International Standard

ISO 18674-7

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 7: Measurement of strains: Strain gauges

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

Partie 7: Mesure des déformations : jauges de déformation

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This corrected version of ISO 18674-7:2025 incorporates the following corrections:

— errors in figure keys, formulae, and throughout the text have been corrected.

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 7: Measurement of strains: Strain gauges

1 Scope

This document specifies the measurement of strain by means of strain gauges and strainmeters 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

  — 1-D structural members such as piles, struts, props and anchor tendons;

  — 2-D structural members such as foundation plates, sheet piles, diaphragm walls, retaining walls and shotcrete/concrete tunnel linings;

  — 3-D structural members such as gravity dams, earth- and rock-fill dams, embankments and reinforced soil structures;

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

— evaluating stability during or after construction.

With the aid of a stress-strain relationship of the material, strain data can be converted into stress and/or forces (for 1-D members; see ISO 18674-8) or stresses (for 2-D and 3-D members, see ISO 18674-5).

NOTE 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 strain measuring instruments as part of the geotechnical investigation and testing in accordance with References [1] and [2].

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 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
strain gauge
field instrument for measuring strain

Note 1 to entry: The strain is sensed over the full length of the gauge, commonly by a vibrating wire sensor (VW), an electrical resistance strain gauge sensor or an Fibre Bragg Grating sensor (FBG) with optical sensing).

Note 2 to entry: Typical configurations are strain gauges mounted to a surface of a steel member [see 3.3 and Figures 1 a), 1 b), 3 a) and 3 b)], strain gauges embedded in concrete [see 3.4 and Figure 1 c)], or FBG integrated into the structure or fixed onto the surface [see Figure 3 b)].

Note 3 to entry: A series of FBG sensors with a single lead cable is called an FBG array (see Figure 4).

Note 4 to entry: For mechanical strain gauges, see Reference [3].

Note 5 to entry: Distributed fibre optic strain measurements (DFOS) are not subject to this document, as this new technology is still under intensive development and change. Usage principles and examples for DFOS are given in Annex B.

3.2
strainmeter
strain gauge for measuring strain by means of a displacement measurement

Note 1 to entry: The strain is sensed over the defined gauge length of the strainmeter (see Figure 2).

Note 2 to entry: An extensometer with a defined gauge length, for example a probe extensometer (see ISO 18674-2) has the function of a strainmeter.

Note 3 to entry: A typical configuration is a continuous chain of strainmeters embedded in fill, soil or concrete.

Note 4 to entry: Alternative terms for a strainmeter used in practice are “fill extensometer”, “soil strainmeter”, “soil extensometer”, “embankment extensometer” or “linear continuous extensometer“.

Note 5 to entry: The term strainmeter is sometimes (incorrectly) used for specific strain gauge sensors, e.g. rebar strainmeter.

3.3
surface-mounted strain gauge
strain gauge designed for attachment at the surface of a structural member

Note 1 to entry: There are different types of instruments for surface-mounting: spot-weldable, arc welded and adhesive bonded strain gauges.

3.4
embedment strain gauge
strain gauge for the embedment in a medium

Note 1 to entry: Typically, the medium is mortar, grout, reinforced concrete, shotcrete or mass concrete.

Note 2 to entry: See Figure 1 c).

3.5
instrumented reinforcement bar
piece of reinforcement bar into which a strain gauge is integrated

Note 1 to entry: When installed alongside the structural reinforcement, this is commonly known as a "sister bar".

Note 2 to entry: When installed as part of the structural reinforcement this is commonly known as a "rebar strain meter".

Note 3 to entry: Sister bars and rebar strain meters measure the same parameter: overall strain in a reinforced concrete element. The difference in their use is that when using sister bars the overall steel area in the structural element increases slightly leading to a reduction of the actual strain at the measuring section.

Note 4 to entry: See Figure 5.

3.6
gauge length
L
initial length over which the strain is measured by the strain gauge or initial length over which the displacement is measured by a strainmeter

Note 1 to entry: For vibrating wire strain gauges and strainmeters the length is defined by the mounting blocks, end plates or anchors.

