innovation in
geotechnical
instrumentation

Arc Weldable Vibrating Wire Strain Gauge (VWSG-A) Instruction Manual

---

Document Number: ELM0086 A

Release Date: December 06, 2017

RST INSTRUMENTS LTD.
11545 Kingston St.,
Maple Ridge, BC
CANADA V2X 0Z5

SALES + SERVICE + MANUFACTURING:
604 540 1100 | info@rstinstruments.com
TOLL FREE (USA & Canada) | 1-800-665-5599

www.rstinstruments.com

TABLE OF CONTENTS

LIST OF FIGURES AND EQUATIONS

LIST OF TABLES

1 INTRODUCTION

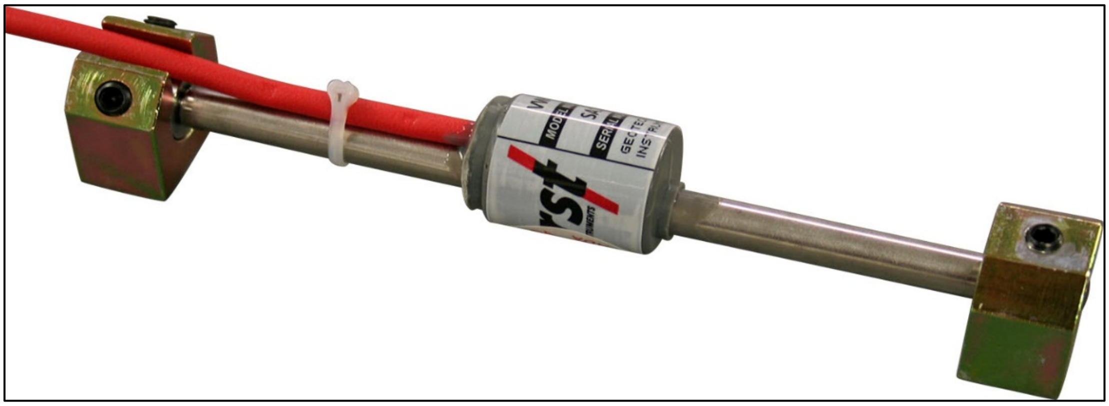

FIGURE 1-1 RST VWSG-A VIBRATING WIRE STRAIN GAUGE

RST VWSG-A Vibrating Wire Strain Gauges are designed to measure long term strain. Application examples include driven steel piles, steel struts, steel props, and steel or concrete tunnel linings. They may be directly attached to steelwork or concrete surfaces using mounting blocks. Stress changes can then be calculated based on strain measurement changes if the material modulus is known.

Vibrating Wire Strain Gauge (VWSG) instruments measure strain using the vibrating wire principle. A length of high tensile steel wire is anchored and tensioned between two mounts within the body of the instrument. An encapsulating sealed stainless steel tube protects the vibrating wire from the external environment.

RST VWSG-A Vibrating Wire Strain Gauges are manufactured in various configurations to suit particular mechanical applications. They are supplied with various types of end blocks and terminations to enable the strain gauges to be attached or embedded into a variety of materials and configurations.

1.1 VIBRATING WIRE READOUT UNITS

RST VWSG-A Vibrating Wire Strain Gauges may be read using the RST VW2106 Vibrating Wire Readout Unit or other manufacturer’s vibrating wire readout units or data loggers equipped with vibrating wire excitation modules. Ensure the correct frequency sweep is being applied to the vibrating wire sensors by the vibrating wire readout unit to prevent false readings.

NOTE: STRAIN GAUGE READINGS ARE NORMALLY DISPLAYED IN B UNITS (FREQUENCY^2 * 10^{-3}) ON RST VW2106 READOUT UNITS. USERS MUST CONSULT THE RST VW2106 VW READOUT INSTRUCTION MANUAL FOR DETAILED READING INSTRUCTIONS.

RST VWSG-A Vibrating Wire Strain Gauges may require different sweep frequency ranges to provide correct B Unit output readings, depending on the manufacture date. The operator must consult the Strain Gauge Calibration Record Sheet in order to confirm these requirements.

RST VWSG-A Vibrating Wire Strain Gauge instruments use a sweep frequency of 450 to 1200 Hz. However, the operator must always refer to the VW Calibration Record Sheet for the VWSG-A Strain Gauge sensor to determine the correct sweep frequency required to obtain a correct reading.

The sweep frequency for the VW2106 VW Readout Unit can be easily changed in the field. Refer to the VW2106 VW Readout Unit Instruction Manual for instructions on how to change the sweep frequency setting.

2 SAFETY

VWSG-A Strain Gauges end fittings are sealed by a pair of Viton O-rings within a protective outer steel tube to ensure the strain gauge is completely waterproof to protect against external fluid pressures in excess of 250psi.

3 SURFACE INSTALLATION

3.1 INSTALLATION OF THE MOUNTING BLOCKS

VWSG-A Strain Gauges are supplied in an un-tensioned state and require the initial tension to be pre-set by the installer in the direction of the expected strain movement.

The basic mounting arrangement consists of a pair of steel mounting blocks holding the ends of the strain gauge securely in place. VWSG-A Strain Gauges can be supplied with a wide range of steel mounting blocks to enable the strain gauge to be fixed to steel structures by arc welding or onto concrete surfaces using drill-in anchors or epoxy glue.

1. Ensure the two steel mounting blocks are located in perfect alignment and exact distance on the steel surface where the installation is to occur. Errors in measured strain calculations will occur if the steel mounting blocks are installed at the correct distance apart.

2. Locate the temporary spacer bar and place it in between the two mounting blocks.

> **CAUTION: THE STEEL SPACER BAR IS SUFFICIENTLY RIGID TO RESIST ANY BENDING OR DISPLACEMENT CAUSED BY THE WELDING INSTALLATION PROCESS. VWSG-A STRAIN GAUGES ARE NOT RIGID ENOUGH TO WITHSTAND THE FORCES WHICH COULD BE INDUCED BY THE WELDING PROCESS. INCORRECT SUBSEQUENT READINGS AND DAMAGES TO THE INSTRUMENT MAY RESULT IF A TEMPORARY SPACER BAR IS NOT USED.**

3. Locate the spacing jig that is used to set the steel spacer bar in alignment and correct length with the two steel mounting blocks.

4. Tighten the mounting block set screws into place on the steel spacer bar.

5 Remove the locked strain gauge assembly from the spacer jig. Set it in place on the prepared steel surface in preparation to be arc welded in place. Refer to Figure 3-1.

