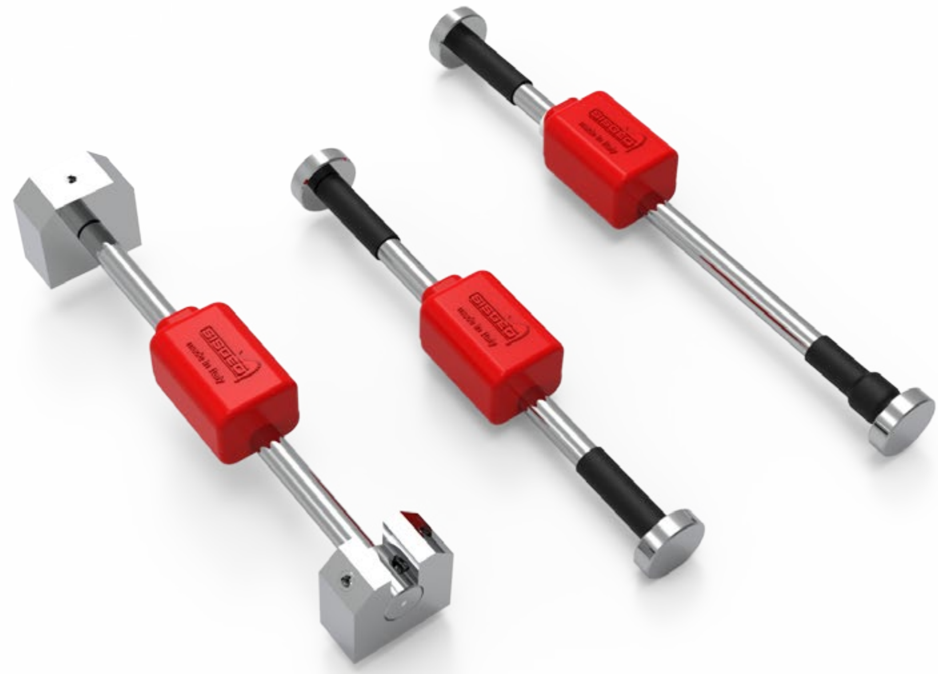
_ VIBRATING WIRE STRAIN GAUGES AND REBARS

USER MANUAL



STRAIN GAUGES
& THERMOMETERS

INDEX

Notes on the use of product

For safe and efficient use of the product, please read carefully the following instructions before starting any operation.

Any use of the product other than the one described in this manual shall be considered the user's full responsibility.
The same applies for any unauthorized modifications.
In addition to the hereby listed standards, the user must comply with the provisions of the current legislation regarding personal safety and health together with all other persons in the workplace.
SISGEO is not responsible for any accident, breakdown or other problems due to lack of knowledge and / or non-compliance with the requirements contained in this manual.
Check that the product has not been damaged during the transport.
Verify that the package includes all items as well as any requested optional accessories; if anything is missing, please promptly contact SISGEO.
The user must strictly follow all the operations described in this manual.
Maintenance or repair of the device is permitted only by authorized operators.
These operators must be physically and intellectually suitable.
For information about instrument or to order spare parts, always specify the product information which can be found on the identification label.
When replacing parts, always use ORIGINAL SPARE PARTS.

Symbols

Pay particular attention to the following instruction.

Identification

Instruments can be clearly identified by
- the batch number (written on the Compliance Certificate)
- the serial number (s/n) engraved on the instrument
- the label on the instrument
- the label on the cable

Note

The present Manual is issued by SISGEO in English Language and should be available in other different languages.
In order to avoid discrepancies and disagreements on the interpretation of the meanings, Sisgeo Srl declares that English Language prevails.
All the information in this document is the property of Sisgeo S.r.l. and should not be used or reproduced without permission from Sisgeo S.r.l.
We reserve the right to change our product without prior notice.

INTRODUCTION

VIBRATING WIRE STRAIN GAUGES measure strains on steel, in concrete or in reinforced concrete structures. Once integrated with the constructions to be monitored, they change the electric signal according to the strains.
These strain gauges use the vibrating wire principle: a steel wire is tensioned between two blocks which are anchored onto a steel surface or cast into concrete. Changes of strain (i.e. deformations) will cause a change of the wire's tension. This leads to a change of the wire's resonant frequency. Placed next to the center of the wire, a pair of coils produces the wire's vibration. Dedicated readouts are able to detect the correct resonant frequency of the gauge.
For each structure to be monitored, a specific arrangement of several strain gauges is necessary to understand the global behavior. Commonly a pair of gauges is used into/onto a beam element in order to calculate the bending moments as well as the normal force.

VIBRATING WIRE REBAR STRAIN METERS are "rebars" (reinforcing rod for concrete) which incorporate a vibrating wire strain gauge element. A thermistor is included in each strain meter.
Rebars strain meters are designed to be welded into rebar cage and become an integral part of it.

DESCRIPTION

VIBRATING STRAIN GAUGES

They consist in a hollow cylindrical body with the internal steel wire tensioned between the two ends. Outside, a resin cover protects the coils. An internal thermistor allows temperature measurement.

