial compressive strength

- a) Where the rock is sound the strength of the foundation rock is generally much in excess of the design requirements, provided the walls of the discontinuity are closed and they are favourably oriented. Refer to Fig. 1 of IS 12070, with respect to the applied forces then the data to be investigated shall be as given in 6 of IS 12070.

$$Q_s = q_c N_j N_d A_p + q_c \pi D l_s \alpha \beta \quad \dots(1)$$

where

- Q_s = safe load capacity of pile, in tonnes;
- q_c = uniaxial compressive strength of rock, T/m^2 ;
- N_d = depth factor = $0.8 + 0.2 l_s/D$, limited to 2;
- A_p = area of pile toe, $\pi D^2/4$;
- D = diameter of pile, in m;
- l_s = socket length into the rock, in m;
- α = rock socket slide resistance reduction factor (Fig. 1);
- β = rock socket correction factor (Fig. 2); and
- N_j = values as per Fig. 2 of IS 12070 are applicable, when the spacing of

discontinuity is greater than 300 mm and aperture (opening) of discontinuities less than 10 mm (15 mm if filled with soil or rock debris. Otherwise Table 4 of IS 12070 is applicable).

α values are given in Fig. 1 based on rock strength and values of β in Fig. 2 based on mass factor.

Where the rock is relatively homogeneous and competent and comparable with concrete in strength, in Equation (1).

- q_c = safe strength of concrete, T/m^2 ;
- N_j = 0.3;
- α = 0.05;
- β = 1; and
- N_d = 1.

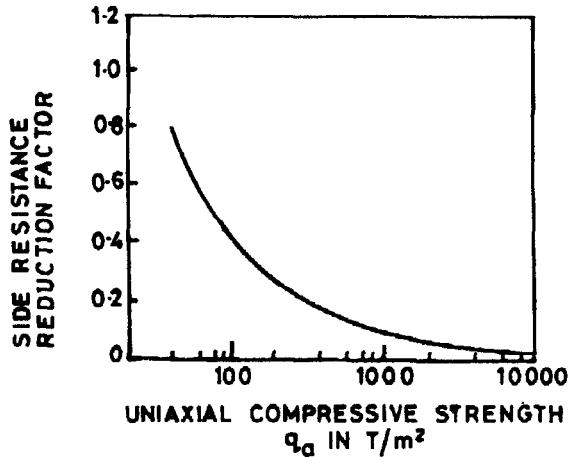


FIG. 1 SIDE RESISTANCE REDUCTION FACTOR REFLECTING VARIATION OF ROCK STRENGTH

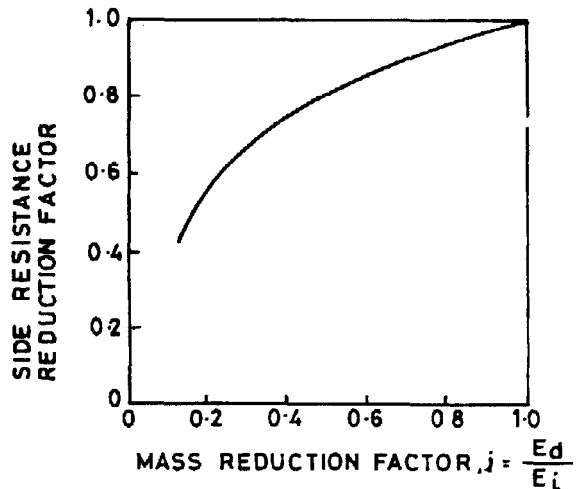


FIG. 2 SIDE RESISTANCE REDUCTION FACTOR REFLECTING VARIATION OF MASS FACTOR

6.5.1.2 Based on pressuremeter test

This method is suited for weathered or closely jointed rocks and for soft rocks.

$$Q_u = [P_o + K_b (P_1 - P_o)] A_p + f_i \pi D l_s \quad \dots(2)$$

where

- Q_u = ultimate pile capacity in compression, T;
- P_o = overburden pressure at the elevation of pile tip, T/m^2 ;
- K_b = bearing capacity coefficient depending on socket length as given in Table 2;
- P_1 = limit pressure determined from pressuremeter test in the zone extending two times the pile diameter above and below pile toe (top), T/m^2 ; and
- f_i = frictional resistance component.

