IS 7436 ( Part 1 ) : 1993

( Reaffirmed 1998 )

भारतीय मानक

# नदी घाटी परियोजनाओं में संरचनाओं के लिये मापों के प्रकारों की मार्गदर्शिका और मापन उपकरणों की अवस्थापन चुनाव की कसौटी

## भाग 1 मिट्टी और राकफिल बाँधों के लिए

( पहला पुनरीक्षण )

*Indian Standard*

# GUIDE FOR TYPES OF MEASUREMENTS FOR STRUCTURES IN RIVER VALLEY PROJECTS AND CRITERIA FOR CHOICE AND LOCATION OF MEASURING INSTRUMENTS

## PART 1 FOR EARTH AND ROCKFILL DAMS

*( First Revision )*

UDC 627·824·058



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

*August* 1993

Price Group 3

Hydraulic Structures Instrumentation Sectional Committee, RVD 16

## FOREWORD

This Indian Standard ( First Revision ) was adopted by the Bureau of Indian Standards, after the draft finalized by the Hydraulic Structures Instrumentation Sectional Committee had been approved by the River Valley Division Council.

Increase in the height of structures and varied topographical conditions have focussed attention to the study of the behaviour of structures in the construction as well as operation stage, both from the point of view of safety and knowledge of behaviour pattern. In addition, various assumptions which are commonly made either explicitly or implicitly in the dam design need verification.

A number of these structures in India have been located in regions of seismic activity. Hence, there is a need to establish adequate instruments both in the structure as well as the foundation to evaluate and understand the influence of various parameters in the structural performance.

Periodical and timely observations will provide the means of evaluating the behaviour of the structure and, if need be, take appropriate remedial measures on the basis of observed data. It is, therefore, imperative that adequate means should be established within the structure so that measurements of vital significance can be made and compared with design criteria.

It is emphasized that field measurements cannot eliminate all the uncertainties of earth and rockfill dam design, construction and operation and they are no substitute for proper understanding of the problems involved.

This standard was first published in 1974. A revision of the standard has been taken up to incorporate certain changes found necessary in the standard in the light of comments from the users. The major changes in this revision are inclusions in clinometers and choice of instruments to measure movements.

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*

# GUIDE FOR TYPES OF MEASUREMENTS FOR STRUCTURES IN RIVER VALLEY PROJECTS AND CRITERIA FOR CHOICE AND LOCATION OF MEASURING INSTRUMENTS

## PART 1 FOR EARTH AND ROCKFILL DAMS

*( First Revision )*

## 1 SCOPE

**1.1** This standard covers the various types of measurements needed for monitoring the behaviour of earth and rockfill dams and provides guidelines for choice of instruments and their locations.

**1.1.1** Generally the same type of instruments are suitable for earth and rockfill dams. For the latter, however, graded material is used between the rockfill and the instrument so that the instrument does not get damaged by the rock pieces.

## 2 REFERENCES

The Indian Standards listed below are necessary adjuncts to this standard :

| *IS No.* | *Title* |
|---|---|
| 4967 : 1968 | Recommendations for seismic instrumentation for river valley projects |
| 4986 : 1983 | Code of practice for installation of raingauge (non-recording type) and measurement of rain ( *first revision* ) |
| 5225 : 1969 | Specification for raingauge, non-recording |
| 5235 : 1969 | Specification for raingauge, recording |

## 3 TYPES OF MEASUREMENTS

### 3.1 Pore Pressure, Movements and Seepage

**3.1.1** *Pore Pressure*

The measurement of pore pressure is probably the most important and usual measurement to be made in the embankments. Their measurement enables the seepage pattern set up after impounding of reservoir to be known, the danger of erosion to be estimated, at least partially, and the danger of slides in the dam and abutments to be estimated if the reliable shear strength is known. Valuable information about behaviour during construction and drawdown is obtained.

**3.1.2** *Movements*

Measurement of movements is as important as the measurement of pore pressures. Movements conforming to normal expectations are basic requirements of a stable dam. An accurate measurement of internal and external movements is of value in controlling construction stability. The measurement of the plastic deformation of the upstream and downstream slopes under the cycles of reservoir operation may indicate the likely development of shear failure at weak points.

**3.1.3** *Seepage*

Measurement of seepage through and past a dam, may indicate erosion or blocking of downstream drains and relief wells, by increase or decrease of seepage, respectively at constant reservoir conditions. Seepage and erosion along the lines of poor compaction and through cracks in foundations and fills may specially be indicated by such measurements.

