WE MONITOR THE PRESENT WITH THE INSTRUMENTS OF THE FUTURE

INSTALLATION MANUAL

Vertical Array

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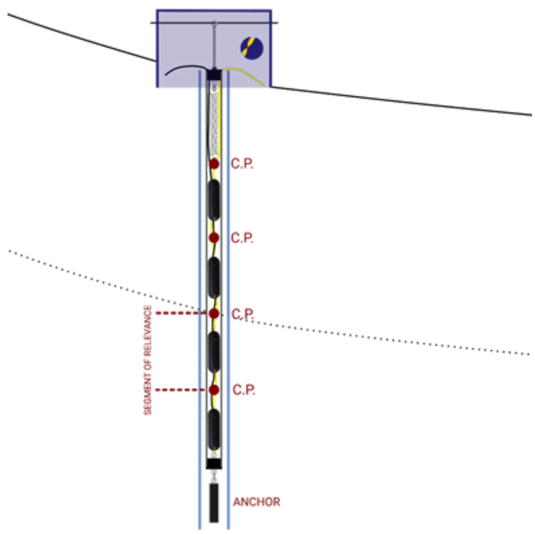
Product Description

The Modular Underground Monitoring System (**MUMS**) is an advanced solution for automatic, remote, multi-parameter monitoring.



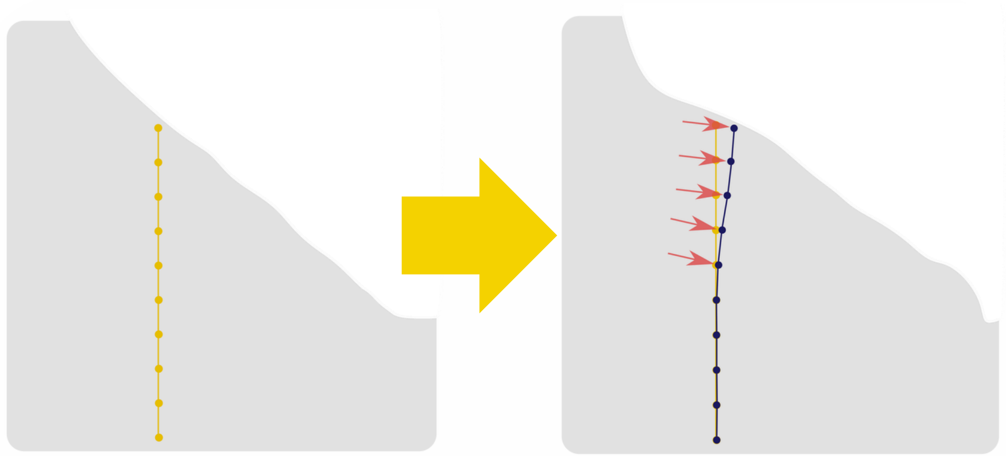
Vertical Array is an innovative inclinometer designed to monitor the **3D displacements** at different depths. It is composed by a sequence of IP69 hermetically sealed nodes in a chain joined by a Kevlar rope and a four-pole electrical cable. Each node (**Tilt Link HD V**) includes a high-resolution 3D MEMS accelerometer sensor, a magnetometer and a thermometer, while it is possible to include nodes for the measure of water level (**Piezo Link**).

Depending on project requirements, it is possible to **define** the **number** of measuring **sensors**, **spacing** and **total length** of the instrument. The Vertical Array is usually supplied inside a plastic tube (optional) that serves as protection and permits to record larger displacements.

By knowing the distance between nodes, the spatial position of sensors (calculated from MEMS data), and their orientation relative to North (using magnetometer data), specialized algorithms can determine the **instrument's exact position in space**. This enables **precise tracking** of the **displacements** in the monitored structure.

Vertical Array offers significant benefits over traditional instruments, including simpler installation, lower costs, minimal operator involvement, enhanced durability, and higher reliability.

