RST INSTRUMENTS LTD.

Vibrating Wire Strain Gauge

Model VWSG-E1/E2/E3

Instruction Manual

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Vibrating Wire Strain Gauge Model VWSG-E1/E2/E3

Product: Vibrating Wire Strain Gauge Model VWSG-E1/E2/E3
Installation Manual

Document number: ELM0003C
Revision: 1.4
Date: December 5, 2002

Table of Contents

Appendices

Tables

Equations

Figures

1 INTRODUCTION

The RST Model VWSG-E1 Vibrating Wire Strain Gauge is designed primarily for long-term strain measurements in mass concrete, in structures such as foundations, piles, bridges, dams containment vessels, tunnel liners, etc. See Figure 1.

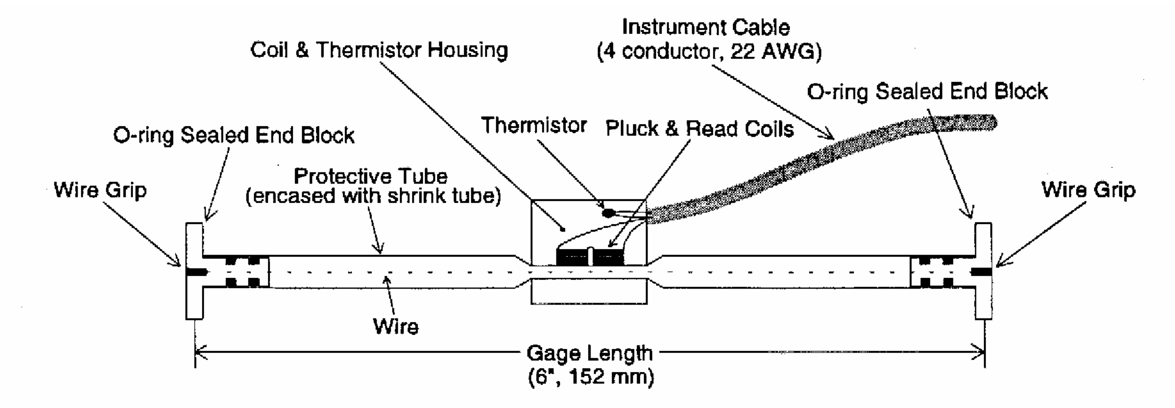

Figure 1 – Model VWSG-E1 Vibrating Wire Strain Gauge

The Model VWSG-E2 Vibrating Wire Strain Gauge is designed for direct embedment in grout, mortar and small aggregate concrete. See Figure 2.

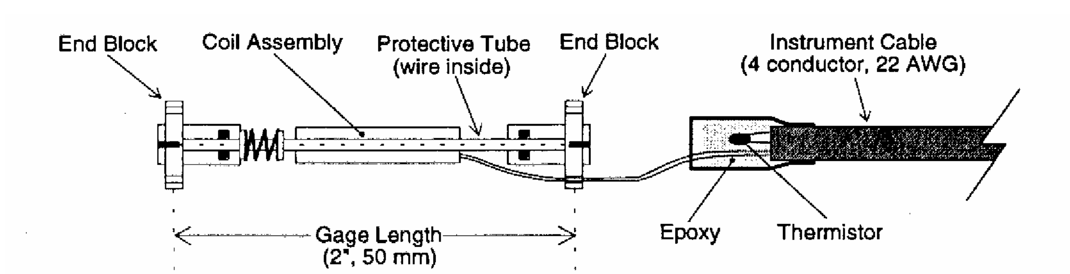

Figure 2 – Model VWSG-E2 Vibrating Wire Strain Gauge

The Model VWSG-E3 Vibrating Wire Strain Gauge is designed for embedment in large aggregate concrete (greater than ¾ inch). The standard gauge length for the Model VWSG-E3 is 10 inches; other gauge lengths are available (Model VWSG-E5 = 12 in., Model VWSG-E6 = 14 in, etc.). See Figure 3.

