Proceedings of the 7th International Conference on Geotechnical and Geophysical Site Characterization
Barcelona, 18 - 21 June 2024

Installation of load cells in ground anchors

Eusebio Aceñero[1], *Tony* Laqué [2#], and *Óscar* Pérez[1]

[1]*Aginteco Consulting e Ing., Sierra de Guadarrama 37-D, 28830 San Fernando de Henares, Madrid (Spain)*
[2]*InGeoLAC, Sierra de Guadarrama, 35, 28830 San Fernando de Henares, Madrid (Spain)*
[#]*Corresponding author: instrumentacion@ingeolac.com*

ABSTRACT

Load cells are used to measure tension (kN, tonne-force) in ground anchors and tendons in pre- or post-tensioned structures. Before installing and commissioning, it is strictly necessary to know the characteristics of the anchors to control as well as the installation and service scenery. Although it may look a simple assignment, there are several issues before supplying and installing a load cell: geometry of the anchor head, measurement range, expected precision, type of output signal and data transmission, temperature variations in the structure, and foreseen service life. The sort of tensioning jack and load steps are additional, unavoidable points to consider. By installing a load cell on a tieback, this is transformed into a measurement element, helping to understand the performance of the anchor as well as that of the surrounding area, medium- and long-term. To ensure load cells' values are correct, we must take extra care with installation. Otherwise, the outcome will be flawed, and it will lead to erroneous conclusions and actions, with the subsequent increase in risk and money loss. In this paper, we share our experience regarding design, installation, and follow-up of load cells as elements to monitor the behaviour of anchored and post-tensioned structures and their area of influence.

Keywords: ground anchor; load cell; post-tension tendon; tieback performance.

1. Introduction

Load cells are the most popular systems used to monitor the behaviour of an anchor in the ground (Figure 1). The installation of these measurement systems must be comprehensive and precise, the main considerations to take into account being:

- Types of structures to anchor.
- Ordinary types of load cells.
- Load cell range (FS).
- Anchor head: Dimensions and design.
- Unexpected readings.
- Quantity of load cells to install.

Below, we elaborate on these points.

2. Types of structures to anchor

The kind of structure to anchor and the type of anchoring system define load cells' design. To keep things simple, we will divide the structures into:

- Structural concrete.
- Ground engineering structures.
- Struts and linear structures, as a particular case within ground engineering applications.

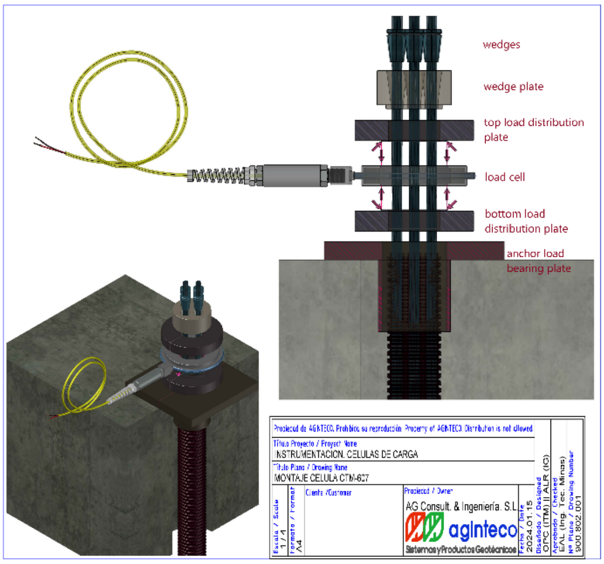

Figure 1. Main parts when installing a load cell.

2.1. Load cells in structural concrete elements

In a precast concrete plant, compression stresses are applied to concrete elements before (pre) or after (post-tensioning) concreting. Post-tensioning is also used in construction projects, on-site (Figure 2).

Anchor blocks for pre- and post-tensioning are specifically designed according to the number of strands. In this case, the difference between the outside and the inside diameters is usually small, resulting in a narrow annular section.

It is recommended to verify that the dimensions of the load cell fit the anchor block. When in production at the precast concrete plant, load cell calibration period should be six (6) months or shorter.