Table 2 Values of K_b

Socket Length Pile Diameter	0	1	2	3	5	7
K_b	0.8	2.8	3.6	4.2	4.9	5.2

Values of f_i depending on limit pressure are given in Fig. 3, for:

$p_1 < 150 \text{ t/m}^2$ in highly weathered rocks; and

$$f_i = \left(\frac{P_1}{3} + 3 \right) \text{t/m}^2 \text{ for moderately weathered rocks.}$$

The value of f_i should be limited to 0.05 times the safe strength of concrete.

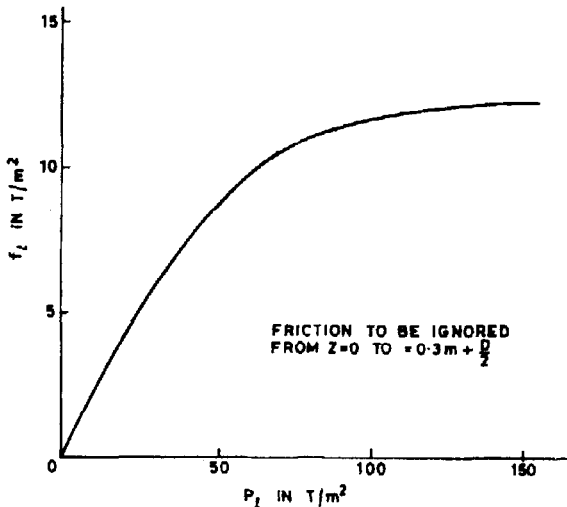


FIG. 3 FRICTIONAL RESISTANCE OF PILES (SOFT, WEATHERED ROCKS)

6.5.1.3 Estimation of compression capacity using shear strength parameters

$$Q_u = C_u N_c \times \pi D^2 / 4 + \alpha C_s \pi D l_s \quad \dots(3)$$

where

- Q_u = ultimate capacity of pile in compression, T;
- C_u = shear strength of rock below pile tip, T/m^2 ;
- N_c = bearing capacity factor (equal to 9);
- C_s = average shear strength of rock adjacent to the shaft in the socketed length (Fig. 4), T/m^2 ;
- α = 0.9 (recommended value);
- F_s = 6 (factor of safety); and
- l_s = socket length, m.

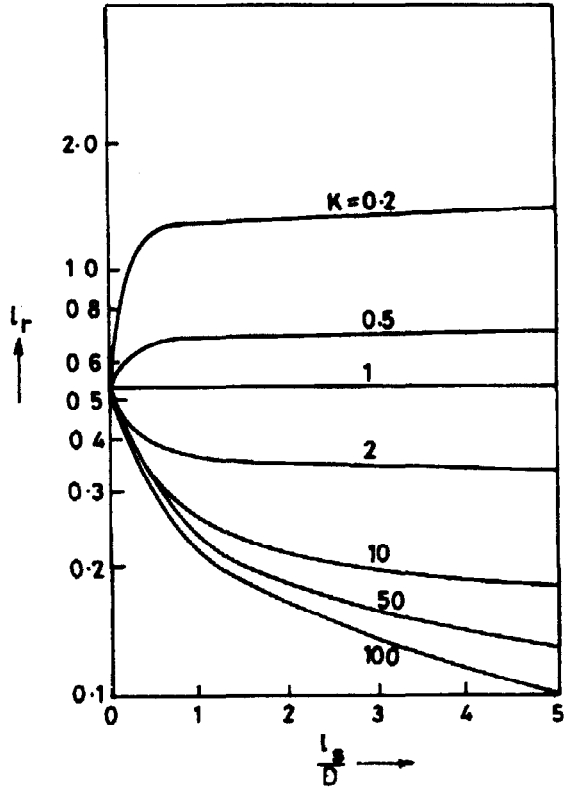


FIG. 4 INFLUENCE FACTORS FOR SETTLEMENT WITH DIFFERENT EMBEDMENT RATIOS (OF SOCKET LENGTH)

The above method is applicable for siltstone, mudstone and weathered sandstone. The partially mobilized frictional resistance offered by the soil may be neglected.