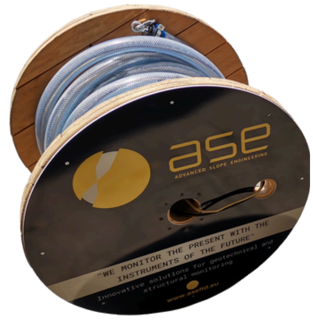
Further customization details are available on the ASE website.



System Components

The following items must be on-site at the time of installation.

Array



The Vertical Array inclinometer is available in different formats: with or without an external protective tube, and packaged on a reel or in a box. In this manual, we will refer to **Option A** as the system without an external protective tube, **Option B** as the system with an external protective tube and a length of less than 50 m, and **Option C** as the system with an external protective tube and a length greater than 50 m. A "+" will indicate the presence of at least one piezometric sensor.

The external diameter for Option B and C is 50 mm ± 5 mm, and the system comes wound on a reel, allowing easy unrolling into the borehole once positioned. For Option A, the diameter is 37 mm ± 1 mm, and it can be supplied in a lightweight box, with nodes lowered manually into the borehole.

Datalogger

To test the proper functionality of the MUMS instrument before and during installation, it is recommended to have an on-site control unit capable of reading the ModBus RTU protocol, along with a compatible power supply system and, if needed, a data transmission system. This control unit can either be the one later used for monitoring or a backup unit.

Borehole

The borehole must be completed before the installation date and meet the following specifications:
- Total length equal to the length of the Vertical Array instrument plus 2 meters;
- For Option B, a diameter of at least 3 inches for instruments shorter than 50 meters, and at least 4 inches for longer instruments (Option C);
- For Option A, a minimum borehole diameter of 3 inches;
- The borehole must be self-supporting or supported using PVC, ABS, and/or aluminum casing;
- The borehole must be cleared of mud and water.

Casing

The borehole must be lined with PVC, ABS, or aluminum casing (not supplied by ASE S.r.l.) with a diameter of at least 3 inches for Option A or Option B, and with a diameter of at least 4 inches for Option C instruments. If one or more piezometers are present, the external casing must be made of PVC and appropriately slotted at the relevant depths.

Infilling material

Depending on the specific case and project requirements, the backfill material (not supplied by ASE S.r.l.) can be either fine gravel (with an average diameter of approximately 1.3 mm, ranging between 1.1 and 1.5 mm) or cement grout with the following composition:
- 50 kg of cement (37%)
- 5 kg of bentonite (4%)
- 80 liters of water (59%).

Granular Bentonite

In the case of Option A+, it is advisable to use small-diameter granular bentonite (not supplied by ASE S.r.l.) to isolate the initial and final portions of each piezometer screen.

Inspection Pit and Threaded Rod

In all cases, it is useful to install an underground inspection pit at the tube head, with holes at both ends, where a threaded rod (maximum diameter of 15 mm, not supplied by ASE S.r.l.) can be placed. This rod will serve as a temporary support system for the array during the borehole filling phases and as a permanent support system during the installation phases.

Other accessories

Other useful accessories (some strongly recommended) include:
- Corrugated tubing to protect the electrical cables of the Array along their path to the control unit;
- A funnel, for backfilling the borehole with fine gravel;
- A hammer, for backfilling the borehole with fine gravel;
- One or more Innocenti poles (if the control unit is not wall-mounted) to secure the data acquisition unit and any solar panel for battery recharging;
- An electrical tester capable of measuring voltage, electrical resistance, and continuity;
- A flat-head screwdriver and a cross screwdriver;
- An electrical cable puller to guide the Array cables through the corrugated tubing;
- Electrician's scissors;
- A wire stripper, in case electrical connections need to be restored;
- Plastic cable ties of various diameters;
- A measuring tape;
- Electrical tape;
- For Options B and C, a tripod to support the reel housing the Array.

Before starting the installation, it is important to have all the necessary materials on-site.

