International Summer School
Orvieto-Todi
20-26 August 2023

Geotechnical Monitoring

POTENTIALITY OF MONITORING SYSTEMS

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FIELD *Todi, Italy, 21 August 2023*

The two worlds of engineering

Geotechnical engineers work
in two totally different worlds.

FIELD

The two worlds of engineering

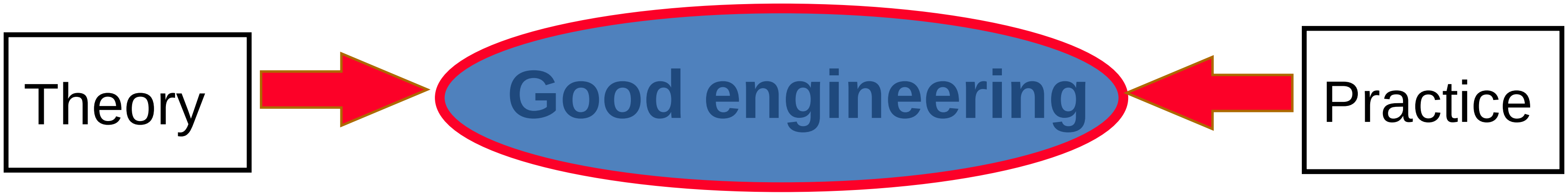
- A theoretical world

Where thoughts, ideas and events can be quantified and calculated to as many decimal points as desired.

The two worlds of engineering

- A practical world

Where observations and events can only be described in a general way.



How do we become good engineers?

- We must strive to improve our understanding of the theoretical basis for our work.
- We must strive to gain a better understanding of the real world of engineering practice, and
- We must strive to narrow the gap between these two totally different worlds of theory and practice.

HOW DO WE BRIDGE THE GAP?

Theory

Practice

HOW DO WE BRIDGE THE GAP?

Theory INSTRUMENTATION Practice

Instrumentation helps bridges the gap!

Theory INSTRUMENTATION Practice

Numerical data, the end product of instrumentation and measurement provides a quantitative link between theory and practice.

That is why instrumentation and performance monitoring have come be such an important part of geotechnical engineering.

POTENTIALITY OF MONITORING SYSTEMS

- Monitoring is a tool we can use to reach a goal.
- First of all we have to know which goal we want to reach and why, which path we want to follow, which resources we can use.
- In other words, we have to have a clear view of the whole process, than we can act.

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WHY MONITORING?

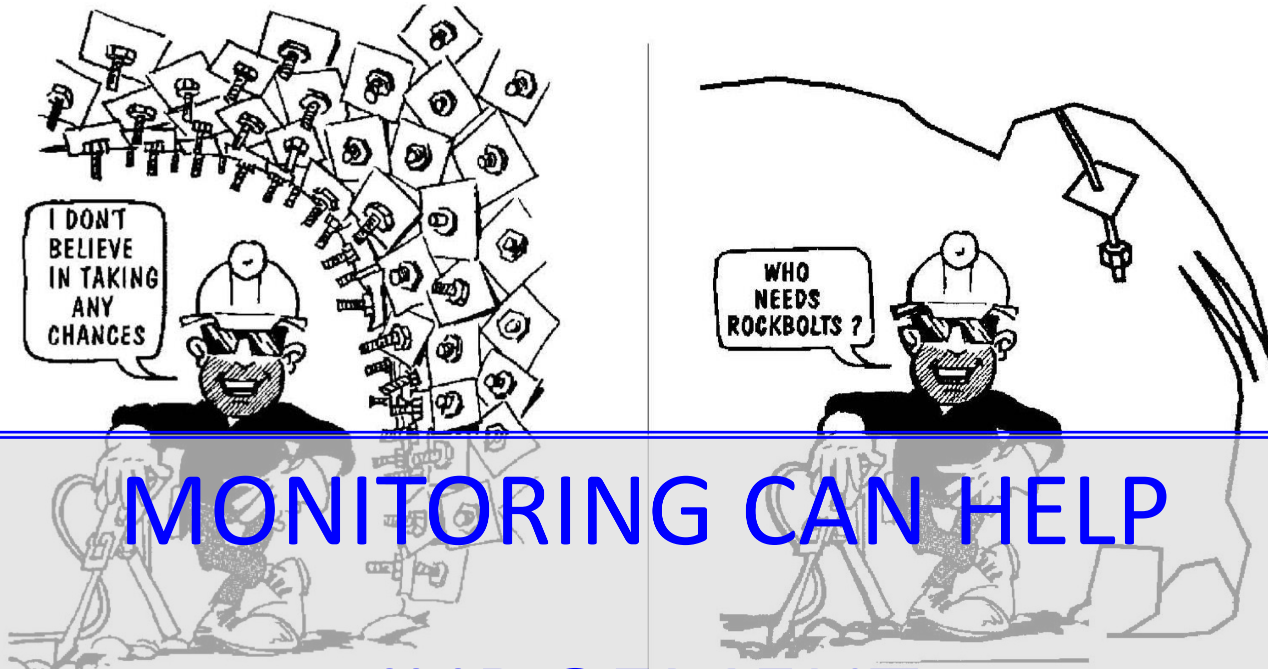
- To Improve the design,
- To Reduce the costs,
- To Increase the safety,
- To Increase the knowledge, and
- To Enable the control of the site

If correctly used.....

FIELD

Factor of Safety and Probability of Failure

How does one assess the acceptability of an engineering design? Relying on judgement alone can lead to one of the two extremes illustrated in Figure 1. The first case is economically unacceptable while the example illustrated in the drawing on the right violates all normal safety standards.



MONITORING CAN HELP JUDGEMENT

Figure 1: Rockbolting alternatives involving individual judgement. (Drawings based on a cartoon in a brochure on rockfalls published by the Department of Mines of Western Australia.)