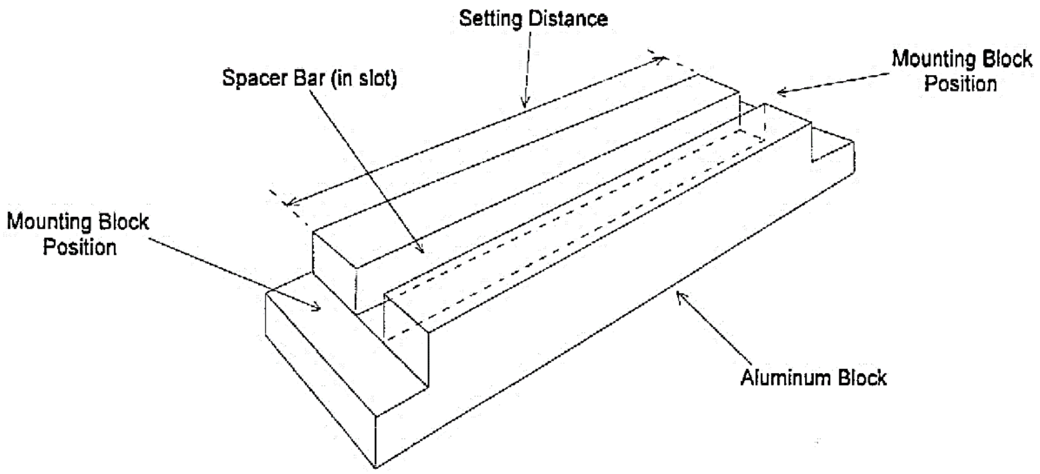

FIGURE 3-1 SPACING JIG

6 Connect a M4 cone point set screw into a circumferential “Vee” groove at one end of the strain gauge. Refer to Figure 3-2.

7 Clamp the strain gauge in the milled slot at the top of the other mounting block using two M4 dome point set screwed placed through the back at opposing angles. Refer to Figure 3-2.

8 One mounting block has a single M4 cone point set screw that connects into a circumferential "Vee" groove at one end of the Strain Gauge. The other mounting block has a milled slot at the top to allow the plain end of the Strain Gauge to be clamped in place using two M4 dome point set screws placed through the block at opposing angles. Refer to Figure 3-2.

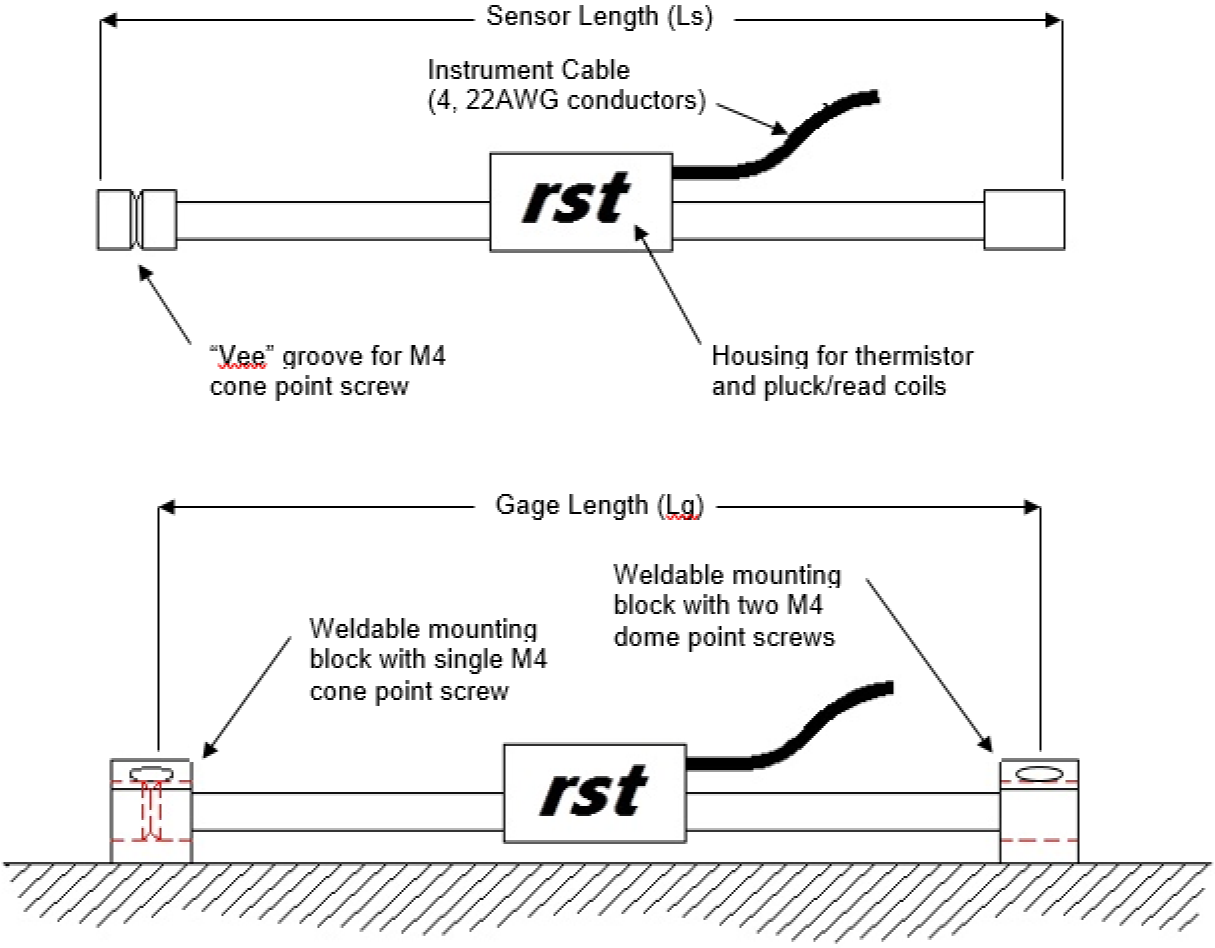

FIGURE 3-2 VWSG-A GENERAL ARRANGEMENT

3.2 ARC WELDING THE MOUNTING BLOCKS

It may be advantageous to have additional installers and multiple spacer bars available for use to speed up the installation process when many strain gauges are being installed at one site.

1. Clean the steel surface where the installation is planned, using a wire brush to remove all scale, rust, and dirt. The surface must also be cleaned with a solvent if oil or grease contamination is evident.

2. Remove the assembled steel spacer bar and steel mounting blocks from the spacing jig and press firmly against the steel surface. The spacer bar can be used as a handle to hold the assembly in place during the welding work.

3. The outer edges of the mounting blocks are now ready to be arc welded to the steel surface in the order shown in Figure 3-3.

   Do not weld any place on the flat end surfaces of the steel mounting blocks, as it could prevent the spacer bar removal.

CAUTION: DO NOT TO WELD ANY PLACE ON THE FLAT END SURFACES OF THE STEEL MOUNTING BLOCKS WHICH COULD PREVENT THE SPACER BAR REMOVAL.

FIGURE 3-3 WELDING SEQUENCE FOR THE MOUNTING BLOCKS

4 Avoid build-up of excessive heat, which could result in deformation of the intended mount alignment. Cooling should be carried out with a wet rag following each weld pass. The welds must be secure, but not excessively large in order to avoid the introduction of stresses and distortion into the surrounding steel.