Installation Procedure

The installation process consists of several stages, including preliminary tests, positioning the tool in the borehole, certification testing, filling the borehole, installing the control unit and related accessories, and initiating monitoring activities.

Phase 1 - Hole drilling

The first on-site operation is drilling the borehole, which should be planned based on the drilling director's expertise, the soil or rock quality, and the required borehole depth. To ensure easy installation of the Vertical Array, the borehole should be at least 90 mm in diameter (larger diameters simplify installation) and should extend 2 meters beyond the intended Array length. If the borehole walls are not self-supporting, it is recommended to install a temporary PVC support pipe with an internal diameter of at least 3 inches (see specifications on page 4). This PVC pipe can remain in place after installation, as it does not affect system performance. The space between the PVC pipe and borehole should be filled with the same material used between the MUMS Array and the PVC pipe. For Arrays with pore pressure sensors, openings should be cut into the PVC pipe at specified locations.

If the borehole is stable, the MUMS system can be installed without the PVC pipe, but the choice to use it is left to the installation supervisor. ASE recommends using the PVC pipe to prevent damage or misplacement of the MUMS system.

Before inserting the instrument, it is also advisable to remove water from the borehole with a compressor to ease descent.

Installation can also be performed using a new or existing inclinometer casing, provided it has been inspected. Reusing an existing borehole saves time and cost. If the inclinometer casing is deformed, the MUMS system can be installed directly into the casing without its protective pipe.

Phase 2 - Preparation of the external support system

Before proceeding with the installation of the Vertical Array, it is necessary to prepare the support system. This involves setting up a pit with holes on both sides to pass a threaded rod with a diameter not exceeding 15 mm. When the instrument is lowered into the borehole, for Options B and C, this rod will pass through the lifting eye at the top of the chain, while for Option A, it can be used to secure the aramid fiber rope. In both cases, the rod will secure the system during the cementation or backfilling phase and provide additional support for the inclinometer during active monitoring.

Phase 3 - Preliminary test

Before placing the equipment in the borehole, it is recommended to verify its functionality through preliminary tests conducted with the supplied control unit or a backup unit. This involves connecting the Array's electric clamp to the RS485 port of the control unit, following this color scheme: red cable - positive power, black cable - negative power, white cable - positive signal, green cable - negative signal (refer to the control unit manual for correct wiring).

If the Array is not yet configured, input the information into the control unit according to specifications on the compliance certificate and/or Geo-Atlas platform. Conduct at least three readings, expecting at least one complete reading from all sensors. If a sensor shows an error code, repeat the reading until a full set of readings is obtained. If the error is persistent, suspend installation and contact the designated ASE technician or use the contacts listed in the manual.

Each Array undergoes thorough testing and certification at ASE S.r.l. prior to shipment. Acceptance of the equipment on-site is contingent upon these verification tests. If these tests are not performed or no data is available to verify the recorded values, the Array is considered fully accepted, and ASE S.r.l. assumes no responsibility for any malfunctions.

Phase 4 - Array insertion

Once the initial test reading is successfully completed, the array can be inserted into the borehole, following the specific procedures for the previously described options.
In all cases, the first step is to attach the counterweight to the bottom of the chain. The counterweight serves several purposes: increasing the overall weight of the array to facilitate the lowering of the sensors, keeping the nodes in near-vertical positions, and providing a fixed point during monitoring by anchoring to the stable zone.

For Option A, simply tie the rope to the anchor using a knot. It is recommended to use knots that tighten under tension, such as common rock climbing knots.

For Options B and C, connect the anchor and the terminal part of the array using the quick link provided with the equipment, ensuring it is properly tightened afterward.

Option A

For Option A, the inclinometer is lowered into the borehole by simply inserting the anchor and the rope into it, ensuring the yellow cable (aramid fiber rope) is always held and never released. As a safety measure, the cable can be tied to a bar wider than the borehole, serving as a safety system to prevent the instrument from falling into the borehole.

