

भारतीय मानक

कंक्रीट और सिंचाई बाँधों के लिए विस्थापन मापी युक्तियों  
का संस्थापन रख-रखाव और प्रेक्षण — रीति संहिता

भाग 1 साहुल द्वारा विक्षेप मापन  
( पहला पुनरीक्षण )

*Indian Standard*

INSTALLATION, MAINTENANCE AND  
OBSERVATION OF DISPLACEMENT MEASURING  
DEVICES IN CONCRETE AND MASONRY  
DAMS — CODE OF PRACTICE

PART 1 DEFLECTION MEASUREMENT USING PLUMB LINES

( *First Revision* )

ICS 17.040; 93.160

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**BUREAU OF INDIAN STANDARDS**  
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NEW DELHI 110002

## FOREWORD

This Code (Part 1) (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 Water Resources Division Council.

Measurements of relative horizontal displacements of points in the interior of a dam provide the simplest and direct method of the structural behaviour of the dam. Measurements of structural deformation over a considerable period of time (several years) furnish information regarding the general elastic behaviour of the entire structure and foundation and provide a means for determining the elastic shape of the deflected structure which will permit distinction of load and thermal deflection components and with precise alignment data, provide for estimating the amount of translation or sliding.

Deflection cycles of remarkable uniformity in amplitude and period become clearly evident from the initiation of observations if any deviation is apparent. Study of this deviation helps in detecting development of distress conditions in structure or foundation.

Depending upon the amount and type of related and supporting information available, plumb line observations can be used for ascertaining the elastic and inelastic physical properties of the concrete or masonry and foundation rocks.

Relative displacements are measured by means of collimators and by the use of plumb lines with pendulums placed inside a shaft in the dam. The displacement of the wire is measured normal to and parallel to dam axis in straight gravity dams (radial and tangential direction in case of arch dams) with respect to fixed points in the shaft.

Though the measurement of displacement by pendulums is restricted to significant individual points or change of direction of significant lines, pendulums are the foremost instruments for the observation of behaviour of dam.

Using micrometer microscope accuracy as high as 0.05 mm can be obtained.

Two types of plumb lines are in use, namely (a) Direct plumb line, also designated as pendulum; and (b) Inverted plumb line.

Direct plumb lines are used for measurement of the relative horizontal deflections of points inside the dam, relative to a reference point in the lowest gallery, available closest to the base of the dam. As it is not advisable to instal the permanent deflection measuring equipment for plumb line observations while the construction is in progress, on account of the great likelihood of damage to such costly equipment, it is a usual practice to instal temporary plumb lines for observations during construction. Observations are made on temporary plumb line till such a time that the permanent deflection measuring equipment is installed.

In the case of a inverted plumb line the vertical line is established by anchoring the bottom point of the plumb line and fixing a float to the top point. Depending on how deep the bottom point is anchored so as to be free from the influence zone of the dam and reservoir load, the deflections of points in the dam as observed are more or less absolute.

For choice and location of instruments in masonry and concrete dams, reference is made to IS 7436 (Part 2) : 1997 'Guide for types of measurement of structures in river valley projects and criteria for choice and location of measuring instruments: Part 2 Concrete and masonry dams (*first revision*)'.

This Code is being published in two parts as follows:

- a) Part 1 Deflection measurement using plumb lines, and
- b) Part 2 Geodetic observation.

This Code was first published in 1991. The present revision has been taken up to incorporate the knowledge gained during the use of this Code. The main changes incorporated in this revision are as following:

- a) The words 'Regular plumb line' and 'Reverse plumb line' have been replaced by 'Direct plumb line' and 'Inverted plumb line' respectively,
- b) Wordings of 4 and 10.1 have been modified so as to explain the text in a better way, and
- c) 8.2 and 8.3 have been added.

The composition of the Committee responsible for the formulation of this standard is given at Annex A.

*Indian Standard*

**INSTALLATION, MAINTENANCE AND  
OBSERVATION OF DISPLACEMENT MEASURING  
DEVICES IN CONCRETE AND MASONRY  
DAMS — CODE OF PRACTICE  
PART 1 DEFLECTION MEASUREMENT USING PLUMB LINES  
( *First Revision* )**

**1 SCOPE**

This Code gives the details of the installation, maintenance and observation of direct and inverted plumb line for measurement of horizontal deflections of points inside a concrete or masonry dam.