5 Cool the welds and the mounting blocks with a water soaked rag.

6 Slacken the three set screws. Remove the temporary spacer bar.

7 Clean away all welding slag and splatter using a wire brush and welding hammer. Do not damage the steel mounting blocks.

8 If the strain gauge is to be protected by a cover plate, threaded studs intended to hold the cover plates in place will need to be welded in place at this time before the VWSG-A Strain Gauge is installed.

A low power arc welder or special stud welder may be used for stud welding. The hex head of small bolts (approximately 3/16” to 1/4” size) should weld flush to the steel surface.

9 It is recommended to apply a coat of rust preventative paint over the weld points to inhibit corrosion that could occur over time.

3.3 INSTALLATION TO MEASURE CONCRETE SURFACE STRAINS

Concrete surface strains can be measured by attaching the VWSG-A Vibrating Wire Strain Gauge to the concrete surface using one of the following methods as shown in Section 3.3.1 and Section 3.3.2.

3.3.1 Installation on Concrete using Groutable Anchors

Vibrating Wire Strain Gauges may be mounted on concrete surfaces by welding M10 steel anchor bars onto the bottoms of the strain gauge mounting blocks. The mounting blocks are connected to the steel spacer bar using the same procedure described in Section 3.2 for welded mounting blocks.

1 Position and space the mounting blocks properly using the spacing jig.

2 Use a template to drill two 70 mm deep x M12 holes in the concrete surface. Ensure the spacing for the M10 anchors is correct.

3 Grout the anchors into the pre-drilled holes using either a fast setting hydraulic cement or a high strength epoxy.

4 Remove the spacer bar after a full grout set is achieved. The VWSG-A Strain Gauge is ready to be installed.

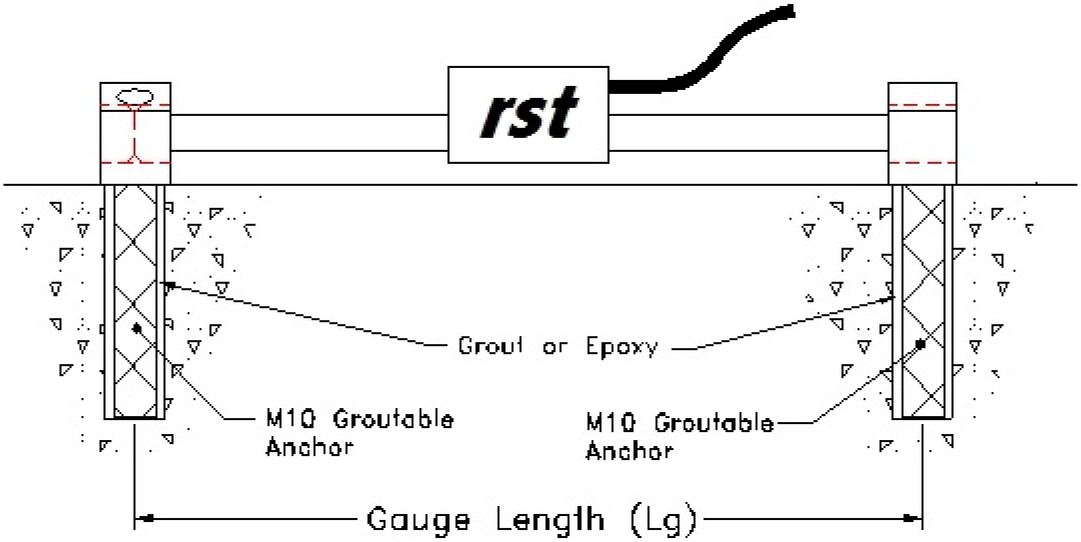

FIGURE 3-4 INSTALLATION ON CONCRETE USING GROUTABLE ANCHORS

3.3.2 Installation on Concrete using Epoxy

The standard steel mounting blocks can be epoxied directly on to a concrete surface, in some cases, with proper care.

CAUTION: THE EPOXY USED MUST BE CAPABLE OF BEING CURED AT THE TEMPERATURE OF THE INSTALLATION LOCATION. NOTE THAT THE CONCRETE SURFACE MAY BE COOLER THAN THE SURROUNDING AMBIENT AIR TEMPERATURE.

1 Ensure the concrete surface is clean and dry and has a certain amount of roughness to allow epoxy bonding. Sand, chip, and clean as required.

2 Remove the plating on the underside of the mounting blocks.

3 Roughen the steel surface with a coarse emery cloth.

4 Cure the epoxy. Note that the concrete surface may be cooler than the surrounding ambient air temperature.

3.4 SETTING THE INITIAL TENSION OF THE STRAIN GAUGE

Key construction sequence of events and key instrument installation steps will need to be identified for every strain gauge installation. Successful installations will take both these interdependent activities into detail.

The strain gauges must be examined before and after each key construction sequence events and each instrument installation step to ensure that the instrument function has not been disrupted.

The installer must also investigate the ongoing work at site to identify any unforeseen construction procedures/problems that have potential to put the installation at risk.

Determine whether the strain gauge will be measuring compressive or tensile strains prior to installing the VWSG-A Strain Gauge.

1. Insert the strain gauge sensor into the mounting block end with the “Vee” groove. Refer to Figure 3-2.
2. Slide the strain gauge into the mounting block holes. Tighten the single set screw into the one “Vee” groove only.

NOTE: THE VIBRATING WIRE CALIBRATION RECORD SHEET MUST BE CONSULTED FOR EACH VWSG-A STRAIN GAUGE BEING INSTALLED TO DETERMINE THE CALIBRATION OF THE INSTRUMENT AND THE READING FREQUENCY TO STRAIN RELATIONSHIP WHICH IS REQUIRED FOR SET-UP OF THE INITIAL TENSION OF THE STRAIN GAUGE, BETWEEN THE TWO FIXED MOUNTING BLOCKS.

3. Attach the VWSG-A strain gauge readout wires to a vibrating wire readout unit.
4. Gently push or pull the free end of the strain gauge to set a preload tension in the strain gauge in the direction that either compressive or tensile strains are expected to occur.

   The usable range of a VWSG-A Strain Gauge is approximately 3000 micro-strains between 1000 and 4000 micro-strains. The mid-range reading is approximately 2500 micro-strains.

   Set the strain gauge between 3000 and 3500 micro-strains for monitoring expected compressive strains. Set the strain gauge between 1500 and 2000 micro-strains for monitoring expected tensile strains.

NOTE: DIRECT STRAIN GAUGE READINGS WILL BE PROVIDED TO THE OPERATOR IN B UNITS [(VW FREQUENCY)^2 X 10^{-3})] DURING INSTALLATION WORK FROM THE RST VW2106 READOUT BOX.

