भारतीय मानक

कंक्रीट और चिनाई बाँधों में प्रतिवत्न मापन युक्तियां – संस्थापन, चालू करना तथा प्रेक्षण – रीति संहिता

Indian Standard

STRESS MEASURING DEVICES IN CONCRETE AND MASONRY DAMS — INSTALLATION, COMMISSIONING AND OBSERVATIONS — CODE OF PRACTICE

ICS 93·160

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

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Hydraulic Structures Instrumentation Sectional Committee, RVD 16

FOREWORD

This Indian Standard 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.

A stress meter is designed to measure total force over a sensing area. It is used for measurement of stresses in any direction depending upon its mounting.

Unbonded strain gauge type and vibrating wire type instruments are used for measuring the compressive stress in concrete and masonry dams. This standard covers details regarding both these types of instruments.

Indian Standard

STRESS MEASURING DEVICES IN CONCRETE AND MASONRY DAMS — INSTALLATION, COMMISSIONING AND OBSERVATIONS — CODE OF PRACTICE

1 SCOPE

This standard covers the details of installation, commissioning and observation procedures of unbonded strain gauge type and vibrating wire type stress meters in concrete and masonry dams.

2 REFERENCE

The Indian Standard IS 7436 (Part 2) : 1974 'Guide for types of measurements for structures in river valley projects and criteria for choice and location of measuring instruments: Part 2 Concrete and masonry dams' is a necessary adjunct to this standard.

3 INSTRUMENT

3.1 Unbonded Strain Gauge Type Stress Meter

3.1.1 Unbonded strain gauge type stress meter (*see* Fig. 1) consists of a mercury filled diaphragm shaped like a plate with a chamber that contains measuring unit protruding from one side. The diameter of sensing diaphragm is at least 12 times its thickness. The centre of the plate under measuring unit chamber is flexible

