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Instruction Manual

Model 3000

Load Cell

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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 crosslot struts and 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 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.
- ⇒ As a check on the load as determined by the hydraulic pressure applied to the jack during proof-testing on tiebacks, rockbolts, etc. **For this purpose the user should be aware that because of the many variables the agreement cannot be guaranteed better than +/-20%.**

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 plate for permanent installations or above the anchor plate for proof-testing. Figures 1 and 2 show the two different installations.

1.2. Load Cell Design and Construction

The Model 3000 Load Cell is made from an annulus of high strength steel or aluminum. Electrical resistance strain gages are cemented around the outside of the annulus and connected in a Wheatstone Bridge circuit. Half the gages measure vertical strains; half the gages measure circumferential strain. Typical specifications are given in Appendix A. Appendix B illustrates typical wiring diagrams. Note that the GK-501 Readout Box uses a remote sensing technique to reduce the cable effects. This means that Load Cells for use with the GK-501 have 6 conductor cables (3 individually shielded twisted pairs). See Appendix B for connector wiring.

An outer shell protects the gages from damage and 'O'-rings on either side of the gages ensure that the load cell is fully waterproof. Figure 3 shows a typical load cell.

The cable is attached to the cell through a 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 either a GK-501 Readout Box manufactured by Geokon or a Model P3 Strain Indicator Box manufactured by Vishay which, when adjusted to "Full Bridge", a gage factor of 1.000 and a balance position of 5.00,

gives the same reading as the GK-501. Alternatively the P3 can be set up to readout directly in engineering units – ponds, tons, kips, etc,

