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Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 8: Measurement of loads: Load cells

Reconnaissance et essais géotechniques — Surveillance géotechnique par instrumentation in situ —

Partie 8: Mesure de charges: Cellules de charge

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Contents

Foreword

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This document was prepared by Technical Committee ISO/TC 182, *Geotechnics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical Investigation and Testing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 18674 series can be found on the ISO website.

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Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 8: Measurement of loads: Load cells

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This document specifies the measurement of forces by means of load cells carried out for geotechnical monitoring. General rules of performance monitoring of the ground, of structures interacting with the ground, of geotechnical fills and of geotechnical works are presented in ISO 18674-1.

This document is applicable to:

— performance monitoring of geotechnical structures such as anchors, tiebacks, piles, struts, props and steel linings;

— checking geotechnical designs and adjustment of construction in connection with the observational method;

— evaluating stability during or after construction.

This document is not applicable to devices where the load is purposely applied to geotechnical structures in the wake of geotechnical field tests such as calibrated hydraulic jacks for pull-out tests of anchors or load tests of piles.

NOTE 1 This document fulfils the requirements for the performance monitoring of the ground, of structures interacting with the ground and of geotechnical works by the means of load cells as part of the geotechnical investigation and testing in accordance with References [2] and [3].

NOTE 2 ISO 18674-7 is intended to define the measurement of forces by means of strain or displacement gauges.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

ISO 18674-1:2015, *Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 1: General rules*

3 Terms and definitions

For the purposes of this document the terms and definitions given in ISO 18674-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
load cell
field instrument for monitoring forces acting in geotechnical structures

Note 1 to entry: Load cells are commonly placed at an end of a structural member where forces are transmitted from one member to another.

EXAMPLE Load cell at the anchor head where the force acting in the anchor tendon is transmitted to a retaining wall.

Note 2 to entry: Common load cells are electric (see 3.2) and hydraulic (see 3.3) measuring principles.

Note 3 to entry: Indispensable components of load cells are a load bearing element and load distribution plates for transmitting forces between structural members.

Note 4 to entry: Load cells are not useful for fully grouted rock bolts.

3.2
electric load cell
instrument with an elastically-behaving body which deforms under the applied force, where the resulting deformation is measured by electric sensors

Note 1 to entry: An example of such body is a steel cylinder (see Figure 2).

Note 2 to entry: For typical electric sensors, see 5.2.4.

3.3
hydraulic load cell
instrument with a flat liquid-filled compartment where the force to be monitored acts normal to the flat distribution plates on the sides of the compartment and where the pressure in the liquid of the compartment is measured by a pressure measuring device

Note 1 to entry: See Figure 3.

Note 2 to entry: The compartment is formed by two steel plates, welded together around their peripheries, where the intervening cavity is filled with a liquid (de-gassed fluid).

3.4
anchor load cell
purpose-designed load cell with a centric passage to accommodate the anchor tendon

Note 1 to entry: See Figure 4.

Note 2 to entry: The tendon typically comprises a bar, strands or wires.

3.5
nominal range
range over which the load cell is calibrated

Note 1 to entry: Other terms which are used in practice are, for example, load range, nominal load, capacity, full-scale capacity or measuring range.

Note 2 to entry: Outside of the nominal range, the load cell is not calibrated and therefore the measurements are not reliable.

3.6
over range
maximum load that can be applied on the load cell, without damaging the load cell

Note 1 to entry: Other terms which are used in practice are, for example, “overrange capacity” or “overload”.

4 Symbols and abbreviated terms

Symbol	Name	Unit
B	smallest dimension in cross section of structural member	m
D_o	outer diameter	m
F	axial force acting in a member	N
FS	full scale	-
H	height	m
P_a	installation load	N
P_e	effective axial load	N
F_R	reaction force in the anchor head	N
P	axial load	N
R_T	pile toe resistance	N
T	temperature	°C
t	elapsed time	s, min, h, d
z	depth	m
α	angle between the tendon at the anchor head and the anchor axis	degree

5 Instruments

5.1 General

5.1.1 A load cell can be either electric (see 5.2) or hydraulic (see 5.3).

NOTE Other types of load cells, such as mechanical or photo-elastic are not considered in this document.

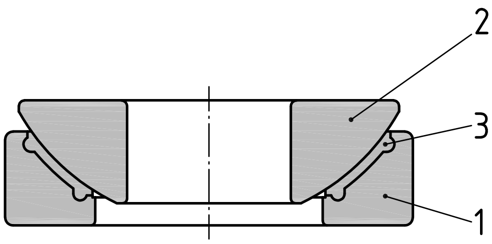
5.1.2 The maximum load anticipated in the lifetime of the monitoring project plus a margin of 10 % to 30 % shall not exceed the nominal range of the load cell after installation (see 6.1.1.7).

NOTE 1 Too large a margin reduces the accuracy of the measurements.

NOTE 2 The measurement in the lower end (5 % to 10 %) of the nominal range is often less accurate.

5.1.3 At the measuring location, the force acting in a structural member shall be transmitted through the load cell via load distribution plates. Spherical distribution plates may be used to improve an aligned load distribution.

NOTE See Figure 1 for an example of a spherical distribution plate.



Key

1 concave plate

2 convex plate

3 PTFE fabric

Figure 1 — Spherical load distribution plate (example)

5.1.4 The load cell shall have a specified load bearing element.

EXAMPLE See 1 in Figure 2 and 2 to 4 in Figure 3.

5.1.5 The material of the load bearing element (e.g. 1 in Figure 2) of the cell should be mechanically stable.

EXAMPLE Heat-treated steel grade S355J2+N according to Reference [4].

5.1.6 The influence of temperature on the load measurement shall be considered and documented. Exposure of the load cell to direct sunlight or other heat sources should be avoided or minimised. The load cells should be designed to minimize temperature errors.

NOTE 1 The readings of load cells are affected by temperature changes. The use of temperature-compensated sensors decreases the influence of temperature changes on the measurements. Information for temperature correction of the load cell are commonly provided by the manufacturer.

NOTE 2 Independent temperature measurements in the vicinity of the load cell assist in the evaluation of the load measuring results.

NOTE 3 Temperature changes can also affect the loads within the structural members, see ISO 18674-1:2015, 5.3.1.

