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USERS' MANUAL

VIBRATING WIRE STRAIN GAGE

MODEL EDS-20V-E EMBEDMENT TYPE



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Contents

1	INTRODUCTION	1
1.1	Features	1
1.2	Applications	1
1.3	Conventions used in this manual	2
1.4	How to use this manual	2
2	VIBRATING WIRE STRAIN GAGE	3
2.1	Operating principle	3
2.2	General description	3
2.3	Cable	4
2.4	Taking readings with the model EDI-54V vibrating wire indicator	5
2.5	Tools & accessories	5
2.6	Sample test certificate	6
3	INSTALLATION PROCEDURE AND TROUBLESHOOTING	7
3.1	Preparation of the sensor before installation	7
3.2	Extension of cable	7
3.3	Installation and positioning of embedment type strain gages	8
3.3.1	Piles and drilled shafts	8
3.3.2	Segmental lining for machine bored tunnels	9
3.3.3	Pre-cast model EDS-20V-E strain gage in a mould before embedment	9
3.3.4	Embedment procedure for single strain gage in mass concrete	10
3.4	Taking initial reading	11
3.5	Care of cable	12
3.6	Lightning protection	13
3.7	Trouble shooting	13
3.7.1	Symptom: Strain gage reading unstable	13
3.7.2	Symptom: Strain gage fails to give a reading	14
4	GENERAL CONSIDERATIONS	15
4.1	Conversion of reading to strain changes	15
4.2	Stress strain relationship	15
4.3	Strain gages for specific applications	15
5	THERMISTOR - TEMPERATURE RESISTANCE CORRELATION	16
5.1	Temperature resistance equation	16
5.2	Temperature effect	17
6	WARRANTY	18

1 INTRODUCTION

Encardio-rite model EDS-20V-E strain gage is intended primarily for strain measurement. It is mainly used in pile foundations, segment lining of tunnels, rafts and concrete structures etc.

The strain gage incorporates the latest vibrating wire technology to provide digital readout on a remote vibrating wire indicator or data acquisition system on magnitude and distribution of compressive and tensile strain in concrete structures and other areas of application where strain measurement is required. As an Encardio-rite convention, the '+' sign indicates tensile strain and the '-' sign indicates compressive strain. Main purpose of the strain gage is to indirectly quantitatively determine stress and its variation with time. Change in stress is obtained by multiplying the measured strain by modulus of elasticity. It can measure strains up to 3000 μ strain.

The gage has a very high compliance requiring less than 3 kg of force to tension the wire by 3000 μ strain. All gages have the vibrating wire pre-tensioned ready for use. Encardio-rite has two different models also, model EDS-11V and model EDS-21V-E (when high range strain is required).

1.1 Features

Encardio-rite model EDS-20V-E is the electrical strain gage of choice as its frequency output is immune to external noise, it is able to tolerate wet wiring common in geotechnical applications and is capable of transmission of signals to long distances. It has the following features:

- Thermally aged to minimize long term drift
- Rugged and reliable
- Can be used for embedment in soil or concrete.

The advantage of the vibrating wire strain gage over more conventional electrical resistance (or semiconductor) types lies mainly in the use of a frequency, rather than a voltage as the output signal from the strain gage. Frequency may be transmitted over a long cable length without appreciable degradation caused by variations in cable resistance, contact resistance, or leakage to ground.

The thermal coefficient of expansion of the embedment strain gage is near about that of concrete. Corrections for temperature variation are therefore seldom required (in field use). In case correction is required for any specific application, it is best to embed a strain gage from the same batch in a representative concrete block and conduct actual temperature tests under controlled conditions. The difference in thermal coefficient of expansion so obtained can then be applied as a temperature correction.

For conditions requiring temperature measurement, a thermistor is permanently encapsulated inside the plucking coil assembly.

1.2 Applications

Several strain gages embedded at the same site at different angles and places can also be used to measure plane and three dimensional stress.

As concrete exhibits autogenous growth due to thermal effects, creep, chemical reaction and change in moisture content etc., stress measurement by the strain gage may need to be corrected by mounting an additional strain gage near the existing ones in no stress conditions.

This user's manual covers description of the vibrating wire strain gage & its accessories, procedure for embedment of sensor in a concrete structure, method of taking observations and recording data.

NOTE: The strain gage is not suitable for measurement of dynamic strain.

1.3 Conventions used in this manual

WARNING! Warning messages calls attention to a procedure or practice, that if not properly followed could possibly cause personal injury.

CAUTION: Caution messages calls attention to a procedure or practice, that if not properly followed may result in loss of data or damage to equipment.

NOTE: Note contains important information and is set off from regular text to draw the users' attention.

1.4 How to use this manual

This users' manual is intended to provide you with sufficient information for making optimum use of vibrating wire strain gages in your applications.

NOTE: The installation personnel must have a background of good installation practices and knowledge of the fundamentals of geotechnics. Novices may find it very difficult to carry on the installation work. The intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

A lot of effort has been made in preparing this instruction manual. However the best of instruction manuals cannot provide for each and every condition in the field, which may affect the performance of the sensor. Also, blindly following the instruction manual will not guarantee success. Sometimes, depending upon field conditions, the installation personnel will have to consciously depart from the written text and use their knowledge and common sense to find the solution to a particular problem.

To make this manual more useful we invite your valuable comments and suggestions regarding any additions or enhancements. We also request you to please let us know of any errors, that you may find while going through this manual.

The manual is divided into a number of sections. Each section contains a specific type of information. The list given below tells you where to look for in this manual if you need some specific information.

For understanding the principle of vibrating wire strain gage: See § 2.1 'Operating principle'.

For description of the strain gage and accessories available: See § 2.2 'General description'.

