IS 2911 (Part 4) : 2013

भारतीय मानक

पाइल नींव की डिज़ाइन और निर्माण — रीति संहिता

भाग 4 पाइलों का भार परीक्षण

(दूसरा पुनरीक्षण)

Indian Standard

DESIGN AND CONSTRUCTION OF PILE FOUNDATIONS — CODE OF PRACTICE

PART 4 LOAD TEST ON PILES

(Second Revision)

ICS 91.100.30:93.020

B U R E A U O F I N D I A N S T A N D A R D S
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Soil and Foundation Engineering Sectional Committee, CED 43

FOREWORD

This Indian Standard (Part 4) (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.

Pile load test is the most direct method for determining the safe loads on piles including its structural capacity with respect to soil/rock in which it is installed. It is considered more reliable on account of its being *in-situ* test than the capacities computed by other methods, such as static formula, dynamic formulae and penetration test data. There are widely varying practices followed for load tests on piles. Particularly, the difficulties regarding the establishment of an acceptable criterion, for determining the ultimate and safe bearing capacity of piles, and predicting the pile group behaviour from the test data obtained from individual load test on single piles cannot be under estimated as the factors affecting are many. However, an attempt is made to bring out a unified approach to the various aspects of load test on piles.

This standard (Part 4) was first published in 1979 to cover load test on piles. The other parts of this standard are as follows:

(Part 1) Concrete piles
(Part 2) Timber piles
(Part 3) Under-reamed piles

The standard was first revised in 1985 to give more details in regard to the rate of loading and unloading and the details of the situations when the different types of tests are conducted. Later Amendment No. 1 to the standard was issued in May 1989 modifying the test load for routine test of piles.

It has now been felt that the provisions regarding the load test 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 this revision following major modifications have been incorporated:

a) Definitions of various terms have been modified as per the prevailing engineering practice;
b) The frequency for initial test has been modified;
c) The test load for initial test pile has been added; and
d) In case of both vertical load test and pull-out test, separate criteria for determining safe load of piles have been specified on the basis of diameter of piles.

For rock socketed piles and for piles through rock, assessment of safe load for different mode of loadings shall conform to IS 14593 : 1998 ‘Design and construction of bored cast *in-situ* piles founded on rocks — Guidelines’.

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

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 4 LOAD TEST ON PILES

(Second Revision)

1 SCOPE

1.1 This standard (Part 4) covers the load test on all types of piles covered in IS 2911 (Part 1/Sec 1), IS 2911 (Part 1/Sec 2), IS 2911 (Part 1/Sec 3), IS 2911 (Part 1/ Sec 4), IS 2911(Part 2) and IS 2911 (Part 3) and provides guidelines for determination of safe load based on the following types of loadings:

a) Vertical load test (compression),
b) Lateral load test, and
c) Pull-out test.

1.1.1 High strain dynamic test, statnamic test and embedded load cell method are beyond the scope of this standard.

1.2 Load tests under vibratory loads, moments and other forces and sequence of loading under special circumstances like yield load capacity of buckling piles are not covered in this standard.

2 REFERENCES

The standards listed below 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 indicated below.

IS No.	*Title*
1904 : 1986	Code of practice for design and construction of foundations in soils — General requirements (*third revision*)
2911	Design and construction of pile foundations — Code of practice:
(Part 1)	Concrete piles,
(Sec 1) : 2010	Driven cast *in-situ* concrete piles (*second revision*)
(Sec 2) : 2010	Bored cast *in-situ* concrete piles (*second revision*)
(Sec 3) : 2010	Driven precast concrete piles (*second revision*)
(Sec 4) : 2010	Precast concrete piles in prebored holes (*first revision*)
2911	Code of practice for design and construction of pile foundations:
(Part 2) : 1980	Timber piles (*first revision*)
(Part 3) : 1980	Under reamed piles (*first revision*)

3 TERMINOLOGY

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

3.1 Cut-Off Level — It is the level where a pile is cut-off in order to make structural connection to the pile caps or beams or any other structural components at that level.

3.2 Datum Bar — A rigid bar placed on immovable supports.

3.3 Total 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.

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

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

3.6 Group Test — A minimum of three piles shall be considered as group for the purpose of testing.

3.7 Initial Load Test — A test intended to be conducted on initial test pile at the initial stage of the project to determine the load carrying capacity of the pile by loading either to its ultimate load or to two and half times the estimated safe load whichever occur earlier.

NOTE — In case of sites where large negative drag is anticipated and piles with deep cut-off levels, test load shall be selected by analytical approach. Wherever applicable, estimated negative drag shall be added to the test load while testing the initial test pile for initial load test.

3.8 Initial Test Pile — One or more piles, which are not working piles, may be installed to assess the load carrying capacity of a pile.

3.9 Kentledge — Dead-weight used for applying a test load on piles.

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

3.11 Routine Test — It is carried out on a working pile with a view to check whether pile is capable of taking the working load assigned to it without exceeding permissible settlement.

3.12 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.

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

3.14 Working Load/Design Load — The load assigned to a pile as per design.

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

3.16 Constant Rate of Penetration (CRP) — In this method, test pile is made to penetrate the soil at a constant speed while the force applied at the top of the pile to maintain the rate of penetration is continuously measured. As a result of the pile movement the soil is progressively stressed until it fails in shear; when that occurs the ultimate load of the pile is reached.