REFER TO SECTION 8 FOR A DETAILLED EXPLANATION OF HOW THE MICRO-STRAIN VALUES ARE CALCULATED FROM THE VIBRATION FREQUENCY OF THE VIBRATING WIRE STRAIN GAUGES.

IT IS RECOMMENDED THAT THE OPERATOR PREPARE A SPREADSHEET IN ADVANCE OF THE FIELD INSTALLATION WORK TO PROVIDE QUICK CORRELATIONS BETWEEN B UNIT READINGS, FREQUENCY, AND MICRO-STRAIN AT QUARTERLY POINTS THROUGHOUT THE STRAIN GAUGE RANGE.

5 Tighten the two cone point set screws at the end of the mounting block (opposite “Vee”) to retain the desired initial Strain Gauge reading once the desired micro-strain reading (B Unit equivalent) has been achieved.

NOTE: THE MICRO-STRAIN READING WILL LIKELY CHANGE SLIGHTLY DURING THIS OPERATION AS THE STRAIN SETTINGS ARE VERY SENSITIVE TO MECHANICAL CHANGES. A RESET MAY BE REQUIRED IF THE STRAIN GAUGE READING CHANGES SIGNIFICANTLY FROM THE TARGETED LEVEL.

6 Secure all the output wiring from the strain gauge.

7 Gently tap the end blocks with the plastic handle of a small screwdriver to relieve any residual stresses or mechanical hang-ups. Repeat tapping until a stable B Unit output reading is achieved.

8 Re-check the output reading from the strain gauge. Reset the strain gauge to an acceptable setting if the reading has moved too much from the desired set point.

Mid-range value will be sufficient for most strain gauges. The strain gauge set point can be offset from the center of the range in either the compressive or tensile directions as required. Note that:

- For the monitoring of higher compressive strains, the strain gauge would be set at a higher frequency than 50% of range so that more range would be available in the negative direction.
- For the monitoring of higher tensile strains, the strain gauge would be set at a lower frequency than 50% of range so that more range would be available in the positive direction.

3.5 INITIAL READINGS

Take and document the initial reading carefully as all future strain gauge readings will be compared back to the initial reading.

It is recommended to take several baseline readings over several days.

Temperature differentials will impact strain gauge readings. Take the initial reading set in the early morning hours when temperatures are the most iso-thermic and the instruments will be the most stable.

Steel structures will require an initial strain readings to distinguish the strain differential that has been caused by subsequent readings.

3.6 GAUGE PROTECTION

3.6.1 Corrosion Protection

Rust inhibiting paint should be applied to all weld points if the strain gauge instrument installations are intended for long term use. Unchecked corrosion over time can impact the connection of the strain gauge instrument to the underlying steel structure, which could alter the instrument output.

3.6.2 Thermal Protection

Avoid thermal input from direct sunlight on strain gauge instruments as any resulting heat rise on the steel body will have a large impact on the instrument output and mechanical function.

Heat shields and insulation can be installed in an attempt to provide protection from thermal input, but the heat influence at certain times of the day and under certain weather conditions may render a portion of the daily output data unusable.

Ensure a full set of daily base readings are established each day prior to dawn when everything at the site will be most isothermal. This daily base data set will help to interpret changes that are actually occurring and will indicate when and where reading inputs cannot be trusted.

All temperature data will need to be logged and archived for later use. The temperature data should be plotted with movement data which will indicate any relationships and clearly establish the influence of temperature.

3.6.3 Mechanical Protection

Strain gauge instruments are very sensitive to mechanical interference. It is highly recommended that guards and cover plates be installed over and around instruments that could be at risk to avoid unwanted mechanical influence or disturbance.

Any sudden reading changes from a strain gauge instrument should be inspected to check for any obvious signs of an external mechanical event, such as being struck, lifted, or having a vertical load applied.

The cables from mounted strain gauges need to be adequately protected from mechanical damage and excessive wear over time. Rigid or flexible conduit, steel guards, barriers, or covers may be supplied by RST as custom parts.

4 LIGHTNING PROTECTION

VWSG-A Vibrating Wire Strain Gauges, unlike numerous other types of Vibrating Wire instruments available from RST, do not have any integral lightning protection components included. Integral surge protection devices are normally not required as the installation environment is usually well grounded and provides adequate protection.

The entire instrumentation system will need to be considered, such as when multiple instruments are connected to a network which covers a large area. The network could be subject to transient and/or induced currents which could damage sensors or data acquisition equipment.

External surge protection may be required to reduce the risk of damage and data loss. The following suggestions for surge protection are provided:

- Components such as plasma surge arrestors (spark gaps) may be installed if a strain gauge is connected to a terminal box or multiplexer. Terminal boxes and multiplexers available from RST provide built-in locations for installation of these surge protection devices.
- Lightning arrestor boards and enclosures are available from RST. They are installed at the exit point of the instrument cable from the structure being monitored. The enclosure has a removable top, so in the event the protection board (Surge 4C) is damaged, the user may easily service the components or replace the board. A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the Strain Gauges. See Figure 4-1.

Additional information is available from RST on surge protection schemes and other alternatives.