If cementing is planned, the injection tube can be taped to the sensors or the rope and lowered alongside the instrumentation.

If one or more piezometric sensors are present (Option A+), ensure the porous stone is securely screwed in place. If the porous stone becomes detached for any reason, it must be reattached underwater to avoid air bubbles forming on the sensor. In this case, the array cannot be cemented, and the borehole will be filled with fine gravel instead.

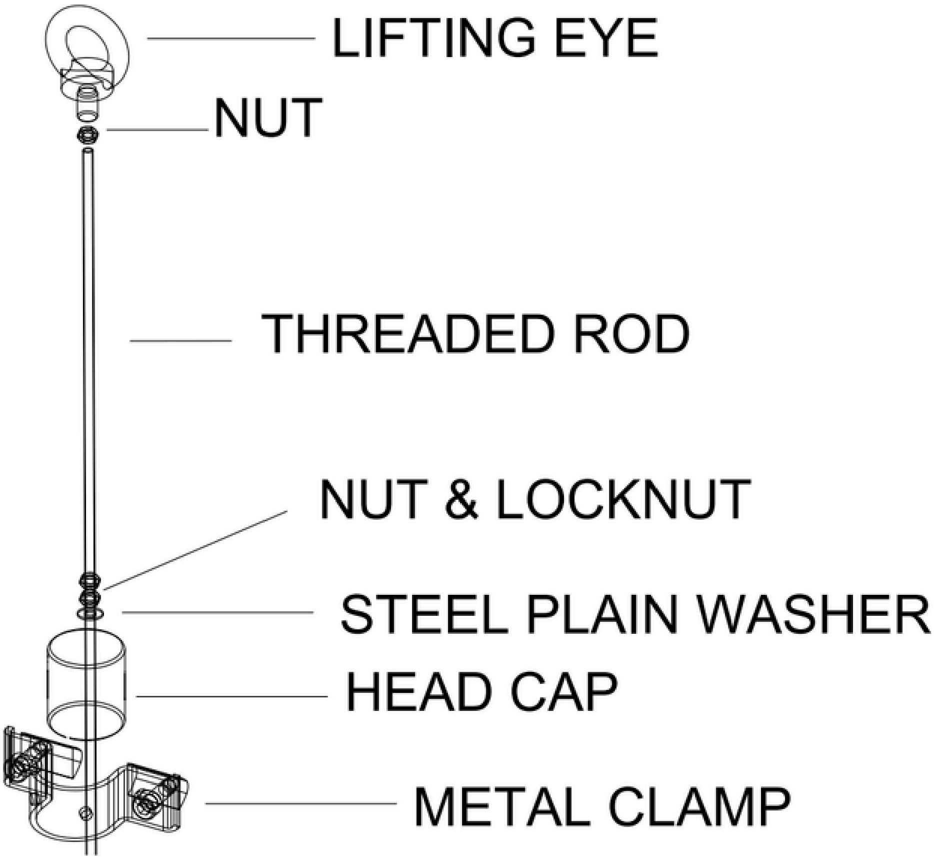
Option B or C

For Option B or C, place the reel housing the inclinometer on a suitable tripod and unroll it into the borehole. As the inclinometer descends into the borehole, its apparent weight will increase. When the threaded top rod becomes visible, hold it firmly (or use a temporary system to keep it suspended) and apply maximum tension by pulling it outward, then tighten the nut and locknut. Proper tensioning significantly reduces the stabilization time required for the Array after installation. After tensioning the rod, it is normal for it to extend several centimeters (up to 40–50 cm). If the excess portion does not fit within the pit and extends beyond the support system level, it must be cut, taking care to preserve the threading.

During this operation, it is essential to support the Array, which can be done by securing the yellow rope to a bar while simultaneously clamping the uncut portion of the rod with jaws. After cutting the excess rod, remove the lifting eye and nut, and reattach them to the remaining portion of the rod, ensuring the nut is fully tightened against the lifting eye.