**SECTION 1 DIRECT PLUMB LINE****2 PRINCIPLE AND CONSTRUCTION**

Plumb line essentially consists of a rust resistant wire suspended from the top of the plumb line well (shaft) provided for the purpose in the body of the dam, by some suitable suspension arrangement and carrying a heavy plumb bob (weight) immersed in a damping fluid contained in a can provided at the bottom of the plumb line well (*see* Fig. 1). Observation recesses are provided at the bottom and at suitable intermediate locations of the plumb line well (shaft) wherein are fixed deflection measuring equipments for observations of position of the plumb wire with respect to a fixed reference mark in the observation recess. The observations may be made mechanically by directly reading the position of the wire against scales fixed to the observation recess walls, as in the case of temporary plumb lines or by using micrometer microscope. Difference of the observed values of wire position from the reference-readings (initial readings) when processed, provide values of the dam deflections at the level of suspension and at the level of observation recesses relative to the lowest measuring point of the plumb line.

**3 EQUIPMENT**

**3.1** The various components that constitute the plumb line, temporary or permanent and equipment for observation of dam deflection are as under.

**3.2 Plumb Line Assembly****3.2.1 Shaft**

The shaft for housing the plumb line wire should be a vertical formed hole of about 450 mm diameter. Where the shaft is located closer to the reservoir face of the

dam, it is preferable to line the shaft. Observation recesses at gallery locations are provided and fitted with airtight steel doors to prevent draft effect and unauthorized tampering of wire, after installation.