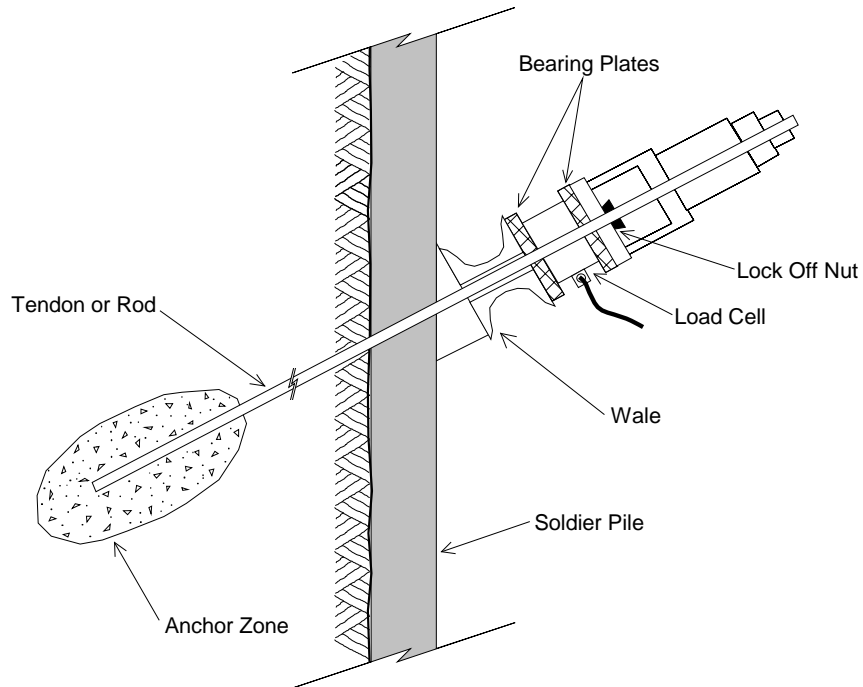


Figure 1 - Load Cells on Tiebacks for the Permanent Monitoring of Loads

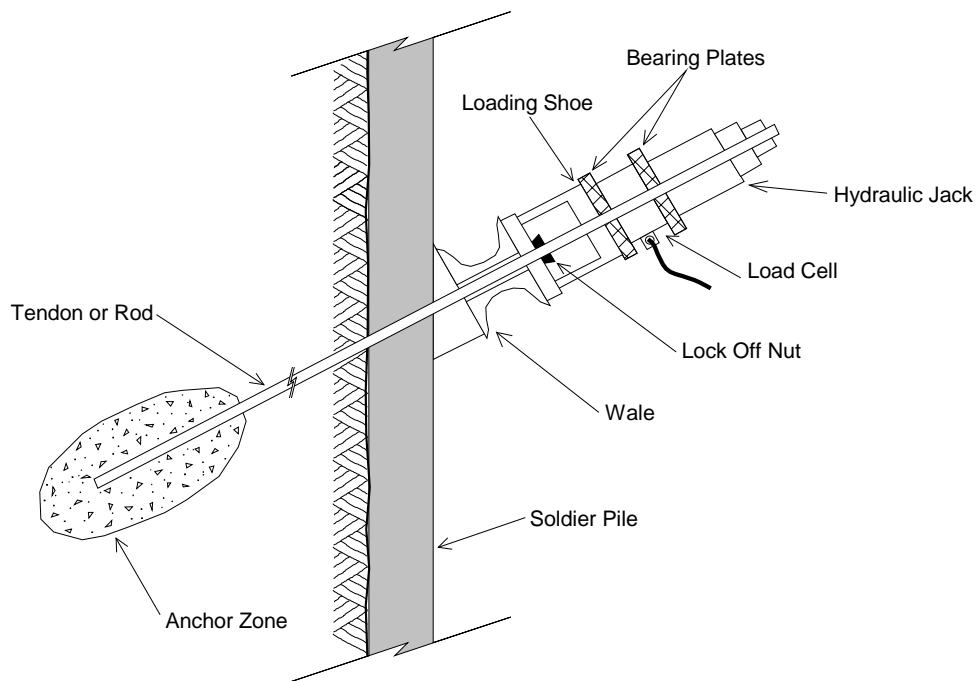


Figure 2 - Load Cells On Tiebacks For Proof Testing Only

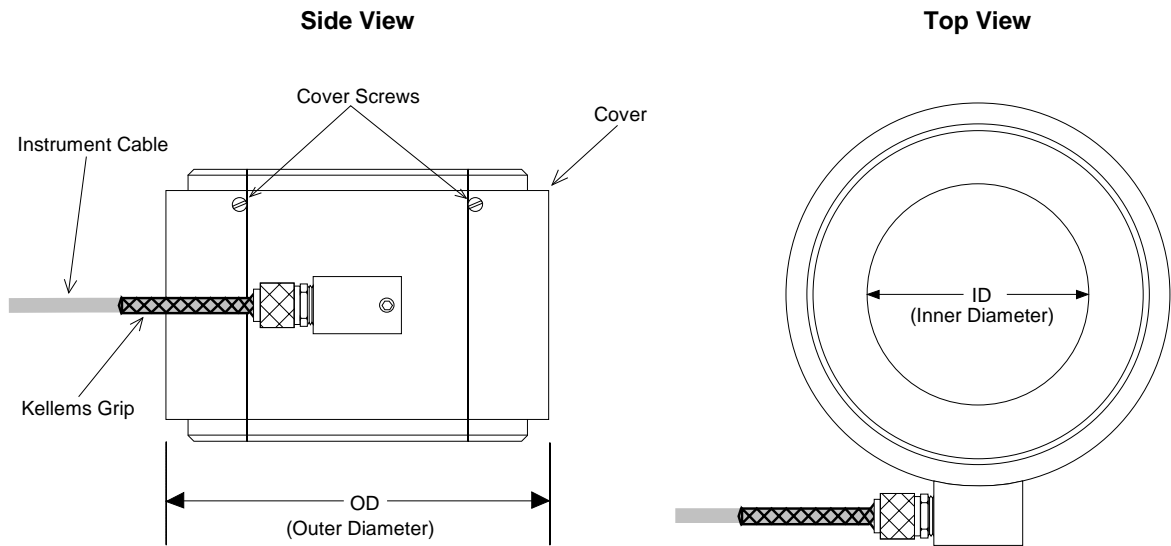


Figure 3 - Model 3000 Load Cell

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

Figure 4 shows a typical load cell system.