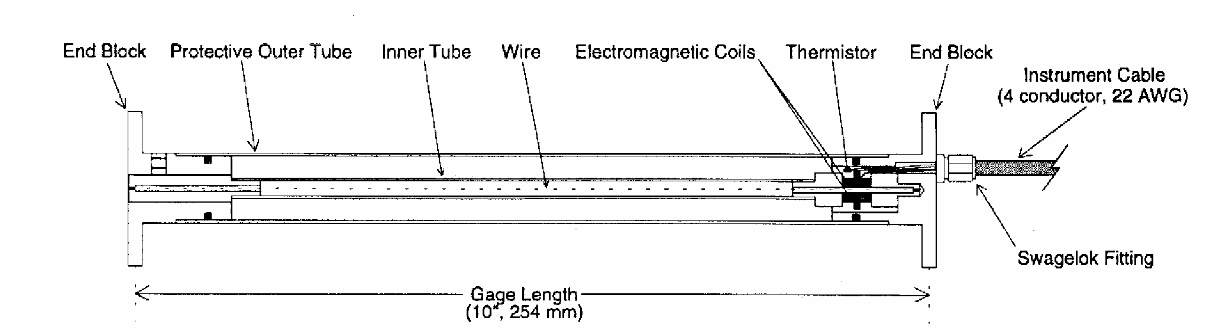

Figure 3 – Model VWSG-E3 Vibrating Wire Strain Gauge

The primary means of gauge placement is direct embedment in concrete by pre-attaching the gauge to rebar or tensioning cables, pre-casting the gauge into a concrete briquette which is subsequently cast into the structure, or grouting into boreholes in the concrete.

Strains are measured using the vibrating wire principle: a length of steel wire is tensioned between two end blocks that are firmly in contact with the mass concrete. Deformations in the concrete will cause the two end blocks to move relative to one another, altering the tension in the steel wire. This change in tension is measured as a change in the resonant frequency of vibration of the wire. Excitation and readout of the gauge frequency is accomplished by electromagnetic coils, which are located close to the wire.

Portable readouts or dataloggers available from RST such as the models VW2102, VW2104, or CR10, used in conjunction with any of these vibrating wire strain gauges, will provide the necessary voltage pulses to pluck the wire and convert the measured frequencies so as to display the reading directly in microstrain units.

This manual contains installation instructions, readout and data reduction procedures, and troubleshooting guidelines.

PLEASE NOTE THE FOLLOWING:

- *These Vibrating Wire Embedment Strain Gauges are not suitable for measurement of dynamic or rapidly changing strains.*
- *Do not rotate or pull on the gauge end blocks as this may cause permanent damage.*

2 GAUGE INSTALLATION

The VWSG-E1/E2/E3 strain gauges are supplied fully sealed and pre-tensioned with the plucking Coil Mounted. A preliminary check is advisable and this is made by connecting to the readout box and observing the displayed readout (see readout instructions, Section 3). The observed reading should be around the mid-range position (see Table 1). Pressure on the gauge ends should make this reading decrease.

Check the resistance between the two lead wires (usually red and black). For the Model VWSG-E1 it should be around 150 ohms. For the Model VWSG-E2 it should be around 50 ohms. For the Model VWSG-E3 it should be around 180 ohms. Remember to add the cable resistance at approximately 14.7Ω/1000' or 48.5Ω/km (at 20°C, multiply by 2 for both directions). If the gauge contains a Thermistor check its resistance (usually the white and green lead wires) with an ohmmeter. Check the reading against that which should be obtained at the existing ambient temperature. See Appendix C for the resistance to temperature conversion and resistance vs. temperature table.

Return any faulty gauges to the factory. Gauges should not be opened in the field.

2.1 PLACING THE GAUGE IN CONCRETE

The VWSG-E1/E2/E3 strain gauges are normally set into the concrete structure in one of two ways: either by casting the Unit(s) into the concrete mix directly or by pre-casting the unit(s) into briquettes, which are subsequently cast into the structure.