Next, pass the support system through the lifting eye and the two holes of the pit. The chain will now be in a stable configuration and no longer needs to be supported.

If cementing is planned, the injection tube can be taped to the external protective tube and lowered alongside it. In cases where one or more piezometric sensors are present (Option B+ or C+), the Array cannot be cemented, and the borehole will be filled with fine gravel instead.



Phase 5 - Second test

Before proceeding with the borehole backfilling, an operation that makes the instrument non-recoverable, it is important to perform a second test to verify the proper functionality of the instrument. This involves connecting the Array's electric clamp to the RS485 port of the control unit, following this color scheme: red cable - positive power, black cable - negative power, white cable - positive signal, green cable - negative signal (refer to the control unit manual for correct wiring).

Conduct at least three readings, expecting at least one complete reading from all sensors. If a sensor shows an error code, repeat the reading until a full set of readings is obtained. If the error is persistent, suspend installation and contact the designated ASE technician or use the contacts listed in the manual.

It is strongly recommended to proceed with the subsequent steps only if the second test has been successfully passed with certainty. ASE S.r.l. assumes no responsibility in cases where products have not been properly tested before and during installation.

Phase 6 - Borehole backfilling

As previously described, the borehole backfilling can be carried out using two different methods, keeping in mind that only one method is possible if at least one piezometric sensor is present.

Filling with cement mortar

In the case of filling with cement mortar, the mixture must have the following composition:
- 50 kg of cement (37%);
- 5 kg of bentonite (4%);
- 80 liters of water (59%).

Cementing is performed from the bottom upwards until reaching ground level, ensuring that no voids are created. A few days after the injection, the mixture will likely shrink, and it may be necessary to re-cement the top portion.

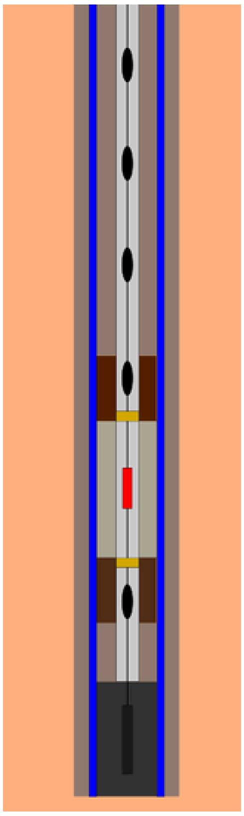
Filling with fine gravel

In the case of filling with fine gravel, the Array becomes more flexible and should be able to withstand greater deformations, albeit with reduced accuracy for small deformations. The procedure is slower and requires more attention.

First, if possible, it is recommended to cement the anchor at the bottom of the borehole. After waiting a few minutes for the initial setting of the cement, begin inserting the fine gravel by slowly pouring it from the top, in small doses, using a funnel or directly by hand. DO NOT empty the bag directly into the borehole. As the gravel descends, lightly tap the outside of the PVC pipe with a hammer to facilitate the descent of the filling material. In narrow diameters or if the Array is not perfectly vertical, the fine gravel may become stuck at certain points and fail to descend further. In this case, pour water into the borehole and gently move the Array until the blockage is cleared. Continue as described until reaching ground level, paying close attention to avoid creating voids.

If voids form, they will interfere with monitoring activities, causing displacements that could occur with the first rain or, in any case, months after installation, which are merely the material readjusting in the borehole.

Installation with one or more piezometer(s)



If one or more piezometric sensors are present, attention must be paid to the proper windowing. Each sensor will have its own area of influence, where the outer PVC pipe will be slotted to allow groundwater to enter. Within the PVC pipe, the same windowing must be replicated, ensuring that the borehole is filled from the bottom with fine gravel up to the start of the first window. At that point, the section must be isolated by inserting bentonite granules. It is recommended to begin the isolation at a depth of at least the piezometer depth + 50 cm. Once the bentonite plug is in place, the area of interest for the piezometric sensor can be filled with the same fine gravel used for the regular borehole filling or with sand. After completing this section, a new bentonite plug should be placed in the same manner described earlier, at least 50 cm above the piezometer, and fine gravel should be added until ground level is reached, repeating the procedure for each piezometer present.