5.2 Electric load cells

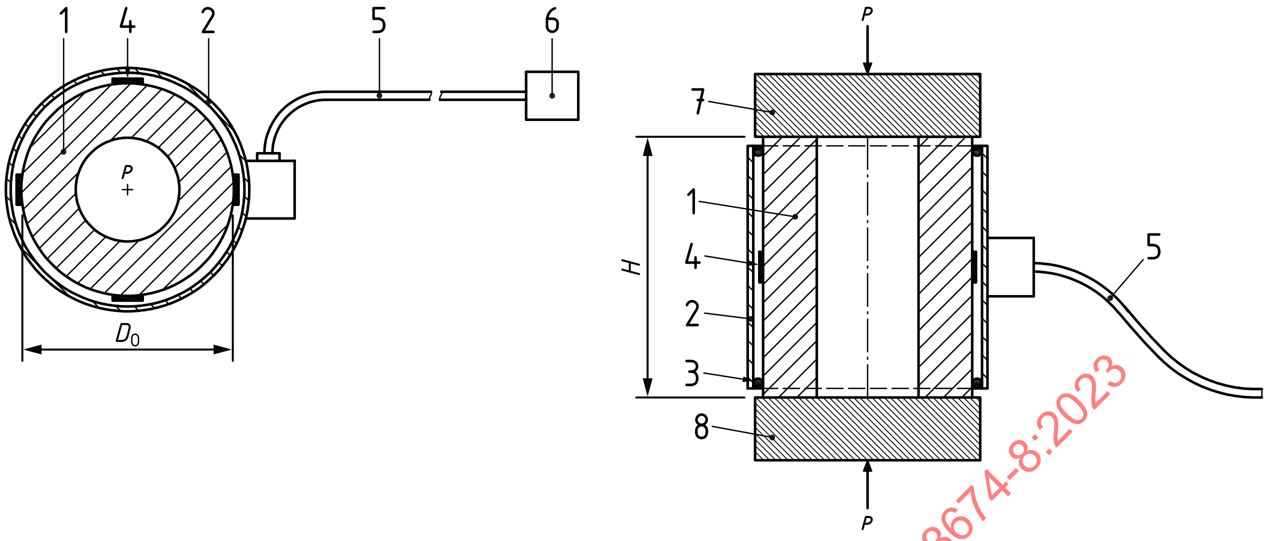
5.2.1 Electric load cells should have features as shown in Figure 2.

NOTE The load bearing element is usually either a solid cylinder or a hollow cylinder, see 1 in Figure 2.

5.2.2 Cylindrical load bearing elements should have a height H to outer diameter D_o ratio within the range of $0,1 \leq H/D_o \leq 2$.

NOTE 1 $H/D_o > 2$ tends to decrease the stability of the load cell assembly.

NOTE 2 The quality of the measurements of load cells with low ratios of H/D_o can be more sensitive to imperfections on alignment, placement and load distribution plates.



a) Top view

b) Side view

Key

D_o outer diameter of load bearing element (1)
P load
H height of load bearing element (1)
1 load bearing element (here: hollow cylinder)
2 protective cylindrical cover
3 O-ring
4 electric sensor (here: full-bridge strain gauges)
5 electric cable
6 control and readout unit
7 upper load distribution plate
8 lower load distribution plate

Figure 2 — Features of an electric load cell (example, see Reference [5])

5.2.3 The deformation of the load bearing element shall be measured by electrical sensors.

5.2.4 The sensor can be based on either strain gauge, piezo-electric, vibrating wire or capacitive measuring principles, configured in such a way that the influence of eccentric loading is minimised.

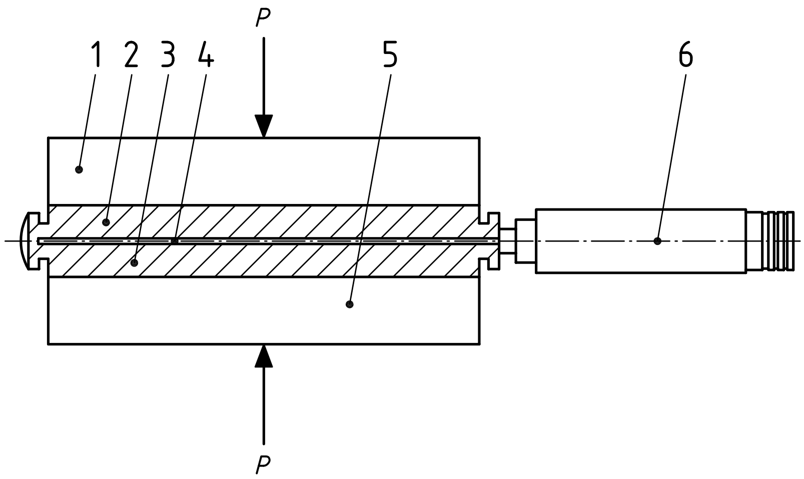
NOTE 1 The influence of eccentric loading can be typically minimised by using multiple sensors spaced evenly around the cylinder and at equal distance from the axis.

NOTE 2 The output signal of an electrical strain gauge load cell can depend on the power supply of the logging device, when not properly designed.

5.3 Hydraulic load cells

5.3.1 Hydraulic load cells should have features as shown in Figure 3.

NOTE Elements 2, 3 and 4 of Figure 3 form a liquid-filled compartment. Any change in the magnitude of the load *P* results in a change of the pressure of the liquid in the compartment (4 in Figure 3).



Key

P	load	4	liquid-filled compartment
1	upper load distribution plate	5	lower load distribution plate/bearing plate
2/3	load cell plates	6	pressure measuring unit (here: electric pressure transducer)

Figure 3 — Features of a hydraulic load cell

5.3.2 The pressure measuring unit (6 in Figure 3) should be positioned as close as practically feasible to the liquid-filled compartment.

NOTE An increased spacing between the liquid-filled compartment (4) and the pressure measuring unit (6) results in a decreased stiffness of the load measuring system influencing the measurement.

5.3.3 The pressure measuring unit can be either a Bourdon gauge or an electric pressure transducer.

5.4 Instruments for specific applications

NOTE See Annex A.

5.4.1 Anchor load cells

5.4.1.1 Anchor load cells shall have an axial centric passage to accommodate the anchor tendon.

NOTE See Figures 1 and 4.

5.4.1.2 Anchor load cells can be of an electric (see 5.2) or hydraulic type (see 5.3).

5.4.1.3 At the measuring location, the anchor load shall be transmitted through the load cell via load distribution plates. The load distribution plates shall be designed to withstand yielding at capacity load and to limit distortions when distributing the load to the structure.

NOTE 1 See 7 and 8 in Figure 2 and 1 and 5 in Figure 3.

NOTE 2 Common are heat-treated steel load distribution plates of a H/D_o-ratio of about 0,22 to 0,30.

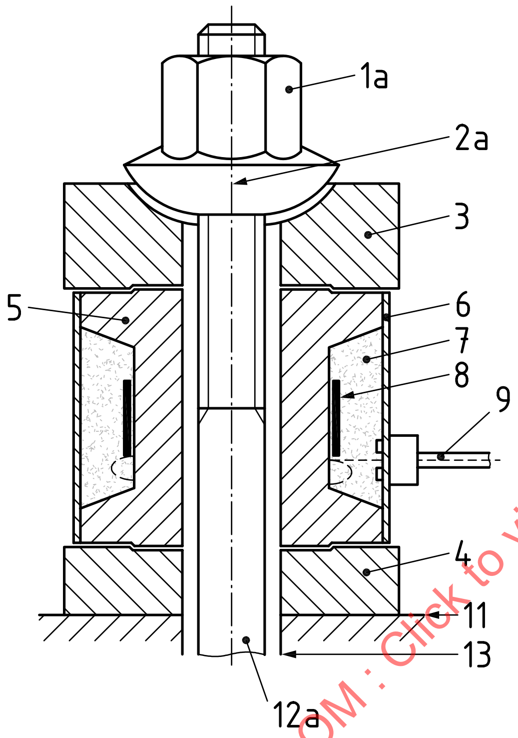
NOTE 3 The plate between the bearing element and the load cell (8 in Figure 2 and 5 in Figure 3) is commonly referred to as bearing plate.

