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USERS' MANUAL

VIBRATING WIRE SPOT WELDABLE STRAIN GAGE

MODEL EDS-20V-SW



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1 INTRODUCTION

Encardio-rite model EDS-20V-SW strain gage is intended primarily for long-term strain measurement. It is suitable for surface mounting by spot welding on a steel structures such as a bridge, pile, tunnel lining and support etc. or by epoxy bonding on a steel structure, concrete or rock surface.

The strain gage incorporates the latest vibrating wire technology to provide digital readout on a remote vibrating wire indicator EDI-54V or data acquisition system ESDL-30/EDAS-10, on the magnitude and distribution of compressive and tensile strain in 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 strain gage is to indirectly quantitatively determine stress and its variation with time. Change in stress is obtained by multiplying the measured strain by the modulus of elasticity.

The gage has a very high compliance requiring less than 3 kg of force to tension the wire by 3000 μ strain.

The EDS-20V-SW has a gage wire length of 50.8 mm and is generally used where there are space restrictions. As another option, Encardio-Rite model EDS-20V-AW arc weldable strain gage is also available. This gage is much more robust than the EDS-20V-SW, has a gage wire length of 150 mm and provides better averaging of the strain value in the structure.

For embedment in soil or concrete, Encardio-rite recommends EDS-11V electron beam welded strain gage. Alternatively, lower cost EDS-20V-E embedment strain gage may be used for short term applications.

1.1 Features

- Spot weldable or epoxy bondable
- Waterproof
- Thermally aged to minimize long term drift
- Reliable

Advantage of vibrating wire strain gage over more conventional electrical resistance (or semiconductor) types lies mainly in use of a frequency, rather than a voltage, as 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 gage is approximately the same as that of the steel surface to which it is attached (and very similar to that of concrete). Corrections for temperature are therefore seldom required. For conditions requiring temperature measurement, a thermistor is permanently encapsulated inside the sensor (plucking coil assembly).

This users' manual covers description of the vibrating wire strain gage & its accessories, procedure for installation of the sensor on a steel structure, method of taking observations and recording data.

1.2 Applications

Model EDS-20V-SW strain gage is suitable for spot welding or adhesive bonding applications in field or laboratory testing requiring minimal installation time. After minimal surface preparation, spot welding is easily accomplished with a stored-energy hand-probe spot welder. The gage is useful immediately after welding and lead wire attachment. Environmental protection is as easily applied to or installed over a welded gage as an adhesive bonded gage.

Encardio-rite model EDS-20V-SW is the electrical strain gage of choice as its frequency output is almost immune to external noise; it is able to tolerate wet wiring conditions common in geotechnical applications and is capable of transmission of signals to long distances. It has applications in measurement of positive or negative strain on a steel structure, concrete or rock surface including:

- Measurement and monitoring of strain and consequently stress in steel structures.
- Study of stress distribution in the supporting ribs of under ground cavities and tunnels.
- Testing and stress analysis of pot bearings for bridges.
- Analysis and monitoring of stress in steel piles and struts.
- Measurement of strain in steel constructions, concrete and rock surfaces.

NOTE: EDS-20V-SW 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: Installation personnel must have a background of good installation practices and a knowledge of fundamentals of geotechnics. Novices may find it very difficult to carry on installation work. 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 performance of the instrument. 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, which 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 essential tools and accessories: See § 2.4 'Tools and accessories required for installation'.

For installation of strain gage: See § 3.2 'Installation on steel surface by spot welding'.

For installation of strain gage: See § 3.3 'Installation on steel surface by epoxy bonding'.

For installation of strain gage: See § 3.4 'Installation on concrete surface by epoxy bonding'.

For typical applications: See § 4 'General considerations'.

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 fixed length stretched magnetic wire is plucked by a coil/magnet assembly, 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 or model EDAS-10 data acquisition system.

The wire is plucked by a coil magnet. Proportionate to the tension, the wire resonates at a frequency (f). The strain (ϵ) in the 5.08 cm long magnetic wire can be determined as follows:

	f	=	$[\sigma g/\rho]^{1/2}/ 2l$ Hz
where:	σ	=	tension of wire in kg/cm ²
	g	=	980 cm/sec ² (acceleration due to gravity)
	ρ	=	density of wire in kg/cm ³
	l	=	length of wire in cm

The relationship between stress, strain and the modulus of elasticity can be expressed as $\sigma/\epsilon = E$. As length of wire in the strain gage is 5.08 cm and $E = 2.11 \times 10^6$ kg/cm², the formula can be reduced to approximately:

$$\epsilon = 3.896 \times 10^{-4} f^2 \mu \text{ strain [equation 2.1]}$$

NOTE: The value $3.896 \times 10^{-4} \mu$ 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 strain gage is very low and the magnetic strain gage wire in it precisely follows the deflection of the steel section (or the concrete 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 wire used in all Encardio-rite vibrating wire sensors is 11.0 ppm per °C at 25°C. It is almost the same as that of the steel surface to which it is attached.