### 3.2 Strains and Stresses

Design analysis of earth and rockfill dams is based on radical simplifications of the stress pattern and the shape of the rupture planes. Stress measurements, therefore, require considerable judgement in interpretation. Accurate measurement of stress is difficult and distribution of stress in earth and rockfill dams is complex. Strains may be calculated from displacements or measured directly.

### 3.3 Dynamic Loads (Earthquakes)

Earthquake causes sudden dynamic loading and measurement of vibrations in dams located in areas subjected to seismicity is important for evolving design criteria for such conditions.

### 3.4 Other Measurements

**3.4.1** *Reservoir and Tail Water Level*

Reservoir and tail water heads being one of the principal loading to which a structure is subjected, the measurement of reservoir and tail water levels is essential for interpretation and realistic assessment of the structural behaviour of the reservoir retaining structure.

**3.4.2** *Wave Height*

Records of wave height data along with wind velocity and other pertinent data help in deciding free board requirements more realistically.

**3.4.3** *Rainfall*

This measurement is necessary for interpretation of pore water pressure and seepage development in earth dams.

3.4.4 *Data About Material Properties*

The knowledge of properties of materials which are relevant to the type of measurement are essential for interpretation of instrument observations.

## 4 PLANNING INSTRUMENTS SYSTEM

4.1 Careful attention should be given to planning an instrumentation system to ensure that required information is obtained both during construction as well as during the life of the structure. The requirements of the system and the procedures to the used for analyzing the observations should be formulated in detail and selection of measuring devices and their location chosen to meet these requirements.

4.1.1 In general, from the consideration of usefulness of data obtainable, no instruments except for seepage, rainfall and reservoir water levels are required for dams up to 30 m height. Although this limit may seem superfluous, the actual requirements may be best guided by consideration of foundation and construction materials, the importance of the structure, design methods and criteria adopted. Provision of instruments for measuring pore pressures and movements should be provided for structures having greater height. Provision of instruments for measuring strain and stress and dynamic effects of earthquake may be made for a few selected cases where dam heights are more and adequate trained staff is available. An earth or rockfill dam with weak soils in the foundation of embankment is to be treated as a special case irrespective of its height and instruments should be provided to suit the observation requirements from the points of view of safety and collecting data for future similar designs.

4.1.2 Where dam lengths are more and foundation strata varies along the length, location of instruments at two or three sections should be considered.

4.1.3 Measuring instruments for pore water pressures and movements should be installed in close proximity so that analysis and interpretation of data is meaningful.

4.1.4 Suitable access should preferably be available for taking measurements throughout the year.

4.2 Installation of instruments should be made under constant surveillance of a qualified responsible individual.

4.3 Instruments should be guarded against damage or destruction by construction operations.

## 5 INSTRUMENTS FOR MEASURING MOVEMENT

### 5.1 Vertical Movement Gauges

5.1.1 *Surface Markers*

Surface marker points consist of steel bars which are driven vertically into the embankment or the ground and embedded in concrete. A reference base line is established on a firm ground outside the area of movement due to reservoir and embankment load. Position of surface stakes or markers fixed on the embankment are determined by survey with reference to this line. It measures horizontal movements also.

5.1.1.1 Surface markers may be established on lines parallel to the centre line of the dam at 50 to 100 m centres. The lines may be at the edge of the top width of the dam, at the edge of berms or at suitable intervals along the slope, at the toe of the dam and at 50 m and 100 m from toe if foundation soil is not firm. These may be provided both on upstream and downstream slopes excepting locations on upstream slope which remain throughout the year below lake water.

5.1.2 *Cross-Arm Installation*

It consists of telescopic steel casing to which are attached horizontal cross-arms at predetermined vertical intervals. As the soil settles, sections of casing are dragged down and these are thus relocated in their new positions by lowering down the casing a problem fitted with retractable claws which engage the bottom of each section in turn or by using an electrical probe. Cross-arms are used in order to eliminate any possibility of the casing sections not settling along with the surrounding soil.

5.1.3 *Hydraulic Device*

It is made from two 50-mm diameter brass pipe nipples soldered to a common diaphragm. Pipe caps are secured at both ends of the assembly which is then mounted vertically on a steel base plate for anchorage in the embankment. The diaphragm separates the upper (air) chamber from the lower (overflow) chamber and encloses a plastic float valve which prevents water from entering the air chamber during flushing of the lower chamber. Three 8-mm outer diameter plastic tubes are embedded in trenches which are excavated to maintain continuous downward slopes to the instrument terminal. The instrument terminal is equipped with a pump, air compressor and high precision pressure gauges.

