GEOKON

The World Leader in Vibrating Wire Technology

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Instruction Manual

Model 4900

Vibrating Wire Load Cell

(Doc Rev N, 03/08)

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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.

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 vibrating wire strain gages are embedded; 3-6 strain gages are used to minimize the effects of off-center or eccentric loading. The strain gages and internal wiring are protected by an outer steel shell or a protective steel band. O-ring seals are used on the individual gages to prevent the ingress of moisture. Additional O-ring seals are used on the load cell with the steel outer cover. See Figures 4 and 5 for typical load cells. 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.

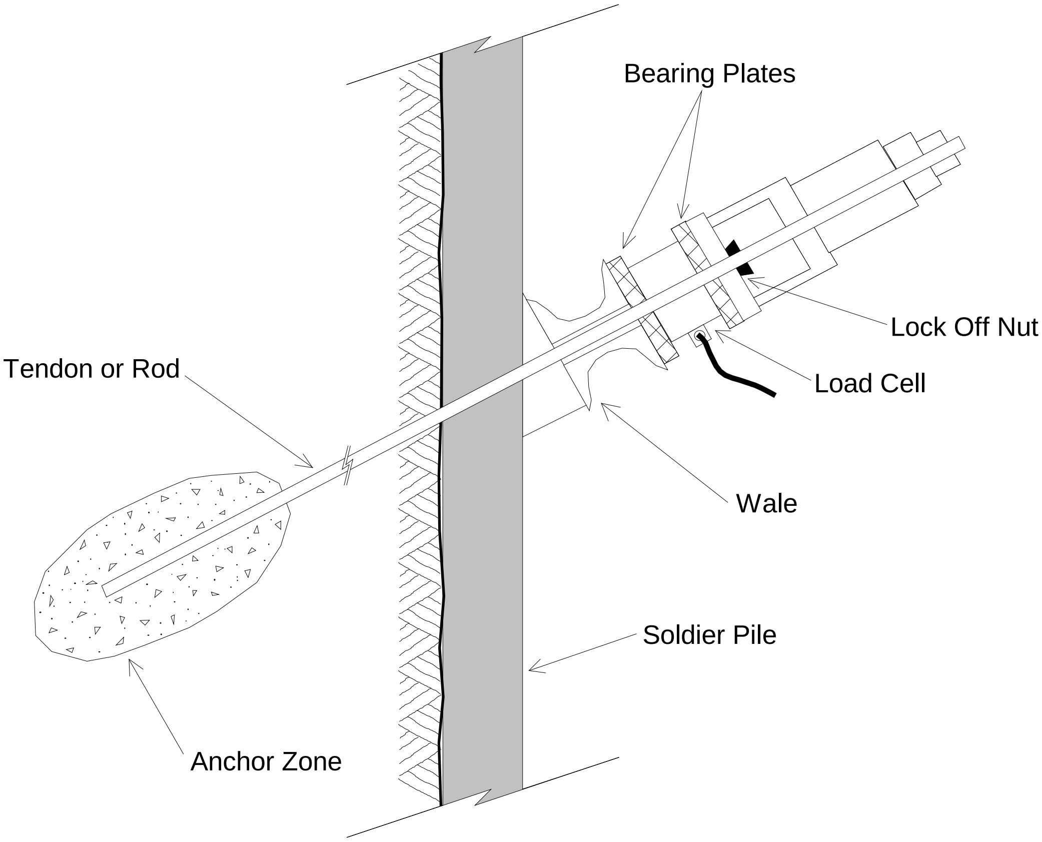


Figure 1 - Load Cell on Tieback for the Permanent Monitoring of Load

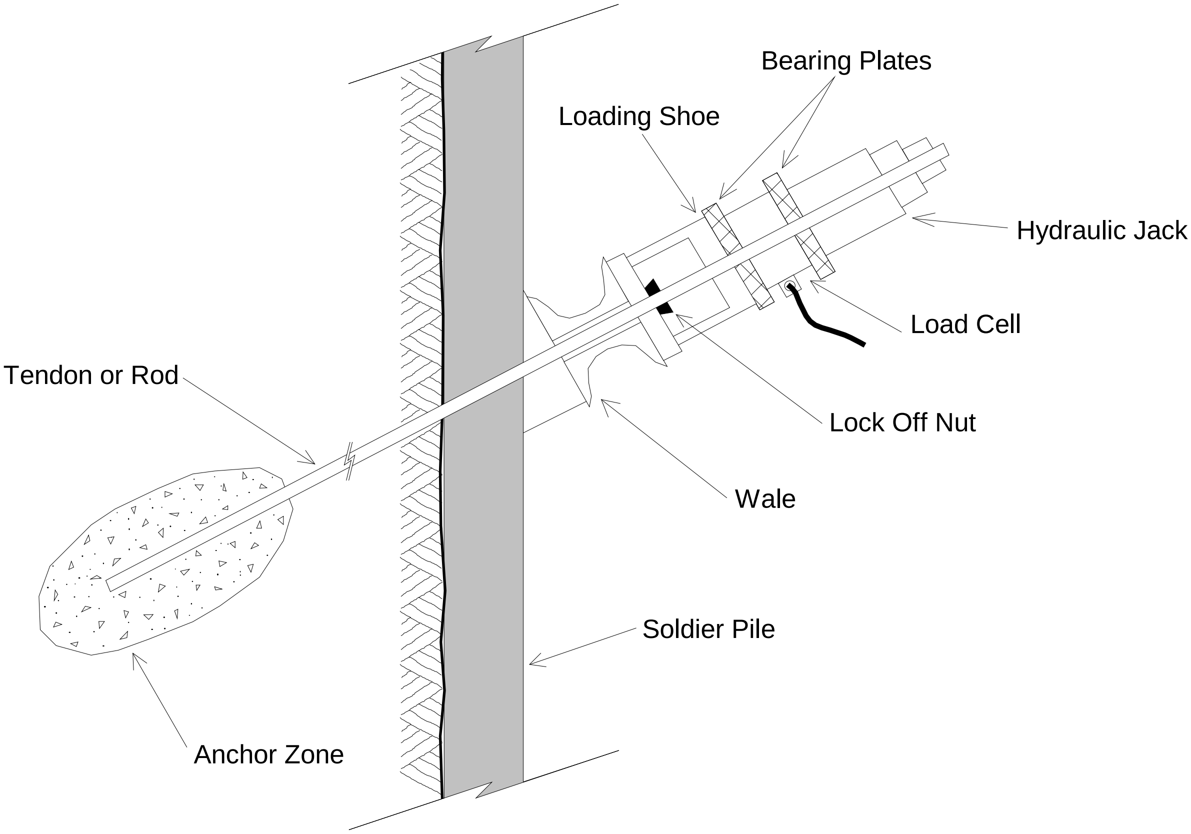


Figure 2 - Load Cell on Tieback for Proof Testing Only

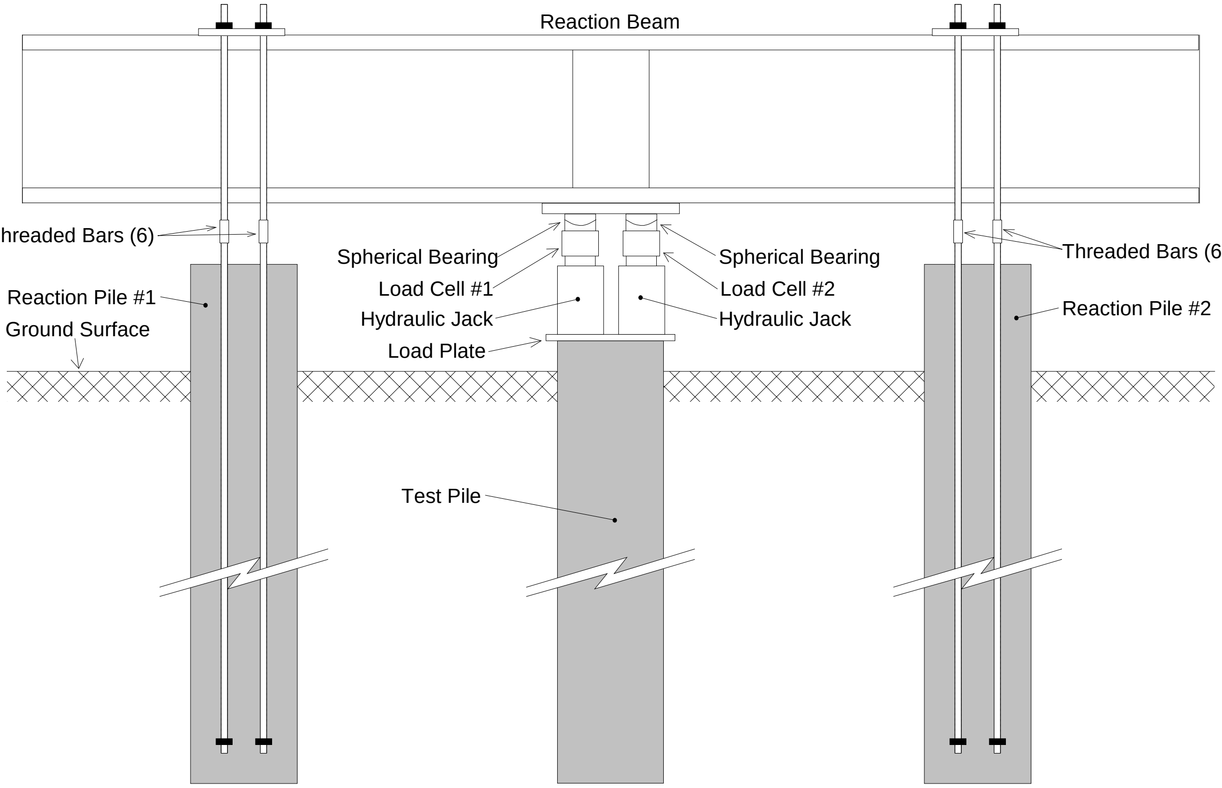


