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USERS' MANUAL

VIBRATING WIRE STRAIN GAGE

MODEL EDS-21V-AW ARC WELDABLE EXTENDED RANGE



Doc. # WI 6002.109. R01 | October 2018

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1 INTRODUCTION

The Encardio-rite model EDS-21V-AW strain gage is intended primarily for long-term high-range strain measurement. It is suitable for surface mounting by welding on steel structures such as bridges, piles, wye sections, pressure shafts, tunnel linings and supports etc. It can measure strains up to 5000 μ strain. The primary means of attachment is by conventional arc welding, but by alteration of the end blocks it can be adapted to monitor strain changes on concrete or rock surfaces using anchors grouted into boreholes.

For embedment in soil or concrete, Encardio-rite recommends the model EDS-11V electron beam welded, the model EDS-20V-E normal range or EDS-21V-E extended range embedment strain gage.

The strain gage incorporates the latest vibrating wire technology to provide digital readout on a remote vibrating wire indicator on the magnitude and distribution of compressive and tensile strain in steel 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 the modulus of elasticity.

The gage has a very high compliance requiring less than 4.5 kg of force to tension the wire by 5000 μ strain. It can be fixed by welding or epoxy bonding or a pair of setscrews. All gages have the vibrating wire pre-tensioned ready for use.

1.1 Features

- Thermally aged to minimize long-term drift
- Rugged and reliable
- Can be used on concrete and rock surfaces

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. The 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 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 plucking coil assembly.

This users' manual covers the description of the vibrating wire strain gage & its accessories, the procedure for installation of the sensor on a steel structure, method of taking observations and recording data. The model EDS-21V-AW requires a dummy strain gage and a welding jig to facilitate installation.

1.2 Applications

Encardio-rite model EDS-21V-AW 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 applications in the 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 underground cavities and tunnels.
- Testing and long-term analysis of the stress distribution of Wye sections.
- Monitoring and long-term analysis of stress in pressure shafts.
- Measurement of strain in steel constructions, concrete and rock surfaces.

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

1.3 Conventions used in this manual

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

CAUTION: Caution messages call 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 the 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, 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 specifications: See § 2.3 'taking readings with EDI-51V'.

For essential tools and accessories: See § 2.4 'Tools and accessories required for installation'.

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

For applications on concrete: See § 3.2 'Installation of arc weldable strain gage'.

For applications on concrete: See § 3.3 'Measurement of strain on a concrete surface'.

For complete operating procedure of Vibrating Wire readout unit EDI-54V: See Doc. # WI 6002.

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

For deciding where to install strain gages: See § 4.3 'Positioning of weldable strain gages'.

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

For temperature effects: See § 5.1 'Temperature effects'.

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:

$$\begin{array}{lcl} \mathbf{f} & = & \mathbf{[\sigma g/\rho]^{1/2}/ 2l \text{ Hz}} \\ \text{Where: } \sigma & = & \text{tension of wire in kg/cm}^2 \\ & g & = \text{980 cm/sec}^2 \\ & \rho & = \text{density of wire in kg/cm}^3 \\ & l & = \text{length of wire in cm} \end{array}$$

The relationship between stress, strain and the modulus of elasticity can be expressed as $\sigma/\varepsilon = E$. The length of the wire in the strain gage is 16.4 cm, $\rho = 7.8 \times 10^{-3} \text{ kg/cm}^3$ and $E = 2.11 \times 10^6 \text{ kg/cm}^2$. Consequently, the formula can be reduced to:

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

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 readout unit is able to display this directly in μ strain.

NOTE: The value $4.051 \times 10^{-3} \mu \text{ strain/Hz}^2$ is known as the effective gage factor of the strain gage. It varies from strain gage to strain gage. For the correct gage factor of the strain gages supplied to you, please refer to its 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 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 magnetic plucking wire used in all Encardio-rite vibrating wire sensors is 11.0 ppm per $^{\circ}\text{C}$ at 25°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, which can be welded to

the steel 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. The model EDS-21V-AW provides further protection by suitably sealing the joints with heat shrinkable tubes. In addition to this, a special waterproofing compound seals the plucking coil in the sensor assembly from any ingress of water. The sensor assembly in the model EDS-21V-AW 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. To mount the strain gage, two annular mounting blocks (one with one grub screw and the other with two grub screws) are accurately positioned and aligned by a dummy gage and welded to the structure. The dummy gage is then finally replaced by the actual strain gage and clamped in position. One of the cylindrical end blocks has a 'V' groove around its circumference. The annular mounting block with one grub screw is fixed to this cylindrical end block. Groutable reinforced bar annular mounting blocks are available for surface mounting the strain gage to a concrete or rock surface. Refer to figure 3.5.