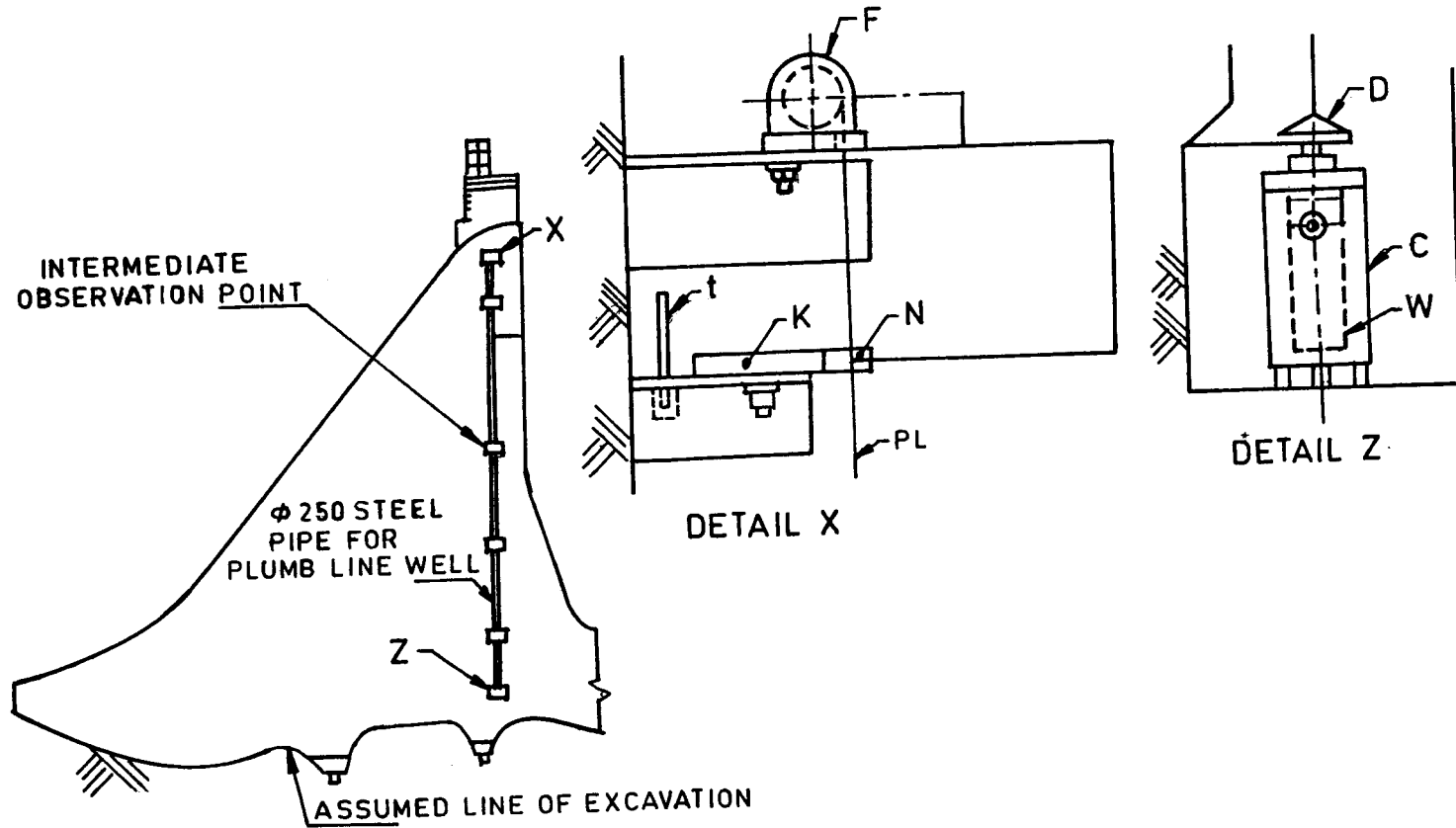
**3.2.2 Suspension Assembly**

The plumb line wire is suspended at the upper end of the shaft by means of a collet and nut in the centre of a heavy steel suspension spider (*see* Fig. 2) placed over the shaft opening. Alternatively the arrangement shown in Fig. 1 detail *X* may be used. The suspension device *F* consists of a roller bearing protected by housing. Below the suspension device *F* is the topmost clamping point or the point of rotation in the fixed plate *K*. The observations of the plumb line at any other point are thus relative to this point *N*. This separation of the rotation point from the supporting device ensures that the topmost point of rotation of the plumb line is not influenced in any way by the plumb weight.

For accurate measurement a thermometer stud must be fixed at right angle to the support. It can be made from a piece of iron piping 40 mm long, 12 mm external diameter and 8-9 mm internal diameter. One end of the tube is closed by a bottom of 3 mm thickness. In half the width of the beam a hole of corresponding diameter is bored and the stud is pressed in. The edges are elastically or autogeneously welded in order not to weaken the girder. The stud is used to receive a mercury thermometer. The diameter of the thermometer should not exceed 8 mm. The change in distance of the plumb line pivot from the wall due to change in temperature can be computed from the temperature readings.

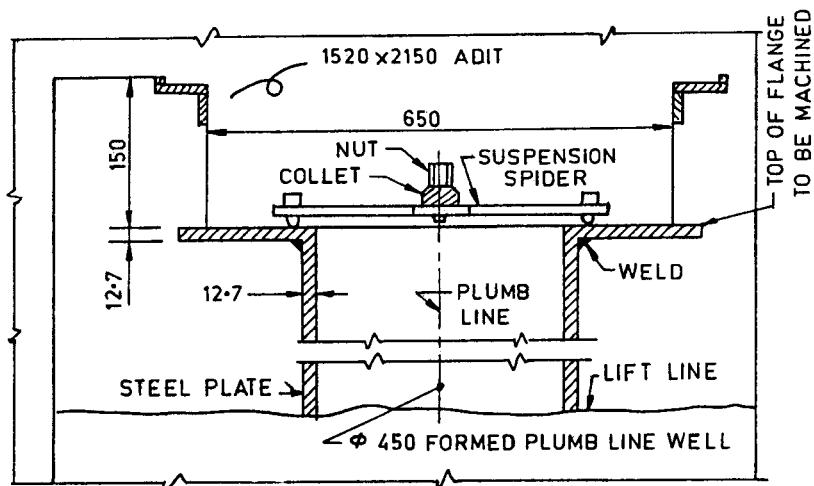
**3.2.3 Wire Plumb Bob and Dashpot**

In order to obtain a greater measuring accuracy, the plumb bob must be as heavy as possible. But an upper limit is given by the strength of the wire. A suitable material for the wire is rust proof and corrosion resistant special steel having a strength of about 150 N/mm<sup>2</sup>. Stainless steel wire of about 1.2 mm and