Figure 3 - Load Cells for Load Monitoring during Pile Load Test

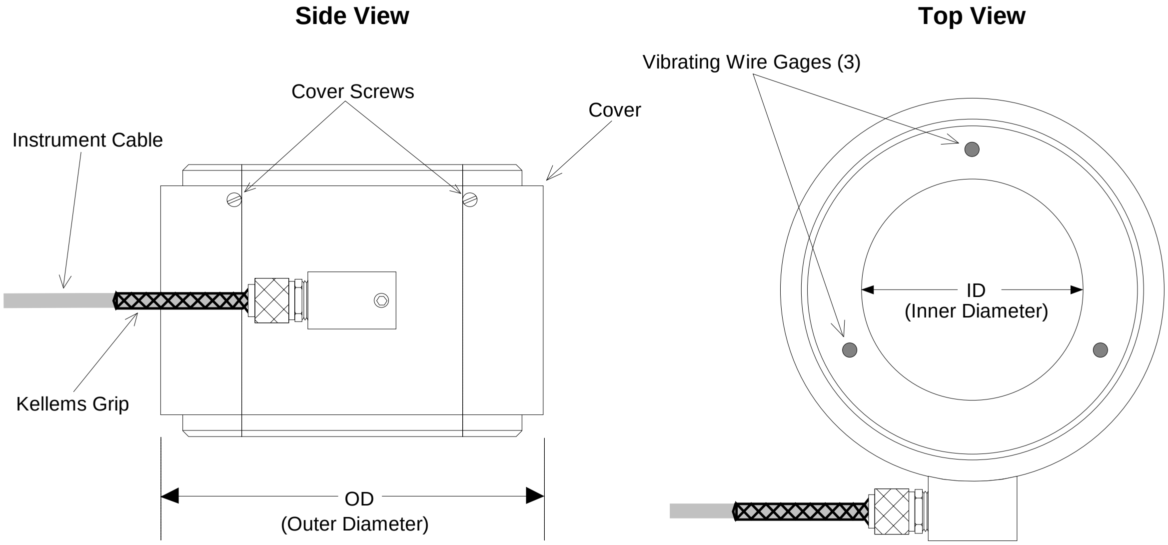


Figure 4 - Model 4900 (3 Gage) Vibrating Wire Load Cell

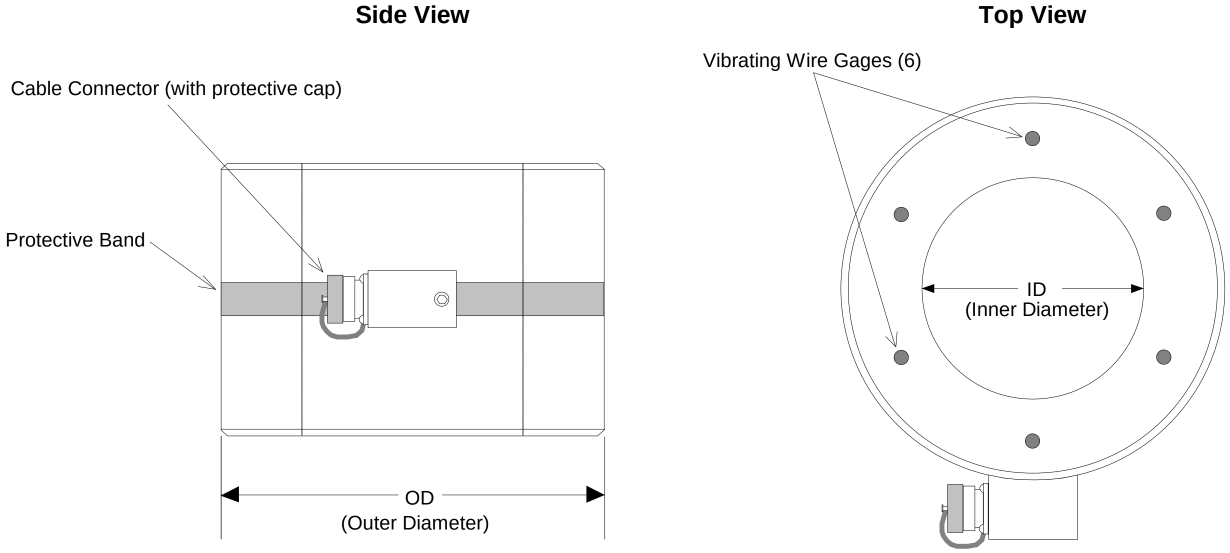


Figure 5 - Model 4900 (6 Gage) Vibrating Wire Load Cell

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

Figure 6 shows a typical load cell system.

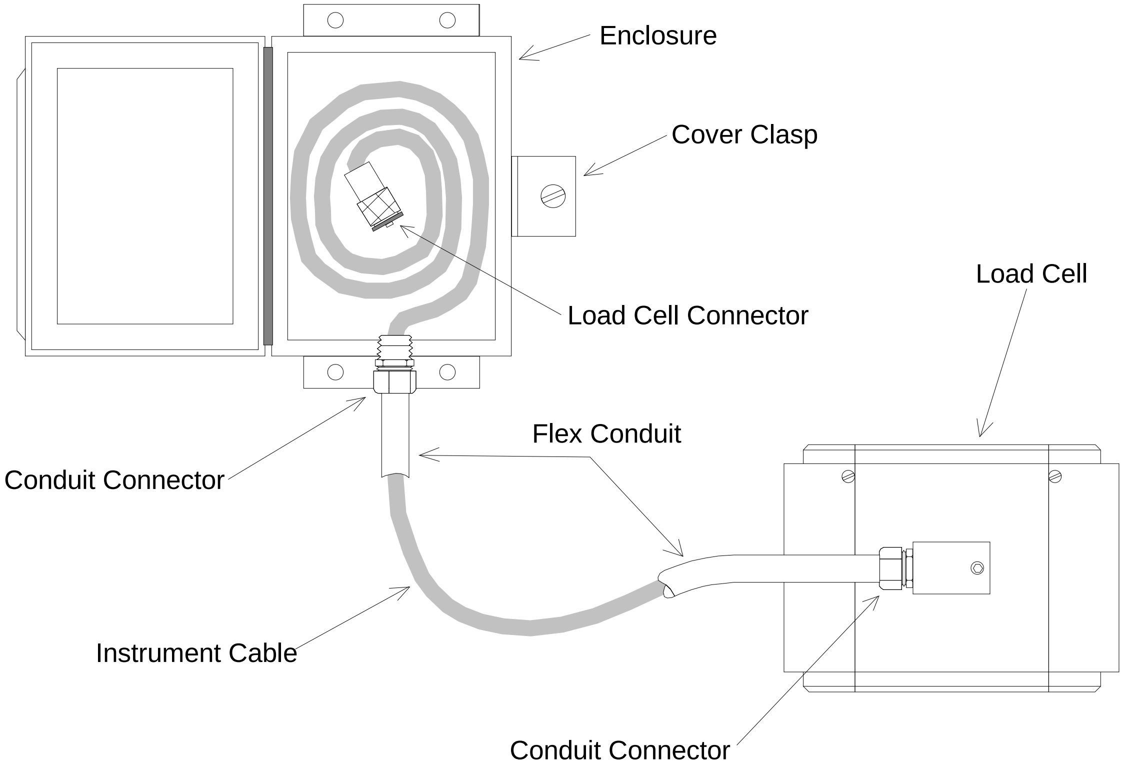


Figure 6 - Typical Load Cell System

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:

<u>1.2.1. Warping of the Bearing Plates and Bearing Plate Design</u>

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.

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.

<u>1.2.2. Bearing Plate Friction</u>

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 cycled to 120% 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 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

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 6 shows a typical load cell system.

3. TAKING READINGS

3.1. Operation of the GK-401 Readout Box

The GK-401 is a basic readout for all vibrating wire gages.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. If using the flying leads, see the wiring chart in Appendix C.1. for the appropriate connections.

1. Turn the display selector to position "B". Readout is in digits (Equation 1).
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. Take readings on all gages, then compute the average.
3. The unit will automatically turn itself off after approximately 4 minutes to conserve power.

3.2. Operation of the GK-403 Readout Box

3.3.1. 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.

3.3.2. 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 7 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 7 - 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 <u>only on channel 7</u> (or 17, 27, etc.). It should <u>not</u> 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 **<u>must first be converted to Kips or metric tons</u> 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 <u>necessary to put a negative sign in front of the factor</u>** 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 <u>ROW number</u>, 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.