If strain gage is epoxy bonded to concrete and correction for thermal expansion is required, the coefficient of thermal expansion of concrete must be known. It varies from around 10 to 13 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 steel 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 that can be welded to the steel structure. The strain gage option also costs less.

The Encardio-rite vibrating wire strain gage basically consists of a high tensile strength wire made of a magnetic material stretched between two stainless steel cylindrical end pieces. The gage length is 62 mm and the wire is sealed in a stainless steel tube by a set of double "O" rings fixed on each end piece. This to a great extent ensures resistance to corrosive, humid, wet and other hostile environmental conditions.

The gage is pre tensioned by a small compression spring. Initial tension can be set during manufacture, allowing for maximum range in tension or compression as required. A stainless steel foil tab fixed to each end piece enables the gage to be spot-welded or fixed in place by epoxy.

The coil/magnet assembly (sensor) is encapsulated in a moulded protective cover. The sensor is permanently fixed to the structure. On reinforced or tieback bars, the sensor is held in place by cable ties. On flat surfaces it is secured in position by a spot-weldable strap. The gage is designed for flat surfaces.

CAUTION: The strain gage is a delicate and sensitive instrument. It should be handled with care. Twisting it or applying any force on it will result in permanent damage to the strain gage. Also installing it on an uneven surface will damage it. Ensure that surface on which strain gage is installed is flat.

It is recommended that a few extra strain gages be always ordered to take care of any possibility of getting damaged in transit or during installation. The sensor coil assembly is sturdy and hardly gets damaged during installation.

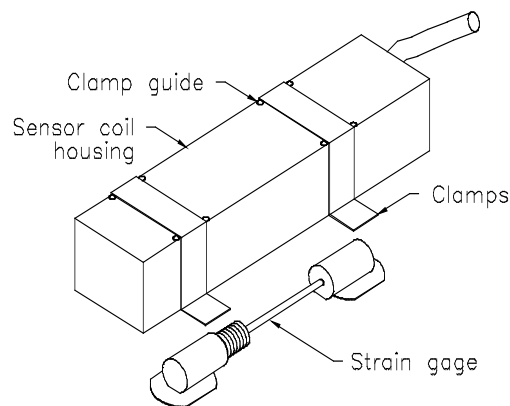


Figure 2.1 – Encardio-rite model EDS-20V-SW

Displacement of end pieces is always proportional to the variation in strain. Any change in strain directly affects tension of the wire, resulting in a corresponding change in frequency of vibration of the wire. Change in frequency of the vibrating wire is accurately measured by a vibrating wire indicator calibrated to indicate the strain. Encardio-rite manufactured vibrating wire sensors uses the Encardio-rite model EDI-54V vibrating wire indicator irrespective of the parameter being measured.

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.

2.2.1 Cable

Four core PVC jacketed shielded cable, CS-1303 suitable for upto 60°C standard. 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. Refer to § 3.5.

It is also possible to extend cable at site by using proper crimp terminals and epoxy encapsulating the joint.

2.3 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.



Fig 2.3 – Vibrating wire indicator

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.

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-SW spot weldable 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 installed at a particular location and properly stable.

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/adapter 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.

For operating complete operating procedure please refer 'Doc. # WI 6002.112'

2.4 Sample test certificate



TEST CERTIFICATE

Vibrating wire strain gage calibration

Type : Spot weldable type water proof strain gages

Model : EDS-20V-SW

Range : $\pm 1500 \mu$ -strain

Mfg. Sl. No. : xxxx

Batch Calibration Factor

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

Batch No. : W 07	Calibration date	: 09 – 07 – 2020
	Temperature	: 30 °C

Calibration factor gage #1 : 3.648E-01 microstrain /digit

Calibration factor gage # 2 : 3.662E-01 microstrain /digit

Average calibration factor (G) : **3.655E-01 micro strain /digit**

(1 digit = Hz²/1000)

Microstrain (μ s) is calculated with the following equation:

$$\text{Linear} : (\mu\text{s}) = G (R1-R0)$$

R1 is current reading & R0 is initial reading in 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.

Note : Mfg.Sl.No.of Gage and Coil should be the same at the time of installation..

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Linear Calibration Constants for Data Loggers

Note : The constants will be used to read the Sensor Output in engineering unit (*micro-strain*)

For ESDL-30 Data Loggers

Feed A2 = 0
Feed A1 = G / 1000
Feed A0 = -(G X R0)

For EDI-54V Data Loggers

Feed A5,A4,A3,A1 = 0
Feed A2 = G / 1000
Feed A0 = -(G X R0)

Where G is Gage Factor and R0 is initial readings in Digits at the time of installation.

