



Vibrating Wire Embedment Strain Gauge
(VWSG-E)
Instruction Manual

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Vibrating Wire Embedment Strain Gauge (VWSG-E)

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Product: Vibrating Wire Embedment Strain Gauge (VWSG-E)
Instruction Manual

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1 INTRODUCTION

RST VWSG-E Vibrating Wire Strain Gauges are designed for the measurement of strains in Civil and Structural Engineering. VWSG-E Type Strain Gauges may be directly embedded within mass concrete. Stress changes within these materials can then be calculated, based on the strain measurement changes, if the modulus of the material is known.

Vibrating Wire Strain Gauges consist of a length of high tensile steel wire anchored into, and tensioned between, two end blocks. An encapsulating sealed stainless steel tube protects the Vibrating Wire from the external environment. Relative movements of the end blocks result in a change in the tension of the Vibrating Wire causing a change in the resonant frequency of the wire when it vibrates.

Vibrating Wire Strain Gauge (VWSG) instruments measure strains using the vibrating wire principle. A length of special steel wire is pre-tensioned between two mounts located within the body of the VWSG instrument. The VWSG instrument is then securely attached between two mounting blocks that have been welded to the steel surface which is being studied. Deformations (i.e.- strain changes) along the steel surface will cause the two welded mounting blocks to move slightly relative to one another, thus altering the tension of the Vibrating Wire within the VWSG instrument. The tension in the Vibrating Wire is measured by plucking the wire and then measuring its resonant frequency of vibration. In practice, the Vibrating Wire is plucked periodically by an electromagnetic coil positioned next to the wire and its resonant frequency is measured by means of the same electromagnetic coil.

There is a linear relationship between the change in length of the Vibrating Wire Strain Gauge and the square of the resonant frequency of the Vibrating Wire. A Vibrating Wire Readout Unit (RST Model VW2106) supplies an excitation pulse (frequency sweep) to the Strain Gauge Vibrating Wire. The resulting Strain Gauge output resonant frequency is read by the VW2106 Vibrating Wire Readout Unit which is displayed in B Units on the Readout Unit display.

RST VWSG-E Vibrating Wire Strain Gauges can be read using other manufacturers Vibrating Wire Readout Units and/or dataloggers equipped with vibrating wire excitation modules. However, care must be taken to ensure that the correct frequency sweep is being applied to the VW sensors by the Vibrating Wire Readout Unit, otherwise false readings will result.

VWSG-E Vibrating Wire Strain Gauges are manufactured in various configurations to suit particular mechanical applications and are supplied with various types of terminations to enable the Strain Gauges to be embedded into a variety of materials and in many different configurations.

This manual contains general information concerning Vibrating Wire Strain Gauge installation, set-up, troubleshooting and data reduction, together with typical installation details.

The user is directed to read this manual thoroughly before undertaking any installation work with RST Vibrating Wire Strain Gauges.

1.1 NOTES ON VIBRATING WIRE READOUT UNITS

Vibrating Wire readout units and Vibrating Wire datalogger excitation modules, supply an excitation pulse or frequency sweep to the coils of the Vibrating Wire Strain Gauge, which causes the Vibrating Wire to oscillate at its resonant frequency. The coils of the Strain Gauge transform this frequency into a sinusoidal output, with the output frequency corresponding to the resonant frequency of the Strain Gauge Vibrating Wire. This output frequency is detected by the readout or the datalogger unit and may be displayed in various parameters, dependent upon the particular manufacturers' readout unit design.

Note: Strain Gauge readings are normally displayed in B units ($\text{Frequency}^2 * 10^{-3}$) on RST VW2106 Readout Units. Users must consult the Instruction Manual for the RST VW2106 VW Readout Unit (RST Manual ELM0042H) for detailed reading instructions.

Depending on the date of manufacture, VWSG-E Vibrating Wire Strain Gauges may require different sweep frequency ranges in order to provide correct B Unit output readings. The operator must consult the Strain Gauge Calibration Record Sheet for the instrument to be read, in order to confirm these requirements.

In general, VWSG-E 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-E Strain Gauge sensor to be read, in order 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 (ELM0042H) which provides instructions on how to change the sweep frequency setting.