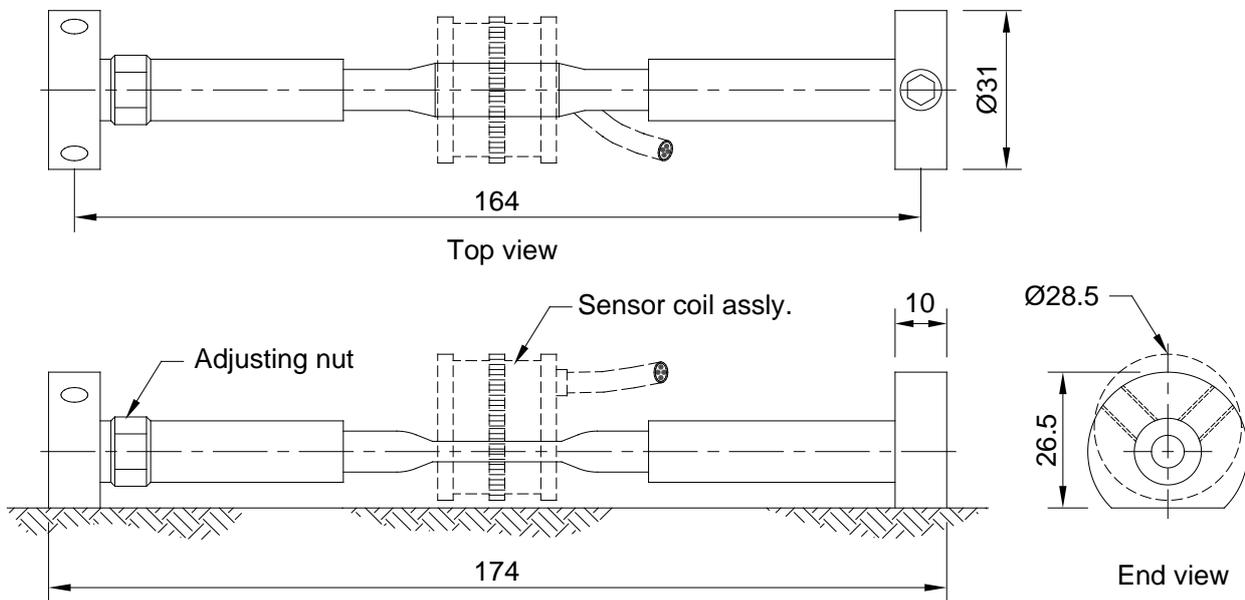


Figure 2.1 - dimensional details with mounting blocks

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

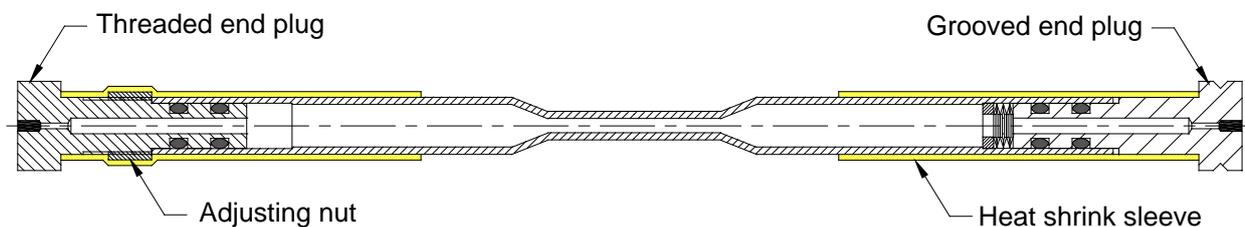


Figure 2.2 – sectional view

For mounting on wire ropes special mounting brackets as illustrated in figure 2.3 are available.

Displacement of end blocks is always proportionally 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. All vibrating wire sensors manufactured by Encardio-rite use the same vibrating wire read-out unit model EDI-54V irrespective of the parameter being measured.

The model EDI-54V vibrating wire indicator, used in conjunction with the vibrating wire strain gage, will provide 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 up to 60°C standard or CS-0404 suitable for upto 80°C on request. Color code is as follows:

Red/Black	VW sensor
Green/White	Thermistor

2.2.2 Accessories

- Weldable annular mounting blocks (one set provided with each strain gage).
- EDS-21 groutable reinforced bar annular mounting blocks (instead of weldable end blocks). Refer to figure 3.5.
- EDS-22 dummy strain gage. Refer to figure 3.1 & 3.3.
- EDS-23 mounting jig. Refer to figure 3.2
- EDS-24 cover plate with mounting jig. Refer to figure 3.4
- EJB-12-2 junction box
- EDI-54V vibrating wire indicator

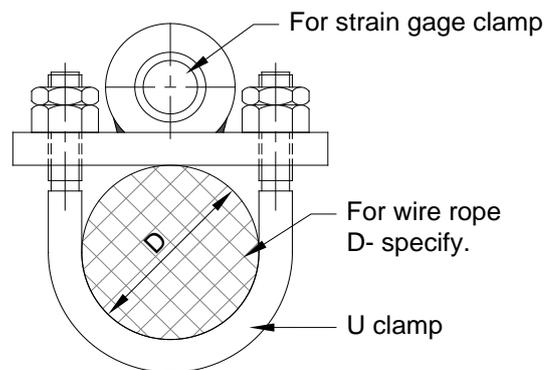


Figure 2.3 – Mounting on wire rope

In case a number of strain gages have to be mounted, it saves time to have several dummy strain gages. They do not cost much and help in installing several sets of mounting brackets simultaneously on the steel structure to be monitored. Once all the mounting brackets are welded in position, the dummy strain gages can together be replaced with the actual strain gages.