Here below are listed all VW strain gauge types from SISGEO:

- 0VK4000VS00 Arc-weldable strain gauge for steel structures;

- 0VK4000VSC0 Surface strain gauge for concrete or rocky surfaces;

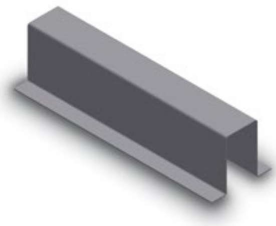
- 0VK4000SM00 shotcrete strain gauge to be installed into shotcrete linings or if is important to adjust the pre-tensioning of the gauge

- 0VK4200VC00 embedded strain gauges to be cast into fresh concrete;
- 0VK4200VCHP embedded strain gauges to be cast into deep concrete elements where the static pressure is high before the concrete cure (depth greater than 30-40m)

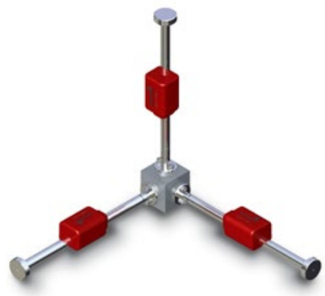
Some accessories can be supplied for the gauge's installation:

- 0VK400JIG00 welding jig for setting the exact distance between the mouting blocks;

- 0VK400COVER Steel protective cover for models VK4000-VS/VSC;



- 0VK42VC3D00 3D Rosette mounting block in order to position N.3 VK4200-VC/VCHP in 3 perpendicular directions.



<u>VIBRATING WIRE REBARS (AVAILABLE ONLY ON REQUEST)</u>

They consist in a piece of reinforcement steel (rebar), instrumented with a vibrating wire strain gauges covered by thermal retractable sheath. An internal thermistor allows temperature measurement.

PRELIMINARY CHECKS

Before starting the installation we recommend to check the instruments connecting to a portable readout (see "Taking Measurements"). Pay attention to the pre-tension that should match approximately mid-range for VK4200 type.

Useful tools (not supplied), for different type of strain gauges or rebars:

- allen key SW3
- iron tie / nylon tie / adhesive tape
- welder
- hard foam or extruded polystyrene
- drilling machine
- additional steel rebars

INSTALLATION

IMPORTANTE NOTE

Pay attention that the ends of the strain gauges should NEVER be rotated or pulled excessively. This can cause wrong readings or even irreparable damage to the instrument.

INSTALLATION OF EMBEDDED STRAIN GAUGES IN CONCRETE

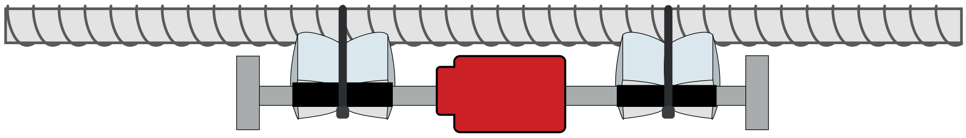
The common method for the installation of embedded strain gauges is described as follows:

1. Mark the position of each sensor and its orientation;
2. If necessary, place a rebar (or a pair of rebars) at the desired position (e.g. if there are no steel reinforcements available);
3. Place 2 pieces of hard foam (or extruded polystyrene) between the gauge and the rebar if the gauge has to be installed along it;
4. Tie the strain gauge firmly with nylon ties around each styrofoam piece, or directly around the protective black sheath at both ends. It is important that the end flanges are not in contact with the rebar;
5. Tie the cable along available rebars, avoiding the cable to touch the sensor's end flange.

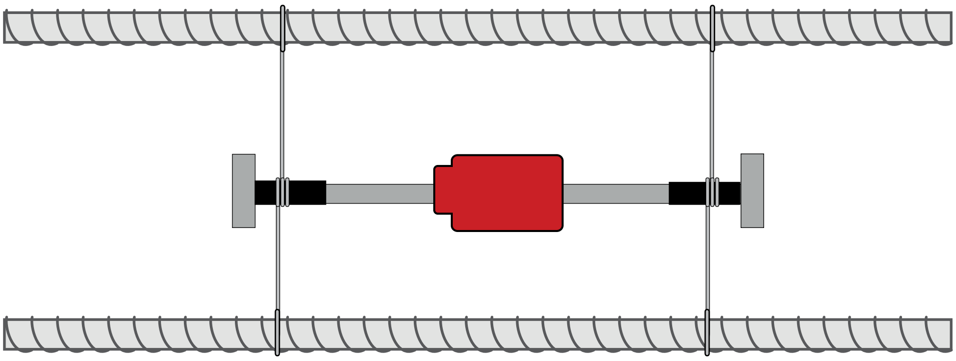
An alternative method consists in using iron ties to 'suspend' the gage between parallel rebars. To perform this, prepare 2 pairs of long wires, fold them in 2, twist each wire around the sensor body protected with some rubber and twist the free side of the folded wire around the closest rebar. Repeat this operation on the parallel rebar, as well as on the other side of the sensor (see pictures hereafter).
Better is, to tie a pair of steel rebars perpendicular to the available parallel rebars, at an interdistance of around 100mm. Then, tie the sensor body on these new rebars.

NOTE: the iron tire wire is generally used, but if for some reason the wire is not perfectly surrounded with concrete, there could appear a competition between this iron wire and the internal measuring wire, that will lead to a wrong measurement. Therefore it is advised to use nylon ties, or to use some rubber layer between the iron tie and the sensor's body.