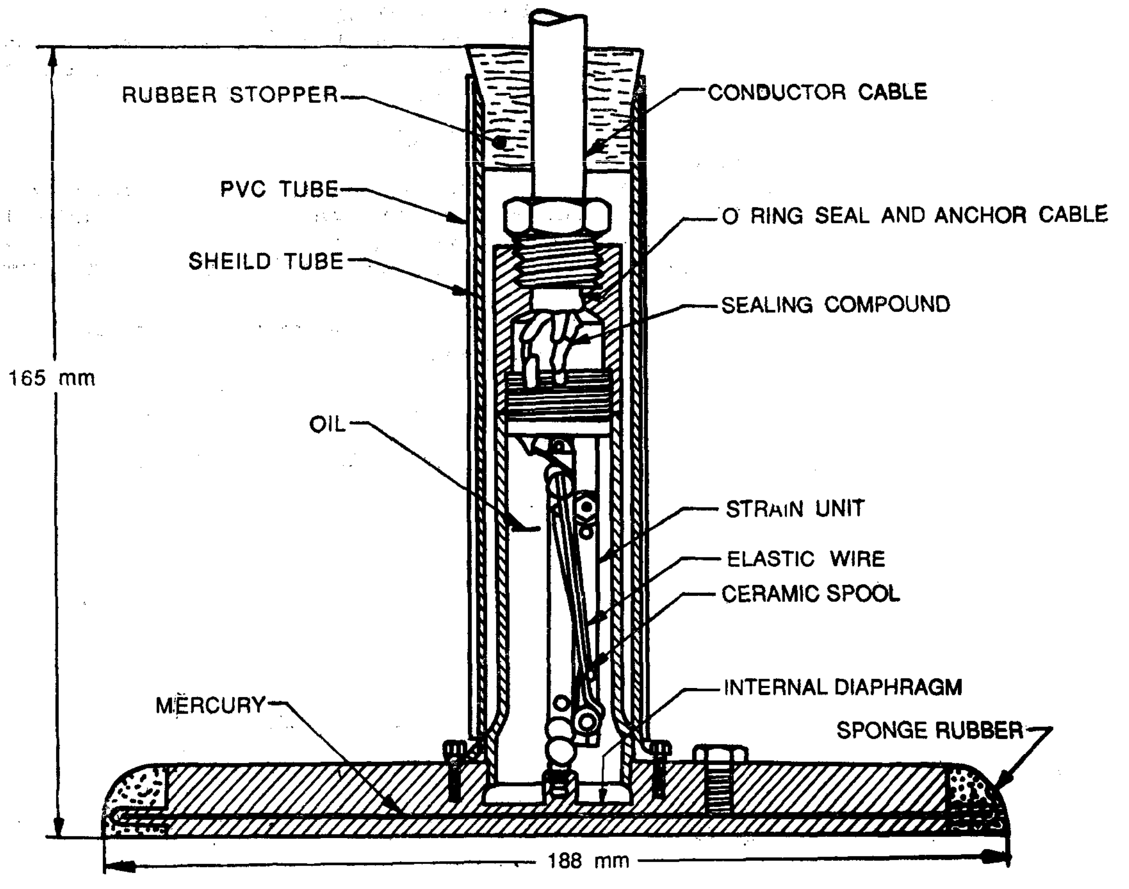

FIG. 1 TYPICAL UNBONDED STRAIN GAUGE TYPE STRESS METER

because of a cavity in the centre of the plate. The mercury causes plate to deflect elastically in direct proportion to the intensity of pressure on the diaphragm. The measuring unit consists of an unbonded strain gauge type strain meter which measures the intensity of stress. The variation in intensity of stress changes the resistances of the wires. The ratio of these resistances is a measure of stress. The change in resistance also occurs due to temperature. Hence, the temperature can be determined by measuring the total value of change of resistances of wires in series. Therefore, a requisite temperature correction needs to be applied to arrive at the actual stress value. The measurement readings should be taken by test set working on Wheatstone's bridge principle and recorded on a suitable data form.

3.2 Vibrating Wire Type Stress Meter

3.2.1 Vibrating wire type stress meter is a flat jack type device with pinch tube using vibrating wire principle (*see* Fig. 2). The device consists of a silicon oil filled flat jack connected by tube to a vibrating wire pressure transducer. A pinch tube is also provided connected to flat jack. The vibrating wire pressure transducer consists of a high strength steel wire, fixed to a diaphragm of the pressure transducer, which changes its vibration frequency as per stress applied to the flat jack and sensed as oil pressure operating on the pressure transducer diaphragm. A coil mag net assembly (*see* Fig. 2) is used to pluck or induce vibrations in steel wire. A digital read out unit which also supplies excitation signal to the coil magnet assembly, displays the frequency of vibrations. A calibration chart or an equation or a simple gauge factor supplied by the manufacturer is used to determine the stress from the frequency reading.

3.2.2 A stress meter using a circular plate similar to the one used in unbonded strain gauge type stress meter is also available with vibrating wire type strain gauge instead of unbonded strain gauge.

4 DETERMINATION OF NUMBER AND LOCATION

The locations for stress measurements in the representative blocks selected to install stress meters are generally decided by the designer of the dam in comparison to the strain meter locations. Generally strain meters are employed to detrmine stresses as the stress meters are costlier. However, stress determination from strain measurements is affected by factors such as temperature effect and autogeneous growth of concrete. Yet installation of stress meters on all points of interest is not economically viable when compared to installation of strain meters along with no-stress-strain meter. The optimum combination of strain meters and stress meters would be to install at least a stress meter close to the strain meter installation location (*see* IS 7436 [Part 2) : 1974].

5 INSTALLATION

5.1 Satisfactory operation of a stress meter is dependent almost entirely upon obtaining full contact between the meter plate surface and adjacent concrete. The installation procedure

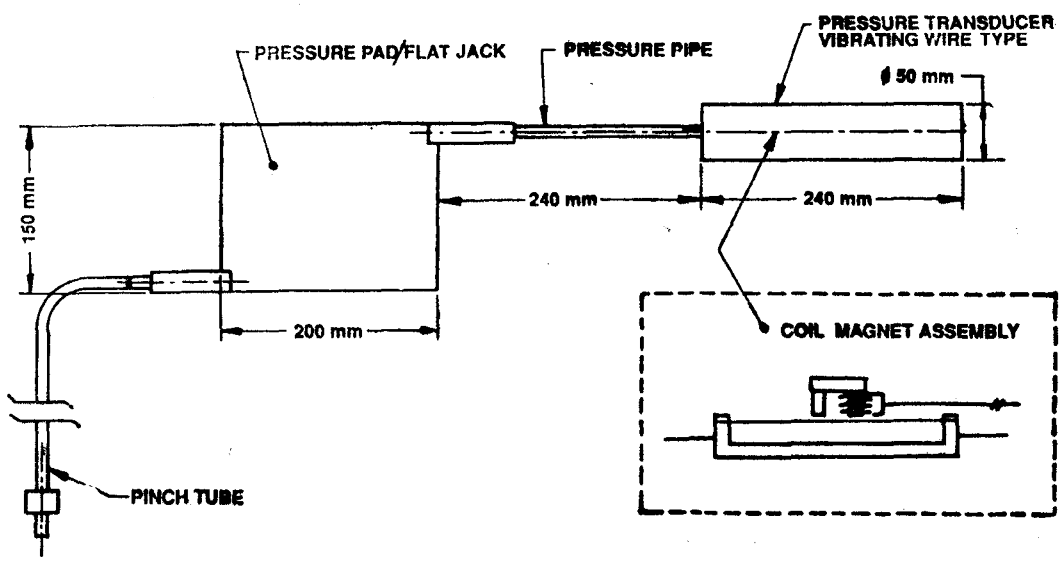

FIG. 2 VIBRATING WIRE TYPE FLAT JACK STRESS METER

used, therefore, shall avoid formation of air pockets and eliminate, as far as practicable, collection of water beneath the meter that may result from bleeding.