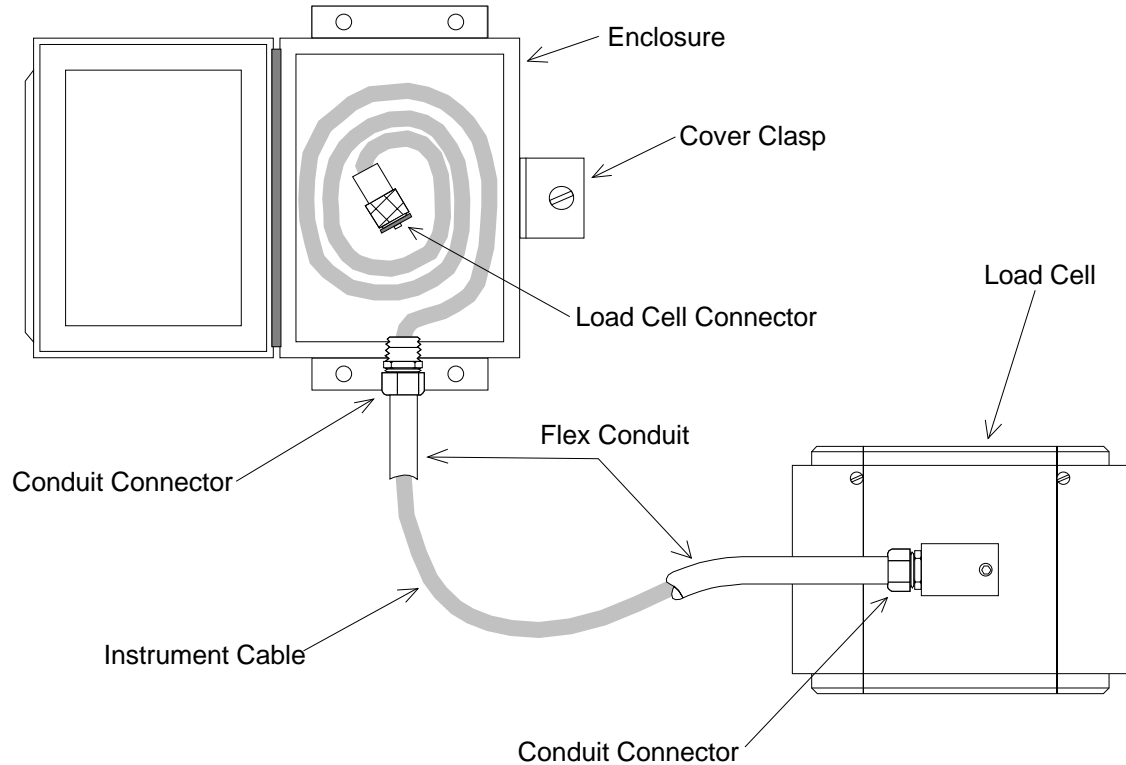


Figure 4 - Typical Load Cell System

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 calibration can vary by as much as $\pm 20\%$** , 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 which 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.

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 will 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 individual electrical resistance strain gages, cemented to the cell, being connected together in a full Wheatstone Bridge circuit. 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 cause only slight ($< \pm 5\%$) variations in the load cell output and calibration. This is certainly an attractive feature of the electrical resistance type load cell.

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

It is important that a load cell behave elastically, i.e. that the no-load zero will not change with time. This can be achieved in two ways. First, it is important to use only the highest quality strain gages and adhesives. Geokon uses transducer grade strain gages along with scrupulous observation of the best installation practices and adhesive post curing techniques.

Geokon Model 3000 Load Cells are designed so as to keep the normal working stresses below 50% 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 of an aluminum load cell is 200% and for a steel load cell 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. 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). At the same time a reading should be taken of the reference standard when plugged into the readout box. A reference standard is provided with all Geokon Load Cell Readout Boxes; it is located inside the lid. With the Geokon GK-501 Readout Box, plug the standard in and take a reading. With the Vishay Model P3 Strain Indicator, follow the instructions of the Model P3 manual to obtain the output in engineering units or, set the gage factor to 1.00 and the balance control to 5.00. These controls should always be left in these positions. Take note of the reference standard reading for future reference. The reading of this standard should not vary with time and provides a means of checking the stability of the readout box. It also provides a means of going from one readout box to another in the event that this is necessary. All load cell users should ensure that such a reference standard is kept on hand at all times and is used in the manner suggested.