6.5.1.4 Structural capacity

The piles shall have necessary structural strength to transmit loads imposed on it, ultimately to the rock as per IS 2911 (Part 1/Sec 2).

6.6 Settlement

Settlement for piles could be estimated from one of the following methods.

6.6.1 Based on IS 8009 (Part 2), settlement 'S' can be estimated as follows:

$$S = S_p + S_i \quad \dots(4)$$

where, S_p is elastic compression and is given by:

$$S_p = \frac{PL}{A_p E_p}$$

S_i = immediate settlement of pile

L = length of the pile

$$S_i = \left[\frac{PD(1-\mu^2)I}{A_p E_d} \right] \quad \dots(5)$$

where

S = total settlement of the pile;

S_p = elastic compression of pile;

S_i = immediate settlement of pile;

P = design load on pile;

E_p = modulus of elasticity of pile;

μ = poisson's ratio of rock;

E_d = modulus of deformation of rock mass;

E_i = modulus of deformation of rock material; and

I = influence factor [value of influence factor can be taken as specified in IS 8009 (Part 1)].

6.6.2 For homogeneous and stratified rock mass, the following method shall be used for computing the settlement:

$$S = \left[\frac{PD}{9 \alpha_m E_m A_p} \right] \quad \dots(6)$$

where

E_m = average pressuremeter modulus in the zone extending 3 diameters below the pile toe

α_m = a coefficient which is a function of the structure of the rock mass (see also Table 3)

Table 3 Values of α_m

Spacing of Discontinuities (m)	3.0	0.9-3.0	0.3-0.9	0.1-0.3
α_m	1	0.75	0.5	0.25

This method is applicable to homogeneous and stratified rock masses. In the latter case the modulus to be used in the formula is taken as the weighted average of the moduli measured in the different strata, provided the moduli do not differ by more than a factor 10.

The effect of thin horizontal joints or compressible seams cannot be taken into account in this method and the results may be misleading if such joints or seams occur.

6.6.3 For settlements of pile with both adhesion and end bearing, for varying rock moduli ranging from moderately weathered to very strong rock, the following method shall be used for computation:

$$S = \left[\frac{2 Pl_r}{E_d l_s} \right] \quad \dots(7)$$

where

P = design load, T;

E_d = modulus of the rock mass, T/m²;

l_r = influence factor as given in Fig. 4; and

l_s = length of socket.

6.6.4 The elastic compression of pile shall be added to the settlement estimated from 6.6.2 and 6.6.3.

6.7 Lateral Load Capacity

6.7.1 The capacity of a socketed pile to withstand lateral loads depends on the rigidity of the pile as well as the load-deformation characteristics, thickness of the soil and rock strata in which the pile is socketed.

6.7.2 For calculating the capacity of the pile socketed in rock requires determination of the depth of fixity, lateral deflection and maximum moment. Three different embedments of pile in rock are encountered and the design is made accordingly.

- Pile passing through soil of considerable thickness [Fig. 5(a)],
- Intermediate thickness of soil and rock [Fig. 5(b)], and
- Pile fully embedded in rock [Fig. 5(c)].

6.7.3 Design Considerations

6.7.3.1 Case (a)

When the rock into which the pile penetrates is covered by a relatively thick layer of soil Fig. 5(a), the influence of the rock is negligible, and the method of estimation for capacity can be done similar to the method as mentioned in IS 2911 (Part 1/Sec 2).

6.7.3.2 Case (b)

In case of intermediate pile Fig. 5(b), the end restraint condition of the socketed pile should be accounted for in the estimation of the lateral capacity, that is:

$$\text{if } \frac{L_s}{R} < 4 \quad \dots(8)$$

where

L_s = length of pile in soil, and

R = relative stiffness factor as per IS 2911 (Part 1/Sec 2).