In any case, it is recommended to cement the upper portion of the Array to prevent rainwater from entering the borehole.

Phase 7 - Cable connection

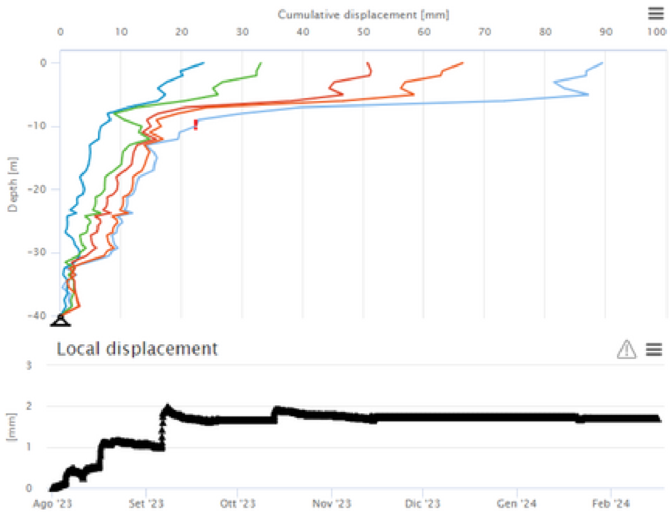
Once the operations in the borehole are completed, the cables must be connected to the control unit and/or any radio module present. It is recommended to protect the Vertical Array cable, both in any underground sections and above-ground parts, by using corrugated tubing (the MUMS system's four-wire electric cable has a diameter of about 6.2 mm) until reaching the box containing the control unit or the slave radio module. As previously described, the connections are as follows: red cable - power +, black cable - power -, white cable - signal +, green cable - signal -. Depending on the model of the control unit, the order of the wires in the terminal block may vary. Once the Array is wired to the data logger, it is advisable to perform at least three certification readings to confirm the installation completion before proceeding with the start of automatic monitoring.

Phase 8 - Automatic monitoring

Once monitoring begins, the instrument is automatically read by the control unit, and the data is transmitted to the calculation center. There is no longer any need to visit the site, and the monitoring managers will have a real-time overview of the evolution of any 3D displacements, as well as other parameters such as the daily average velocity and acceleration of movements, displacement direction, temperature profile along the vertical and its evolution over time, and, if piezometric and barometric sensors are present, the interstitial pressure, groundwater level (free and/or under pressure), and atmospheric pressure.

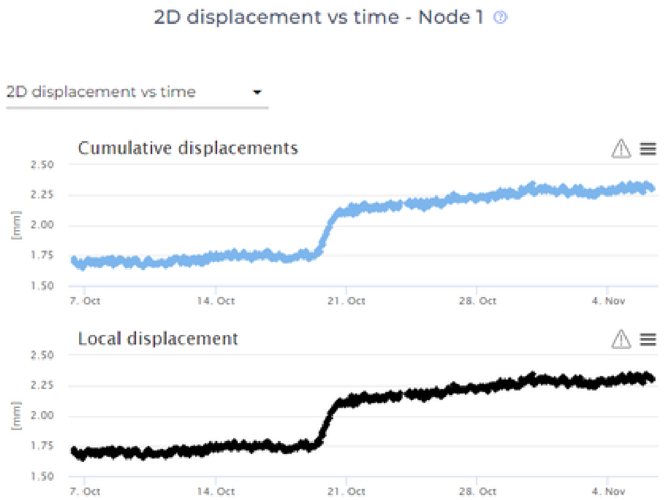
Monitoring activity

During automatic monitoring, the instrument provides multi-parametric results.