3.17 Cyclic Load Test — It is carried out on initial test piles to determine contribution from skin friction and point bearing load by loading and unloading in cycle.

4 NECESSARY INFORMATION

The following information is necessary for pile(s) on which test is proposed:

a) Pile type including material and reinforcement details, group of piles, if any;
b) Method of driving/installation with record including date of casting, date of testing, formation level, cut off level as per relevant pile data sheets given in IS 2911 (Part 1/Sec 1 to 4);
c) Pile depth(s) and details of cross-section(s);
d) Type of test desired;
e) Layout of the pile(s) — Space available around and position in the group for single pile test;
f) Depth of water table and sub strata details with applicable test results;
g) Back up calculations for arriving the safe load and ultimate load capacity;
h) Availability and provision of type of piles or anchors or kentledge for reaction;
j) Nature of loading/loading plan with a particularly mention of pile(s) which may be free standing when scour is expected;
k) Permissible load considered in design; and
m) Any other information concerning planning and conducting the tests including the relevant past experience concerning similar test(s).

5 TYPES OF TESTS

There are two types of tests, namely, initial and routine test for each type (mode) of loading (that is, vertical, lateral and pull-out).

5.1 Initial Test

This test is required for one or more of the following purposes:

a) Determination of ultimate load capacity and arrival at safe load by application of factor of safety,
b) To provide guidelines for setting up the limits of acceptance for routine tests,
c) To get an idea of suitability of piling system, and
d) To have a check on calculated load by dynamic or static approaches.

5.1.1 The number of initial tests may be selected as given below depending upon the nature of sub-strata, number of piles and past experience at the site.

a) For small size projects (for piles less than 1 000 numbers), a minimum of two tests.
b) For large size projects (for piles more than 1 000 numbers), a minimum of two tests for first 1 000 piles and additional one test for every additional 1 000 piles and part thereof.

The frequency of testing stipulated above is applicable for each diameter of pile and rated capacity of pile in each type (mode) of loading. The number of tests may be increased/decreased depending upon whether the strata is erratic/uniform, subjected to a minimum of two tests.

5.1.2 The test load provision in the initial load test shall not be less than the estimated safe load multiplied by the minimum factor of safety of 2.5.

5.1.3 Initial test piles should be installed by the same technique, same type of equipment as that proposed

for working piles. Separate test piles shall be installed for different type (mode) of loadings (namely, vertical, lateral and pull-out). Initial pile load tests shall preferably be carried out prior to execution of piling job.

5.2 Routine Test

This test is required for one or more of the following purposes:

a) Checking the safe load as determined from static analysis [*see* IS 2911 (Part 1/Sec 1 to 4), IS 2911 (Part 2) and IS 2911 (Part 3)];
b) Detection of any unusual performance contrary to the findings of the initial test, if already done; and
c) Workmanship.

The number of tests shall be 0.5 percent of the total number of piles, subject to a minimum of one (1) test. The number of tests may be increased up to 2 percent in particular cases depending upon the nature, type of structure and sub-strata condition.

5.2.1 The piles to be tested for routine tests may preferably be selected on the basis of the following:

a) Abnormal variation in concrete consumption.
b) Sudden drop in concrete level during construction of piles.
c) Problems encountered during boring and tremie operation.
d) Significant variation in depth of pile with respect to other adjoining piles and boring record.
e) Anomalies observed during the driving operation in case of driven piles.
f) Piles under sensitive locations of structures.
g) Any doubt arising from non destructive test results.

NOTES

1 Number of tests mentioned in **5.1.1** (a), **5.1.1** (b) and **5.2** are applicable separately for each type (mode) of loading (that is, vertical, lateral and pull-out), subject to design requirements.

2 Number of tests mentioned in **5.1.1** (a), **5.1.1** (b) and **5.2** are also applicable separately for each diameter of pile and rated capacity of pile.

6 GENERAL REQUIREMENTS APPLICABLE TO ALL TYPES OF TESTS

6.1 Pile test may be carried out on a single pile or a group of piles as required. In case of pile groups, caps shall be provided such that the required conditions of actual use are fulfilled. Pile cap can also be provided for single pile to accommodate load testing jacks, etc.

6.2 Generally the load application and deflection measurement should be made at the pile top. Datum bars should rest on firm ground.

6.3 In particular cases where upper part of pile is likely to be exposed later on due to scour, dredging, liquefaction or otherwise then capacity contributed by that portion of the pile during load test shall be duly accounted for or simulated by provision of larger diameter casing around the pile up to scour depth, dredge level or liquefiable depth. The pile groups in these conditions shall be tested without their cap resting on the ground.

6.4 The test should be carried out at cut-off level wherever practicable, otherwise suitable allowance shall be made in the interpretation of the test results/ test load, if the test is not carried out at cut-off level.

6.4.1 Alternatively, in case of vertical load test conducted at a level higher than cut-off level or in case the soil parameters over the depth between the ground level and cut-off level is ambiguous, an annular space shall be created to remove the effect of skin friction above cut-off level by providing an outer casing of suitable diameter larger than the pile diameter. However, effect of over burden pressure may be taken into account for analysis of vertical pile load test.