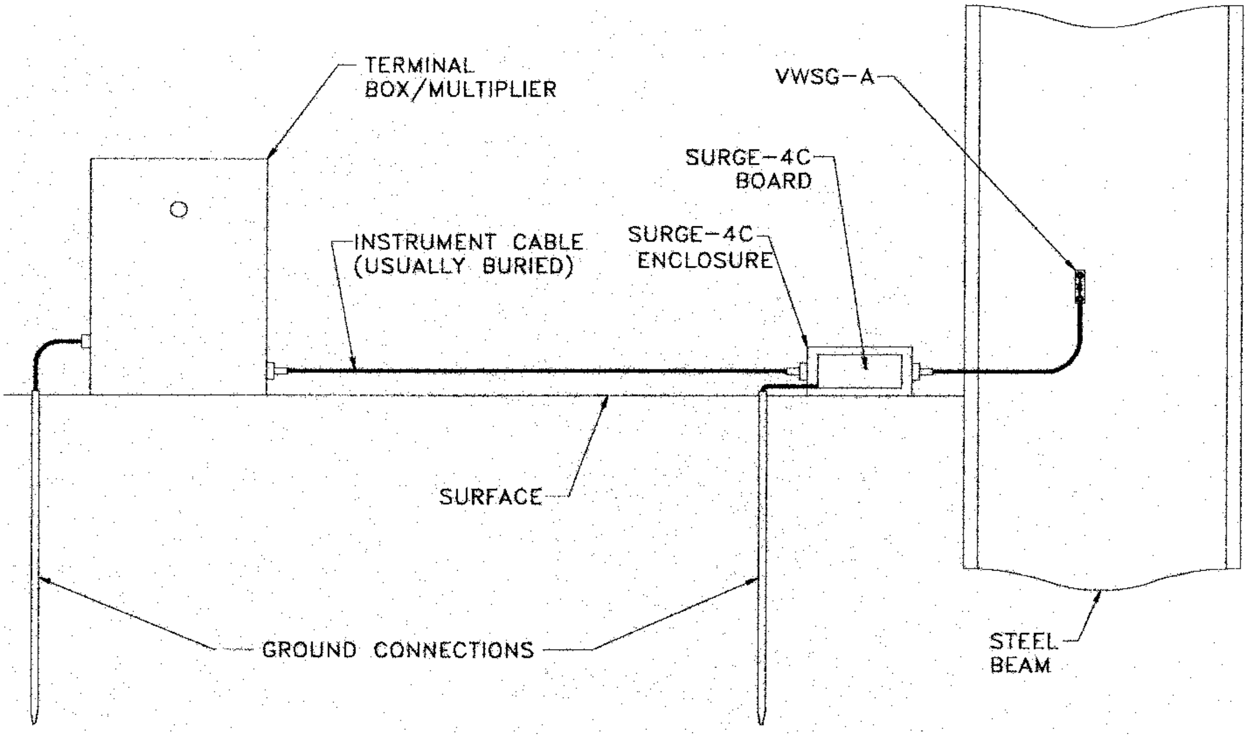

FIGURE 4-1 LIGHTNING PROTECTION SCHEME

5 TAKING READINGS WITH VW2106 READOUT UNIT

5.1 CABLE AND WIRING

TABLE 5-1 VWSG-A GAUGES

Wire Color	Function
Red	Strain Gauge Excitation
Black	Strain Gauge Excitation
White	Thermistor
Green	Thermistor
No Shield Wire	

Cables supplied with the strain gauges may be readily extended using electrical wire/cable of the same or greater gauge size. Cable extension does not affect the output or accuracy of vibrating wire strain gauges since the gauge outputs a frequency signal which is unaffected by the resistance of an additional cable length.

CAUTION: ALL WIRE/CABLE SPLICES MUST BE PROPERLY INSULATED AND PROTECTED. IT IS RECOMMENDED THAT THE NUMBER OF SPLICES BE MINIMIZED DUE TO THE INHERIT RISKS THAT SPLICING POSTS TO THE OVERALL WIRING INTEGRITY OF AN INSTALLATION.

Always maintain the polarity identification of the sensor by connecting same color wires to the same color when splicing.

All cable joints should be protected by a fully waterproofed epoxy based splice. The RST CT-1100 Epoxy Splice Kit is recommended.

Cable running in difficult locations, such as deep bored piles and diaphragm walls, should be fully protected from damage by tremied concrete and tremie pipes. Effective cable protection includes running the cables in thick walled UPVC ducting and tying the ducting to adjacent reinforcing bars.

Cable protection from high accelerations is particularly important if VWSG-A surface mount gauges are to be used on steel driven piles. Contact RST for advice on these applications.

5.2 RST VW2106 VIBRATING WIRE READOUT OPERATION

The RST VW2106 Vibrating Wire Readout is the basic manual readout box for all vibrating wire type instruments, including vibrating wire strain gauges. The VW2106 Readout can be programmed to log vibrating wire readings and is also able to apply calibration constants which will convert frequency readings into engineering units.

Refer to the VW2106 manual for details of the operation and use of the RST VW2106 Vibrating Wire Readout unit.

5.3 TAKING A MANUAL READING USING THE RST VW2106 READOUT

The following instructions outline the basic steps needed to take a manual reading with the VW2106 Readout Unit:

1. Connect the vibrating wire instrument leads to the VW2106 terminal strip quick-connects. Match the wire colors to the colors indicated at the terminal strip.
    - Red and Black are from the vibrating wire coils.
    - Green and White are from the thermistor sensor.
2. Turn on the readout unit by pressing any key.
3. Wait for the readout to go through its start-up procedure. It will automatically default to the reading screen.
4. The vibrating wire B-unit reading (f^2x10^{-3}) will appear at the top of the screen. The temperature (°C/°F) will appear at the bottom of the screen.

5 Record the reading and move to the next instrument. Connect the vibrating wire sensor wires to the terminal strip quick-connects in the same manner as in Step 1.

6 The operator can listen to the plucking of the vibrating wire coil by simultaneously pressing the up/down arrows for several seconds. A speaker icon will appear on the display. This will verify if the vibrating wire coil is functional and is being plucked.

7 Manual readings on sensors which contain multiple gauges (such as load cells) are performed by connecting the instrument to the expansion port with the appropriate connector. Refer to the VW2106 VW Readout Instruction Manual for further instructions.

8 The VW2106 Readout unit will automatically turn itself off after approximately 5 minutes to conserve power if there is no input provided by the user.

Refer to the below table indicating the various sweep frequencies provided by the RST VW2106 VW Readout Box for reading VW sensors.

Table 6-1 displays the following sweep frequencies are used for reading strain gauge instruments:

TABLE 6-2 SWEEP FREQUENCIES FOR READING VW SENSORS

Sweep Setting	Frequency Range	Instrument Type
A Sweep	450-6000 Hz	Wide Sweep
B Sweep	1200-3550 Hz	Piezometer, Strain Gauge, Borehole Stressmeter, Jointmeter, Crackmeter, Displacement, Settlement, Temperature, Load Cells
C Sweep	450-1200 Hz	Strain Gauge (Arc Weldable)
D Sweep	450-1200 Hz	Strain Gauge (Embedment)
E Sweep	1000-3600 Hz	Strain Gauge (Spot Weldable)
F Sweep	2500-6000 Hz	Borehole Stressmeter
U Sweep	1200-3550 Hz	User Specified Frequency

5.4 INITIAL READINGS

Subsequent strain gauge readings will always be referenced to some initial or inferred zero strain reading. The initial reading should be taken when the structure is in an unloaded or unstressed state.

For example, in the case of driven piles, the initial readings may not take place until some time well after the pile installation, but just before additional loading is added. Extreme care must be taken with the establishment of the initial reading set, to ensure that the readings are valid and that the details of the load state are clearly known and recorded at that time.

Care must be taken to ensure that ostensibly unloaded structures are not being influenced by the ambient temperatures, bending moments within the structure, or other physical stresses at the time that the initial readings are being taken.

It is always good practice to take a set of readings late in the afternoon, immediately following the head of day to understand how the ambient temperatures may be effecting the base strain readings. Take another set in the early morning before sunrise.

It will be impossible to properly evaluate or interpret the later loaded results if these issues are not understood and taken into account by the initial readings.