The dummy strain gage can, if required be manufactured at site. The dimensions are given in the note preceding § 3.2.2.

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.

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

The model EDI-54V vibrating wire indicator (figure 2.3 (a)) 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-21V-AW arc 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 fixed.

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.



Fig 2.3 (a) – Vibrating wire indicator

2.4 Sample test certificate

TEST CERTIFICATE

Model : EDS-21V-AW
 Instrument : Arc weldable type waterproof extended range strain gage
 Range : 5000 μ -strain
 Mfg.SI No. : A25927

Date : 06/10/2018
 Ambient Temp : 28 deg C

Input		Observed Frequency			Average	Average	Best Fit Data		Poly Fit Data	
Disp. (mm)	Strain (μ strain)	Cycle 1 (Hz)	Cycle 2 (Hz)	Cycle 3 (Hz)	Frequency (Hz)	Digit	Calculated μ strain	Error (%) FS	Calculated μ strain	Error (%) FS
0.000	0	693	693	695	694	481	9	0.18%	2	0.03%
0.165	1006	857	858	859	858	736	997	-0.18%	1000	-0.12%
0.330	2012	1000	999	999	999	999	2014	0.04%	2020	0.16%
0.495	3018	1120	1120	1122	1121	1256	3011	-0.15%	3014	-0.08%
0.655	3994	1229	1229	1228	1229	1510	3995	0.02%	3994	0.00%
0.820	5000	1330	1331	1331	1331	1770	5005	0.09%	5000	0.01%

where digit = frequency²/1000

Polynomial Constants

A₃ = 3.108E-08
 A₂ = -1.308E-04
 A₁ = 4.040E+00
 A₀ = -1.915E+03

Linear Constants

m = 3.874E+00
 c = -1.854E+03

Strain "S" is calculated with the following equation :

Linear : S (μ strain) = m (R₁) + c
 Polynomial : S (μ strain) = A₀ + A₁ (R₁) + A₂ (R₁)² + A₃ (R₁)³

where R₁ is current reading in digit.

Pin configuration/wiring code:

Red & black : Signal

Green & white : Thermistor

Tested By :

2.5 Tools & accessories required for installation

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

1. Dummy strain gage
2. Mounting jig
3. Temperature controlled soldering iron 25 Watt
4. Rosin 63/37 solder wire
5. Acetone (commercial)
6. Rust preventive paint
7. Chipping hammer
8. Wire brush
9. 250 mm flat file
10. 12 mm round file
11. Spanner 18/19
12. Hacksaw with 150 mm blade
13. Cable cutter
14. Surgical blade with holder
15. Wire stripper
16. Pliers 160 mm
17. Screw driver 20 cm
18. Allen key M6
19. Cloth for cleaning (lintless)
20. Digital multimeter
21. Vibrating wire indicator (EDI-54V)

3 INSTALLATION PROCEDURE AND TROUBLE SHOOTING

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 and if possible, also installation of the strain gage on the steel structure should be done at a covered location remote from the dirt and adverse weather which may exist at the work site.

Check the working of the sensor as follows:

- Measure the coil resistance by a digital multimeter between the red and black leads. It should lie between 130-150 Ohm. Determine the resistance at the 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 Ohm.
- The resistance between any lead and the protective armor should be > 500 m Ohm.
- Connect the sensor to the model EDI-54V portable vibrating wire indicator. The initial offset reading in frequency should be stable. Its value should be approximately equal to the frequency value mentioned in its test certificate for the unloaded condition.

NOTE: The strain gage's initial tension is set at the factory prior to 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 0-5000 μ strain.

- A simple' effective method of checking whether the sensor is responding to changes in strain is as follows:
 - Press the two ends of the strain gage gently between the forefingers and verify that the frequency reading on the vibrating wire indicator decreases. Pulling the 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.
- Remove the sensor from the strain gage.

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.