<u>3.3.3. Terminal Emulation Enhancements</u>

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.  6554.  6654.  6589.  6521.  6522.  6566.3
      3      3      1      0      2      2
     .      .      .      .      .      .        .
     .      .      .      .      .      .        .
     .      .      .      .      .      .        .
```

Approximately every 5 seconds the display will be updated.

<u>3.3 Operation of the GK404 Readout Box</u>

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

3.4. 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. The GK-401 readout Box does not read temperatures – a digital ohmmeter is required.

1. 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 and GK-404 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.

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

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 (Figure 8).
K is the conversion factor (optional) as listed in Table 1.

This equation is the same as the one shown on the calibration sheet; see Figure 8.

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 7290.2 (see Figure 8) and a current reading (R_1) of 6500. The Calibration Factor is 0.2439.tonnes per digit.

$$\mathbf{L = (7290 - 6500) \times 0.244 = 192.76\ tonnes.}$$

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, also, 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).

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 145 and 218 tonnes. could be represented by the following equation;

$$\mathbf{L = ((6687 - 6500) \times 0.251) + 145 = 191.94 \text{ tonnes.}}$$

The gage factor 0.251 is calculated from the slope of the line between a load of 145 and 218 tonnes, i.e.,

$$(218 - 145)/(6687 - 6396)$$

Similarly, between a load of 0 and 73 tonnes;

$$\mathbf{L = (7298.5 - R_1) \times 0.234 \text{ tonnes}}$$

A polynomial expression to fit the data would be:

$$\mathbf{L = (((R_1)^2 \times A) + (R_1 \times B) + C)) \times CF}$$

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.
K is the conversion factor (optional) as listed in Table 1.

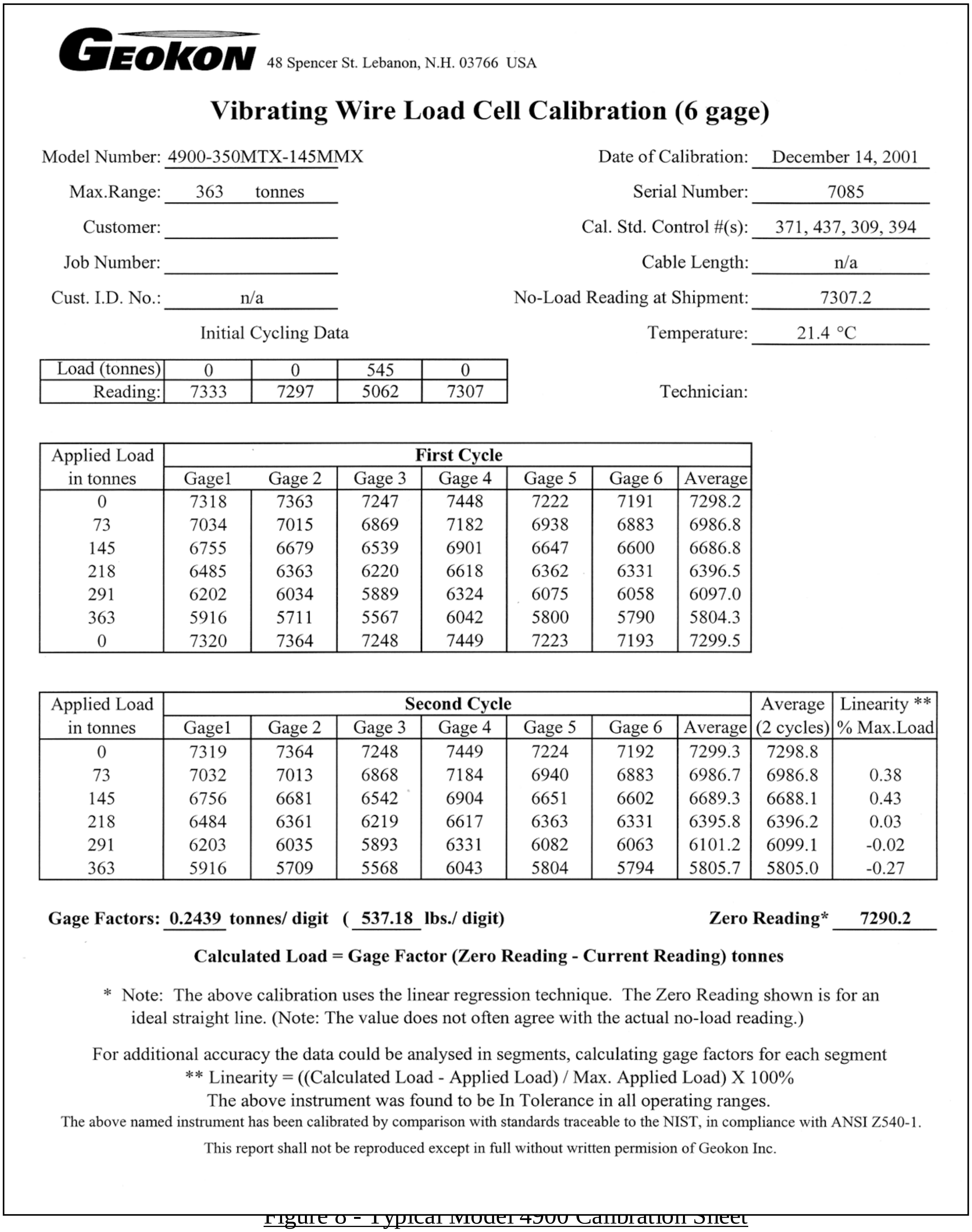
4.2. Temperature Correction Factor

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 1.5 digits per °C . So the load, corrected for temperature, would be

$$\mathbf{L = G\ [\ (R_0 - R_1) -1.5\ (T_0 - T_1)\ ]\ x\ K}$$

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, N.H. 03766 USA

Vibrating Wire Load Cell Calibration (6 gage)

Model Number:	4900-350MTX-145MMX	Date of Calibration:	December 14, 2001
Max.Range:	363 tonnes	Serial Number:	7085
Customer:		Cal. Std. Control #(s):	371, 437, 309, 394
Job Number:		Cable Length:	n/a
Cust. I.D. No.:	n/a	No-Load Reading at Shipment:	7307.2
		Temperature:	21.4 °C
		Technician:	

Initial Cycling Data

Load (tonnes)	0	0	545	0
Reading:	7333	7297	5062	7307

Applied Load in tonnes	**First Cycle**						
	Gage1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Average
0	7318	7363	7247	7448	7222	7191	7298.2
73	7034	7015	6869	7182	6938	6883	6986.8
145	6755	6679	6539	6901	6647	6600	6686.8
218	6485	6363	6220	6618	6362	6331	6396.5
291	6202	6034	5889	6324	6075	6058	6097.0
363	5916	5711	5567	6042	5800	5790	5804.3
0	7320	7364	7248	7449	7223	7193	7299.5

Applied Load in tonnes	**Second Cycle**							Average	Linearity **
	Gage1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Average	(2 cycles)	% Max.Load
0	7319	7364	7248	7449	7224	7192	7299.3	7298.8	
73	7032	7013	6868	7184	6940	6883	6986.7	6986.8	0.38
145	6756	6681	6542	6904	6651	6602	6689.3	6688.1	0.43
218	6484	6361	6219	6617	6363	6331	6395.8	6396.2	0.03
291	6203	6035	5893	6331	6082	6063	6101.2	6099.1	-0.02
363	5916	5709	5568	6043	5804	5794	5805.7	5805.0	-0.27

Gage Factors: 0.2439 tonnes/ digit (537.18 lbs./ digit) **Zero Reading* 7290.2**

Calculated Load = Gage Factor (Zero Reading - Current Reading) tonnes

* Note: The above calibration uses the linear regression technique. The Zero Reading shown is for an ideal straight line. (Note: The value does not often agree with the actual no-load reading.)

For additional accuracy the data could be analysed in segments, calculating gage factors for each segment
** Linearity = ((Calculated Load - Applied Load) / Max. Applied Load) X 100%
The above instrument was found to be In Tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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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]	3 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, Red 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=9.5 mm (0.375")

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:

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

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 Vibrating Wire 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, (see calibration sheet page 14) 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.

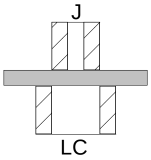
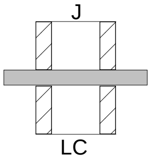
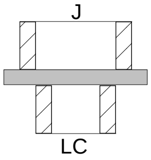
This bending is particularly apparent if there is a mismatch in size between the load cell and the hydraulic jack. If the hydraulic jack is larger than the load cell there is a tendency for it to try to wrap the intervening bearing plate around the load cell. If the hydraulic jack is smaller than the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

Report on Recent Testing

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;

75 ton capacity................ 1.5" thick
200 ton capacity.............. 2.5" thick
350 ton capacity.............. 3.0" 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.

Acceptance criteria for the service behaviour of ground anchorages

by G. S. LITTLEJOHN*, BSc(Eng), PhD, CEng, FICE, MIStructE, FGS

1. Introduction

WHILST DEGREE OF proof loading and acceptable limits for load-extension behaviour are generally in close agreement throughout the world, by contrast acceptance criteria related to service behaviour are widely divergent in regard to duration of monitoring, and whether load relaxation or creep displacement should be monitored.

Engineers in countries such as Britain, USA, South Africa and Australia tend to favour relaxation criteria, e.g. a prestress loss of up to 5% in 24 hours (Britain), whereas in South America, Continental Europe and Eastern Block countries, engineers prefer creep criteria, e.g. a creep displacement of up to 4mm in 72 hours (France), or a creep rate of less than 0.135mm/m of free tendon for every tenfold increase in time (Czechcslovakia). All these criteria have been used as upper thresholds of acceptability in practice, but it is widely recognised by the specialists concerned that the figures are arbitrary in nature and often incompatible except for a specific free tendon length, cross-sectional area and elastic modulus.

For economic as well as operational reasons the time involved in stressing and testing anchorages on a construction site should be minimised. Thus many engineers have attempted to classify ground which is susceptible to creep, e.g. fine grained as opposed to coarse grained soils in DIN 4125, in order to reduce the period of monitoring down to 1 hour. Since these particle size distinctions are not always reliable for this purpose, a standard sequence of time intervals is ideally required so that only the behaviour of the anchorage dictates the overall period of monitoring and not a prior judgement of the type of ground.

