The World Leader in Vibrating Wire Technology

48 Spencer Street
Lebanon, NH 03766, USA
Tel: 603•448•1562
Fax: 603•448•3216
E-mail: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Model 4900

Vibrating Wire Load Cell

(Doc RevU, 7/15)

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1. INTRODUCTION

1.1. Theory of Operation

Geokon load cells are of an annular design primarily for use on tiebacks and rockbolts. They may also be used during pile load tests and for monitoring loads in struts, tunnel supports, etc.

In practically all cases, the load cells are used in conjunction with a hydraulic jack, which applies the load, and with bearing plates positioned on either side of the load cell.

NOTE that to protect the lead wires routed in a groove in one face of the load cell we do not allow the use of a washer made from lead, copper, rubber or other soft material bearing against this surface.
If a soft washer is used be sure it is used only on the other face – the one that does not have the annular epoxy-filled groove.

The load cell is frequently used:

- ⇨ To confirm the load as determined by the hydraulic pressure applied to the jack during proof testing on tiebacks, rockbolts, etc.
- ⇨ To provide a permanent means of monitoring the load throughout the life of the tieback, rockbolt, strut or support, etc.
- ⇨ To provide an electronic output for automatic data gathering.

Load cells are positioned so that the tensile load in the tieback or rockbolt produces a compressive load in the load cell. This is done by trapping the load cell between bearing plates positioned between the jack and the structure, either below the anchor head for permanent installations or above the anchor head for proof-testing. Figures 1 and 2 show the two different installations.

Figure 3 illustrates load cells being used for load monitoring during a pile load test.

1.2. Load Cell Design and Construction

The Model 4900 Load Cell body is constructed in the form of a high strength steel cylinder in which 3 to 6 vibrating wire strain gages are embedded to measure the change of strain in the cylinder as it comes under load. Multiple gages are needed to account for the effects of off-center or eccentric loading. Figures 4 shows a typical load cell.

See Appendix A for complete specifications.

The cable is attached to the cell through a waterproof gland or a connector. If the load cell is equipped with the waterproof gland, a strain relief, in the form of a Kellem's grip, prevents the cable from being pulled out of the cell. Cables have thick PVC jackets and can be terminated in a connector to mate with terminal boxes or the Load Cell Multiplexer for use with the GK-403 Readout Box manufactured by Geokon. See Appendix C for cable and connector diagrams.