When casting the gauge directly into the structure care must be taken to avoid applying any large forces to the end blocks during installation. This is most imperative when installing the VWSG-E2. The models VWSG-E1 and VWSG-E3 can be wired into position by wiring directly to the tube (see Figure 4). The wires should not be tied too tightly since rebar and/or tension cables tend to move during concrete placement and vibration. Care should be taken not to damage the cable with the vibrator. The gauge can also be placed directly into the mix if it can be assured that the orientation will be correct after the gauge placement.

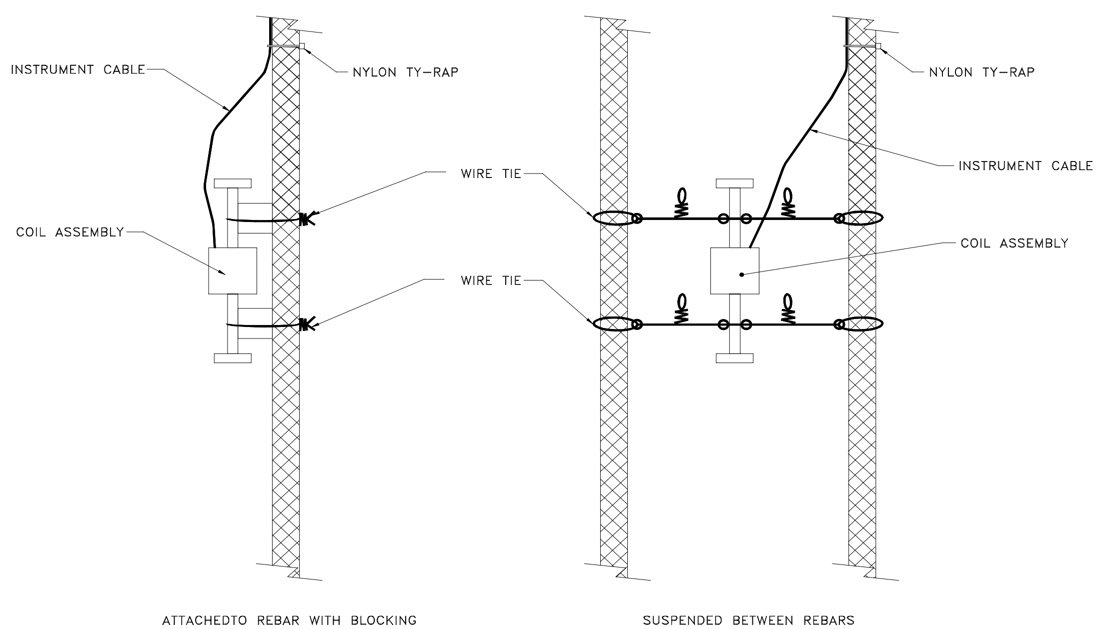

Figure 4 – Attaching VWSG-E1 Strain Gauges to Rebar

Note the following instructions to suspend the model VWSG-E1 strain gauge between rebar;

1. Wrap a layer of self-vulcanizing rubber tape around the gauge in the two places shown in Figure 4 (around the tie points). The rubber layer serves as a shock absorber, dampening any vibrations of the suspension system. Sometimes, without the rubber layers, as the tie wires are tightened the resonant frequency of the tie wires interferes with the resonant frequency of the gauge. This results in unstable readings or no readings at all. This effect disappears once the concrete has been placed.
2. Select a length of soft iron tie wire, the kind normally used for tying rebar cages together. Twist it 2 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 wire, one on either side of the gauge, at a distance of about 3cm from the gauge body. Repeat this process at the other end of the gauge.
4. Position the gauge between the rebar and twist the wire ends twice around the rebar, then around itself.
5. Tighten the wire and orient the gauge by twisting on the loops.
6. Slip on the plucking coil and affix using a hose clamp. Tie the instrument cable off to one of the rebar using nylon Ty-Raps™.