This Paper discusses the interpretation of short-term service behaviour in relation to on-site suitability and routine acceptance tests, with the objective of recommending universally applicable criteria based on load relaxation or an equivalent creep displacement. In addition, it is suggested that short duration acceptance tests of less than 1 hour are possible provided that the accuracy of the monitoring equipment is sufficient to record a trend towards stabilisation.

On-Site Suitability Tests are carried out on anchorages constructed under identical conditions as the working anchorages and loaded in the same way to the same level. The period of monitoring should be sufficient to ensure that prestress or creep fluctuations stabilise within tolerable limits. These tests indicate the results which should be obtained from the working anchorages.

Routine Acceptance Tests are carried out on every anchorage and demonstrate the short-term ability of the anchorage to support a load which is greater than the design working load and the efficiency of load transmission to the fixed anchor zone. A proper comparison of the short-term results with those of the On-Site Suitability Tests provides a guide to longer term behaviour.

2. General proposals

For the service monitoring of complete anchorages as part of On-Site Suitability Testing the period of observation should be long enough to provide a predictive capacity for long-term service behaviour. With this background of information equivalent monitoring under Acceptance Testing need only confirm progressive stabilisation and a similar pattern in the short term as that indicated by the On-Site Suitability Tests.

Both load relaxation and creep displacement are important but load is proposed as the major parameter to be monitored since anchorages are designed for structural purposes in the main and working loads with load safety factors are specified. Thus the client or engineer is concerned if load reduces. In addition, load is relatively simple to monitor and also sensitive to fixed anchor displacement, so that both parameters can be measured, creep indirectly. Thus, for a typical tendon having a free length of 10m, a working stress of 1kN/mm² and a Young's modulus of 200kN/mm², a 3mm change of extension is equivalent to a 6% change of load. For a time interval of 1 day it is noteworthy that both these figures are similar to arbitrary limits which are already established in practice (Littlejohn & Bruce, 1977).

It is further proposed that the time intervals are based on Δt equal to 5 minutes, and a sequence of Δt, $3\Delta t$, $10\Delta t$, $30\Delta t$, $100\Delta t$, etc. (Huder, 1978). These intervals may permit short-term acceptance testing of 50 minutes if accurate monitoring ($< 1\%$) is applied, and for each interval a single relaxation or creep criterion can be established which will automatically ensure stabilisation. In such a case the readings when plotted against log time will give a straight line. Whilst the duration of the test and the intermediate time intervals proposed are based on field experience and simplicity, the recommendations should not preclude different observation periods provided that sufficient data are accumulated to permit an accurate assessment of service performance in relation to the acceptance criteria.

A 6% load loss figure is specified in Table I at 1 day based on proximity to current practice, and for the time intervals recommended the rate of prestress loss should reduce to 1% initial residual load or less before the period of monitoring is terminated.

TABLE I. ACCEPTANCE CRITERIA FOR RESIDUAL LOAD-TIME BEHAVIOUR

Period of observation (minutes)	Permissible loss of load (% initial residual load)
5	1
15	2
50	3
150	4
500	5
1 500 (say 1 day)	6
5 000 (say 3 days)	7
15 000 (say 10 days)	8

As an alternative to monitoring load relaxation, the creep displacement criteria of Table II are proposed, where 1% Δ_e is the displacement equivalent to the amount of tendon shortening caused by a prestress loss of 1% of initial residual load:

$$\Delta_e = \frac{\text{initial residual load} \times \text{free tendon length}}{\text{area of tendon} \times \text{elastic modulus of tendon}}$$

Based on these concepts the following recommendations are presented for On-Site Suitability Tests and routine Acceptance Tests.

3. On-Site Suitability Tests

3.1 General

Provision should be made within the terms of a contract for on-site tests to prove the suitability of the anchorages for the conditions on site.

They should be constructed in exactly the same way and located in the same ground as the working anchorages and should be used as standards against which the performance of the working anchorages can be judged.

At least the first three anchorages should be subjected to Suitability Tests

TABLE II. ACCEPTANCE CRITERIA FOR DISPLACEMENT-TIME BEHAVIOUR AT RESIDUAL LOAD

Period of observation (minutes)	Permissible displacement (% of elastic extension, Δ_e, of tendon at initial residual load)
5	1
15	2
50	3
150	4
500	5
1 500 (say 1 day)	6
5 000 (say 1 days)	7
15 000 (say 10 days)	8

---

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TABLE III. RECOMMENDED LOAD INCREMENTS AND PERIODS OF OBSERVATION FOR ON-SITE SUITABILITY TESTS

Temporary anchorages		Permanent anchorages		Period of observation (minutes)
Load increment (% T_w)		Load increment (% T_w)		
1st load cycle*	2nd & 3rd load cycles	1st load cycle*	2nd & 3rd load cycles	
20	20	20	20	5
	40		40	5
50	60	50	60	5
	80		80	5
100	100	100	100	5
	120		120	5
			140	5
125	125	150	150	15
100	100	100	100	5
50	50	50	50	5
20	20	20	20	5

*For this load cycle there is no pause other than that necessary for the recording of extension data.

with further tests for each category of anchorages envisaged in the works. Anchorages are categorised by (*a*) geometry, e.g. vertical or inclined, and (*b*) ground type, e.g. clay, or gravel.

3.2 Proof loads

The maximum proof load should generally be 125% T_w and 150% T_w for temporary and permanent anchorages, respectively, where T_w is the working load of the anchorage.

3.3 Load-extension data

Load-extension data should be plotted continuously over the range 20 to 125% T_w for temporary anchorages (20 to 150% T_w for permanent anchorages) with load increments not greater than 20% T_w where extensions are being carefully monitored. During unloading, extensions at not less than two load decrements in addition to datum, should be measured preferably occurring at one third points with respect to the proof load (Table III).

Each stage loading in the 2nd and 3rd cycles should be held for at least 5 minutes and the extension recorded at the beginning and end of each period. For proof loads this period is extended to at least 15 minutes with an intermediate extension reading at 5 minutes. On completion of the 3rd load cycle, reload in one operation to 110% T_w and lock-off. Re-read the load immediately after lock-off to establish the initial residual load. This moment represents zero time for monitoring load/displacement-time behaviour (**3.6**, **3.7**).