Figure 2. Control of post-tensioning works in a concrete slab during building construction.

2.2. Load cells in ground engineering structures

To confine and stabilize ground deformation in structures such as retaining walls, slopes, bridge abutments, slabs with heave pressure, etc., we apply tensile stress to bar or cable anchors, generally in situ.

It is mandatory to know:

1. Type of anchor to install, i.e. bar or strands, passive or active, temporary (service lifespan ≤ 2 years) or permanent (service lifespan > 2 years), above or below groundwater level.
2. Any loads supported by the anchor.

The dimensions and the kind of load cell to install vary as a function of the type of anchor as well as its test and service loads. Anchor head protection is compulsory for a service lifespan > 2 years (Figure 3).

Figure 3. Stress state monitoring for a retaining wall by means of load cells in permanent anchors, with automatic hourly readings.

2.3. Load cells in struts and linear structures

The loads on struts supporting open excavations are controlled by load cells, measuring the total load on the entire strut section (Figure 4).

Extensive experience is essential to install a load cell to monitor a strut, as fitting a load cell in a strut can alter both the loading conditions in the strut and in the load cell itself.

It is advisable to install strain gauges to control bending, compression, and torsion in struts. In this application, values recorded by a load cell in a strut will directly correlate with measurements obtained by strain gauges.

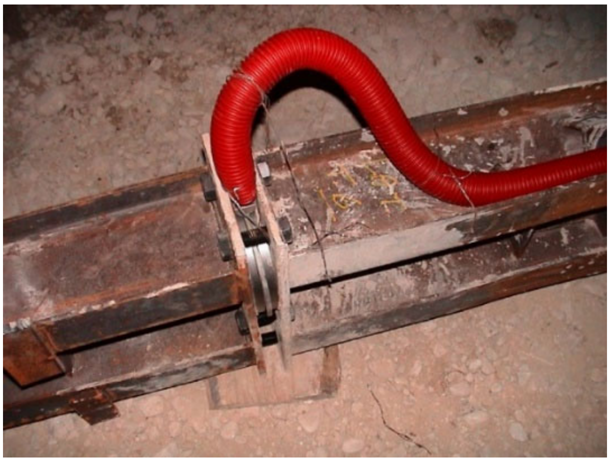

Figure 4. Strut ready for installation in an open excavation, monitored with a load cell.

3. Ordinary types of load cells

Factors to consider when choosing a load cell include:

- Expected monitoring duration.
- Accuracy required.
- Equipment for data reading, acquisition, and transmission.
- Resistance to unpredictable events on-site (impacts, signal cable cutting, etc.), and to weather (IP rating).

The main types of load cells commercially available on the market and most widely used are:

- Hydraulic.
- Electric with strain gauges.
- Vibrating wires.

Load cells usually incorporate compensation systems for small temperature variations of a few degrees Celsius. Apart from Bourdon-type, all other load cells are factory fitted with lightning protection.

Most load cell manufacturers supply load cells with a sensor to measure system's temperature. In this way, temperature corrections are applied if necessary.

Mounting surfaces should be flat and parallel for optimum performance and the use of anchor bearing plates and load distribution plates is recommended.

A calibration certificate must be supplied with each load cell and shall be kept at hand when working with the load cell, specially on-site.

The following sections explain the characteristics of each type of load cell.

3.1. Hydraulic load cells

Hydraulic anchor load cells (Figure 5) are made up of two circular steel plates, with a central hole to allow anchor rod or anchor strands going through. These two plates are machined and welded together in such a way that an intermediate space is created, filled with a special oil, and connected to a pressure gauge, displaying force (kN) or pressure (bar) values. They are very handy and easy to install, these cells being the lowest in precision.

Readings are taken with the naked eye on a Bourdon's type glycerine manometer, close-up or with binoculars. A piezo-resistive (4-20 mA, V) or vibrating-wire (Hz) pressure transducer can be mounted on these, with readings on the signal cable.

Hydraulic load cells' accuracy is ≤ ±1% full scale (FS), the usual ranges (FS) being 250 kN ↔ 2500 kN (25.5 tf ↔ 254.9 tf), other ranges on request.