5.1.4 *Geonor Probe*

It consists of a three-pronged tip connected to a double rod which is lowered down a bore hole or driven in soft ground to desired depth. When the outer rod is held and the inner rod driven with hammer, the three prongs are forced out in the surrounding soil. The outer rod is then uncovered from, the tip and withdrawn a few centimetres. The top of the inner rod, which remains in contact with the anchored tip is used as a reference point to measure the settlement of the tip. This device is particularly well suited for measuring settlements of soft foundations under low embankments.

5.1.5 *Foundation Settlement Measuring Device*

It is a base plate placed on the foundation line with a vertical column of steel tubings. The position of the base plate is determined by a surrounding device lowered from the top open end of the steel tubings.

5.1.6 *Magnetic Probe Extensometer*

This system consists of a magnet/leed switch probe of approximately 15 mm diameter connected to an indicator with a marker connecting cable. Magnetic ring markers with stainless steel spring parts are installed over a series of PVC access pipes of 33 mm outer diameter and 27 mm inner diameter jointed together.

The probes when lowered through the access pipe will give indications in the indicator where the magnet marker rings are located. When settling takes place the marker rings will move with the soil and the fresh positions of the marker rings indicate the amount of settlements with respect to earlier logged position.

**5.1.7** *Induction Coil Type Extensometers*

This induction coil type extensometers consist of an electrical probe made of PVC and having a diameter of 35 mm or 43 mm which houses a primary electrical exit. The probe is connected to an indicator electrical cable. Indicator has a volt/ammeter to measure the voltage/current increase when the primary coil enters a secondary coil, when there is a steel marker ring or plate, it will indicate a current/voltage which could be read through the indicator. Series of marker rings installed over a corrugated PVC pipe installed over a PVC access tubes or inclinometer tube should help monitoring the settlement.

**5.2 Horizontal Movement Gauges**

**5.2.1** *Cross-Arm Installation for Measurement of Horizontal Movement*

This installation is similar to that described in **4.1.2** but instead of cross-arms fixed at different sections there are two vertical plates at the same level placed at a certain distance apart. The relative horizontal movements between the two cross-arms are measured by transmitting the same by means of a cable to a pair of counterweights, which move vertically in the tubing. A sounding probe similar to that used in measurement of vertical movement installation determines the position of the counter-weights.

**5.2.2** *Inclinometers*

Plastic or aluminium tubing is placed vertically in the dam with its bottom anchored to firm unyielding stratum. The inclination of the tubing is measured by a sensitive electrical inclinometer, step by step, starting from the bottom of the tubing. Horizontal movements are computed by integrating the movements starting from the bottom, on the basis of changes in the inclination. Vertical movements may also be measured by using telescoping couplings for connecting the sections of the tubings and noting the positions of the ends of each section by a mechanical latching device, or if metal rings are embedded in the end portions of plastic tubing, by an electromagnetic device. Each section of tubing is anchored to the surrounding soil mass by fixing flanges or collars to the tubing. Alternatively, when an electromagnetic sounding device is used, the plastic tubing passes through encircling metal discs which are free to move along with the earth mass and the position of these discs are determined by the device.

**5.2.3** Horizontal movements may also be measured by running an electromagnetic probe through telescoping plastic tubing laid horizontally across the dam axis.

**5.2.4** In medium and high dams tension cracking can occur near the abutments in the core as well as shell zones as a result of differential settlement and surface irregularities in the abutment profile. Sharp slopes may also contribute to transverse cracking in the core. Horizontal strains in the range of 0.1 to 0.3 percent cause cracking in earth dams. Therefore, horizontal strain need to be measured near the abutments by providing soil extensometers to detect tension zones.

Soil extensometers consist of two plate anchors welded to two stainless steel rods protected by telescoping tubes. The strain measuring device mounted on the rods may be bonded resistance strain gauge, vibrating wire strain gauge or potentiometer and is electrically connected to a remote readout. Soil extensometer should be provided in two groups near the top of dam on each abutment only up to quarter length of the dam from the abutment both in core as well as shell zones.