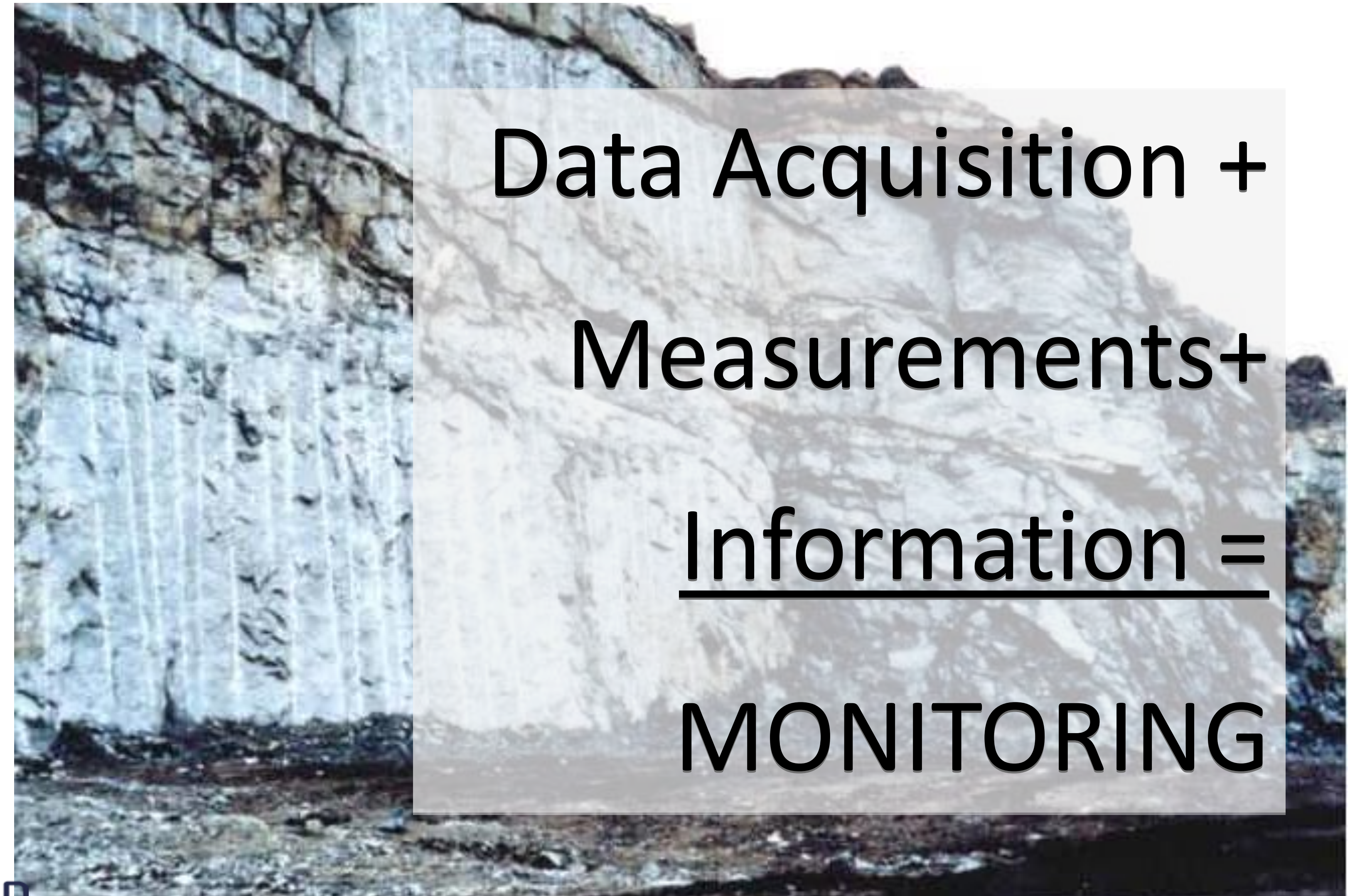
Source: Evert Hoek "Practical Rock Engineering"

Modern Monitoring Systems also enable:

- To get warning, as well as “early warning” signals
- To activate Alarms
- To spread information on large scale
- To set-up remote control Centers
- To make “real time” processing of data
- To issue reports

FIELD

What is “Monitoring” ?




Monitoring +
Intervention =
CONTROL

The Mission of Monitoring

The “Mission” of Monitoring is:

“Provide as much information as possible in the simplest and most complete form to be used by those who have to make decisions”

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"Information" is the result of processing, gathering, manipulating and organizing data in a way that adds to the knowledge of the receiver. In other words, it is the context in which data is taken.

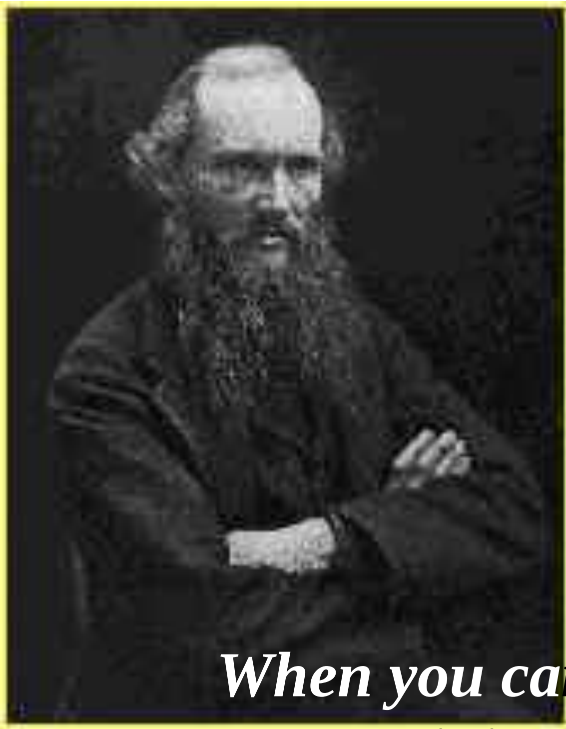
FIELD

MONITORING SYSTEMS

Monitoring Systems include:

- **Hardware** (instruments – connections – acquisition units)
- **Software** (data acquisition package – data processing package – data analysis package)
- **Procedures** (installation - management - maintenance – data presenatation)
- **Personnel** (installation – management – maintenance – inspection – analysis – presentation – development)

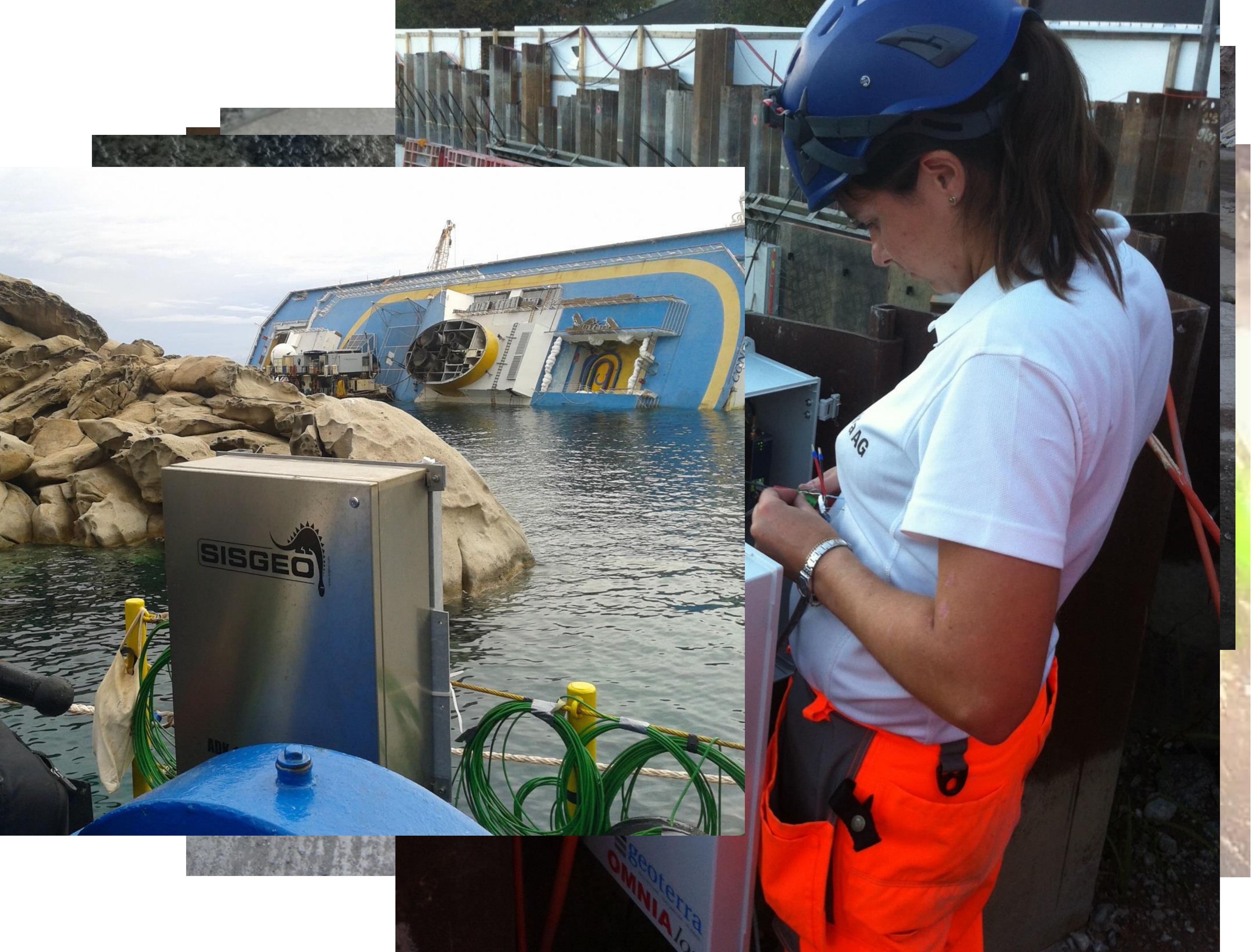

TOGETHER
TO REACH
THE GOAL



Data

When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be.