6.4.2 Whereas, in case of lateral load test, test load shall be applied at cut-off level; otherwise lateral displacement at cut-off level shall be determined based on measurements done at different level. However, the acceptance criteria of deflection shall be at cut-off level or scour level or dredge level or liquefiable depth, as the case may be.

6.5 Load cells may be used for measuring load.

6.6 In case of off-shore and marine piles, simulated load test may be conducted on-shore.

6.7 Plotting of load displacement curve shall be done on rational basis by selecting suitable scale for load and settlement axis.

7 VERTICAL LOAD TEST (COMPRESSION)

7.1 General

In this type of test, compression (vertical downward) load is applied to the pile top by means of a hydraulic jack against rolled steel joist or suitable load frame with adequate kentledge and the settlement is recorded by suitably positioned dial gauges/LVDTs. Maintained load method as given in **7.2** should be used for determination of safe load. However, for specific requirements cyclic and CRP methods, which are alternate methods, may be used as mentioned in **7.3** and **7.4**. The general requirements applicable for these

three methods are given from **7.1.1** to **7.1.6**, as may be applicable.

7.1.1 *Preparation of Pile Head*

The pile head should be chipped off to natural horizontal plane till sound concrete is met. The projecting reinforcement should be cut-off or bent suitably and the top finished smooth and level with cement plaster or similar synthetic material where required. A bearing plate with a mark at the centre should be placed on the head of the pile for the jacks to rest. Finished pile head level may be measured prior and after the load test by suitable survey instrument.

7.1.2 *Application of Load* (*not Applicable to CRP Method*)

The test should be carried out by applying a series of vertical downward incremental load each increment being of about 20 percent of safe load on the pile. For testing of raker piles it is essential that load is applied along the axis of the pile.

7.1.3 *Reaction*

The reaction may be obtained from the following:

a) Kentledge placed on a platform supported clear of the test pile. In case of load test below under-pinned structure, the existing structure, if having adequate weight and suitable construction may serve as kentledge. The centre of gravity of the kentledge should coincide with the axis of the pile and the load applied through the jack should also be coaxial with this pile. If multiple jacks are to be used, these shall be arranged in parallel and connected to a single hydraulic pump and pressure gauge.

b) Anchor piles with centre-to-centre distance from the test pile not less than 3 times the test pile shaft diameter subject to minimum of 2 m. If the anchor piles are permanent working piles, it should be ensured that their residual uplift is within limits. Care should be exercised to ensure that the datum bar supports are not affected by heaving up of the soil.

c) Rock anchors with distance from the nearest edge of the piles at rock level being 2 times the test pile shaft diameter or 1.5 m, whichever is greater.

NOTE — In case wedge failure governs in the pile anchors/ rock anchors, the pile distance should be suitably maintained to avoid interference of the wedge with the test pile.

7.1.3.1 The reaction to be made available for the test should be 25 percent more than the final test load proposed to be applied.

7.1.4 *Settlement* (*not Applicable to CRP Method*)

7.1.4.1 Settlement shall be recorded with minimum 4 dial gauges of 0.01 mm sensitivity for both single pile and groups. The dial gauges shall be placed symmetrically and at equal distances from the pile(s) and normally held by datum bars resting on immovable supports at a distance of 3 *D* (subject to minimum of 2.0 m) from the edge of the piles, where *D* is the pile stem diameter of circular piles or diameter of the circumscribing circle in the case of square or non-circular piles.

7.1.4.2 From safety point of view and to minimize the disturbance to datum bars, it is preferable to use remotely controlled linear variable differential transducers (LVDT) with a digital read out for recording the settlement. The LVDTs shall be calibrated.

7.1.4.3 Finished pile head level may be measured prior and after the load test by suitable survey instrument.

7.1.5 The safe vertical load on single pile for the initial test should be least of the following:

a) *For piles up to and including 600 mm diameter:*
   1) Two-thirds of the final load at which the total displacement attains a value of 12 mm unless otherwise required in a given case on the basis of nature and type of structure in which case, the safe load should be corresponding to the stated total displacement permissible; and
   2) Fifty percent of the final load at which the total displacement equal to 10 percent of the pile diameter in case of uniform diameter piles and 7.5 percent of bulb diameter in case of under-reamed piles.

b) *For piles more than 600 mm diameter:*
   1) Two-thirds of the final load at which the total displacement attains a value of 18 mm or maximum of 2 percent pile diameter whichever is less unless otherwise required in a given case on the basis of nature and type of structure in which case, the safe load should be corresponding to the stated total displacement permissible; and
   2) 50 percent of the final load at which the total displacement equal to 10 percent of the pile diameter in case of uniform diameter piles and 7.5 percent of bulb diameter in case of under-reamed piles.

7.1.5.1 However, routine test shall be carried for a test load of at least 1.5 times the working load; the maximum

settlement at the test load being not greater than 12 mm for piles diameter up to and including 600 mm and 18 mm or 2 percent of pile diameter whichever is less for piles of diameter more than 600 mm.

7.1.6 The safe vertical load on groups of piles for initial test shall be least of the following:

a) Final load at which the total displacement attains a value of 25 mm unless otherwise required in a given case on the basis of nature and type of structure; and
b) Two-thirds of the final load at which the total displacement attains a value of 40 mm.