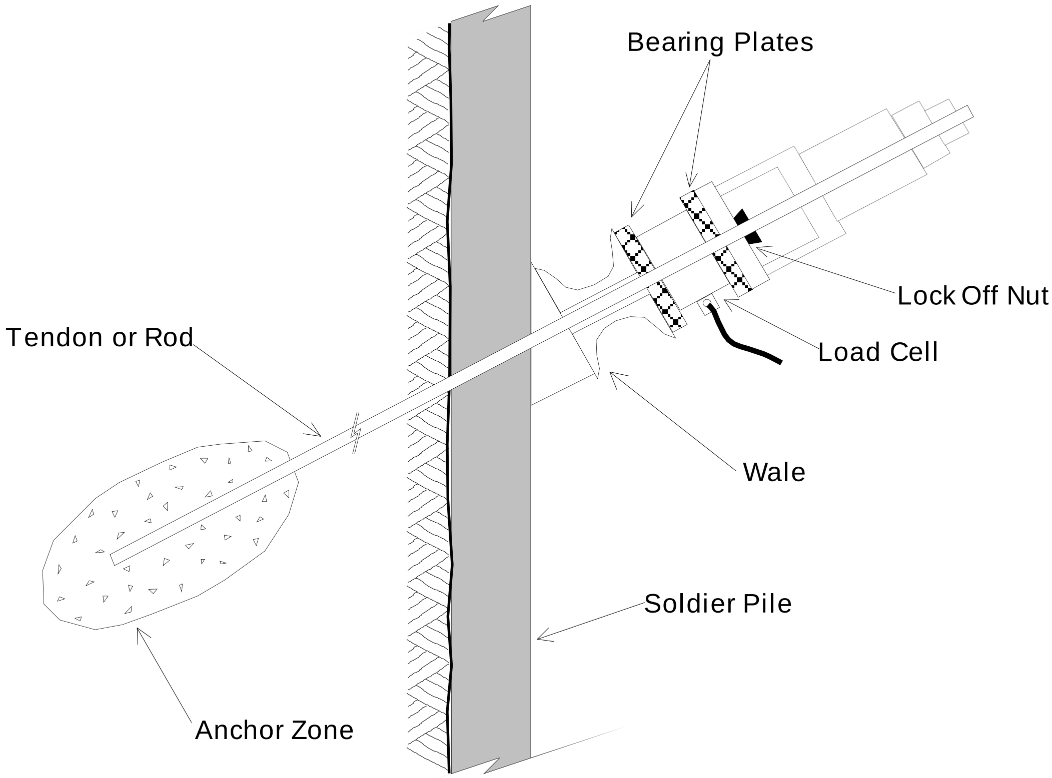

Figure 1 - Load Cell on Tieback for the Permanent Monitoring of Load

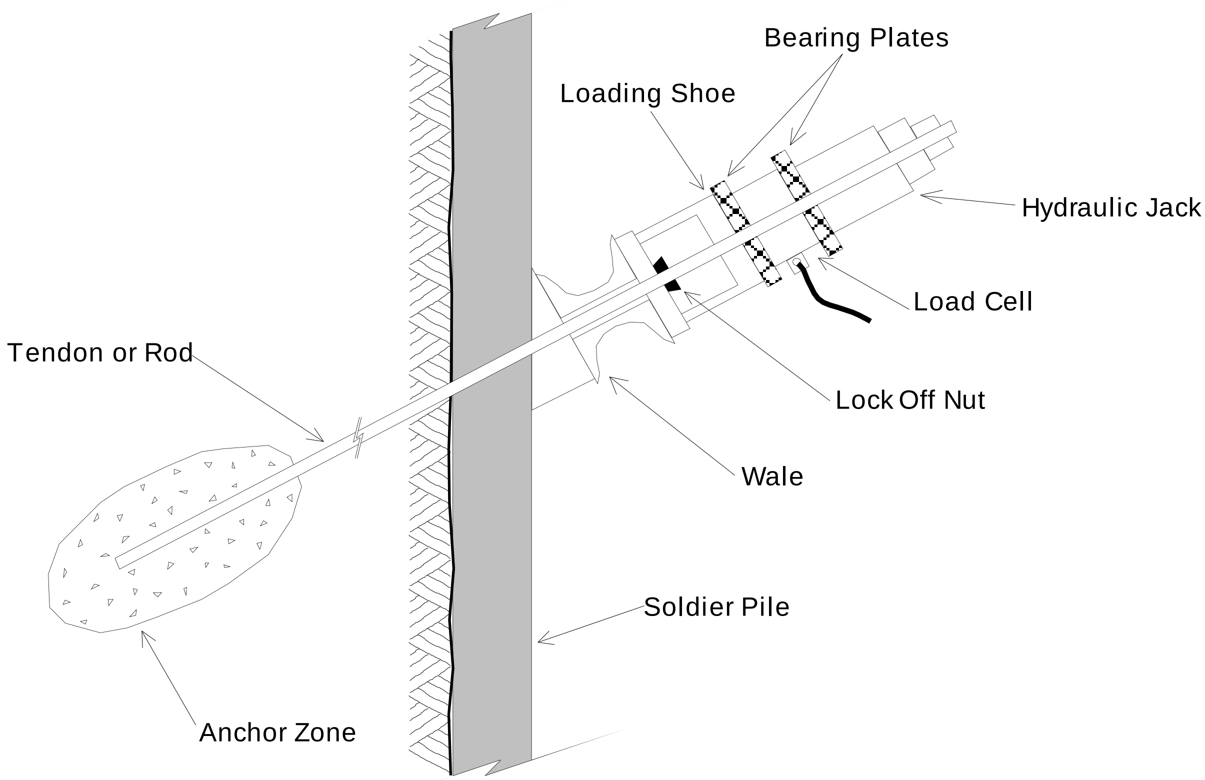

Figure 2 - Load Cell on Tieback for Proof Testing Only

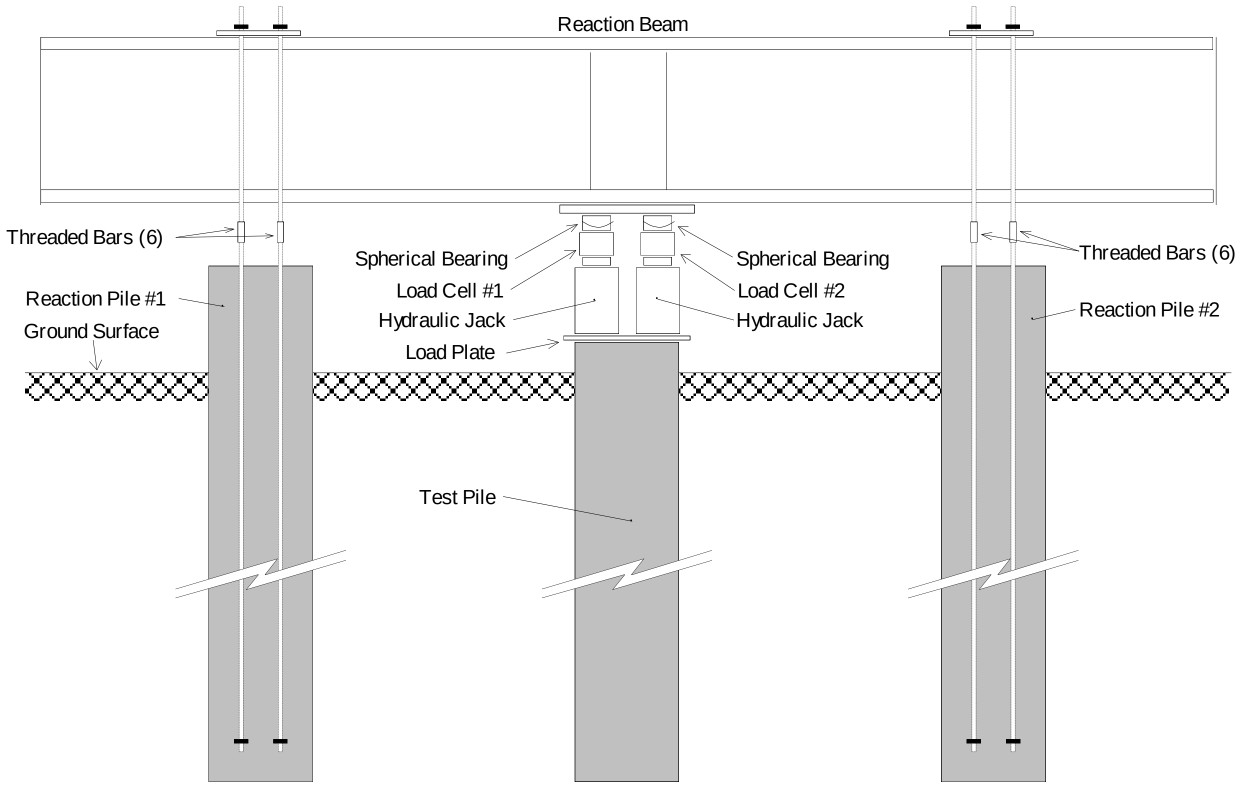

Figure 3 - Load Cells for Load Monitoring during Pile Load Test

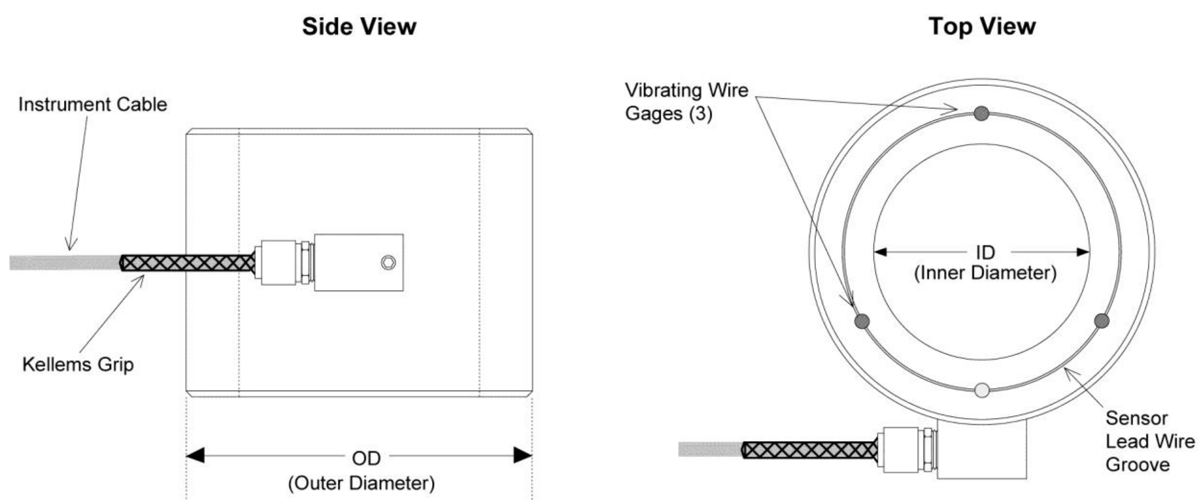

Figure 4 - Model 4900 (3 Gage) Vibrating Wire Load Cell

Additional cable protection can be obtained by either using armored cable or by placing the cable inside flex conduit.

Figure 5 shows a typical load cell system.