The contribution of the rock can also be accounted for taking into account the variation in the modulus of subgrade reaction with depth.

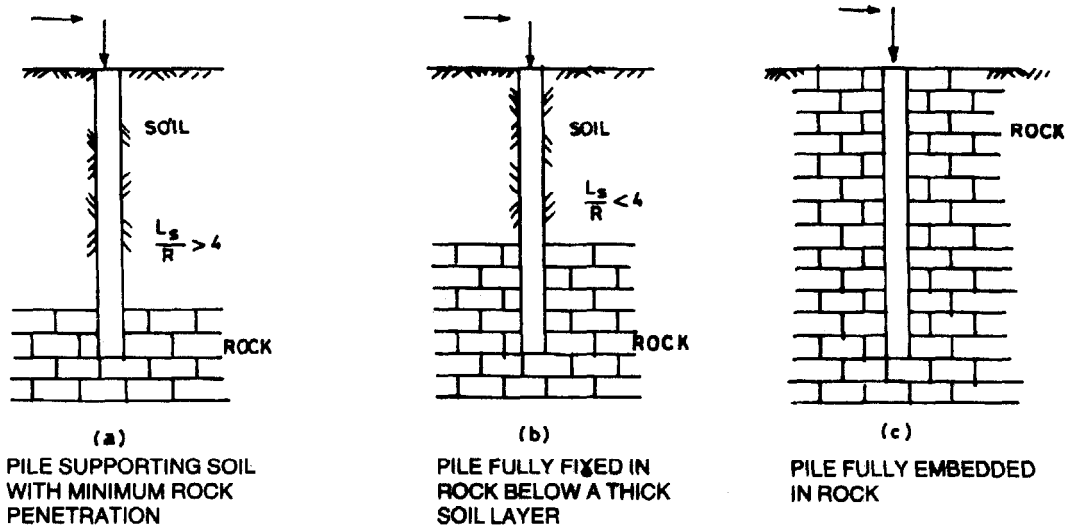


FIG. 5 DIFFERENT AMOUNTS OF EMBEDMENTS IN ROCKS

6.7.3.3 When the pile is fully embedded in rock, as shown in Fig. 5(c) with a higher modulus than that of the pile material, the lateral capacity it can resist is determined by the capacity of its section to resist shear forces.

6.8 Uplift Capacity

6.8.1 Socketed piles can be designed to resist uplift forces either by enlarging or belling the base, or by developing sufficient side wall shear resistance. While belling the base of pile is common in soils, this can be an expensive and difficult operation in rock. Moreover, since a significant amount of side wall shear resistance is developed in rock sockets, it is usually more economical to deepen the socket in rock than to construct a shorter, belled socket.

6.8.2 Uplift Resistance in Side Wall Shear

6.8.2.1 The preliminary design for uplift/tension piles, can be carried out using the methods given for compression piles with due allowance for side adhesion and the factors shall be as per IS 12070. However, full scale uplift load tests should be performed to determine the allowable side wall shear resistance and the load displacement behaviour.

6.8.2.2 The results of load-displacement tests performed on tension piles can be used to calculate the shear stress developed on the side wall and the actual displacement can be compared with the theoretical displacement from elastic theory for compression piles.

In all cases the minimum length of socket is 2 times the socket diameter of pile.

6.9 Factors Affecting the Load Capacity and Settlement of Socketed Pile

- a) Geometry of the socket defined by the length to diameter ratio;

- b) Modulus of deformation of the rock mass both around the socket and below the base;
- c) Strength of the rock in the walls of the socket and below the pile;
- d) Condition of the side walls with respect to roughness, and the presence of drill cuttings or bentonite cakes;
- e) Condition of the end of the pile with respect to the removal of drill cuttings and other loose material from the bottom of the socket;
- f) Layering in the rocks and the response of seams with differing strengths and moduli;
- g) Settlement of the pile in relation to the elastic limit of side wall shear strength;
- h) Creep of the material at the rock-concrete interface resulting in increasing settlement with time; and
- j) Effect of ground water table.