VW Readout Units use set sweep frequencies to pluck the Vibrating Wire in the sensor. The VW Readouts Units include options for several different sweep frequencies. A higher sweep frequency is required to read VW sensors which will have higher resonant frequencies readings. While a lower sweep frequency is required to read VW sensors which will have lower resonant frequency readings.

If the sweep frequency applied, is inappropriate to the natural resonance of the VW sensor being read, the output readings will be erratic and unstable. If this problem is noted to be occurring, the sensor sweep frequency should be checked on sensor VW Calibration Record sheet.

2 INSTALLATION INTO CONCRETE

2.1 VWSG-E STRAIN GAUGE FOR CONCRETE EMBEDMENT

VWSG-E Embedment Strain Gauges are used for the determination of strains in mass concrete structures such as bored piles, diaphragm walls, concrete dams etc.

These Strain Gauges are fully sealed by laser welding and are supplied pre-tensioned. Since their intended use is for concrete embedment, the initial wire tension is set up for the measurement of compressive strains. Each Strain Gauge is fitted with a pair of coils and a thermistor.

No adjustment of the initial wire tension is possible by the User, without specialized equipment and instructions.

VWSG-E Strain Gauges are normally installed into concrete pours by tying the Strain Gauges to adjacent reinforcing bar or alternatively casting the Strain Gauges into briquettes, which are subsequently tied to reinforcing bar. The preferred method is to directly install the Strain Gauge into concrete rather than using the briquette method, which may reduce reading accuracy due to boundary effects.

In many cases, the end user will require the conversion of the strain readings into stress values. To do this requires knowledge of the modulus of the placed concrete. It is noted that the concrete modulus does vary, and it cannot be assumed that briquette modulus and the mass concrete modulus will be the same.

If accurate stress values are required, irrespective of the method chosen, it is important that concrete samples are taken of the mass concrete pour to establish the modulus of that concrete. Note that care must be taken to ensure correct techniques in sampling, curing and subsequent testing are followed.

It is often useful to cast a reference Strain Gauge into a concrete sample, which can be cured in similar conditions to that of the mass concrete, and which can be loaded in a test machine to directly establish the stress/strain relationship.

When casting a Strain Gauge directly into the structure, care must be taken to avoid applying any large forces to the end blocks during the installation. The instrument can be wired into position as depicted in Figure 5. The tie wires should not be tied too tightly since re-bar and/or the instrument cables tend to move during concrete placement and vibration. Care should be taken not to damage the instrument cable with a vibrator or other placement tools. Also, placement of the concrete from height could easily result in damage to an installed Strain Gauge.

Note: For concrete pours where the concrete will be consolidated using power vibrators, the construction labour MUST be made aware of Strain Gauge locations and supervised at all times to prevent damage to the instruments or wiring from the vibrator equipment.

A Strain Gauge can also be placed directly into placed concrete, if it can be assured that the gauge orientation will remain unchanged.

2.2 VWSG-E STRAIN GAUGE ATTACHMENT

The following directions are provided for attaching model VWSG-E Strain Gauges within a re-bar cage.

Direct Attachment to Re-Bar with Blocking

1. Wrap a layer of self-vulcanizing rubber tape around the Strain Gauge at the two locations where the gauge will be mounted to the re-bar (refer to Figure 5).
2. The rubber tape layer serves as a shock absorber, dampening any vibrations coming from the suspension system and the re-bar. Sometimes, without the use of rubber tape layers, as the tie wires are tightened, the resonant frequency of the tie wires interferes with the resonant frequency of the Strain Gauge. This results in unstable readings or no readings at all prior to the placement of the concrete. Noted that this effect will disappear once the concrete has been placed and has attained an initial set.
3. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together (not high tensile stainless-steel wire). Twist it 2 to 3 times around the body of the Strain Gauge, over the rubber strips, about 3 cm from the gauge_ends.
4. Wire two spacer blocks onto the re-bar cage at the installation location. The blocks should be located in alignment with the upper and lower rubber tape layers.
5. Tightly secure the Strain Gauge to the two spacer blocks and re-bar using the soft iron wire.
6. Tie the instrument cable off to a nearby re-bar using nylon Ty-Raps™.