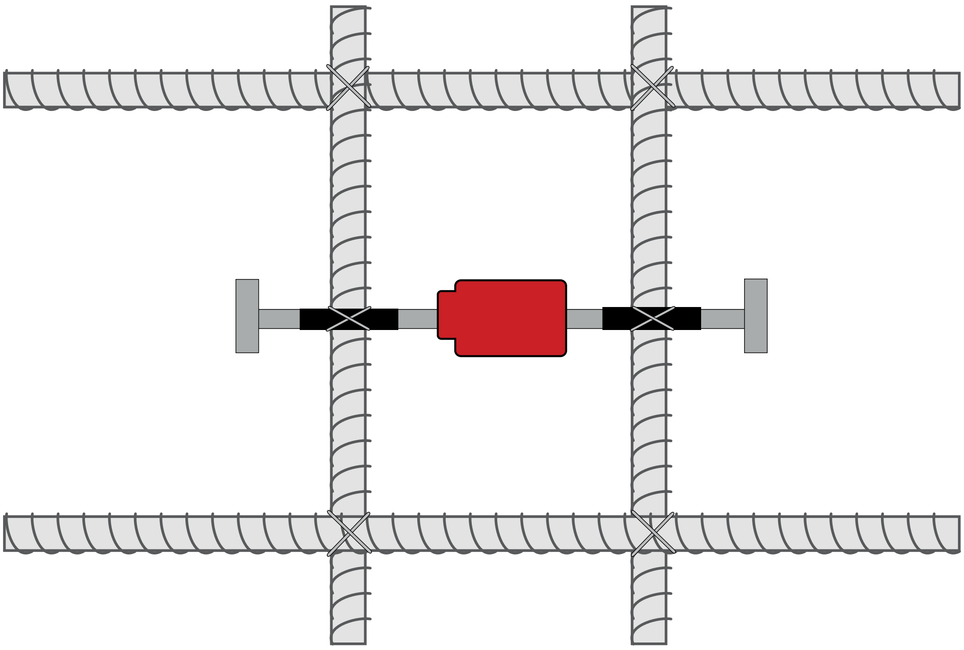
NOTE: the iron tie should not be tensioned too much in order to do not deform the strain gauge itself and damage it.



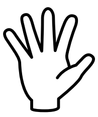
Classical method



Suspended method



Alternative rebar method



IMPORTANT NOTES:

- Choose the 0VK4200VCHP model for any application where the installation depth is greater than 30-40m
- Choose the 0VK4000SM00 if the pre-tension has to be adjusted.
- Never pour concrete directly on the sensors, as it might damage them.
- Always keep the shield continuity inside the cable, splicing it at any junction until reaching the terminal box or switch panel or datalogger.

INSTALLATION OF EMBEDDED STRAIN GAUGES IN SHOTCRETE

Model: 0VK4000SM00 (could be also used into cast concrete)

This installation has to be performed by trained personal. Shotcrete is a harsh condition for strain gauges, which are small and sensitive instruments. In any case it is strongly recommended NOT to sprinkle shotcrete directly on the sensors.

Due to the robotisation of this method, it is almost impossible to avoid the sensors to be sprinkled directly. It is recommended to insert cables into individual protective tubes.

Two procedures allow the installation in safer conditions:

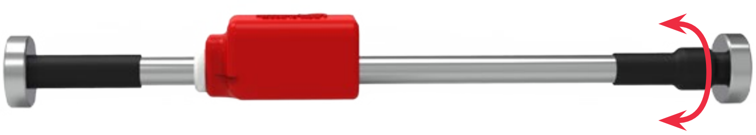
1. Cast each sensor into specimen tubes/bricks with the same concrete which will be used on the site. These specimens/bricks will be installed on site and sprinkled with shotcrete WITHIN 3 DAYS after their concrete cured.
2. Cover manually the sensors with fresh sprinkled shotcrete. Doing this, the sprinkled shotcrete will not damage the sensors. It is important to use the sprinkled concrete which contains all components that permits to sustain on vertical surfaces or a roof.

For any chosen method, please respect the following steps:

- If needed, adjust the pre-tension of the gauge, connecting the wires to a readout (see chapter "Taking Measurements"). Hold the collar on the longer branch then turn the end-flange next to it. Turn clockwise to lower the reading (more extensive range), or turn counter-clockwise to increase the reading (more compressive range).
- After the adjustement, cover with plastic tape the adjustement collar and nearby gauge tube in order to prevent incoming of cement milk.
- For method 1, insert the strain gauge into a mold with suitable dimensions, keeping the gauge suspended and centered (you can use the suspended method at p.7), then pour concrete and let it cure. Then, pull out the concreted gauge from the mold.
- If needed, anchor rebars at the desired positions in order to set the final position and direction of each gauge.
- Tie the gauges (or bricks/specimen tube) onto the available supports with nylon or iron ties (no styrofoam if the gauge is pre-cast in concrete specimens).
- Insert each cable into protective tubes and lay them firmly at any available surface.

IMPORTANT NOTES:

Always keep the shield continuity inside the cable, splicing it at any junction until reaching the terminal box or switch panel or datalogger.



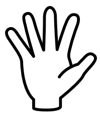
USE OF TRIAXIAL BLOCK FOR A 2D-3D ROSETTE

Models: 0VK4200VC00, 0VK4200VCHP

If the project requires a strain measurement along 2 or 3 perpendiculat axis, it is possible to use the dedicated block 0VK42VC3D00.
This block allows to insert the end-flange of 1 up to 3 strain gauges. Each flange is held with two screws.

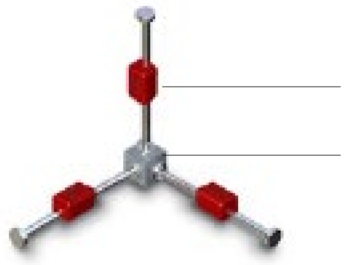
To use the 0VK42VC3D00 rosette block, please proceed as follows:

- Connect 2 or 3 sensor flanges on the rosette mounting block and screw them firmly.
- Install the gauges assembly with the same methods as described in the previous chapters, using 1, or better, 2 sensors to tie onto rebars.



Important is to avoid the assembly to move during the concreting phase.

- Lay the cables and protect them if needed, paying attention not to let the cables in contact with the flanges.



HOW TO CREATE A NO-STRESS CELL (NO-STRESS STRAIN GAUGE)

When installing strain gauges into shotcrete or classical cast concrete that is affected by outside conditions, these environmental effects on the sensors may be deduced from the load-induced strains with means of a statistical analysis (see APPENDIX 4). Doing this way, the effects are compensated over the whole structure, including the sensor itself.