Note 2 to entry: For a Fiber Bragg Grating (FBG) strain gauge, depending on the mounting, the gauge length is either the length of the grating or the distance between the mounting blocks / end plates, anchors or spots of adhesive (see Figures 3 and 4).

4 Symbols

Table 1 lists all symbols and subscripts used in this document.

Table 1 — symbols

Symbol	Definition	Unit
A	area	m^2
C_T	thermo optic coefficient	MHz/°C
C_ε	strain transfer coefficient	MHz/%
D	diameter	m
d	distance	m
E	Young's modulus	Pa
F	normal force	N
H	height	m
L	gauge length	m
s	spacing between strain gauge sensing element and steel surface	mm
T	temperature	°C
t_{web}	web thickness	mm
W	width	m
α_T	coefficient of linear thermal expansion	K^{-1}
ΔT_i	change in temperature at location *i*	°C
$\Delta\varepsilon_i$	change in strain at location *i*	- [a]
$\Delta\nu_{bi}$	change in Brillouin peak frequency at location *i*	MHz
ε	strain	- [a]
ε_{ax}	axial strain	- [a]
με	micro strain	μm/m
ν_b	Brillouin peak frequency	MHz
σ	stress	Pa
[a] Strain and strain changes are expressed as an elongation per m, so m/m, resulting in a dimensionless parameter.		

5 Instruments

5.1 General

5.1.1 When using strain gauges for geotechnical monitoring, distinctions should be made between:

a) the type of the strain measuring instrument (strain gauge type versus strainmeter);

b) the location of the measuring point (at the surface of a structural member versus embedded in a medium);

c) the measurement principle of the instrument (e.g. vibrating wire (VW), Fiber Bragg Grating (FBG) or electrical resistance);

d) the material in or on which the instrument is placed (e.g. steel, concrete, soil…).

Table 2 and Figures 1 to 5 show different types of instruments, the location of the measuring point and measurement principles .

NOTE 1 Annex D provides an overview of the various types of strain gauge and strainmeters in some common geotechnical applications.

NOTE 2 Examples of typical application for various types of strain gauges and strainmeters are presented in Annex E.

Table 2 — Types of strain gauges and strainmeters in geotechnical monitoring

Strain measuring instrument and common configuration	Location of measuring point	Member / medium	Common gauge length, *L* (mm)	Common sensor	Subclause
surface-mounted strain gauge	at the surface of a structural member	steel [a]	5 to 150	vibrating wire (VW), FBG	5.2.1
		concrete [b]	50 to 350		
embedment strain gauge	inside medium	concrete [c]	50 to 500		5.2.2
strainmeter		fill [d]	1 000 to 3 000	displacement transducer	5.3

[a] For example, reinforcing bar, steel pile, sheet pile, strut.

[b] For example, pillars, girder, beam.

[c] For example, concrete pile, diaphragm wall, gravity dam, shotcrete tunnel lining.

[d] For example, earth dam, rock-fill dam, embankment.

5.1.2 In line with the sign convention for most geotechnical engineering applications, compressive strain should be taken as positive.

NOTE 1 Within the ISO 18674 series, this sign convention is adopted in ISO 18674-4, ISO 18674-5 and ISO 18674-8, however not ISO 18674-2. The latter (extensometers) adopts the sign convention established in geodesy.

NOTE 2 In ISO 18674-1, no unified rules were set on the sign convention for geotechnical monitoring instrumentations, as the sign convention is often context dependent. It is emphasized that a clear sign convention is to be made for each application (see ISO 18674-1:2015).

5.1.3 The instrument shall be selected such that it has negligible influence on the elastic stiffness of the monitored structure.

5.1.4 The measuring range of the instrument shall be selected according to the expected strain range within the project. The measuring range of the instrument shall be 25 % higher than the expected strain in the member to measure.

NOTE Many types of vibrating wire strain gauges and strainmeters allow the adjusting of the range starting point towards tension or compression.

5.1.5 If the stiffness of the medium is changing in time (e.g. in course of curing or consolidation of the medium), an instrument should be selected which is designed for a low stiffness in the strain measuring direction.