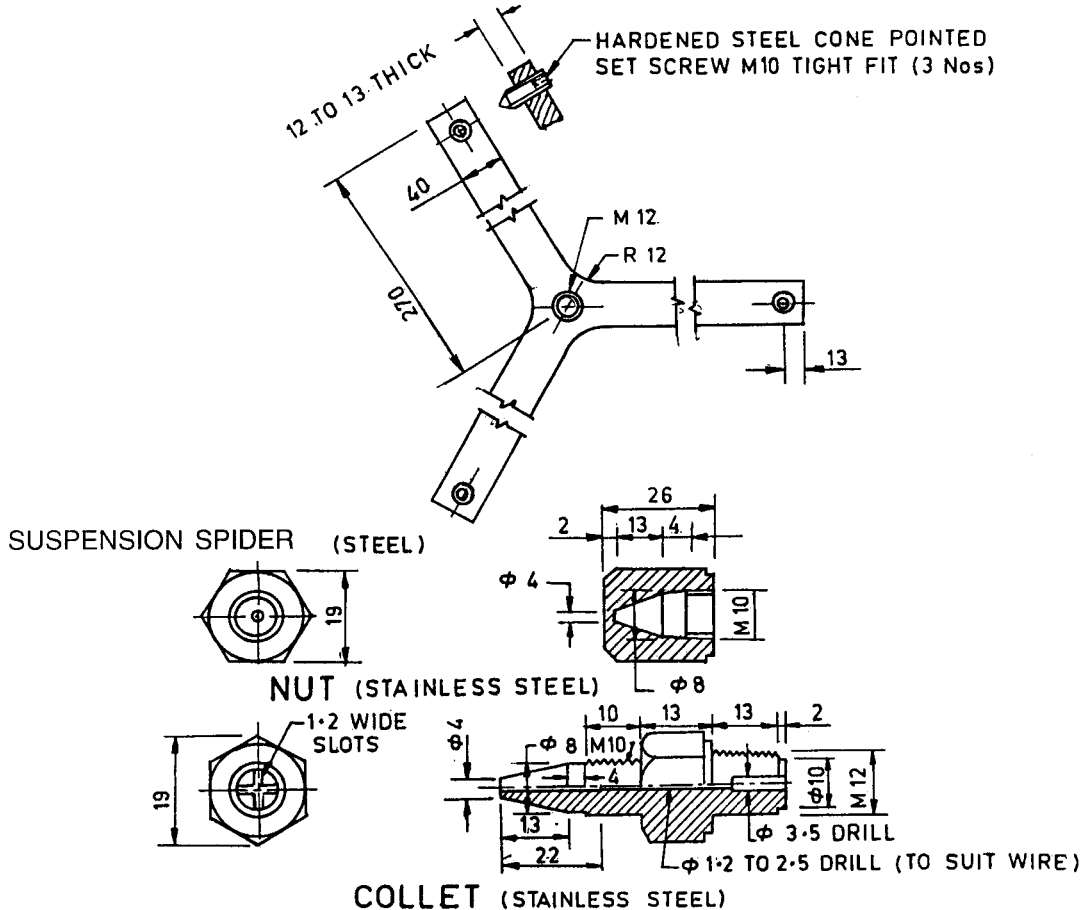


- |   |                        |
|---|------------------------|
| <i>F</i> = Plumb Line Suspension Device | <i>t</i> = Thermometer |
| <i>K</i> = Clamping Plate               | <i>PL</i> = Wire       |
| <i>N</i> = Plumb Line Pivot             | <i>W</i> = Weight      |
| <i>C</i> = Container for Damping Fluid  | <i>D</i> = Drip Cover  |

FIG. 1 PLUMB LINE ASSEMBLY



**SUSPENSION ASSEMBLY**  
(COVER PLATE REMOVED)



All dimensions in millimetres.

FIG. 2 DEFLECTION MEASURING EQUIPMENT

2.5 mm diameter may be used for the plumb line, for plumb bobs weighing 150 N and 350 N respectively. An invar wire having low coefficient of thermal expansion may be used for long plumb lines in an environment susceptible to large variations in temperature.

The weight of the plumb bob depends on the length of the plumb line, mode of measurement and the desired accuracy of measurement. Solid brass cylinder weighing about 150 N and 350 N may be used as a plumb bob for optical and mechanical mode of measurements respectively for the line length of 30 m to 200 m. For mechanical mode of measurement the plumb bob is much heavier than that for optical mode of measurement, to reduce the small horizontal displacement produced by the contact arm of the instrument to a negligible amount. The cylinder dimensions should be such so as to keep it immersed in non-corrosive damping oil contained in galvanized steel container for damping possible vibrations of the wire.

**3.2.4** Suitable arrangement should be made to prevent moisture condensation from falling into the oil. Where it happens to be excessive, a deflecting metal cover may be clamped around the wire a few centimetres above the dashpot to prevent cumulative contamination of oil.

### **3.2.5 Intermediate Observation Points**

These can be provided if access to plumb line is possible at intermediate elevations.

## **3.3 Deflection Measuring Equipment**

### **3.3.1 Temporary Plumb Line During Construction**

For temporary plumb line, any arrangement providing measurement of plumb line position against scales fixed in the observation recesses parallel and normal to dam axis is suitable. The scales should be rust resistant and with vernier arrangement.

It may be further improved by providing an electric circuit so that the contact of the moving point attached to the vernier with the plumb line is indicated by lighting a lamp. This reduces personal error in establishing the contact. More accurate instruments like micrometer screw can be used instead of vernier for measuring the deflection. The choice of a particular design depends on the desired accuracy. A sophisticated instrument of this type is described below.

### **3.3.2 Permanent Plumb Line**

It is desirable to use micrometer microscope for better accuracy in measurement of deflection.