3.4 Proof load-time data

If the proof load has not reduced during the 15 minutes by more than 5% after allowing for any temperature changes, and movements of the anchored structure, the anchorage may be deemed to have satisfied this stage. If a greater loss of prestress is recorded, this should be investigated and a diagnosis recorded.

3.5 Displacement-time data at proof load

As an alternative to **3.4** the proof load can be maintained by jacking and the anchor head displacement monitored after 15 minutes. If the creep is less than 5% Δ_e the anchorage may be deemed to have satisfied this stage.

If a greater displacement is recorded, this should be investigated and a diagnosis recorded.

3.6 Residual load-time data

Load-time data should be monitored commencing at 110% T_w and continuing for 10 days with observation periods in accordance with Table I and using either load cells or grade *A* pressure gauges.

Where the load has not attained a constant value after allowing for temperature, structural movements and relaxation of the tendon, the above test should be extended by monitoring at 7-day intervals approximately for a period up to 30 days or until the load becomes constant, whichever is the lesser period.

Readings within the first 1 500 minutes should only be attempted where the monitoring equipment has a relative accuracy* of at least 0.5%. Where the monitoring involves a stressing operation, e.g. lift-off check without load cell, an absolute accuracy† less than 5% is unlikely and the observation periods are 1, 3 and 10 days, although more frequent observations may be made if considered appropriate.

Where the loss of load is monitored accurately the rate of loss from the initial residual load should reduce to 1% or less per time interval for the observation periods (Table I). Alternatively, where less accurate monitoring is applied, losses should not exceed 6%, 7% or 8% of initial residual load at 1, 3 and 10 days, respectively. For prestress gains see **4.10**.

3.7 Displacement-time data at residual load

As an alternative to **3.6** displacement-time data may be monitored commencing at 110% T_w and continuing for 10 days with observation periods in accordance with Table II and using dial gauges or steel rule.

Where the displacement has not reached a constant value after allowing for temperature, structural movements and creep of the tendon, the above test should be extended by monitoring at 7 day intervals approximately for a period up to 30 days or until the displacement becomes constant, whichever is the lesser period.

Restressing or constant load methods may be used to monitor the displacement at initial residual load. At each monitoring period the anchorage may be restressed and the increment of tendon displacement (ram extension may be sufficient if the bearing plate is fixed) to regain the lock-off load (initial residual load) is recorded after which the stressing load is released. Alternatively, the load can be held constant with the aid of the jack pump and the displacement of the tendon with time may be measured direct (Fig. 1). This method is particularly suited to short duration testing. In both cases, however, the datum for the displacement readings, e.g. bearing plate for restressing system or the tripod base (Fig. 1) for the constant load system, should be surveyed accurately for movement, otherwise the displacement readings may be erroneous.

Rate of displacement should reduce to 1% Δ_e or less per time interval for the observation periods in Table II.

Where less accurate monitoring is applied, displacement should not exceed 6% Δ_e, 7% Δ_e or 8% Δ_e at 1, 3 and 10 days, respectively.

3.8 Number of load or displacement measurements

In order to minimise errors, particularly where a restressing operation is involved without a load cell, e.g. at 1, 3 and 10 days, each reading for **3.6** or **3.7** should be taken at least three times and the results averaged.

3.9 Final lock-off

If the anchorages are to be used in the works, and on completion of the on-site suitability test the cumulative relaxation or creep has exceeded 5% initial residual load or 5% Δ_e respectively, the anchorage should be restressed and locked-off at 110% T_w.

4. On-Site Acceptance Tests

4.1 General

Every anchorage used on a contract should be subjected to an acceptance test in accordance with **4.2-4.7** with the exception of low capacity tensioned rock bolts used in secondary reinforcement,

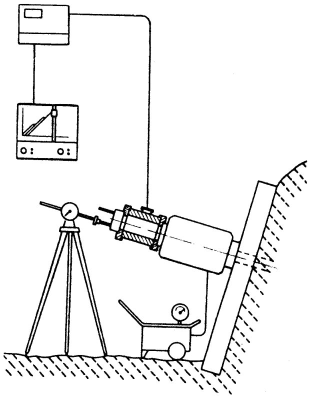

Fig. 1. Typical method of measuring tendon displacement using a dial gauge

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* *Relative accuracy* refers to the deviation from the measured va'ue, i.e. the error in measurement where small changes in load or displacement are monitored against time.

† *Absolute accuracy* is the deviation from the true va'ue, i.e. where the measuring instruments have been calibrated against dead weight apparatus or loading machines and the accuracy is known.

where the anchorage may be loaded to the proof load (**3.2**), checked for fixed anchor displacement and then locked off at 110% T_w. For guidance the permanent fixed anchor displacement should not exceed 20mm and 5mm for mechanical anchorages, e.g. expansion shell, and straight shaft anchorages, e.g. cementitious or resin cartridge, respectively, otherwise an investigation as to the cause and need for additional anchorages should be undertaken.

4.2 Proof loads

The maximum proof load should be in accordance with **3.2**.

4.3 Load-extension data

Load-extension data should be plotted continuously over the range 20 to 125% T_w for temporary anchorages (20 to 150% T_w for permanent anchorages) using load increments not more than 25% T_w where extensions are being carefully monitored. During unloading, extensions at not less than two load decrements, in addition to datum, should be measured preferably occurring at one-third points with respect to proof loads (Table IV).

Each stage loading in the 2nd cycle should be held for at least 5 minutes and the extension recorded at the beginning and end of each period. For proof loads this period is extended to at least 15 minutes, with an intermediate extension reading at 5 minutes.

On completion of the 2nd load cycle, reload in one operation to 110% T_w and lock-off. Re-read the load immediately after lock-off to establish the initial residual load. This moment represents zero time for monitoring load/displacement-time behaviour.

4.4 Proof load-time data

The proof load-time data should be in accordance with **3.4**.

4.5 Displacement-time data at proof load

The displacement-time data should be in accordance with **3.5**.

4.6 Residual load-time data

Using accurate monitoring equipment the residual load may be monitored at 5, 15 and 50 minutes.

If the rate of load loss reduces to 1% or less per time interval for the specific observation periods above after allowing for temperature, structural movements and relaxation of the tendon in accordance with the manufacturer's data, the performance of the anchorage is satisfactory. If the rate of load loss exceeds 1%, further readings may be taken at observation periods up to 10 days (Table I).