For operating Vibrating wire readout unit: See 'Doc. # WI 6002.112'

For accessories: See § 2.3 'Specifications'.

For installation of strain gage: See § 3 'Installation procedure and trouble shooting'.

For computing structural load or stress: See § 4.2 'Stress strain relationship'.

For temperature measurement by thermistor: See § 5 'Thermistor - temperature resistance correlation'.

2 VIBRATING WIRE STRAIN GAGE

2.1 Operating principle

The vibrating wire strain gage basically consists of a magnetic, high tensile strength stretched wire, one end of which is anchored and the other end is displaced proportionally to the variation in strain. The stretched wire is thermally aged to minimize long-term drift and changes in calibration.

The strain gage works on the principle that if a coil/magnet assembly plucks a fixed length stretched magnetic wire; its frequency of vibration is proportional to the tension in the wire. Any change in strain, directly affects the tension in the wire, resulting in a corresponding change in its frequency of vibration. The strain is proportional to the square of the frequency that can be measured and displayed directly in μ strain by Encardio-rite's EDI-54V vibrating wire indicator.

The wire is plucked by a coil magnet. Proportionate to the tension, the wire resonates at a frequency 'f', which can be determined as follows:

$$f = [\sigma g / \rho]^{1/2} / 2l \text{ Hz}$$

Where: σ = tension of wire in kg/cm²
 g = 980 cm/sec²
 ρ = density of wire in kg/cm³
 l = length of wire in cm

The relationship between stress, strain and the modulus of elasticity can be expressed as $\sigma/\epsilon = E$. The length of the wire in the strain gage is 15 cm, the centre distance between the annular end blocks is 14.9 cm and $E = 2.11 \times 10^6$ kg/cm². Consequently the formula can be reduced to:

$$\epsilon_{15} = 4.051 \times 10^{-3} f^2 \mu \text{ strain}$$

To summarize, any variation in strain causes the strain gage to deflect. This changes the tension in the wire thus affecting the frequency of vibration of the wire when it is vibrating at its natural frequency. The strain is proportional to the square of the frequency and the read out unit is able to display this directly in μ strain.

NOTE: The value $4.051 \times 10^{-3} \mu$ strain/Hz² is known as the effective gage factor of the strain gage. It varies within limits from batch to batch. For the correct "effective gage factor" of the strain gages supplied to you, please refer to the batch test report provided.

The modulus of elasticity of the strain gage is very low and the magnetic strain gage plucking wire in it precisely follows the deflection of the concrete structure (or the steel section or rock surface) on which the strain gage is mounted. It is not affected by the material or the coefficient of thermal expansion of the strain gage element or its body.

NOTE: The coefficient of thermal expansion of the magnetic plucking wire used in all Encardio-rite vibrating wire sensors is 11.0 ppm per °C.

2.2 General description

A strain gage is used where a load cell cannot be conveniently interposed to measure stress in a structure for reason of geometry, capacity or economy and where load and stress can be worked out with reasonable accuracy from knowledge of the relationship between stress and strain (modulus of elasticity). In such a case, it is very convenient to have a strain gage, which can be embedded in the concrete structure.

The Encardio-rite vibrating wire strain gage basically consists of a high tensile strength wire made out of a magnetic material stretched between two stainless steel cylindrical end blocks. The wire is sealed in a stainless steel tube by a set of double "O" rings fixed on each end block. This to a great extent ensures resistance to corrosive, humid, wet and other hostile environmental conditions. Further protection is

provided by suitably sealing the joints with heat shrinkable tubes. In addition to this, a special water proofing compound seals the plucking coil in the sensor assembly from any ingress of water. The sensor assembly in the model EDS-20V-E is consequently supplied integral with the rest of the gage.

The tube is flattened in the middle to accommodate a sensor (coil/magnet assembly) in the constriction. The displacement of the end blocks is always proportionally to the variation in strain. Any change in the strain directly affects the tension of the wire, resulting in a corresponding change in frequency of vibration of the wire. The change in the frequency of the vibrating wire is accurately measured by a vibrating wire indicator calibrated to indicate the strain. All vibrating wire sensors manufactured by Encardio-rite use the same vibrating wire indicator irrespective of the parameter being measured.