Each reading from the control unit delivers seven values:

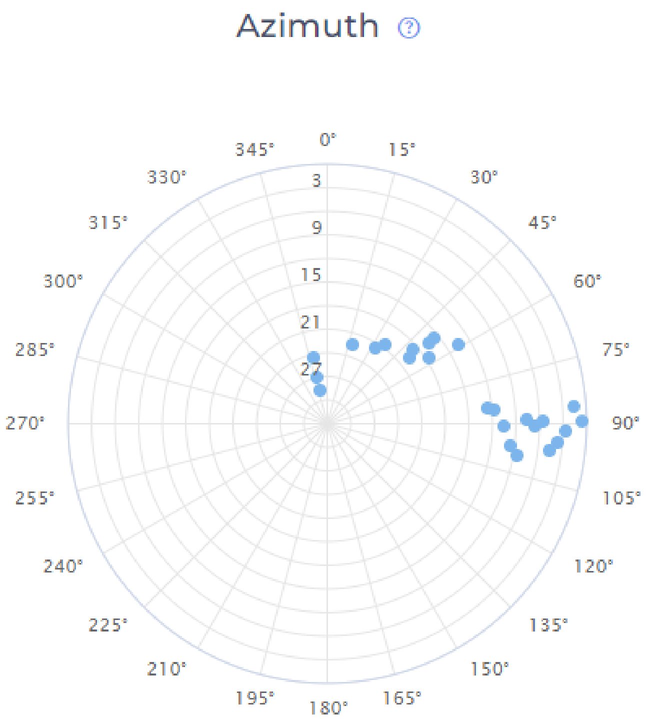
1. The first three represent the inclination angles (in degrees) along the X-Y-Z axes;
2. The next three indicate the magnetic field (in Gauss) measured along the same axes;
3. The seventh parameter is the sensor temperature (in degrees Celsius).



Using these values, several critical results can be derived, including:

- Local and cumulative displacements along the magnetic North-South and East-West directions;
- Local and cumulative 2D displacements;
- Displacement ratio and acceleration of local and cumulative movements;
- Direction of observed displacements;
- Temperature evolution along the vertical profile and over time;
- 3D deformation profile.

Each sensor node is assigned a unique serial number, with lower serial numbers corresponding to greater depths. The last serial number refers to the sensor closest to the ground surface.



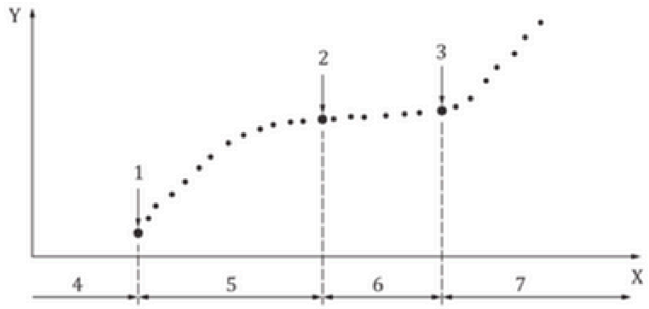
If a piezometric sensor is included, it outputs data in electrical units, requiring conversion via the calibration certificate provided. This data represents the absolute pressure detected. When combined with the barometric sensor data (also converted using its calibration parameters), it enables calculation of:

- The water column height above the piezometer;
- The groundwater level, adjusted for free or confined aquifers (the latter as a theoretical level).

During the initial monitoring phase, it is completely normal to observe displacements, sometimes significant, which gradually decrease over time. These movements are associated with the stabilization of the instrument within the borehole and the filling material. Stabilization times can vary greatly depending on the installation methods, ranging from a few days to several months.

To determine the starting date for calculating relevant results, it is recommended to observe the displacement curve for each sensor. When this curve approaches a horizontal asymptote (point 2 in the ISO standard reported below), the sensor is most likely fully stabilized.