Note these special instructions for attaching the VWSG-E2 or VWSG-E3 to rebar;

- When installing the VWSG-E2 do not wrap the iron tie wire around the body of the gauge. The gauge could be damaged due to its delicate construction. Use the holes in the end blocks to affix the gauge to the rebar, being sure that the gauge is not tensioned or compressed in the longitudinal direction.
- When installing the VWSG-E3 it is not necessary to wrap the tie points on the gauge body with self-vulcanizing tape.

2.2 USING PRE-CAST BRIQUETTES OR GROUTING

An alternate method to the above is to pre-cast the gauges into briquettes of the same mix as the mass concrete and then place these in the structure prior to concrete placement. The briquettes should be constructed not more than 1 days and not less than 1 day prior to installation. The briquettes should be continuously cured with water prior to placement in the mass concrete.

Embedment gauges can also be used in shotcrete and in drilled holes in rock or concrete, which are subsequently grouted. When used in shotcrete special care should be taken to protect the lead wires. Encasing them in conduit or heavy tubing has been used effectively to protect the cable. The gauges can be placed by packing the immediate area around the gauge by hand and then proceeding with the shotcrete operation.

2.3 CABLE PROTECTION AND TERMINATION

The cable from the strain gauges can be protected by the use of flexible conduit, which can be supplied by RST

Terminal boxes with sealed cable entries and covers are also available, allowing many gauges to be terminated at one location with complete protection of the lead wires. The panel can have built-in jacks or a single connection with a rotary position selector switch.

Cables may be spliced to lengthen them without affecting the gauge readings. Always maintain polarity by connecting color to color. Always waterproof the splice completely, preferably using a splice kit (epoxy based) such as the 3M Scotchcast™ kit, model 82-A1.

Cables may be terminated by stripping and tinning and connected by clipping to the patch cord from the readout box. Alternatively a plug may be used which will connect directly into the readout box or to a receptacle on a special patch cord.

2.4 LIGHTNING PROTECTION

The VWSG-E1/E2/E3 Embedment Strain Gauges, unlike numerous other types of instrumentation available from RST do not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors. Usually this is not a problem as the gauges are installed within concrete or grout and somewhat isolated from potentially damaging electrical transients. However, there may be occasions where some sort of lightning protection is desirable, for example where the gauge is in contact with rebar that may be exposed to direct or indirect lightning strikes. Also, if the instrument cable is exposed, it may be appropriate to install lightning protection components, as the transient could travel down the cable to the gauge and possibly destroy it.

Note the following suggestions:

- If the gauge is connected to a terminal box or multiplexer components, 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 locations for installation of these components.
- Lighting 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 that the protection board is damaged, the user may 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 gauge. See Figure 5. Consult the factory for additional information on these or alternate lightning protection schemes.