Tested By :

2.5 Tools & accessories required for installation

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

- 2.5.1 Temperature controlled soldering iron 25 Watt
- 2.5.2 63/37 rosin core solder wire
- 2.5.3 Acetone (commercial)
- 2.5.4 Chipping hammer
- 2.5.5 Wire brush
- 2.5.6 Silicone carbide emery paper
- 2.5.7 250 mm flat file
- 2.5.8 12 mm round file
- 2.5.9 Hacksaw with 150 mm blade
- 2.5.10 Cable cutter
- 2.5.11 Surgical blade with holder
- 2.5.12 Wire stripper
- 2.5.13 Pliers 160 mm
- 2.5.14 Screw driver 20 cm
- 2.5.15 Drafting tape
- 2.5.16 Sample metal strips (to set spot welding parameters)
- 2.5.17 Cloth for cleaning (lint less)
- 2.5.18 Epoxies such as Loctite 406; Loctite™ 7075 activator with Loctite™324 adhesive
- 2.5.19 Waterproofing compound such as Dow Corning RTV 3145 or 3140 GE Silicones RTV 1200
- 2.5.20 Digital multimeter
- 2.5.21 Vibrating wire indicator (EDI-54V)
- 2.5.22 Capacitive discharge spot welder - 50 Watt-second

3 INSTALLATION PROCEDURE AND TROUBLE SHOOTING

3.1 Preparation of the sensor before installation:

Check sensor for proper functioning before installation. This should be done in an environmentally clean atmosphere, conducive to maintaining good quality at location like a steel yard or warehouse.

3.1.1 Check working of sensor as follows:

- Coil resistance measured by digital multimeter between red and black leads should lie between 130-150 Ohm. Determine resistance at room temperature from thermistor temperature resistance chart in § 5. It should be equal to measured resistance between green and white sensor leads. For example, for room temperature of 25°C, this resistance would be 3,000 Ohm.
- The resistance between any lead and the protective armour should be > 500 M Ohm.
- Place the strain gage on a flat surface. Position the sensor coil housing on the strain gage.
- Connect sensor to model EDI-54V portable vibrating wire indicator. The initial offset reading in frequency should be stable.
- Press 'TEMP' key on vibrating wire indicator. The display will indicate the room temperature.
- Remove sensor coil housing from strain gage.

3.1.2 Check epoxy, adhesive and adhesive tape for expiry date (if any).

CAUTION: The strain gage is a delicate and sensitive instrument. Handle it with care. Twisting it or applying any force on it will result in permanent damage to the strain gage. Also installing it on an uneven surface will damage it. Ensure that surface on which strain gage is installed is flat.

It is recommended that a few extra strain gages be always ordered to take care of any possibility of getting damaged in transit or during installation. The sensor coil assembly is sturdy and hardly gets damaged during installation.

3.2 Installation of EDS-20V-SW strain gage on steel surface by spot welding

NOTE: Strain changes indicated by the strain gage mounted on a structure are relative to the initial strain level existing in it at the time of fixing the strain gage. The strain gage has no way of determining the initial strain existing in the structure. For this reason it is recommended that the strain gages should be mounted on the sections in unstressed condition.

Wherever possible, gages should be installed at least 24 hours before erection of the structural member at site. This allows time for stabilization of strain gage before taking the initial reading.

3.2.1 Although surface preparation for spot welding is less critical than for adhesive bonding, the surface must be flat; free of grease, rust, scale, oxides and surface irregularities for efficient welding.

- Degrease specimen with an appropriate solvent.
- Using a wire brush clean the flat steel surface on which the strain gage is to be mounted of all scale, rust, dirt and oil.
- Smoothen flat surface by light grinding, abrasion with silicon-carbide paper or filing.
- Thoroughly wash with an appropriate solvent to remove all residues.

NOTE: Encardio-rite spot weldable gage EDS-20V-SW is suitable for installation on a flat surface such as a strut, plate or a rectangular section. In case it is to be installed on a round bar, ensure that the section on which it is bonded is made flat by Surface Grinding. A hand grinder will hardly be able to give a flat surface on a round bar suitable for mounting the EDS-20V-SW gage. Please also note the sensor coil of the gage is 87 mm L x 22 mm W x 18 mm H. For proper installation, the flat surface should therefore exceed 87 mm x 22 mm.

WARNING! Safety goggles should always be worn during all installation processes. Serious and permanent eye injury could otherwise occur. In case of accident, secure immediate medical attention.

NOTE: Best results are obtained with a 20 Watt-second (minimum) capacitive-discharge spot welder, with a repetition capability of at least 15 welds per minute. It is recommended that the welder employs a spring-type ground clamp to ensure a low-resistance connection between the welder "common" terminal and specimen. Use a welding electrode with a spherical tip approximately 0.8 mm in diameter. If tip sticks to foil tab, use a 400 grit sand paper to clean and round off the tip. This may any way be done periodically.