Suspended Attachment to Re-Bar Mat

1. Wrap a layer of self-vulcanizing rubber tape around the Strain Gauge at the two locations where the gauge will be mounted to the re-bar mat (refer to Figure 5).
2. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together (not high tensile stainless-steel wire). Twist it 2 to 3 times around the body of the Strain Gauge, over the rubber strips, about 3 cm from the gauge_ends.
3. Twist two loops in the upper wire, one on either side of the Strain Gauge, at a distance of about 3cm from the gauge body. Repeat this process at the lower end of the gauge.
4. Position the Strain Gauge between two vertical re-bars and twist the wire ends twice around the re-bar, then around itself.
5. Tighten the wire by twisting on the loops, and orient the Strain Gauge.
6. Tie the instrument cable off to a nearby re-bar using nylon Ty-Raps™.

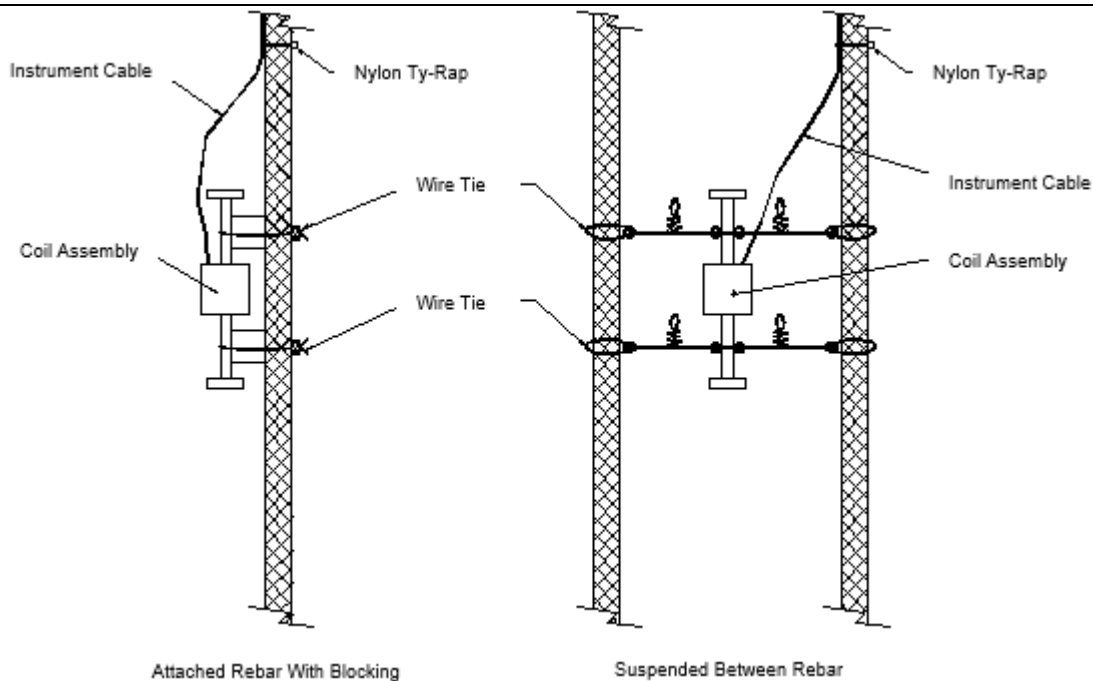


Figure 1 – Attaching VWSG-E Strain Gauges to Re-bar

2.3 USING PRE-CAST BRIQUETTES OR GROUTING

An alternate instrumentation method is to pre-cast Strain Gauges into briquettes of the same concrete mix as the future concrete batch and then place these instrumented briquettes into the structure prior to the concrete placement. The briquettes should be between 24 and 48 hours old when they are installed and the new concrete is placed. Prior to installation and concrete placement, the briquettes should be continuously cured with water.

Embedment Strain Gauges can also be installed in shotcrete and in drilled holes in rock or concrete, which are subsequently backfill grouted.