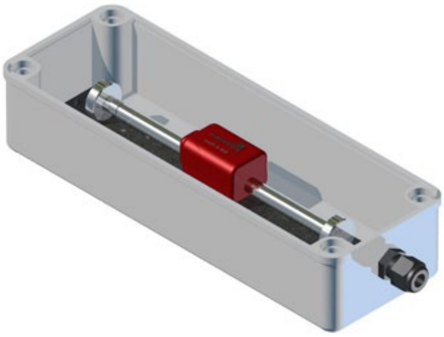
An alternative method consists in using an additionnal strain gauge placed into a dedicated insulation frame that is integrated inside the concrete: this is the "no-stress cell", that we will from now describe as "NSC". The NSC is connected to the same monitoring system as the other active sensors installed into the structure, or has to be measured with a VW-readout at the same time as the neighboring active sensors.

NSC-readings can be then be utilized to compensate the other strain gauge readings from all environmental effects that can influence concrete elements (temperature, humidity, etc...).

Main conditions in order to well-use the NSC are :

- the NSC should contain exactly the same concrete as around it (i.e. structural element), cast at the same date/time from the same delivery/mix;
- the NSC-box must have sufficient dimensions and insulation thickness;
- the insulation material has to be suitable and compressible;
- the orientation of the NSC box must prevent for any load-induced strain;
- one NSC for each structural element (concrete tunnel ring, pile, retaining wall, etc...).

A basic but efficient solution is to build a 5-face box composed with 5 polystyrene panels (or one single extruded block). Important is to suspend the strain gauge inside the box with means of iron or nylon ties, and let the signal cable run out of the box.



This box is then firmly fixed to the reinforcement steel rebars inside the structural element, before to cast the concrete. The orientation of the 'open side' is critical and has to respect these two criteria:

- the concrete has to fill 100% of the inner volume with a gravity method;
- the open side should not receive the main load inside the structural element.

Suggested **minimal** inner dimensions for a VK4200 strain gauge (consider material thickness for the outer dimensions) : L x w x H = 250 x 150 x 150 mm.

NOTE : for Shotcrete, this NSC method is also possible but by protecting the insulation panels with i.e. wood panels. The design of the box should also be changed in relation to the concrete layer thickness. Please refer also to the previous chapter for preparation of shotcrete strain gauges.

INSTALLATION OF ARC-WELDABLE STRAIN GAUGES

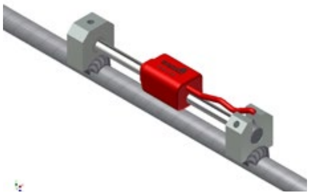
Firstly, clean the surface to be welded (grind any paint or rust).
The common method for arc-welded strain gauges installation is described as follows:

Insert the mounting jig into the two mounting blocks. The open block is placed against the jig's flange. The plain block is placed on the grooved part.

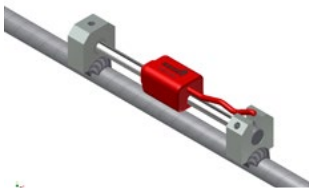
Lay the blocks onto a flat surface and tighten the allen screws. The plain block will have its screw entering into the jig's groove.

Lay the assembly onto the steel structure to be welded.
Weld each block on its narrow sides.

Once the jig is cold, unscrew and remove it from the mounting blocks.



Insert the strain gauge into the welded blocks. Pay attention to the grooved end-part of the cylindrical tube. This side has to be laid into the opened block. Tighten the 2 allen screws into the groove.



Connect the gauge to a readout and adjust precisely the sensor by pushing on the free side. Adjust to mid-range (typically around 2500 microstrain) or any other desired value and tighten the single screw.

Once all strain gauges of the zone are installed, lay their protected cables using welded pins or cable channels.

Upon each sensor is better to use a protective cover, i.e. 0VK400COVER. This cover should be welded lightly in order not to disturb the local strain field. Take and report a reading before and after performing any local welding around the sensor as it might change the reading values.

Best use of expanding foam inside the cover in order to minimize the thermal effects.

IMPORTANT NOTES:

- Always keep the shield continuity inside the cable, splicing it at any junction until reaching the terminal box or switch panel or datalogger.
- Welding operation should be performed by trained and authorized personal. In particular, attention should be paid not to put the welding electrode on the jig or on the allen screws. Welding near cables is also a delicate operation.
- **NEVER WELD the mounting blocks using the strain gauge itself since it will damage it irremediably. ALWAYS use the mounting jig.**

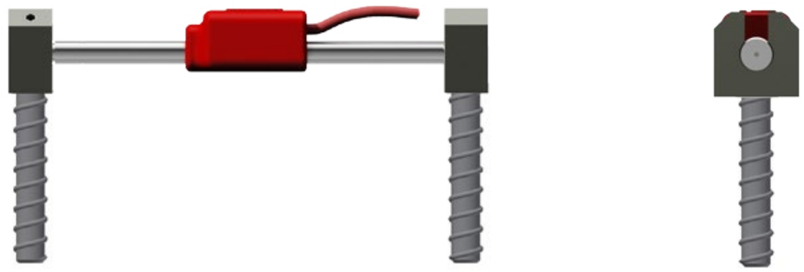
Refer to APPENDIX 5 for some position suggestions of the arc-weldable gauges.