7.1.6.1 However, routine test on group of piles shall be carried for a test load of at least equal to the working load; the maximum settlement of the test loading in position being not exceeding 25 mm.

NOTE — For differential settlements, IS 1904 shall be referred.

7.2 Maintained Load Method

This is applicable for both initial and routine test. In this method, each stage of loading shall be maintained till the rate of movement of the pile top is not more than 0.2 mm/h or until 2 h have elapsed, whichever is earlier subject to a minimum of 1 h. The maximum test load shall be maintained for 24 h.

7.2.1 *Duration of Vertical Loading*

7.2.1.1 Vertical loading on single pile shall be continued till one of the following takes place:

a) *In case of initial load test:*
   1) Applied load reaches 2.5 times the safe estimated load; or
   2) Maximum settlement of pile exceeds a value of 10 percent of pile diameter in case of uniform diameter piles and 7.5 percent of bulb diameter in case of under-reamed piles.
b) *In case of routine load test:*
   1) Applied load reaches 1.5 times the working load; or
   2) Maximum settlement of pile exceeds a value of 12 mm for piles diameter up to and including 600 mm and 18 mm or maximum of 2 percent of pile diameter whichever is less for piles of diameter more than 600 mm.

7.2.1.2 Vertical loading on group of piles shall be continued till one of the following takes place:

a) *In case of initial load test*:
   1) Applied load reaches 2.5 times the safe estimated load; or
   2) Maximum settlement of pile exceeds a value of 40 mm.
b) *In case of routine load test*:
   1) Applied load reaches the working load; or
   2) Maximum settlement of pile exceeds a value of 25 mm.

7.3 Cyclic Method

This method is used in case of initial test to find out separately skin friction and point bearing load on single piles of uniform diameter. The procedure as given in Annex A or by suitable instrumentation may be used.

7.4 CRP Method

This method which is used for initial test is generally considered to be more suitable for determining ultimate load capacity than by the maintained load test but the load/deflection characteristics are quite different from those of the maintained load test and cannot be used to predict settlement of the pile under working load conditions. This method should not be included in routine test. The procedure is given in Annex B.

8 LATERAL LOAD TEST ON PILES

8.1 The test may be carried out by introducing a hydraulic jack with gauge between two piles or pile groups under test or the reaction may be suitably obtained otherwise. If it is conducted by jack located between two piles or groups, the full load imposed by the jack shall be taken as the lateral resistance of each pile or group. The loading should be applied in increments of about 20 percent of the estimated safe lateral load.

8.2 The next increment should be applied after the rate of displacement is less than or equal to 0.1 mm per 30 min subject to minimum of 30 min.

8.3 In case of unapproachable cut-off levels, displacements shall be read by using at least two dial gauges or LVDTs of 0.01 mm sensitivity (*see* Fig. 1) spaced at 30 cm and kept horizontally one above the other on the test pile and the displacement shall be interpolated at cut-off level from similar triangles. However, for approachable cut-off levels, one dial gauge or LVDT placed diametrically opposite to the jack shall directly measure the displacement. Where, it is not possible to locate one of the dial gauges in the line of the jack axes, there two dial gauges may be kept at a distance of 30 cm at a suitable height and the displacement interpolated at load point from similar triangles.

NOTES

1 One of the methods for keeping dial gauge on pile surface is

to chip off uneven concrete on the side of the pile and to fix a glass piece of 20 to 30 mm square. The dial gauges tips shall rest on the central portion of the glass plate.

2 In case the hydraulic jack is placed in between test pile and reaction pile, one dial gauge or LVDT shall be suitably placed on reaction pile to measure the displacement of reaction pile.

8.4 The safe lateral load on the pile for initial test, for both free head and fixed head shall be taken as the least of the following:

a) Fifty percent of the final load at which the total displacement increases to 12 mm;
b) Final load at which the total displacement corresponds to 5 mm; and
c) Load corresponding to any other specified displacement as per performance or design requirements.

8.4.1 Routine lateral load test shall be carried out for a test load equal to the working load; the maximum deflection of test loading in position shall not exceed 5 mm.

NOTES

1 The above displacement is at the cut-off level of on-shore piles and at the scour line/mud line of off-shore piles, as the case may be.

2 In actual practice the piles are partially fixed or fixed. Accordingly, to derive the advantage of increased lateral load due to partial fixity/fixity condition, it is desirable to carryout (a) Lateral load test on group of piles with pile cap; or (b) Single pile may be tested for lateral load under sustained vertical load.

3 Suitable analytical method may be considered to interpret load test results carried at free head condition to fixed head condition.

9 PULL-OUT TEST ON PILES

9.1 Uplift force may preferably be applied by means of hydraulic jack(s) with gauge using a suitable pull-out set up. Pile top shall preferably be at cut-off level. Displacement measurement shall be made at pile top with at least two dial gauges placed at diametric opposite ends of pile.