***Lord Kelvin* (1827 - 1907)**


SISGEO
geoterra
OMNIA

Instrument Selection

✓ It is mandatory to know:

WHAT TO MEASURE

- THE EXPECTED VALUES
- THE METROLOGICAL SPECS
- THE OPERATIVE CONDITIONS

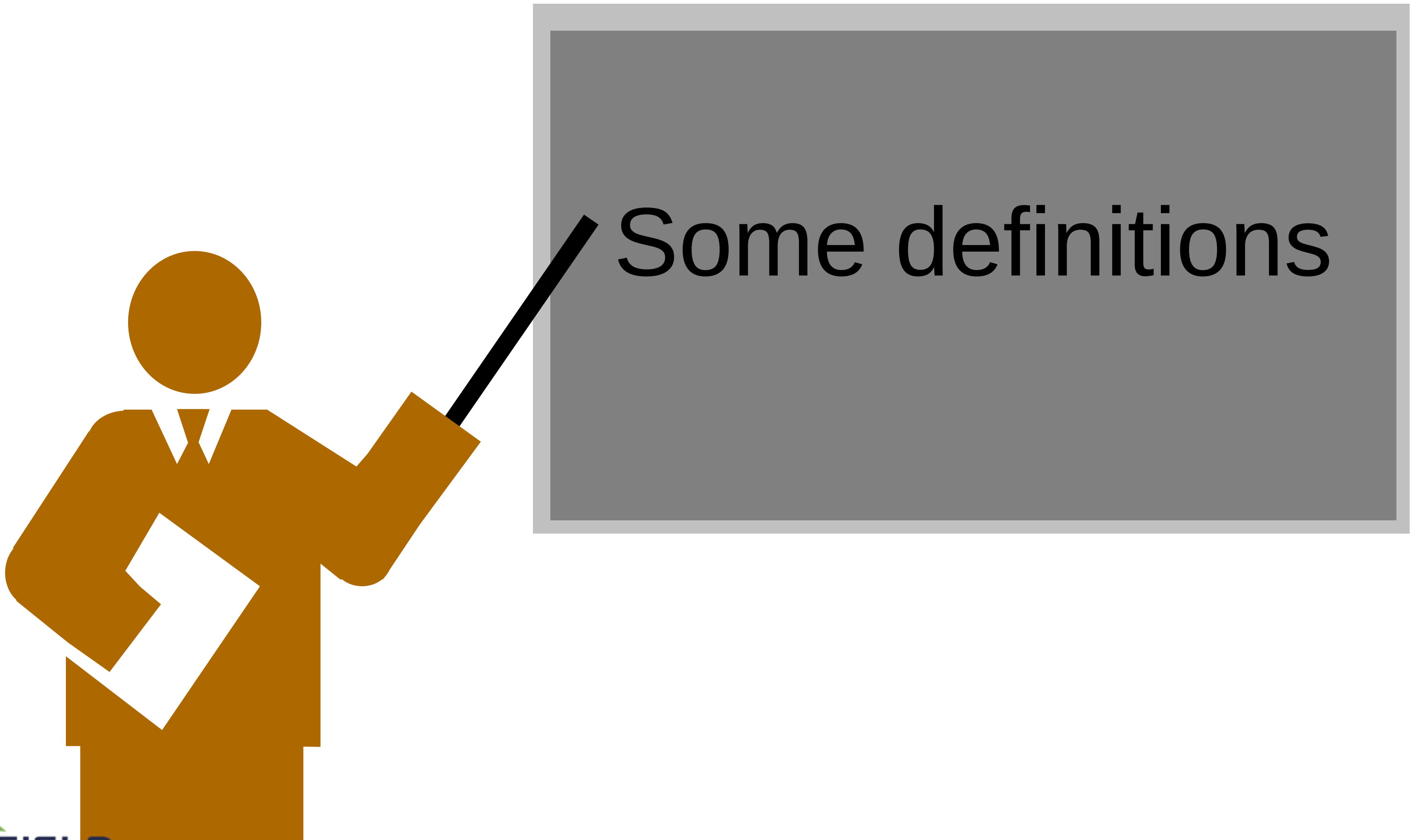
THE EXPECTED VALUES

- MEASURING RANGE: max expected value
  min expected value

- AVERAGE VARIATIONS: short term
  long term
  periodic effects

- MINIMUM SIGNIFICANT VALUE: smallest detectable variation

Sensors



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Accuracy & repeatability

- Accuracy
  - Degree of conformity of an indicated value to a *recognized* accepted value. Degree of agreement between the measured value and the true value.
- Repeatability
  - The closeness of agreement among a number of consecutive measurements of the output for the same input under the same operating conditions.

Linearity and hysteresis

- Linearity
  - Deviation of a plotted response from a straight line.
- Hysteresis
  - The summation of all effects wherein the measurement yields different values when the same value of the input is applied first in an increasing and then in a decreasing direction.

Resolution and sensitivity

- Resolution
  - The smallest change in the reading of an instrument which is observable as a measurement is made.

- Sensitivity
  - The smallest quantity observable as a measurement is being made.

Metrological specifications

- ACCURACY: +/- % of full scale (f.s.)

  (f.s.= 50 mm, acc=0.25%f.s. ➔ +/- 0.125 mm)

- RESOLUTION: % of full scale (f.s.)

  (f.s.= 50 mm, res=0.01%f.s. ➔ 0.0005 mm)

- LINEARITY: % of full scale (f.s.)

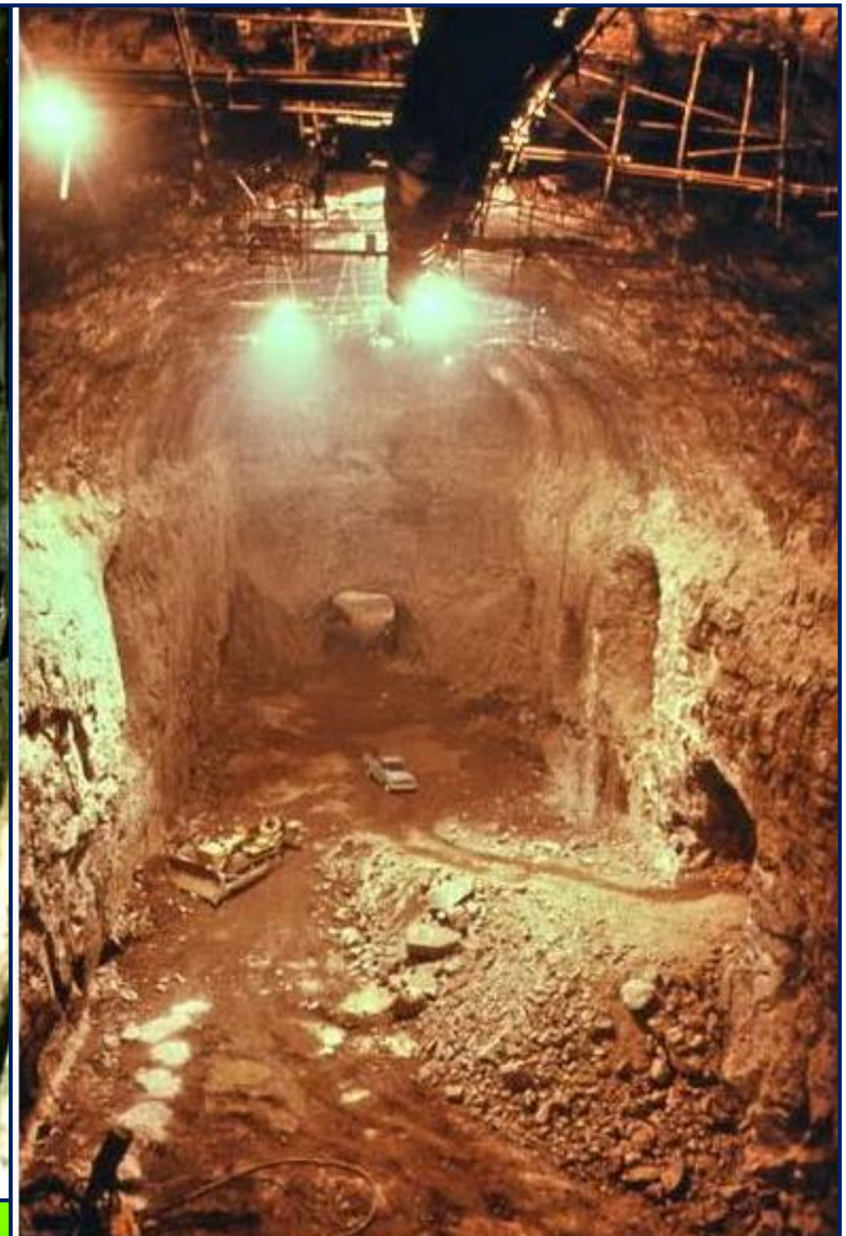
  (f.s.= 50 mm, lin=0.1%f.s. ➔ +/- 0.05 mm)