### **3.3.2.1 Micrometer microscope**

a) *Reference and microscope — support bars*  
Within each observation recess two vertical 12 mm thick plates welded to form a right angle are placed in a position to contain the plumb line within the 90° quadrant formed by the plates. A stainless steel micrometer microscope support bar and reference bar each extend at right angle from each of the above plates, as shown in Fig. 3.

b) *Micrometer carriage and microscope*  
As shown in Fig. 3 carriage is constructed in such a manner that its base slides over carriage rod and anchored by conepoint screws seating into drilled recesses in the rod. Lead screw knob provides for reading to the nearest 0.05 mm. The carriage should have a total travel range sufficient to cover the anticipated horizontal deflection.

Microscope of 20-21 power and focussing through 37 mm having cross hair in the eye piece has been found suitable for observations of plumb lines in observation recesses detailed in Fig. 1.

## **4 INSTALLATION**

It is advisable to instal the plumb line assembly as soon as possible after completion of the structure. Care should be taken for keeping the plumb line wire at the centre of the plumb line shaft by adjusting suspension device suitably. Initial reading should be recorded and treat this reading that is reading at the time of installation as zero.

### **4.1 Deflection Measuring Equipment for Use with Micrometer Microscope**

#### **4.1.1 Recess Fixture Installation**

The recess fixture should be assembled as shown in Fig. 3. Drill holes for expansion anchors and reinforcing dowels in the recess concrete. Drilling of these holes should be done carefully to ensure desired accuracy in alignment. Alignment may be maintained by using a small wood jig, set on the floor of the recess to hold the fixtures level and parallel to the faces of the recess. Exact alignment is to be obtained by small transit so as to set up and turn 90° in galleries.

Grout the anchors and steel dowels in place when fixtures have been oriented to desired positions. Make final check for carriage rod alignment and then encase this frame in concrete. Instal permanent plumb line as described below.

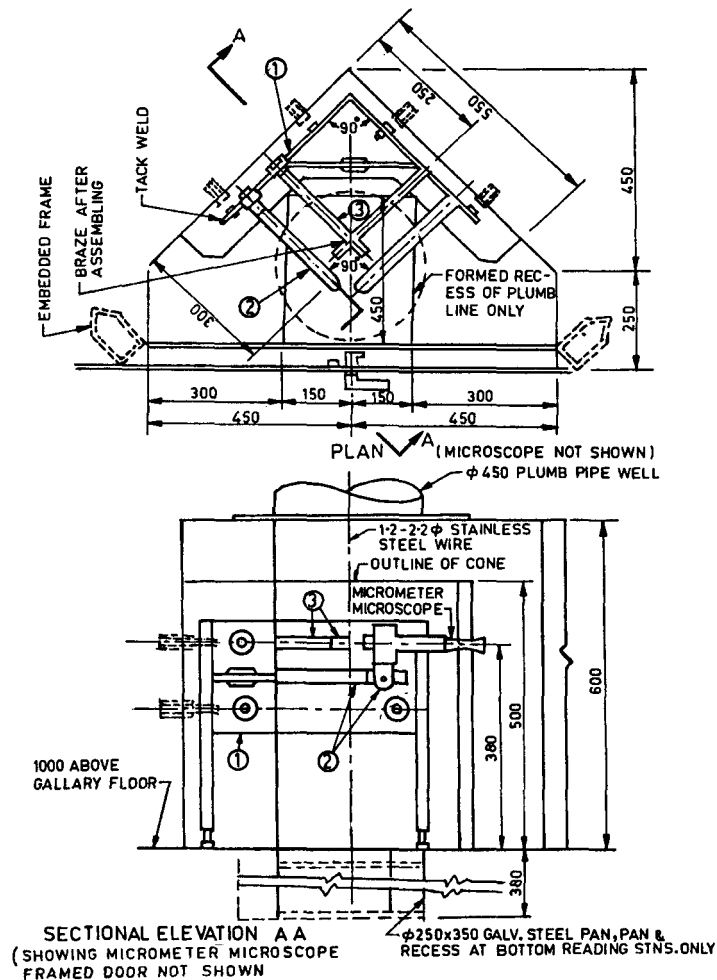


FIG. 3 DEFLECTION MEASURING EQUIPMENT

#### 4.1.2 Suspending the Plumb Line

The permanent plumb line should be located at or near the centre of the net opening of the shaft, which should be determined suitably by suspending a transit plumb bob on string or cord of a length sufficient to reach from the top of the shaft to the lower most point (see Fig. 2). Kinks and twists in the wire should be avoided when installing the same. The wire previously wound on a spool in a reeling rack is threaded through a hole in the centre of the plumb bob plug, removed previously, the interior of which contains a recess. The wire is twisted around a short nail and hot solder poured in the cover of the nail to fill the recess. After the solder has cooled, the plumb bob plug is lowered

through the shaft to the lower most point. When the plumb bob plug is at the level of the damping pot, the plug is screwed into the bob, lowered into the damping pot and sufficient oil is added to cover the plumb bob.