NOTE — One of the methods for pull-out tests that may be used is where hydraulic jack is made to rest on rolled steel joist(s) resting on two supports on the ground. The jack reacts against a frame attached to the top of the test pile such that when the jack is operated, the pile gets pulled up and the reaction is transferred to the ground through the supports which are at least 2.5 *D* away from the test pile periphery (where *D* is pile stem diameter of circular piles or diameter of the circumscribing circle in the case of square piles). The framework can be attached to the pile top with the reinforcement bars which may be threaded or to which threaded bolts may be welded. As an alternative it is sometimes preferable to use a central rod designed to take pile load and embedded centrally in the pile to a length equal to the bond length load required. It will have threads at top for fixing it to the framework. For larger loads the number of rods may have to be more and depending on the set-up these may be put in a line or in any other symmetrical pattern. For routine tests, the framework is normally attached to the reinforcing bars but a central rod may also be used in case the upper portion of the pile is required to be built up.

9.2 The test pile shall have adequate steel to withstand pulling. In some cases, in order to allow for neck tension in a pull-out test, it may be necessary to provide additional reinforcement in the piles to be tested.

9.3 The pull-out load increments and consequent displacement readings shall be read as in the case of vertical load test.

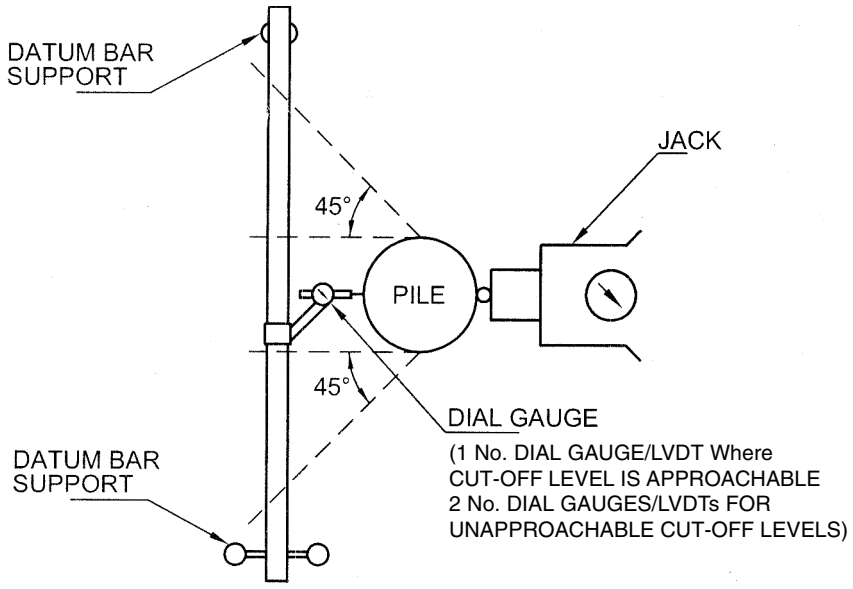


FIG. 1 POSITION OF DATUM BAR SUPPORTS

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

a) *For piles up to and including 600 mm diameter:*
   1) Two-thirds of the load at which the total displacement is 12 mm or the load corresponding to a specified permissible uplift; and
   2) Half of the load at which the load displacement curve shows a clear break (downward trend).

b) *For piles more than 600 mm diameter:*
   1) Two-thirds of the load at which the total displacement is 18 mm or maximum of 2 percent of pile diameter whichever is less or the load corresponding to a specified permissible uplift; and
   2) Half of the load at which the load displacement curve shows a clear break (downward trend).

9.5 The initial test shall be carried out up to 2.5 times the estimated safe uplift load or until the load displacement curve shows a clear break (downward trend).

9.6 Routine test shall be carried out to 1.5 times the working load or 12 mm total displacement for piles diameter up to and including 600 mm and 18 mm or maximum of 2 percent of pile diameter, whichever is less for piles of diameter more than 600 mm, whichever is earlier.

9.7 Pull-out test shall be carried out preferably on initial test piles. In case it is found necessary to conduct pull out test on working piles the following considerations shall be made:

a) To check that the pile shaft is designed to cater for such uplift load; and
b) To limit the displacement within elastic deformation of pile beyond which the test should be discontinued.

10 RECORDING OF DATA AND PRESENTATION

10.1 The pile test data essentially contains three variables, namely, time, load and displacement. These are to be recorded sequentially for the tests under consideration and recorded in a suitable tabular form along with the information about the pile.

10.2 The data may be suitably presented by curves drawn between the variables and safe loads shown on the graphs. Load displacement curve shall be an essential part of presentation.

ANNEX A
(*Clause* 7.3)
CYCLIC LOAD TEST METHOD

A-1 METHOD

Alternate loading and unloading shall be carried out at each stage as in **7.1.2** and each loading stage shall be maintained as in **7.2** and each unloading stage shall be maintained for at least 15 min and the subsequent elastic rebound in the pile should be measured accurately by dial gauges or LVDTs as in **7.1.4**.

A-2 ANALYSIS OF RESULTS FOR FRICTIONAL RESISTANCE

A-2.1 Graphical Method

A-2.1.1 The analysis shall be done as explained in Fig. 2.

A-2.1.2 Assuming that there is no compression in the pile, plot a graph relating total elastic recovery and load at the pile top.

A-2.1.3 Draw a straight line through the origin and parallel to the straight portion of curve I to divide the load into two parts and thereby obtain approximate values of point resistance and skin friction.