5.1.6 For an instrument installed on matrix or composite material, sturdiness and the gauge length of the strain instrument shall be selected considering the size of the aggregates in the medium. The ratio of the gauge length to the largest aggregate should be more than 5.

5.1.7 In order to measure homogenous strain, strain instruments shall not be located at or near the ends of a structural member or connection points with other structural members. A distance of at least three times the width or the diameter, of the member can be considered as sufficient.

NOTE Recommended distance in dynamic load testing (see Reference [10]) is a distance at least 1,5 times the width or diameter of pile.

5.1.8 The temperature shall be monitored at the measurement point or at a representative location.

NOTE Commercially available vibrating wire strain gauges generally have integrated temperature sensors. FBG sensors usually have loose sensing (dummy) elements for compensation of temperature effects or integrated temperature sensors.

5.1.9 Temperature effects on the instrument as well as on the structure itself shall be taken into account when reporting and analysing the data.

NOTE 1 Temperature effects on the stresses in the structural members are often large and insufficiently known; see Annex C.

NOTE 2 The use of strain gauges compensated for specific materials (steel, aluminium, concrete) avoids the need to correct the measured strain to obtain the structural strain and calculate the stress.

5.1.10 When FBG sensors are used in series, FBG shall be manufactured with different Bragg wavelengths.

NOTE The number of FBG that can be in series will depend on the FBG interrogator as well as the amount of strain to be measured.

5.2 Strain gauges

5.2.1 Surface-mounted strain gauges

5.2.1.1 The fixing and the type of strain gauge should be selected depending on the surface onto which it is to be mounted.

NOTE 1 Micro spot-welded gauges [see Figure 1 a)] are commonly applied to rebars. Arc-welded gauges [see Figure 1 b)] are commonly applied to larger steel members such as struts, steel sets or sheet piles.

NOTE 2 The advantages of the micro spot-welded gauge are its small size and the minimization of the errors that result from bending of the member due to the close proximity of the strain gauge to the surface of the member.

NOTE 3 If adequate space is available on a steel surface, an arc-welded version is commonly preferred, see Reference [4].

NOTE 4 Adhesive bonding is commonly applied on compound material or for FBG sensors on steel. FBG strain arrays are sometimes bonded into pre-manufactured grooves of steel members for better protection.

NOTE 5 Strain gauges based on the electrical resistance principle (foils sensors) are commonly applied using adhesive bonding to a surface.

5.2.1.2 When arc-welding is applied, a dummy rod should be used as a spacer whilst the mounting blocks are welded [see key reference 1 in Figure 1 b)]. After welding, the dummy rod can be replaced by the strain gauge sensor [see key references 2, 3 and 4 in Figure 1 b)].

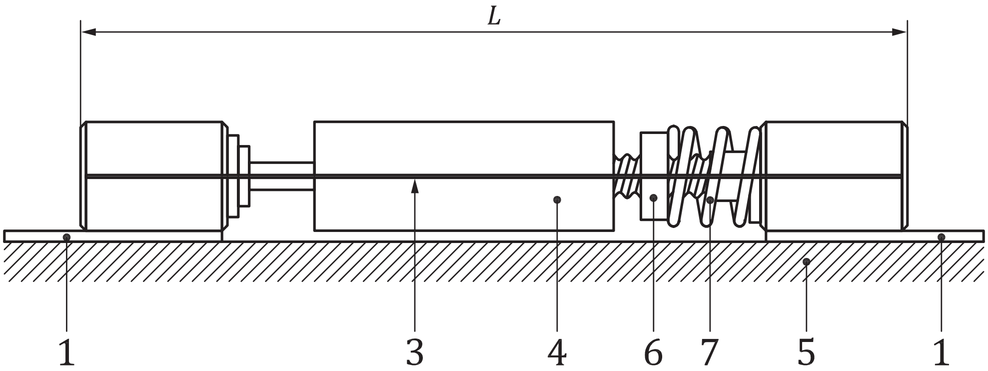
NOTE This procedure is carried out to shield the sensitive strain sensor from arc-welding effects.