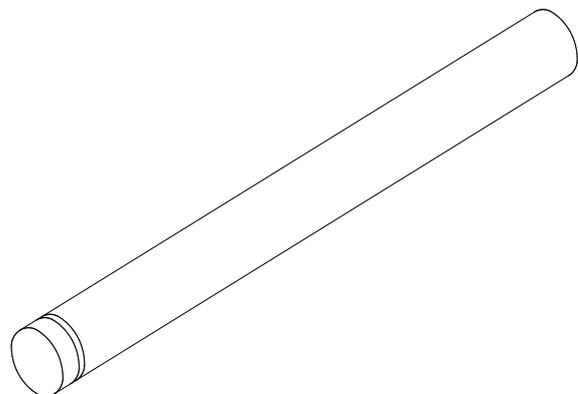


Figure 3.1 - dummy strain gage

3.2 Installation of arc weldable strain gage

Wherever possible, gages should be installed around 100 hours before the erection of the structural member at site. This allows time for stabilization of the strain gage before taking the initial reading.

The EDS-21V-AW strain gages are supplied fully sealed and pre-tensioned from the factory. Depending on the requirement mentioned in the order, these can be supplied either set at the mid-range or set to measure strain predominantly compressive or tensile in nature. Fine adjustment can be done by holding the adjusting nut and rotating the end plug (figure 3.2). Connect the cable of the strain gage to vibrating wire indicator EDI-54V and feed the linear gage factor (given in the test certificate of the strain gage) and the initial frequency (IR) in its setup memory. Rotate the end block clockwise to decrease the initial reading and counter-clockwise to increase the initial reading.



Figure 3.2 – fine tension adjustment

NOTE: Excessive rotation of the end block can damage the wire inside the strain gage. Limit the rotation to less than a quarter pitch (rotation of 1 full pitch will result in a strain of approximately 5000 μ strain).

A better method to adjust the initial reading is described in § 3.2.6.

3.2.1 Use the dummy strain gage (figure 3.1) and the mounting jig (figure 3.3) to properly position the annular mounting blocks. The mounting blocks are supplied in pairs. The first has a single conical point Allen head grub screw; the other has two oval point grub screws. Position the two mounting blocks with the dummy strain gage in between, over the mounting jig and tighten the grub screws. Take care that the inner surfaces of the mounting blocks are flush with the jig and they also rest flush on the base of the jig. Excess pressure on the grub screws should be avoided as this only damages the dummy strain gage.

Alternatively, place the mounting blocks on a surface plate with the dummy strain gage in between. Tighten the M6 grub screws with an Allen key taking care that the faces of the dummy strain gage coincide with the end faces of the two mounting blocks. Ensure that the bottom face of the mounting blocks sits flush with the surface plate and there is no wobble in the mounting blocks.

The mounting blocks are now aligned and

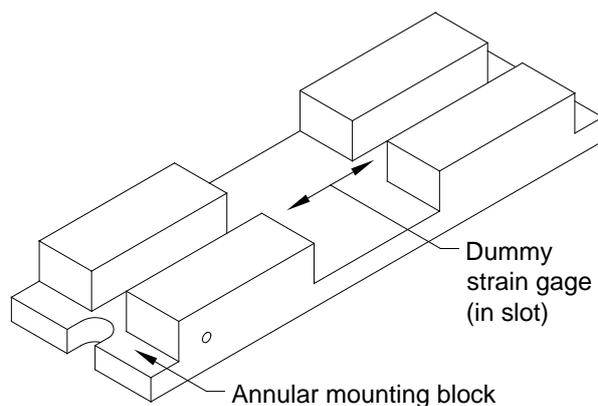


Figure 3.3 - mounting jig

ready to be welded to the steel structure. In case a number of strain gages have to be welded, it is advisable to procure several dummy strain gages.

NOTE: The dummy strain gage is a stainless steel rod 12.8 mm ϕ x 175 mm long. It has a 1 mm deep 'V' groove at a distance of 8 mm from one end. In case it is not available, you may get it manufactured at the site giving a tolerance of ± 0.1 mm on the dimensions.

3.2.2 Using a wire brush clean the steel surface on which the strain gage is to be mounted of all scale, rust, dirt and oil. Remove the mounting blocks and dummy strain gage assembly from the mounting jig and place them in position on the steel surface. Press them firmly against the steel surface using the dummy strain gage as a handle. Weld the edges of the mounting blocks in the order as shown below in figure 3.4.

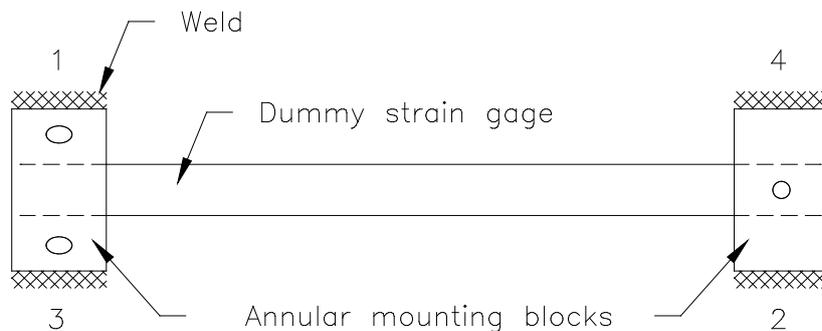


Figure 3.4 - welding sequence

NOTE: Avoid excessive heat as it may distort the steel surface. **Do not weld the flat end surfaces** of the mounting block, as this will prevent removal of the dummy strain gage.