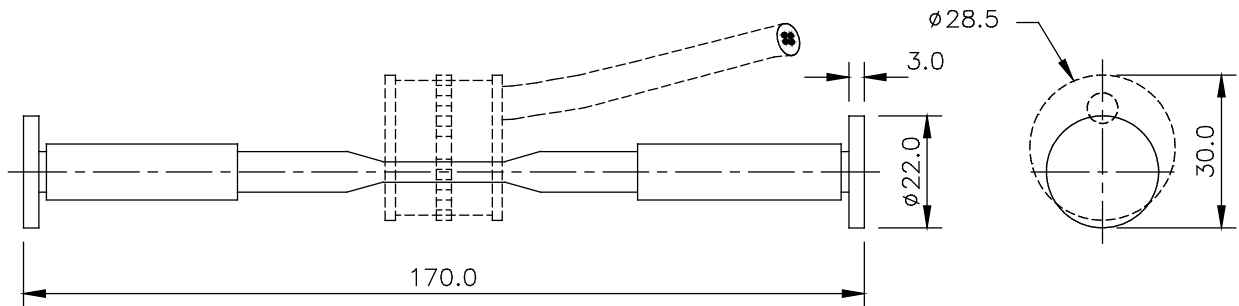


Figure 2.1 - dimensional details

For a sectional view of the strain gage refer to figure 2.2

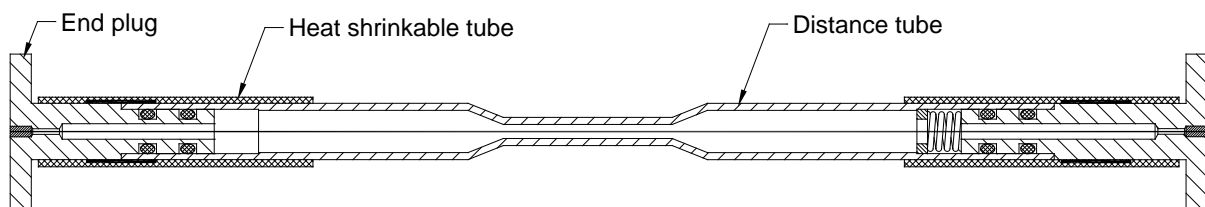


Figure 2.2 – Sectional View

The model EDI-54V vibrating wire indicator, used in conjunction with the vibrating wire strain gage, will provide the necessary voltage pulses to pluck the wire and will convert the resulting frequency reading directly into strain units by means of an internal microprocessor.

2.3 Cable

Four core PVC insulated shielded cable, CS-1303 suitable for upto 60°C standard or CS 0404 suitable for upto 80°C on request. Colour code is as follows:

Red/Black	VW sensor
Green/White	Thermistor

Sometimes it is easier to terminate cables from several strain gages in a junction box and carry the signals to the observation station or multiplexer collectively through a multi core cable. Standard junction boxes are available from Encardio-rite for this purpose. If required, lightning protection can also be provided in the junction box or even otherwise. Refer to § 3.6.

2.4 Taking readings with the model EDI-54V vibrating wire indicator

The model EDI-54V vibrating wire indicator (figure 2.3) is a microprocessor-based read-out unit for use with Encardio-rite's range of vibrating wire sensors. It can display the measured frequency in terms of time period, frequency, frequency squared or the value of measured parameter directly in proper engineering units. It uses a smartphone with Android OS as readout having a large display with a capacitive touch screen which makes it easy to read the VW sensor.

The EDI-54V vibrating wire indicator can store calibration coefficients from 10,000 vibrating wire sensors so that the value of the measured parameter from these sensors can be shown directly in proper engineering units. For transducers with built-in interchangeable thermistor, it can also display the temperature of the transducer directly in degree Centigrade.

The vibrating wire indicator has an internal non-volatile memory with sufficient capacity to store about 525,000 readings from any of the programmed sensors. Each reading is stamped with the date and time the measurement was taken.

Refer instruction manual WI-6002.112 of model EDI-54V for entering the transducer calibration coefficients. The gage factor of the model EDS-20V-E embedment strain gage is given in the batch test certificate provided with every supply of strain gage. The initial reading IR will be the actual reading in digits from the strain gage after it is embedded and properly set in concrete.

An internal 6 V 4 Ah rechargeable sealed maintenance-free battery is used to provide power to the vibrating wire indicator. A battery charger is provided to charge the internal battery which operates from 90 V to 270 V AC 50 or 60 Hz V AC mains. A fully discharged battery takes around 6 hours to get fully charged. The indicator uses a smartphone as a readout that has its own internal sealed rechargeable Li-ion maintenance battery as a power source. A separate battery charger/adaptor unit for the smartphone, operating from universal AC mains supply is supplied with each EDI-54V indicator unit.

The EDI-54V vibrating wire indicator is housed in an impact resistant plastic moulded housing with weatherproof connectors for making connections to the vibrating wire transducer and the battery charger.

2.5 Tools & accessories

The following tools and accessories are recommended for proper installation of the strain gage:

- Temperature controlled soldering iron 25 Watt
- 63/37 rosin core solder wire
- Acetone (commercial)
- Hacksaw with 150 mm blade
- Cable cutter, Wire stripper
- Surgical blade with holder
- Pliers 160 mm
- Digital multimeter
- Vibrating wire indicator (EDI-54V)



Fig 2.3 – EDI-54V Vibrating wire indicator

2.6 Sample test certificate

Calibration certificate

Type : Embedment type water proof strain gages

Model : EDS-20V-E

Range : $\pm 1500 \mu$ -strain

Mfg. Sl. No. : From xxxxxx to xxxxxx

Batch Calibration Factor

Sensor supplied against the above order belong to the batch no. mentioned below:-

Batch No. : U 07

Calibration date : 02.07.2018

Temperature : 30°C

Calibration factor gage #1

3.960 microstrain /digit

Calibration factor gage # 2

3.974 microstrain /digit

Average calibration factor
(1 digit = Hz²/1000)

3.967 microstrain /digit

The above named instrument has been calibrated by comparison with slip gages sl. no. 0001343 (calibration certificate no.16/WL/9134) traceable to National Physical Laboratory, New Delhi.

Checked By

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3 INSTALLATION PROCEDURE AND TROUBLESHOOTING

3.1 Preparation of the sensor before installation

The first step is to check the sensor before installation for proper functioning. This should be done in an environmentally clean atmosphere, conducive to maintaining good quality at a location like a steel yard or warehouse. All preliminary work on the sensor should be done at a covered location remote from the dirt and adverse weather that may exist at the work site.

Check the working of the sensor as follows:

- Measure the coil resistance by a digital multimeter between red and black leads. It should lie between 130-150 Ω . Determine the resistance at room temperature from thermistor temperature resistance chart in § 5. This resistance should be equal to that between pins marked green and white. For example, in case the room temperature is 25°C, this resistance would be 3,000 Ω .
- The resistance between any lead and the protective armour should be > 500 M Ω .
- Connect the sensor to the model EDI-54V portable vibrating wire indicator. Initial offset reading in frequency should be stable. A frequency of 870 Hz corresponds to a tension equivalent to around 3,000 μ strain in the wire. The nominal reading range of the strain gage is 1,500 to 4,500 μ strain. Strain gages in lower frequency range are specifically used for tension applications and in higher frequency range for compression applications.