A-2.1.4 From the approximate value of skin friction and knowing the loads on top of pile, compute the elastic compression of the pile corresponding to these loads, by the following formula:

$$\Delta = \frac{\left(T - \frac{F}{2}\right)L}{AE}$$

where

Δ = elastic compression of pile, in cm;
T = load on pile top, in kgf;
F = frictional resistance, in kgf;
L = length of the pile, in cm;

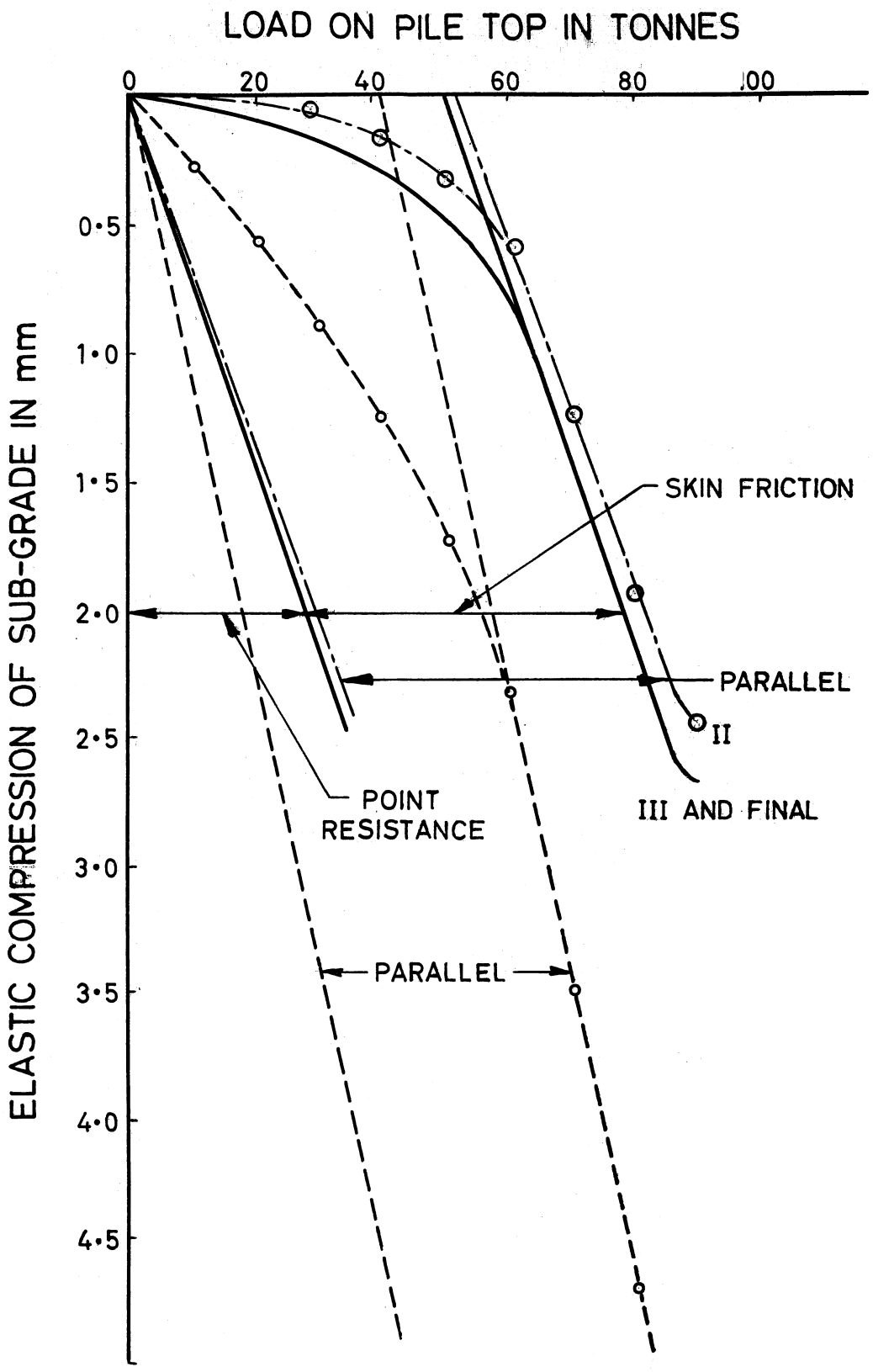


FIG. 2 ANALYSIS OF CYCLIC LOAD TEST DATA FOR SEPARATION OF SKIN FRICTION AND POINT RESISTANCE

A = cross-sectional area of the pile, in cm^2; and

E = modulus of elasticity of the pile material, in kgf/cm^2.

(The value should normally be measured from an exposed portion of pile stem by means of compressometer during the load test itself.)

A-2.1.5 Obtain values of the elastic compression of the sub-grade by subtracting the elastic compression of the pile from the total elastic recovery of pile and plot the graph relating these new values to the corresponding loads on pile top. When elastic compression of the subgrade works out negative, the negative value shall be ignored until the value is positive.

A-2.1.6 Repeat the procedures given in **A-2.1.3** to obtain new values of skin friction.

A-2.1.7 The process of further approximations covered in **A-2.1.6** may be repeated further to any desired extent, but usually the third curve would give sufficiently accurate values for skin friction for practical purposes.