3.2.3 Let the mounting blocks cool to room temperature, using a water soaked rag if required, before slackening the grub screws to remove the dummy strain gage.

3.2.4 Use the chipping hammer and wire brush to clean away all welding slag.

3.2.5 Insert the strain gage into the holes in the mounting blocks. Take care that the grooved end of the gage is on the side of the mounting block with the single grub screw. Tighten the grub screw hard down into the 'V' groove on the strain gage.

3.2.6 Wire tension can be made to increase or decrease by pushing the sensor in the direction of the free end or away from it. When the desired tension is obtained, the free end is firmly secured inside the mounting block by tightening down hard the two grub screws.

3.2.7 To stabilize the reading, tap the mounting blocks gently after the grub screws have been tightened. The reading may alter slightly during this operation, which is normal.

CAUTION: Great care should be taken while tightening the strain gage between the mounting blocks such that no torque or bending moment is applied across the length of the strain gage.

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

NOTE: In case a number of gages are to be installed, it is good practice to have more than one dummy strain gage.

3.2.8 Apply a coat of any standard rust preventative paint on the weld joints to minimize the effect of corrosion.

3.2.9 Care should be taken that the installed strain gages and the cable are properly protected. Most strain gages require protection from water and 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. A typical protection by using a cover plate is illustrated in figure 3.5.

CAUTION: Strain gages and cables require protection from water and from mechanical damage caused by normal construction activity, welding, vehicular traffic and vandalism. Gages usually require protective covers, bolted, welded or epoxied to the 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

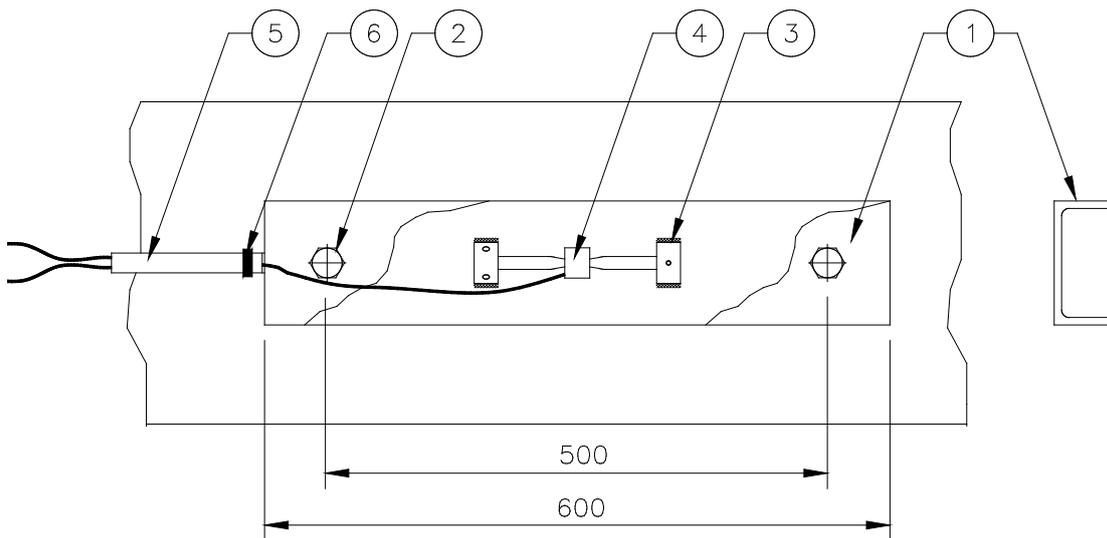


Figure 3.5 - typical protection

attaching a stiff cover plate at only one end of the structure or using a rubber gasket in between.

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 150 mm of the strain gage as this may distort the underlying steel surface and give rise to spurious readings. It is recommended to avoid welding 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 point where cable comes out of the structure such that cable identity is not lost if 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.

3.2.10 Connect the model EDI-54V vibrating wire indicator to the 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 constitutes the calibration constants required to be fed into the EDI-54V vibrating wire indicator for any Encardio-rite model EDS-21V-AW weldable strain gage. For the actual value of gage factor refer to test certificate supplied along with the strain gage.

NOTE: The initial frequency reading is very important because all future readings are referred to it to determine any change in stress. Consequently, a minimum of two readings should be taken after installation and these should be repeatable. 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. 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 has been fed into the vibrating wire indicator as a calibration constant.

3.2.11 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 ue' (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 ue' or if the structure is subjected to compression, a typical reading may be '-437.2 ue'.

NOTE: It is preferable to install the strain gage on the steel member in the unloaded condition, i.e., prior to its installation. The initial readings will then correspond to zero load. Otherwise the initial reading will correspond to some unknown load level and subsequent readings will be in comparison to this initial reading taken as zero. For further details, refer to § 4.2.