NOTE: Sample metal strip is supplied with each gage package for test welding and determining proper weld-energy setting and electrode force. A setting of approximately 10 watt-seconds, with firm electrode force, will generally produce satisfactory welds. After practice weld, pull metal strip from specimen surface. With satisfactory weld, a small slug of metal will break away from either metal strip or specimen at the weld. In case weld-energy is less, metal strip will pull off without any holes torn in it. In case weld energy is too much, metal strip will discolour or get burnt.

Insufficient force applied to gun or dirt between gage and specimen may result in sparking. If weld area unduly deforms, this may be due to higher weld energy or excessive force on gun.

3.2.2 Align gage on specimen surface with help of two short pieces of drafting tape across lower portion of foil tabs of the gage assembly as shown in figure 3.1.

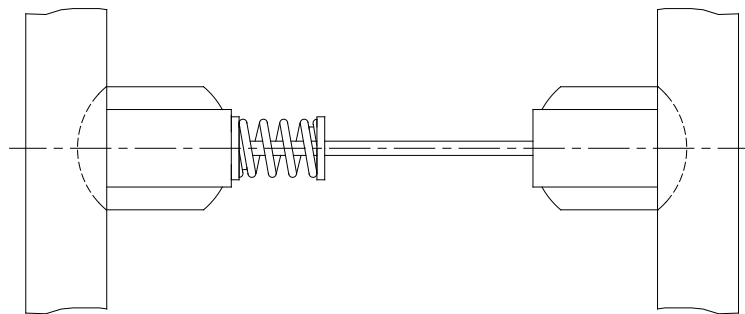


Figure 3.1

3.2.3 Tack foil tab on spring side in place with a few spot welds on each side of the gage. Remove drafting tape on the spring side by peeling it back directly over itself, being particularly careful not to distort the foil tab during tape removal. Complete spot welding the foil tab on the spring side spacing the welds at approximately 1.0 mm center distances.

3.2.4 Place rectangular sensor coil on the strain gage and take a frequency reading. By gently pulling or pushing the free end of the strain gage and retaping the foil tab, it may be possible to readjust to some extent the initial tension in the strain gage. However, be very careful when this is done as you may permanently distort and damage the strain gage in the process.

3.2.5 Tack the foil tab on the other side as per procedure described in 3.2.3. Tap the end pieces gently.

NOTE: It is good practice to tap the end pieces gently. This helps in improving the initial stability of the gage as it re-adjusts its position over the "O" ring seals between the end pieces and the protective stainless steel tubing.

3.2.6 Apply several drops of a low viscosity cyanoacrylate adhesive at the edge of the spot welded foil tabs. The adhesive will wick into the small gap between the tab and the substrate. Loctite 406 with a viscosity of 20 cps is a suitable cyanoacrylate adhesive for this purpose.

NOTE: After gage is installed, it should be protected from corrosion. Even though gage is made of stainless steel, corrosion can occur at points where it is spot welded to substrate. The substrate may corrode. Use of Loctite 406 as detailed above is very suitable for this purpose. Loctite 406 also improves the bond between the foil tab and the sub-substrate.

3.2.7 Apply a layer of waterproofing compound over the foil tabs and around them to further protect gage from corrosion. Be particularly careful at the point where the foil tab is under the stainless steel tube. Any of the following water proofing compounds may be used:

- Dow Corning RTV 3145 or RTV 3140
- GE Silicones RTV 1200

3.2.8 Paste rectangular sensor coil on the substrate over a coat of the water proofing compound. Take care that the water proofing compound does not flow over to the area which joints the stainless steel tube to the end piece. If this happens, it may restrict movement of the strain gage magnetic wire inside the gage by preventing the stainless steel tube from freely sliding over the 'O' ring.

3.2.9 Use spot welder to weld the two clamps over the sensor coil housing, securing the housing to the substrate. While placing the clamps over the sensor coil housing ensure that the clamps are positioned between the pair of embossed locating points on the housing. This ensures that the sensor coil housing cannot accidentally slip out of the clamps.

3.2.10 After fixing clamps apply water proofing compound around rectangular sensor housing on substrate.

3.3 Installation of EDS-20V-SW strain gage on steel surface by epoxy bonding

Please carefully go through instructions given in §3.2 to augment instructions given below.

3.3.1 Smoothen and clean flat surface where strain gages are to be fixed by light grinding, wire brushing and/or sanding. Degrease with a degreasing solvent.

3.3.2 Mark location where strain gages are to be fixed and direction of strain measurement with a marker pen. The identification code giving location and tag number should be clearly written down with a marker pen on the structure near the position where strain gages are to be fixed.

3.3.3 Apply Loctite™ 7075 activator to the steel surface with a brush where the first strain gage is to be fixed. Apply Loctite™324 adhesive to the underside of the two fixing pads of the strain gage element.

3.3.4 Press the strain gage element over the activated surface and keep pressed for 2/3 minutes keeping the strain gage element tube parallel to the direction of strain measurement.