The freely suspended bob is adjusted to an elevation just below the oil level in the dashpot, and the wire permanently fixed at the suspension point. The closing nut of spring collet is tightened to securely grip and hold the plumb line wire.

#### 4.1.3 Marking Reference Points

After installation of the plumb line, plumb bob and placement of the plates is completed a permanent reference mark is scratched on the 5 mm diameter

stainless steel plug fixed in the flat face of each marker rod, care being taken to scratch the line vertically against the prevailing position of the wire.

**4.2** Deflection measuring equipment for use with co-ordimeter or co-ordiscope. The detailed instructions given by the manufacturer for installation of the equipment should be followed.

## 5 OBSERVATIONS

**5.1** Before taking a reading the plumb line wire is slightly tapped to make sure of the sensitive reaction by observing through the microscope or by reading the dials of the co-ordimeter. When vernier scales are used this practice may not be feasible as personal factor is involved in taking the reading. However, free movement of the plumb line wire should be checked periodically.

If intermediate observation points described in **3.2.5** are provided, they are turned in from top to bottom and the corresponding readings are taken.

After the readings are taken the wire is released by swinging out the clamping plates from bottom to top.

### 5.2 Observations with Micrometer Microscope

The observations are taken in following steps:

- a) Set the micrometer carriage and microscope assembly on a carriage rod and clamp the entire assembly in a position such that the reference mark and the plumb line fall within the range of the micrometer slide.
- b) Focus eye piece sharply on the system of cross hairs.
- c) Focus objective lens on the marker rod. Move the slide and microscope to the left of the reference mark and then by means of the microscope slide wheel, bring back the slide until reference mark is centered at the cross hair intersection, and record micrometer slide position.
- d) Repeat operation approaching reference mark from the right side record micrometer slide position.
- e) Focus objective lens on the plumb line and move slide and microscope to the left, bringing it slowly to coincide the cross hair intersection with left edge of the wire. Read and record micrometer slide position. Continue movement of the slide till cross hair pattern is centred over the right edge. Read and record micrometer slide position.
- f) Repeat operation approaching plumb wire edges from right side and reach and record

micrometer slide position, when the right and left edge of the wire coincide with the cross hair intersection.

- g) Difference of the average of step (c) and (d) readings and average of step (e) and (g) readings represents the position of the plumb line wire with respect to the reference mark.
- h) Repeat step (c) through (g) twice more from the same support bar.
- j) Repeat step (a) through (h) for the second pair of carriage and marker rod.

### 5.3 Observations with the Co-ordimeter

Taking observation with a co-ordimeter is simple. The reading of the left (scale 1) and right (scale 2) of the co-ordimeter are taken and the longitudinal and transverse deflections worked out.

## 6 FREQUENCY OF OBSERVATIONS

Weekly observation should be made during the first filling of the reservoir after which fortnightly schedule of reading may be adopted. More frequency schedule of reading may be adopted when rate of reservoir rise is fast. At least one reading must be obtained for the highest and lowest reservoir level attained every year.

## 7 FORM OF RECORD

Data observed from the plumb should be recorded in a printed form which should be designed to suit the measuring equipment, namely, vernier scales or microscope. The same should be got printed sufficiently in advance at the time of commencement of the observations.

Two copies of each set of observation should be prepared, the original be sent to the design office or officer responsible for processing observed data and the other copy retained at the site.

## 8 ANALYSIS OF DATA

**8.1** Magnitude of dam deflection at the level of suspension point or at any particular observation recess location relative to the lowest point of plumb line is obtained by subtracting the magnitude of movement of plumb line wire at that level from that obtained at lowest level of the plumb line wire. Deflection values so computed should be plotted to show the deflected shape of the dam. Continuous plots of deflection at the various observation levels, with corresponding reservoir level against time should be maintained for watching the deflection trends and behaviour of the dam.

**8.2** Typical deflected shape of the dam be obtained during minimum and maximum reservoir level by



plotting measured deflection normal to axis of dam at various elevations of the dam.

**8.3** Deflection normal to the dam axis *versus* reservoir water level during filling and depletion of the reservoir during the entire year be plotted for at least three years showing minimum three sets of filling and depletion for plotting purpose.

## SECTION 2 INVERTED PLUMB LINE

### 9 PRINCIPLE AND CONSTRUCTION

For the direct plumb line the relative displacements are determined by considering that the reference point, namely, the point corresponding to the lowest reading station, remains fixed and does not experience any shift in its position. In actual practice, however, the reference point itself undergoes horizontal displacement on account of the foundation horizontal displacement under operating loads. So in order to obtain correct evaluation of the displacements of dam points it is essential to ascertain the magnitude of foundation displacement and hence the shift of point corresponding to the lowest reading station resulting from varying reservoir level.