5.2 Installation of Unbonded Strain Gauge Type Stress Meter

5.2.1 The unbonded strain gauge type stress meter should be placed in horizontal (stem vertical) or vertical (stem horizontal) or sloping (stem sloping) position as described in **5.2.2** to **5.2.9.4**.

5.2.2 When concrete has reached an elevation 150 mm below the finished level of the proposed lift, stress meter cable should be laid up to the proposed location of the meter and embedded in concrete In order to avoid damage to the cable, before embedding its ends should be sealed with sealing compound and tape.

5.2.3 After concrete in the lift is complete and has initially set, a conical hole 300 mm at bottom and 900 mm at top should be dug in it at the proposed location of the stress meter. Care should be taken that the cable is not damaged while digging.

5.2.4 On the next day, after the concrete has hardened, the cavity should be cleaned to remove all the loose material and water. Projecting aggregate corners should be chipped away and brushed to ensure clean surface.

5.2.5 Now 6 mm thick layer of mortar consisting of one part cement and two parts sand finer than 600 micron sieve should be spread on the base of the hole and levelled. Excessive trowelling should be avoided. The mortar layer should be left as such for 1 1/2 hours.

5.2.6 The seal from the cable end should be removed and it should be spliced with the ends of the stress meter cable. The joint may be sealed properly with cable jointer.

5.2.7 Any water on the top of the mortar layer should be removed. A plastic mortar consisting of about 80 g of cement and 120 g of sand finer than 600 micron sieve should be prepared with just enough water to retain its plasticity. This mortar should be placed in a cone shape in the middle of the hole. Stress meter should now be placed on this mortar cone and pressed down with reciprocal rotary motion about vertical axis till meter is properly seated and there should be no possibility of air bubble or water pocket remaining below it.

5.2.8 The meter should be held firmly in place and the hole should be backfilled with concrete having 75 mm maximum size aggregate. The sides of the hole should be treated with mortar before concrete filling to ensure proper bond. Backfilling should be done in such a way that there is no dislocation or disturbance to the meter. Concreting should be finished 75 mm above the surface of the lift. It should be protected from traffic till the mortar is thoroughly set. Figure 3 illustrates the entire process of installation.

5.2.9 Stress meters could also be placed in vertical position (stem horizontal) within fresh concrete near top of the lift. In order to carry out this work steps given in **5.2.9.1** to **5.2.9.4** should be followed.

5.2.9.1 A hole of about 300 mm should be dug at the meter location after concrete placement in lift is completed.

5.2.9.2 The meter should be placed in position and fresh concrete should be placed around in thin layers. Cobbles, if any, should be removed. The place should then be tamped carefully but thoroughly.

5.2.9.3 Care should be taken to check alignment and position of the meter to ensure proper orientation and position as back filling progresses.

5.2.9.4 The area around this work should be protected till concrete is completely and thoroughly set.

5.2.10 Vibrating wire type device with circular plate, shown in Fig. 4, should be installed in the manner described in **5.2.9**.

5.3 Installation of Vibrating Wire Type Stress Meter

5.3.1 *Flat Jack Type Stress Meter*

5.3.1.1 The transducer or meter received at the site should be checked for its functionality by connecting the transducer cable terminals to the digital display unit. The unit should give frequency display for no stress applied to meter.

5.3.1.2 The place of installation and measuring direction for the stress meter should be determined on installation plan and its type and serial number be recorded on the plan.

5.3.1.3 The cable length for each stress meter should be determined according to installation plan and with 10 percent extra allowance.