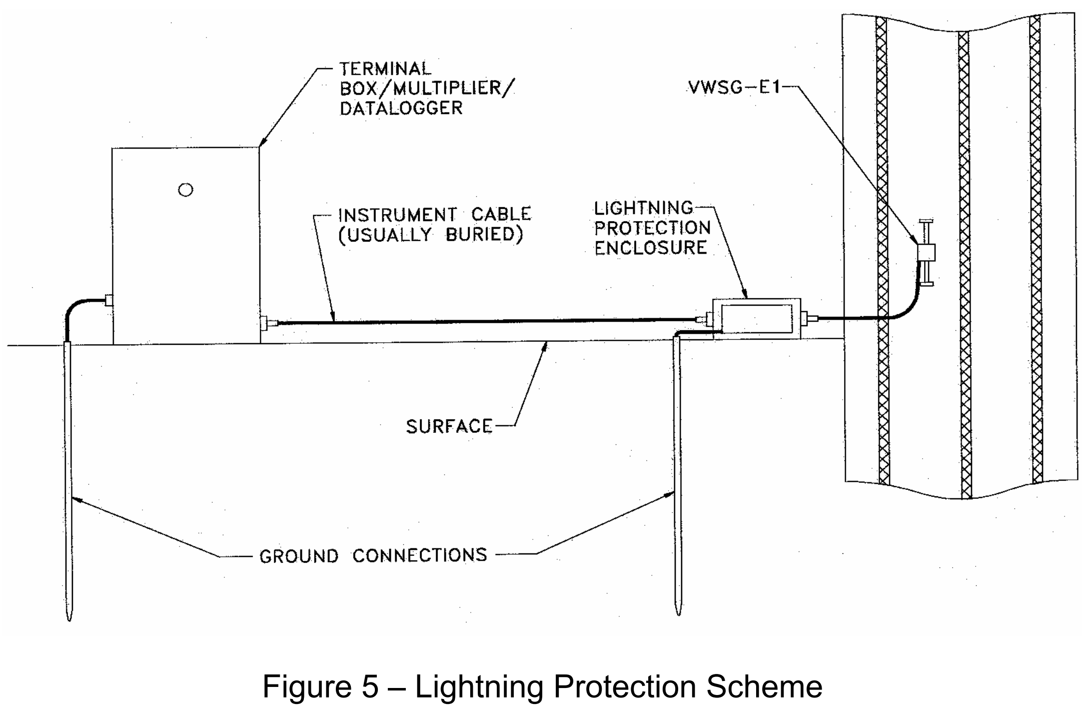

Figure 5 – Lightning Protection Scheme

3 TAKING READINGS

The following three sections describe how to take readings using readout equipment available from RST

Model:	VWSG-E1	VWSG-E2	VWSG-E4	VWSG-E3/E5/E6
Readout Position:	D	E	A	B
Display Units:	Microstrain ($\mu\varepsilon$)	Microstrain ($\mu\varepsilon$)	Period ($1/fx10^6$)	Digits (f^2x10^{-3})
Frequency Range:	400-1000Hz	1200-2800 Hz	800-1600 Hz	1400-3200Hz
Mid-Range Reading:	2500 $\mu\varepsilon$	2500 $\mu\varepsilon$	833 μseconds	6000 digits
Minimum Reading:	1000 $\mu\varepsilon$	1000 $\mu\varepsilon$	1250 μseconds	2000 digits
Maximum Reading:	4000 $\mu\varepsilon$	4000 $\mu\varepsilon$	625 μseconds	10000 digits

Table 1 - Embedment Strain Gauge Readout Positions

3.1 OPERATION OF THE VW2102 READOUT BOX

The VW2102 is a basic readout for all vibrating wire gauges.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gauge, the green lead for the shield drain wire. The VW2102 cannot read the Thermistor (see Section 3.4).

1. Turn the display selector to position "A", "B", D or "E". See Table 1 for correct position.
2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Record the value displayed. If zeros are displayed or the reading is unstable see section 5 for troubleshooting suggestions.
3. The unit will automatically turn itself off after approximately 4 minutes to conserve power.

3.2 OPERATION OF THE VW2104 READOUT BOX

The VW2104 can store gauge readings and also apply calibration factors to convert readings to engineering units. Consult the VW2104 Instruction Manual for additional information on Mode "G" of the Readout. The VW2104 reads out the thermistor temperature directly in degrees C.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gauge, the white and green leads are for the Thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "A", "B", D or "E". See Table 1 for correct position.
2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Record the value displayed. If zeros are displayed or the reading is unstable see section 5 for troubleshooting the suggestions.
3. The unit will automatically turn itself off after approximately 4 minutes to conserve power.

3.3 CR10 DATALOGGER

The following parameters are recommended when using the strain gauges with the CR10 based datalogger:

See Table 2 for the recommended Gauge Factor entry to convert to microstrain when using the embedment strain gauges with the CR10 Datalogger Configuration Software. Table 2 also lists the starting and ending frequency settings for the excitation sweep when writing a program for the CR10 using the P28 vibrating wire measurement instruction. Alternately, if a calibration sheet is supplied with the strain gauge the exact values can be calculated from the start and end frequencies of the calibration. To maximize the stability and resolution of the sensor, a relatively narrow band of excitation frequency should be selected. One could calculate these settings by taking an initial reading and then setting the starting frequency to 200 Hz below and the ending frequency 200 Hz above.