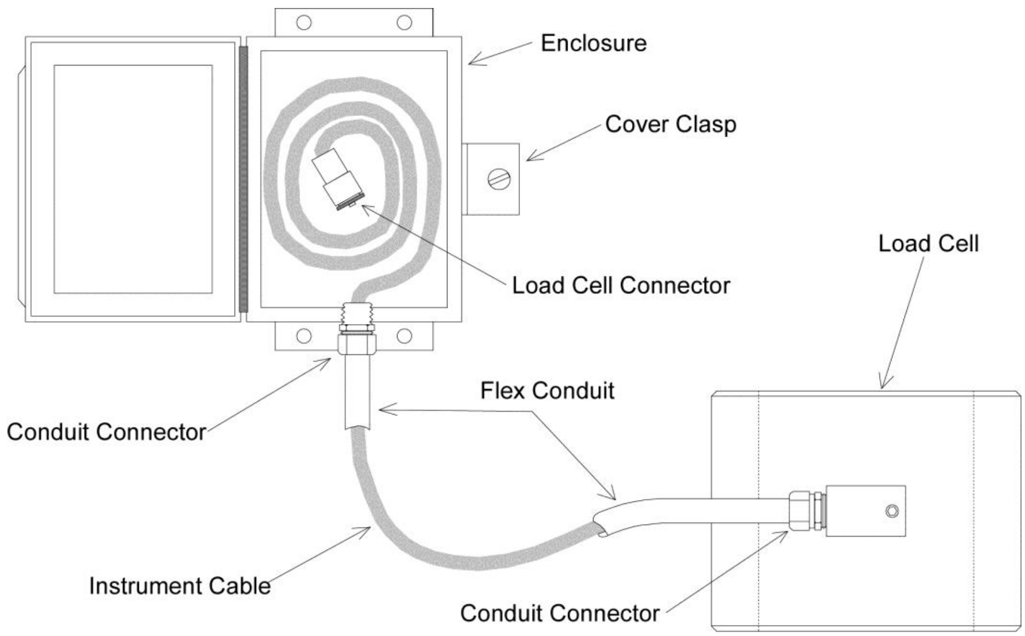

Figure 5 - Typical Load Cell System

Annular load cells, because of their design, are inherently susceptible to varying conditions of end loading, unlike solid load cells, which can be designed with button shaped ends so that the load always falls in a uniform, predictable fashion. Thus, the output and calibration of an annular load cell can be affected by end effects produced by:

a) **Warping of the bearing plates.**
b) **Friction between bearing plate and load cell.**
c) **Eccentric loading.**

All of these effects can be accumulative so that the calibrations can vary by as much as ±20%, unless special precautions are taken. Considering each effect in turn:

1.2.1. Warping of the Bearing Plates and Bearing Plate Design

Warping of the bearing plates is caused primarily by a size mismatch between the hydraulic jack and the load cell. A jack larger than the load cell tends to wrap the intervening bearing plate around the load cell, causing the center of the load cell to "hourglass" or pinch inwards causing the load cell to under-register.

Conversely, a hydraulic jack, smaller than the load cell, will try to punch the intervening bearing plate through the center of the load cell, making the center of the load cell barrel outwards causing the load cell to over-register. Both effects are exacerbated by bearing plates that are too thin.

For further details on this topic, the reader is referred to Appendices C and D.

NOTE that to protect the lead wires routed in a groove in one face of the load cell we do not allow the use of a washer made from lead, copper, rubber or other soft material bearing against this surface.

If a soft washer is used be sure it is used only on the other face – the one that does not have the annular epoxy-filled groove

Minimum bearing plate thickness is one inch (25 mm) where load cell size matches hydraulic jack size, i.e., the load bearing annulus of the load cell falls within the load bearing annulus of the hydraulic jack. For any other condition of size mismatch, the bearing plates should be at least two inches thick and even thicker where the size mismatch is extreme or the loads large.

Bearing plates should be flat and smooth. The normal rolled steel plate surface is adequate. It is not necessary to have machined or ground surfaces. Where plates are cut from larger plates, using cutting torches, the edges should be carefully cleaned to remove welding slag and solidified molten lumps.

Consideration should be given to calibrating the load cell using the same bearing plates as will be used in the field. Also, it is possible to simulate the size of the hydraulic jack using a suitably sized metal donut between the upper platen of the testing machine and the upper bearing plate. Load cells calibrated in this way, will be much more likely to agree with the hydraulic jack in the field.

1.2.2. Bearing Plate Friction

Friction between the bearing plate and the load cell can radically affect the performance of a load cell. Interposing deformable plates or lubricant between the bearing plates and the load cell in the field can cause the load cell to over-register, perhaps by as much as 10%. Again, for best results, it is important to calibrate the load cell in the laboratory under the same loading conditions as will be used in the field.

End effects of this nature can be reduced somewhat by using tall load cells. A rough rule of thumb for good load cell design calls for a load cell height at least 4 times the wall thickness of the loaded annulus. On some jobs where there are space restrictions calling for a pancake style load cell, friction between bearing plates and load cell can give rise to large hysteresis effects between loading and unloading cycles.

1.2.3. Eccentric Loading

Eccentric loading of load cells is the rule rather than the exception. Rarely is the axis of the tieback, rockbolt or strut at right angles to the surface on which the anchor plate or strut rests. In the case of tiebacks using multiple tendons, it is quite common for loads in individual tendons to vary markedly, one from the other, despite best efforts to avoid this happening. Also, struts are rarely at right angles to the soldier piles they may be supporting.

These factors combine to produce conditions in which the load cell experiences higher loads on one side than on the other. This effect is compensated for by the strain gages embedded in the wall of the cell being individually read and the average strain calculated. Thus, the higher strains on one side are balanced by lower strains on the other and the average strain is not affected. Thus, even gross amounts of load eccentricity can cause only slight ($< \pm 5\%$) variations in the load cell output and calibration.

Eccentric loading can be minimized by using spherical bearing plates, but this is expensive and is rarely done. Spherical seats may be of some value during pile load testing where uniformity of the load on the top of the pile is highly desirable.

1.2.4. Elastic Behavior

Geokon Model 4900 Load Cells are designed so as to keep the normal working stresses below 30% of the yield stress of the load cell material.

Load cells are over-ranged from 120% to 150% of the design load prior to calibration so that, as long as the load cell is never overloaded above this range, the no-load reading will not change. The normal over-range capacity for a steel load cell is 300 to 400% before the load cell will fail.

If a load cell is over-ranged and the no-load reading is shifted due to plastic yielding of the cell, then the cell should be returned to the factory for inspection and re-calibration. Note, however, that while the no-load zero may shift, the calibration constant will probably not be affected.

1.2.5. Temperature Effects

Temperature compensation is achieved by using vibrating wire strain gages whose thermal coefficient is the same as that of the load cell material. Normally, the temperature coefficient of the load cell is insignificant being -1.5 digits per °C. (see Section 4.2). (In special cases, if required, the coefficient can be measured at the factory). It should be remembered, however, that temperature changes on the loaded rockbolt, tieback, or strut can produce real changes of load and these will be recorded by the load cell.