NOTE: The strain gage's initial tension is set at the factory prior to the shipping depending on the client's requirement. It can be mid-range or suitable for tensile or compressive applications. However, the full range shall be ± 1500 μ strain.

- A simple effective method of checking whether sensor is responding to the changes in strain is as follows:
 - Press two ends of strain gage gently between the fore fingers and verify that the frequency reading on vibrating wire indicator decreases. Pulling ends gently will increase the frequency reading. Do not apply excessive tension, as the magnetic wire could break.
 - This change in reading ensures that the deformation produced by straining the strain gage is transmitted to the vibrating wire sensing element.
- Press the 'TEMP' key on the vibrating wire indicator. The display will indicate the room temperature.

CAUTION: The strain gage is a delicate and sensitive instrument. It should be handled with care. Twisting it or applying too much force on it may result in permanently damaging it. While checking the strain gage, do not apply too much tension as the wire may break.

3.2 Extension of cable

Very careful and skilled cabling is required in installation of strain gage as sensor/cable joint and a large part of the cable is permanently embedded and no future access is available for maintenance or corrective action.

Unless specifically requested, strain gage is supplied with a standard 1 m length of four core shielded cable. Most users use their own standardized cable and have devised their own methods of cable extension depending upon their application. Several methods of cable extension are available. One of the methods is described in Encardio-rite doc. # WI 6002.11S - model ECS-05 cable splicing kit operating manual. After completing the cable extension, make sure to check the working of the sensor again following the procedure described above in § 3.1.

3.3 Installation and positioning of embedment type strain gages

Strain gage is a very versatile sensor. There is no 'standard' method of placement and embedment of strain gages. Location at which strain gages are to be installed is determined by the purpose of measurement, access available and protection required during and after installation. If stress is required, to be measured at a particular point, the gage can simply be located at that point. It is however not so simple in most measurements. Generally speaking, to get the true picture on stress or the loading pattern, strain has to be monitored at a number of points.

Measurement of strain at one point would be sufficient if no bending was occurring in the member; for example, near a centre of long thin member subjected to a tensile load. In most applications, bending moments are the rule rather than exception, and bending will take place about a neutral axis. To take care of bending effects and uneven stress, more than one strain gage is required to be mounted at each cross section of the structural member. The number of gages are determined by the nature of application and the accuracy of measurement

A few schemes successfully deployed in the field for installation are given below:

3.3.1 *Piles and drilled shafts*

Piles and drilled shafts normally involve simple cross sections subjected to compression and some bending. Location of strain gages should be selected carefully, taking into consideration any bending involved.

For installation, soft iron wires are usually used to attach the strain gage to nearby reinforcing bars. Normally, the tie wires/cable ties should be aligned perpendicular to the axis of the strain gage such that any movement of reinforcing bars, during the pouring of the concrete, will not exert a pull on the strain gage and distort or damage it.

Tie wires/cable ties should normally be tied around the protective tube and not the flanges to prevent any loading of the flanges due to the tie wires/cable ties getting tensioned.

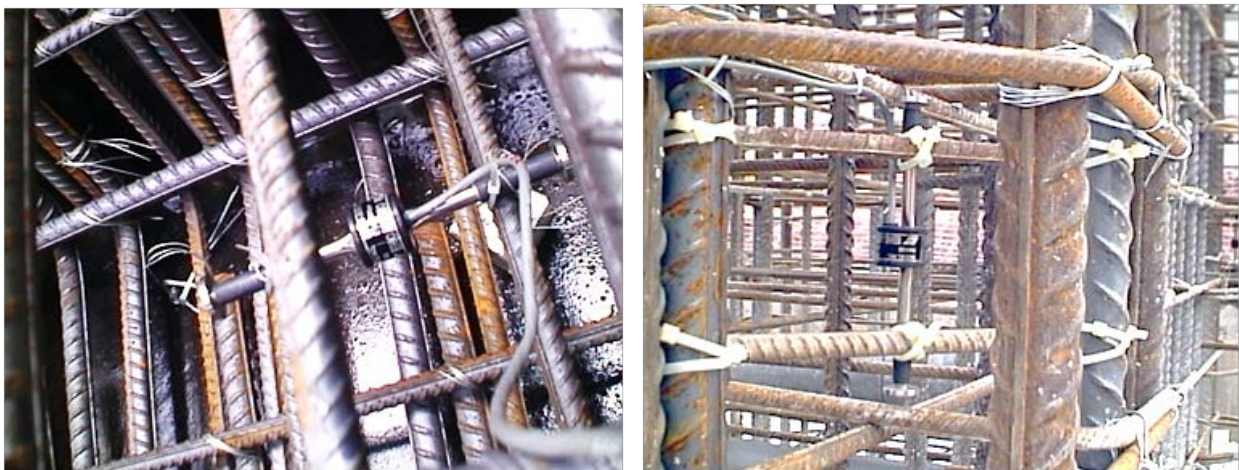


Figure 3.1 – Installation of embedment strain gage on rebar

3.3.2 Segmental lining for machine bored tunnels

Method of tunnel construction involves:

- Excavation by TBM and simultaneous erection of segmental concrete lining that provides both support and a final lining.
- The concrete segments are casted earlier and then transported to site. Easy way to install the instruments in segments (during concreting) is illustrated in the three adjoining pictures.
- Adjoining picture shows mounting of an Encardio-rite concrete pressure cell and a few Encardio-rite embedment strain gages in different axis before concreting. The bottom picture shows the segment being completed.