Model:	**VWSG-E1**	**VWSG-E2**	**VWSG-E3**	**VWSG-E4**	**VWSG-E5**	**VWSG-E6**
Gauge Factor:	3.304	0.391	0.3568	1.422	0.3624	0.3665
Start Frequency (P28):	4 (400 Hz)	12 (1200 Hz)	14(1400 Hz)	8 (800 Hz)	14(1400 Hz)	14(1400 Hz)
End Frequency (P28):	10(1000 Hz)	28(2800 Hz)	32(320OHz)	16(1660 Hz)	32(3200 Hz)	32 (3200 Hz)

Table 2 - Embedment Strain Gauge Datalogger Parameters

3.4 MEASURING TEMPERATURES

All Vibrating Wire Strain Gauges are equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal Thermistor

1. Connect an ohmmeter to the two Thermistor leads coming from the strain gauge (Since the resistance changes with temperature are large, the effect of cable resistance is usually insignificant).
2. Lookup the temperature for the measured resistance in Table C-1, Alternately the temperature could be calculated using Equation C-1.

Note: The VW2104 readout box will read the Thermistor and display temperature in ^{o}C.

4 DATA REDUCTION

Readings on channel D of either the VW2102 or VW2104 Readout Box are displayed directly in microstrain based on the theoretical equation:

$$\mu\varepsilon_{theory} = (f^2 \times 10^{-3}) \times GF$$

Equation 1 - Microstrain Conversion

Where $\mu\varepsilon$ is the theoretical microstrain, *f* is the resonant frequency of the vibrating wire in Hertz and *GF* is the theoretical gauge factor which depends on the Model number as shown in Table3.

Model:	VWSG-E1	VWSG-E2	VWSG-E3	VWSG-E4	VWSG-E5	VWSG-E6
Factor:	3.304	0.391	0.3568	1.422	0.3624	0.3665

Table 3 - Embedment Strain Gauge Factors

4.1 CONVERSION OF THE READINGS TO STRAIN CHANGES

In practice the method of wire clamping shortens the vibrating wire slightly causing it to over-register the strain. This effect is removed by applying a batch gauge factor (B) supplied with each gauge (a typical batch gauge factor is 0.980 ± 0.01). Then

$$\mu\varepsilon_{apparent} = (R_1 - R_0)B$$

Equation 2 - Apparent Strain Calculation

Where R_0 is the initial reading on channel D and R_1 is a subsequent reading.

Note: when (R_1-R_0) is positive, the strain is tensile. The apparent strain may need correction for temperature changes. See section 4.3.

4.2 STRAIN RESOLUTION

When using the VW2102 Readout on display setting D (VWSG-E1) or "E" (VWSG-E2) the strain resolution is ±1 microstrain, throughout the range of the gauge. Greater resolution can be obtained by reading the gauge in the period mode (display units are microseconds) on display setting "A”. In the period mode, the resolution at the upper end of the strain range (period of 10,000 µseconds) is 0.8 microstrain, whereas at the lower end (period of 20,000 µseconds) the resolution is 0.1 microstrain. In mid-range the sensitivity is 0.3 microstrain.

When using the VW2104 Readout on display setting D (VWSG-E1) or "E" (VWSG-E2), the strain resolution is ±0.1 microstrain, throughout the range of the gauge.

4.3 TEMPERATURE CORRECTIONS

Temperature variations of considerable magnitude are not uncommon, particularly during concrete curing; therefore it is always advisable to measure temperature along with every measurement of strain. Temperature induced expansions and contractions can give rise to real changes of stress in the concrete if the concrete is restrained in any way, and these stresses are superimposed on any other load related stresses.