5.4.1.4 The hole for feeding the anchor tendon through a load distribution plate shall be in the centre of the plate.

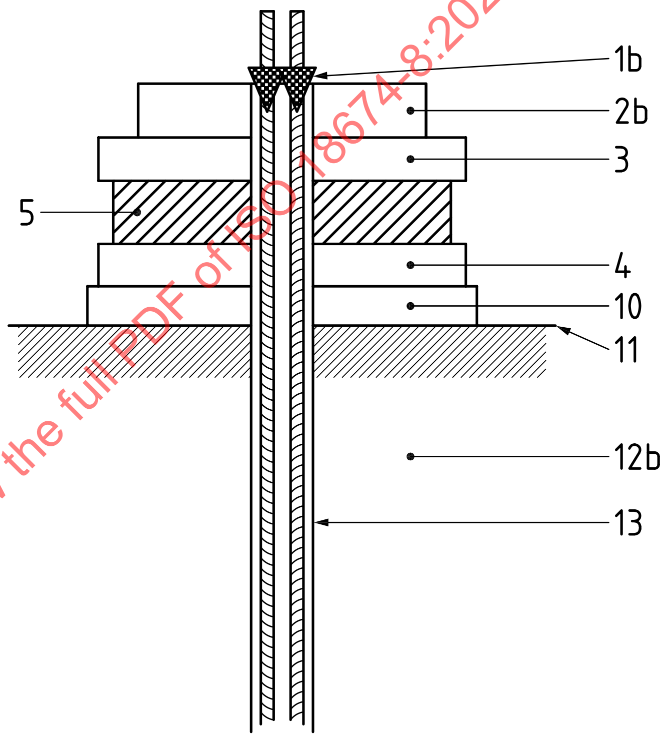
5.4.1.5 For anchor tendons, spherical seats or wedges may be used to improve aligned load distribution.

NOTE 1 See Figures 4 a) and b).

NOTE 2 Deviations from the perpendicular alignment between the load distribution plates and the anchor tendon generate a force component which acts in transverse direction of the load cell. This effect, which affects the accuracy of the anchor load measurement, cannot be avoided by a spherical nut or wedges, see 6.1.1.4 to 6.1.1.6.



a) Spherical seat for a bar tendon



b) Wedges for two strand tendons

Key

1a nut
1b wedge
2a spherical seat
2b head plate
3 upper load distribution plate
4 lower load distribution plate
5 load bearing element
6 protection sleeve
7 potting
8 electric sensor
9 electric cable to readout
10 bearing plate
11 ground surface
12a bar tendon
12b strand tendon
13 borehole wall

Figure 4 — Schematic layout of anchor head devices for aligning different types of tendons

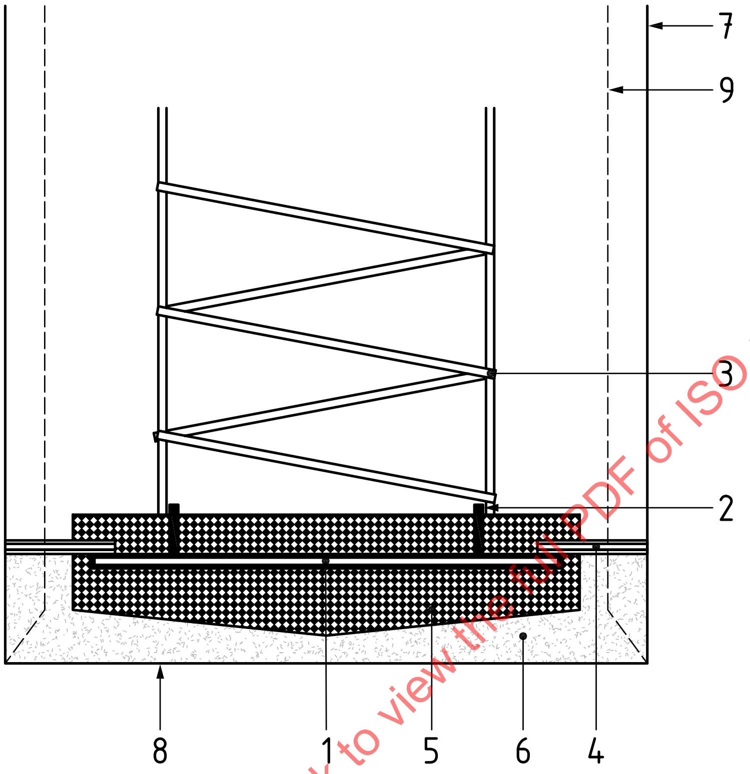
5.4.2 Load cell for cast-in-place concrete piles

5.4.2.1 When monitoring the performance of a cast-in-place concrete pile, a load cell may be located at the toe of the pile. In this case, the layout of the load cell should be as in Figure 5.

NOTE 1 The load at the top of the pile is commonly measured by means of strain gauges, see Reference [1].

NOTE 2 A load cell at the head or at another location between toe and head is commonly associated with pile testing procedures where a load is actively applied and systematically varied and where the deformational response of the pile is considered in dependency of the applied load.

NOTE 3 Outside of pile testing, the use of a load cell at the head of the pile is limited to situations where only axial loads are expected during the lifetime of the pile, as the presence of the load cell can influence the load transfer to the pile.



Key

1 hydraulic load cell embedded in (5)

2 weld ring

3 reinforcement cage

4 ring of compressible material (e.g. synthetic rubber)

5 conical plug (e.g. mortar)

6 concrete/mortar bed

7 borehole wall

8 bottom of borehole

9 casing inner wall (where applicable)

Figure 5 — Schematic layout of a hydraulic load cell at the base of a cast-in-place concrete pile (example, see Reference [6])

5.4.2.2 In case of a pile diameter greater than 1,00 m, an array of at least three load cells can be used. Number and position (layout/geometry) of the load cells shall be designed to minimize eccentricity. Distribution plates shall be designed to equally distribute the load into the load cells.

5.5 Measurement accuracy

5.5.1 The measurement accuracy is predominately controlled by the design of the mounting devices, the quality of the installation of these devices with regard to axiality (see 6.1.1.5) and eccentricity (see 6.1.1.6) and changes of the ambient temperature at the measuring location.

NOTE For strand tendons, the angle formed by the cables at the anchor head with respect to the anchor axis produces a transverse effect that is absorbed by the (upper) distribution plate. The measured axial load component is smaller than the actual strand load (see 7.4).

5.5.2 For anchor load cells, the central hole of the cell shall be large enough to avoid a contact of the cell with the anchor tendon and, thus, the development of transverse loads to the cell resulting in reduced overall accuracy and possible damage to the cell.

6 Installation and measuring procedure

6.1 Installation

6.1.1 General

6.1.1.1 Load cells should be installed concurrently with the structural member.

NOTE This simplifies the placement and alignment of the cells and the associated load distribution plates. It also ensures a full record of the load history.