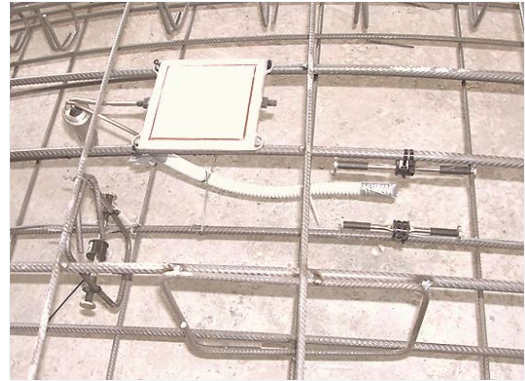


Figure 3.2 – Strain gage installed with pressure sensor in concrete segments



Figure 3.3 Concrete segments with strain gages and pressure cells installed inside

3.3.3 Pre-cast model EDS-20V-E strain gage in a mould before embedment

The following pictures shows the method to be followed. The strain gages are casted separately in small concrete blocks and then later on embedded in the mass concrete.



Figure 3.4 Strain gage casted in small concrete blocks for embedment in mass concrete

3.3.4 **Embedment procedure for single strain gage in mass concrete**

The mounting of a single strain gage is usually done by embedding it near the top of a lift. The embedment procedure is described below:

- 3.3.4.1 At any particular chainage where a single strain gage is to be installed, raise the level of the concrete structure (example – concrete dam) to around 25 cm below requisite elevation. Mark the positions on concreted surface where strain gages have to be installed. Raise the level of concrete by around 50 cm leaving a trench of around 1 m x 1 m at the marked positions.
- 3.3.4.2 Back-fill trench to the level to provide a bed, in case the strain gage is to be mounted horizontally. For strain gage to be installed vertically or at an inclination, back fill to the level that the strain gage would be fully covered.
- 3.3.4.3 For strain gage to be installed horizontally, lay it in the correct position and direction. For strain gage to be installed vertically or diagonally, use a battery operated drill machine to make a hole for the gage in the correct position and direction. Insert the strain gage in to the hole.
- 3.3.4.4 Check angles, direction and depth. A protractor level is most useful for this application. A plumb line and 60 cm wide angle protractor may be alternatively used.
- 3.3.4.5 Vibrate around a deeply embedded gage or hand puddle around a shallow gage.
- 3.3.4.6 Continue back filling by hand and shoveling, using the same concrete as the mass concrete used in the construction and hand puddle. When concrete is poured over the strain gage, take care not to move the strain gage. Pour the concrete by hand until a 10 cm cushion is built up on the top of each gage.
- 3.3.4.7 Finish with light shallow vibrations and protect the area with a light board barrier. Mark with area with yellow painted metal stakes so that the strain gage installation is not damaged before the concrete sets in.
- 3.3.4.8 The procedure for cable laying is separately dealt in § 3.5.

NOTE: For embedment and long term monitoring in a concrete dam, Encardio-rite offers the model EDS-11V strain gage. This is a very sturdy electron beam welded strain gage. Taking proper precautions, the model EDS-20V-E can also be used for embedment in a concrete dam. For information and instructions on how to install EDS-20V-E in a concrete dam, the user is recommended to go through instruction manual doc. # WI 6002.16 for EDS-11V strain gage.

A special spider shown below in figure 3.5 can be ordered from factory if it is required to mount a group of EDS-20V-E strain gages in different orientations at any given location in a concrete dam.

CAUTION: Special precaution and care should be taken if group of EDS-20V-E strain gages are mounted on spider and used for embedment in a concrete dam. The EDS-20V-E is not as sturdy as EDS-11V strain gage. Please ensure that the EDS-20V-E's are not twisted or bent during assembly on spider or when being covered by concrete. This will result in the strain gages becoming ineffective.