3.3 Measurement of strain on a concrete surface

Surface strains on concrete can be measured with the EDS-21V-AW vibrating wire strain gage by attaching the strain gage to the concrete surface by any of the following two methods:

3.3.1 Position the two model EDS-21 groutable reinforced bar annular mounting blocks on the dummy strain gage according to the procedure described in § 3.2.1. These mounting blocks are different from those used for welding on steel structures and are illustrated in figure 3.5.

- 3.3.2 Drill two 16 mm ϕ holes 65 mm deep at a center distance of 149 mm on the concrete surface using a template for this purpose.

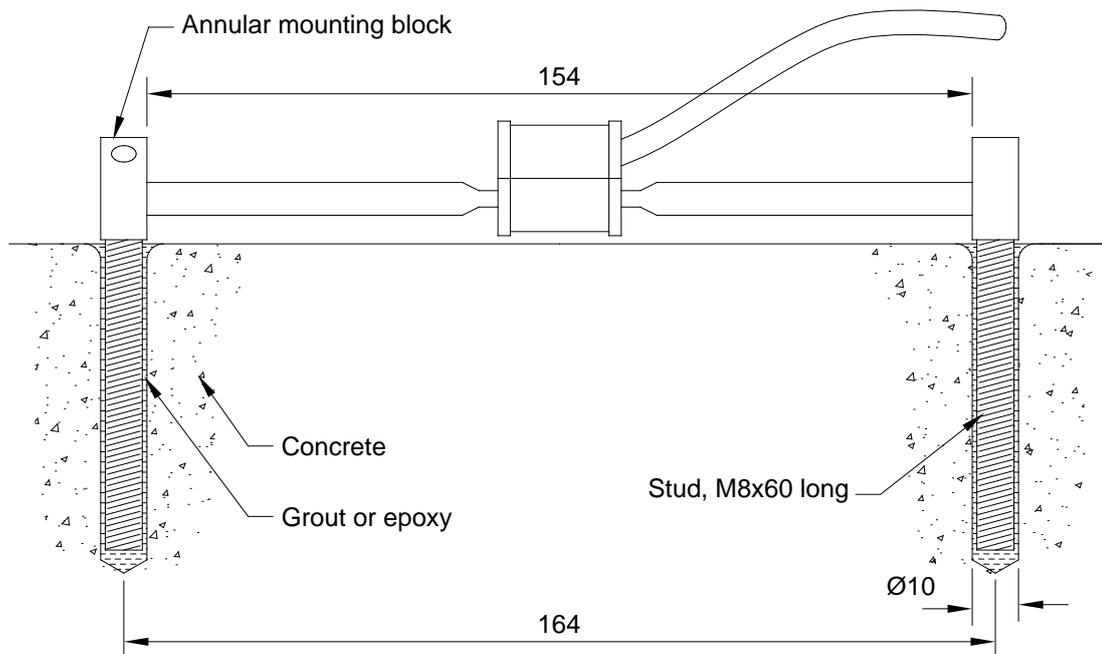


Figure 3.5 - mounting on concrete surface

- 3.3.3 Grout the reinforced bar annular mounting blocks and dummy strain gage assembly into the drilled holes in the concrete using either a fast setting cement or a high strength epoxy.
- 3.3.4 With proper care it may be possible to mount the standard annular mounting blocks to the concrete surface with a room temperature curing epoxy. If this procedure is followed, the concrete surface should be carefully sanded and cleaned and the plating should be removed from the underside of the mounting blocks.
- 3.3.5 After the annular mounting brackets have properly set, slacken the grub screws to remove the dummy strain gage.
- 3.3.6 Use a wire brush to clean away any concrete or epoxy deposited on the mounting brackets.
- 3.3.7 Generally, follow instructions 3.2.5 to 3.2.12.

3.4 Care of cable

- 3.4.1 Protect the 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 the 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.
- 3.4.2 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.
- 3.4.3 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. For cable jointing compound please contact factory.

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.

3.4.4 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 ensure correct splicing if the cable is cut or, broken.

3.5 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-21V-AW 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.

3.6 Trouble shooting

After installation, the strain gage is usually inaccessible. Maintenance and troubleshooting of the model EDS-21V-AW vibrating wire strain gage are 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.

3.6.1 *Symptom: Strain gage reading unstable*

- Check the insulation resistance. The resistance between any lead and the protective armour should be $> 500 \text{ M Ohm}$.
- 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. In such a case, if the gage is accessible, loosen the two grub screws in the mounting blocks. The internal spring in the strain gage will restore the reading. The gage can now be set to a new datum and the grub screws re-tightened. If the gage still does not respond, the sensor or the strain gage or both may be replaced.

3.6.2 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 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. In such a case, if the gage is accessible, loosen the two grub screws in the mounting blocks. The internal spring in the strain gage will restore the reading. The gage can now be set to a new datum and the grub screws re-tightened. If the gage still does not respond, the sensor or the strain gage or both may be replaced.