6.1.1.2 The forces shall be transmitted from the structural member through the cell only.

6.1.1.3 Load distribution plates shall be placed outside the load bearing element and on the structural member to distribute the load evenly.

6.1.1.4 The load cell shall be installed taking into consideration the orientation as well as the location of the axis of the structural member.

NOTE See 6.1.1.5 and 6.1.1.6.

6.1.1.5 The axis of the load cell shall be aligned parallel to the axis of the structural member and the distribution plates should be perpendicular to the axis of the load cell and the structural member. A deviation of ±5° is permissible.

NOTE Any non-parallelity leads to a transverse loading of the load cell which affects the quality of the measurement.

6.1.1.6 Load cells and distribution plates shall be centred in the axis of the structural member. An eccentricity of < 3 % of the diameter of the load bearing element of the cell is permissible.

EXAMPLE If the outer diameter D_o of the load bearing element of a load cell is 200 mm, the maximally permissible off-set of the load cell would be 6 mm.

NOTE In the case that the diameter of the cell is small relative to the sectional area of the structural member, a possibility is to install an array of load cells as per 5.4.2.2 or to provide the structural member with a suitable adapter.

6.1.1.7 The load on the load cell shall not exceed the over range value during installation.

NOTE Over range value according to the specifications of the manufacturer. Typically, the over range of commercially available load cells is up to 1,5 times the nominal range.

6.1.2 Anchor load cells

6.1.2.1 The installation of the load cell shall commence when the anchor tendon is inserted, and the bearing plate is placed. The lower load distribution plate shall be set onto the bearing plate and fixed centrally in position.

NOTE Centraliser bushings are useful for centring and aligning the plate correctly.

6.1.2.2 Once the bearing plate and the lower load distribution plate are set, the anchor load cell and upper load distribution plate shall be installed, and the anchor tightened. Provisional supporting devices may be used throughout the installation and tightening procedures.

6.1.2.3 The load measurement should commence prior to and during stressing, during and after the lock-off of the anchor, to check for any loss of load during the installation process and to allow the effective load applied to be evaluated.

6.1.2.4 Load cells and load cell cables shall be protected against weather effects and mechanical damage by a suitable protective cap.

6.1.2.5 Anchor heads with load cells for permanent applications should be placed in recesses or niches in the structure.

NOTE The niches are often filled with grease or resin, which improves the long-term protection.

6.1.2.6 For load cells on permanent anchors, provisions may be made for a replacement of the load cell.

NOTE The working life of electric anchor load cells is commonly limited to 20 to 25 years, often shorter.

6.1.3 Load cells at the base of cast-in-place concrete piles

6.1.3.1 The load cell shall be prepared for installation by attaching the cell to the bottom of the reinforcement cage.

NOTE For this purpose, the load cells are often equipped with a weld ring, see 2 in Figure 5.

6.1.3.2 The hydraulic lines and/or electric cables to the cell shall be aligned along longitudinal bars of the reinforcement cage and secured, e.g. by wires. The lines and cables shall be marked and protected from damage.

NOTE The preparatory work of 6.1.3.1 to 6.1.3.2 is commonly carried out above ground at the construction site.

6.1.3.3 A conical plug/plate should be underneath the load cell.

NOTE 1 See 5 in Figure 5.

NOTE 2 A conical plug assists in achieving a form-fitting contact of the cell with the concrete or mortar bed at the bottom of the borehole (see 6.1.3.4) and thus with the ground beneath the pile.

NOTE 3 The conical plug is commonly factory-assembled to the cell.

6.1.3.4 Prior to installing the ready-made assembly of 6.1.3.1 to 6.1.3.3 into the borehole, the bottom of the borehole shall be cleaned of debris and subsequently fully covered by a concrete or mortar bed.

6.1.3.5 The assembly shall be lowered into the borehole until the cell is in full contact with the fresh concrete or mortar bed.

6.1.3.6 Concrete or mortar at the periphery of the load cell shall be prevented, as the full load needs to act on the load cell.

NOTE 1 This is typically achieved by attaching an outer ring of compressible material to the cell, taking care that this material is not totally squeezed under the overburden pressure of freshly poured concrete of the pile.

NOTE 2 See 4 in Figure 5.

6.1.4 Load cells for struts across excavations

6.1.4.1 The placement of a load cell in struts shall be designed in cooperation with the structural engineer.

NOTE A load cell changes the static system and safety.

6.1.4.2 The load cell shall be placed at one end of the strut together with the mounting elements.

NOTE 1 Other locations of the load cell have repercussions on the stability of the strut.

NOTE 2 For load measurements along a strut by means of strain gauges, see Reference [1]. A combination of strain gauges and load cells can be applied for redundancy.

6.1.4.3 The load cell should be installed concurrently with the strut.

6.1.4.4 When struts are exposed to solar radiation and other temperature effects, temperature shall be measured, and its effect shall be taken into account.

NOTE See ISO 18674-1:2015, 5.3.2.

6.2 Carrying out the measurement

6.2.1 Instrumentation check and calibration

6.2.1.1 Before installation, the functionality of the load cell shall be checked by performing the tests suggested by the manufacturer. For general function checks and calibrations, reference is made to ISO 18674-1:2015, 5.6.

6.2.1.2 A calibration certificate shall be supplied by the manufacturer for each load cell delivered. The time span between calibration and installation of the cell shall not exceed 12 months.

6.2.1.3 The calibration of the cell shall be performed by using a universal testing machine of the accuracy class 1.0 in accordance with ISO 7500-1.

NOTE For more details and alternative calibration procedures, see Reference [7], 13.2.

6.2.1.4 At the site, the acceptance test which is performed when loading/installing the anchor may be used as a function check for the load cell.

NOTE 1 The difference in the measured loads between the tensioning device and the load cell can be up to 10 %, taking into account 7.3 and 7.4.

NOTE 2 See 5.5 for information on measurement accuracy, the same issue applies to the load cell system and the tensioning device.

NOTE 3 See Reference [8].

6.2.1.5 During the monitoring program, a function check of the load cell can be performed.

NOTE 1 This is often referred to as a lift-off test.

NOTE 2 See Reference [9], 9.10.6.

6.2.1.6 The manual readout unit for electrical load cells should be calibrated regularly, according to the manufacturer's recommendations and at least every two years.

6.2.2 Measurement

The measurement shall be carried out in accordance with ISO 18674-1:2015, Clause 7.

7 Data processing and evaluation

7.1 Data processing and evaluation of the measurements shall be carried out according to ISO 18674-1:2015, Clause 8.

EXAMPLE See Annex B.

7.2 The effect of temperature changes and solar radiation shall be considered.

NOTE The evaluation of loads is often supported by structural modelling.

7.3 When comparing anchor load cell data with those of a calibrated hydraulic jack of a tensioning device, it shall be understood that hydraulic jacks are designed for application of load, and not for measurement of load.

NOTE 1 The load indicated by the tensioning device is likely to be different to that of the load cell.