A-2.2 Analytical Method

A-2.2.1 From straight line portion of curve (*see* Fig. 2) calculate the value of constant from the equation (1).

$$m = \frac{\Delta_s - \left(\frac{\Delta_T}{AE}\right)L}{\Delta_T} \quad \ldots (1)$$

where

m = constant;

Δ_s = change in total elastic settlement of pile top ($S_b - S_a$), in cm;

S_b = elastic settlement at any point 'b' on the straight line;

S_a = elastic settlement at any point 'a' on the straight line;

Δ_T = change in applied load ($T_b - T_a$), in kgf;

T_b = applied load at the point 'b';

T_a = applied load at the point 'a';

L = length of pile, in cm;

A = cross-sectional area of pile, in cm^2;

E = elastic modulus of the material of the pile, in kgf/cm^2; and

T = load on pile top, in kgf.

A-2.2.2 Calculate the corrected settlement for different load increment by equation (2).

$$S = mT \quad \ldots (2)$$

where

S = corrected settlement, in cm; and

T = total load on pile top, in kgf.

A-2.2.3 Knowing value of m and S compute skin friction and point bearing by solving simultaneous equations (3) and (4).

$$T = P + F \quad \ldots(3)$$

$$S = mP + \frac{\left(T - \frac{F}{2}\right)L}{AE} \quad \ldots(4)$$

where

P = point bearing, in kgf; and

F = skin friction, in kgf.

ANNEX B
(*Clause* 7.4)
CRP TEST

B-1 PROCEDURE

B-1.1 The load shall be measured by a load cell having sensitivity of at least 1 percent of the desired test load. If a pressure gauge is used, the same should be used with a loading ram to give the desired sensitivity. The penetration (deflection) should be measured by means of dial gauges/LVDTs held by a datum bar resting on immovable supports at a distance of at least 3 D (subject to a minimum of 1.5 m) away from the test pile edge where D is defined in **7.1.5**. One of the dial gauges/LVDTs will be selected for conducting the test. With continuous application of pressure on the pile top by operating of the jack, a person watches the rate of settlement of the dial gauge/LVDT against a stop watch held in his hand and directs the pump operator to pump faster or slower or at the same rate as needed to maintain the prescribed rate of settlement say at every 0.25 mm settlement, he gives an indication to take readings. Immediately, other persons record the pressure gauge readings and other dial gauge/LVDT

readings. The pump supplying the jack may be hand or mechanically operated. For force up to 200 tonne hand pumping is convenient. If a mechanical pump is used, it should, for preference, have an 'infinite variable' delivery, controlled either by a bleed valve or a variable speed drive.

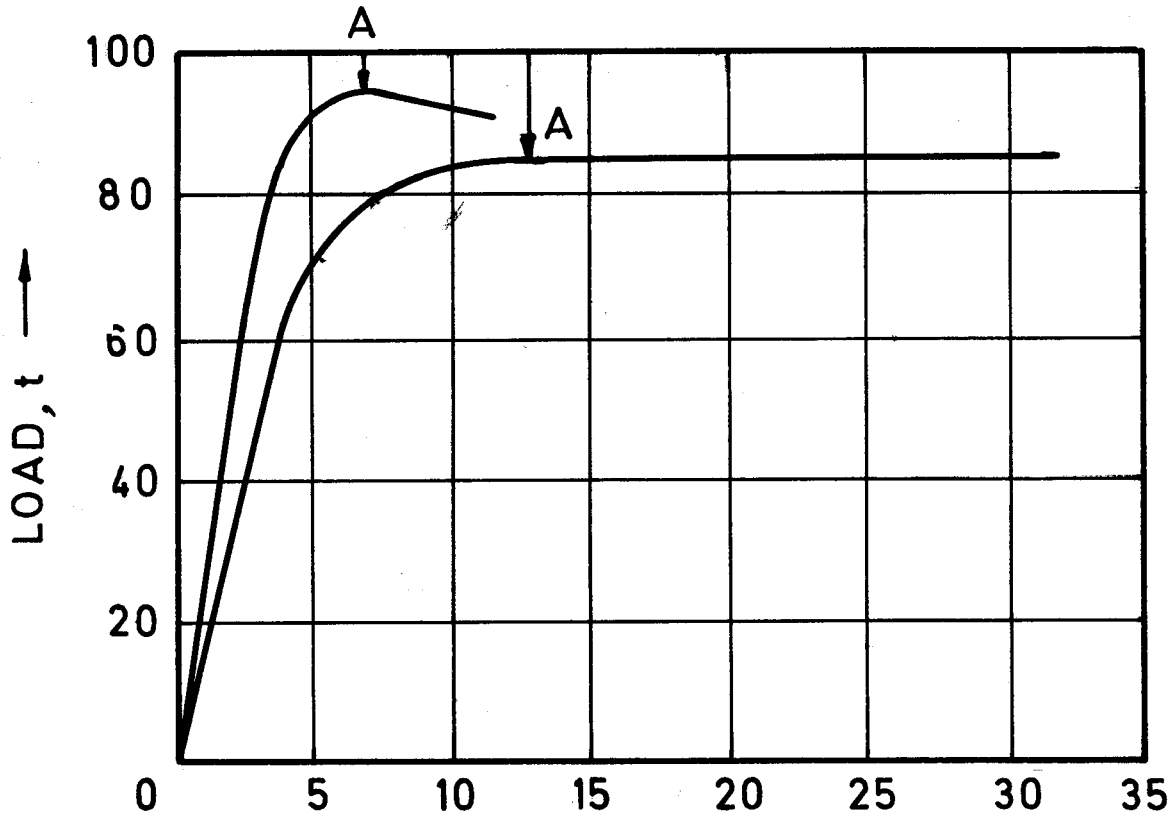
B-1.2 The jack should be operated to cause the pile to penetrate at uniform rate which may be controlled by checking the time taken for small increments of penetration and adjusting the pumping rate accordingly. Readings of time, penetration and load should be taken at sufficiently close intervals to give adequate control of the rate of penetration. A rate of penetration of about 0.75 mm per minute is suitable for predominantly friction piles. For pre-dominantly end-bearing piles in sand or gravel, rate of penetration of 1.5 mm/min may be used. The rate of penetration, if steady, may be half or twice these values without significantly affecting the results. The test should be carried out for the penetration more than 10 percent of the diameter of the pile base.