When used in shotcrete special care needs to be taken to protect the lead wires from damage due to the shotcreting process. Encasing the wiring in conduit or heavy tubing has been used effectively for protection. The Strain Gauges can also be placed by hand-packing the immediate area around the Strain Gauge and then proceeding with the shotcrete placement operation.

2.4 CABLE PROTECTION AND TERMINATION

The cables from embedded Strain Gauges need to be adequately protected from mechanical damage during installation and concrete placement. This can be accomplished by the use of rigid or flexible conduit, guards and covers. Most of these items can be custom supplied by RST.

Cables may be terminated by stripping and tinning the ends. Connection to a VW 2106 Vibrating Wire Readout Unit or a datalogger unit is usually done with bare wire connection to terminal strips. In some cases, a special patch cord is supplied to connect the VW output wires directly into a port on the VW 2106 Readout Unit.

Terminal boxes with sealed cable entries and covers are also available. This will allow many Strain Gauges to be terminated at one location, with complete protection of the lead wires. To facilitate readings, the Strain Gauge wiring can be terminated as built-in jack connectors or as a single connection with a rotary position selector switch.

Cables may be spliced to lengthen them without affecting the Strain Gauge readings. When splicing, always maintain polarity by connecting same color to same color. Always ensure the splice is completely sealed and waterproofed. Use of an RST CT-1100 Epoxy Splice Kit is recommended for all splices.

3 LIGHTNING PROTECTION

VWSG-E 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 because the installation environment, which is usually well grounded, provides adequate protection.

However, to be effectively isolated, the entire instrumentation system needs to be considered. This is of particular concern when multiple instruments are connected into a network which covers a large area. In this case, the network could be subject to transient and/or induced currents which could damage sensors and/or data acquisition equipment.

In this case, external surge protection may be required to reduce the risk of damage and data loss. The following suggestions for surge protection are provided:

- If the Strain Gauge is connected to a terminal box or multiplexer, components such as plasma surge arrestors (spark gaps) may be installed in the terminal box/multiplexer to provide a measure of transient protection. 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 that install 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 6.
- Additional information is available from RST on surge protection schemes and other alternatives.