If the readout box is changed during the period that the load cell is being read out, then this may entail some apparent change in the load cell readings. Geokon's GK-501 and Vishay P3 Readout Boxes are manufactured to close tolerances, and all readout boxes of this types will give practically the same readings with the standard plugged in. The magnitude of the change can be determined by first plugging the reference standard into the old box, and then into the new box, the difference in the readings will provide a measure of the correction which must be applied to all the load cell readings taken by the new readout box.

Note that the Vishay Model P3 Strain Indicator can also be made to give the readout directly in engineering units, i.e., kips or tons etc. Follow the instructions that are supplied by Vishay.

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 GK-501 and Vishay P3 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. The normal rolled finish on the plates is good. Plates may need to be machined flat if they are warped. Make sure that the bearing plates completely cover the load bearing surface of the load cell. Centralize the rockbolt or tie-back inside the load cell. Where the load cell I.D. is much bigger than the rockbolt or tie-back, a centralizer bushing can be used.

Where the anchor block of a multi-tendon tie-back 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 4 shows a typical load cell system.

3. TAKING READINGS

3.1. Using the Geokon GK-501 Readout Box

The user is referred to the GK-501 Instruction Manual for additional information on the following instructions: The GK 501 readout box displays $mV/V \times 4000$

1. Connect the load cell to the readout box by means of the 10 pin input connector.
2. Switch the power switch to the "ON" position.
3. Switch the selector switch to the "x1" position.
4. Read the display and record.
5. If the applied load is so high that the display recording goes above 19,999 then move the selection switch to x 0.5" and read the display. When recording the data, remember to multiply the reading by 2.
6. See the GK-501 Instruction Manual for further instructions.

3.2. Using the Vishay Micro-Measurements P3 Readout Box

Follow the instructions of the P3 manual, as described in Appendix E, to obtain the displayed output directly in engineering units.

Setting the gage factor to 1.000 will cause the P3 readout box to display the same units as the GK501.

4. DATA REDUCTION

4.1. Load Calculation when reading the output in digits on the GK501

The basic units utilized by Geokon for measurement and reduction of data from Model 3000 Load Cells when read using the GK501 readout box are "digits". The calculation of digits is based on the following equation;

$$\text{Digits} = \text{mV/V} \times 4000$$

Equation 1 - Digits Calculation

Where; mV is the output of the Wheatstone bridge circuit in millivolts.
V is the excitation supplied to the Wheatstone bridge circuit in volts.

Load is calculated from digits by determining a change in reading (in digits) and then multiplying by the appropriate calibration factor. See the following equation:

$$L = (R_1 - R_0) \times K \times CF$$

Equation 2 - Load Calculation Using Linear Regression

Where; L is the load in lbs. or kg.
R₀ is the initial no-load reading.
R₁ is the current reading.
K is the calibration factor as supplied on the Calibration Sheet (Figure 5).
CF 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 5.

From→ To↓	Lbs.	Kg.	Kips	Tons	Metric Tons
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 Tons	0.0004535	0.001	0.4535	0.907	1

Table 1 - Engineering Units Conversion Multipliers

For example, a Model 3000 has an initial no-load reading (R₀) of 2010 (see Figure 5) and a current reading (R₁) of 8498. The Calibration Factor is 15.15 lbs. per digit.

$$L = (8498 - 2010) \times 15.15 = 98,293 \text{ lbs.}$$

Note that the equations assume a linear relationship between load and strain readings, and the linear coefficient is obtained using regression techniques which may introduce a substantial non-linearity around the zero reading. 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 5, the load between 90,000 and 120,000 lbs. could be represented by the following equation;

$$L = ((8498 - 7953) \times 15.03) + 90,000 = 98,191 \text{ lbs.}$$

The gage factor 15.03 is calculated from the slope of the line between a load of 90,000 and 120,000, i.e.,

$$K = \frac{(120,000 - 90,000)}{(9949 - 7953)} = 15.03$$

Similarly, between a load of 0 and 30,000;

$$L = (R_1 - 2013) \times 15.38$$

A polynomial expression to fit the data would be:

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

Equation 3 - Load Calculation Using Polynomial

Where; L is the load in lbs. or kgms.
 R_1 is the current reading.
 A, B and C are the coefficients derived from the calibration data.
 CF is the conversion factor (optional) as listed in Table 1.