INSTALLATION OF SURFACE ANCHORED STRAIN GAUGES

Model: 0VK4000VSC0

Firstly, level the local material if needed in order to obtain a plain surface.
The installation steps are described as follows:

- Mark the position of the 2 anchors, at an interdistance of 150mm.
- Drill 2 holes at min. Ø13mm to a depth of min. 65mm.
- Blow the holes in order to extract the dust.
- Inject a grout or any bi-component resin suitable for rebars in concrete, then insert the 2 mounting blocks, using the mounting jig 0VK400JIG00 in order to have a perfect alignment and interdistance of the blocks.
- Once the anchors are bound to the material, remove the jig using the allen screws and place the strain gage inside the mounting blocks. Pay attention to place the grooved end into the open block with 2 screws (refer to model 0VK4000VS0 for some illustrations).
- Tighten the 2 screws into the groove.
- Connect the gauge to a readout and adjust precisely the sensor by pushing on the free side. Adjust to mid-range or any other desired value and tighten the single screw.
- Disconnect from the readout, lay the cables and protect them if necessary and protect the sensor with a 0VK400COVER. Best use of expanding foam inside the cover in order to minimize the thermal effects.



IMPORTANT NOTE: Always keep the shield continuity inside the cable, splicing it at any junction until reaching the terminal box or switch panel or datalogger.

INSTALLATION OF VIBRATING WIRE REBARS

NOTE: never hold the VW rebar through the cable in order to avoid any damage of the cable and instrument-cable connection.

Usually the rebar strain meter is installed by welding in series with the reinforcing steel that is to be instrumented on site. The strain meter is of sufficient length that it may be welded in place without damaging the internal strain gauge element. Anyway, care should still be taken to ensure that the central portion of the strain meter does not become too hot, as the plucking coil and protective epoxy could melt. Take care not to damage or burn the instrument cable during welding.

Connect the instrument cable to a readout before and after the welding operations in order to verify the reading.

After welding, route the instrument cable along the rebar system and tie it off every meter using nylon cable ties. Avoid using iron tie wire to secure the cable as the cable could be cut.

TAKING MEASUREMENTS

The measurements (or readings) are taken connecting the cable wires to a readout or a datalogger according to the following scheme:

	Color	Function
VW strain gauges	Red	VW +
	Black	VW -
	White	Thermistor +
	Green	Thermistor -
	Shield	Shield

If the cable are spliced or jointed to a multicore cable, check and ensure the conductor's continuity and the color scheme.

DATA MANAGEMENT

SISGEO readouts provide the deformation measure directly in με (microstrains).
The conversion is based on the following equation:

$$\mu\varepsilon = (f^2 \times 10^{-3}) \times G$$

where:
f : is the wire vibration frequence in Hertz
G: is the gauge factor that is written on the "Compliance Certificate" within each delivery.

Note: the factor ($f^2 \times 10^{-3}$) is also named "Digit"

G nominal values for the main models are:

- VW weldable strain gauge 0VK4000VS00 = 4.043
- VW surface mounting strain gauge 0VK4000VSC0 = 4.043
- VW embedment strain gauges 0VK4200VC00 = 3.814
- VW rebar 0VKBAR00000 = 0.392

The follow-up measurements refer to the reference measurement.

$$\Delta\mu\varepsilon = L_i - L_0$$

where:
L_0 = reference measurement [με]
L_i = follow-up measurement in [με]

NOTE: Please refer to APPENDIX 2 for the definishion of "Reference measurement"

Reference reading (or reference measurement) shall be taken carefully once the installation is performed, after the stabilization and baseline period, and the instrument is in operating conditions.
The strain could be used in order to calculate stresses or forces, according to Hooke's law:

$$\sigma = \varepsilon \times E$$

where:
σ = stress [MPa]
ε = deformation [10^6 με in m/m]
E = Elastic modulus of material [MPa]

and the general formula :

$$F = \sigma \times S$$

where:
σ = stress [MPa], equivalent to a pressure in N/mm^2
F = Force [N]
S = surface of the section [m^2]

Temperature reading

SISGEO readout and dataloggers display the temperature of the gauge internal thermistor directly in °C. If the thermistor resistance value is taken, please use the conversion formula in APPENDIX 1.

TROUBLESHOOTING

Problem	Possible cause	Solution
Measure not stable	Instrument out of range	VK4200VS : None if already embedded VK4000VC : re-adjust the sensor
	Cable shield not connected	Connect the shield
	Electromagnetic fields generated by engines, generators, antennas, welders or high voltage lines nearby	Identify and remove the cause. Shield the signal cable.
	Insulation loss	None
	Grounding not well done	Provide efficient grounding
Wire not detected	Cable cut or damaged.	Measure the resistance between the red and black conductors. Acceptable values : 160Ω ± 10% (consider also cable length) If damage found, repair the cable: cable splicing kit is available at SISGEO.
	Uncorrect wiring	Make proper wiring

MAINTENANCE

After-sales assistance for calibrations, maintenance and repairs, is performed by SISGEO's Customer Care Department.
The authorization for shipment shall be activated by requesting an RMA ticket (Return Manufacturer Authorization).
Please open our Support Portal by clicking on ASSISTANCE menu of SISGEO web site, create your account and then fill in the RMA form clicking on "Request a new RMA".

Please read carefully the instruction published on Sisgeo's Support Portal.

Send back the instrument/equipment with the complete accessories, using suitable packaging, or, even better, the original ones.
The shipping costs shall be covered by the sender.

Please return to the following address, with correct delivery documentation, reporting the RMA code received:

SISGEO S.r.l.
Via F.Serpero, 4/F1
20060 MASATE (MI)

Customer Care Department e-mail: ***assistance@sisgeo.com***

APPENDIX 1

THERMISTOR TEMPERATURE CONVERSION

Resistance to temperature equation:

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

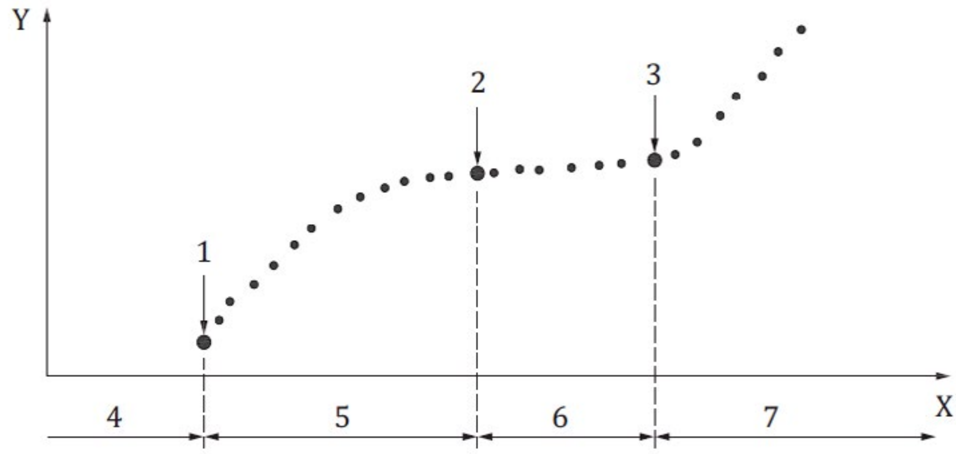
Where:
T= temperature in °C
LnR= natural Log of the thermistor resistance
A= 1.4051xe-3 (coefficents calculated over the -50° to +70°C span)
B= 2.369xe-4
C=1.019xe-7

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
16.60K	-10	5971	10	2417	30	1081	50
15.72K	-9	5692	11	2317	31	1040	51
14.90K	-8	5427	12	2221	32	1002	52
14.12K	-7	5177	13	2130	33	965.0	53
13.39K	-6	4939	14	2042	34	929.6	54
12.70K	-5	4714	15	1959	35	895.8	55
12.05K	-4	4500	16	1880	36	863.3	56
11.44K	-3	4297	17	1805	37	832.2	57
10.86K	-2	4105	18	1733	38	802.3	58
10.31K	-1	3922	19	1664	39	773.7	59
9796	0	3784	20	1598	40	746.3	60
9310	-1	3583	21	1535	41	719.9	61
8851	2	3426	22	1475	42	694.7	62
8417	3	3277	23	1418	43	670.4	63
8006	4	3135	24	1363	44	647.1	64
7618	5	3000	25	1310	45	624.7	65
7252	6	2872	26	1260	46	603.3	66
6905	7	2750	27	1212	47	582.6	67
6576	8	2633	28	1167	48	562.8	68
6265	9	2523	29	1123	49	543.7	69
						525.4	70

APPENDIX 2

DEFINITION OF DISTINCT MEASURING POINTS DURING A GEOTECHNICAL MONITORING PROJECT AS FOR ISO 18674-1

The standard ISO 18674-1 well describe the various measuring points distributed along the project timing. Here below are the description and definition as for the standard:



1 - initial measurement: it is the first measurement after installation.

2 - zero measurement: it is the measurement carried out after stabilization of installation effects.
The zero measurement is often taken as reference for subsequent measurements, as it is commonly related to local space and time coordinates.
The zero measurement is commonly carried out with increased measuring effort, e.g. repetition of measurements, to provide a reliable datum for subsequent measurements.

3 - reference measurement: it is a measurement which serves as reference base for previous and subsequent measurements.
The reference measurement is also known as datum measurement.
A new reference measurement is often used for a new construction phase.
The reference measurement is often derived from several measurements.

4 - installation period

5 - stabilization period

6 - period of baseline measurements: measurements carried out, subsequent to the zero measurement, over a period of time before any construction starts, to help in the definition of changes that occur from causes other than construction.
EXAMPLE Seasonal changes in groundwater levels, tidal and moisture content changes, climatic changes such as temperature, and incidence of sunlight.

7 - construction period

X - time
Y - reading

APPENDIX 3

EVALUATION OF TEMPERATURE EFFECTS ON STEEL ELEMENTS INSTRUMENTED WITH VW STRAIN GAUGES

This paragraph shows only suggestions for data anlysis. Sisgeo hereby declines any responsibility for the use of those suggestions that have to be evaluated by the construction designer.

If the instrumented structural element is exposed to big temperature changes (typically if exposed to sunlight) the strain gauge normally will adapt very fast to ambient temperature changes. On the other hand, the structural element, due to its big mass, will often adapt only several hours later. The strain gauge and the structural element will only compensate for temperature effects if both temperatures, the one of the strain gage and the temperature of the structural element, are the same. To achieve this, is important to:
- protect the strain gauge from direct sunlight using i.e. white protection box and insulating materilal such as special foams or polystirene
- take the readings, if possible, at conditions where these differences are minimal, i.e. after and during cloudy daytime, early in the morning, when effects to exposure to sunlight are minimal.

Now, the coefficient of thermal expansion of the strain gauge is quite equal to the coefficient of thermal expansion of a steel structural element where the instrument is installed. Therefore, for an unrestrained steel structural element, an increase or decrease in temperature will result in contraction or expansion of both the steel and the instrument simultaneously, resulting in a zero strain reading.

Conversely, when a steel structural element has fixed ends, the restrained ends will prevent any increase in length due to a temperature increase although thermal expansion is occurring within the steel. This tendency to expand will create compression throughout the steel element that will be read by the strain gauge. The contraction of steel during a decrease in temperature will create a similar phenomenon that results in an extension reading by the strain gauge. As the steel structural element expands and contracts due to temperature change, a change is registered on a strain gauge even if the structural element and the instrument have equal thermal coefficiant of expansion.

Readings from strain gauges (both strain and temperature) on steel elements, typically taken several times each day, give the change in strain reading due to incremental temperature changes. The period of data collectin for such goal is called by the ISO 18674-1 the “period of baseline measurements”: it should not involve any constructive work nor meteorological hazards that might affect the monitored system (see APPENDIX 3).

The stress data (microepsilon) can be graphically plotted against the temperature data (°C). Usually this graph shows a straigh line relationship: the slope of the trend-line of this relationship is the thermal factor F_T (microepsilon / °C) that can be used for data analysis.