Alternatively, where less accurate monitoring is applied, e.g. lift-off check without load cell, if the total loss at 1 day does not exceed 6% of initial residual load the performance of the anchorage is satisfactory. If the load loss exceeds 6%, further observations may be taken at 3 days, and if necessary at 10 days, when the total loss should not exceed 7% or 8% respectively.

If, after 10 days the anchorage fails to hold its load in accordance with Table II, the anchorage should be deemed to have failed.

Following an investigation as to the cause of failure and dependent upon the circumstance the anchorage should be (*i*) abandoned and replaced, (*ii*) reduced in capacity, or (*iii*) subjected to a remedial restressing programme (**4.10**).

4.7 Displacement-time data at residual load

As an alternative to **4.6** displacement-time data may be obtained at the specific observation periods of **4.6**. Restressing or constant load methods may be used to monitor the displacement at initial residual load (**3.7**).

Using accurate monitoring equipment, if the rate of displacement reduces to 1% Δ_e or less per time interval for the observation periods 5, 15 and 50 minutes, after allowing for temperature, structural movement and creep of the tendon in accordance with the manufacturer's data, the performance of the anchorage is satisfactory. If the rate of displacement exceeds 1% Δ_e, further readings may be taken at observation periods up to 10 days (Table II).

Where less accurate monitoring is applied, e.g. lift-off check without load cell, if the total displacement at 1 day does not exceed 6% Δ_e, the performance of the anchorage is satisfactory. If the displacement exceeds 6% Δ_e, further observations may be taken at 3 days, and if necessary at 10 days, when the total displacement should not exceed 7% Δ_e or 8% Δ_e respectively.

If after 10 days the anchorage fails to hold the displacement in accordance with Table II the anchorage should be deemed to have failed, and subsequent actions should be in accordance with **4.6**.

4.8 Final lock-off

On completion of the acceptance test, if the cumulative relaxation or creep exceeds 5% initial residual load or 5% Δ_e, respectively, the anchorage should be restressed and locked-off at 110% T_w.

TABLE IV. RECOMMENDED LOAD INCREMENTS AND PERIODS OF OBSERVATION OF ON-SITE ACCEPTANCE TESTS

Temporary anchorages		Permanent anchorages		Period of observation
Load increment (% T_w)		Load increment (% T_w)		
1st load cycle*	2nd load cycle	1st load cycle*	2nd load cycle	(minutes)
20	20	20	20	5
50	50	50	50	5
	75		75	5
100	100	100	100	5
			125	5
125	125	150	150	15
100	100	100	100	5
50	50	50	50	5
20	20	20	20	5

*For this load cycle there is no pause other than that necessary for the recording of extension data

4.9 Interaction of anchorages

Where fixed anchors are closely spaced, e.g. less than 1m, or anchor heads are located on a single waling or structural unit, or a group of anchorages ties back a re-entrant corner, interaction between anchorages may occur during stressing and subsequent service. When testing an isolated anchorage in such circumstances it may be prudent to check adjacent anchorages during the same period, preferably one day, even if an acceptance test has already been carried out on some of the anchorages in question (Littlejohn & Macfarlane, 1974).

4.10 Remedial action for failed anchorages

Where an anchorage fails at the ground/grout interface, a first estimate of the new load may generally be taken as the maximum load at failure divided by 1.6 or 2.0 for temporary and permanent anchorages, respectively.

Where the anchorage has passed its proof-loading and failure is solely related to the relaxation or creep criterion (**4.6** or **4.7**) a provisional reduction divisor of 1.2 is tentatively recommended in the absence of field data at the present time, and service monitoring should be repeated at the new reduced load in accordance with **4.6** or **4.7**.

Where a remedial stressing programme is considered appropriate, the initial residual load (110% T_w) is regained by stressing, and service monitoring (**4.6** or **4.7**) is repeated. This principle has been applied successfully in stiff/hard clay where the preliminary stress history provides a preloading effect (Littlejohn, 1970) thereby consolidating the ground local to the fixed anchor, which in turn gives an enhanced performance during subsequent service.

Where prestress gains are recorded monitoring should continue to ensure stabilisation of prestress within a load increment of 10% T_w. Should the gain exceed 10% T_w a careful diagnosis is required to ascertain the cause and it will be prudent to monitor the overall structure/ground/anchorage system. If, for example, overloading progressively increases due to insufficient anchorage capacity in design or failure of a slope, then additional support is required to stabilise the overall anchorage system. Destressing to working load values should be carried out as prestress values approach proof loads, e.g. 120% and 140% T_w in the case of temporary and permanent anchorages, respectively, accepting that movements may continue until additional support is provided.

5. Relationship between relaxation and creep acceptance criteria

Table V illustrates by worked example the relationship between the acceptance criteria for load-time (Table I) and displacement-time (Table II), and their respective sensitivities to initial residual load (100kN and 1 000kN) and free tendon length (5m, 10m and 20m) for observation periods of 5 min, 15 min, 50 min and 1 500 min (say 1 day).

Tendon details:

Nominal area of single strand = 100mm^2
Elastic modulus = 200kN/mm^2
Initial residual load (1 strand) = 100kN
Initial residual load (10 strands) = 1 000kN

TABLE V. RELATIONSHIP BETWEEN LOAD-TIME AND DISPLACEMENT-TIME ACCEPTANCE CRITERIA

Period of observation (minutes)	Free tendon length (metres)	Limiting loss of load		Limiting creep displacement	
		Single strand (kN)	Ten strands (kN)	Single strand (mm)	Ten strands (mm)
5	5	1	10	0.25	0.25
	10	1	10	0.5	0.5
	20	1	10	1	1
15	5	2	20	0.5	0.5
	10	2	20	1	1
	20	2	20	2	2
50	5	3	30	0.75	0.75
	10	3	30	1.5	1.5
	20	3	30	3	3
1 500	5	6	60	1.5	1.5
(1 day, say)	10	6	60	3	3
	20	6	60	6	6

For the common range of free tendon lengths quoted either acceptance criterion may be applied quite independently. For short free tendon lengths (< 5m), rate of prestress loss becomes the more appropriate criterion, whilst for long free tendon lengths (> 30m) it is clear that rate of displacement is the more important parameter to limit and therefore more appropriate as an acceptance criterion. To take account of free tendon length in the example quoted, a single creep criterion of 0.05mm/m of free tendon length per time interval would be appropriate. On some contracts with a wide variety of tendon lengths it may be more convenient to specify a limiting creep criterion in such units.

6. Stressing and monitoring equipment

6.1 General

