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Indian Standard

IN-SITU PERMEABILITY TEST

PART 2 TESTS IN BEDROCK

(Second Revision)

ICS 93.020

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

June 2006
FOREWORD

This Indian Standard (Part 2) (Second Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Geological Investigations and Subsurface Exploration Sectional Committee had been approved by the Water Resources Division Council.

Exploratory drilling is an important feature of subsurface exploration for foundation studies at the river valley project sites. The examination of cores from the drill holes gives a general idea of the physical condition of the rock formations existing at and below the foundation. Water percolation tests, if performed in the holes, are of significance in interpreting the drilling data and in supplementing the information obtained by visual examination of the cores. The results of the water percolation tests can also be used to determine the permeability of the strata pierced by the drill hole. The value of coefficient of permeability obtained from the test, which is the overall value for the rock mass including loss into cracks, fissures, joints, fault zones, etc, is fairly accurate for most of the civil engineering studies and provides an approximate estimate of the possible leakage that may take place through specific zones of rock in the foundations upon impoundment of the reservoir. The main utility of permeability information is for assessment of foundation status and to decide whether grouting is warranted. Adequate information regarding the extent and pattern of grouting that may be required in the foundation of the contemplated structures and an overall estimate of the groutability of the bedrock zones can also be estimated from the results of these tests. The exploratory hole which is drilled at great cost and expense of time should be made maximum use of and the practice should be to conduct water percolation tests in every hole as the drilling proceeds. Water percolation test performed in the holes gives valuable data for design. The importance of the tests, therefore, cannot be overemphasized for the foundation studies at river valley project sites. This standard has been published in two parts. The other part in the series is:

Part 1 Tests in overburden

In the formulation of this standard due weightage has been given to international coordination among the standards and practices prevailing in different countries in addition to relating it to the practices in this field in the country.

This standard was first published in 1973 and revised in 1985. This revision has been done in view of changes in technology and in field experience. An illustration depicting lugeon patterns for various occurrences, as well as their interpretation, has been incorporated in this version.

In the formulation of this standard it has been assumed that the execution of its provisions is entrusted to appropriately qualified and experienced people, for whose guidance it has been prepared.

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

IN-SITU PERMEABILITY TEST

PART 2 TESTS IN BEDROCK
(Second Revision)

1 SCOPE

This standard (Part 2) lays down recommendations for performing the pumping in permeability test, in which water is pumped under pressure into the test section, of bedrock through drill holes, wherein the sides of the hole do not collapse during the period of exploration and testing. The single and double packer methods are both covered. This standard describes the tests normally conducted in exploratory holes.

2 REFERENCES

The following standards 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 these standards are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

<table>
<thead>
<tr>
<th>IS No.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>4464:1985</td>
<td>Code of practice for presentation of drilling information and core description in foundation investigation (first revision)</td>
</tr>
<tr>
<td>6066:1994</td>
<td>Recommendations for pressure grouting of rock foundations in river valley projects (second revision)</td>
</tr>
<tr>
<td>6935:1973</td>
<td>Method for determination of water level in a bore hole</td>
</tr>
</tbody>
</table>

3 TERMINOLOGY

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

3.1 Single Packer Method — Method in which one packer is used in the drill hole. In this case, the test section is between the bottom of the bore hole and the packer as shown in Fig. 1A.

3.2 Double Packer Method — Method in which two packers are used in the drill hole. In this case, the test section is between the two packers as shown in Fig. 1B.

Fig. 1 Permeability Test Both in Single and Double Packer Method
4 EQUIPMENT

4.0 The equipment given in 4.1 to 4.8 is required for water percolation tests in the drill holes.

4.1 Drilling Equipment — A drill rig and/or accessories for lowering and driving the casing pipe.

4.2 Water Meter — Capable of reading up to 0.5 l in accuracy. The water meter should be periodically checked and calibrated.

4.3 Pressure Gauge — Pressure gauge of range 4 kg/cm², 10 kg/cm² or 16 kg/cm² should be chosen depending on the maximum pressure desired for testing. This will give suitable least count reading for test accuracy. Where centrifugal pumps are not available and reciprocating pumps have to be used, they should be used with siphon or air dome attachment in order to enable correct measurement of testing pressures.