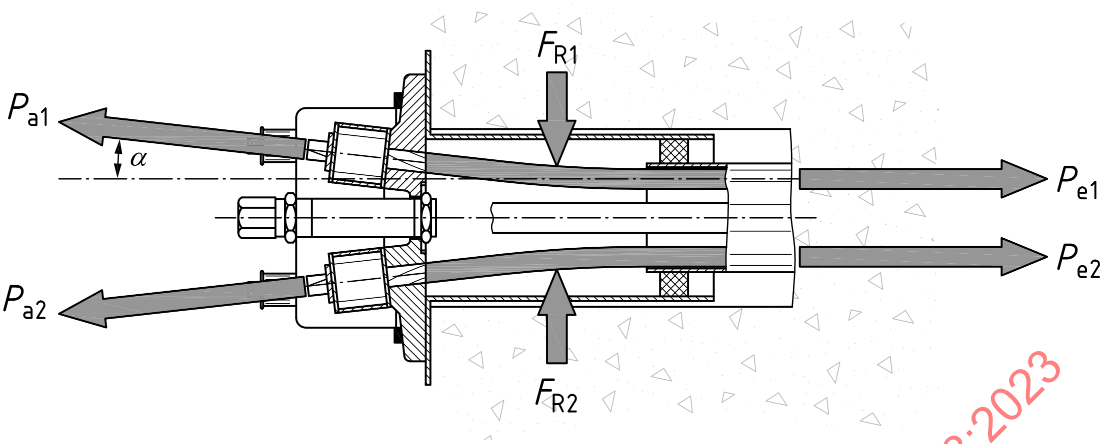
NOTE 2 When locking-in the anchor, there is a relaxation of the load.

7.4 In addition to 7.3, the angle formed by a strand tendon at the anchor head with respect to the axis of the anchor borehole shall be considered.

NOTE 1 See Figure 6.

NOTE 2 The requirement applies to multi-strand tendons, in particular to multi-unit tendons.

NOTE 3 The effective axial load of a strand into the anchor P_e will be the applied installation load P_a multiplied by cos α.



Key

P_{a1}, P_{a2} installation load of strand i (hydraulic jack)

P_{e1}, P_{e2} effective axial load

F_{R1}, F_{R2} reaction force in the anchor head

α angle between the directions of a strand at the anchor head and the borehole axis

Figure 6 — Layout of a typical anchor head incorporating a strand tendon

8 Reporting

8.1 Installation report

The installation report shall be in accordance with ISO 18674-1:2015, 9.1.

8.2 Monitoring report

The monitoring report shall be in accordance with ISO 18674-1:2015, 9.2.

Annex A
(informative)

Geotechnical applications

Table A.1 provides an overview of the two principal cell types where the load is directly monitored in some common geotechnical applications. Indirect load monitoring options are often based on the measurement of strain (see Reference [1]). The classification, as shown in Table A.1, can assist in the instrument selection. In the case that a geotechnical application is not included in Table A.1, the closest application can be considered for the selection.

Table A.1 — Guide for the selection of load cell types in geotechnical applications

Column	**Application**		**Suitability of load measurement method**	
			load cell	
			electric	hydraulic
A	Anchor & tie-backs		+	+
B	Struts in braced excavation		+/- [a]	+/- [a]
C_1	Cast-in-place pile	at toe	-	+
C_3		between toe and head	- [a]	- [a]
D	Steel arch support & props		+	+

Key

for geotechnical applications

+ likely to be suitable
+/- possibly suitable
- likely to be unsuitable

[a] In these cases, indirect measurements are indicated (see Reference [1]).

Annex B
(informative)

Measuring examples

B.1 General

Examples of various types of load cells and typical applications are presented as follows:

a) Electric load cell: Monitoring of strand anchors during construction works in an urban deep excavation (see B.2).

b) Electric load cell: Monitoring of a temporary open excavation (see B.3).

c) Electric anchor load cells: Monitoring of a permanent anchored retaining wall in a slope (see B.4).

d) Hydraulic load cells at the toe of cast-in-place concrete piles (see B.5).

Each example contains information that is typically included in a report in accordance with ISO 18674-1:2015, Clause 9.

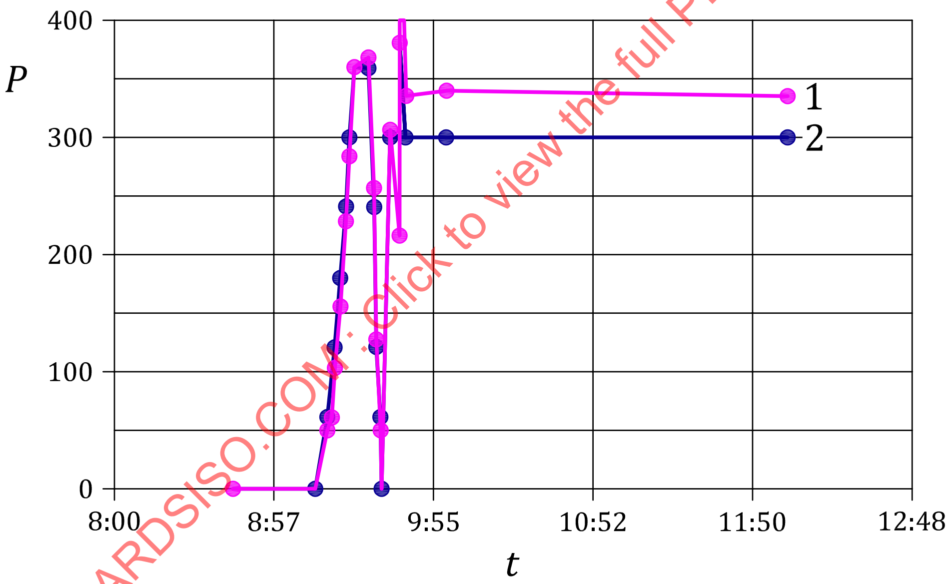
B.2 Electric load cell: Monitoring of strand anchors during construction works in an urban deep excavation

a)	Owner of the project	GRANDISTAZIONI S.p.A. Rome, Italy.
b)	Name and location of the project	Deep excavation in Torino – Italy.
c)	Name of the company carrying out the monitoring project	ITALFERR S.p.A., Rome – Italy.
d)	Monitoring project	Measurement of anchor loads, tilt and displacement of retaining walls. Critical issues are related to the adjacent station structure – 2 m – and a very crowded road with tram tracks at 1,5 m distance (see Figure B.1).
e)	Type of ground	Sandy gravel.
f)	Instrumentation	Electric load cells (strain gauges) (see Figure B.2), supplemented by tiltmeters and surveying targets.
g)	Installation of load cells	Cells have been installed on the head of some selected anchors and loaded in course of the anchor pre-stressing (see Figure B.3). Steel distribution plates have been used to enable the load to be transferred to the cells minimizing eccentricity and distributing it in the expected way.
h)	Commissioning	After verification of the correct functioning of the cells and reaching the final depth of the excavation.
i)	Measurements	Both manually (during installation and preliminary operations) and automatically. For the automatic measurements multichannel data loggers with GSM remote connection have been used.

j)	Measuring uncertainty	0,3 % FS as per data sheets. Temperature effects have been analysed and correlation used (see Figures B.4 and B.5). Two different measuring ranges have been used according to the anchors loads: 500 to 1 000 kN full scale.
k)	Principal results of the monitoring project	Measurements have been used to verify the loads in anchors and their evolution during the excavation. Supplemented by tilt and displacement measurements, the measured values have been used to assess the safety of the excavation.
l)	Assessment and evaluation	High frequency – 30 min – logging together with alert and alarm thresholds as well as verification of the automatic measurements by periodic manual measurements and comparison of the different parameters significantly contributed to assess the safety of the construction activities and to verify the design hypothesis.