As a consequence of reducing the period of monitoring for acceptance tests, more accuracy and control are required on site, which implies careful choice of appropriate equipment and regular calibration.

6.2 Stressing equipment

Stressing equipment for wire, bar and strand tendons should preferably tension the whole of the tendon in one operation. However, both single unit and multi-unit operations are used in practice.

The design of the jack should permit the tendon elongation at every stage to be measured to an accuracy appropriate for the test requirements. Accuracy of reading may be as low as ± 0.2mm for short duration (< 1 hour) testing of rate of relaxation or creep but for conventional proof-loading cycles or long duration testing (> 1 day), an accuracy of ± 1mm should normally be sufficient.

Hydraulic pumps should be rated to operate through the pressure range of the stressing jack. The controls of the pump should allow the tendon extension to be easily adjusted to the nearest millimetre whether the jack is opening or closing. The pressure gauge should be mounted such that it is reasonably free of vibration during pumping.

6.3 Load cells

Where the basic characteristics of a load cell are being established by the manufacturer, consideration should be given to the following series of tests in order to simulate the service conditions to which the load cell may be subjected, e.g. eccentric loading effects (McLeod & Hoadley, 1974).

- (*i*) Routine calibration using centric loading and rigid flat platens at 20°C, say.
- (*ii*) As in (*i*) but using (*a*) concave inclined platens, (*b*) convex inclined platens and (*c*) 0.3mm sheets with irregular spacing to simulate uneven bedding (Fig. 2).
- (*iii*) Eccentric loading between rigid flat plates, with eccentric distance up to 10% cell diameter.
- (*iv*) If torsion is anticipated during service, an appropriate torque should be applied during a test between rigid flat platens to gauge the effect.
- (*v*) Inclined platens up to 1° with centric loading.
- (*vi*) On completion of the appropriate series of tests, the cell should finally be subjected to a repeat routine calibration (*i*).

For routine calibration the load cell should be delivered to the laboratory at least one day before the test to permit sufficient time for the cell to attain the correct ambient temperature (20°C). The cell should be subjected to centric loading between rigid flat platens using a testing machine with an absolute accuracy not exceeding 0.5%.

Bearing in mind that the load cell may not have been used for some time, it may be prudent to load cycle the cell two or three times over its full loading range until the zero and maximum readings are consistent. The load increments and decrements should not exceed 10% of the cell's rated capacity and short pauses at these intervals need only be long enough to take careful readings.

To measure the specific effects of temperature, a centric loading test using rigid flat platens should be carried out at temperatures above and below ambient (20°C), say 40°C and 0°C, respectively.

For each individual test the absolute accuracy should be monitored. Where a worst combination of circumstances is envisaged this situation should be simulated since the total error is not necessarily the sum of the individual errors.

The information created from the series of tests above should be compiled into a basic specification, together with any long-term stability results. In addition a recommended operating range should be indicated, e.g. 10-100% of rated capacity.

The resolution of the read-out equipment should be appropriate for the accuracy specified, and accuracies down to 1-10kN are available. Wherever possible read-out equipment should be calibrated along with the load cell.

Load read-out or recording instruments should not have more than 10m of electrical cable and should be calibrated with the actual cable to be used on site. The instrument should be provided with input voltage indicators whether mains or battery operated.

6.4 Frequency of calibration

Jacks should be calibrated at least every year using properly designed test equipment with an absolute accuracy not exceeding 0.5% and the test records should tabulate the relationship between the load carried by the jack and the hydraulic pressure when the jack is in the active mode with load both increasing and decreasing.

The jack calibration should be checked prior to the start of tensioning on each contract and a calibration curve prepared for each jack.

The calibration should extend from zero over the full working range of the jack and should be established for the opening (load rising) and closing (load falling) operation of the jack so that the friction hysteresis can be known when repeated

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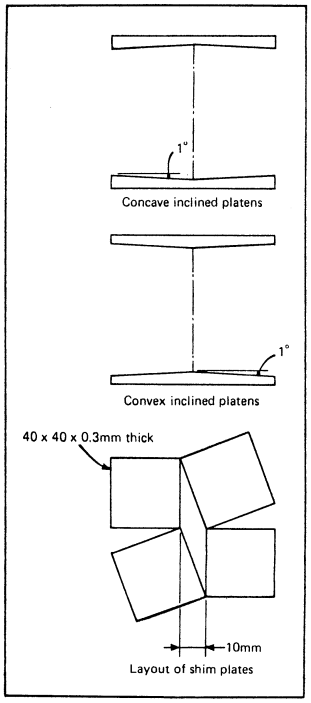

Fig. 2. Typical types of platen to simulate uneven bedding

Acceptance criteria for ground anchors

(concluded from page 29)

loading cycles are being carried out on the tendon.

Pressure gauges should be calibrated either every 100 stressings or after every 30 days, whichever is the more frequent, against properly maintained Class *A* gauges, or whenever they have been subjected to shock. If a group of three gauges is employed in parallel this frequency of calibration does not apply.

Load cells should be calibrated every 200 stressings or after every 60 days use, whichever is the more frequent, unless complementary pressure gauges used simultaneously indicate no significant variation, in which case the interval between calibrations may be extended up to a maximum of one year when a routine calibration should be carried out using properly designed test equipment with an absolute accuracy not exceeding 0.5%.

7. Final remarks

During acceptance testing of production anchorages one of the prime objectives is to ensure that the service load locked-off after stressing is stable.

The alternative methods employed in practice of monitoring rate of load relaxation or rate of creep displacement are made compatible in these proposals, and a standard series of time intervals is recommended when monitoring either parameter.

The shorter the time scale the greater the accuracy of measurement required. Where a relative accuracy of 0.5% can be provided the minimum period of monitoring is 50 minutes c.f. one day for simple lift-off checks.

To give a background of service behaviour against which to judge the performance of production anchorages, at least three On-Site Suitability Tests are recommended where accurate high frequency testing over a period of hours is combined with a minimum overall period of observation of 10 days.

It is hoped that this routine collection of data related to relaxation or creep for different types of ground and anchorage load and geometry will improve understanding of the service behaviour of anchorages and lead to improved design procedures in future. In the short term such data can establish that overload allowances applied to the working load at initial lock-off are adequate. At the present time an overload of 10% T_{10} is commonly applied which appears to be realistic in most cases.

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