5.2.1.3 When mounting blocks are used, these can have set screws acting in different directions.

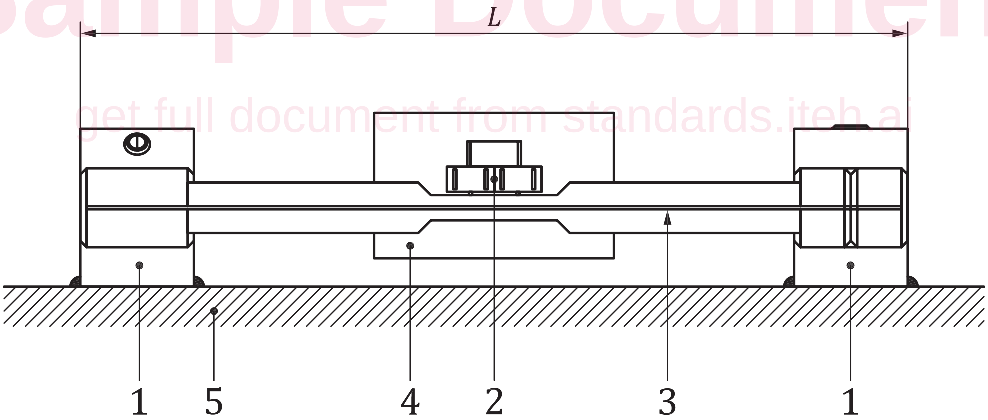
NOTE 1 As example, see Figure 12 for the position and acting direction of the set screws.

NOTE 2 For examples with mounting blocks see Figures 3 c) and Figure 4 a).

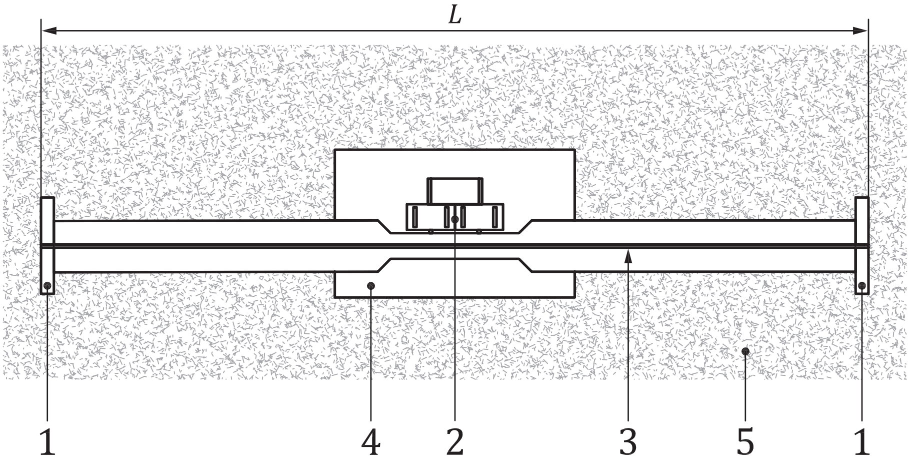
5.2.1.4 For gauge length installation of FBG strain arrays and FBG strain gauges, the cable / sensor shall be pre-tensioned. The pretension level shall consider the strain to be measured.



a) Spot-weldable strain gauge



b) Arc-weldable strain gauge

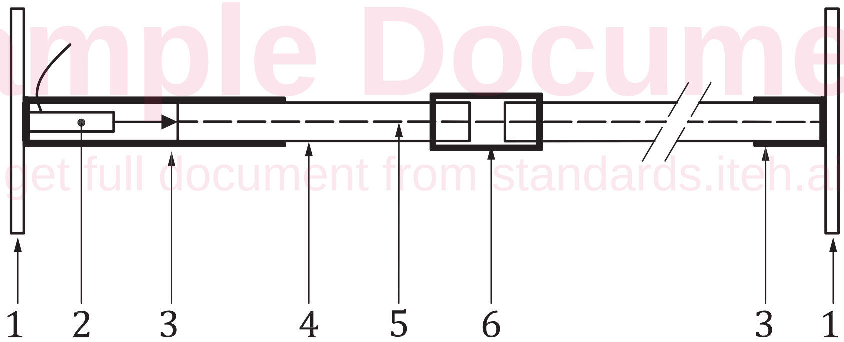


c) Embedment strain gauge

Key

1 anchor/flange, mounting block/tab
2 plucking coil
3 steel vibrating wire
4 protection housing
5 substrate/medium (e.g. steel/concrete)
6 screw nut on setting screw
7 spring