Figure B.1 — View of the working site
(Top right: The Porta Nuova Station; top left: road with tram tracks)

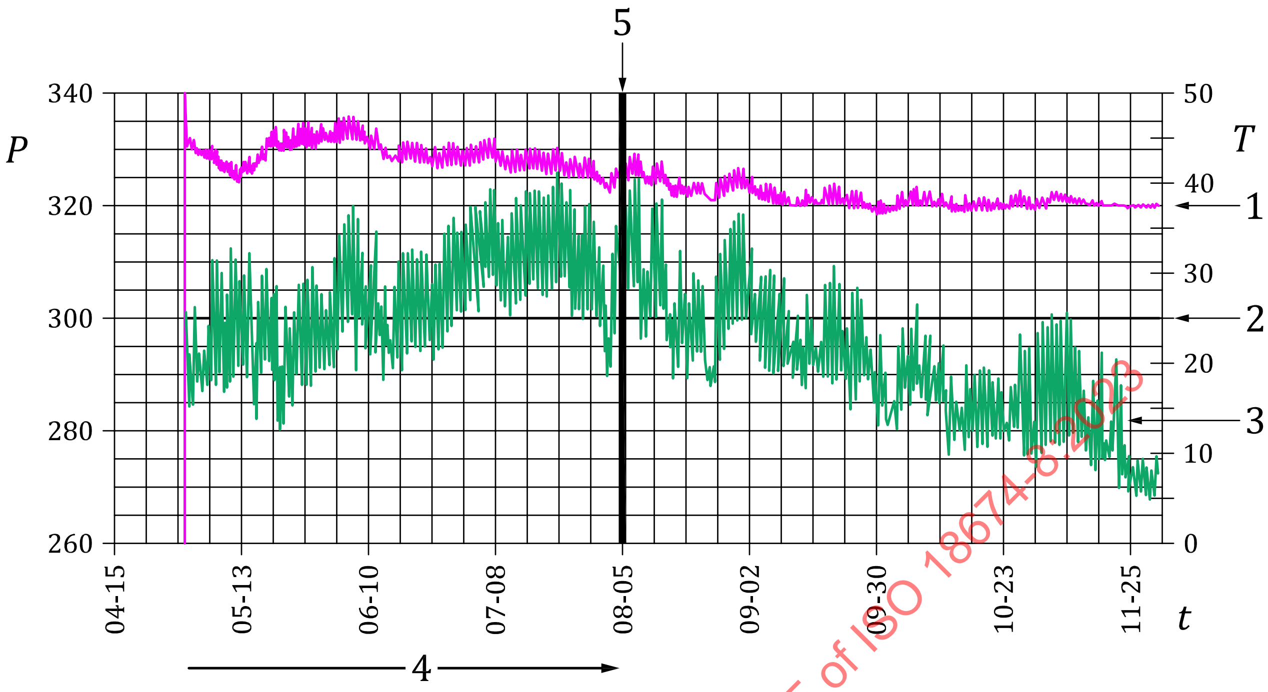
Figure B.2 — Electric load cell on steel beam with load distribution plates for an anchor with multiple strand tendons



Key

1	load measured in a load cell	*P*	load [kN]
2	load applied by a calibrated jack	*t*	time of installation [h:min]

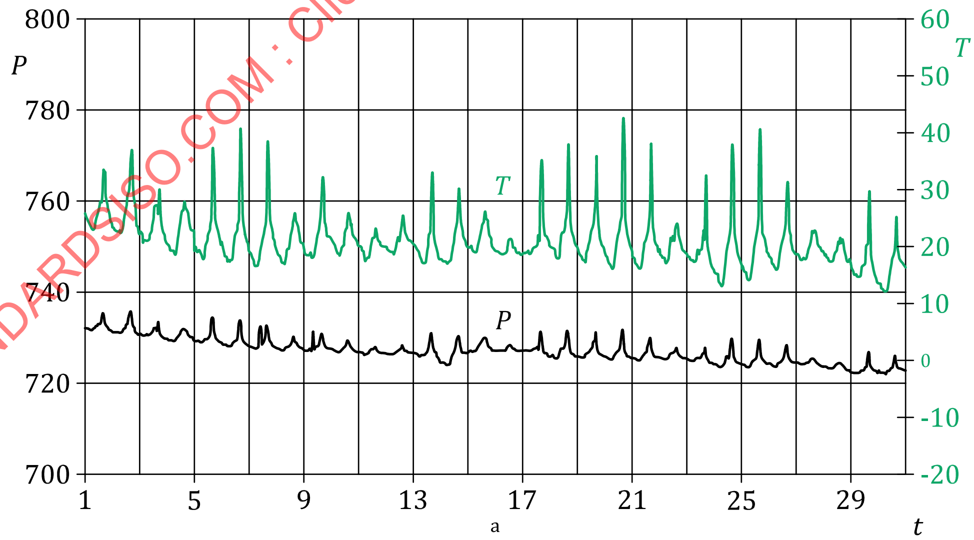
Figure B.3 — Example of the anchor load evolution during the load cell installation



Key

P	load [kN]	1	load measured in a load cell	4	elapsed time during the excavation
t	time [month-d]	2	load applied by a calibrated jack	5	end of excavation work
T	temperature [°C]	3	ambient temperature measured		

Figure B.4 — Load and temperature measurements for a period of eight months, during and after the excavation works



Key

P load measured in a load cell [kN] *T* temperature [°C] *t* time [d]