6 DATA INTERPRETATION

6.1 CONVERSION OF B UNIT READINGS TO THEORETICAL MICRO-STRAIN

The VW2106 Vibrating Wire Readout unit provides B Unit readings which are related to the resonant vibration frequency of the Vibrating Wire sensor. This relationship to reading frequency is provided in the following equation.

$$B\ Unit = \left(f^{2} x 10^{-3}\right)$$

EQUATION 6-1 VIBRATION FREQUENCY TO B UNIT RELATIONSHIP

Conversion of the B Unit reading to theoretical micro-strain is carried out using a Vibrating Wire Calibration Factor ($\mathrm{CF_T}$), as show in Equation 6-2. For each type and design of vibrating wire strain gauge, a theoretical $\mathrm{CF_T}$ is established based on the design of the instrument, which includes the vibrating wire type used and the length of the installed wire. This theoretical initial $\mathrm{CF_T}$ is called the Theoretical Gauge Factor for that instrument type and is applied to all VWSG instruments manufacture using the same design.

$$\mu\varepsilon = \mathrm{CF_T}\left(f^{2} x 10^{-3}\right)$$

$$\mu\varepsilon = \mathrm{CF_T}\left(B\ \ \mathrm{Unit}\right)$$

EQUATION 6-2 THEORETICAL MICROSTRAIN

Where;

$\mu\varepsilon$ - microstrain units – Theoretical

- Where one microstrain is the strain which will produce a deformation of one part per million

CF_T - Strain Gauge Calibration Factor – Theoretical for the sensor design

- Equals 4.062 $\mu\varepsilon$ / B Unit

f - Resonant frequency of the Vibrating Wire

In practice, the actual physical properties of the vibrating wire used and the manufacturing process, which effectively slightly shortens the free strain length of the vibrating wire, will cause the instrument to slightly over-register an applied strain.

This manufacturing effect is removed by carrying out batch calibrations of completed VWSG instruments and establishing a Batch Calibration Factor. For the sensors used for RST Vibrating Wire Strain Gauges, the Batch Calibration Factor is typically around 0.975 +/- 0.010 (0.965 to 0.985).

$$CF = \mathrm{CF_T} \text{ x } \mathrm{BCF}$$

EQUATION 6-3 BATCH CALIBRATION FACTOR CORRECTION

Where;

CF - From the Sensor Calibration Sheet

CF_T - Varies from batch to batch, but is generally around 0.975 +/- 0.010

BCF - Subject to change, if the manufacturing process changes

The user must ensure that copies of the VW Calibration Record sheet are available for each installed vibrating wire strain gauge sensor. Take care to understand the Calibration Factors which are provided on the Calibration Sheet and the relationship which exists between the Theoretical Calibration Factor and the Batch Calibration Factor.

Example Calculation – Change in Strain

- For a Model VWSG-A Arc Weldable Strain Gauge

- VW Readings taken using Sweep C at 450 to 1200 Hz

Initial B Unit Reading = 684 B Units

- Before load is applied
- Frequency f = 827 Hz
- CF = 3.960 $\mu\varepsilon$ / B Unit

Strain = 684 B Units x CF
Strain = 684 B Units x 3.960 $\mu\varepsilon$ / B Unit = 2708.6 $\mu\varepsilon$

Final B Unit Reading = 724 B Units - After load is applied
- Frequency f = 851 Hz

Strain = 724 B Units x CF - CF = 3.960 $\mu\varepsilon$ / B Unit
Strain = 724 B Units x 3.960 $\mu\varepsilon$ / B Unit = 2867.0

Net Strain Change:

Net B Unit Reading Change = + 40 B Units
Net Strain Change = B Unit Change x CF
Net Strain Change = + 40 B Units x 3.960 $\mu\varepsilon$ / B Unit = **+ 158.4 $\mu\varepsilon$**

Net Strain Change = Initial Strain Reading - Final Strain Reading
= 2708.6 $\mu\varepsilon$ - 2867.0 $\mu\varepsilon$ = **+ 158.4 $\mu\varepsilon$**

6.2 CONVERSION OF READINGS TO STRAIN CHANGES

Vibrating Wire Strain Gauges are built registering an initial strain due to the manufacturing process, which fixes the vibrating wire at an initial tension. This initial strain setting is removed by carefully establishing base reading as part of the installation procedure and then comparing all subsequent readings to the original base reading. The True Strain is calculated Equation 6-4.

$$\mu\varepsilon_{true} = \left(R_1 - R_0\right)$$

EQUATION 6-4 TRUE STRAIN CALCULATOR

Where;

R_0 is the initial strain reading	$\mu\varepsilon$
R_1 is a subsequent strain reading	$\mu\varepsilon$

Note:

When ($R_1 - R_0$) is positive	The strain is TENSILE
When ($R_1 - R_0$) is negative	The strain is COMPRESSIVE

6.3 STRAIN RESOLUTION

The VW2106 Vibrating Wire Readout unit provides B Unit readings with a resolution of 0.1 B Units. The resolution of the micro-strain measurements can be calculated as follows using Equation 6-5:

$$\mu\varepsilon = CF\,(B\ \text{Unit})$$

$$\mu\varepsilon = CF\,(0.1)$$ - Strain Reading Resolution

EQUATION 6-5 MICRO-STRAIN RESOLUTION

Where; $\mu\varepsilon$ is micro-strain
CF is the Strain Gauge Calibration Factor ($\mu\varepsilon$ / B Unit)

6.4 CONVERTING STRAINS TO STRESSES

Strain changes with time are computed from strain gauge readings taken at various times and by comparison with some initial readings taken at time zero. This initial reading is best taken when the structural member is under no load, such as when the gauges should be mounted while the member is still in the steel yard or warehouse.

This is not always possible and often strain gauges are installed on members which are under some existing load so that subsequent strain changes always take off from some unknown datum. A technique exists, called the "Blind Hole Drilling Method" (Photolastic 1977), whereby residual or existing stresses can be measured. The procedure is to cement a strain gauge rosette to the surface and then to analyze the strains caused by drilling a short blind hole in the center of the rosette. However, it is a well-known fact that strains can be locked into the steel during its manufacture.

Sometimes it is possible, especially where temporary supports are being monitored, to measure the strain in the structural member after the structure has been dismantled. This no-load reading should agree with the initial no load reading if one was obtained. Any lack of agreement would be an indication of gauge zero drift although the possibility of some permanent plastic deformation of the member should not be overlooked, particularly where measured strains were high enough to approach the yield point.

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

In the case of a steel structure, a strain gauge measures the strain at one point on the surface, and this would be sufficient if it could be guaranteed that no bending was occurring in the member. In practice, this will occur near the center of long thin members subjected to tensile loads. Elsewhere, bending moments are the rule rather than the exception, and there will be a neutral axis around which bending occurs.

If bending effects are to be considered, then more than one strain gauge is required at each cross section of the structural member. At least three gauges are required, and very often more, for a complete analysis. On a circular pipe strut, three gauges spaced 120° around the strut's periphery would suffice (four would be preferable). On an H pile or I beam, at least four strain gauges would be called for, while on sheet piling two gauges back to back on either side of the pile would be needed.

Where a member is subjected to bending and only the front surface is accessible, such as a steel tunnel lining or the outside of sheet pilings, the bending moments can be measured by installing two strain gauges different distances from the neutral axis.