For example, a Model 3000 Load Cell has a current reading (R_1) of 8498. The polynomial coefficients, A, B and C are 0.000003528, 15.0999 and -30195.6, respectively.

$$L = 252.8 + 128,319.0 + -30195.6 = 98,376.2 \text{ lbs.}$$

4.2. Load Calculation when reading the output in millivolts.

When the output is measured in millivolts the power to the load cell must be a regulated voltage so that the mV/V output can be scaled properly. The excitation voltage must be measured at the load cell itself and this requires the 6 wire remote sensing circuit shown in appendix B. Then use the mV/V gage factor shown on the calibration sheet an example of which is shown in Figure 5.

For example, using the data from the calibration sheet. If the excitation voltage at the load cell is 2.5 volts and the measured output is 1.8mV the corresponding load is

$$825,886 \times (1.8/2.5) = 594,638 \text{ lbs}$$



48 Spencer St. Lebanon, N.H. 03766 USA

Load Cell Calibration Report

Model Number: 3000-1000-6 Calibration Date: August 19, 2008
 Max. Range (lbs.): 1,000,000 No-Load Reading at Shipment: -57
 Serial Number: 2546 Calibration Instruction: CI-3000GP
 Cable Length: 20 ft. Technician: *Jill Bellavance*

Initial Cycling Data

Load (lbs.):	0	0	1,200,000	0
Reading:	-55	-52	5716	-55

Calibration

Applied Load in lbs.	Readings from GK-501 readout box ***				Linearity ** % Max. Load
	Cycle 1	Cycle 2	Average	Change	
0	-52	-58	-55		-0.02
200,000	908	905	906	961	-0.21
400,000	1894	1889	1891	985	0.07
600,000	2875	2872	2873	982	0.31
800,000	3832	3835	3833	960	0.08
1,000,000	4787	4790	4788	955	-0.25
0	-52	-50			

*** or Vishay Micro-Measurements P3 readout box set to Gage Factor 1.0

Linear Gage Factor: 206.00 lbs./ digit **Regression Zero:*** -54

Calculated Load = Gage Factor (Current Reading - Regression Zero Reading) lbs.

Gage Factor: 825,886 lbs./ mV/ V **Output at Full Scale Load:** 1.211 mV/ V

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

** Linearity = ((Calc. Load - Applied Load) / Max. Applied Load) X 100%

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 5 - Model 3000 Calibration Sheet

5. TROUBLESHOOTING

5.1. Readouts

Problems with the readout box can be resolved by reading the standard reference plug. If the reading here is seen to change appreciably, this could be an indication of readout box instability. It is frequently advisable to have a back-up readout available. In any event, the readout box should be kept clean and dry at all times. Replace batteries as required and store the box in a warm dry place when not in use so that any moisture is driven from the interior as much as possible.

Both the GK-501 and P3 Readout Boxes have low battery voltage indicators. In the case of the GK-501 the batteries should be kept charged as per the instruction manual. In the case of the P3 the two 'D' size alkaline batteries should be changed following the instructions of the Model P3 manual.

Instability caused by electrical interference from nearby power lines, generators, welders, etc. can be minimized by making sure that the cable shield is connected to the readout box ground.

5.2. Load Cells

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 soldered, mechanically strong, 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 Aqua Seal (Cooper Power Systems Cat. No.104742-2 (pads) or 104742 (roll)), wrapped in vinyl tape, may be used to cover a splice.

Check the load cell wiring. The wiring diagram and pin-out are shown on pages 13 and 14. If the load cell is working properly the resistances between the various pins should be as follows:

For the larger load cells, between pins A and D, B and C = 700 ohms, between pins A and B, A and C, B and D, C and D = 525 ohms. Between pins J and B, C and K = 0 ohms, between pin F and any of the other pins = infinite ohms

For the smaller load cells, the same as above except substitute 350 for 700 and 260 for 525.

Failure of the load cell to agree with the load as indicated by a hydraulic jack could be caused by one or more of the factors discussed in Section 2.