The general equation of the system (steel memember + strain gauge) would be:

$$\Delta\mu\varepsilon_{\text{measured}} = \Delta\mu\varepsilon_{\text{temp. induced}} + \Delta\mu\varepsilon_{\text{applied load}}$$

is known that:

$$\Delta\mu\varepsilon_{\text{measured}} = (L_i - L_0)$$

and so can be utilized the F_T thermal factor to calculate the temperature-induced strain:

$$\Delta\mu\varepsilon_{\text{temp. induced}} = (T_1 - T_0) \times F_T$$

Then it can be deduced the strain due to construction activities only:

$$\Delta\mu\varepsilon_{\text{applied load}} = (L_i - L_0) - [(T_i - T_0) \times F_T]$$

NOTE: The F_T factor might change over the time and construction activities, because the behaviour of the steel structural element can change. It is therefore suitable to check this factor F_T in a regular manner when the activities stop (i.e. construction pause or during the week-end).

APPENDIX 4

EVALUATION OF TEMPERATURE EFFECTS IN CONCRETE ELEMENTS INSTRUMENTED WITH EMBEDDED VW STRAIN GAUGES

This paragraph shows only suggestions for data anlysis. Sisgeo hereby declines any responsibility for the use of those suggestions that have to be evaluated by the construction designer.

As already described in the previous paragraph, when a structural element has fixed ends, the restrained ends will prevent any increase in length due to a temperature increase. The tendency to expand will create compression throughout the concrete structural element that will be read by the strain gauge. The temperature changes also affect the embedded strain gauge, made by steel, that has different characteristics than concrete: this difference should be considered.
Therefore the strain measurement should be corrected with the following formula that keep in consideration the different thermal coefficient of expansion of concrete and strain gauge:

$$\Delta\mu\varepsilon_{\text{temp. induced + external induced}} = (L_i - L_0) + [(T_i - T_0) \times (CE_S - CE_C)]$$

where
L_i = Actual strain reading (με)
L_0 = Reference strain reading (με)
T_i = Actual temperature (°C)
T_0 = Temperature during reference measurement (°C)
CE_S = Steel's Coefficient of Expansion, equal to 12.2 microstrain/°C
CE_C = Concrete's Coefficient of Expansion, about 10 microstrain/°C

With the prevoius formula, the calculation includes both temperature-induced strain and external-induced strain (i.e. caused by construction activities).
Now, to separate the temperature induced strain from all the other induced strain it is necessary to read strain and temperature data several times each day. These measurements will give the change in strain readings due to incremental temperature changes. The period of data collectin for such target is called by the ISO 18674-1 the "period of baseline measurements": it should not involve any constructive work nor meteorological hazards that might affect the monitored system (see APPENDIX 3).
The strain data (microepsilon) should be graphically plotted against the temperature data (°C). Usually this graph shows a straigh line relationship: the slope of the trend-line of this relationship is the thermal factor "F_T" (microepsilon / °C).
This thermal factor may be used to calculate the temperature-induced stress:

$$\Delta\mu\varepsilon_{\text{temp. induced}} = (T_1 - T_0) \times F_T$$

Then it can be deduced the external-induced strain. If we can define that the main external factors arise from construction activities, we can say that:

$$\Delta\mu\varepsilon_{\text{external induced}} = (L_i - L_0) + [(T_i - T_0) \times (CE_S - CE_C)] - (T_1 - T_0) \times F_T$$

NOTE: The F_T factor might change over the time and construction activities, because the behaviour of the steel structural element can change. It is therefore suitable to check this factor F_T in a regular manner when the activities stop (i.e. construction pause or week-end).

APPENDIX 5

SUGGESTIONS ON HOW TO PLACE THE STRAIN GAUGES ON STEEL MEMBERS

This paragraph shows only suggestions for instrument installation place. Sisgeo hereby declines any responsibility for the use of those suggestions that have to be evaluated by the construction designer.

By measuring the strain and strain distribution it is possible to calculate the normal force by multiplying the change in strain with the cross sectional area and with the E-modulus of the structural element. The strain has to be therefore measured at different locations around the cross section to cover the stress field of the structure.
If the bending moment is to be monitored or detected then, also by using strain gauges at the correct locations around the structural member and measuring the strain distribution, the change in curvature can be calculated. By multiplying the change in curvature with the moment of inertia and with the E-modulus of the structural element, the bending moment in one or two directions can be calculated and monitored.

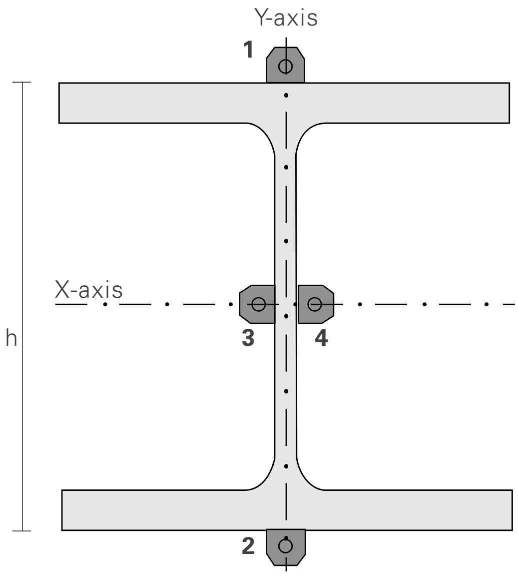
Hereafter we have listed some proposals for arranging strain gauges on a structural element. Calculating load from a measured strain distribution is done by applying mechanical engineering methods. These methods are not discussed here.