3.3.5 Apply layer of waterproofing compound over and around foil tabs to protect gage from corrosion. Be particularly careful at point where foil tab is under the stainless steel tube. Use any of following water proofing compounds:

- Dow Corning RTV 3145 or alternatively Dow Corning RTV 3140
- GE Silicones RTV 1200

NOTE: Take care that water proofing compound does not flow over to area which joints stainless steel tube to the end piece. If this happens, it may restrict movement of the strain gage magnetic wire inside the gage by preventing the stainless steel tube from freely sliding over the 'O' ring.

3.3.6 Position the sensor coil housing over the strain gage element such that the cable end is opposite to the spring end of the strain gage (the housing will not seat properly in reverse orientation). Mark the perimeter of the sensor coil housing using a marking pencil and remove the sensor coil housing.

3.3.7 Apply water proofing compound as a thin layer all over the marked perimeter. Place the sensor coil housing over the strain gage and press firmly to displace excess adhesive between the sensor coil and substrate. cover all the joints well with the water proofing compound.

3.3.8 Apply Loctite™ 7075 activator to the area where the clamps of sensor coil housing will rest on the steel surface. Apply Loctite 324 to the underside of the clamp tabs that will rest on the steel surface. Position the fixing clamps over the sensor coil housing and keep the clamp tabs pressed on either side of the sensor coil housing for 2/3 minutes. Alternatively, waterproofing compound mentioned above could also be used for fixing the steel clamps. After fixing the clamps apply water proofing compound to the clamps and area around the clamps on the substrate.

3.3.9 Check coil output with model EDI-54V vibrating wire indicator to ensure proper installation of gage.

NOTE: To let adhesive bonds gain full strength, avoid unnecessary handling of the mounted elements including the length of cable just adjacent to the strain gage for the next 24 hours.

NOTE: Avoid significant change in strain level of the strain gage mounted steel section for the next 24 hours till adhesive has properly set.

3.4 Installation of EDS-20V-SW strain gage on steel surface by epoxy bonding

Follow instructions generally as per § 3.3. For bonding on concrete surface or stone use Loctite cleaner 7063 to ensure surface is clean dry and free from oil/grease. Use Loctite Metal set S3 two component epoxy for bonding, following instructions as given by manufacturer.



Figure 3.2 Initial thermal protection by insulation tape

3.5 Mechanical protection and care of cable

3.5.1 Avoid direct sunlight on strain gages. In case this is not possible, use thermocole sheets or foam insulation tape in conjugation with duct tape to provide proper protection against direct sunlight. Refer to figures 3.2 & 3.3.

3.5.2 User or designer should ensure proper protection method for installed strain gage and cable. Strain gages require protection from water and mechanical damage caused by normal construction activity, vehicular traffic and vandalism. A typical protection by using a cover plate is illustrated in figure 3.4 on next page.



Figure 3.3 Further thermal protection by duct tape

CAUTION: Ensure proper protection of sensor and cable from water and mechanical damage caused by normal construction activity, welding, vehicular traffic and vandalism. Gages may require protective covers, bolted, welded or epoxied to structure. Protective covers should not distort or stiffen the structure. Excessive force applied in tightening and welding operations may cause deceptive or spurious strains at the location. Possible solutions are attaching a stiff cover plate at only one end of the structure or using a rubber gasket in between.

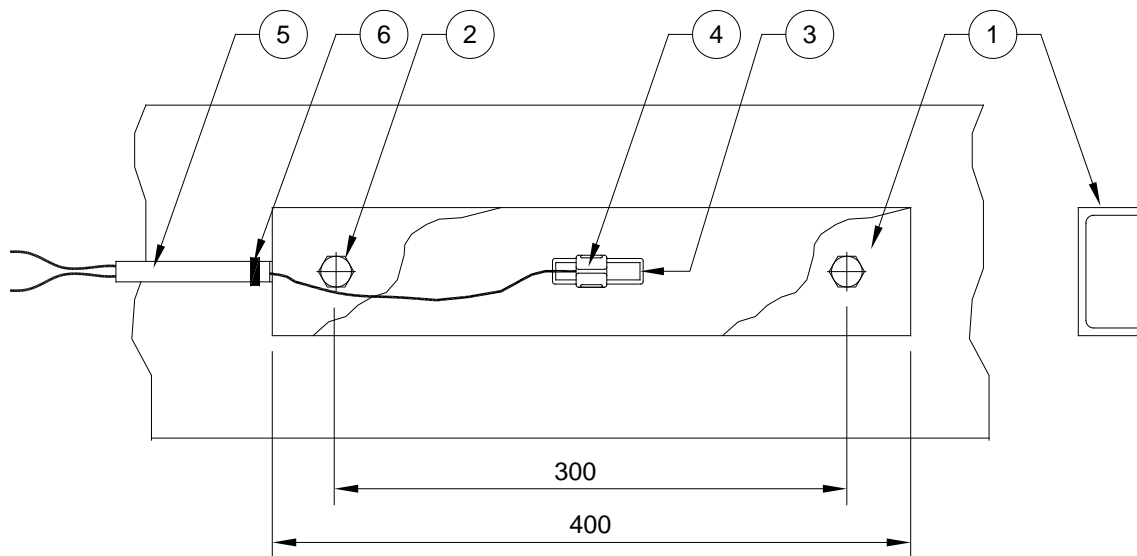


Figure 3.4 - Typical protection

- 1 Cover plate
- 2 M12 x 75 long hex bolt, washer and nut
- 3 Strain gage
- 4 Sensor
- 5 Flexible conduit
- 6 Conduit clamp