APPENDIX A - SPECIFICATIONS

A.1. Model 3000 Load Cell Specifications

Available Ranges¹:	100, 150, 200, 300, 500, 600, 1000, 1500, 2000 kips
Accuracy²:	see footnote below
Linearity:	0.5% FSR
Resolution³:	0.025% FSR
Repeatability⁴:	0.1% FSR
Temperature Effect:	0.02% FSR/°C
Temperature Range:	-20 to +80° C 0 to 110° F
Overrange⁵:	200% for aluminum 300 to 400% for steel
Input Resistance:	350 or 700 Ω
Output Resistance:	350 or 700 Ω
Excitation Voltage:	2 to 15 VAC or DC
Maximum Excitation Voltage:	30 V
Cable Type⁶:	3 twisted pair (6 conductor) 22 AWG Foil shield, PVC jacket, nominal OD=9.5 mm (0.375")

Table A-1 Model 3000 Load Cell Specifications

Notes:

¹ Other ranges available.

² The accuracy of the testing machine used to calibrate the cells is $\pm 1/4\%$ F.S. traceable to NIST. The system accuracy depends on end loading conditions as described in the text. If field conditions are well duplicated during actual calibration the accuracy should be within ± 5 F.S. Failure to duplicate conditions can cause calibration variations of $\pm 20\%$ in extreme cases.

³ Minimum, depends on the readout instrument and technique.

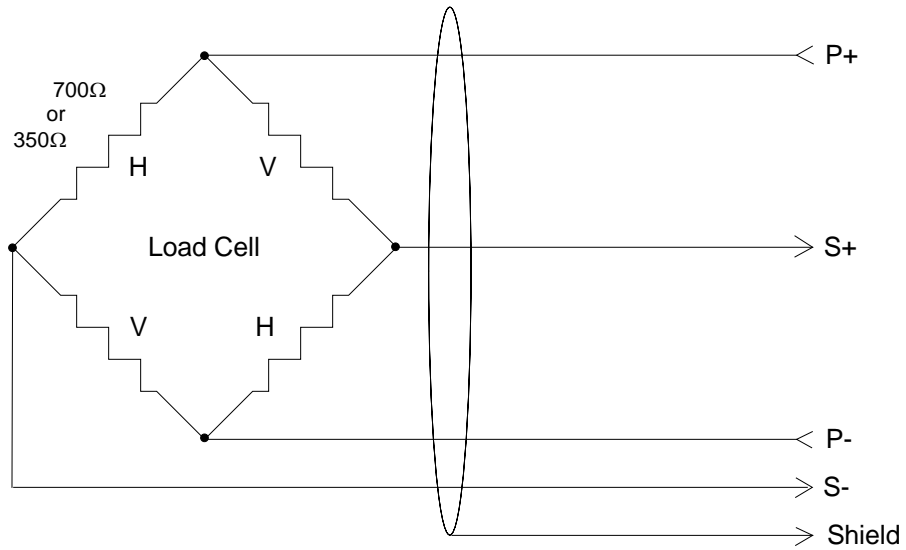
⁴ Repeatability under the same loading conditions. This does not take into account hysteresis and any changes in the loading conditions.

⁵ Overrange without failure But both the no load zero and the calibration may change. If it exceeds 120% FS

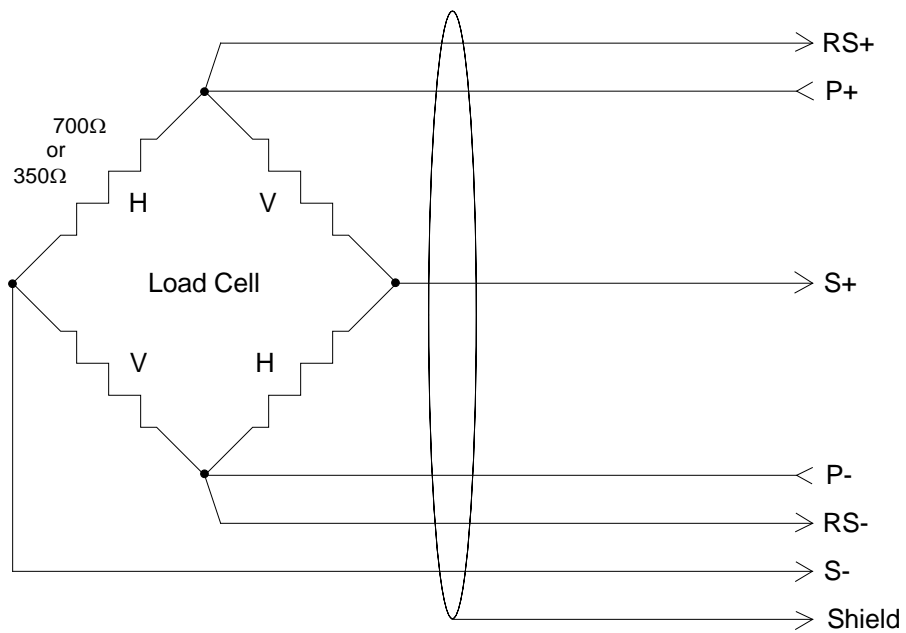
⁶ Other cable types available.