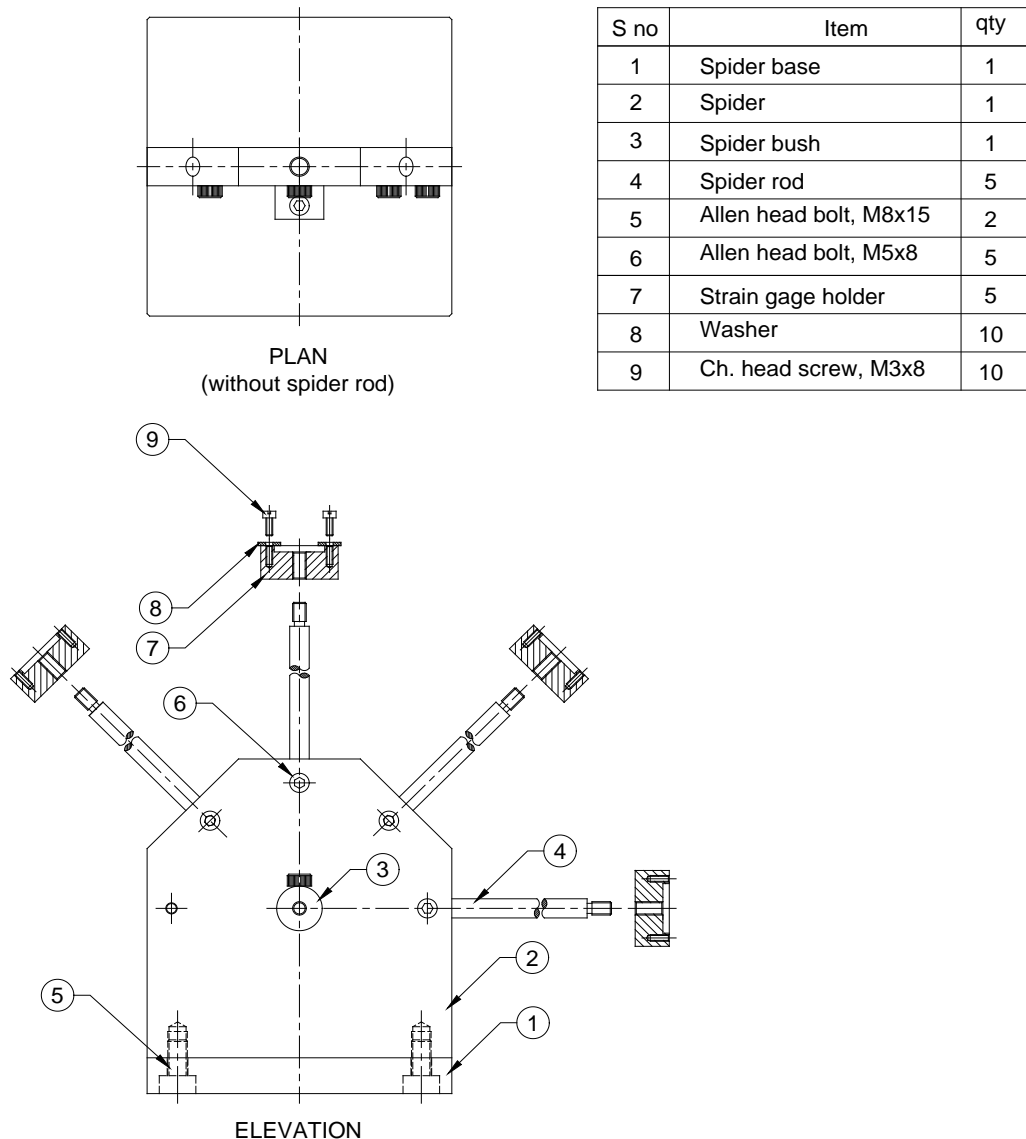


Figure 3.1 Strain gages installed in different orientations on spider/rosette

3.4 Taking initial reading

- 3.4.1 While concrete sets, take daily strain gage temperature reading (by pressing TEMP button) and frequency $2/1000$ (digits) reading (by pressing FREQ2 button) of EDI-54V read-out logger. Go on taking these reading till concrete sets properly. Initial reading 'IR' to be entered in EDI-54V should be considered only after concrete sets properly and reading in digits is almost constant. The initial reading in digits is very important because all future readings are referred to this initial reading to determine any change in stress. The initial reading in digits along with the gage factor (around 4.051×10^{-3} strain/Hz²), constitute the calibration constants required to be fed into the EDI-54V vibrating wire indicator as set-up data for any Encardio-rite model EDS-20V-E embedment strain gage. The exact gage factor varies from batch to batch and is given in the batch test certificate provided with each supply of strain gages.
- 3.4.2 Feed the calibration constants. The EDI-54V is programmed to accept this initial reading as 'IR' in set-up data. The indicator will then prompt to enter the gage factor 'GF'. Enter the gage factor as specified in the batch test certificate. After set-up ends restart indicator. In engineering units mode for this channel, pressing the 'UNITS' key on the vibrating wire indicator will now display around '0.0 ue' (micro strain). Any subsequent reading at any other time by pressing the 'UNITS' key will show an increase or decrease from this reading and automatically give the microstrains developed

during the period. For example, in case tension increases, vibrating wire indicator may show a reading of '1243.0 ue' or if the structure is subjected to compression, a typical reading may be '-437.2 ue'.

NOTE: The initial frequency reading is very important because all future readings are referred to this initial reading to determine any change in stress. Consequently a minimum of two readings taken daily after installation should be repeatable. It is good practice to take readings regularly during the first few days to ensure that the data is stable and a correct initial reading is fed into the vibrating wire indicator as a calibration constant. In case the readings are not repeatable within a certain tolerance, the installation, strain gage or the vibrating wire indicator may be defective. The cause must be evaluated and if there is a problem, it should be rectified.

3.5 Care of cable

3.5.1 Care should be taken that the installed strain gages and the cable are properly protected. Most strain gages require protection from mechanical damage caused by normal construction activity, vehicular traffic and vandalism. Proper protection methods have to be devised by the user or the designer.

CAUTION: Strain gages and cables require protection from mechanical damage caused by normal construction activity, welding, vehicular traffic and vandalism.

3.5.2 Protect cable from accidental damage by heavy equipment or flying rocks and debris. Use any practical method to protect the cable. The cable can be protected by routing it through a flexible conduit. The cable may be intentionally left slack inside the conduit to accommodate local deformation. Conduits should not be used where flow of water along the instrument leads must be prevented. In case conduits are not used and the cable is subjected to tensile or compressive strain, great care should be taken to prevent conductors from breaking or protruding out of the insulation. As a general rule, cables should be routed through zones of least differential strain.

3.5.3 Keep the ends of the lead wires clean and dry. In case several strain gages are installed at the same location, they may be terminated in an IP-67 terminal box and a multi-core cable used for transmitting the readings to any central observation post.

3.5.4 Cables may be spliced to lengthen them, without affecting gage readings. The cable joint should be made watertight by using an epoxy based splicing kit. Cable jointing compound R-pack 3M Scotch Cast 450 resin and hardener MSH 283 is normally used in India. Any suitable two component cable jointing compound available in your Country can be used in place of this compound.

CAUTION: In case extra cable is required, it should always be removed from a spool by rotating the spool. This will reduce chances of nicking, bending or twisting of the cable.

3.5.5 Cable should be marked with permanent markers by the use of stainless steel or plastic tags stamped with the appropriate strain gage number. The tags should be such that they do not damage or cut the cable. Temporary identification can be done by writing the serial number of the strain gage, its code number and the location at which it is installed, on a strip of paper, placing the strip on the cable and covering it with a transparent plastic cello tape. Permanent identification is necessary to prevent errors in making proper connections and to ensure correct splicing if cable is cut or broken.