4.4 Pump — Preferably a centrifugal pump of minimum capacity 500 l/min capable of producing pressure up to 30 kg/cm².

4.5 Water Pipes, Connections and Swivels, Drill Rods, Perforated Rods and Other Fittings— See Note.

NOTE — When drilling is in progress, no additional water pipes, swivel, etc. are necessary. The drill rods and other equipment as used in drilling may be used for conducting percolation tests.

4.6 Packers — Leather cup packers are generally used in rock formations where holes drilled retain their proper size. Mechanical packers are commonly used in moderately hard formations where the holes drilled are up to 20 percent oversize. Pneumatic packers made up of neoprene rubber can be used for all types of formations and are generally preferred for soft rock formations where the holes drilled are more than 20 percent over size.

4.7 Equipment for Measuring Water Level in the Drill Holes — See IS 6935.

NOTE — When drilling is in progress, no additional water pipes, swivel, etc. are necessary. The drill rods and other equipment as used in drilling may be used for conducting percolation tests.

4.8 Stop Watch, capable of measuring capacity up to 1 h and should have least count of 1 s.

5 QUALITY OF WATER TO BE USED FOR THE TEST

The tests described are of the pumping-in type, that is, they are based on measuring the amount of water accepted by the ground through the open bottom of a pipe or through an uncased section of the hole. Unless clear water is used, these tests are invalid and can be grossly misleading. The presence of even small amounts of silt or clay in the water used in the test will result in clogging of the test section and will give permeability results that are too low. Efforts should be made to assure supply of clear water by means of a settling tank or a filter. It is also desirable, where the climatic conditions demand, to raise the temperature of added water higher than ground temperature so as to preclude the creation of air bubbles in the test section that can greatly reduce the acceptance of water.

6 PROCEDURE

6.1 General

The water percolation tests, covered by this standard, should be conducted in uncased and ungrouted sections of the drill holes. The procedure adopted consists of pumping water into the test section and is therefore called 'pumping-in type'. Packers are employed for conducting these tests and depending upon the use of one packer or two packers the method is designated as single or double packer method respectively. Examination of the drill cores and the results of water tests obtained during drilling will usually indicate whether a double packer test in any isolated section or sections of the drill hole is required. In certain formations, it may not be possible to use the packer, or there is a danger of the packer being stuck in the hole. In such cases, a better method would be to grout the earlier stage, extend the bore hole and carry out the test. The tests are based on measuring the amount of water accepted by the test section (of the hole) confined by a packer/packers while water is pumped into it. The layout of equipment for the test is as shown in Fig. 2.

6.1.1 The single packer method as shown in Fig. 1A is used where the full length of the hole cannot stand uncased/ungrouted in soft rocks, such as sand rock (soft sandstone), clay shale or due to highly fractured and sheared nature of the rocks or where it is considered necessary to have permeability values along with drilling (for example where multiple aquifers are present).

Double packer method may be adopted where the rocks are sound and the full length of the hole can stand without casing/grouting, as shown in Fig. 1B. The specific advantage of double packer method is that critical rock zones can be tested by confining them with packers. The disadvantage of the double packer method is that leakage through the lower packer can go unnoticed and lead to over estimation of water loss. Wherever time permits, single packer method would be preferable.
6.1.2 Single Packer Method

The method used for performing the water percolation tests in a section of the drill hole using a single packer is as shown in Fig. 1A. In this method, the hole should be drilled to a particular depth desirable for the test. The core barrel should then be removed and the hole cleaned with water until clear water returns. The packer should be fixed at the desired level above the bottom of the hole and the test performed in accordance with the procedure laid down in 6.3. After performing the test, the entire assembly should be removed. The drilling should then be proceeded with till the next test section has been drilled for performing the test. In this manner the entire depth should be tested alongside with the advancement of drilling.