Temperature can also affect the strain gauge itself since increasing temperatures will cause the vibrating wire to elongate and thus go slack. This would give an indication of what would appear to be a compressive strain in the concrete. This effect is balanced to some degree by a corresponding compressive stretching of the wire caused by expansion of the concrete in which the gauge is embedded or to which the gauge is attached. If the concrete expanded by exactly the same amount as the wire, then the wire tension would remain constant and no correction would be necessary. However the coefficient of expansion of concrete, C_2, is approximately 10.4 microstrain/ºC so that a correction for temperature is required to be equal to:

$$+ (T_1 - T_0) \times (C_1 - C_2)$$

Equation 3 – Correction for Temperature

And the true, load related strain in concrete is given by

$$\mu_{true} = (R_1 - R_0)\, B + (T_1 - T_0)\,(C_1 - C_2)$$

Equation 4 – True, Load Related Strain Calculation

Note: *Users should use their own values of C_2 if known.*

Example:

R_0 = 3000 on channel D

R_1 = 2900 on channel D

T_0 = 20ºC

T_1 = 30ºC

B = 0.975 (Batch calibration factor)

The Apparent strain = (2900 - 3000) 0.975 = -97.5 µstrain (compression)

The True, load related strain = (2900 - 3000) + (30 - 20) x (12.2 - 10.4) = -82 µstrain (compression)

4.4 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.

It is difficult to compensate for these unwanted strains. An attempt may be made, or it may occur naturally, to keep the concrete under a constant condition of water content. But this is frequently impossible on concrete structures exposed to varying weather conditions. Sometimes an attempt is made to measure the shrinkage and/or swelling effect by casting a strain gauge inside a concrete block which remains unloaded but exposed to the same moisture conditions as the active gauges. Strains measured on this gauge may be used as a correction.

4.5 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 a gradually increasing strain may, in fact, be strain due to creeping under a constant sustained load.

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

4.6 Effect of Autogenous Growth

In some old concrete, with a particular combination of aggregates and alkaline cements, the concrete may expand with time as it undergoes a chemical change and recrystallization. This expansion is rather like creep but in the opposite direction. It is difficult to account for.

5 TROUBLESHOOTING

Maintenance and troubleshooting of these strain gauges are confined to periodic checks of cable connections and maintenance of terminals. Once installed, the gauges are usually inaccessible and remedial action is limited.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Strain Gauge Readings are Unstable

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct?
- ✓ Is the strain reading outside the specified range (either compressive or tensile) of the instrument? Gauge may have become too slack or too tight; inspection of the data might indicate that this is a possibility.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Move the equipment away from the installation or install electronic filtering. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger.
- ✓ Does the readout work with another gauge? If not, the readout may have a low battery or be malfunctioning.

Symptom: Strain Gauge Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gauge leads for the VWSG-S (usually red and black leads) is 180Ω, ±10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<100Ω) a short in the cable is likely. Splicing kits and instructions are available from the factory to repair broken or shorted cables. Consult the factory for additional information.
- ✓ Does the readout or datalogger work with another strain gauge? If not, the readout or datalogger may be malfunctioning.

Appendix A – SPECIFICATIONS

A.1 Strain Gauge

Model:	**VWSG-E1**	**VWSG-E2**	**VWSG-E4**	**VWSG-E3**	**VWSG-E5**	**VWSG-E6**
Range (nominal):	3000 με					
Resolution:	1.0με[1]	0.4με[1]	1.0με[1]	0.4με[1]	0.4με[1]	0.4με[1]
Accuracy:	2.0% FSR[2]					
Stability:	0.1% FS/yr					
Linearity:	2.0% FSR					
Thermal Coefficient:	12.2με/°C					
Frequency Range:						
Dimensions (gauge): (Length x Diameter)	6.125 x 0.750” 155 x 19mm	2.25 x 0.625” 57 x 16mm	4.125 x 0.750” 105 x 19mm	10.250 x 2” 260 x 50mm	12.250 x 2” 311 x 50mm	14.250 x 2” 362 x 50mm
Dimensions (coil):	0.875 x 0.875” 22 x 22mm	N/A				
Coil Resistance:	150Ω	50Ω	50Ω	180Ω	180Ω	180Ω
Temperature Range:	-20 to +80°C					

Table 4 – Strain Gauge Specifications

Notes:

[1] Depends on the readout, figures in Table 4 pertain to the VW2102 Readout.