6.10 Spacing of Piles

Similar provision as laid down in IS 2911 (Part 1/Sec 2).

6.10.1 For pile founded in bed rock spacing of twice the pile diameter may be adopted. In case of weak and weathered rock a minimum spacing of two-and-a-half times the pile diameter may be provided.

6.11 Pile grouping similar provisions as laid down in IS 2911 (Part 1/Sec 2).

6.11.1 Pile cap design shall conform to the provisions laid down in IS 2911 (Part 1/Sec 2).

6.12 Factor of Safety

6.12.1 Factor of safety should be judiciously chosen considering the various factors. However, the minimum factor of safety on static formula shall be 6. The final selection of factor of safety shall take into consideration the load settlement characteristics of the structure as whole at a given site.

6.12.2 The factor of safety may be increased in case of unfavourable conditions of rock, deterioration with time, vibrations from the structure/equipments.

6.13 Transient loading similar provision as laid down in IS 2911 (Part 1/Sec 2).

6.14 Overloading similar provisions as laid down in IS 2911 (Part 1/Sec 2).

6.15 Reinforcement similar provisions as laid down in IS 2911 (Part 1/Sec 2).

7 MATERIALS AND STRESSES CONFORMING TO IS 2911 (Part 1/Sec 2)

Cement steel and materials and methods of manufacturer of concrete shall conform to the provisions of IS 2911 (Part 1/Sec 2).

8 WORKMANSHIP

Workmanship shall conform to IS 2911 (Part 1/Sec 2). Control of piling installation, concrete operations, method of placing concrete, convenience of installation, concrete above cut off level, cause and remedies for defective piles, recording of piling data shall conform to the provisions of IS 2911 (Part 1/Sec 2). In addition to the above, after ensuring cleaning of pile bore including socket as specified concreting shall be done immediately and shall be uninterrupted.

9 LOAD TEST

9.1 To confirm the estimated load capacities in compression, lateral and in pullout modes, pile load test shall be conducted on initial pile. The number of test, test procedure, method of test shall be similar to the provision of IS 2911 (Part 4). Test on working pile shall also be carried out. The interpretation of results shall be made by competent geotechnical engineer as given in the following clauses.

9.2 Vertical Load Test

9.2.1 The initial test pile may be tested up to two-and-a-half times the estimated safe load or up to failure load whichever occurs earlier.

9.2.2 The safe load on single pile shall be the least of the following:

- a) Fifty percent of the load at 12 mm settlement unless otherwise required in a given case on the basis of performance requirement.
- b) One third of the ultimate failure load.

9.2.3 Routine load test shall be carried out for a test load of at least one-and-a-half times the working load, the maximum settlement of test loading in position shall not exceed 8 mm.

9.3 Lateral Load

9.3.1 The initial test pile may be tested up to two-and-a-half times the estimated safe load or up to failure load whichever occurs earlier.

9.3.2 For piles embedded in rock [Fig. 5 (b) and 5 (c)], the safe lateral load should be least of the following:

- a) Fifty percent of the final load at which the total displacement increases to 8 mm.
- b) Final load at which the total displacement corresponds to 4 mm.
- c) Load corresponding to any other displacement.

9.3.3 Routine load test shall be carried out for a test load of at least one-and-a-half times the working load, the maximum deflection of test loading in position shall not exceed 4 mm.

9.3.4 For condition of Fig. 5(a), the provisions of IS 2911 (Part 4) will be applicable.

9.4 Pullout Load

9.4.1 The initial test may be tested up to two-and-a-half times the estimated safe load or up to failure whichever occurs earlier.

9.4.2 The safe load shall be taken as the least of the following:

- a) Fifty percent of the load at which the total displacement is 12 mm or the load corresponding to a specified permissible uplift.
- b) Forty percent of the load at which the load displacement curve shows a clear break.

ANNEX A

(Foreword)

COMMITTEE COMPOSITION

Rock Mechanics Sectional Committee, CED 48

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PROF P. K. JAIN	University of Roorkee, Roorkee
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