2. INSTALLATION

2.1. Preliminary Tests

Before installing the load cell, it should be checked by connecting it to the readout box and taking a no-load reading. This reading, when compared with that given in the calibration data provided with the load cell, will show if the cell is functioning properly. The two readings should agree within about ±50 digits (assuming that the same readout box is used for both readings). See section 3 for readout instructions.

2.2. Load Cell Installation

2.2.1. Transportation

When transporting load cells, do not pull on the cable and, in particular, do not carry the load cell by the cable. On the larger load cells threaded holes are provided in the ends to allow eyebolts to be attached for lifting purposes.

2.2.2. Initial No-Load Reading

Before installing the load cell be sure to take the no-load reading. This reading is very important since it is the reading that will be subtracted from all subsequent readings in order to calculate the load. Note that each load cell has a different no-load reading, which is not zero. See Section 3 for operation of the Readout Boxes.

2.2.3. Installation on Tie-Backs and Rockbolts

NOTE that to protect the lead wires routed in a groove in one face of the load cell we do not allow the use of a washer made from lead, copper, rubber or other soft material bearing against this surface.
If a soft washer is used be sure it is used only on the other face – the one that does not have the annular epoxy-filled groove

Load cells should be installed between flat steel bearing plates of sufficient thickness: 1 inch thick where load cell and jack are about the same size and 2" to 3" thick where size mismatches are greater. Plates should be machined flat. Make sure that the bearing plates completely cover the load-bearing surface of the load cell. Centralize the rockbolt or tieback inside the load cell. Where the load cell I.D. is much bigger than the rockbolt or tieback, a centralizer bushing can be used.

Where the anchor block of a multi-tendon tieback bears directly on the load cell, make sure that the load cell bearing surface is completely covered by the anchor block. If the load cell is not completely covered, then make sure that the calibration was performed using the anchor block. If the calibration was performed without the anchor block then for best results consideration should be given to recalibration with the anchor block.

Shield the cable for possible damage from blasting or traffic. Protect the end of the cable or the cable connector from dirt by either using a cap on the connector or by storing the end of the cable and/or connector inside a small box. Figure 5 shows a typical load cell system.

3. TAKING READINGS

3.1. Operation of the GK-403 Readout Box

3.1,1. Using the Flying Leads

If the load cell cable does not have a connector the individual leads will be identified as shown in the wiring diagrams in Appendix C.1. Each sensor is read in turn by plugging the flying leads into the terminal box at the “TRANSDUCER” port and then clipping either the red or black clip to the lead marked “common” and the black or red clip in turn to the leads marked #1, #2, #3, etc. The blue clip should be connected to the cable shield and the green and white clips to the cable leads marked “thermistor”.

Switch the GK-403 “DISPLAY” selector switch to “B”. The sensor output is displayed in digits. Read each channel in turn and record in a field book and/or by depressing the “STORE” button. When using the “STORE” button it will be necessary to use the joystick to set the appropriate I.D. Marker on the display screen before the “STORE” button is depressed to distinguish individual gages (and load cells) from each other.

When the thermistor leads are hooked up the temperature at the load cell is automatically displayed on the display screen in °C.

The GK-403 will turn itself off after about 2 minutes.

3.1.2. Using a Load Cell Module

The Model GK-403 Load Cell Module acts as a multiplexer or automatic switch that can be used to automatically read all active sensors, calculate the average reading change, apply the gage factor and display the load in engineering units on the display screen. The 10 pin load cell cable connector is plugged into the module and the lead from the module is plugged into the “TRANSDUCER” port on the GK-403.

Note that the 10 pin load cell connector should not be plugged directly into the GK-403.

The current readings on all the active channels can be viewed by switching the “Display” selector to Channel B and by operating the joystick. If desired, these current readings or the active channels can be recorded directly into a field book and used later to calculate the load manually.

Care must be taken in setting up the GK-403 to read loads automatically and the reader is referred to the GK-403 manual for further details. The essential procedure is as follows:

The GK-403 is switched to “DISPLAY” setting “G”. When this is done a display of the type shown in Figure 6 will be observed on the display screen.

```
11/22/91  15:43
  NOW    23.7 C
   6547.3digLDCB
 ROW: 1  COL: 1
 ID:Load Cell 1
 11/22/91  15:42
  MEM    23.6 C
   6547.1digPOSB
```

Figure 6 - Mode G with Load Cell Module

- From the Main Menu select Option 3 and set the correct date and time

- From the Main Menu select Option 5 “Gage Params” and then Option 6, “Switch Position” and set the switch position to B

- Escape to the main reading screen and use the joystick to set the “Row” to “1” and “Col” to “1”. The displayed date should be correct and the displayed “LDC” should be at “B”. The temperature should be indicated in the top right hand corner.

- The easiest way to distinguish between load cells is to use the column (COL) number. It will be seen that the columns run from 1 to 7 and then jumps to column 11 to 17 and then jumps to 21 to 27 etc. all the way to 241 to 247. Columns 8, 9 and 0 are never displayed. Load cells with 6 sensors will use all columns 1 through 6 (or 11 through 16 etc.) while load cells with 3 or 4 sensors will use only this number of channels and channels 4, 5, 6 or 5 and 6 will remain blank. The first load cell can be read on COL 1 to7, the second on COL 11 to 17, the third on COL 21 to 27 etc.

- With the COL number set to 1 and the load cell at zero load it is now necessary to set the zero readings. This is done by selecting the “ZERO” option from the “GAGE PARAMS” menu. Now select option 2 “Use current reading as F (zero)”. This automatically sets the zero reading to the current reading on channel 1 and also performs the same function on all the other active channels from 1 to 6 so it is not necessary to repeat this process on the other active channels. Now when the COL number is set to 7 the displayed load number should be close to zero corresponding to zero load.

(Note that if the load cell has a load on it the above procedure cannot be used. Instead Option 3 on the Zero Factor menu must be selected and then the zero numbers entered manually from the calibration sheet for each of the active channels. There is a shortcut to this procedure: the average zero reading can be taken from the calibration sheet and input directly into channel 7 (17, 27, etc.). The drawback to this is that only channel 7 (17, 27, etc.) will show the load in engineering units while the rest of the active channels will show only the readout digits. This would make it more difficult to see the change in digits displayed on each active channel and to appreciate the degree of uniformity or non-uniformity of the load applied to the load cell.)

- The gage factor shown on the calibration sheet, usually in lbs/digit or kgm/digit, must be entered only on channel 7 (or 17, 27, etc.). It should not be entered on any of the active channels 1 through 6 etc. **(The gage factor on channels 1 thru 6 should be set to 1.000).** So return to the main menu and set COL reading to 7 (or 17, 27, etc.). However there are two important provisos, which is that the gage factor on the calibration sheet **must first be converted to Kips or metric tons before it is entered.** This is necessary in order not to overrange the limited capacity of the GK-403 readout screen. So a calibration factor of say 152.4 lbs/digit must be converted to 0.1524 Kips/digit. Secondly, **it is necessary to put a negative sign in front of the factor** so +0.1524 becomes –0.1524.