5.3.1.4 Concrete in immediate vicinity of the flat jack should be free from coarse aggregates. Thus, before the filling process, the flat jack should be surrounded by fine grained concrete by hand, without leaving any hollow space so that full pressure acts on total surface of the

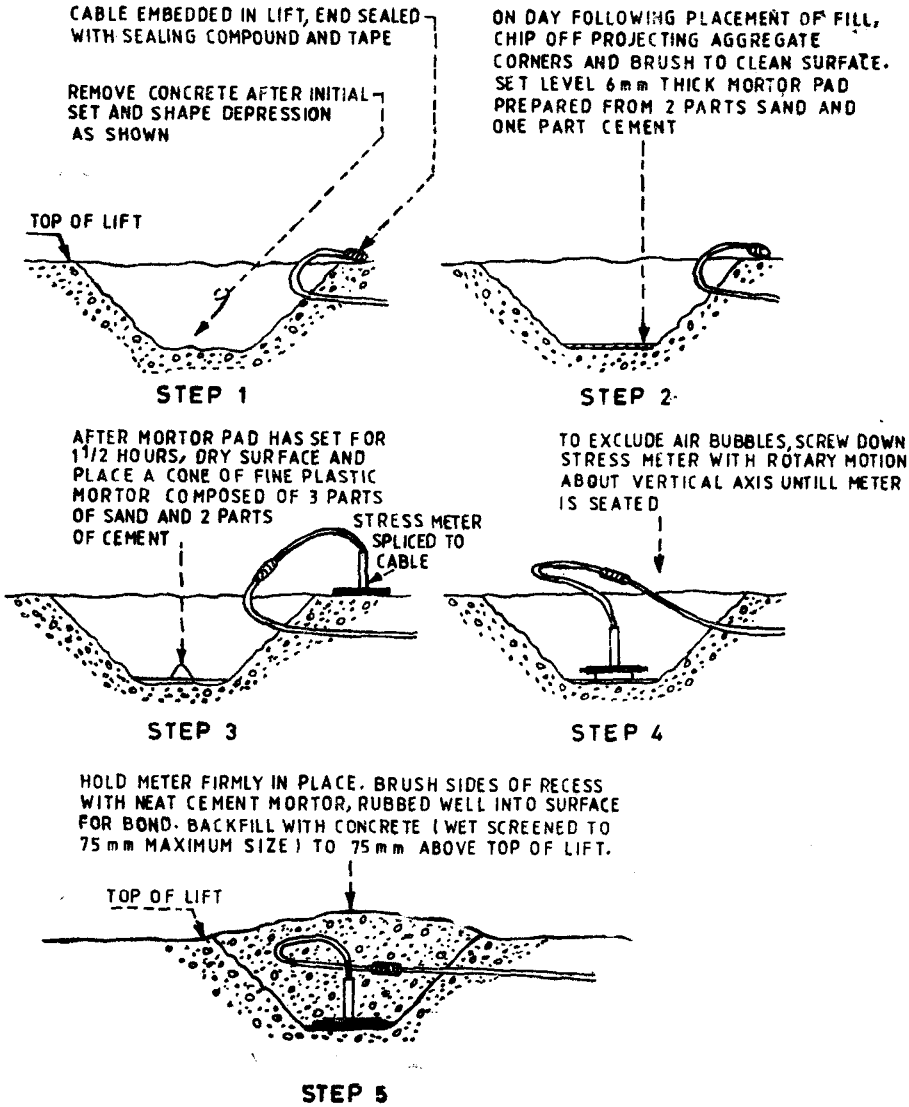

FIG. 3 INSTALLATION PROCEDURE OF UNBONDED STRAIN GAUGE STRESS METER

flat jack. Care should also be taken that the pinch tube is accessible till the lift is complete (*see* Fig. 5).

5.3.1.5 Cable should be covered by concrete as soon as possible in order to prevent damage to the cable as construction work progresses.

5.3.1.6 While setting, the concrete of the first filling or lift may cause a gap around the flat jack due to shrinkage. The flat jack may be inflated to bridge the gap.

5.3.1.7 The pinch tube provided with the flat jack should have sufficient length, so that after first filling of concrete over the stress meter, a length of about 50 cm is available for pinching.

5.3.1.8 The pinching should be started at the tip of the tube.

5.3.1.9 The stress meter should be connected to readout instrument during the process of pinching. Frequency reading should be monitored during the process. When the flat jack makes contact with concrete, there will be sudden change in reading. This new reading should then be recorded.