Consider the example of an I beam shown in Figure 6-11. Four strain gauges (1, 2, 3 and 4) are welded in two pairs back to back on the central web. The gauges are at a height (d) above the center of the web (axis yy) and at a distance (2c) apart. The I beam has a flange (2b wide) and a web (2a deep).

The axial stress is given by averaging the strain reading from all four strain gauges and multiplying by the modulus.

$$\sigma_{axial} = \frac{(\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4)}{4} * E$$

EQUATION 6-6 AXIAL STRESS CALCULATION

The stress due to bending is calculated by looking at the difference between pairs of gauges mounted on opposite sides of the neutral axis. Thus, the maximum stress due to bending about axis yy is given by:

$$\sigma_{yy} = \frac{(\varepsilon_1 + \varepsilon_3) - (\varepsilon_2 + \varepsilon_4)}{4} * \frac{b}{d} * E$$

EQUATION 6-7 STRESS DUE TO BENDING ON AXIS YY

The maximum stress due to bending about axis xx is given by:

$$\sigma_{xx} = \frac{(\varepsilon_1 + \varepsilon_2) - (\varepsilon_3 + \varepsilon_4)}{4} * \frac{a}{c} * E$$

EQUATION 6-8 STRESS DUE TO BENDING ON AXIS XX

$$\sigma_{\max imum} = \sigma_{axial} + \sigma_{xx} + \sigma_{yy}$$

EQUATION 6-9 MAXIMUM STRESS

In all of the above calculations pay strict regard to the sign of the strain.

Note that the total strain, at any point in the cross section, is the algebraic sum of the bending strains and the axial strain. It will be seen that the strains in the outer corners of the flange can be a lot higher than the strains measured on the web and that failure of the section can be initiated at these points. Hence the importance of analyzing the bending moments.

The above consideration would also seem to lead to the conclusion that, from the point of view of obtaining the greatest accuracy, the best location for the strain gauges would be on the outer comers of the flanges as shown in Figure 6-12. The disadvantage of having the gauges located here lies in the difficulty of protecting the gauges and cables from accidental damage. A much more severe problem arises from the fact that each of the 4 gauges can be subjected to localized bending forces which affect only one gauge, but not the others. It is always necessary to locate gauges in pairs, one on either side of the neutral axis of the part of the I beam to which the gauge is attached. Therefore, the configuration of Figure 6-11 is preferable (added advantage that gauges located on the web are much easier to protect).

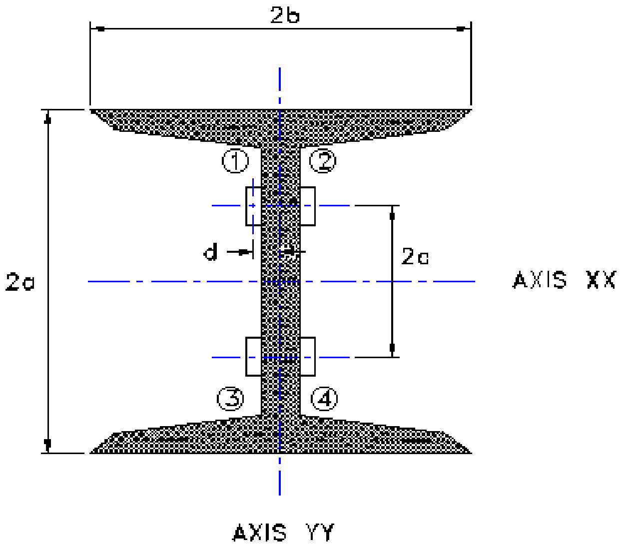

FIGURE 6-10 **STRAIN GAUGES MOUNTED ON CENTRAL WEB. AXIAL STRAIN AND BENDING MOMENTS ABOUT BOTH XX AND YY AXES**

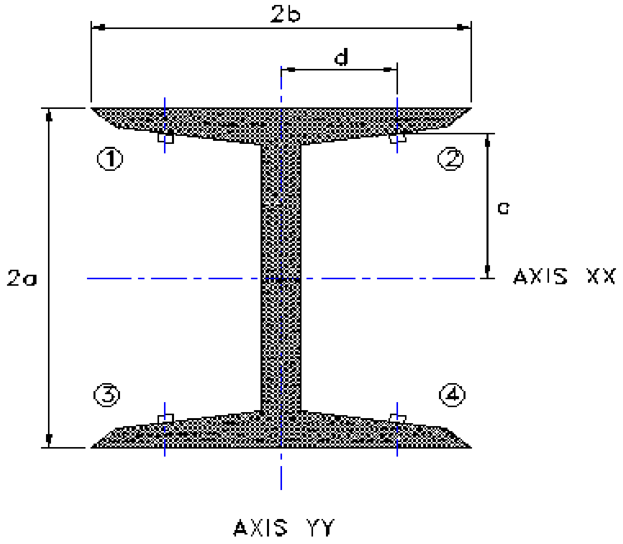

FIGURE 6-11 **STRAIN GAUGES MOUNTED ON FLANGES (NOT RECOMMENDED)**

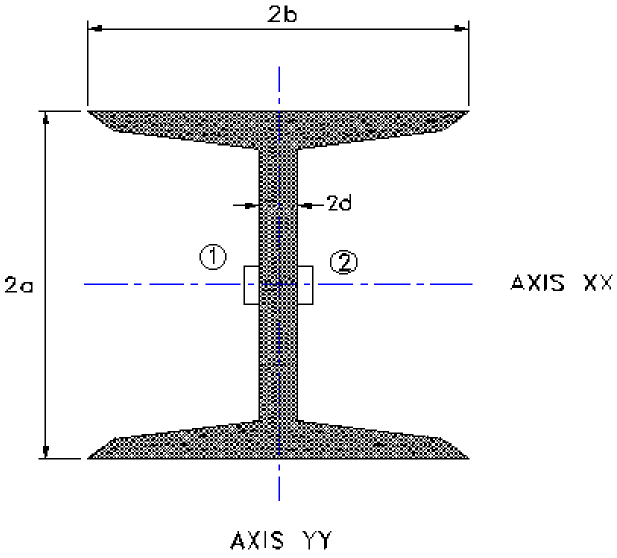

FIGURE 6-12 AXIAL STRAIN MEASUREMENT AND BENDING MOMENT ABOUT YY AXIS ONLY

If it is decided that only two strain gauges per cross-section are to be used, then the configuration shown in Figure 6-13 will give the axial strains and the bending moment around the minor YY axis only.

This configuration has the advantage of positioning the strain gauges and cables where they are easy to protect. In fact, the cable from one gauge can be passed through a hole drilled in the web, so that the two cables can be protected easily be a single conduit.