B-1.3 As the test proceeds a curve between load and penetration should be drawn to determine when the ultimate load capacity has been reached.

B-2 ULTIMATE LOAD CAPACITY

B-2.1 The curve of load *versus* penetration in the case of a predominantly friction pile will represent either a peak and the subsequent downward trend, or a peak and then almost a straight line, as shown in Fig. 3A. The peak load marked *A* in Fig. 3A will represent the ultimate load capacity of pile.

B-2.2 In the case of predominantly end-bearing pile the curve will be similar to that shown in Fig. 3B and the ultimate load capacity may be taken as the load corresponding to the penetration equal to 10 percent of the diameter of the pile base.



3A PREDOMINANTLY FRICTION PILES

FIG. 3 LOAD *versus* PENETRATION CURVE IN CRP TEST — (*Continued*)

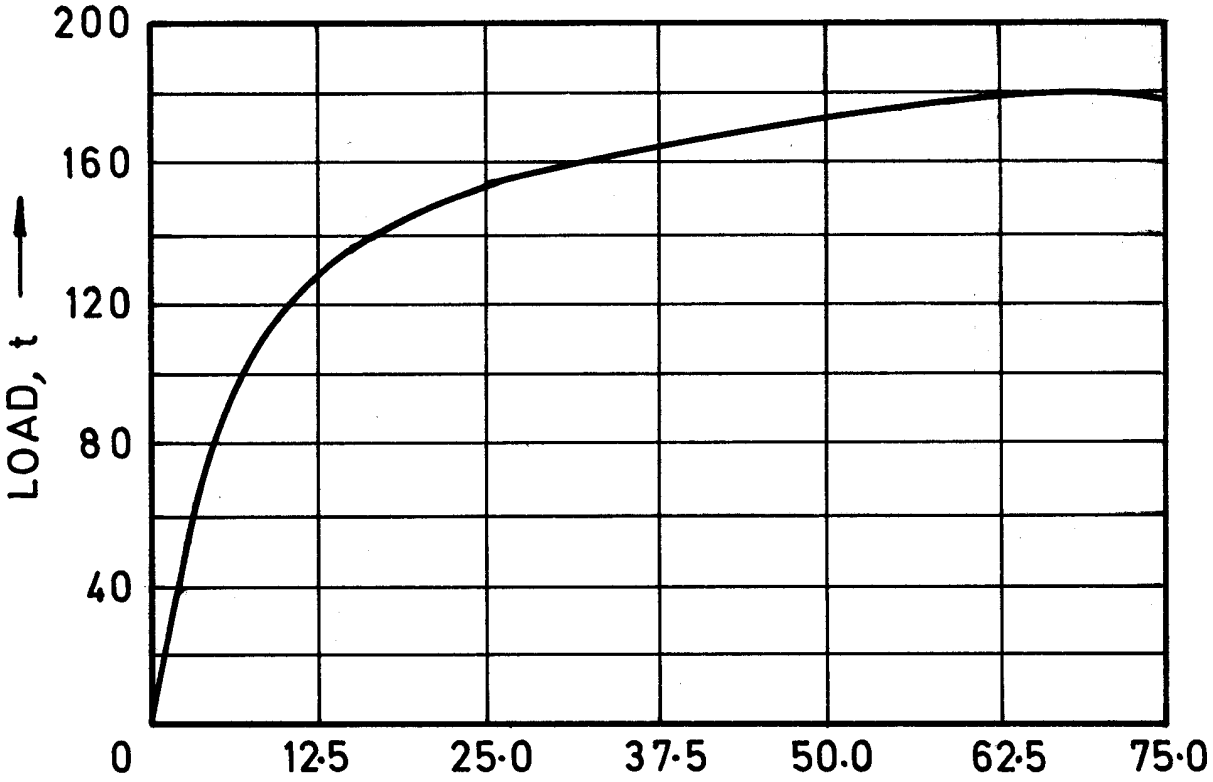


FIG. 3 LOAD *versus* PENETRATION CURVE IN CRP TEST