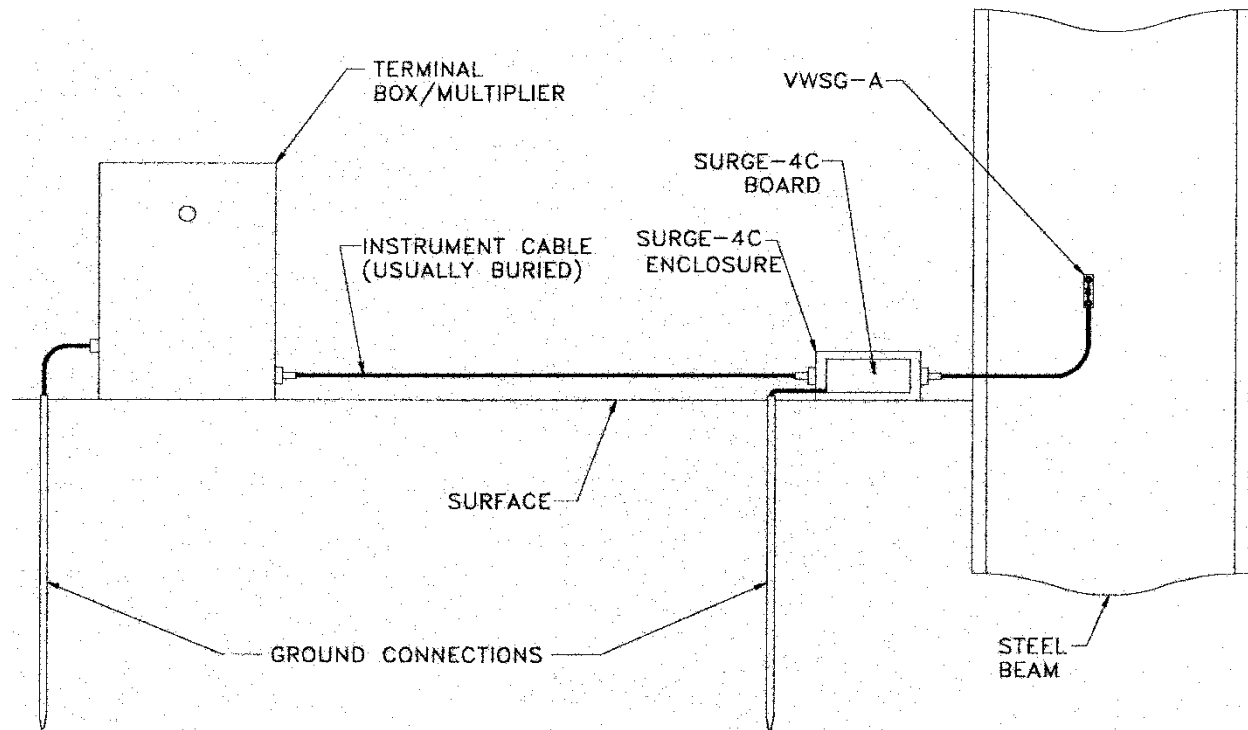


Figure 2 - Lighting Protection Scheme

4 GENERAL INSTALLATION GUIDELINES

Golden Rule Number 1: CHECK, CHECK AND CHECK AGAIN!

For every Strain Gauge installation, the installer needs to identify the key construction sequence events and the key instrument installation steps that will occur at the site. A successful installation must take into account both of these interdependent activities in detail.

The Strain Gauges must be checked 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 site construction procedures or problems that could potentially put the installation at risk.

For example; The installation of an Embedment VW Strain Gauge in a reinforced concrete pile would typically encounter the following checkpoints to ensure the instrument function and to be able to immediately troubleshoot any problems, before proceeding with the next step of the construction work or the installation.

Manual readings and Strain Gauge function checks would occur at the following pre-determined points:

- 1) Prior to shipping to the job site; Pre-shipping by RST
- 2) Immediately upon receipt at site; By the client
- 2) Immediately prior to installation in the field
- 3) Immediately following installation of the Strain Gauge onto the re-bar cage
- 4) During and following addition of extension cabling to the instrument
- 5) Following installation of protective ducting/conduit
- 6) Following attachment ducting/conduit to re-bar cage
- 7) Following installation of first re-bar cage into the excavation
- 8) Following splicing of second re-bar cage onto the first re-bar cage
- 9) Following installation of second re-bar cage into the excavation
- 10) Following subsequent re-bar cage splices and installations (multiple)
- 11) Immediately prior to and following the initial concrete backfill placement
- 12) Immediately prior to and following each successive concrete backfill lift
- 13) Immediately following the completion of the concrete backfill work
- 13) Periodically during curing of the pile concrete
- 14) Immediately before breakout of the pile top
- 15) Immediately after breakout of the pile top
- 16) Immediately after forming of the pile cap
- 17) Immediately prior to and following the concrete placement of the pile cap.

A similar schedule of key construction and instrumentation steps/events should be prepared for all installations.

This type of planning, based on critical steps/events in the construction schedule and the instrument installation, should form a key component of a correctly planned installation.

5 TAKING READINGS WITH VW2106 READOUT UNIT

5.1 CABLE AND WIRING

VWSG-E gauges:

- 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 affect the accuracy of VW Strain Gauges since the gauge outputs a frequency signal which is unaffected by the resistance of an additional cable length.

However, it is noted that all wire/cable splices must be properly insulated and protected. And to due to the inherit risks that splices pose to the overall wiring integrity of an installation, it is recommended that the number of splices be minimized.

When splicing, always maintain the polarity identification of the sensor by connecting same color wires to the same color.

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

Cable runs in difficult locations such as deep bored piles and diaphragm walls should be fully protected from damage by tremied concrete and tremie pipes. Running cables in thick wall UPVC ducting and tying the ducting to adjacent reinforcing bar has been found to be very effective.

5.2 OPERATION OF THE VW2106 VW READOUT BOX

The VW2106 is the basic manual readout box for all Vibrating Wire type instruments, including Vibrating Wire Strain Gauges. Details of the operation and use of the VW2106 readout box is found in RST Instruction Manual (ELM0042H).