CAUTION: In case a cover plate is used for protection of the strain gage, the hex head of the studs to hold the cover plate in position should be arc welded in place before the strain gage is clamped in position between the mounting blocks. A welding jig is required to correctly position the studs.

CAUTION: The cover plate is manufactured from sheet metal or channel section. It is bolted over the top of the strain gage. The retaining nuts used to hold the cover plate over the studs should not be tightened very hard and also, the studs should not be positioned within 125 mm of the strain gage as this may distort the underlying steel surface and give rise to spurious readings. It is recommended that welding be avoided anywhere near the gage as this may cause large local distortion of the steel surface.

CAUTION: The single most important factor leading to loss of worthwhile data from sensors is losing track of identification of cable ends. Proper identification and marking of cables is generally taken most casually. Care should be taken to put an identification tag at the point where 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. Gage and lead wires must be protected from mechanical damage and from water.

- 3.5.1 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.
- 3.5.2 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.
- 3.5.3 Cables may be spliced to lengthen them, without affecting gage readings. The cable joint should be made water tight by using an epoxy based splicing kit. Cable jointing compound MS 853 with hardener MSH 283 (Mahendra Engineering & Chemical Products Ltd.) is stocked by Encardio-rite and is available in 100, 200 and 500 cc packing. Crimp terminals and a crimping tool are also available from Encardio-rite.

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

- 3.5.4 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 insure correct splicing if cable is cut or, broken.

3.6 Taking initial reading

- 3.6.1 Connect model EDI-54V vibrating wire indicator to strain gage and take the initial frequency and temperature reading. The initial frequency reading is very important because all future readings are referred to this initial reading to determine any change in stress. The initial frequency, along with the gage factor (check batch certificate for actual gage factor), constitute the calibration constants required to be fed into the EDI-54V vibrating wire indicator for any Encardio-rite model EDS-20V-SW spot weldable strain gage.

NOTE: Initial frequency reading is very important because all future readings are referred to this initial reading to determine any change in stress. A minimum of two readings should be taken after installation and these should be repeatable. In case 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. It is good practice to take readings regularly during first few days to ensure that data is stable and a correct initial reading has been fed into the vibrating wire indicator as a calibration constant.

- 3.6.2 Feed the calibration constants in the model EDI-54V vibrating wire indicator and store the initial frequency and temperature readings. Pressing the 'UNITS' key on the vibrating wire indicator will now display '0.0 $\mu\epsilon$ ' (micro strain). Any subsequent reading at any other time by pressing the 'UNITS' will show an increase or decrease from this reading. For example, in case tension increases, the vibrating wire indicator may show a reading of '1243.0 $\mu\epsilon$ ' or if the structure is subjected to compression, a typical reading may be '-437.2 $\mu\epsilon$ '.

3.7 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-SW 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 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 strain gage is mounted close to a junction box or a multiplexer, the surge arrestor component can be mounted in 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 that 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.

3.8 Troubleshooting

After installation, the strain gage is usually inaccessible. Maintenance and troubleshooting of the model EDS-20V-SW 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.

3.8.1 *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 vibrating wire indicator works with another strain gage? If not, 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.

3.8.2 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 Ohm meter. It should be within 130 - 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-SW 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 is in elastic limits and temperature is recorded, conversion from strain to stress is straight forward. In case of concrete, it is not so straight forward 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.

If a no load reading has been taken and the structure is eventually dismantled, it is advisable to take the frequency reading at zero load once again. This frequency reading should agree with the initial no load reading. Any lack of agreement would be an indication of gage zero drift although the possibility of some permanent plastic deformation of the member should not be overlooked; particularly where measured strain is high enough to approach the yield point.

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 Positioning of weldable strain gages

The location at which strain gages are to be installed is determined by the purpose of measurement, access available and the 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. In most applications 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 on the surface would be sufficient if no bending was occurring in the member; for example, near the center of a long thin member subjected to 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 is determined by the nature of application and the accuracy of measurement required. Some suggestions are given below:

4.3.1 Steel pile or strut

As a loaded pile moves downward in the soil in response to load, skin friction (shearing stress) along the soil pile interface, resists it's sliding down. The remaining support to the pile is provided by the base or tip of the pile resting against the foundation. To determine the magnitude of tip load and skin friction, strain gages are mounted at the tip and at various levels on the steel pile. (For concrete piles, Encardio-rite recommends the model EDS-11V strain gage for skin friction.).