Application on different shapes of structural elements

Steel structural elements are often constructed as H-Beams, rectangular tubes or circular tubes. They range from sizes of 100mm up to 800mm height or diameter. Sometimes they are even bigger.

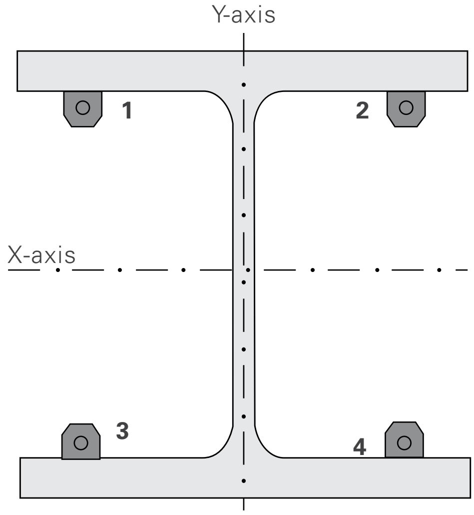
1 - Example for installation on a H-beam

Have the sensors installed symmetrically to the H-Beam. This largely simplifies detection of the normal forces and bendings.
Two sensors is the minimum that we suggest to evaluate the normal force in a small H-beam.
With sensors 1 and 2, only axial strains and bending moment around X-axis can be monitoreed.
With sensors 3 and 4, only axial strains and bending moment around Y-axis can be monitoreed.



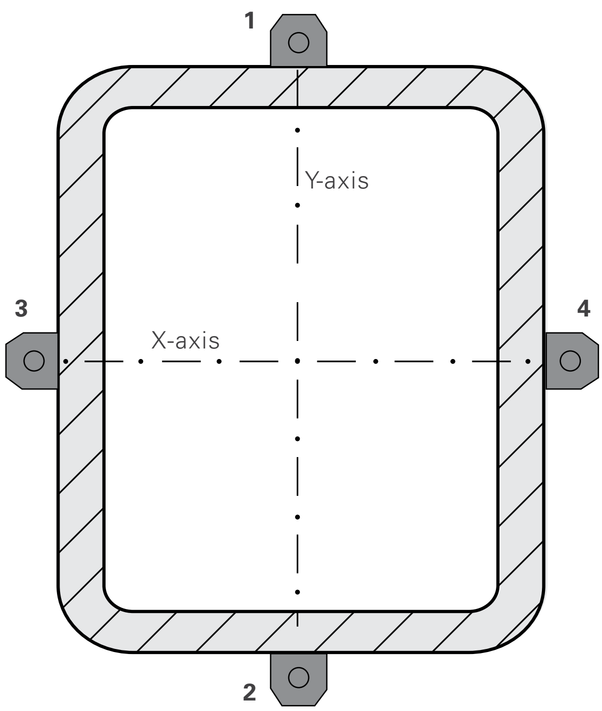
For outside installations exposed to sunlight and for long term installations, it is advised to protect the sensors with white housing over a length of 3 x h (h is the height of H-beam) to achieve a mechanical protection and to optimize thermal conditions at the measuring section. Run all the cables here and fix the cables every 1m with welded bolts or silicon rubber.

An alternative configuration with 4 sensors is in the sketch here following:



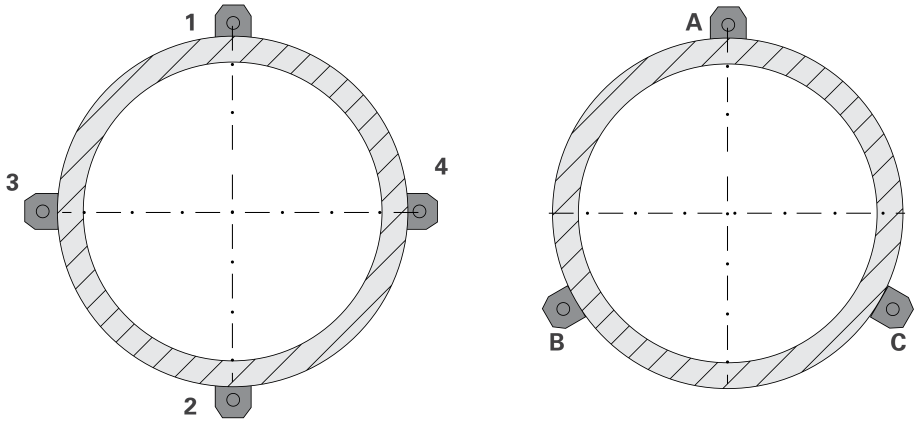
2 - Example for installation on a rectangular tube

For normal force evaluation, minimum 2 sensors are needed, 1 and 2 or 3 and 4. The best solution is to use 4 instruments positioned in points 1, 2, 3 and 4.
If moment forces in the x and y directions are to be detected, then we suggest to have following sensor installed at location 1, 2, 3 and 4.
Run the cables best at the upper side, if strut is oriented horizontally (optimal to protect against mechanical damages when the excavation works are proceeding below the struts).



3 - Example for installation on a circular tube

For normal force evaluation, minimum 2 sensors are needed, 1 and 2 or 3 and 4. The best solution is to use 4 instruments positioned in points 1, 2, 3 and 4. A configuration with 3 sensors at 120° is also acceptable (sensors positioned in A, B and C).
If moment forces in the x and y directions are to be detected, then we suggest to have sensors installed in position 1, 2, 3 and 4.
Run the cables best at the upper side, if strut is oriented horizontally (optimal to protect against mechanical damages when the excavation works are proceeding below the struts).



4 - Position of the strain gages along the structural element

To avoid end/edge effets along a structural element, consider that strain and stress have a planar distribution over the cross section in a distance of approx. 2-3 times the height/diameter of the element. We therefore propose to have the strain gages at a minimal distance from a load transfer point of 4 to 5 x h (with h = height of the profile)