This measurement is made possible by the use of inverted plumb line, which essentially consists of a rust-resistant wire the lower end of which is attached to an anchor grouted to the bottom of a drilled hole in the foundation while the suspension point (upper end) is attached to a float which is buoyed up by water in a covered tank. To reduce evaporation, the water is covered by a film of oil.

If the suspension point and float arrangement of the inverted plumb line is installed in a gallery in which the plumb bob and damping medium for the regular plumb line is housed and the arrangement is so positioned as to permit observation of the inverted plumb line at an elevation corresponding to the lowest reading station elevation of the regular plumb line, the horizontal deflection at this elevation as noted by the reverse plumb line can be added algebraically to the relative horizontal deflections of points in the dam at higher elevations as noted by the direct plumb line to give the absolute horizontal deflections of these points.

However, if the inverted plumb line is extended all the way up to the topmost available observation station, values of the absolute horizontal deflections of dam points become directly available by simple difference of the initial and successive observations.

### 10 EQUIPMENT

The items of equipment and other features required for installation and use of inverted plumb line, typical installation of which is shown in Fig. 4.

#### 10.1 Hole

Hole shall be of 100 mm diameter so as to permit free positioning and movement of the wire in it even after maximum horizontal displacement of the foundation. The depth of the hole shall be such that the anchorage point of the lower end of the wire in the foundation is considered free from deformation due to dam and reservoir loads.

The hole has to be cased but for the bottom 1 to 1.5 m which portion is filled with grout for anchoring the lower end of wire attached to an anchorage unit.

#### 10.2 Wire and Deflection Measuring Equipment

See 3.2.3 and 3.3.

#### 10.3 Float

Float is essentially a double walled hollow cylinder of steel covered at top and bottom but having a central hole through the top and the bottom cover for threading the plumb wire from below and connecting it to the suspension collet fitted in a suspension spider centrally supported on top of the float. The central opening in the float should be of sufficient size to accommodate horizontal deflection of the dam at float level without contact with the plumb wire.

The size and height of the cylindrical float has to be designed in accordance with buoyancy principle to provide the specified liquid level below the top of the float as also below the top level of the cylindrical pipe welded in the centre of the tank bottom to provide continuation of the plumb line opening for extension of the plumb wire through it.