5.3.1.10 The cable routing should be determined in advance on cable installation plan.

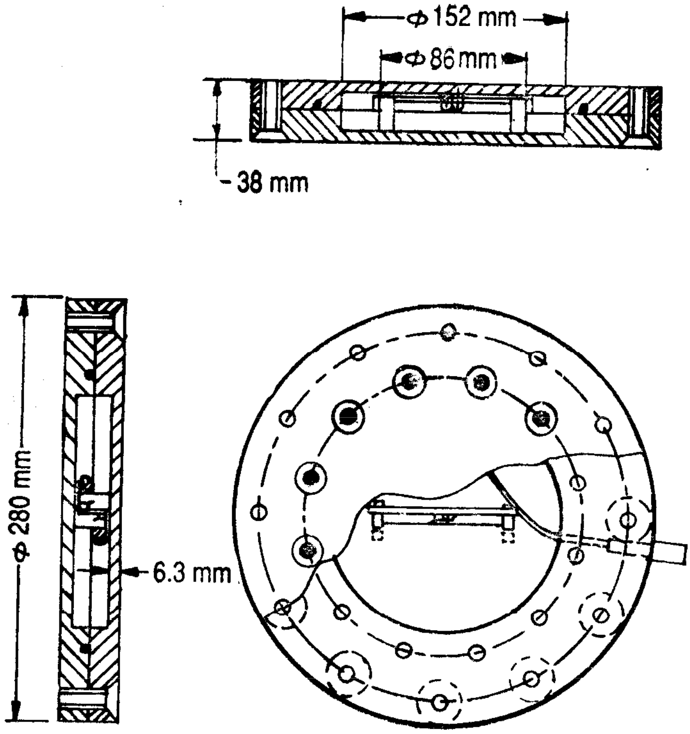

FIG. 4 SECTION THROUGH VIBRATING WIRE TYPE STRESS METER WITH CIRCULAR PLATE

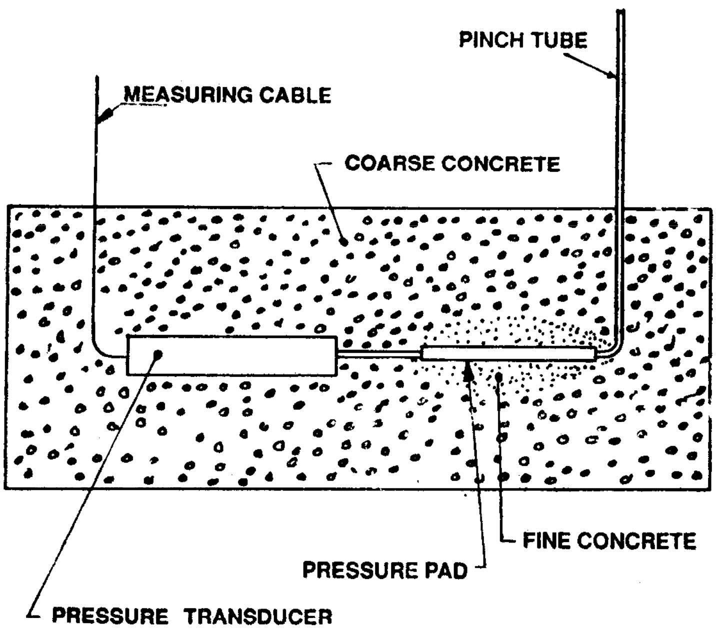

FIG. 5 INSTALLATION OF THE FLAT JACK STRESS METER

5.3.1.11 Cable should not be exposed on open ground without necessary and sufficient protection. An open cable is dangerous as it may act as aerial with a danger of impermissibly high voltage getting induced in the cable by atmospheric discharges during rainy season. It may be advisable to have built-in over-voltage protection inside the transducer.

5.3.1.12 The cable may be placed loose in wave line fashion.

5.3.1.13 If necessary, the cable may be protected by flexible high pressure hose or tube.

5.3.1.14 The free ends of the installed cable should be terminated immediately in watertight distribution boxes. Care should be taken not to leave cable ends on open ground. In case cable ends cannot be connected to distribution boxes immediately it may be protected by protective cap and appropriate compound (*see* Fig. 6).

5.4 Identification of Cables and Stress Meters

5.4.1 Each stress meter should be identified by a letter prefixed, designating the type of instrument and numbered subsequently. The normal prefix letters used for stress meter are 'SM'. The instrument identification number is stamped or punched on a band which is crimped to the cable about 900 mm from the stress meter end. A similar band is crimped about 300 mm from the free end of the cable. In addition, a few more markers consisting of the identification number marked on white tape and covered with linen and friction tape, should be placed around the cable near the free end.

5.5 Terminal Boards

5.5.1 *Location of Terminal Boards*

5.5.1.1 Permanent facilities for terminating the cable ends and for taking readings should be provided. These should be provided as terminal boards and should be usually located in blockouts on walls of galleries nearest to the group of instruments. The reading stations for all embedded instruments in a monolith should be located in that monolith as far as possible, in order to avoid running cable leads across contraction joints. Separate terminal board recesses for different types of instruments may be required. Where a gallery or similar semi-protected location is not available, conveniently accessible exterior location may be selected, and the facilities secured against unauthorised tampering.

5.5.2 *Lighting*

Normal gallery lighting may not be usually adequate and a supplementary fixture for lighting should be provided at the terminal board station.