For steel piles, strain gages provide the basic instrumentation scheme. Weldable vibrating wire strain gages are installed on pipe piles or H-piles. Figure 4.1 shows three strain gages mounted axially on the outside of the pipe pile at 120° to each other. On a circular pipe strut three gages would suffice (four would be preferable). In case the diameter of the pipe pile is large and/or it is a closed end pipe pile, the strain gages may be mounted on the inside for greater safety from damage.

Figures 4.2 shows four strain gages per section mounted on the web of a driven H-pile. It is recommended that two strain gages each be mounted back-to-back on the web at two locations as close to the flanges as possible. Gages at these locations can usually be protected adequately, using welded channels, angles, or corner strips.

Damage to gages and cable during driving must be prevented by taking all precautions. In case there is likelihood of damage at the tip of the pile, gages should be welded above the area of potentially damage. Gages welded to the pile should be protected with robust cover plates tapered down toward the pile tip. Cables should be protected by steel angles or channels. An effective method involves welding channels to the pile, with 150 mm long windows for pulling through the cable and clamping it at suitable intervals. The cables should not be dangling and should be supported during driving. The windows are finally closed by welding small lengths of channel to the pile. The cables must be protected beyond the point of exit from the channel with flexible metallic conduit. During driving, the cables and metallic conduit may be passed around a curved guide or large diameter pulley mounted near the pile head, on the pile or hammer. A rope may be tied to the ends of the cables and held at the ground surface to prevent damage as the pile is driven.

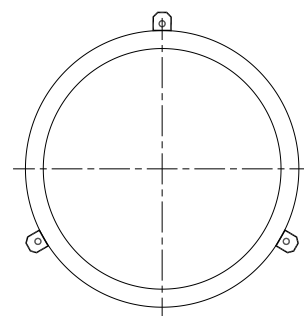


Figure 4.1

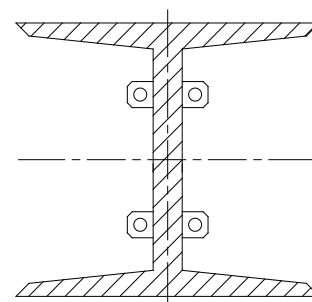


Figure 4.2

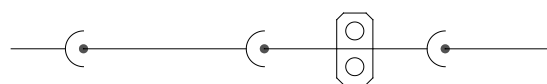


Figure 4.3

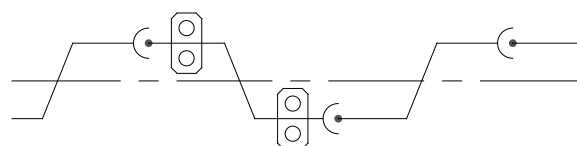


Figure 4.4

For sheet pile in tension two strain gages back to back on the opposite sides of the sheet midway between the clutches is recommended. Refer to figure 4.3. Example is sheet pile used for a cofferdam.

For sheet pile walls subjected to bending, a pair of strain gages on each of the outer portions of the Z-shape is recommended. The strain gages are mounted along the length of the sheet pile. Refer to figure 4.4

4.3.2 I-Beam

For an I-beam subjected to axial load, two strain gages may be mounted back to back at the center of the web as illustrated in figure 4.5. The axial stress may be determined as follows:

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$$\sigma_{axial} = \frac{\epsilon_1 + \epsilon_2}{2} \times E$$

Strain gages mounted on web

For an I-beam subjected to axial as well as bending load, four strain gages may be mounted back to back on the web as illustrated in figure 4.6. The axial stress may be determined as follows:

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$$\sigma_{axial} = \frac{\epsilon_1 + \epsilon_2 + \epsilon_3 + \epsilon_4}{4} \times E$$

For calculating the stress due to bending consider the difference between pairs of gages mounted on opposite sides of the neutral axis. The maximum stress due to bending about the xx axis is determined as follows:

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$$\sigma_{xx} = \frac{(\epsilon_1 + \epsilon_2) - (\epsilon_3 + \epsilon_4)}{4} \times \frac{a}{c} \times E$$

Similarly, the maximum stress due to bending about the yy axis is determined as follows:

$$\sigma_{yy} = \frac{(\epsilon_1 + \epsilon_3) - (\epsilon_2 + \epsilon_4)}{4} \times \frac{b}{d} \times E$$