APPENDIX B - WIRING AND CONNECTOR PINOUTS

B.1. Model 3000 Load Cell Wiring Diagram



B.2. Model 3000 Load Cell Wiring Diagram With Remote Sense



B.3. Model 3000 Load Cell Wiring

Bendix (10 pin)	Amp (6 pin)	Circuit Label	Description	Internal Load Cell Wiring	Geokon Purple Cable
A	C	S-	Bridge Output -	White	White's Black
B	B	P+	Bridge Excitation +	Red	Red
C	A	P-	Bridge Excitation -	Black ¹	Red's Black
D	D	S+	Bridge Output +	Green ¹	White
E		NC	No Connection		NC
F	E	G	Ground for shield		Bare Drain Wires
G		NC	No Connection		NC
H		NC	No Connection		NC
J		RS+	Remote Sense +	Red ²	Green
K		RS-	Remote Sense -	Black ²	Green's Black

Notes:

¹ Green and black wires switched on Geokon load cells prior to serial number 1190.

² Non-remote sense is optional and must be specified at the time of ordering.

Note that the GK-501 is set up for remote sense of the excitation voltage at the load cell, which requires a 6 conductor cable (3 twisted pairs). If the load cell is not set up for remote sense and only has 4 conductors, then it will be necessary to modify the cable plug so that pins J and B and pins K and C are shorted together, otherwise the load cell cannot be read.

B.4. P3500 Connection

Binding Post Color	Bendix Pin	Label	Description	Geokon Purple Cable
Red	B	P+	Bridge Excitation +	Red
Black	D	P-	Bridge Excitation -	Red's Black
White	A	S-	Bridge Output -	White's Black
Green	C	S+	Bridge Output +	White
Yellow		D120	No Connection	NC
Yellow		D150	No Connection	NC
Silver	F	Shield	Shield Connection	Bare Drain Wires

APPENDIX C - 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, throughout the industry, that the effects of eccentric loading and uneven and/or warped bearing plates, frictional effects on the bearing surfaces, 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, perhaps with the addition of a spherical seat, so that there is little or no eccentric loading and 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 electrical resistance strain gage load cells, the gages are usually located on the outer surface of the load bearing cylinder at its mid-section.

Report on Recent Testing

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

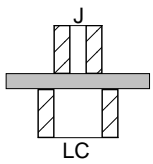
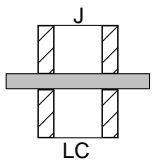
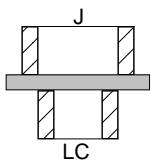
A load cell with a bearing surface of 4" ID, 5¾" OD was used.

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;

- 200 ton capacity1.5" thick
- 500 ton capacity2" thick
- 1000 ton capacity3" to 4" thick

Conclusion

The consequences of all this would seem to indicate that, **for best results, the load cell calibration should be performed in the field with the actual hydraulic jack that will be used**; or in the laboratory, with both load cell and jack 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 some 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 4 strain gages should be used (Dunnicliff 1988' Section 13.2.6) increasing to 8 or 12 in number 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 D - ACCEPTANCE CRITERIA FOR GROUND ANCHORS

Acceptance criteria for the service behaviour of ground anchorages

by G. S. LITTLEJOHN*, BSc(Eng), PhD, CEng, FICE, MStructE, 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 ten-fold increase in time (Czechoslovakia). 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.