5.5.3 *Protection from Moisture*

To reduce corrosion at the cable terminals and terminal board connections, usually a serious problem in dam galleries, an electrical strip heater or incandescent lamp, which is to be kept permanently on, should be installed within the terminal board recess. A bulb provided in the recess for lighting may also serve this purpose.

5.5.4 *Installing Terminal Equipment*

After all cable leads have been brought into a terminal board recess, surplus lengths of cables should be cut off and the end of individual conductors prepared for permanent connection to the panel board or terminal strip. Proper care should be taken for identification of the cables and meters.

6 COLLECTION OF COMPLEMENTARY DATA

6.1 Collection of related and supporting data pertaining to structural behaviour is an integral part of the instrumentation programme and

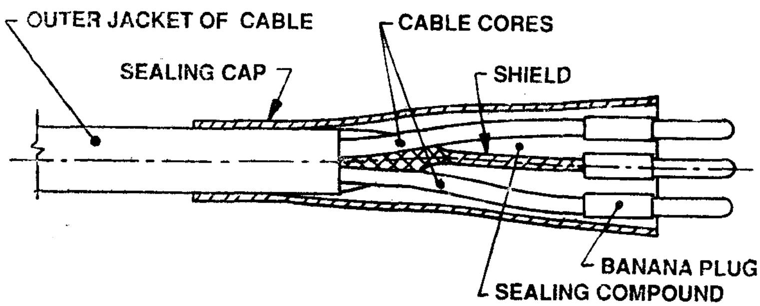

FIG. 6 CABLE END PROTECTION

should proceed concurrently with the installation of the instruments and the readings of the embedded instruments. Types of information required to support or clarify the instrument observation results include the following:

a) *Construction Progress* — Schematic concrete or masonry placing chart showing lift placement dates, concrete placing temperatures and lift thickness.

b) *Concrete Mixes* — Cement contents, water-cement ratios and typical combined aggregate gradings for interior and exterior mixes.

c) *Fine Aggregate* — Typical fine aggregate gradings before and after mixing.

d) *Air Entrained* — Amount of entrained air, admixture used, how introduced.

e) *Cement Type* — Source of procurement, physical and chemical properties, including heat of hydration.

f) *Aggregates* — Types, geologic classification, petrographic description, sources, and chemical properties.

g) *Curing and Insulation* — Type and method of curing, type, location and duration of insulation protection, if any.

h) *Pool Elevations* — Daily reservoir and tail-water elevations.

j) *Foundation Conditions* — Final rock elevations, unusual geological features.

Most of the information listed above may be usually available from investigations carried out prior to and during the project design stage or may be obtained under usual construction control operations.

6.1.1 Observers should be alert to detect cracks or similar evidences of structural distress which may develop, and record time of occurrence, initial size and extent, and subsequent changes in size and extent, and any corrective action taken.

7 OBSERVATIONS

7.1 The test set working on Wheatstone's Bridge principle may be used to measure ratio of resistances and series resistance of the stress meter of unbonded strain gauge type. The test set should have accuracy to measure a ratio up to 0·01 percent and resistance up to 0·01 ohm respectively.

7.2 A digital readout unit should be used for recording observations of vibrating wire type stress meter.

7.3 Frequency of Reading

The maximum interval between the successive readings should be as below:

Periods	*Suggested Maximum Interval Between Readings*
1) *During construction*:	
On installation of meter	
First 24 hours	3 hours
Next 24 hours	6 hours
Thereafter for next 14 days	Daily
Thereafter	1 week
During temporary halt in construction	1 month
2) *During initial filling*:	1 week
3) *During operation*:	
First year	15 days
Thereafter for next 5 years	1 month
Thereafter	3 months

NOTE — The interval between successive readings as suggested above is the maximum interval that should be adopted under normal conditions. The intervals should be suitably changed in case of unusual occurrences like earthquakes, floods, etc.

8 RECORD OF OBSERVATIONS AND METHOD OF ANALYSIS

8.1 The observations taken should be suitably recorded. Rocommended proformae for the record of observations and transfer of observations on permanent record in the office are given in Annex A, B and C for unbonded strain gauge type and in Annex D, E and F for vibrating wire type stress meters. The data sheet forms may be got printed in advance upon which the observations can be noted as they are taken and for preparation of permanent record. A method of analysis of data obtained by the observations of embedded meters is given in Annex C.

8.2 Calibration data should be supplied by the manufacturer. Calibration constant of unbonded strain gauge type meters as indicated by the manufacturer should be revised when longer conductor cables are used. The conductor cable introduces an extra resistance which does not change with stress, thus making the meter less sensitive. The equation for revising the calibration constant for stress meter is:

$$C' = C + \frac{YC}{R}$$

where

C' = new calibration constant,

C = original calibration constant,

Y = resistance of a pair of conductor cables, and

R = stress meter resistance at approximate temperature to be expected after embedment.