- The correct units must now be set on channel 7 (17, 27, etc.) from the “Units” option on the “Gage Params” screen. Set to either “Kip” or “mtn”.

- It will be wise to check the validity of the readings by comparing the displayed load readings on channel 7 with the load calculated from the readings on the active channels taken with the display switch on the GK-403 readout box set to position B.

- Readings on all channels can be stored in the GK-403 memory at any time by depressing the “SELECT/STORE” button. To distinguish sets of readings taken at different times use the ROW number, by advancing the row number with every set of readings. Any sets of readings at any particular time can be accessed and inspected by scrolling through the ROW numbers. Note that storing data on any ROW number will erase and write over any data already stored on that ROW.

- A useful feature of the GK-403 is its ability to display the previous readings taken on any channel. On the main screen the reading is at the bottom of the screen. Thus any sudden changes of load from one time to the next are immediately apparent.

3.1.3. Terminal Emulation Enhancements

Pressing <ENTER> on the host computer while in terminal emulation with the GK-403 will transmit the status of the Readout. If the Display Mode selected is G, the individual readings for the Load Cell as well as the calculated average (or load) will display. The following illustrates;

```
<<gk403 STATUS>>
  Date & Time: 09/11/92  11:42
  Switch Pos: G
  REF/COL#:    11    Load Cell Module attached.
  Temperature:   22.3
        xx1         xx2         xx3         xx4         xx5         xx6   xx7(avg)
     6543.3      6554.3      6654.1      6589.0      6521.2      6522.2   6566.3
       .           .           .           .           .           .         .
       .           .           .           .           .           .         .
       .           .           .           .           .           .         .
```

Approximately every 5 seconds the display will be updated.

3.2 Operation of the GK404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.

The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire (blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **B** and the MODE button to select **Dg** (digits).

Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.

The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

3.3 Operation of the GK405 Readout Box

The GK-405 Vibrating Wire Readout is made up of two components:

- the Readout Unit, consisting of a Windows Mobile handheld PC running the GK-405 Vibrating Wire Readout Application
- the GK-405 Remote Module which is housed in a weather-proof enclosure and connects to the vibrating wire sensor by means of:

1) Flying leads with alligator type clips when the sensor cable terminates in bare wires or,

2) connection by means of a 10 pin connector..

The two components communicate wirelessly using Bluetooth®, a reliable digital communications protocol. The Readout Unit can operate from the cradle of the Remote Module (see Figure 7) or, if more convenient, can be removed and operated up to 20 meters from the Remote Module

Figure 7   GK405 Readout Unit

3.3.1 Readout in digits

1. Switch on the Handheld Field PC by depressing the power button at the lower right.

2. Wait 70 seconds for the Handheld to warm up. After the Windows Mobile Screen appears wait another 20 second. (This wait is only when the box is first switched on. When in the sleep mode the box will wake up instantly). Once the box has been switched on it can be left in sleep mode.

3. Plug the flying leads into the 10 pin connector marked 'Load Cell' on the side of the box. Connect the flying leads color for color to the leads on the strain gage. Or if the strain gage has a 10 pin connector connect it directly to the 10 pin connector marked 'Sensor' on the side of the box.

4. Now Press 'Start' {if it fails to respond press 'Unlock')

5. Select 'GK405 VW Readout'

6. Press the Blue tooth button on the base of the GK405 the blue light will start blinking

7. After a few seconds the Bluetooth button on the readout box should now show a steady blue light indicating that a connection has been made between Handheld and base.

8. On the Live Reading Screen 'Display Mode' will show 'B' and the 'Sensor Index' 'Avg'

9. The screen now displays the average digit reading of all the strain gage in the load cell.

10. Record this reading in a field book.

Due to the lengthy warm-up period when first switching on the box it is best to leave the readout in a sleep mode if more than one reading are to be taken during the course of the day. This is done by first pressing ‘Menu’ and then select ‘Close GK405’ then pressing the Handheld power button momentarily. To switch the readout box off completely hold the power button down for few seconds until a ring tone is heard.

Writing data into a field book for later transferring to a spreadsheet is in many ways the best approach to take, For further details concerning storage of the readings in the readout box consult the GK405 Instruction Manual. If the readout is requied in units of load then use the following instructions:

3.3.2 Readout in Load units

Before you can store readings in the readout box you need to create a workspace where you can identify the load cell and configure the load cell parameters - gage factor , zero reading, units, etc., You need to do this for each load cell.

For each load cell a sensor file must be created. On the Workspace screen press and hold ‘Project Sensors then hit ‘Add Sensor’.

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11. Hit the keyboard icon at the bottom center of the screen and use the keyboard to enter the Load cell identification name and/or number
12. Select the sensor model number, 4900, from the drop-down menu
13. From the drop down menu insert the number of gages in the load cell.
14. Select the ► arrow to reach the next page
15. Select ‘Linear’ (If selecting ‘Polynomial’ follow the instructions for entering the A,B and C coefficients).
16. Select ‘Output Calculation’ to $G(R_1-R_0)$ in the dropdown menu,
17. Using the keyboard set the zero reading equal to the initial Regression Zero shown on the calibration sheet. (See Appendix G for further explanation)
18. Using the keyboard set the ‘Gage Factor’ equal to the Gage Factor given on the calibration sheet. Don’t forget the negative sign.
19. Leave “Gage Offset ‘ at zero
20. Select the ► arrow to reach the next page,
21. Select ‘Measure’ to ‘Load’.
22. Select the input units equal to the gage factor units.
23. Select the desired output units that will show on the display.
24. Select the ► arrow to reach the next page
25. For most application the temperature coefficient is not important in which case leave the ‘Sensor Correction’ at ‘disabled’

26. Select ‘Menu’ and ‘Save the Settings’.

27. Select ‘Applications’

28. Select ‘Live Readings’

29. Select ‘With Selected Sensor’ (the same one created in Step 11)

30. The readings should now be in units of load.

31. To store data hit the ‘Store’ icon on the screen. The readings will be stored under that particular load cell file, the one created in Step 11.

Note that if one of the strain gages fails a red warning will appear on the display. The readout box will continue to display the average reading of the remaining strain gages.
At any time in the Live Reading screen, when ‘Raw Readings’ is selected it is possible to display the reading on each individual strain gage in the load cell. This can be useful in assessing the degrre of eccentricity of the applied load,

3.4. Measuring Temperatures

Each Vibrating Wire Load Cell is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. See the wiring chart in Appendix C.1. for the appropriate connections.

1. If an ohmmeter is used, connect the ohmmeter to the two thermistor leads coming from the load cell. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)
2. Look up the temperature for the measured resistance in Table B-1. Alternately the temperature could be calculated using Equation B-1.