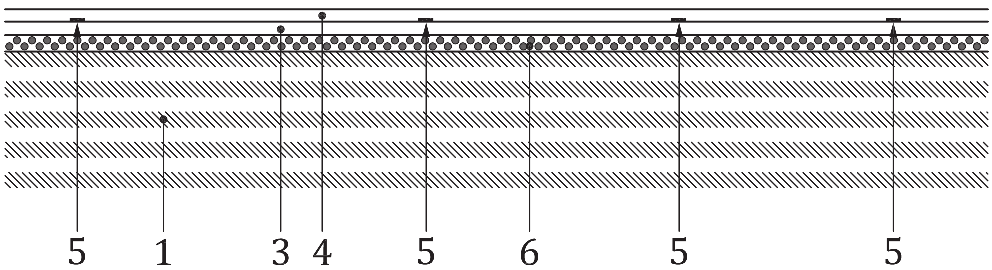
Figure 1 — Features of vibrating wire strain gauges



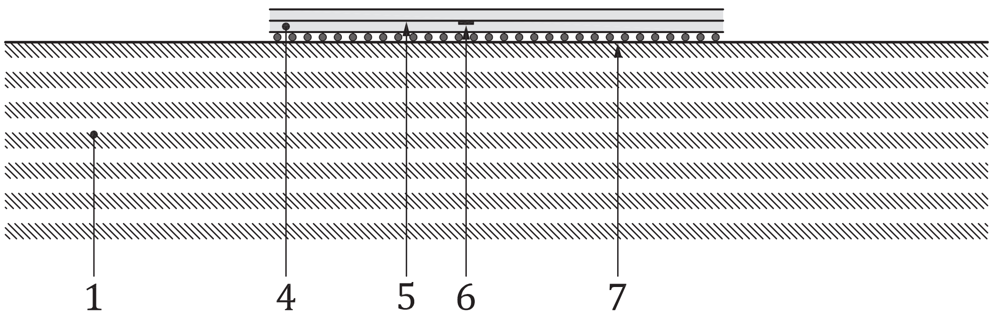
Key

1 anchor (here illustrated as flanges)
2 displacement transducer with electric cable
3 guide
4 telescopic tube
5 extension rod
6 sleeve