With the best possible precautions, mistakes may still occur. Tags may get lost due to the cables getting accidentally damaged. Encardio-rite uses the convention that looking from the observation post towards the sensor, the cable from the most distant sensor is always at the left hand side. In that order, the cable from the closest sensor is at the extreme right.

CAUTION: The single most important factor leading to loss of worthwhile data from sensors is losing track or identification of cable ends. Proper identification and marking of cables should not be taken casually. Care should be taken to put an identification tag at the point where the cable comes out of the structure such that cable identity is not lost if the cable gets cut or damaged. Route the cable properly to the location where readings have to be taken, taking care that it is suitably protected. Lead wires must be protected from mechanical damage and their ends from water.

CAUTION: To take care of any of any settlement and/or contraction of concrete due to temperature effects, the cable should be zigzagged by providing a uniformly distributed slack of around 0.5 m in a 15 m length of each cable.

3.6 Lightning protection

Lightning during thunderstorms can induce short spikes of sufficiently high electrical energy in the wires connecting the vibrating wire sensor to the readout instrument that can damage the coils in the sensor assembly. Some measure of lightning protection for the vibrating wire sensor is recommended if the sensor is mounted in the field or in open areas and connected to the readout instrument through long wires. However, these protection schemes will not protect the sensor against direct or near direct lightning strikes. Lightning protection is generally not required if the connecting wire is very short, say only a few meters in length, or both the sensor and the vibrating wire indicator is used inside a shielded structure, e.g. a building.

The EDS-20V-E vibrating wire strain gage is not available with any integral lightning protection component. If lightning protection is desired one of the following options may be used:

- Surge arrestors like Gas Discharge Tubes (GDT) or TransZorbs[®] (registered trademark of General Semiconductor Industries) may be fixed to the gage cable as near to the gage as possible and epoxy potted in place. The ground conductor would have to be connected to an earthing stake or the steel structure itself.
- If the strain gage is mounted close to a junction box or a multiplexer, the surge arrestor component can be mounted in the junction box or the multiplexer box itself. Encardio-rite can provide junction boxes and multiplexers with lightning protection installed as an option (specify while ordering).
- Lightning arrestor boards and enclosures are available from Encardio-rite, which can be installed at the exit point of the structure being monitored. Consult the factory for additional information on these or alternate lightning protection schemes.

3.7 Trouble shooting

After installation, the strain gage is usually inaccessible. Maintenance and troubleshooting of the model EDS-20V-E vibrating wire strain gage is consequently limited to periodic checks of cable connections and maintenance of terminals. In case of easy accessibility, either the strain gage or the sensor or both can be replaced, if required.

3.7.1 *Symptom: Strain gage reading unstable*

- Check the insulation resistance. The resistance between any lead and the protective armour should be > 500 M Ohm.
- Check if the vibrating wire indicator works with another strain gage? If not, the vibrating wire indicator may have a low battery or be malfunctioning. Consult the manual of the vibrating wire indicator for charging or trouble shooting instructions.
- Use another vibrating wire indicator to take the reading.

- Check if there is a source of electrical noise nearby. General sources of electrical noise are motors, generators, transformers, arc welders and antennas. If so, the problem could be reduced by shielding from the electrical noise.
- The reading may be outside the specified range (either compressive or tensile) of the strain gage? The gage may have become too slack or too tight. Inspection of data collected might indicate this possibility.

3.7.2 Symptom: Strain gage fails to give a reading

- The cable may be cut or crushed? Check the nominal resistance between the two gage leads using an Ohmmeter. It should be within 120 - 150 Ohm.
- Check if the vibrating wire indicator works with another strain gage? If not, the vibrating wire indicator may have a low battery or be malfunctioning. Consult the manual of the vibrating wire indicator for charging or trouble shooting instructions.
- Use another vibrating wire indicator to take the reading. The reading may be outside the specified range (either compressive or tensile) of the strain gage? The gage may have become too slack or too tight. Inspection of data collected might indicate this possibility.

4 GENERAL CONSIDERATIONS

4.1 Conversion of reading to strain changes

By selecting the channel number and pressing the 'UNITS' key, the EDI-54V readout when connected to an EDS-20V-E strain gage, will display the change in strain directly in μ strain. Thus, the change in strain between the initial state (ϵ_0) and any subsequent state (ϵ_1) can be directly read on the EDI-54V vibrating wire indicator. Compressive strain is indicated by a '-' sign and tensile strain by a '+' sign.

$$\mu\epsilon_{\text{apparent}} = (\epsilon_1 - \epsilon_0)$$

4.2 Stress strain relationship

$$\frac{\sigma}{\epsilon} = E$$

Strain data is rarely of interest. Whereas strain gages measure strain or deformation of the structure, the designer is more interested in the structural load or stress. This requires a conversion from the measured strain to computed stress. In case of steel, if modulus of elasticity is known, deformation in elastic limits and temperature is recorded, conversion from strain to stress is straightforward. In case of concrete, it is not so straightforward and the same accuracy should not be expected as is in the case of steel structures. In case of concrete, it is difficult to precisely determine the modulus of elasticity as it depends upon several factors like composition, stress on concrete and furthermore it also varies with time.

Strain changes with time are computed from strain gage readings taken at different intervals, and by comparing with some initial reading taken at time zero. Selection of the initial reading depends upon the purpose of the measurement. If actual stress in the structural member is required, the initial reading is best taken when the structural member is under no load, i.e., the gages should be mounted while the member is perhaps evenly supported on a flat surface in a steel storage yard or warehouse. However, if the strain gage readings are to be used in determining the change in stress or load imposed on the structural member, initial reading should be taken after erection of the member.