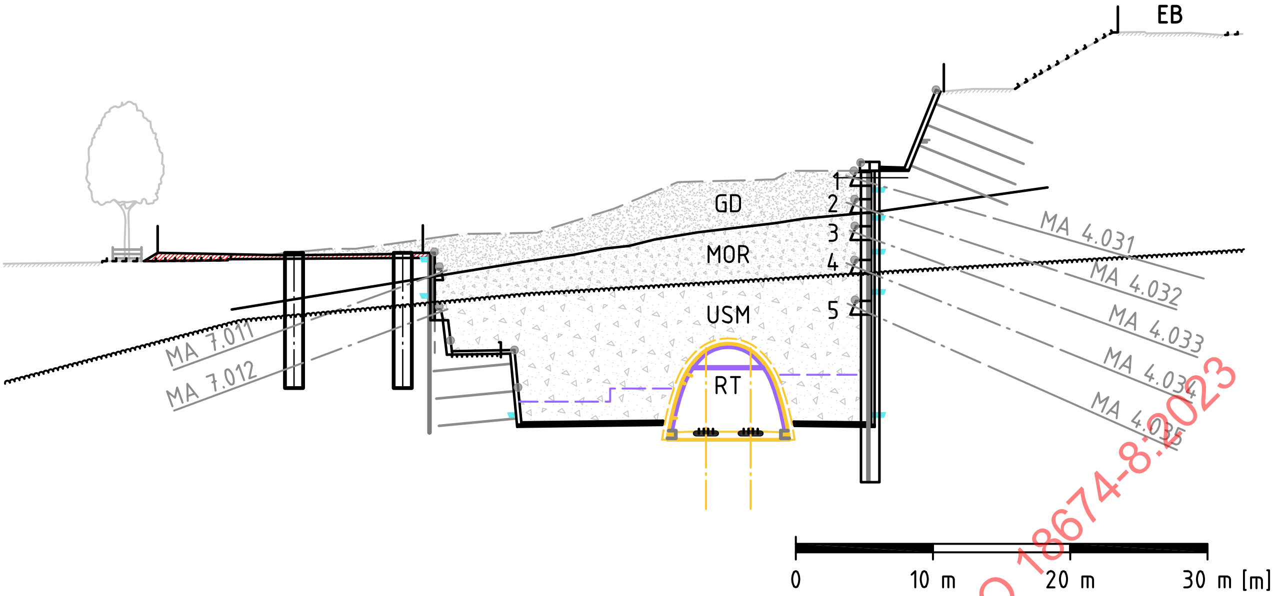
[a] September 2015.

Figure B.5 — Evolution of load and temperature during one month

B.3 Electric load cell: Monitoring of a temporary open excavation

a) Owner of the project	Regional Transport Berne - Solothurn (*RBS — Regionalverkehr Bern – Solothurn)*.
b) Name and location of the project	Cut-and-cover railway tunnel in the approach to the Berne main station adjacent to an existing tunnel. Dimension of the excavation: length 165 m; width 22 m to 40 m; depth 20 m. Excavation walls supported by bored piles (diameter 1,3 m, spacing 2 m to 2,5 m, depth up to 27 m), horizontal concrete beams and post-tensioned anchors (total length up to 38 m) (see Figures B.6 to B.8).
c) Name of the company carrying out the monitoring project	Various companies.
d) Monitoring project	Monitoring of the excavation, adjacent buildings and the existing railway tunnel during and after the excavation, essentially in respect to: — loads from post-tensioned anchors distributed into concrete beams and piles — displacements of the beams by geodetic measurements — horizontal deflections of the vertical piles by in-place inclinometers — displacements of the ground by multipoint rod extensometers (in selected positions in combination with soil nailing)
e) Instrumentation	Electric anchor load cells; Automated tachymeters; In-place inclinometers.
f) Instrumentation details	63 anchor load cells in 18 sections. Automatic reading. Three tachymeters covering 34 monitoring sections. About six survey points (targets) per section. Total number of targets: 220. Automatic reading. Number of in-place inclinometers: 23. Automatic reading. Number of multi-point extensometers: 2.
g) Commissioning of the monitoring system	Step-by-step, in tune with excavation progress.
h) Measurements	Measuring interval of instruments and geodetic survey:

	— every hour during excavation of top slopes above the first row of tiebacks and during the initial excavation of the umbrella arch (10-meter length) — every two hours during excavation in front of the tieback pile wall — every eight hours once the excavation is complete
i) Measuring uncertainty	Anchor load (load cell): ±1 kN Geodetic monitoring: ±1 mm Inclination (in-place inclinometer): ±0,2 mm/m
j) Principal results of the monitoring project	The initial load tests of the anchors showed that the assumed bearing capacity in the glacial deposits could not be achieved, which required an additional row of post-tensioned anchors. A conservative design of the anchors was chosen to reduce the likelihood of needing additional anchors, as this would have required scaffolding at high costs. The loads of the post-tensioned anchors increased with the excavation works, within the preset limits (see Figure B.9).
k) Assessment and evaluation of the measuring results	The readings of the anchor load cells were compared with the load test results and design loads of the anchors and monitored with respect to time and the depth of excavation.
l) Location and date of submission of the report	Spring. D. (2018). RBS Bern Station Expansion: Project Development from the client's perspective, Proc. Swiss Tunnel Congress 2018, 124 – 137.



Key

MA	measuring anchor: anchor with a load cell	GD	glacial deposits: ice- marginal
1,2,3,4,5	number of the load cell	MOR	glacial moraine
EB	existing building	USM	lower fresh water molasse (bedrock)
RT	existing railway tunnel		

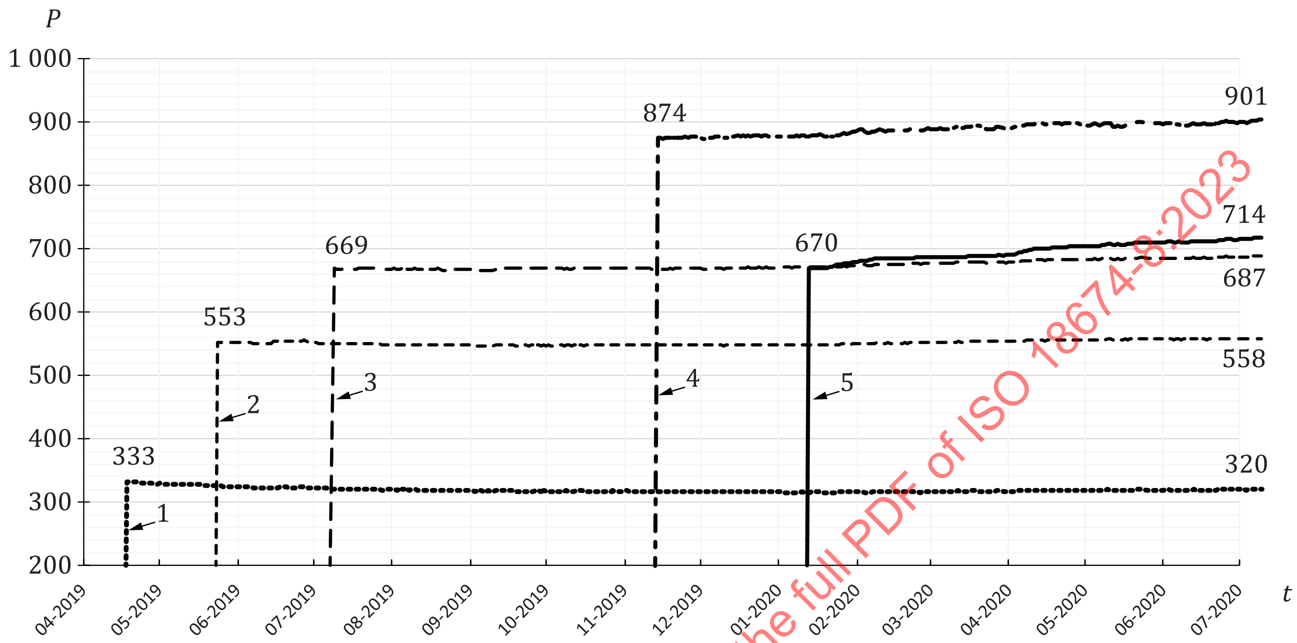
Figure B.6 — Example of a load cell monitoring section (simplified)

NOTE Bored pile wall with horizontal beams and post-tensioned anchors.