The VW2106 Readout can be programmed to log VW instrument readings. Instructions can be found in the RST Instruction Manual (ELM0042H).

The VW2106 Readout is also able to apply calibration constants which will convert frequency readings into engineering units. Instructions for this application can be found in the VW2106 Host Software, as detailed in the VW2106 Host Software Instruction Manual (ELM0053D).

5.3 VW2106 READOUT OPERATION

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

- Connect the VW instrument leads to the VW 2106 terminal strip quick-connects. Match the VW wire colors to the colors indicated at the terminal strip. Red and Black are from the VW coils. Green and White are from the Thermistor sensor.
- Turn on the readout unit by pressing any key. The readout will go through its startup procedure, and automatically default to the reading screen.
- The operator must refer to the VW Calibration Record sheet for the VWSG-E Strain Gauge sensor which is to be read in order to determine correct sweep frequency to use 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 (ELM0042H) which provides instructions on how to change the sweep frequency settings.

- The VW B-unit reading ($f^2 \times 10^{-3}$) will appear at the top of the screen, along with the temperature ($^{\circ}\text{C}/^{\circ}\text{F}$) at the bottom of the screen.
- Record the reading and move onto the next instrument, connecting the VW sensor wire to the terminal strip quick-connects, in the same manner.
- If required, the operator can listen to the plucking of the VW coil by simultaneously pressing the up/down arrows for several seconds. A speaker icon will appear on the display. This will verify if the VW coil is functional and is being plucked.
- Manual readings on sensors which contain multiple gauges (i.e. load cells) are performed by connecting the instrument to the *Expansion* port with the appropriate connector. For details on this function, refer to the VW2106 VW Readout Instruction Manual (ELM0042H).
- To conserve power, the VW2106 Readout unit will automatically turn itself off after approximately 5 minutes, if there is no input provided at the user interface.

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

Note the following Sweep Frequencies used for reading Strain Gauge instruments:

C Sweep – Used for Arc Weldable Strain Gauges

D Sweep – Used for Embedment Strain Gauges

E Sweep - Used for Spot Weldable Strain Gauges

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

5.4 INITIAL READINGS

Subsequent Strain Gauge readings will always be referenced to some initial or inferred zero strain reading. Normally, 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 sometime 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, not only to ensure that the readings are valid, but also to ensure 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.

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

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

6 DATA INTERPRETATION

6.1 CONVERSION OF B UNIT READINGS TO THEORETICAL MICROSTRAIN

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.

$$B \text{ Unit} = (f^2 \times 10^{-3})$$

Equation 1 – Vibration Frequency to B Unit Relationship

Conversion of the B Unit reading to theoretical microstrain is carried out using a Vibrating Wire Calibration Factor (CF_T), as show in the below equation. For each type and design of Vibrating Wire Strain Gauge, a theoretical 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 CF_T is called the Theoretical Gauge Factor for that instrument type and is applied to all VWSG instruments manufacture using the same design.

$$\mu\varepsilon = CF_T (f^2 \times 10^{-3})$$

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

Equation 2 – Theoretical Microstrain

Where; $\mu\varepsilon$ - microstrain units – Theoretical
 - Where one microstrain is the strain that will produce a deformation of one ppm
 CF_T - Strain Gauge Calibration Factor – Theoretical for sensor (4.062 $\mu\varepsilon$ / B Unit)
 f - Resonant frequency of the Vibrating Wire

However, 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).

$$CF = CF_T \times BCF$$

Equation 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 VW Stain Gauge Sensor. Care must be taken 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-E Embedment 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

Strain = 684 B Units x CF

- CF = 3.960 $\mu\epsilon$ / B Unit

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

Final B Unit Reading = 724 B Units

- After load is applied
- Frequency f = 851 Hz

Strain = 724 B Units x CF

- CF = 3.960 $\mu\epsilon$ / B Unit

Strain = 724 B Units x 3.960 $\mu\epsilon$ / B Unit = 2867.0 $\mu\epsilon$

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 $\mu\epsilon$ / B Unit = **+ 158.4 $\mu\epsilon$**