6.1.3 Double Packer Method

The method used for performing the water percolation tests in a section of the drill hole using a double packer is as shown in Fig. 1B. In this method, the hole should be drilled to the final depth desired and cleaned with water until clear water returns. Two packers connected to the ends of a perforated drill rod of a length equivalent to the test section should be fixed in the drill hole. The bottom of the perforated rod should be plugged before the double packer tests are proceeded with. The test may be done from bottom upwards or from top downwards. However, it is convenient and economical to start the tests from the bottom of the hole and then work upwards.

6.2 To verify the presence of ground water table, the water level in the hole should be depressed either by evacuation with compressed air or bailing out with stand shell. After this operation is completed, if three consecutive readings of the water level taken at 10 min to 15 min intervals are constant, then this water level
may be taken as the ground water level. The time interval may have to be increased to 30 min in less permeable formations (see IS 6935). This measurement is done for determining the hydrostatic pressure in the test zone and this value is used for calculating the permeability of the horizon. If these measurements indicate that there is no water table or piezometric head, this fact should be mentioned in the report.

6.3 The tests are recommended to be performed in 1.5 m to 3 m test sections so that the entire hole is covered, depending upon the geological conditions; as for example in sections passing through a shear zone or a highly jointed zone a lesser length of section should be used (see 7.3). The test length should not, however, be less than 5 times the diameter of the borehole.

6.3.1 Under piezometric conditions, the piezometric head in separate horizons should be ascertained by measurement of water level after installation of packer in the hole.

6.4 Water should then be pumped into the section under pressure. The pressure should be maintained until the readings of water intake at intervals of 5 min show a nearly constant reading of water intake for one particular pressure at the collar. The constant rate of water intake should be noted. It is recommended that the tests be commenced with a low pressure at the collar and increased limited to the availability of suitable rock cover to prevent uplift or till a maximum pressure equivalent to \( H + x \) (where \( H \) is the hydraulic head to which the strata would be subjected to due to the contemplated structure and \( x \) is the loss due to friction) is achieved. Frictional loss may be determined by means of charts as given in Fig. 3A, Fig. 3B and Fig. 3C and added to the test pressure. In order to avoid upheaval of the rock foundation test pressures are generally limited to the following:

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Rock Type</th>
<th>Limit of Test Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Applied to the Test Zone of Rock Load (see Note)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kg/cm²/m</td>
</tr>
<tr>
<td>i)</td>
<td>Unconsolidated or poorly consolidated sedimentary formations</td>
<td>0.115</td>
</tr>
<tr>
<td>ii)</td>
<td>Consolidated horizontally bedded sedimentary formations</td>
<td>0.175</td>
</tr>
<tr>
<td>iii)</td>
<td>Hard igneous and metamorphic rocks</td>
<td>0.230</td>
</tr>
</tbody>
</table>

NOTE — These pressures are applicable for testing in exploratory holes for determining in-situ permeability. For testing to determine the groutability of the formation higher pressures may be needed (see IS 6066).

6.5 Cyclic Test

In special circumstances cyclic tests are performed to evaluate the washability and groutability of joints of rock or their extent. Cyclic tests for assessment of permeability are useful in computing Lugeon values. These tests are started at low pressures, the test pressures being built up to the maximum applicable pressure by increments and decreased in the same order until the original pressure is reached. Generally, for the performance of the cyclic tests four ranges of pressure should be chosen which may be fixed at 25 percent, 50 percent, 75 percent and 100 percent of the pressures selected for the test section based either on
suitable rock cover or maximum equivalent of reservoir head, whichever is applicable (see 6.4).

6.6 In addition to performing the permeability tests at regular intervals of the strata, it is desirable to test critical bedrock zones by confining them along with packers.

7 PRECAUTIONS

7.1 On completion of drilling, the holes should be immediately capped or plugged and protected from entry of dirt, muck, grout or any kind of waste.

7.2 Water level in the drill hole should be recorded before proceeding with the water percolation tests.

7.3 A 1.5 m section is considered suitable for performing the tests. However, the length of the test section should be selected according to the total thickness of the permeable stratum and geological conditions and varied locally to accommodate the packer(s) properly. Short test sections of 1.5 m would be preferred in thin bedded and heterogeneous strata. When the intake of water in the test section is more than that which the pump can deliver, it is advisable to reduce length of the section. Under normal circumstances test sections longer than 3 m are not recommended.