**5.3 Choice of Instruments to Measure Movements**

The cross-arm installation for vertical movements has been a standard practice, it being easier to fabricate and install, but its maintenance is very difficult as slush may enter the pipe and render the device inoperative. Further the use of the assembly appears to be limited to dams of low to medium height because with increasing height the assembly may not remain in plumb and observations by torpedo may become difficult. Alternatively, the hydraulic device can be used for high dams. Where soft foundations are met with, use of Geonor probe is recommended. For the measurement of horizontal movements, the inclinometer is a superior installation as it gives information of horizontal movement along its complete length and the position of sliding surface may be, therefore, determined accurately. Further with the provision of telescoping coupling, metal rings at the ends of sections and metal discs to surround the tubing, vertical movements may be also measured at a little extra cost. The fabrication and installation, however, requires precision and the instrument is much costlier than the cross-arm arrangement. However an alternate device which is easy for installation and observation is based on the principle described in **5.2.2**.

**5.4 Choice of Location of Instruments to Measure Movements**

The installation should be at critical locations where design considerations show weak zones. Soft clays and fissured clay in the foundation are particularly susceptible to long term movements and need a careful watch. By means of surface surveys it may be possible to locate areas in which tension of compression is developing, especially in earth dams, which may help in locating incipient slope instability. While locating a movement device, it should be kept in view that maximum horizontal movements generally occur at mid-slopes and maximum vertical movements occur at mid height of the structure.

## 6 PIEZOMETERS

**6.1** Piezometers commonly used are given in **6.1.1** to **6.1.4**.

**6.1.1** *Porous Tip/Tube Piezometer*

**6.1.1.1** This is a steel or PVC pipe 10 to 40 mm in diameter placed vertically during construction or in a borehole after construction. A porous element is fixed at the bottom of the pipe or alternatively, the lower portion is perforated, and soil prevented from entering the pipe by surrounding the perforated portion by brass wire mesh and a gunny bag filled with filter material. With increase or decrease of pore water pressure in the soil near the perforated portion, water level rises or drops in the pipe and this level is noted by as electrical sounding device or a bell sounder.

**6.1.1.2** The piezometer consisting of PVC vertical pipe 12 to 15 mm outer diameter extending above ground or embankment surface with carborandum/alundum porous tube tip having 37 mm outer diameter and length 30 to 60 cm at the measuring point is known as porous tube type piezometer. It is free from electrolytic action and attack by chemicals in water or soil. It has also less response time compared to ordinary stand pipe piezometer with bottom end open or with perforated bottom section.

**6.1.2** *Closed System Hydraulic Piezometer*

It consists of a porous element which is connected by two plastic tubes to pressure gauges located in a terminal house or terminal well. The terminal house or well contains pumping and vacuum equipment, an air trap and a supply of de-aired water besides pressure gauges. Use of two plastic tube makes possible, circulation of water through the porous element to de-air the system. The pore-water pressure is noted by means of gauges.

**6.1.2.1** There are two types of tips. The foundation type can by installed in a bore hole. The embankment type is required to be placed during construction.

**6.1.3** *Electrical Piezometers*

Electrical piezometer consists of a tip having a diaphragm which is deflected by the pore water pressure against one face. The deflection of the diaphragm is measured by a suitable strain gauge which may be suitably calibrated to read pore water pressure. The strain gauge is either electrical resistance (unbonded strain gauge) type or vibrating wire type.

**6.1.4** *Pneumatic Piezometers*

In the pneumatic piezometers, the diaphragm deflection due to pore water pressure is balanced by a known air/gas pressure and recorded at the outside indicator end using pneumatic pressure gauges or pressure transducers.

**6.2 Choice of Instruments to Measure Pore Water Pressure**

**6.2.1** Piezometer observations are of prime importance and are to be continued over an extended period of time. It is, therefore, imperative that limitations will be imposed as to the selection of particular instruments because of its reliability and durability. Other factors that influence the selection are time lag and sensitivity. The significance of time lag depends to a considerable extent on the nature of the anticipated fluctuations of pore pressure.

**6.2.2** Stand pipes, though durable and reliable, are not generally used for measuring pore pressures during construction, there being no water flow. Installation of a stand pipe in impervious or semi-pervious soils will lead to more time lag. Installation of twin-tube hydraulic piezometers has been a standard practice. Factors considered in its favour include relative economy and availability of materials and ease of installation. But presence of air-bubbles in the tubing which may become difficult to remove is one of the disadvantages. Electrical piezometers have instantaneous response and are available indigenously. A final choice regarding selection will be best judged upon the accuracy of results required, the importance of such records, and the cost involved.