When these types of stress meters are used with an automatic data acquisition or logging system, it is customary to use the calibration constant in terms of voltage change across full bridge instead of ratio change. The conversion equation is:

$$C'' = \frac{25}{C'}$$

where

C'' = new calibration constant in terms of micro volts change per volt of excitation per micro-strain, and

C' = ordinary calibration constant on the resistance ratio basis.

8.3 Vibrating Wire Type Stress Meters

8.3.1 *Zero Reading*

8.3.1.1 Frequency reading should be recorded immediately after the end of pinching process. It is always advisable to record the zero reading when meter has reached a state of stable temperature balance with its surroundings. The cable length has no effect on frequency reading of meters.

8.3.2 *Measurement and Evaluation*

8.3.2.1 Measurements are carried out at the intervals specified in **7.3** during various stages of construction and after.

8.3.2.2 The formula generally used for evaluation of stress in N/m² from frequency reading is:

$$\text{Stress} = K (F_0^2 - F^2) + A$$

where

K = Gauge factor of the meter in N/m² per Hz²;

F_0 = Initial frequency, zero frequency reading in Hz;

F = Final frequency reading in Hz; and

A = Intercept of the best fit curve given by the manufacturer or supplier.

9 SOURCES OF ERRORS

9.1 The following sources of errors should be guarded against while taking measurement by unbonded resistance strain gauge type stress meter and vibrating wire type stress meter:

a) Low voltage of test set batteries (for Wheatstone Bridge type instruments);

b) Loose connections in test set terminals;

c) Loose connections of cable terminals on terminal boards;

d) Imperfect cable splice, resulting from improper matching of individual conductors, improper soldered connections or splice not rendered moisture proof; and

e) Earthing of the readout unit not being perfect.

ANNEX A

(*Clause* 8.1)

PROFORMA FOR THE RECORD OF OBSERVATIONS OF UNBONDED STRAIN GAUGE TYPE STRESS METERS — PRE-EMBEDMENT TESTS

Project...................

Instrument No. ....

Manufacturer's No. ......

Project No. ....

Location.........................

Air temperature.........

Wet bulb temperature.........

1 RESISTANCE BEFORE CABLE SPLICING

i) White-black

ii) White-green

iii) Green-black

iv) Resistance one pair

2 RESISTANCE RATIO (INSTRUMENT ONLY)

i) Direct ratio (white-green-black)

ii) Reverse ratio (black-green-white)

3 INDIVIDUAL CONDUCTOR RESISTANCE

i) Length

ii) Black

iii) Green

iv) White

4 RESISTANCE OF INSTRUMENT AFTER CABLE SPLICING

i) White-black

ii) White-green

iii) Green-black

iv) Resistance one pair

5 RESISTANCE RATIO (INSTRUMENT WITH CABLE)

i) Direct ratio (white-green-black)

ii) Reverse ratio (black-green-white)

Date of test :

Date of embedment :

NOTES :

Name and signature of observer

ANNEX B

(*Clause* 8.1)

PROFORMA FOR THE RECORD OF OBSERVATIONS OF UNBONDED STRAIN GAUGE TYPE STRESS METERS — FIELD READINGS AFTER EMBEDMENT

Project.................................

Zero Reading

Instrument No.	Previous Reading			Current Reading				Reservoir Level m	Observer's Signature
	Date	Resistance (in ohms)	Resistance Ratio	Date	Time	Resistance (in ohms)	Resistance Ratio		

ANNEX C

(*Clause* 8.1)

PROFORMA FOR PERMANENT RECORD OF OBSERVATIONS OF UNBONDED STRAIN GAUGE TYPE STRESS METERS — PERMANENT RECORD

Project .... Sheet No. ....

Stress Meter No. .... Location......................

Calibration Data:

Meter resistance at 0 degree C (A)...ohms (B)

Change in temperature per ohm change in resistance.................................degree C (C)

Ratio at zero stress..% (percent)

Original calibration constant..........................N/m² (kg/cm²) per 0·01% ratio change

Calibration constant corrected for leads.................N/m² (kg/cm²) 0·01% ratio change (D)

Resistance of leads at..............................degree C .... ohms (pair)

Temperature corrections— $[(80\ T/D + 6{\cdot}7)\ 10^{-6} - K] \times E \times F$

80 T/D =

K =

F =

Date	Time	Total Resistance ohms	Lead Resistance ohms	Meter Resistance ohms	Temperature °C	Resistance Ratio Percent	Change in Ratio Percent	Indicated Stress N/m² (kg/cm²)	Estimated 'E' N/m² (kg/cm²)	Correction per °C	Total Temperature Correction	Actual Stress N/m² (kg/cm²)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)