The maximum stress can then be determined as follows:

$$\sigma_{maximum} = \sigma_{axial} + \sigma_{xx} + \sigma_{yy}$$

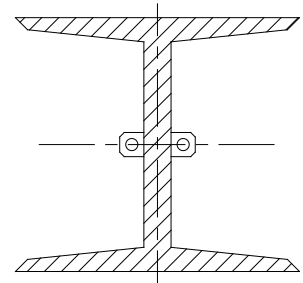


Figure 4.5

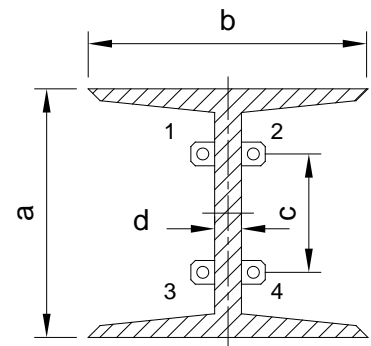


Figure 4.6

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The total stress at any point in the cross section is the algebraic sum of the axial stress and the bending stresses. In all the above calculations strict regard must be paid to the sign of the strain. Please note that the stress in the outer corners of the flange will be much higher than the stress on the web and that failure of the section can be initiated at these points.

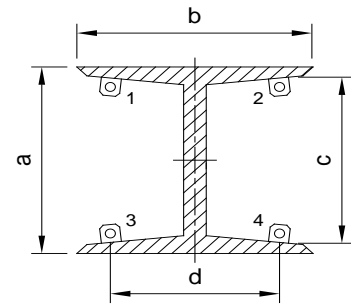


Figure 4.7

4.3.3 Strain gages mounted on flanges

From the above, one leads to the conclusion that the greatest accuracy would be obtained in case the strain gages were mounted on the outer corners of the flanges as shown in figure 4.7. Also, the accuracy of estimating the strain in the flanges is often limited by the relative flimsiness of the web. It is therefore usually better to install four gages on the inner faces of the flanges as far from the web as possible, providing a good compromise between a protected location and the zone of maximum stress.

One of the problems of locating the strain gages at the outer corners lies in the difficulty of protecting them and the cable from accidental damage. A graver problem arises due to each of the four gages being subjected to localized bending stress that affects only that gage and not the others. It is desirable and also necessary to locate the strain gages in pairs, one on either side of the neutral axis of the I-beam to which the gages are attached. From this point of view, the configuration in figure 4.5 is preferable.

The user should weigh the pros and cons and take his own decision on what is best for his application.

The same set of equations are applicable for both the configurations illustrated in figure 4.6 and 4.7.

4.3.4 Pot bearing

A typical scheme for stress analysis of the pot of a pot bearing (figure 4.8) is illustrated in figure 4.9.

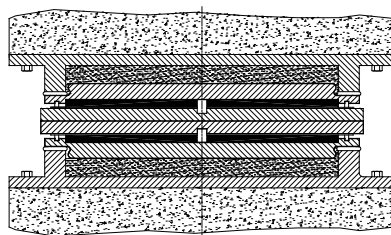


Figure 4.8

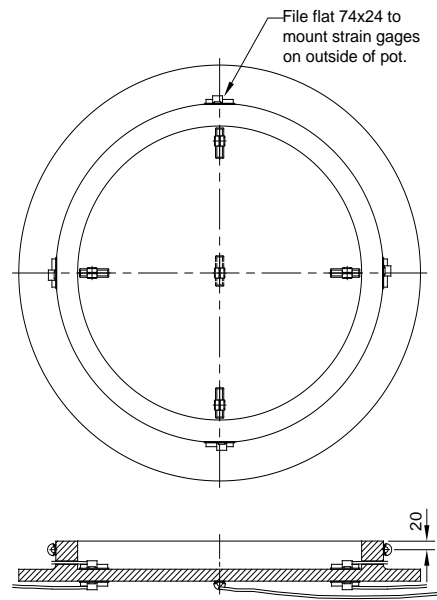


Figure 4.9

5 THERMISTOR - TEMPERATURE RESISTANCE CORRELATION

Thermistor type: Dale 1C3001-B3

Temperature resistance equation

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

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

5.1 Temperature effect

The thermal coefficient of linear expansion of structural steel is around 12 ppm per °C and concrete varies from 10-13 ppm per °C. The thermal coefficient of linear expansion of the vibrating wire is around 11.0 ppm per °C at 25°C. These values are very close. For most applications, when the gage is attached to steel, no temperature correction to the measured strain is really required. This is however only true if the magnetic wire and the underlying steel structure are at the same temperature. If sunlight falls directly on the gage, this would elevate the temperature of the magnetic wire above the surrounding steel and cause the strain gage to show a lower value of the stress as compared to the actual. The strain gage should therefore be shielded from direct sunlight or any radiation.

For the same reason, handling of the strain gage prior to taking a reading should be avoided. Moreover as a rule, take the reading quickly after connecting it to the vibrating wire indicator or allow sufficient time for the gage temperature to stabilize before taking the reading. It is also recommended to take the temperature reading every time the strain reading is made so that any real strain effects caused by temperature changes can be assessed later on. Each Encardio-rite strain gage has a thermistor encapsulated in the sensor and the Encardio-rite model EDI-54V vibrating wire indicator gives the temperature reading directly in °C if connected to the green and white leads from the sensor.

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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