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-21V-AW strain gage, will display the change in strain directly in μ strain. Thus, the change in strain between the initial state (μ_0) and any subsequent state (μ_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.

$$\mu\epsilon_{\text{apparent}} = (\mu_1 - \mu_0)$$

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 the modulus of elasticity is known, deformation is 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 the 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 the application and the accuracy of measurement required. Some suggestions are given below:

4.3.1 Pressure shaft

The steel liner is subjected to high stress at the lower end of the pressure shaft, the water head being high. For measurement of circumferential stress, three or four strain gages are mounted along and parallel to the circumference of the pressure shaft. For measurement of longitudinal stress, three or four strain gages may be mounted in the longitudinal direction as well, but this is generally restricted to places where strength of welded joints is to be monitored or checked. Figure 4.1 shows four strain gages mounted on the circumference at 90° to each other and four in the longitudinal direction at 90° to each other. The asymmetrical expansion of the steel liner when the pressure shaft is in operation, is easily determined by monitoring the strain from the four strain gages mounted along the circumference.

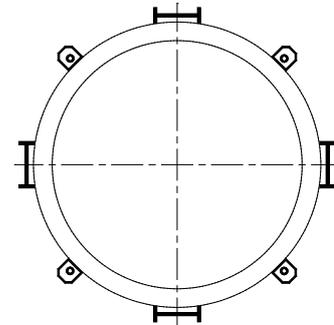


Figure 4.1

For determining the stress at any location on the pressure shaft, the strain value at that point is multiplied by the modulus of elasticity (2×10^6 kg/cm²). The stress value so obtained should generally be lower than the yield stress of the pressure shaft material.

For further elaboration see Encardio-rite application note AN 9604.

4.3.2 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 its 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 and model EPS-30V-I earth pressure cells for tip load).

For steel piles, strain gages provide the basic instrumentation scheme. Weldable vibrating wire strain gages are installed on pipe piles or H-piles. Figure 4.2 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 4.3 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.

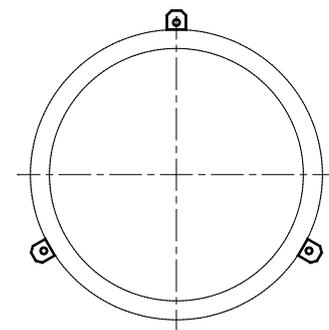


Figure 4.2

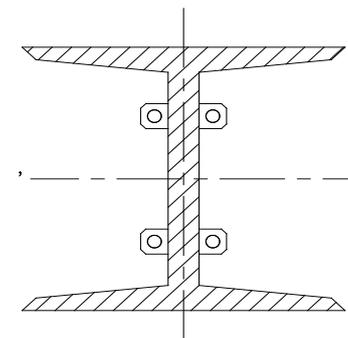


Figure 4.3

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.

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 4.4. Example is sheet pile used for a cofferdam.

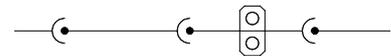


Figure 4.4

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 4.5

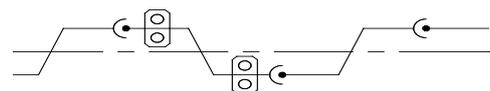


Figure 4.5

4.3.3 Wye section

Wye section may be instrumented for initial testing, especially at the welded joints or for long term monitoring. Stress generated due to any imbalance in flow through the two arms can also be studied (e.g. in case when the cross sectional areas of the two arms are different). Relative sharing of load between the steel liner, the concrete layer and the surrounding rock can also be determined and monitored.

Figure 4.6 gives locations of strain gages mounted on the Wye section at Maneri Bhali stage II. The Wye section was tested for a water head of 260 m. The data obtained gave insight to the designers for future designs of Wye sections.

To measure stress at various points on a Wye section, strain gages are fixed to the surface of the Wye section with the help of mounting brackets, which are arc welded to the body of the Wye section.

The ends of the Wye section are sealed and water pressure applied through one small opening left for the purpose. It is recommended that this sealing be done before the mounting of the strain gages such that any damage to them because of high current due to welding is avoided. The points of maximum strain and consequently maximum stress are thus determined. In case the stress at all the points is less than yield stress, the Wye