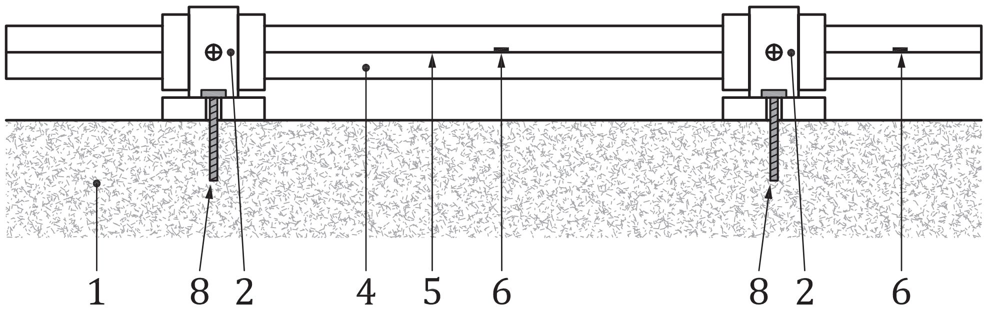
Figure 2 — Features of a strainmeter



a) Spot-weldable FBG strain gauge



b) Adhesive-bonded FBG strain gauge

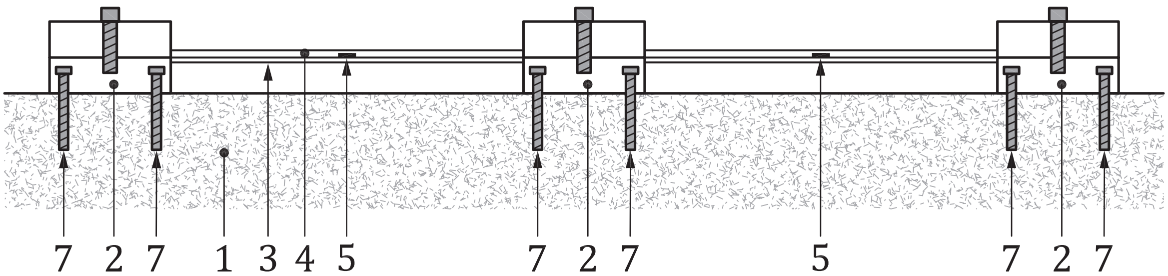


c) Bolt-on FBG strain gauge

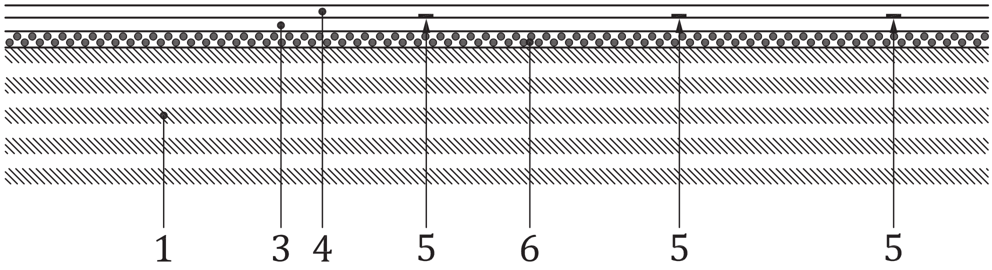
Key

1 medium (steel / concrete)
2 mounting block / end plate
3 welding (row or points)
4 protection housing
5 optical fibre
6 FBG (strain or temperature)
7 epoxy bonding
8 anchor / bolt

Figure 3 — Features of a FBG strain gauge



a) Clamp-mounted FBG strain array (gauge length installation)



b) Adhesive-bonded FBG strain array (continuous or spot)

Key

1 medium (steel / concrete)
2 mounting clamp
3 cable jacket
4 optical fibre
5 FBG (strain)
6 adhesive
7 anchor / bolt

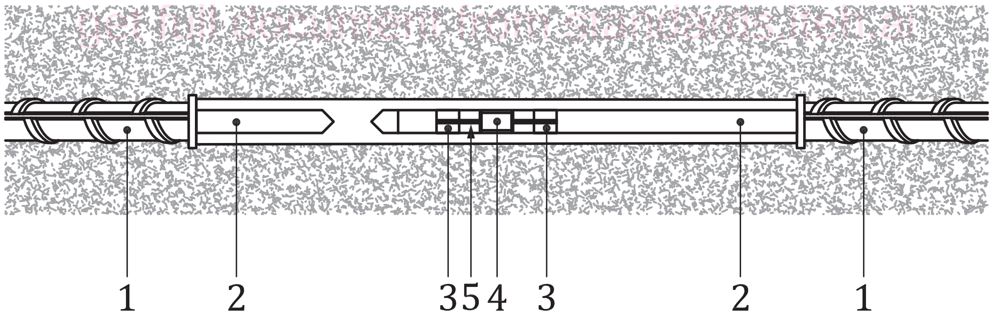
Figure 4 — Features of FBG strain arrays

5.2.2 Embedded strain gauges

5.2.2.1 Embedment strain gauges can be equipped with flanges at both ends of the gauge. The diameter of the flanges should be about 10 % to 20 % of the gauge length and at least twice the diameter of the gauge.

NOTE See Figure 1 c).

5.2.2.2 Instrumented reinforcement bars should be long enough to ensure load transfer from the surrounding concrete.



Key

1 re-bar anchors
2 strain sensor body
3 strain gauge end blocks
4 plucking coil
5 vibrating steel wire

Figure 5 — Features of an instrumented reinforcement bar

5.2.2.3 Embedded FBG strain arrays / cables with a protective coating to avoid direct contact between concrete and the optical fibre and gratings shall ensure that strain from the external coating/jacket is fully transferred to the optical fibre.