Note: The GK-403, GK404 and GK-405 readout boxes will read the thermistor and display temperature in °C automatically.

4. DATA REDUCTION

4.1. Load Calculation

The basic units utilized by Geokon for measurement and reduction of data from Vibrating Wire Load Cells are "digits". Calculation of digits is based on the following equation;

$$\text{Digits} = \left(\frac{1}{\text{Period(seconds)}}\right)^2 \times 10^{-3} \quad \text{or} \quad \text{Digits} = \frac{\text{Hz}^2}{1000}$$

Equation 1 - Digits Calculation

To convert the digits readings to load, the gage readings for each cell must be averaged, then the change in reading average multiplied by the gage factor supplied with the load cell.

$$\mathbf{L = (R_1 - R_0) \times G \times K}$$

Equation 2 - Load Calculation Using Linear Regression

Where; L is the load in lbs. or kg. etc.
R_0 is the **regression** no-load reading in digits (average of all gages).
R_1 is the current reading in digits (average of all gages).
G is the gage factor as supplied on the Calibration Sheet (Figure8). It has a negative sign since as the load increases the reading decreases
K is the conversion factor (optional) as listed in Table 1.

From→ To↓	**Lbs.**	**Kg.**	**Kips**	**Tons**	**Metric Tonnes**
Lbs.	1	2.205	1000	2000	2205
Kg.	0.4535	1	453.5	907.0	1000
Kips	0.001	0.002205	1	2.0	2.205
Tons	0.0005	0.0011025	2.0	1	1.1025
Metric Tonnes	0.0004535	0.001	0.4535	0.907	1

Table 1 - Engineering Units Conversion Multipliers

For example, a Model 4900 has a regression no-load reading (R_0) of 7309 (see Figure 8) and a current average reading (R_1) of 5497. The Calibration Factor is -397 lbs per digit.

$$\mathbf{L = (6408 - 7309) \times -397 = 357{,}700\ lbs.}$$

Note that the equations assume a linear relationship between load and gage readings **over the full load range**, and the linear coefficient is obtained using regression techniques. **Note that when using the Calibration Factor obtained from the regression formula it is necessary to use the regression zero. This may introduce substantial errors at very low loads.** A measure of the amount of non-linearity is shown on the Calibration Sheet in the column entitled "Linearity". (See Figure 8). See Also Appendix

For greater accuracy, the data given can be represented by a polynomial or can be treated as a series of segments over the entire load range.
For instance, in the example of Figure 8, the load between 0 and 180,000 lbs. could be represented by the following equation;

$$\mathbf{L = ((7304 - 6860) \times -405 = 179{,}820\ tonnes.}$$

The gage factor -405 lbs/digit is calculated from the slope of the line between a load of 0 and 180,000 lb, i.e.,

$$(0 - 180{,}000)/(7304 - 6860) = -405 \text{ lbs/digit}$$

A polynomial expression to fit the data would be:

$$\mathbf{L = A*R_1^2 + B*R_1 + C}$$

Equation 3 - Load Calculation Using Polynomial

Where; L is the load in lbs, kgms. etc
R_1 is the current reading (average of all gages).
A, B and C are the coefficients derived from the calibration data.

First Calculate C from the initial average field zero reading, Suppose this is 7305
Then, $0 = -0,00247 * 7305^2 - 367*7305 + C$, from which C = +2,812,740

So when the applied load is 360,000, R_1 = 6409 and

The calculated Load = $-0,00247 * 6409^2 - 367*6409 + 2,812740 = 359,180$ lbs

4.2. Temperature Correction Factor

There is a small correction that can be made for temperatures. As the temperature goes up the average reading of all the sensors will go down by about one digit per °C So the load, corrected for temperature, would be

$$\mathbf{L = G\,[\,(R_1 - R_0) + (T_1 - T_0)\,]}$$

The temperature effect shown above is for a load cell that has not been installed yet and is very minor. There is no telling what the actual temperature effect will be on a load cell that is installed on a tensioned bar or cable. This depends on the length of the bar or cable and on the properties of the surrounding ground. The actual temperature effect can only be arrived at empirically by simultaneous measurements of load and temperature over a short period of time.

4.3. Environmental Factors

Since the purpose of the load cell installation is to monitor site conditions, factors which may effect these conditions should be observed and recorded. Seemingly minor effects may have a real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to: blasting, rainfall, tidal or reservoir levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Load Cell Calibration Report

Model Number: 4900X-900-0

Calibration Date: May 04, 2012

Serial Number: 1139947

Calibration Instruction: CI-4900GP

Max. Range (lbs): 900000

Technician: Stewart Hannah

Cable Length: N/A

Initial Cycling Data

Load (lbs):	0	0	900000	0
Reading:	7358	7305	3902	7303

Applied Load in lbs	First Cycle				Second Cycle				Average (2 Cycles)	Linearity % Max Load	Polynomial Error (%FS)
	Gage 1	Gage 2	Gage 3	Average	Gage 1	Gage 2	Gage 3	Average			
0	7298	7311	7300	7303	7299	7312	7301	7304	7304	0.24	0.07
180000	6880	6899	6795	6858	6883	6899	6797	6860	6859	-0.14	-0.09
360000	6510	6481	6232	6408	6514	6479	6234	6409	6408	-0.27	-0.10
540000	6095	6044	5708	5949	6096	6033	5722	5950	5950	-0.03	0.13
720000	5689	5607	5189	5495	5691	5597	5202	5497	5496	-0.01	0.04
900000	5278	5170	4668	5039	5279	5161	4681	5040	5040	0.12	-0.05
0	7299	7311	7300	7303	7300	7312	7303	7305	7304		

GK-401 Pos. B Readout

Linear Gage Factor (G): -397.0 lbs/digit

Regression Zero (R_0):* 7309

Polynomial Gage Factors: **A: -0.00247** **B: -367** **C:**

Calculate C by setting L=0 and R_1 = initial field zero reading in the polynomial equation

Calculated Load: **Linear, $L = G(R_1 - R_0)$**

Polynomial, $L = AR_1^2 + BR_1 + C$

Linearity = ((Calculated Load - Applied Load) / Max. Applied Load) x 100%

For additional accuracy the data could be analysed in segments, calculating gage factors for each segment

* Note: The above calibration uses a linear regression method. The Zero Reading shown is ideal for straight line computation and does not usually agree with the actual no-load reading.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Figure 8 - Typical Model 4900 Calibration Sheet

5. TROUBLESHOOTING

Problems with the load cell are usually associated with cable damage or moisture getting into the system. Both problems can be minimized by protecting the cable from damage, by visual inspection of the cable in the event that problems arise and by keeping the plug clean and dry at all times. ***Avoid carrying the load cell by the cable.***

Check the cable for damage such as pulling out of the load cell or connector, crushed spots, cuts or kinks. If there is cable damage, the cable should be repaired by cutting and splicing. All splices should be mechanically strong (soldering connections is usually best), well insulated and protected from dirt and moisture with an epoxy based splice kit such as the such the 3M Scotchcast™, model 82-A1. These kits are available from the factory. Alternately, a mastic type sealant, such as AquaSeal (Kearney), and vinyl tape may be used to cover a splice.