To measure actual stress, it is not always possible to take the frequency reading at zero stress and often strain gages are installed on members which are under some existing load so that subsequent strain changes always take off from some unknown datum. Sometimes it is possible, especially where temporary supports are being monitored, to take the initial frequency at zero stress in the structural member after the structure has been dismantled.

Temperatures should be recorded at the time of each reading along with notes concerning construction activity taking place. This data might supply logical reasons for observed changes in the readings.

4.3 Strain gages for specific applications

Embedment strain gage is normally supplied in the range of ± 1500 microstrains for use in both tension and compression applications.

If the customer is going to use the embedment strain gage in a predominantly tension application like in pile pull test, strain gages with a range of more than 1,500 microstrains in tension should be ordered.

If the customer is going to use the embedment strain gage in a predominantly compression application like in pile loading (compression) test, strain gages with a range of more than 1,500 microstrains in compression should be ordered.

5 THERMISTOR - TEMPERATURE RESISTANCE CORRELATION

Thermistor type: Dale 1C3001-B3

5.1 Temperature resistance equation

$$T = 1/[A + B(\text{LnR}) + C(\text{LnR})^3] - 273.2 \text{ } ^\circ\text{C}$$

T = temperature in $^\circ\text{C}$
 LnR = Natural log of thermistor resistance
 A = 1.4051×10^{-3}
 B = 2.369×10^{-4}
 C = 1.019×10^{-7}

Ohm	Temp. $^\circ\text{C}$	Ohm	Temp. $^\circ\text{C}$	Ohm	Temp. $^\circ\text{C}$
201.1k	-50	16.60K	-10	2417	+30
187.3K	-49	15.72K	-9	2317	31
174.5K	-48	14.90K	-8	2221	32
162.7K	-47	14.12K	-7	2130	33
151.7K	-46	13.39k	-6	2042	34
141.6K	-45	12.70K	-5	1959	35
132.2K	-44	12.05K	-4	1880	36
123.5K	-43	11.44K	-3	1805	37
115.4K	-12	10.86K	-2	1733	38
107.9K	-41	10.31K	-1	1664	39
101.0K	-40	9796	0	1598	40
94.48K	-39	9310	+1	1535	41
88.46K	-38	8851	2	1475	42
82.87K	-37	8417	3	1418	43
77.66K	-36	8006	4	1363	44
72.81K	-35	7618	5	1310	45
68.30K	-34	7252	6	1260	46
64.09K	-33	6905	7	1212	47
60.17K	-32	6576	8	1167	48
56.51K	-31	6265	9	1123	49
53.10K	-30	5971	10	1081	50
49.91K	-29	5692	11	1040	51
46.94K	-28	5427	12	1002	52
44.16K	-27	5177	13	965.0	53
41.56k	-26	4939	14	929.6	54
39.13K	-25	4714	15	895.8	55
36.86K	-24	4500	16	863.3	56
34.73K	-23	4297	17	832.2	57
32.74K	-22	4105	18	802.3	58
30.87K	-21	3922	19	773.7	59
29.13K	-20	3748	20	746.3	60
27.49K	-19	3583	21	719.9	61
25.95K	-18	3426	22	694.7	62
24.51K	-17	3277	23	670.4	63
23.16K	-16	3135	24	647.1	64
21.89K	-15	3000	25	624.7	65
20.70K	-14	2872	26	603.3	66
19.58K	-13	2750	27	582.6	67
18.52K	-12	2633	28	562.8	68
17.53K	-11	2523	29	525.4	70

5.2 Temperature effect

The thermal coefficient of expansion of the embedment strain gage is 11.0 ppm/°C and concrete varies from 10 – 13 ppm/°C. Correction for temperature variation is seldom required in field use. In case correction is required for any specific application, it is best to embed a strain gage from the same batch in a representative concrete block and conduct actual temperature tests under controlled conditions. The difference in thermal coefficient of expansion so obtained can then be applied as a temperature correction

6 WARRANTY

The Company warrants its products against defective workmanship or material for a period of 12 months from date of receipt or 13 months from date of dispatch from the factory, whichever is earlier. The warranty is however void in case the product shows evidence of being tampered with or shows evidence of damage due to excessive heat, moisture, corrosion, vibration or improper use, application, specifications or other operating conditions not in control of Encardio-Rite. The warranty is limited to free repair/replacement of the product/parts with manufacturing defects only and does not cover products/parts worn out due to normal wear and tear or damaged due to mishandling or improper installation. This includes fuses and batteries

If any of the products does not function or functions improperly, it should be returned freight prepaid to the factory for our evaluation. In case it is found defective, it will be replaced/repaired free of cost.

A range of technical/scientific instruments are manufactured by Encardio-rite, the improper use of which is potentially dangerous. Only qualified personnel should install or use the instruments. Installation personnel must have a background of good installation practices as intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

The warranty is limited to as stated herein. Encardio-rite is not responsible for any consequential damages experienced by the user. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Encardio-rite is not responsible for any direct, indirect, incidental, special or consequential damage or loss caused to other equipment or people that the purchaser may experience as a result of installation or use of the product. The buyer's sole remedy for any breach of this agreement or any warranty by Encardio-rite shall not exceed the purchase price paid by the purchaser to Encardio-rite. Under no circumstances will Encardio-rite reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

A lot of effort has been made and precaution for accuracy taken in preparing instruction manuals and software. However best of instruction manuals and software cannot provide for each and every condition in field that may affect performance of the product. Encardio-rite neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damage or loss that results from use of Encardio-rite products in accordance with the information contained in the manuals or software.

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