Net Strain Change = Initial Strain Reading – Final Strain Reading

= 2708.6 $\mu\epsilon$ - 2867.0 $\mu\epsilon$ = **+ 158.4 $\mu\epsilon$**

6.2 CONVERSION OF READINGS TO STRAIN CHANGES

In reality, 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, back to the original base reading. The True Strain is calculated by the following equation.

$$\mu\epsilon_{true} = (R_1 - R_0)$$

Equation 3 - True Strain Calculation

Where; R_0 is the initial strain reading - $\mu\epsilon$

R_1 is a subsequent strain reading - $\mu\epsilon$

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. Using Equation 2, the resolution of the microstrain measurements can be calculated as follows:

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

$$\mu\varepsilon = CF (0.1) \quad \text{- Strain Reading Resolution}$$

Equation 4 - Microstrain Resolution

Where; $\mu\varepsilon$ is microstrain

CF is the Strain Gauge Calibration Factor ($\mu\varepsilon / B \text{ Unit}$)

6.4 TEMPERATURE CORRECTIONS

Temperature variations of considerable magnitude are not uncommon in concrete, particularly during the curing period with may take up to several weeks, or longer. Therefore, it is always advisable to measure and record temperature along with every Strain Gauge measurement. Temperature induced expansions and contractions can give rise to real changes of stress within mass concrete. If the concrete is restrained or anchored in any way, the related stresses will be superimposed on any stresses due to temperature. This makes the analysis and interpretation of stresses in concrete structures very complicated and difficult to ascertain with certainty.

Temperature can also affect the Strain Gauge function and accuracy, since increasing temperatures will cause the vibrating wire to elongate slightly and thus provide a lower frequency reading than the external stress field may actually be exerting on the VWSG instrument. This would give a false indication that the concrete is undergoing compressive strain. The coefficient of expansion of the Vibrating Wire Strain Gauge (C1), which is for steel, is approximately 12.2 microstrain / °C.

The effect of the Vibrating Wire within the Strain Gauge expanding due to higher ambient temperature would be offset to some degree by an expansion of the concrete in which the Strain Gauge is embedded or attached. If the concrete expanded by exactly the same amount as the Vibrating Wire, then the wire tension would remain constant and no correction would be necessary. However, the coefficient of expansion of concrete (C2), is approximately 10.4 microstrain / °C. This means that a correction for temperature is required which would be equal to:

$$\text{Temp Correction} = (T_1 - T_0) \times (C_1 - C_2)$$

Equation 5 – Correction for Temperature

And the true load related to the strain in the concrete is given by:

$$\mu_{\text{true}} = (R_1 - R_0) B + [(T_1 - T_0) \times (C_1 - C_2)]$$

Equation 6 – True Load Related Strain Calculation

Example Calculation:

$T_0 = 20\text{ }^\circ\text{C}$ – Initial Temperature

$T_1 = 30\text{ }^\circ\text{C}$ – Final Temperature

$C_1 =$ Coefficient of Expansion for Strain Gauge Steel = 12.2 microstrain / $^\circ\text{C}$

$C_2 =$ Coefficient of Expansion for Concrete = 10.4 microstrain / $^\circ\text{C}$

$R_0 = 3000$ – Initial Strain – microstrain

$R_1 = 2900$ - Final Strain - microstrain

$F_0 = 4.062$ – CFT – Strain Gauge Calibration Factor – Initial Theoretical - microstrain / B Unit

$F_1 = 3.960$ – CF – Strain Gauge Calibration Factor – Corrected by calibration - microstrain / B Unit

$B = 0.975$ - BCF – Batch Calibration Factor = $F_1 / F_0 = 3.960 / 4.062$

Using Equation 10:

Apparent Strain =

$$(2900\ \mu\varepsilon - 3000\ \mu\varepsilon) \times 0.975 =$$

$$-100\ \mu\varepsilon \times 0.975 = -97.5\ \mu\varepsilon \quad \text{(compression)}$$