5.3 Strainmeters

Embedment strainmeters can be either fixed-installed or moved between equally spaced measuring marks embedded in the medium.

NOTE 1 For fixed-installed strainmeters, see Figure 2.

NOTE 2 For moveable strainmeters, see probe extensometer, ISO 18674-2:2016, 5.3.

NOTE 3 In contrast to strain gauges, embedment strainmeters are often aligned in a continuous chain of single strainmeter elements; see Figure 8.

5.4 Instruments for specific applications

5.4.1 Monitoring of 1-D structural members

5.4.1.1 The strain-sensing direction of the instrument shall be along the axis of the 1-D structural member.

NOTE Typical 1-D structural members are concrete pile, steel pile, strut, prop, anchor tendon.

5.4.1.2 The location of the instrument shall be specified in relation to its distance from the axis.

NOTE In the case of Figure 6 a), the measuring location coincides with the axis.

5.4.1.3 When bending moments occur or are to be measured in addition to axial strain the instrumentation design should consider the dimensions of the structural member to define the number and location of strain gauges per measuring section.

EXAMPLE 1 Concrete pile, see Figure 8.

EXAMPLE 2 Steel I-Beam, see Figure 7.

NOTE 1 In the layout of Figure 6 b), there are two opposite strain instrument locations at equal distance, *d*, to the axis. This configuration allows monitoring of axial strain and monitoring of bending of the member in a pre-specified direction.

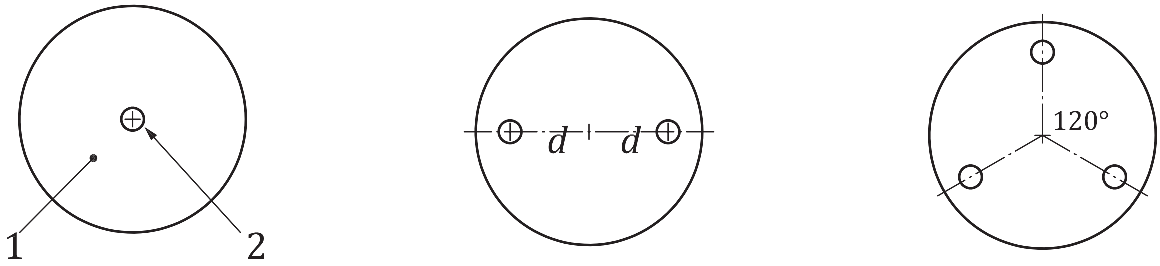
NOTE 2 The configuration of Figure 6 c) allows monitoring of bending in the principal strain directions.

NOTE 3 Pairs of gauges are typically installed as far as possible from the axis of the steel member and opposite across the axis (see Figure 7 for a cross-section of an I-beam identifying axis) so as to detect the strain due to bending when present.

5.4.1.4 Along the axis of a 1-D member, the strain measuring locations may be either discrete or continuous. For discrete locations, strain gauges should be selected; for continuous measuring lines a continuous chain of strainmeters should be used.

NOTE 1 Figure 8 shows an example with discrete and continuous strain gauges in a pile.

NOTE 2 Discrete measuring locations require interpolation of the strain measuring data, particularly in respect to bending. They also might serve as a redundancy check, e.g. for inclinometer measurements (see ISO 18674-3).



a) Axial strain in a pre-specified direction | **b) Axial strain plus bending in principal directions** | **c) Axial strain plus bending**

Key

1 concrete pile
2 strain measuring location
+ pile axis
d distance of strain instrument to axis

Figure 6 — Possible strain monitoring layouts in a concrete pile (cross-section)

a) Strain in ZZ-axis and bending around YY-axis | **b) Strain in ZZ-axis and bending around XX-axis**

Key

1, 2 number of strain gauge
d_1 distance of strain gauge to XX-axis
d_2 distance of strain gauge to YY-axis
a ½ height of I-Beam
b ½ width of I-Beam

Figure 7 — Possible layouts for monitoring of axial strain and bending of a steel I-beam