- HYSTERESIS: % of full scale (f.s.)

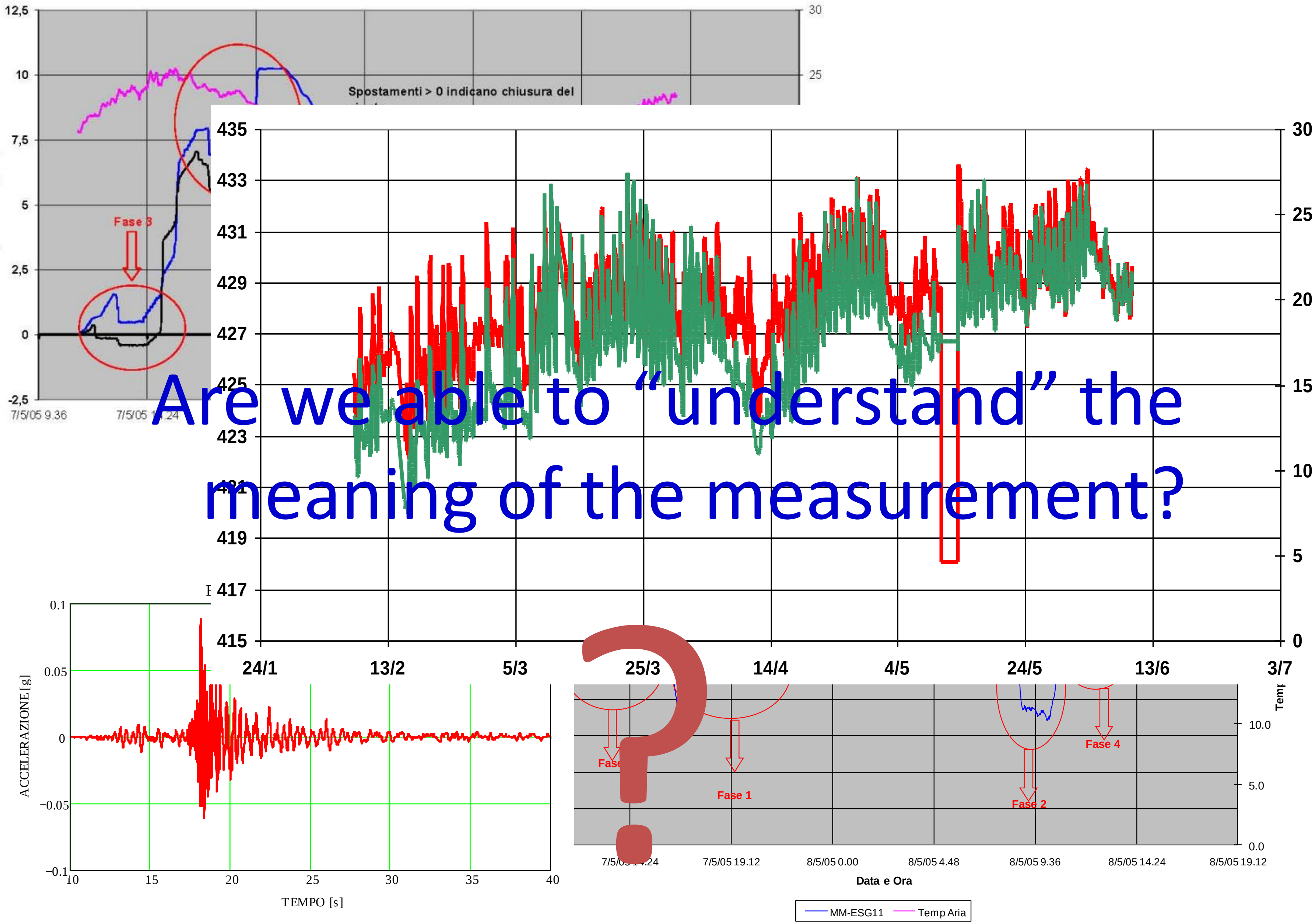
  (f.s.= 50 mm, hys=0.1%f.s. ➔ +/- 0.05 mm)

- REPEATABILITY: % of full scale (f.s.)

  (f.s.= 50 mm, acc=0.05%f.s. ➔ +/- 0.025 mm)



Are we able to “understand” the meaning of the measurement?