Temperature Related Strain =

$$(30\text{ }^\circ\text{C} - 20\text{ }^\circ\text{C}) \times (12.2\ \mu\varepsilon / ^\circ\text{C} - 10.4\ \mu\varepsilon / ^\circ\text{C}) =$$

$$10\text{ }^\circ\text{C} \times 1.8\ \mu\varepsilon / ^\circ\text{C} = 18.0\ \mu\varepsilon \quad \text{(tension)}$$

$$\text{True Load Related Strain} = -97.5\ \mu\varepsilon + 18.0\ \mu\varepsilon = -79.5\ \mu\varepsilon \quad \text{(compression)}$$

6.5 SHRINKAGE EFFECTS

A well known property of concrete is its propensity to shrink as the water content diminishes, or for the concrete to swell as it absorbs water. This shrinkage and swelling can give rise to large apparent strain changes which are not related to load or stress changes. The magnitude of the strains can be several hundred microstrain.

This physical property of concrete makes it very difficult to determine the internal strains, if random wetting and drying cycles are occurring. To compensate for these unwanted strains, an attempt can be made to keep the concrete at relatively constant water content. However, at most sites, this is frequently impossible to do, as most concrete structures are large and are exposed to varying weather conditions.

In some cases, an attempt is made to measure the shrinkage and/or swelling effects due to water content by casting a Strain Gauge inside of a concrete test block, which remains unloaded, but is exposed to the same moisture conditions as the main concrete structure which is instrumented by active Strain Gauges. Strain changes measured by the VW Strain Gauge installed in the reference block, may be used as a correction to other Strain Gauge readings from the main concrete structure.

6.6 CREEP EFFECTS

It is also well known that concrete will creep under a sustained load. What may seem to be a gradually increasing load, as evidenced by gradually increasing Strain Gauge readings, may in fact be strain due to creeping under a constant sustained load.

On some projects, Strain Gauges have been cast into concrete test blocks in the laboratory and then kept loaded by means of springs inside a load frame so that the creep phenomenon can be quantified and used as a correction factor.

6.7 EFFECT OF AUTOGENOUS CONCRETE GROWTH

In some old concretes, which have a particular combination of alkaline and silicate aggregates, and alkaline cements, an internal reaction may occur within the concrete mass which will cause very minor expansion over time, as the concrete undergoes subtle chemical changes and recrystallization. This slow reaction can result in minor expansion and cracking within the concrete mass which can present similar to a slow creep movement. In extreme cases, occurring over many years, the affected mass concrete may eventually breakdown and crumble completely, to some depth below the surface.

This type of internal chemical reaction proceeds very slowly and is therefore very difficult to account for when attempting to accurately measure small strains occurring within concrete structures.

7 TROUBLESHOOTING

- 1) No reading obtained from VW Strain Gauge; display shows "00000" on RST VW2106 readout:
 - a) Strain Gauge red/black wires are disconnected or loose. Check the connections and ensure both wires are correctly connected and tight.
 - b) Check the resistance between these wires with a low voltage multi-meter. The resistance of the Strain Gauge should be about 135 Ohms. High or low resistance could indicate a damaged VW 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 VW Calibration Record sheet for the installed VW 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) Check to ensure the VW2106 Readout is functional by taking a reading from another Strain Gauge.
- 2) Fluctuating readings from a VW Strain Gauge:
 - a) Check the resistance between the red/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) For VWSG-E the Strain Gauges should be pre-installation tested on a solid surface, otherwise the entire gauge may oscillate, causing erroneous and unstable output values.
 - d) Does the VW2106 Readout unit work with another Strain Gauge?
 - e) Are the strain values provided by the Readout, outside of the specified range?
 - f) Is there a source of electrical interference nearby? Noted that problems can be caused by the local presence of power generating equipment or DC to AC Current Inverters. Must move data acquisition and electronic readout equipment away from the source of potential interference, install filtering at the datalogger and connect drain wires to a good quality grounding.

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

Appendix A - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale 41C3001-B3, Alpha #13A3001-B3
 Resistance to Temperature Equation:

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

Equation 7 - Convert Thermistor Resistance to Temperature

- where:
- T = Temperature in °C.
 - LnR = Natural Log of Thermistor Resistance
 - A = 1.4051×10^{-3} (coefficient calculated over the -50 to +150°C. span)
 - B = 2.369×10^{-4}
 - C = 1.019×10^{-7}

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 3 - Thermistor Resistance versus Temperature