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

Symptom: Load Cell Gage 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? Channel A of the GK-401 and GK-403 can be used to read the strain meter. To convert the Channel A period display to digits use Equation 1.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the GK-401 Readout connect the clip with the green boot to the bare shield drain wire of the load cell cable. If using the GK-403 connect the clip with the blue boot to the shield drain wire.
- ✓ Does the readout work with another load cell? If not, the readout may have a low battery or be malfunctioning.

Symptom: Load Cell Gage Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads is 45 to 50Ω. (75, 90 or 180Ω, ±10Ω on some older models) 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 ($<$20Ω) a short in the cable is likely.
- ✓ Does the readout or datalogger work with another load cell? If not, the readout or datalogger may be malfunctioning.

Symptom: Thermistor resistance is too high.

- ✓ Is there an open circuit? Check all connections, terminals and plugs. If a cut is located in the cable, splice according to instructions above.

Symptom: Thermistor resistance is too low.

- ✓ Is there a short? Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions above.
- ✓ Water may have penetrated the interior of the load cell. There is no remedial action.

APPENDIX A - SPECIFICATIONS

A.1. Model 4900 Load Cell Specifications

Available Ranges:[1]	100, 150, 200, 300, 500, 600, 1000, 1500, 2000 kips
Accuracy:	1.0% FSR (or better)
Linearity:	0.5% FSR
Resolution:[2]	0.02% FSR
Repeatability:	0.1% FSR
Temperature Effect:	0.02% FSR/°C
Temperature Range:	–40 to +80° C -40 to 110° F
Frequency Range	1400-3500Hz
Overrange:	150%
Coil Resistance:	45 to 50Ω (70, 90, or 180 Ω on some older models)
Cable Type (3 Gage):[3]	4 twisted pair (6 conductor) 22 AWG, Purple jacket Foil shield, PVC jacket, nominal OD=9.5 mm (0.375")
Cable Type (4 Gage):[3]	4 twisted pair (8 conductor) 22 AWG, Purple jacket Foil shield, PVC jacket, nominal OD=9.5 mm (0.375")
Cable Type (6 Gage):[3]	6 twisted pair (12 conductor) 22 AWG, Orange jacket Foil shield, PVC jacket, nominal OD=12.7 mm (0.5")

Table A-1 Model 4900 Load Cell Specifications

Notes:
[1] Other ranges available.
[2] Minimum, depends on the readout instrument and technique.
[3] Other cable types, i.e. armored, are available.

A.2. Thermistor

Range: -80 to +150° C
Accuracy: ±0.5° C

APPENDIX B - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation:

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

Equation B-1 Convert Thermistor Resistance to Temperature

Where; T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
A = 1.4051×10^{-3} (coefficients 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	141.1	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
77.66K	-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	-34	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	292.4	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	5692	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	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	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 B-1 Thermistor Resistance versus Temperature

APPENDIX C - WIRING AND CONNECTOR PINOUTS

C.1. Load Cell Connector and Cable (standard wiring)

10 pin Bendix PT06A-12-10P	Function	3 Gage VW Load Cell Geokon Purple Cable	4 Gage VW Load Cell Geokon Purple Cable	6 Gage VW Load Cell Geokon Orange Cable
A	Gage #1	Red	Red	Red
B	Gage #2	Red's Black	Red's Black	Red's Black
C	Gage #3	White	White	White
D	Gage #4	NC	White's Black	White's Black
E	Gage #5	NC	NC	Green
F	Gage #6	NC	NC	Green's Black
G	Shield	All Shields	All Shields	All Shields
H	Common	White's Black[1]	Green	Blue
J	Thermistor	Green[1]	Blue	Yellow
K	Thermistor	Green's Black	Blue's Black	Yellow's Black

Notes:
[1] White's black and Green wires are switched on Geokon 3 gage VW load cells prior to serial number 3313.

C.2. GK-403 to Module Connector

Module 10-pin Bendix Plug (PT06F-12-10P)	Interconnect Wire Color (6 Pair)	Interconnect Wire Color (Belden)	Description	Module Board Connection
A	Brown	Brown	VW Gage	JP1-2
B	Brown's Black	Red	VW Gage Ground	JP1-1
C	Red	Orange	Thermistor	JP1-3
D	Red's Black	Yellow	Thermistor Ground	JP1-1
E	Yellow	Green	Shield	JP1-1
F	Yellow's Black	Blue	+12 VDC	JP1-4
G	Green	Violet	Ground	JP1-9
H	Green's Black	Grey	Mux Sense	JP1-9
J	Blue	White	Mux Clock	JP1-8
K	Blue's Black	Black	Mux Type	JP1-9

APPENDIX D - Vibrating Wire Load Cell Gage Factor Recalculation

Note, the following applies only to manual readout. When using the GK403 with the Load Cell Module the absence of any gage is automatically compensated for.

Overview

This appendix describes how to recalculate the gage factor for a Load Cell and then approximate the load where one or more strain gages in the cell have failed after installation.

Procedure

If the load is applied uniformely to the load cell then, as the load changes the change in reading on each gage will be the same and, should one gage fail, the gage factor given on the calibration sheet can be applied to the *average* change of the remaining gages

Note the following example where #3 gage in a six-gage load cell has failed. The load cell gage factor for the six gages is 0.2439 tonnes./digit. If the load is uniformly applied to the load cell, then, to calculate the load we can simply apply this gage factor to the average reading change of the remaining five active gages: in the example below the load on 7/1/02 would be calculated to be 0.2439(7298-6139) = 282.7 tonnes.

In the field however it is a rare condition to have the cell uniformly stressed. So, it may be more accurate to calculate a new gage factor using just the active gages.

In cases where the load is eccentric (in the present example the reading change on gage #3 was higher than the other five gages), we can calculate the new gage factor for the remaining five active gages as follows:

Date	Gage #1	Gage #2	Gage #3	Gage #4	Gage #5	Gage #6	Avg	Load
Initial	7318	7363	7247	7448	7222	7191	7298	0
6/1/02	6485	6363	6220	6618	6362	6331	6396	220.2 tonnes
7/1/02	6202	6034	No Reading	6324	6075	6058	**6139**	293.8 tonnes.

1) Calculate a **new zero load average** using only the initial readings of the five remaining active gages **= 7308**

2) Using only the readings of the active gages #1, #2, #4, #5 and #6 from the time of the last readings, (6/1/02), when all six gages were active, calculate the average reading: = **6432**

3) Calculate the **new gage factor** for the remaining five active gages by dividing the calculated load at the last time when all gages were active, (6/1/02), by the change in the five gage average readings calculated in steps 1 and 2, = 220.2 /(7308-6432) **= 0.2514**. This is the new gage factor to be applied to all subsequent changes of the remaining five active gages

4) Using the averages of the current and initial five-gage readings, calculate the load on 7/1/02 by using the new gage factor. Thus on 7/1/02: (**7308 – 6139**) x **0.2514** = 293.9 tonnes . As will be seen this gives a better result than applying the old gage factor for the six gages to the average reading of the five active gages. (The applied load was 291 tonnes)

5) Repeat step 4 for subsequent readings or repeat all steps if more gages in the load cell fail.