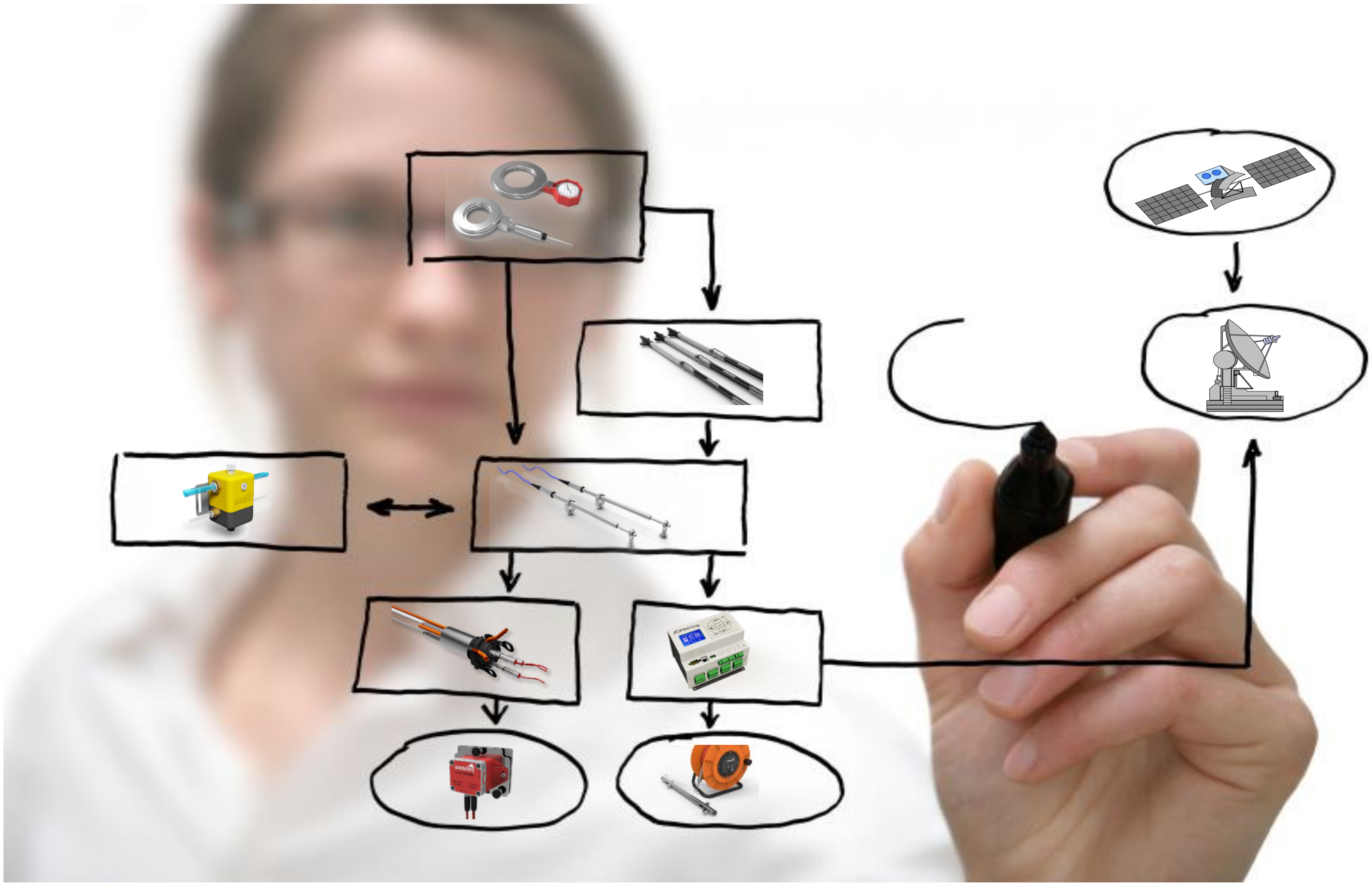


PROBLEMS

- *Problems related to the measurement procedures*
- *Problems related to the instruments bahaviour*
- *Problems related to the influence of unknown factors*

Great attention is requested in data analysis to take into account the possible problems in order to avoid wrong evaluations.

Monitoring



FIELD

BASICS

Commonly used sensors

There are many to choose from

but

how do you decide?

Principal sensor types

- Resistive
  - Electrical resistance strain gauge
- Inductive
  - LVDT, Linear Voltage differental transformer
- Frequency
  - Vibrating-wire strain guge (Acoustic)
- Servo devices
  - Some inclinometers

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Typical output signals

- Low level voltge : microV, mV
- High level voltage : V
- Current : 4 - 20 mA
- Frequency : Hz
- Digital

Resistance strain gauges

- Common types
  - Bonded & unbonded wire strain gauge
  - Bonded foil strain gauge
  - Weldable resistance strain gauge
- Usage
  - Strain measurements
  - Sensing element in transducers

FIELD

Resistance strain gauges

- ↑ Small size
- ↑ Low cost
- ↑ Excellent dynamic response
- ↓ Low level signals require conditioning
- ↓ Require skilled personnel
- ↓ Problems associated with cabling

Vibrating-wire strain gauges

- Pluck type
- Continuous excitation type

- Usage
  - Strain measurements
  - Sensing element in transducers

Vibrating-wire strain gauges

- ↑ Simple to fabricate, acceptable cost
- ↑ Well documented long term stability
- ↑ Robust output signal
- ↓ Large in size
- ↓ Limited frequency response
- ↓ Pluck-type difficult to automate

Theory

INSTRUMENTATION

Practice

What do we normally have to measure?

- Pore pressure
- Earth pressure
- Settlement and deformations
- Load, stress and strain

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Why measure pore pressure?

- Evaluate strength (effective stresses)
- indicator of stress change in the ground
  - Something happened
  - Often the best indicator of incipient failure
- Basis for drawing flow net
- Control construction works
- Determine loading on structures (uplift)

FIELD

Measurement of pore pressure

---------------- Applications -----------------

- Design information
  - initial pore pressure & distribution
  - seasonal variations
- Monitor effects of construction
  - lowering of ground water table
  - assess stability, control rate of construction
- Monitor long-term performance
  - Determine end of primary consolidation

FIELD

Pressure transducers

- Pneumatic
- Electrical resistance strain gauge
  - Bonded & unbonded wire, foil gauges
- Semiconductor strain gauge type
- Vibrating-wire
- Piezoelectric