Figure 5. Hydraulic anchor load cell with Bourdon type pressure gauge.

3.2. Strain gauges' load cells

Electric load cells (Figure 6) consist of a series of electrical resistors (strain gauges) bonded to a steel cylinder and connected in the pattern of a Wheatstone bridge. This kind of circuit compensates the values of unevenly distributed loads and provides a single output signal (mV/V). When the cell is subjected to a load, the resistance of the strain gauges varies, and the output signal is directly proportional to the applied load. The reading on the load cell is taken via a cable connected to a reading unit.

Output usually comes in mV/V, 4-20 mA, V; for thermistor Ω (if any).

Calibration accuracy is ≤ ±0.1% full scale (FS), the usual ranges (FS) being 300 kN ↔ 1500 kN (30.6 tf ↔ 152.9 tf), other ranges on request.

Figure 6. Preparation of a strain gauges' load cell for installation.

3.3. Vibrating wires' load cells

Vibrating wires' load cells (Figure 7) incorporate several vibrating wire sensors inside. These vibrating wires measure the compression of the cell body, made up of high-strength steel. There is the possibility to obtain valid readings under slightly eccentric loading conditions, as the sensors are measured individually and averaged. The reading at the load cell is done either individually for each load cell or using a multi-sensor connector.

Raw output is in Hz or digits; for thermistor Ω (if present).

Precision is ≤ ±0.5% full scale (FS), the usual ranges (FS) being 500 kN ↔ 3000 kN (50.9 tf ↔ 305.9 tf), other ranges on request.

Figure 7. Vibrating wires' load cell in preparation for installation.

4. Load cell range (FS)

When choosing the range of the load cell to install, it is essential to be absolutely sure about the intended load range, including any on-site tests to be carried out during the project. Regardless of the type of load cell, it is critical to take several unloaded readings on-site, prior to installation, including temperature and atmospheric pressure at the time. Next, we will discuss on the main factors to consider when choosing the load cell range (FS).

4.1. Expected loads

It is imperative to know maximum and service loads expected on the anchor. It is advisable that the load cell operates between 50% and 80% of its range (FS). If the ratio loads/range (FS) is ≥1.5, go for higher range cells.

4.2. Reference readings

Always register reference readings in unloaded conditions in the project, prior to installation. Reference value shall be that recorded right before installing, together with temperature and atmospheric pressure. These values shall be the reference ones and not those shown on the calibration certificate. A minimum of three reference readings (load, temperature, atmospheric pressure) must be recorded prior to installation. The difference between the unloaded readings must be within the accuracy percentage of the FS.

4.3. Test loads

There exist several tests typified and standardised in national recommendations, guidelines, and regulations: investigation, suitability, and acceptance, amongst others. Loading and unloading rate should be low during the execution of tests.

As a rule of thumb, we should not exceed the maximum value of a load cell by more than 1.2·FS. In the case of Bourdon pressure gauges, this overload value is zero. Load on cells must never exceed 1.5·FS. Test procedures approved by the Technical Site Management shall be observed.

4.4. Linear or polynomial calculation

Conversion of recorded values into engineering units can be performed using linear or polynomial equations. Whenever needed for calculation, the reference value is the one taken in the project. Conversion factors are available at the manufacturer's calibration certificate. When the loads fall in the lower part of the range (1% ↔ 10% FS), it is common that the observed accuracy is lower than the one specified in the calibration certificate.

In any project, it is good practice to compare the accuracy obtained using linear and polynomial conversion.

5. Anchor head: Dimensions and design

More often than desired, when we make it to site, we notice the components [load cell + load distribution plates] do not fit the anchor head and, as a result and in the best-case scenario, we must work out on-site solutions which do not meet our expectations, eventually influencing the accuracy of the load cell's measurements. In the worst case, it is simply not possible to install the load cell, with the resulting loss of time and money. The following points deal with the procedures to ensure that the dimensions of the anchor head, hydraulic jack, load cell and load distribution plates are correct.