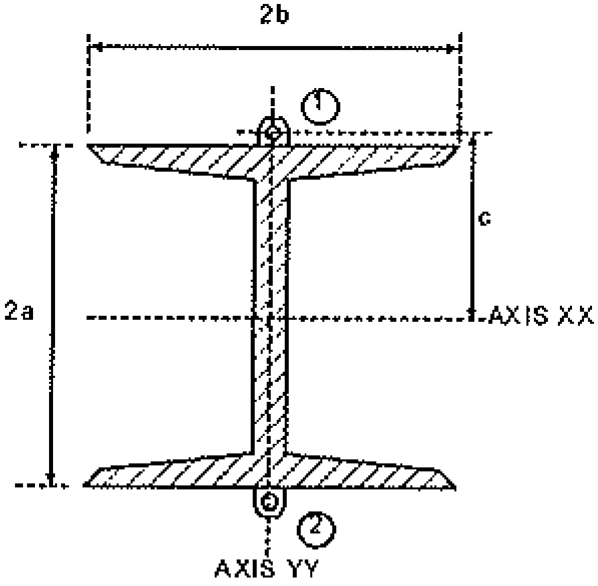

FIGURE 6-13 AXIAL STRAIN AND BENDING MOMENTS ABOUT XX AXIS ONLY

Another alternative strain gauge configuration uses only 2 strain gauges. This configuration allows the calculation of the axial strains and the bending moment around the major XX Axis only. The disadvantage lies in the exposed position of the gauges on the outside of the flanges which will require a greater degree of protection for the gauges and cables.

6.5 TEMPERATURE EFFECTS

The thermal coefficient of expansion of the steel vibrating wire is the same as that for the steel of the structure to which the gauge is attached, so that no temperature correction to the measured strain is required. However, this is only true if the wire and underlying steel structure are at the same temperature. If sunlight is allowed to impinge directly onto the gauge, then this could elevate the temperature of the wire above the surrounding steel and cause large changes in apparent strain. Therefore, always shield strain gauges from direct sunlight.

Also, avoid excessive handling of the gauge prior to reading. Either a) take the reading quickly or b) allow sufficient time for the gauge temperature to re-stabilize before reading. In any case, it is always a good idea to record the temperature every time the strain reading is made so that any real strain effects, caused by temperature changes, can be assessed.

In order to facilitate the measurement of temperature, each strain gauge has a thermistor encapsulated along with the plucking coil. The thermistor is read on the green and white conductors using an ohmmeter or the RST Model VW2104 Readout box. If an ohmmeter is used the relationship between resistance (ohms) and temperature is shown in Appendix B.

6.6 WELDING EFFECTS

Arc welding close to the gauges can cause very large strain on the steel structure. Thus, welding studs onto stronger piles to support lagging or shotcrete reinforcing mesh can cause big strain changes as can welding cover plates or protective channels, etc., over the gauges and cables. Always take gauge readings before and after any arc welding on the steel structure so that corrections can be applied to any apparent strain shifts.

6.7 END EFFECTS

If end effects are to be avoided then strain gauges should be placed away from the ends of struts where they may be influenced by localized clamping or bolting distortions. For most structural members, a distance of 5 feet is sufficient.

On the other hand, end effects may be of some interest because they add to the load induced effects and may be large enough to initiate failure at the ends rather than in the middle of the structural member.

7 TROUBLESHOOTING

1. No reading obtained from a vibrating wire strain gauge. Display shows “00000” on a RST VW2106 vibrating wire readout:

   a) Strain gauge red and/or black wires are disconnected or loose. Check the connections and ensure both wires are correctly connected and tight.

   b) Check the resistance between the red and black wires with a low voltage multi-meter. The resistance of the strain gauge should be approximately 135 Ohms. High or low resistance could indicate a damaged vibrating wire strain gauge sensor or connecting cable. Contact RST for further advice.

   c) Incorrect excitation sweep frequency is being used, which will not produce a stable reading. Check the vibrating wire calibration record sheet for the installed vibrating wire sensor to determine the recommended sweep frequency for the sensor. Change the sweep frequency settings in the VW2106 Readout and re-take the reading.

   d) Ensure the VW2106 Readout is functional by taking a reading from another strain gauge.

2. Fluctuating readings from a vibrating wire strain gauge:

   a) Check the resistance between the red and black wires, which should be nominally about 135 Ohms. Less than 135 Ohms could indicate water ingress into the cable joints or a short circuit.

   b) Incorrect excitation sweep frequency used. Check sweep frequency recommended on the VW Calibration Record sheet.

   c) Ensure the strain gauge was correctly tensioned as part of the installation.

   d) The strain gauges should be pre-installation tested on a solid surface, otherwise the entire gauge may oscillate, causing erroneous and unstable output values.

   e) Ensure the VW2106 Readout unit can conduct readings with another strain gauge.

   f) Ensure the strain values provided by the readout are not outside of the specified range.

   g) Check for a source of electrical interference nearby. Reading problems can be caused by the local presence of power generating equipment or DC to AC Current Inverters. Move data acquisition and electronic readout equipment away from the source of potential interference, install filtering at the data logger, and connect drain wires to a good quality grounding.

Vibrating wire readout units use set sweep frequencies to pluck the vibrating wire in the sensor. The vibrating wire readout units include options for several different sweep frequencies. Output readings will be erratic and unstable if the sweep frequency applied is inappropriate to the natural resonance of the vibrating wire sensor being read. If this problem is noted to be occurring, the sensor sweep frequency should be checked on sensor VW Calibration Record sheet.

Contact RST directly for additional help on troubleshooting issues, if required.

8 SERVICE AND REPAIR

The product contains no user-serviceable parts. Contact RST for product service or repair not covered in this manual.

Appendix A : SENSOR SPECIFICATIONS

Specification	Value
Range	3000 με
Resolution	1.0 με
Accuracy[1]	Batch Calibration: ±0.5%FS Individual Calibration: ±0.1%FS
Zero Stability	0.02%FS/year
Linearity	<0.5%FS
Thermal Coefficient	12.2με/°C
Length (Gage)	150mm
Length (Sensor)	165mm
Frequency Range	450-1200Hz
Coil Resistance	180Ω
Temperature Range	-20 to 80°C
Rated Pressure	2000 kPa

1 – Using curve fitting techniques (second order polynomial)

Appendix B : THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale 41C3001 B3, Alpha #13A3001 B3

Resistance to Temperature Equation:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

EQUATION B-1 CONVERT THERMISTOR RESISTANCE TO TEMPERATURE

where:

T	Temperature in °C
LnR	Natural Log of Thermistor Resistance
A	1.4051 x 10-3 (coefficient calculated over the -50 to +150°C span)
B	2.369 x 10-4
C	1.019 X 10-7

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.11	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342..2	83	107.9	123
77.99K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-35	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	282.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	56.92	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.	53	250.9	93	83.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	3000	25	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

FIGURE B-2 THERMISTOR RESISTANCE VERSUS TEMPERATURE