7.4 The hole should be thoroughly flushed with clear water before the tests are commenced. Where core recovery is good (> 70 percent) holes should be flushed with water under pressure, until the wash water is clear. When the recovery is poor (< 70 percent) and the holes are liable to collapse by the disturbance caused by washing, the holes may be cleared by gentle surging (by moving a rubber block up and down the hole) followed by gentle flushing.

FIG. 3 HEAD LOSS IN PIPE AND DRILL RODS
7.5 Drill rods of 32 mm diameter may be used for conducting the permeability tests. It would, however, always be better to use rods of larger diameter, when available, so that friction losses are reduced to the minimum possible.

7.6 The water swivel used in the test should preferably have a uniform inside diameter to minimize loss of head.

7.7 Location of the pressure gauge between the pump and the water meter or the water meter and the swivel may not measure the actual pressure in the test. In order to get a representative figure of the pressure, it is recommended that the gauge be located between the swivel and the packer.

7.8 Unnecessary bends in the pipe line from the pump to the swivel should be avoided.

7.9 The water used for the tests should be clear and free from silt.

7.10 All joints and connections between the water meter and the packer should be water-tight in order that no water loss occurs between the water meter and the test section.

7.11 At the time of permeability test by single packer or double packer, it should be ensured that the packer/packers are not leaking. A leaking packer usually causes the rise of water level in the hole or the water may even start overflowing from the nipple.

8 COMPUTATION OF EQUIVALENT PERMEABILITY FROM PERMEABILITY TESTS DATA

8.1 The coefficient of permeability should be computed using the formulae as given in Fig. 4. The coefficients Cu and Cs in these formulae may be taken from the graphs as given in Fig. 5 and Fig. 6. For water percolation tests conducted above the water table, the position of the base of Zone I should be found from the curve as shown in Fig. 7. The friction loss of head (L) should be calculated or obtained from Fig. 3A, 3B or 3C. This head should be deducted from the combined head due to gravity and that due to applied pressure. Numerical examples illustrating the use of the formulae are given in Annex A.

8.2 When the permeability tests are conducted in hard rock the water intake is generally due to joints and fractures and not due to inter-granular voids. In such cases, the permeability computed from these tests would correspond to that of the joints and fractures and would represent the equivalent permeability of a homogeneous and isotropic material.

8.3 The water loss may also be expressed in Lugeons. A Lugeon is defined as the water loss of 1 litre/min/m of the drill hole under a pressure of 10 atmospheres maintained for 10 min in a drill hole of 46 mm to 76 mm diameter. As it is difficult to build up pressures of 10 atmospheres at depths of less than 30 m to 45 m in hard massive rock without upheaval/deformation, a unit coefficient of water loss (1 litre/min/m per atmosphere) hereinafter designated as a 'deci-Lugeon', may be adopted for direct evaluation of the order of water-tightness of the rock. The Lugeon pattern for various occurrences during testing, their interpretation and percentage occurrences are as shown in Fig. 8.

9 RECORDING AND PRESENTATION OF DATA

9.1 The details and observations of the test should be suitably recorded. A recommended proforma for the record of results is given in Annex B. These results should also be inserted in the standard drill hole log (see IS 4464). From this data the water intake versus pressure curves for analysing specific foundation problems may be plotted. The pressure versus water losses may be plotted graphically for better visual interpretation as shown in Fig. 9. This interpretation will provide information regarding in-situ condition of joints in the rock mass. The permeability values should be indicated either in Lugeons or cm/s.
**Fig. 4 Formulae for Calculation of Coefficient of Permeability**