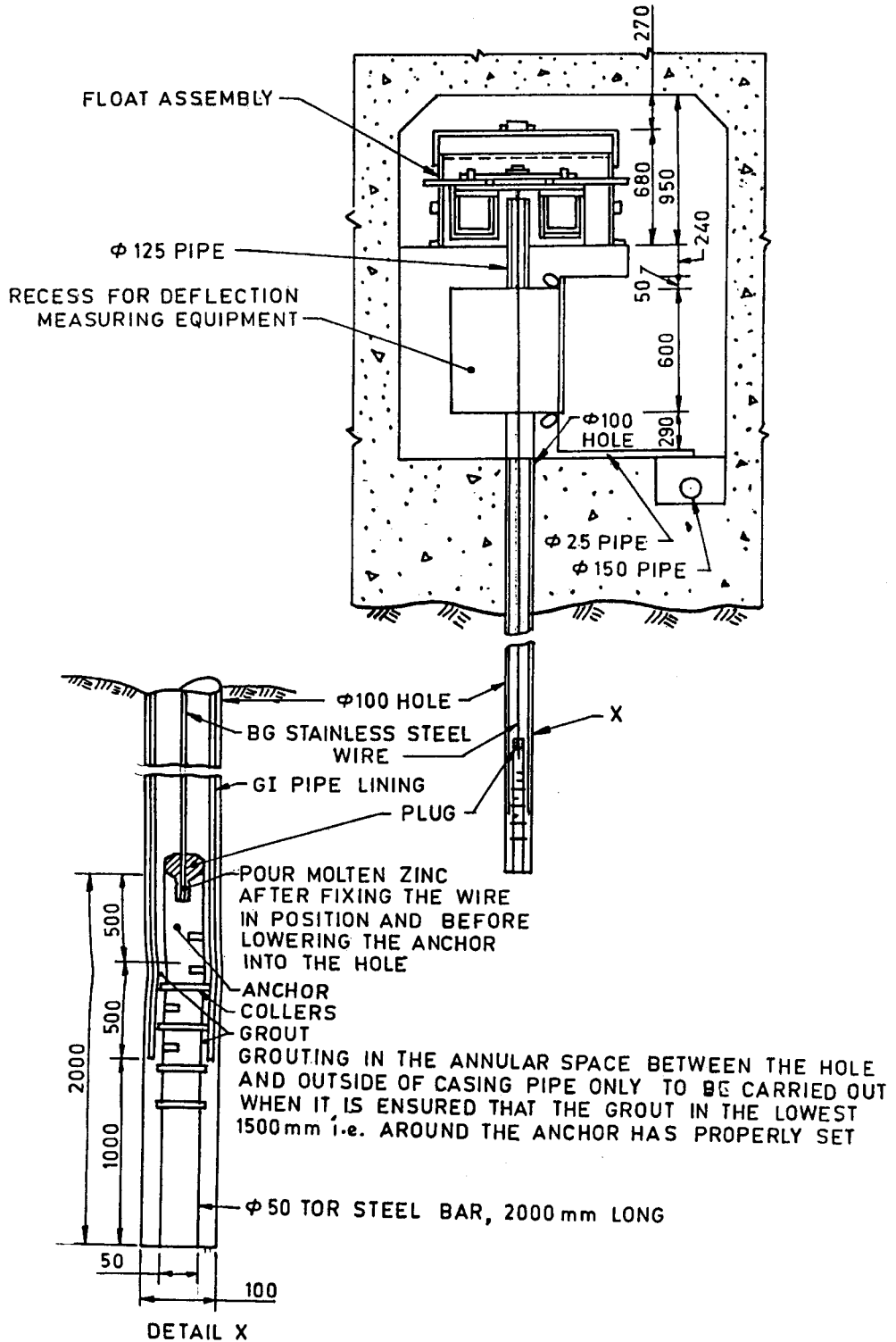
#### 10.4 Tank

The tank is cylindrical in shape and may be fabricated from steel. An upright cylindrical pipe of the same size as that of the plumb well should be welded centrally over the hole in the centre of the tank bottom, to provide continuity of the plumb well for extending the wire to the suspension point on the float. The height of the upright pipe should be such as to preclude over-topping when tank is filled with water to such specified level that the resulting position of the float in the water would cause 150 N/mm<sup>2</sup> of tension in the plumb wire.

The tank should be provided with airtight cover to prevent evaporation of water and tampering of float and suspension assembly. Suitable arrangement should be provided for lifting the tank for repositioning it in case the wire gets in contact with the above mentioned upright cylindrical pipe.

#### 10.5 Concrete Pedestal

Concrete pedestal of adequate size and height should be provided in the gallery for supporting the tank and



All dimensions in millimetres.

FIG. 4 INVERTED PLUMB LINE (DEFLECTION MEASURING EQUIPMENT AND SHEET COVERING NOT SHOWN)

float assembly ensuring vertical continuity of the plumb wire. The height of the pedestal should be sufficient to accommodate observation recess for installation of deflection measuring equipment for observation of the plumb wire.

#### 10.6 Anchorage Unit

This may consist of 37 to 50 mm diameter reinforcing steel bar, about 1.5 to 2 m in length with collars welded to it at suitable spacing to provide the desired anchorage action when grouted in position. Hole of suitable size and depth should be tapped centrally in the top portion of the rod for attachment of plumb wire.

### 11 METHOD OF INSTALLATION

For installation of deflection measuring equipment and suspension assembly (*see* 4.2). For installation of the reverse plum line, stainless steel wire, sufficiently in excess of the length, required for any specified location is wound on a reeling rack and the free end of the wire is passed through the hole in steel plug as mentioned in 4.2 and tied to a small nail and pulled tight. Molten lead or zinc is poured into the recess of

the plug. After the zinc has set, the plug is screwed into the tapped hole on top of the anchorage. The whole anchorage unit assembly is then lowered into the hole and positioned so that wire occupies central position of the net vertical opening of the hole. The grouting of the anchor should be done with a long pipe lowered up to a level of top of grout, that is 1.5 m above the bottom of the hole.

After the grout has set, grouting of the annular space between the casing pipe and the inside of the hole should be done.

The rest of the procedure of threading the plumb wire through collet and supporting the suspension spider is the same as described in 4.1 with the only difference being in this case, spider rests in the specified position on the float top instead of the concrete pedestal.

### 12 OBSERVATIONS, THEIR FREQUENCY, RECORD AND ANALYSIS OF DATA

The observations, their frequency, record and analysis of data are same as in 5 to 8. The deflections in this case are absolute.

## ANNEX A

*(Foreword)*

## COMMITTEE COMPOSITION

## Hydraulic Structures Instrumentation Sectional Committee, WRD 16

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National Hydro Electric Power Corporation Ltd, Faridabad	SHRI BRIJENDRA SHARMA ( <i>Chairman</i> )
AIMIL Ltd, New Delhi	SHRI S. P. GUPTA SHRI S. C. JAIN ( <i>Alternate</i> )
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Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

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### Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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