Explanation for columns including analysis:

col 3 Total resistance of meter as measured in the field, with a 4-conductor cable the meter resistance is measured directly, and this column may be left blank.

col 4 Resistance of the white and black conductors, as measured directly during the splicing operation. As an alternative, a reasonably accurate value for lighting may also serve this purpose.

col 5 Resistance of meter excluding cable leads. It is obtained by subtracting col 4 from col 3.

col 6 Temperature of the meter obtained by subtracting (B) from the cell resistance in col 5, multiplying the difference by (C) and adding the product to (A).

col 7 The resistance ratio of the meter as measured with the test set.

col 8 Total change in resistance ratio (col 7) from a selected initial value, usually the first reading after the concrete masonry has hardened or at about 24 h age. Proper algebraic sign should be shown.

col 9 Multiply value in col 8 by corrected calibration constant (D). Negative values of the ratio changes (col 8) indicate positive pore pressures. Except for minor ratio variation prior to the development of significant pore pressures, the cell will not respond reliably to negative pressures, and all entries in col 9 will represent pore pressure above the oil pressure in the cell chamber which will be approximately atmospheric.

col 10 It is a sustained modulus of elasticity of the concrete as estimated from the laboratory test or from data or other sources. So, it is the reduced modulus of elasticity including the effect of creep with the duration of time for which the temporary correction is being applied. This sustained modulus will often be as low as half the ordinary modulus of elasticity.

col 11 It is correction per degree celsius of change as computed from the equation given in the heading of the sheet.

col 12 It is the total temperature correction for the number of degrees temperature to which it applies. Note that the reference temperature is that 24 hours age in this case. Before that age the concrete is too soft to support such stress and the correction is considered to be negligible. In rich concrete and specially when curing temperature is ensured, the reference temperature need to be taken at 12 hours or some earlier time. This choice makes very little difference and is, therefore, not improved.

col 13 It is the actual stress after applying the temperature correction given in col 12 to the indicated stress given in col 9. Care should be taken to observe the sign of the stress and the correction. The reduction in the resistance ratio means a compressive stress and the temperature correction should be applied so as to reduce the indicated compressive stress when the temperature rises, and vice versa.

ANNEX D

(*Clause* 8.1)

PROFORMA FOR THE RECORD OF OBSERVATIONS OF VIBRATING WIRE TYPE STRESS METERS — PRE-EMBEDMENT TESTS

Project :

Barometric pressure :

Air temperature

Wet bulb temperature :

Project No. ....

Manufacturer ....

Location ....

Date ....

Time ....

Instrument Details :

1. Model No. ....
2. Sl No. ....
3. Instrument No. ....
4. Gauge Factor (K) ....
5. Intercept (A) ....
6. Zero reading frequency ....
7. Date of embedment ....

Explanation of Instrument Details :

1. Model No. given by supplier ....
2. Sl No. given by supplier ....
3. Instrument No. as mentioned in location plan by project. — say SM 12 ... .
4. Gauge factor K, given by manufacturer, in $N/m^2/Hz^2$ or $kg/cm^2/Hz^2$ ....
5. Intercept A, given in N/m^2 ....
6. Zero reading frequency before embedment ....

ANNEX E

(*Clause* 8.1)

PROFORMA FOR RECORD OF OBSERVATIONS OF VIBRATING WIRE STRESS METERS — FIELD READINGS

Project :

Instrument No.	Date	Zero Reading Frequency in Hz	Current Reading Frequency in Hz	Reservoir Level in m	Observer's Signature
1	2	3	4	5	6

ANNEX F

(*Clause* 8.1)

PROFORMA FOR RECORD OF OBSERVATIONS OF VIBRATING WIRE TYPE STRESS METERS — PERMANENT RECORD

Project ....   Sheet No. ....

Instrument ....   Location ....

Calibration Data ....

1. Gauge Factor (K) .... N/m^2 or $kg/cm^2/Hz^2$
2. Intercept (A) .... N/m^2 or kg/cm^2
3. Stress in N/m^2 = or kg/cm^2 $K(Fo^2 - F^2) + A$
4. Fo :   Zero frequency readings in Hz
5. F :   Current frequency readings in Hz

Date	Time	Frequency Reading in Hz	Derived Value of Stress in N/m^2 or kg/cm^2	Remark
1	2	3	4	5

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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 VIII M, V. I. P. Road, Maniktola CALCUTTA 700054	37 84 99, 37 85 61 37 86 26, 37 86 62
Northern : SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 38 43, 60 20 25,
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

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