[2] Accuracy to 1.0% FSR may be achieved through calibration.

A.2 Thermistor (also see Appendix C)

Range: -80 to +150°C

Accuracy: ±0.5°C

Appendix B - THEORY OF OPERATION

A vibrating wire attached to the surface of a deforming body will deform in a like manner. The deformations alter the tension of the wire and hence also its natural frequency of vibration (resonance). The relationship between frequency (period) and deformation (strain) is described as follows:

Model:	VWGS-E1	VWSG-E2	VWSG-E4
Gauge Length (Lg):	6.000 inches	2 inches	4.000 inches
Wire Length (Lw):	5.875 inches	2 inches	2 inches
Gauge Factor:	3.304	0.391	1.422

Table 5 - Embedment Strain Gauge Theoretical Parameters

Note: The examples below are calculated using the VWSG-E1 gauge parameters. Substitute the values from Table 5 for the VWSG-E2/E4 strain gauges. These equations do not apply to the VWSG-E3/E5/E6 strain gauges.

1. The fundamental frequency (resonant frequency) of vibration of a wire is related to its tension, length and mass by the equation:

$$f = \frac{1}{2L_w}\sqrt{\frac{F}{m}}$$

Where;

L_W is the length of the wire in inches.
F is the wire tension in pounds.
m is the mass of the wire per unit length (pounds, sec.^{2}/in.^{2}).

2. Note that:

$$m = \frac{W}{L_w g}$$

Where;
W is the weight of L_w inches of wire (pounds).
g is the acceleration of gravity (386 in./sec.^{2}).

3. and:

$$W = \rho a L_w$$

Where;

ρ is the wire material density (0.283 lb./in.^{3}).
a is the cross sectional area of the wire (in.^{2}).

4. Combining equations 1, 2 and 3 gives:

$$f = \frac{1}{2L_w}\sqrt{\frac{Fg}{\rho a}}$$

5. Note that the tension (F) can be expressed in terms of strain, e.g.:

$$F = \varepsilon_w E a$$

Where;

ε_W is the wire strain (in./in.).

E is the Young's Modulus of the wire (30 x 10^6 Psi).

a is the acceleration due to gravity (386 in./sec.^{2}).

6. Combining equations 4 and 5 gives:

$$f = \frac{1}{2L_w}\sqrt{\frac{\varepsilon_w E g}{\rho}}$$

7. Substituting the given values for E, g and ρ yields:

$$f = \frac{101142}{L_w}\sqrt{\varepsilon_w}$$

8. On channel 'A', which displays the period of vibration, T, multiplied by a factor of 10^6;

$$T = \frac{10^6}{f}$$

9. Combining equations 7 and 8 gives:

$$\varepsilon_w = \frac{97.75 L_w{}^2}{T^2}$$

10. Equation 9 must now be expressed in terms of the strain in the surface of the body to which the gauge is attached. Since the deformation of the body must equal the deformation of the wire:

$$\varepsilon_w L_w = \varepsilon L_g$$

Where;

ε is the strain in the body.

L_g is the gauge length (in inches).

11. Combining equations 9 and 10 gives:

$$\varepsilon = \frac{97.75 L_w^{\ 3}}{L_g} \frac{1}{T^2}$$

Where; (for the VWSG-E1 Strain Gauge)

L_w is 5.875 inches.
L_g is 6.000 inches.

12. Therefore:

$$\varepsilon = 3.304 \times 10^3 \left[\frac{1}{T^2} \right]$$

13. The display on position "D" of the VW2102/4 Readout is based on the equation:

$$\varepsilon = 3.304 \times 10^9 \left[\frac{1}{T^2} \right]$$

Appendix C - 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 C-1 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}

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

Table C-1 - Thermistor Resistance versus Temperature