5.1. Load cell dimensions

Before placing a purchase order, diameters of the load cell and the load distribution plates must be confirmed. The size of the load cell shall be a function of the outside diameter of the bar or the strands' set as well as the intended load. Different manufacturers produce load cells with varying diameters for the same range. Given $\boldsymbol{d}$ as the diameter of the bar or strands' assembly, it is recommended that the minimum inside diameter (ID) of the load cell should be $ID_{min} = \boldsymbol{d} + 5$ mm.

5.2. Load distribution plates

These are needed to ensure the load is evenly distributed over the cell surface. Readings will be affected by distorted or uneven load distribution plates. By default, it is better to use two load distribution plates per cell, although in some cases one may suffice. For loads up to 4500 kN (458.9 tf) the thickness of the distribution plates should be 4 cm ↔ 5 cm.

5.3. Readings hydraulic jack ↔ load cell

It is common practice to compare force values at the hydraulic jack with those measured by the load cell on-site. For this to be meaningful, the outer diameters of the hydraulic jack and the load cell must be equivalent. When these diameters significantly differ, the following happens:

- Ø jack < Ø cell = high values (cell).
- Ø jack = Ø cell = true values (cell).
- Ø jack > Ø cell = low values (cell).

A complete document showing all dimensions and technical characteristics of the hydraulic jack must be available on-site. When in operation, the jack and the load cell shall always be supported on-site by their calibration certificates, which have to be up to date.

Load cells are calibrated at the factory right before shipment. The hydraulic jack is operated with greater frequency between certifications, so it should be assumed that the load cell certificate is more up to date than the jack certificate.

5.4. Eccentric loading

This occurs when the load is not applied in alignment with the axis of the load cell and its distribution plates. Eccentric loading will change the values registered by the load cell because one part will be compressed under higher load than the other. This situation may lead to deformation and breaking of the load cell. The use of multiple sensors inside the load cell minimises the effects of eccentric loading, and the values recorded by the sensors can be averaged. Nevertheless, we must ensure distribution plates are used and proper procedures are followed.

6. Unexpected readings

We must verify that the load cell operates in accordance with the anchor. In this section, we describe a number of situations in which readings at the cell may not match the expected values, and outline some of the possible solutions to be addressed. We describe the most common circumstances resulting in erroneous values when reading a load cell, as well as explain the reason for the instability of the readings, given the case.

6.1. Unsynchronised readings

The reading on the hydraulic jack and the value at the load cell are not taken at the same time. The load applied by the jack decreases when the wedges are locked. When the load is applied too quickly, we must allow for some adjusting time to ensure the load is evenly distributed throughout the anchor and the cell.

It is recommended to perform lift-off tests to simultaneously check the values at the jack and at the cell, in order to identify load transmission losses.

6.2. Hydraulic jack diameter bigger than load cell diameter

This configuration usually leads to erroneous load cell values, resulting in deflection and causing some friction between the cylinder and the seal, i.e. blockage at the jack joint. The hydraulic jack pressure measurement system will register higher values than expected, whilst the load cell readings will be lower than expected.

6.3. Hydraulic jack diameter smaller than load cell diameter

The diameter of the hydraulic jack cylinder is smaller than the size of the load cell. This causes deformation in the load distribution plates and in the cell, resulting in high distortion values in the cell compared to the hydraulic jack, as the load is not evenly distributed.

Although it is not always easy, diameters of the jack and load cell must match. The use of thick distribution plates somewhat minimises the effects of the difference in diameters between the jack and the load cell.

6.4. Temperature effects

Values registered by the load cells will be affected by changes in environmental temperature. It is difficult to distinguish, observing the variations of the readings, how much of the thermal influence affects the load cell itself and what percentage is a consequence of the behaviour of the structural elements surrounding the load cell: reinforced concrete, steel, etc. To understand the effects of temperature changes, it is useful to record load cell values and temperature values when no changes are expected. Another option is to consistently take the reading at the same time of the day, preferably just before sunrise.

6.5. Unstable readings

When confronted with unstable readings on site, we can consider proceeding as described below.