As an alternative to monitoring load

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

relaxation, the creep displacement criteria of Table II are proposed, where 1% $\Delta \epsilon$ is the displacement equivalent to the amount of tendon shortening caused by a prestress loss of 1% of initial residual load:

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

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, $\Delta \epsilon$, 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 1500 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

* Relative accuracy refers to the deviation from the measured value, 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 value, i.e. where the measuring instruments have been calibrated against dead weight apparatus or loading machines and the accuracy is known.

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,

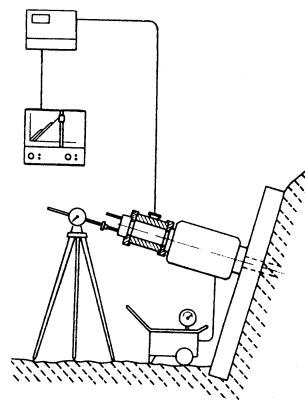


Fig. 1. Typical method of measuring tendon displacement using a dial gauge

where the anchorage may be loaded to the proof load (3.2), checked for fixed anchor displacement and then locked off at 110% T_{wp} . 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_{wp} for temporary anchorages (20 to 150% T_{wp} for permanent anchorages) using load increments not more than 25% T_{wp} 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_{wp} 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_{wp} .

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_{wp}) 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_{wp} . Should the gain exceed 10% T_{wp} 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_{wp} 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 1000kN) and free tendon length (5m, 10m and 20m) for observation periods of 5 min, 15 min, 50 min and 1500 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)	= 1000kN

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

Temporary anchorages		Permanent anchorages		Period of observation (minutes)
Load increment (% T_{wp})		Load increment (% T_{wp})		
1st load cycle*	2nd load cycle	1st load cycle*	2nd load cycle	
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

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
1500 (1 day, say)	5	6	60	1.5	1.5
	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 $\pm 0.2\text{mm}$ 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 $\pm 1\text{mm}$ 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 platens, 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

(concluded on page 36)

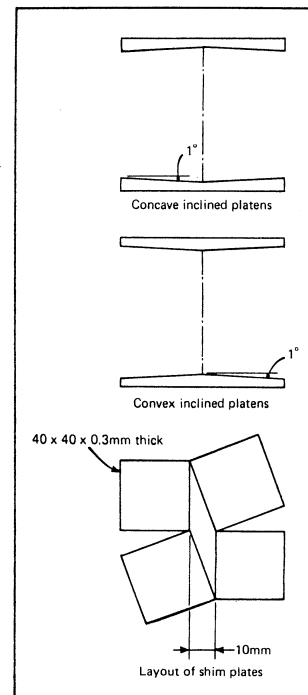


Fig. 2. Typical types of platen to simulate uneven bedding

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_p is commonly applied which appears to be realistic in most cases.

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APPENDIX E - SETTING UP THE VISHAY P3 READOUT BOX TO MEASURE LOADS

IN ENGINEERING UNITS.

Referring to the P3 Instruction manual;

From The Main Screen select '**Bridge Type**' and then select '**Ch 1 FB4 Active**'

From The Main Menu screen and select '**Gage Factor/Scaling**'

- Set the **Units** to lbs tons or kilograms
- Set the **Full Scale** to the full scale value of the load in engineering units taken from the Geokon Calibration Sheet. (E.g. if the load cell has a maximum calibrated load of 60,000lbs enter 60000 (lb) or 30 (ton) in accordance with the units previously chosen.
- Set the **F.S. mV/V** to the mV/V Gage Factor given on the Geokon Calibration Sheet. (If no value is given then the mV/V Gage Factor can be calculated by dividing the Full Scale change of digits by 4000. (E.g. a load cell reads 800 at no load and 14,599 at the full load of 60,000 lbs the F.S. mV/V is $(14599-800)/4000 = 3.440$ mV/V)
- Set the **Dec. Places** to the correct number in accordance with the Units and the Full Scale reading previously chosen.

Now go back to the main Menu screen and select '**Balance**'

- Select the **Mode:** Manual and then **Adjust** the display reading to +00000

Now go back to the main Menu screen and select '**Options**'

- Go to '**Save Setup**' and select. This will save the settings so that the next time the P# is used with this load cell it will be ready to go.

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The P3 readout box is now ready to display the load directly in the engineering units chosen.