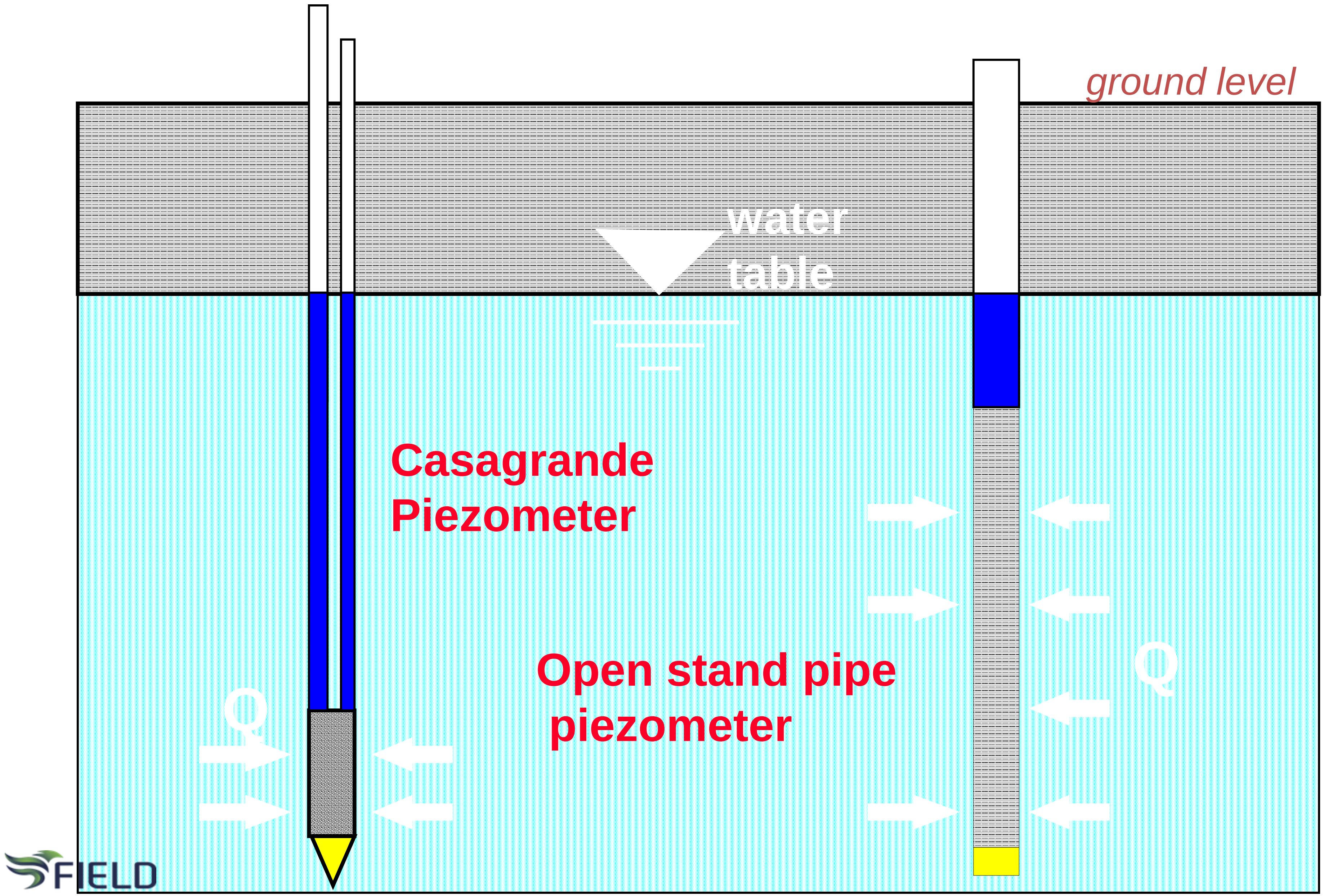
FIELD

Pressure transducers

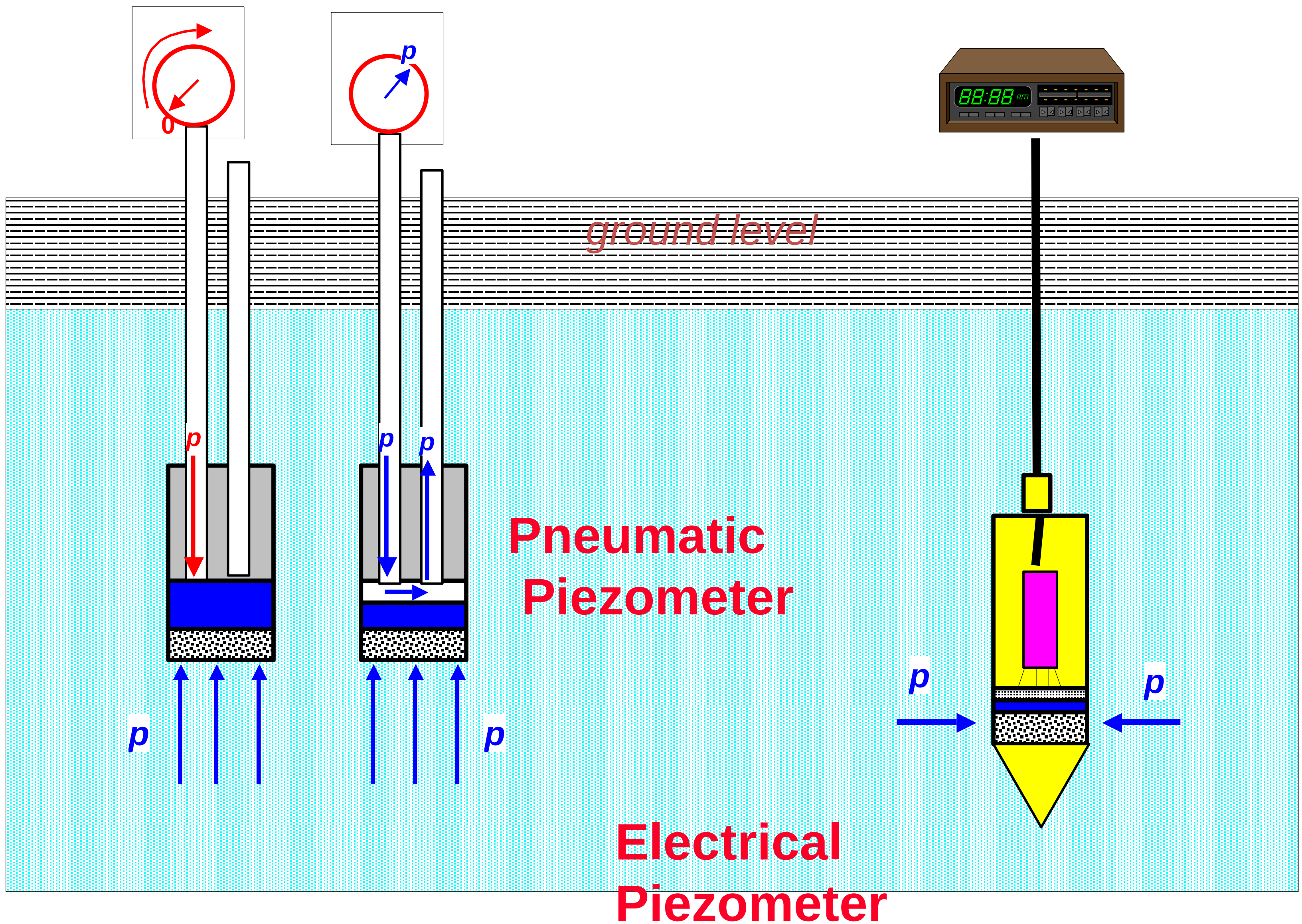
- Usage
  - Pore pressure measurements
  - Water depth measurements
  - Liquid settlement measurement systems
  - Total stress (earth pressure) measurements

FIELD

Hydraulic Piezometers



Piezometer



0
p
p
p
p
p
ground level
88:88
Pneumatic Piezometer
p
p
p
Electrical Piezometer

Casagrande Piezometer

Electrical Piezometer

Theory

INSTRUMENTATION

Practice

Measurement of earth pressure

One of the most difficult parameters
to measure

Why measure earth pressure?

- Determine load on structures
  - Design verification / improve future design
  - Prevent over loading of structure
  - Basis for soil/structure interaction studies

- Determine state of stress in a soil media
  - Design verification
  - Investigate arching phenomena

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Measurement of earth pressure

- On boundaries of structures
  - Retaining structures
- Within a soil medium
  - Embankments
- Not generally done on routine basis
  - Difficult to do
  - Expensive
- Indirect methods of measurement sometimes

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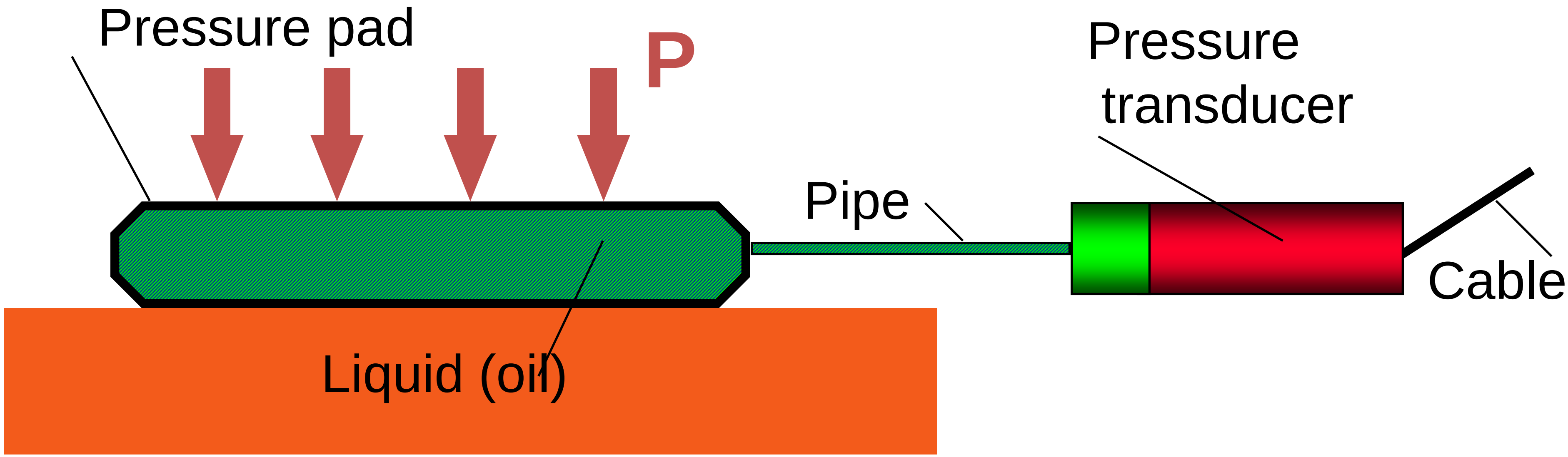
Earth pressure transducers