- **A**: length of test section, in m.
- **a**: surface area of test section, in m² (in method I, a is area of wall plus areas of bottom).
- **C_u**: conductivity coefficient — unsaturated bed (see Fig. 5).
- **C_s**: conductivity coefficient — saturated bed (see Fig. 6).
- **D**: distance from ground surface to bottom of hole, in m.
- **H**: effective head = \( h_1 + h_2 - L \), in m.
- **h_1**: in test above water table, distance between swivel and bottom of hole, in m.
- **h_2**: in test below water table, distance between swivel and water table, in m.
- **h_u**: applied pressure at collar, in m of water.
- **K**: coefficient of permeability in m/s under unit gradient (multiply by 100 to get the value in cm/s).
- **L**: head loss in pipe due to friction in m of water (for quantities less than 18 l/min in 32 mm pipe, it may be ignored).
- **Q**: steady flow into well, in m³/s.
- **r**: radius of test hole in m.
- **S**: thickness of saturated material, in m.
- **T_u**: \( U - D + H \).
- **U**: thickness of unsaturated material, in m.
- **X**: percent of unsaturated stratum \( \times \frac{H}{T_u} \times 100 \) (see Fig. 7).
**Fig. 5** Conductivity Coefficients for Permeability Determination in Unsaturated Strata with Partially Penetrating Cylindrical Test Wells

**Fig. 6** Conductivity Coefficients for Semi-spherical Flow in Saturated Strata through Partially Penetrating Cylindrical Test Wells

For Use in $K = \frac{1}{C_s} \frac{Q}{C_f H}$
Fig. 7 Location of Zone I Lower Boundary for Use in Permeability Determination
Fig. 8 Lugeon Patterns for Various Occurrences During Testing and Their Interpretation and Percentage Occurrences
Depth (m) : 11.55 - 10.00
Assessed k : 1.4 \times 10^{-7} \text{ m/s}
Comments : Laminar flow initially then wash out of fissures or possible leakage past the packer at peak pressures

9A EXAMPLE OF WATER INJECTION TEST RESULT

- Laminar Flow flow
- Turbulent flow (Caused by a few open Fissures or leakage past packer)
- Uplift of ground
- Recovery of ground
- Scour of fissure or movement of packer at high pressure
- Setting of fissures
  - Partial
  - Nearly complete
- Movement of packer at intermediate pressure
  - (i) No erosion
  - (ii) Erosion ground packer
- Combination of circumstances

9B TYPICAL PLOTS FOR WATER INJECTION TEST RESULTS

FIG. 9 WATER INJECTION TEST RESULT
ANNEX A
(Clauses 8.1)

CALCULATION OF PERMEABILITY COEFFICIENT USING PRESSURE PERCOLATION TESTS IN BEDROCK

A-1 ZONE 1

\[ U = 23 \text{ m} \quad D = 7.6 \text{ m} \quad A = 3 \text{ m} \]
\[ r = 0.15 \text{ m} \]
\[ h_1 = 10 \text{ m} \quad h_2 = 1.75 \text{ kg/cm}^2 = 17.5 \text{ m} \]
\[ Q = 0.0013 \text{ m}^3/\text{s} \]

L using 32 mm pipe at 0.0013 m\(^3\)/s = 23 cm loss per 3.05 m section

Distance from swivel to bottom of pipe = 6.7 m

\[ H = 6.7 \times 0.23 = 0.514 \text{ m} \]
\[ T_u = 23 - 7.6 + 27 = 42.4 \text{ m} \]
\[ X = \frac{27 \times 100}{42.4} = 63.6 \text{ percent} \]

Point \( \frac{T_u}{A} \) on Fig. 7 is in Zone 1.

\[ \frac{H}{r} = \frac{24}{0.15} = 180 \]
\[ \frac{A}{H} = \frac{3}{17} = 0.11 \]

\( C_u \) from (Fig. 5) = 62

\[ K = \frac{Q}{C_u H} = \frac{0.0013 \times 100}{62 \times 0.15 \times 27} = \text{cm/s per unit gradient} \]
\[ = 0.00052 \text{ cm/s per unit gradient} \]

A-2 ZONE 2

\[ U = 23 \text{ m} \quad D = 20 \text{ m} \quad A = 3 \text{ m} \]
\[ r = 15 \text{ cm} \]
\[ h_1 = 1.75 \text{ kg/cm}^2 = 17.5 \text{ m} \]
\[ Q = 0.0013 \text{ m}^3/\text{s} \]