Figure 1 — Definition of distinct measuring points during a geotechnical monitoring project in the period up to and including the construction phase



According to **ISO 18674-1:2015** standards, the installation of a borehole inclinometer involves several distinct phases:

- **Point 1** represents the first automatic reading following installation;
- **Point 2** marks the point at which the inclinometer has reached full stabilization.

If Point 2 is followed by a period of relative stability, it becomes possible to assess the precision and repeatability of the installed instrument. This evaluation, conducted during the period between Point 2 and 3, allows the identification of **Point 3**, which corresponds to the date when significant movements begin to occur.

If a sensor fails to respond, it will return a single error code instead of the seven parameters mentioned earlier. A systematic error code may indicate that the sensor is damaged. In the event of sensor failure, the affected sensor is simply bypassed, and monitoring continues for all other points along the vertical.

If the sensors receive insufficient power, they will return an error code and, under no circumstances, will they provide abnormal readings.

Any measurement spikes detected may result from the presence of strong electromagnetic fields or significant vibrations in the immediate vicinity of the inclinometer. Such disturbances, when processed using ASE S.r.l.'s data management system, are automatically identified and filtered out.

Mainteinance

The system, under normal conditions, does not require maintenance activities, which instead may pertain to the control unit and its components (refer to the control unit user manual for more details).
To ensure proper functionality of the Vertical Array, a power supply of at least 12 V is required.

If the system consistently reports an error, it is necessary to check for potential breaks in the electrical cable and, if found, identify their location. Start by confirming that the electrical terminal is correctly connected to the corresponding port on the control unit or radio module and verify the wiring. If no obvious anomalies are detected, inspect the section of the electrical cable outside the borehole. Specifically, if there are no visible breaks or compressions, proceed by cutting the cable just before its entry into the borehole and check the relevant parameters solely for the portion inside the borehole.

Whenever a cut cable needs to be restored or an existing cable extended, a junction box must be installed to connect the two ends of the cable, joining each wire individually. At the end of the process, the box must be sealed using IP68 quick-setting waterproof insulating gel to ensure full impermeability.

Verification Parameters of the Array

A properly functioning array should return specific parameters, which must be measured using a tester. The following parameters must be obtained using a tester with Ohm reading and the two probes on the mentioned wires.

Array with the electrical terminal disconnected from the data acquisition unit and/or the slave radio module

- Red-Black: >1 MOhm
- White-Green: approximately 120 Ohm
- White-Black: approximately 5 KOhm
- Green-Black: approximately 5 KOhm

Array with the electrical terminal connected to the data acquisition unit and/or the slave radio module

- Red-Black: >1 MOhm
- White-Green: approximately 60 Ohm
- White-Black: approximately 5KOhm
- Green-Black: approximately 5KOhm

Final notes

ASE S.r.l. certifies the proper functionality of the MUMS system following the manufacturing, calibration, and water resistance tests conducted in a pressurized autoclave at its factory in Parma, Italy. The products are guaranteed starting from the delivery date, provided they are used correctly and in accordance with the instructions.

Before installation, the Buyer must:

- Perform a functionality test within 7 days of delivery;
- Send the test report to the Seller promptly before proceeding with installation to identify any delivery-related issues.

If the Buyer installs the product without completing the test and submitting the report, the warranty for defects is void, and the Seller is not responsible for any issues found post-installation.

Defects related to improper installation are covered by warranty only if the installation is carried out by the Seller and specified in the sales contract. In all other cases, the warranty is excluded, and the Seller is not liable for any failures due to improper installation.

For any issues, we strongly recommend halting the installation process and contacting us immediately.

OUR MISSION

Develop and disseminate new technologies for monitoring natural phenomena and structures in order to deepen the knowledge of their dynamics, strengthen the theoretical basis for theoretical interpretation and make safer, cheaper and more functional design activities of civil and environmental works as well as Civil Protection procedures.

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