Limitations

This is not a foolproof method: For example, if the load distribution changes in the course of monitoring, the calculations based on the above-described method will be in error

APPENDIX E - LOAD CELL CALIBRATIONS - EFFECTS OF BEARING PLATE WARPING

Introduction

Load cells used to measure loads during testing of tiebacks, driven piles and drilled shafts give calculated loads which are frequently in disagreement with loads calculated on the basis of hydraulic jack pressure and piston area. Because of this, there is a general lack of confidence in load cell data and the fault is often ascribed to manufacturing defects, or to improper, inaccurate calibration procedures. Nevertheless, it is also well known that the effects of eccentric loading and uneven and/or warped bearing plates do have a profound effect on load cell readings. The purpose of this technical note is to provide some insight into these effects.

Load Cell Calibration Procedures

The usual calibration procedure is to use a testing machine to apply a load to a load cell. The measured load cell output is then correlated against the known applied load as measured by the testing machine. Usually, the testing machine has a hydraulic pressure applied to a piston of known cross section area. The testing machine itself is checked out periodically by running tests on a load cell traceable to NIST and there is generally little doubt about the accuracy of the testing machine. Accuracy's of ¼% FS ½% FS or 1% FS are normal.

Usually, the calibration tests are performed between large, flat parallel platens in the testing machine so that there is no bending of the platens, only the elastic compression in the zone immediately bearing against the load cell.

Field Arrangement

Such a state of affairs may not exist on the job site since the bearing surfaces next to the load cell are usually much less rigid, and liable to bending.

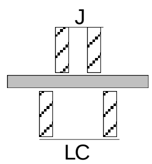
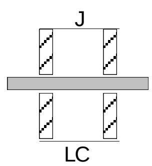
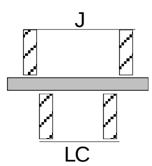
This bending is particularly apparent if there is a mismatch in size between the load cell and the hydraulic jack. If the hydraulic jack is larger than the load cell there is a tendency for it to try to wrap the intervening bearing plate around the load cell. If the hydraulic jack is smaller than the load cell it will try to push the intervening bearing plate through the hole in the load cell.

Thicker bearing plates will bend less, but the effect will never be entirely eliminated. The consequence of this bending can be quite large since the effect on the load cell is to cause it to either barrel out at its mid-section if the jack is too small, or pinch in at its mid-section if the jack is too big. For vibrating wire load cells the gages are usually located in the center of the cell wall, on the neutral axis, thereby minimizing these effects.

<u>Report on Recent Testing</u>

A series of tests were conducted in a testing machine to investigate the magnitude of this effect.

A load cell with a bearing surface of 4" ID, 5¾" OD was used.
Simulated jack A had a bearing surface of 2" ID, 4" OD.
Simulated jack B had a bearing surface of 4" ID, 5¾" OD.
Simulated jack C had a bearing surface of 6" ID, 8" OD.
The maximum applied load was 150 tons.

Jack		Load Cell response to applied load (100%)	
		1" thick plate	2" thick plate
A (smaller)		108%	102%
B (same size)		100%	100%
C (bigger)		96%	98%

From the results it can be seen that if the jack is smaller than the load cell, the load cell will over-register, while a jack bigger than the load cell will cause the load cell to under-register. The effect is bigger if the bearing plate between jack and load cell is thinner.

The correct bearing plate thickness will of course depend on the extent of the mismatch between jack and load cell. However as a rough rule of thumb the following thickness should be required:

100-200 kip load……………...25mm(1”) thick
Up to 400 kip load……………37mm (1.5”) thick
Up to 1000 kip load…………..50mm (2 “) thick
Uo to 2000kip load …………..75mm (3”) thick

Conclusion

The consequences of all this would seem to indicate that, for best results, the load cell calibration should be performed with the actual hydraulic jack that will be used, both being placed in the testing machine at the same time. Or failing that, the load cell should be loaded through a ring, having the same dimensions as the hydraulic jack bearing surface, positioned on the other side of a bearing plate of the correct thickness. In this way one of the variables affecting the agreement between load cell readings and hydraulic jack readings can be removed and the agreement should be that much closer.

This technical note has addressed only the subject of the size mismatch between load cells and hydraulic jacks. Other factors affecting the agreement between load cell readings and hydraulic jack load are important: thus frictional losses within the hydraulic jack can cause under-registering of jack load indications by as much as 15%. (Dunnicliff 1988' Section 13.2.6)

Also annular style load cells are susceptible to end effects and eccentrically applied loads. The height of the load cell should exceed 4 times the wall thickness of the annulus and at least 3 strain gages should be used increasing to 6 as the size of the load cell increases.

References

J. Dunnicliff. 1988. Geotechnical Instrumentation for Monitoring Field Performance, John Wiley & Sons, New York, NY: 577pp.

Appendix F – The Use of the Regression Zero when Using the Linear Gage Factor

It is normal for load cells, having an annular design and for solid load cells that do not have 'button heads' or spherical seated bearing plates, to be susceptible to irregular load distributions at low loads. This is because there is a 'bedding in' process that takes place while the surfaces at both ends of the load cell conform to the surfaces they bear against causing the load cell to deform in an unpredictable way giving rise to strange strain patterns and faulty readings at low loads.
This irregularity of load disappears once the load cell surfaces have 'bedded in' and from that point on the load cell behaves in the a more linear fashion such that there is a constant relationship between the applied load and the observed change in readout as quantified by the linear gage factor shown on the calibration sheet.

Because of this the linear gage factor shown on the calibration sheet has been calculated after excluding the often-anomalous zero reading from the data points. And this gage factor best describes the performance of the load cell at moderate to higher loads

This linear gage factor describes the slope of the best fit line drawn through the calibration data points and the reading where the line intersects the zero load point on the load axis is called the 'Regression Zero' shown on the calibration sheet.

<u>It is important when using the linear gage factor to calculate loads that the value of R0 in the linear equation be equal to the regression zero.</u>

For greater accuracy a 2nd order polynomial can be used to map the data points. In this case the regression zero is replaced by the factor C shown on the calibration sheet.

Now it may be, for a variety of reasons, (e.g., if the load cell is used repeatedly on a number of jobs), that the no load zero reading might change significantly. Again, for greater accuracy, the value of the Regression Zero can be adjusted by an amount equal to the observed change in the no load zero from that shown on the calibration sheet. Similarly the C factor of the polynomial can be adjusted by the amount of the zero load change multiplied by the linear gage factor to convert it into the corresponding load change.