- If we change the readout unit, are the values stable? If so, check the batteries of the readout and its readout cable.
- Do the load cell readings fall out of range? Make sure the intended loads are within the cell FS.
- Have we got a source of electromagnetic interference (EMI) nearby? Keep the EMI away.
- Do we observe temperature effects? Please see 6.4 Temperature effects.
- In vibrating wires' load cells, are we using the correct sweep frequency? Check the sweep frequency on the readout and on the manufacturer's data sheet.
- In strain gauges' load cells, has the cell accidently become part of an electrical circuit? Check the insultation of the body of the cell on any wire: values should be >500 MΩ.
- In hydraulic load cells with a Bourdon pressure gauge, check the fitting of the pressure gauge to the cell is not damaged, confirm the needle goes back to zero when no load is applied, and inspect for possible liquid leakage from the cell.

7. Quantity of load cells to install

When we install a load cell on an anchor or on a linear structural element, this component turns into a measuring and monitoring system for the whole structure.

Following Japan Anchors Association, and in relation to ground anchors in projects involving the safety of persons and structures, instrumentation and monitoring consist in the installation of systems to measure physical quantities during the following phases of the project:

1. Design and execution phase: Investigation tests, suitability tests, acceptance tests and anchor installation, to verify the correlation between the design hypotheses and the observed behaviour.
2. Service phase: To know the condition of the ground anchors.

The use of permanent anchors should not be authorised without the approval of a complete and thorough Monitoring Plan to follow-up during testing, as well as in the short-, medium- and long-term anchor lifespan. Instrumentation and monitoring must be carried out by a specialist company with experience and renowned personnel.

As general practice, the detailed references recommend the installation of load cells on ten percent (10%) of the anchors in service or on three of the project anchors (whichever the greater). Table 8.2 of Tirants d'Ancrage TA 2020 is reproduced below (Table 1), specifying the minimum number of ground anchors to be monitored as a function of the total number of ties. Above 250 ground anchors, one anchor must be instrumented every 20 additional anchors. In particularly critical projects, it may be desirable to monitor all anchors.

Table 1. Minimum number (N_{min}) of anchors to monitor.

Anchors	N_{min}	Anchors	N_{min}
1 to 10	1	93 to 110	9
11 to 20	2	111 to 130	10
21 to 30	3	131 to 150	11
31 to 40	4	151 to 170	12
41 to 50	5	171 to 190	13
51 to 64	6	191 to 210	14
65 to 78	7	211 to 230	15
79 to 92	8	231 to 250	16

In order to monitor the evolution of the measured magnitudes and to be able to take the appropriate decisions before they influence the anchored structure, data must be taken in automatic mode, remotely and in real-time, obtaining a continuous record. This applies to testing, commissioning, and foreseen service life of the anchor. All information must be accessible in digital format and on a web-based or similar data platform, 24H/7D 365D, with private access via username and password.

In case following data analysis, it is decided to adjust the load on the anchors, these shall be fitted with extra cable lengths of $l \geq 60$cm and/or re-loadable anchor heads.

8. Conclusions

When dealing with anchor and tendon load cells, it is essential to draw a plan well in advance on-site activities begin, and to carry out high-quality, in-depth project scheduling to allocate the resources (time, staff) required. Failure to do so will result in a loss of money and increased project risk.

Interpretation of the results must be done in conjunction with an understanding of the environmental, surrounding and contour factors, which will have various effects on the values recorded by the load cell at the ground anchor.

Calibration certificates for the load cells and the hydraulic jack, tests, and installation reports, as well as real-time data must be accessible on a Web data platform, 24 hours / 7 days a week.

References

Comité Français de Mécanique des Sols et de Géotechnique. 2023. *Tirants d'Ancrage TA 2020 – Règles Professionnelles Relatives à la conception, au calcul, à l'exécution, au contrôle et à la surveillance (version 3.0 – 2023)*, (TA 2020 Anchor Tension Systems - Professional Rules for design, calculation, execution, inspection and monitoring (version 3.0 – 2023) English translation).

Japan Anchors Association. 2015. *Inspection and Maintenance Manual for Ground Anchors*, Public Works Research Institute.