**6.3** *Choice of Location for Installation of Piezometer*

Pore water pressures indicate whether the various zones in an earth/rockfill dam are functioning properly. These also indicate the effectiveness of the seepage barrier provided in case of pervious foundations, the effectiveness of chimney filters and horizontal drains provided in the upstream embankment in case of earth dams, etc. As such the piezometers are required to be located at critical points of a cross-section and locations. Typical installation arrangements are shown in Fig. 1. Structures made up of inferior materials or resting on soft, slow draining foundations should have adequate number of piezometers. Piezometers located in the upstream and downstream of the filter and upstream and downstream side of the under seepage barriers casing of not freely draining materials would indicate drawdown pore pressures, and those in the downstream casing would give information about seepage conditions.

## 7 INSTRUMENTS FOR MEASURING SEEPAGE

**7.1** Rectangular or V-notches are fixed at suitable points on the main collecting drains to measure the seepage water. There should be a clear fall over the notch and the approach velocity should be reduced as far as practicable. The head of water is measured by the graduations on the notch and the discharge is calculated by using appropriate formula.

## 8 INSTRUMENTS FOR MEASURING EARTH PRESSURE

**8.1 Earth Pressure Cells**

The usual instrument to measure earth pressure is the earth pressure cell. It uses a stiff diaphragm on which the earth pressure acts. The action is transmitted through an equalizing, confined, incompressible fluid (Mercury) on to a second pressure responsive element, the deflection of which is proportional to the earth pressure acting. The deflection is transformed into an electrical signal by a resistance wire (unbonded strain gauge) or vibrating wire strain gauge and transmitted through a cable embedded in the earth work to a receiver unit on the surface. The measure of the electrical signal indirectly indicates the earth pressure by appropriate calibration.

**8.1.1** The earth pressure cell may be designed to measure effective or total earth pressure or both. When it measures total earth pressures only, piezometers should be placed by their side to measure pore pressure which when deducted from the total earth pressure to give effective earth pressure. For observations of a retaining wall, when it is intended to note the change in the coefficient of earth pressure, clinometers should be fixed to the wall near the earth pressure cell to measure its tilting.

## 9 INSTRUMENTS FOR MEASURING EFFECTS OF DYNAMIC LOADS DUE TO EARTHQUAKES

**9.1** These measurements are made by installing seismographs, accelerographs and structural response recorders in accordance with IS 4967 : 1968.

## 10 INSTRUMENTS FOR MEASURING RESERVOIR AND TAIL WATER LEVELS

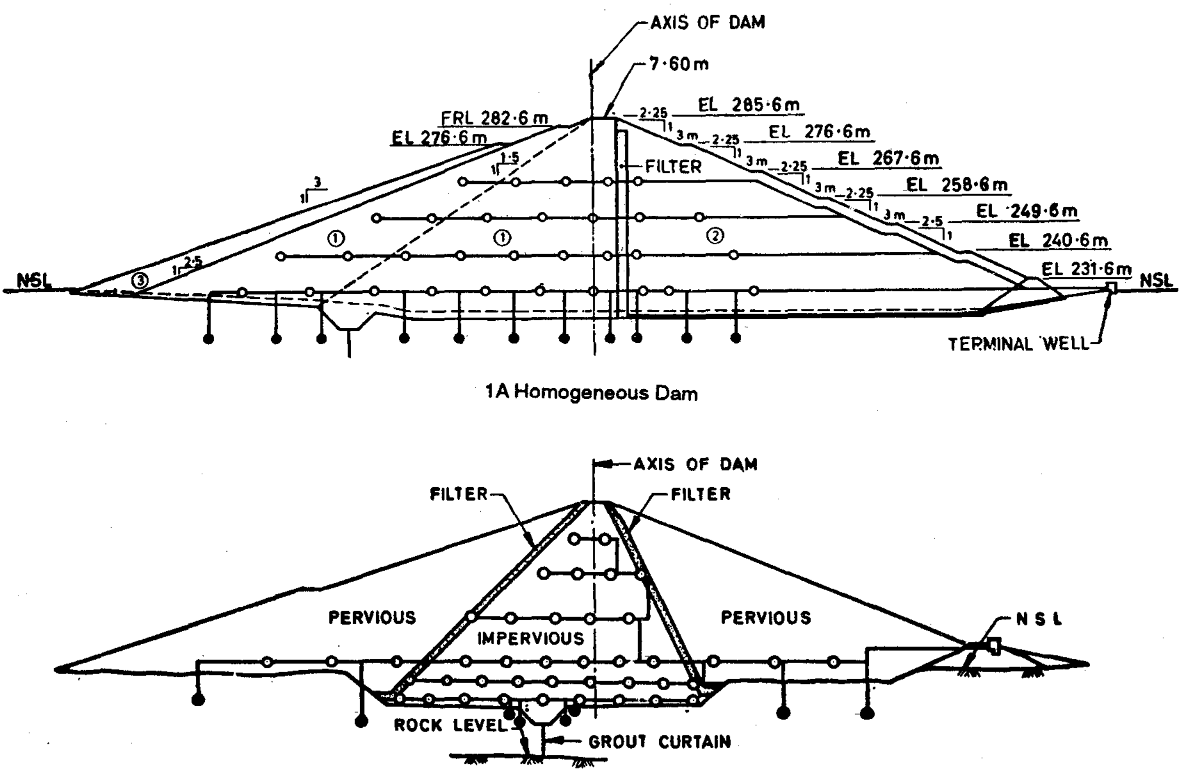
**10.1** Hydrostatic pressure is exerted on a dam by lake water and tail water. Headwater and tail water levels are observed daily by means of gauges (scales) fixed on the dam, at locations conveniently visible. Where the hourly rate of variation of water level is rapid and this information is important for interpretation of observations, automatic continuous water level recorder should be fixed in shafts suitably located.