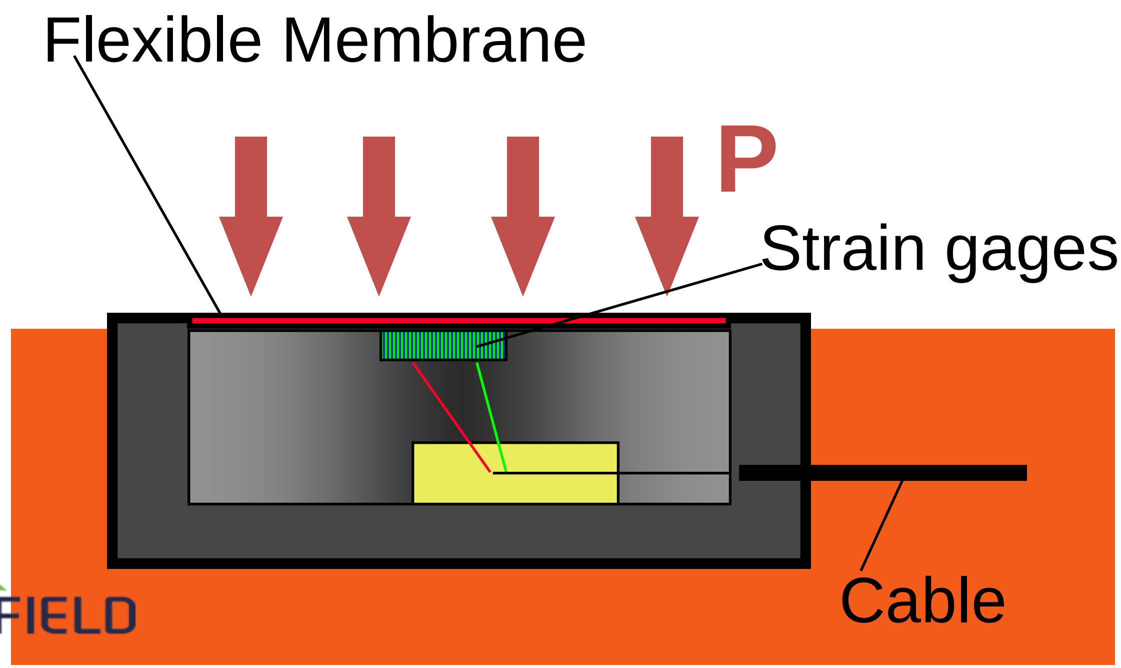
- Should minimize disturbance to stress field
- Design requirements
  - Cell aspect ratio (Thickness to diameter ratio)
  - Deflection to diameter ratio
  - Results on design
    - Relative stiff membranes
    - Large diameter
    - Minimum thickness

Types of earth pressure sensors

- Membrane type
  - Earth pressure deflects a membrane which is sensed by some type of strain gauge
- Hydraulic capsules (flat jack type)
  - Earth pressure converted to fluid pressure which is sensed by a pneumatic device or pressure sensor
- Selection of type to use depends primarily on soil type

Pressure cell





Membrane cell

FIELD

Theory INSTRUMENTATION Practice

Measurement of deformation and movements

What we do most

and

what we do best!

FIELD

Why measure deformation

- A global indicator
  - for assessment of performance and safety
- Provides important data for design verification
  - We have reliable methods for predictions
  - Easily understood
- High level of confidence in measurement

FIELD

Measurements of interest

- Vertical and horizontal ground movements
- Displacements of structures
- Angle changes and distortions of structures

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Methods of measurement

- There are many
  - Survey techniques, manual and automatic
  - Inclinometers
  - Extensometers, joint meters
  - Liquid settlement devices
  - Ring magnets and reed switches
  - Laser displacement sensors
  - Global Positioning System (GPS)

Displacement transducers

- Linear voltage differential transformer
- Linear potentiometers
- Multi-turn rotary potentiometers
- Vibrating-wire extensometers
- Ring magnet/reed switch
- Magnetorestrictive displacement sensor
- Laser position detector

Displacement transducers

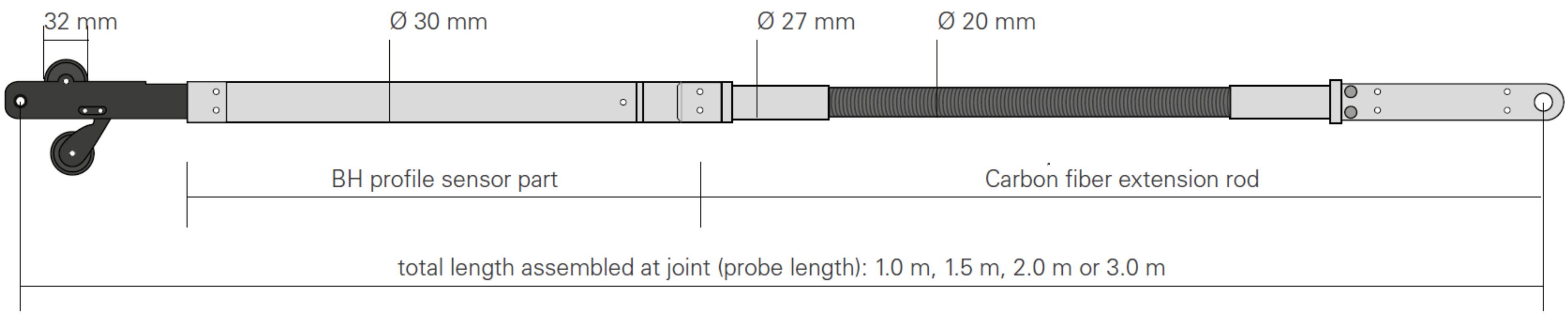
- Usage
  - Settlement measurements
  - Convergence measurements
  - Movements of structures and slopes
  - Tank gaging
  - Large strain measurements