Figure B.7 — Northern part of excavation with existing tunnel (overburden removed with a view from the outside of the tunnel lining)

Figure B.8 — Southern part of the excavation with the portal area of the new tunnel in centre and existing tunnel with the lining exposed

Figure B.9 shows the development of the anchor loads over a seven-month period. The uppermost anchor No. 1, installed in soil, was tensioned in mid-April 2019 to 333 kN, the load dropped slightly until July 2020 to 320 kN. The next anchor (No. 2) was anchored in bedrock with an initial load of 553 kN that remained nearly constant with 558 kN. Similarly with the third level (No. 3) that started with 669 kN and increased slightly to 687 kN. The loads increased most (3 % to 6 %) in the two lowest anchors (Nos. 4 and 5).



Key

t	time [month/year]	MQ	monitoring cross section with number
P	anchor load [kN]	1, 2, 3, 4, 5	reference number of anchor equipped with a load cell

Figure B.9 — Measurements of anchor loads in section MQ 4.02

B.4 Electric anchor load cells: Monitoring of an anchored retaining wall

a) Owner of the project — Community of Olten, Switzerland

b) Name and location of the project — Pile retaining wall “Tannwaldstrasse”, CH – Olten

c) Name of the company carrying out the monitoring project — General contractor, including installation of anchors.

Manufacturing, testing and tensioning of anchors and installation of load cells by sub-contractor.

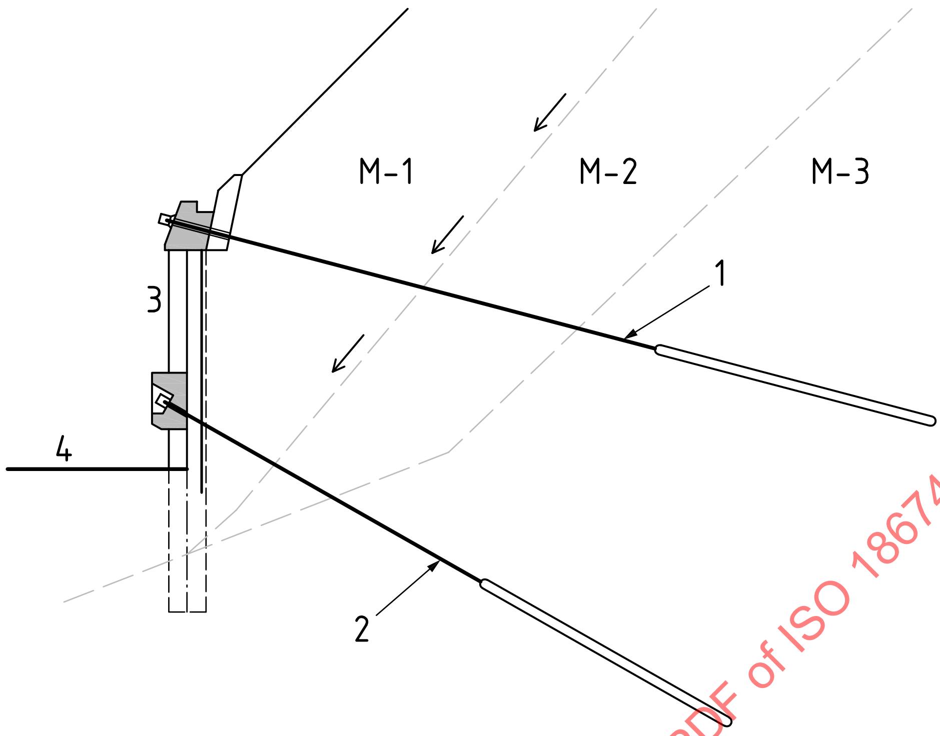
Project and monitoring design and supervision: advisor from Zürich.

d) Monitoring project — For a road, the toe of a steep sliding slope was stabilised by an anchored retaining wall in the 1980ties (see Figures B.10 and B.11).

Inspection in 2007 showed that the pre-tensioned anchors were heavily damaged by corrosion. The anchors were replaced in 2009 and monitoring of anchor loads introduced for a periodic assessment of the slope stability and structural health of the anchored structure.

e) Instrumentation — Eight electric anchor load cells, in combination with four inclinometers.

f)	Instrumentation details	Load cells with overvoltage protection (load bearing element: hollow steel cylinder Ø 139 mm/125 mm, height 80 mm; measuring principle: electric resistance strain gauges).
g)	Installation details	Anchor heads and load cells protected against rain and mechanical damage by protection cap or by placement in a recess. Cables for measurements of anchor loads fixed on the wall in inox reservation tubes and routed to two terminal boxes (one on each end of the retaining wall).
h)	Commissioning of the monitoring system	Step-by-step with installation of the anchors.
i)	Measurements	Measuring interval of the anchor load cells: 1 year Measuring interval of the inclinometers: 6 years
j)	Measuring uncertainty	Unspecified. — Precision of load cells as specified by manufacturer: ±1 % FS. — Difference between measurements of load cells and lift-off load measured by hydraulic jack: ±9 kN (±2 %).
k)	Principal results of the monitoring project	As expected, measurements showed a loss of the anchor loads of about 4 % to 10 % over the first four years after the installation of the anchors. Since then, variations of anchor loads are small (about ±2 %) (see Figure B.12).
l)	Assessment and evaluation of the measuring results	Measurements of the anchor loads show reliable results, allowing for a periodic assessment of the slope stability and of the structural health of the anchored retaining wall (integrity of the anchors).

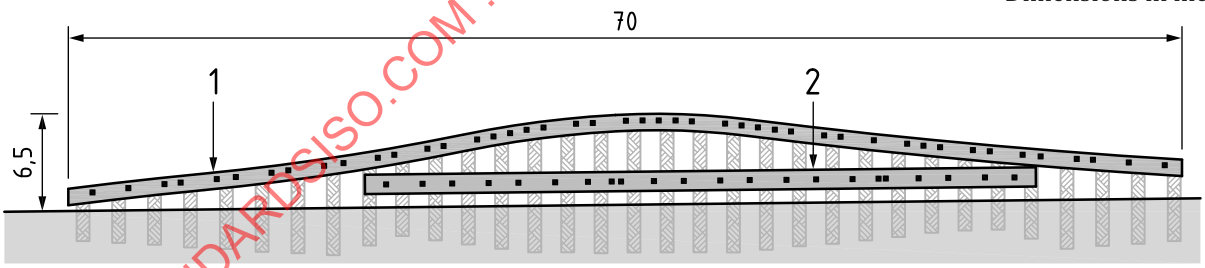


Key

1	upper row permanent anchor	M-1	marl, heavily weathered and debris
2	lower row permanent anchor	M-2	marl, weathered
3	retaining wall	M-3	marl, solid
4	road (“Tannwaldstrasse”)		

Figure B.10 — Schematic cross section of the anchored retaining wall

Dimensions in metres



Key

1 five load cells in 45 upper row permanent anchors, lock-off load 545 kN

2 three load cells in 20 lower row permanent anchors, lock-off load 780 kN

Figure B.11 — Schematic view of the anchored retaining wall