L using 32 mm pipe at 0.0013 m\(^3\)/s = 23 cm loss per 3.05 m section

Distance from swivel to bottom of pipe = 19.6 m

\[ H = 19.6 \times 0.23 = 2.26 \text{ m} \]
\[ T_u = 23 - 20 + 38 = 41 \text{ m} \]
\[ X = \frac{38}{41} \times 100 = 92.5 \text{ percent} \]

A-3 ZONE 3

\[ U = 23 \text{ m} \quad S = 18 \text{ m} \]
\[ D = 30 \text{ m} \quad A = 3 \text{ m} \]
\[ r = 0.15 \text{ m} \]
\[ h_1 = 25 \text{ m} \]
\[ h_2 = 1.75 \text{ kg/cm}^2 = 17.5 \text{ m} \]
\[ Q = 0.0013 \text{ m}^3/\text{s} \]

L using 32 mm pipe at 0.0013 m\(^3\)/s = 23 cm loss per 3.05 m section

Distance from swivel to bottom of pipe = 30 m

\[ H = 30 \times 0.23 = 2.26 \text{ m} \]
\[ T_u = 25 + 17.5 - 2.26 = 40.24 \text{ m} \]
\[ \frac{A}{r} = \frac{3}{0.15} = 20 \]

\( C_u \) from (Fig. 6) = 39

Method 1

\[ K = \frac{2Q}{(C_u + 4) (T_u + H - A)} = \frac{0.0006 \times 10}{(43 \times 0.15) (41 + 38 - 3)} = 0.000583 \text{ cm/s per unit gradient} \]

Method 2

\[ K = \frac{2Q}{(C_u r) (T_u + H - A)} = \frac{0.0013 \times 100}{(39 \times 0.15 \times 40.24)} = 0.000583 \text{ cm/s per unit gradient} \]
ANNEX B
(Clause 9.1)
PROJECT
FORM FOR PRESENTATION OF DATA OF IN-SITU PERMEABILITY TESTS IN BEDROCK

Date

1. Project
2. Drill hole No.
3. Feature
4. Collar elevation
5. Height of the water swivel above the collar of the hole
6. Type of drilling
7. Diameter of drill hole
8. Total depth of the hole
9. Depth tested: From to total
10. Depth to ground water
11. Size of the drill rods/pipe

NOTE (if any)

<table>
<thead>
<tr>
<th>Test Section</th>
<th>Metre Reading of Water Intake Lines</th>
<th>Water Intake litres/min</th>
<th>Water Pressure at Collar kg/cm²</th>
<th>Permeability cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>To</td>
<td>Initial Reading</td>
<td>Reading After 5 min</td>
<td>Reading After 10 min</td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
</tbody>
</table>

1) Where permeabilities of several confined aquifers are tested the piezometric head of each aquifer should be recorded separately.
2) Test to continue till 3 consecutive readings are constant.
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Amendments Issued Since Publication

<table>
<thead>
<tr>
<th>Amend No.</th>
<th>Date of Issue</th>
<th>Text Affected</th>
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BUREAU OF INDIAN STANDARDS

Headquarters :
Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110 002
Telephones : 2323 01 31, 2323 33 75, 2323 94 02
Telegrams : Manakansantha
(Common to all offices)

Regional Offices :

Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg
NEW DELHI 110 002
{ 2323 76 17
2323 38 41

Eastern : I/14 C.I.T. Scheme VII M, V. I. P. Road, Kankurgachi
KOLKATA 700 054
{ 2337 84 99, 2337 85 61
2337 86 26, 2337 91 20

Northern : SCO 335-336, Sector 34-A, CHANDIGARH 160 022
{ 260 38 43
260 92 85

Southern : C.I.T. Campus, IV Cross Road, CHENNAI 600 113
{ 2254 12 16, 2254 14 42
2254 25 19, 2254 23 15

Western : Manakalaya, E9 MIDC, Marol, Andheri (East)
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