## 11 INSTRUMENTS FOR MEASURING WAVE HEIGHTS

**11.1** Automatic wave height recorders are installed to measure wave heights. One type of this instrument provides an electric circuit, which is completed by lake water. The change in level of lake water due to wave, causes change in resistance/capacitance of the circuit which is automatically recorded by a recorder. Suitable calibration of change in resistance/capacitance in terms of change in water level gives the desired observation. The installation of such recorders will be required only for those reservoirs with long fetch which is likely to experience high velocity winds.

## 12 INSTRUMENTS FOR MEASURING RAINFALL

**12.1** Measurement of rainfall at the dam site is made by installing a raingauge (*see* IS 4986 : 1983, IS 5225 : 1969 and IS 5235 : 1969).




1A Homogeneous Dam

1B High Dam (117 m Height)

*Legends*

● Foundation Piezometer Tip

● Embankment Piezometer Tip

(1) Impervious

(2) Relatively Pervious

(3) Pitching

FIG. 1 TYPICAL STATIONS SHOWING PIEZOMETER INSTALLATIONS

## 13 DATA ABOUT MATERIAL PROPERTIES

**13.1** Properties of soils near the instruments should be determined while they are being installed. Grain size distribution, specific gravity and consistency limit tests should be carried out for soils near all types of instruments. Average field density and water content of soil layer in which the instrument is installed should also be noted. In case of instruments for observations of movements, consolidation tests should be done. When measurement of construction pore pressures is contemplated, laboratory construction pore pressure tests should be carried out. Permeability of compacted soils near piezometers should be determined. If assumptions made during stability analysis are to be verified, appropriate shear tests should be done. For earth pressure measurements, laboratory test should be run to determine the coefficient of earth pressure at rest or according to anticipated stress paths.

**Standard Mark**

The use of the Standard Mark is governed by the provisions of the *Bureau of Indian Standards Act, 1986* and the Rules and Regulations made thereunder. The Standard Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well defined system of inspection, testing and quality control which is devised and supervised by BIS and operated by the producer. Standard marked products are also continuously checked by BIS for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

Doc : No. RVD 16 ( 81 )

**Amendments Issued Since Publication**

| Amend No. | Date of Issue | Text Affected |
|---|---|---|
| | | |
| | | |
| | | |

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 331 01 31, 331 13 75

Telegrams : Manaksanstha
( Common to all offices )

Regional Offices :

| | | Telephone |
|---|---|---|
| Central : | Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002 | 331 01 31, 331 13 75 |
| Eastern : | 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola CALCUTTA 700054 | 37 84 99, 37 85 61, 37 86 26, 37 86 62 |
| Northern : | SCO 445-446, Sector 35-C, CHANDIGARH 160036 | 53 38 43, 53 16 40, 53 23 84 |
| Southern : | C. I. T. Campus, IV Cross Road, MADRAS 600113 | 235 02 16, 235 04 42, 235 15 19, 235 23 15 |
| Western : | Manakalaya, E9 MIDC, Marol, Andheri ( East ) BOMBAY 400093 | 632 92 95, 632 78 58, 632 78 91, 632 78 92 |

Branches : AHMADABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. PATNA. THIRUVANANTHAPURAM.

Printed at New India Printing Press, Khurja, India