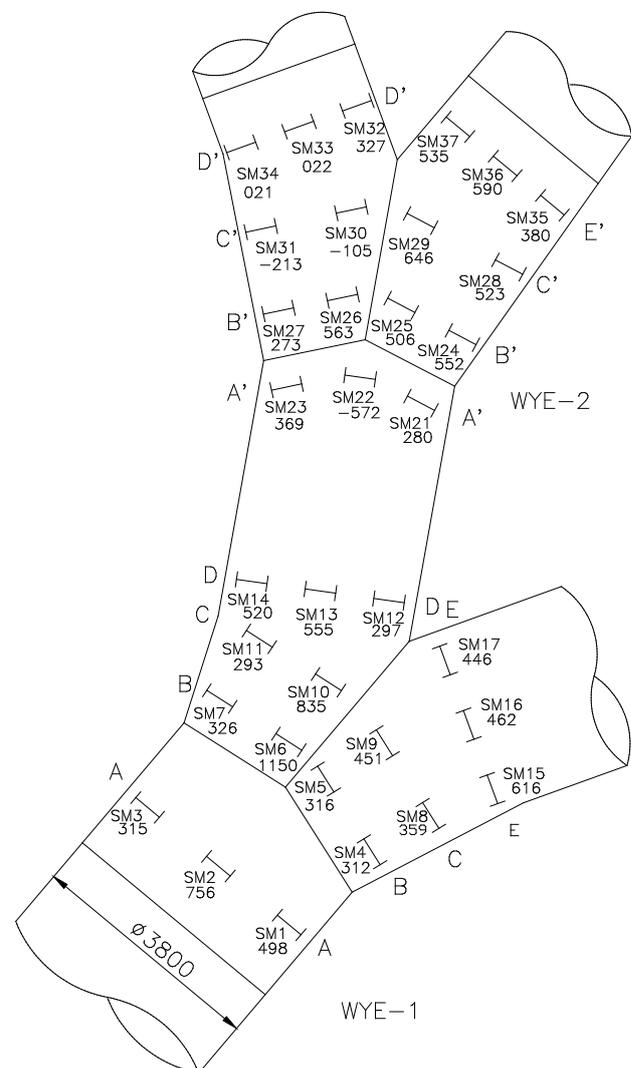


Figure 4.6

section is good and can be safely used.

If long-term monitoring of the stress in the Wye section is required, the strain gages should be left at the points where the stress is high. They should also be left at all the critical points. The balance strain gages should be removed and can be used for other applications. In case the Wye section is concrete lined, these can be mounted in the concrete lining or the concrete rock interface. In case, they are mounted in the concrete lining or the concrete rock interface, it is good practice to mount them at the same section at which the strain gages are retained on the Wye piece. Sharing of load between the steel liner, the concrete layer and the surrounding rock can thus be studied and long-term monitoring of stress can be done, if required. In case strain gages are to be embedded in concrete, it is recommended to use the electron beam welded Encardio-rite model EDS-11V strain gages instead of the model EDS-21V-AW strain gages.

For further elaboration see Encardio-rite application note AN 9604 in which instrumentation of two Wye sections in the same steel structure, feeding into three hydro turbines at Maneri Bhali stage-II in Uttar Pradesh, India is discussed.

4.3.4 I-beams

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 4.7. The axial stress may be determined as follows:

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

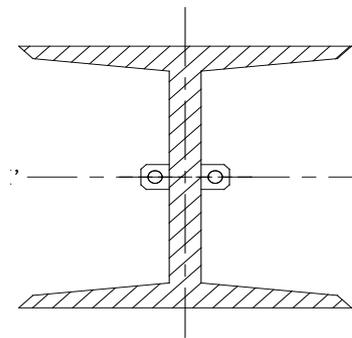


Figure 4.7

4.3.4.1 Strain gages mounted on the 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 4.8. 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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$$\sigma_{xx} = \frac{(\epsilon_1 + \epsilon_2) - (\epsilon_3 + \epsilon_4)}{4} \times \frac{a}{c} \times E$$

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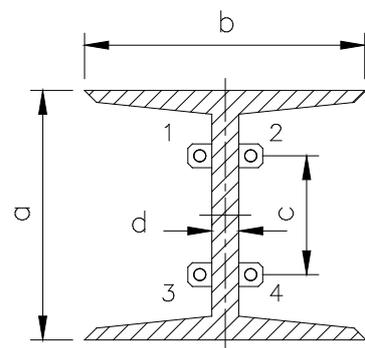


Figure 4.8

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:

Error! Bookmark not defined. $\sigma_{maximum} = \sigma_{axial} + \sigma_{xx} + \sigma_{yy}$

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.

4.3.5 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 4.9. 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, which 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 4.7 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 4.8 and 4.9.

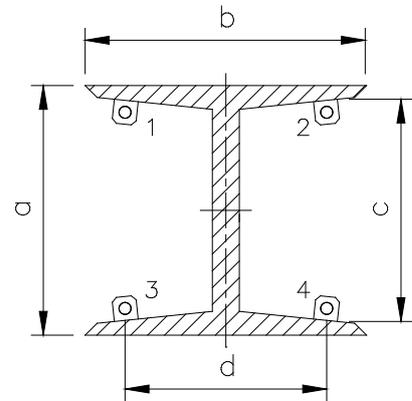


Figure 4.9

5 THERMISTOR - TEMPERATURE RESISTANCE CORRELATION

Thermistor type: Dale 1C3001-B3

5.1 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	-42	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 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/repared 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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