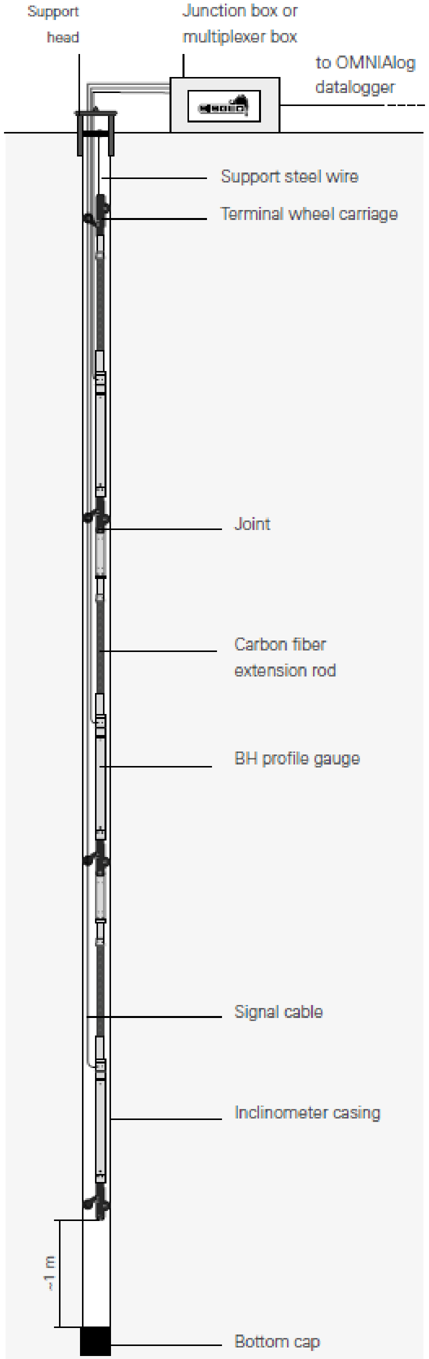
INCLINOMETERS

— BH PROFILE IN-PLACE INCLINOMETERS

BH PROFILE INCLINOMETERS ARE UTILIZED WHERE DISPLACEMENT MONITORING REQUIRES CONTINUOUS BOREHOLE PROFILE

CARBON FIBER ROD IS STIFFER AND LIGHTER THAN COMMON STAINLESS STEEL RODS

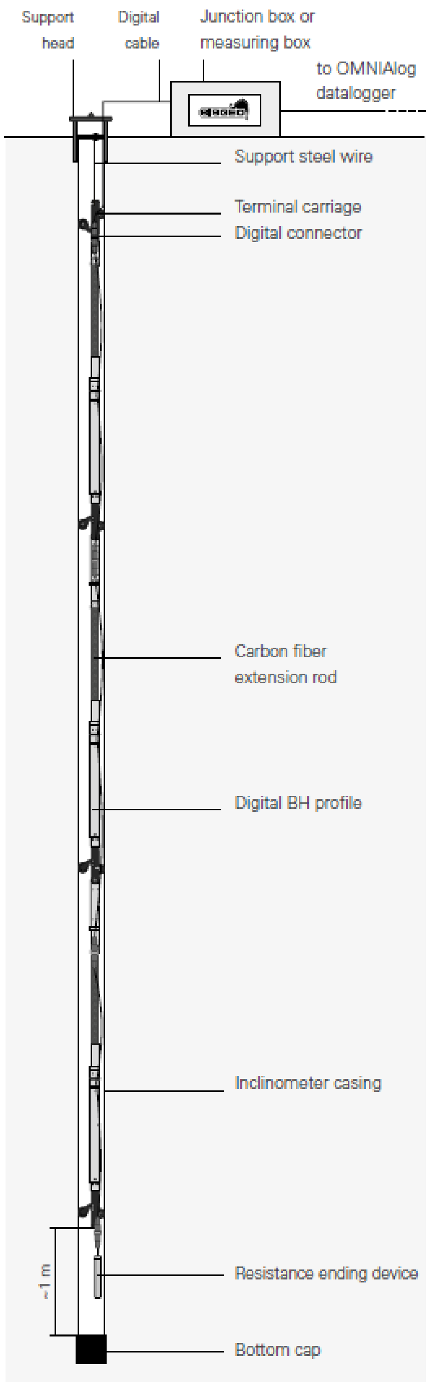




BH PROFILE ANALOGUE INCLINOMETERS

ANALOGUE (4-20MA OUTPUT):

MAX 10-15 PROBES PER BOREHOLE,
EACH PROBE HAS ITS OWN SIGNAL CABLE.

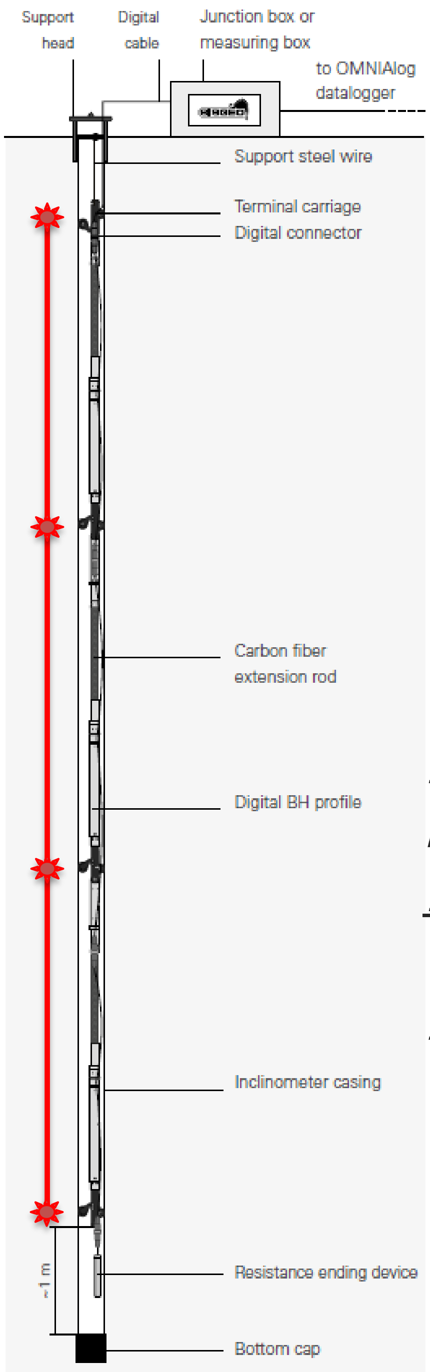


BH PROFILE
DIGITAL INCLINOMETERS

DIGITAL (RS-485 OUTPUT):

UP TO 50 BH PROFILE PROBES PER BOREHOLE (CHAIN WITH MORE THAN 50 PROBES SHOULD BE DISCUSSED WITH SISGEO TECHNICAL DEPARTMENT)
EACH PROBE HAVE TWO SIGNAL CONNECTORS THAT LINK THE PROBES ONE TO EACH OTHER.

SISGEO OFTEN RECOMMENDS USING THE DIGITAL BH PROFILE INSTEAD OF ANALOGUE PROBES DUE TO SIMPLICITY IN INSTALLATION, WIRING AND NUMBER OF PROBES IN ONE CHAIN.

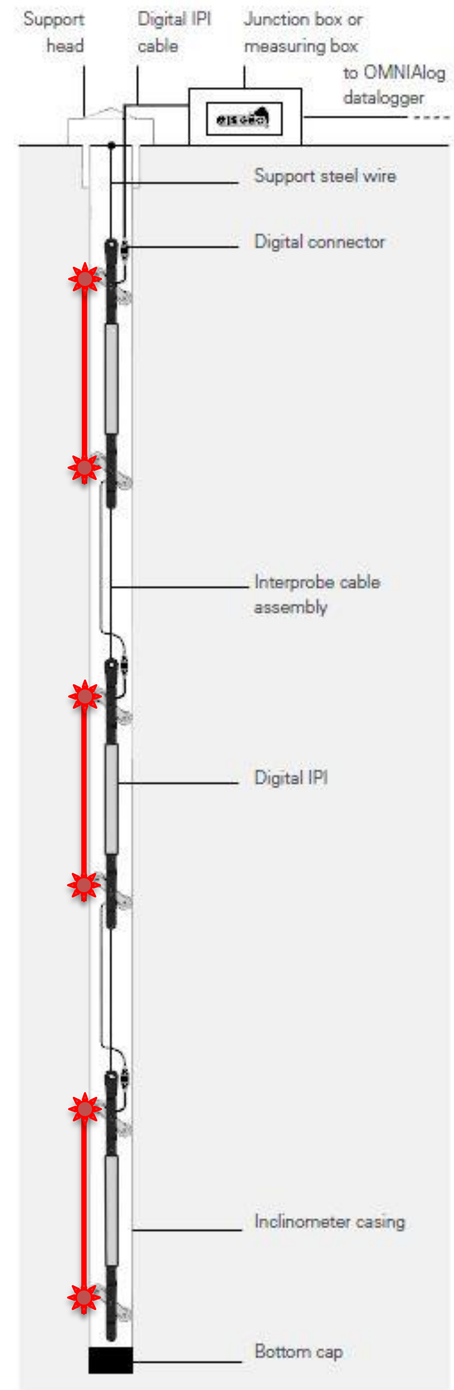


BH PROFILE VS IPI

BH PROFILE PROVIDE <u>CONTINUOUS BOREHOLE PROFILING</u>

(I.E. 30M BOREHOLE WITH 15 BH PROFILE PROBES, 2 M LONG)

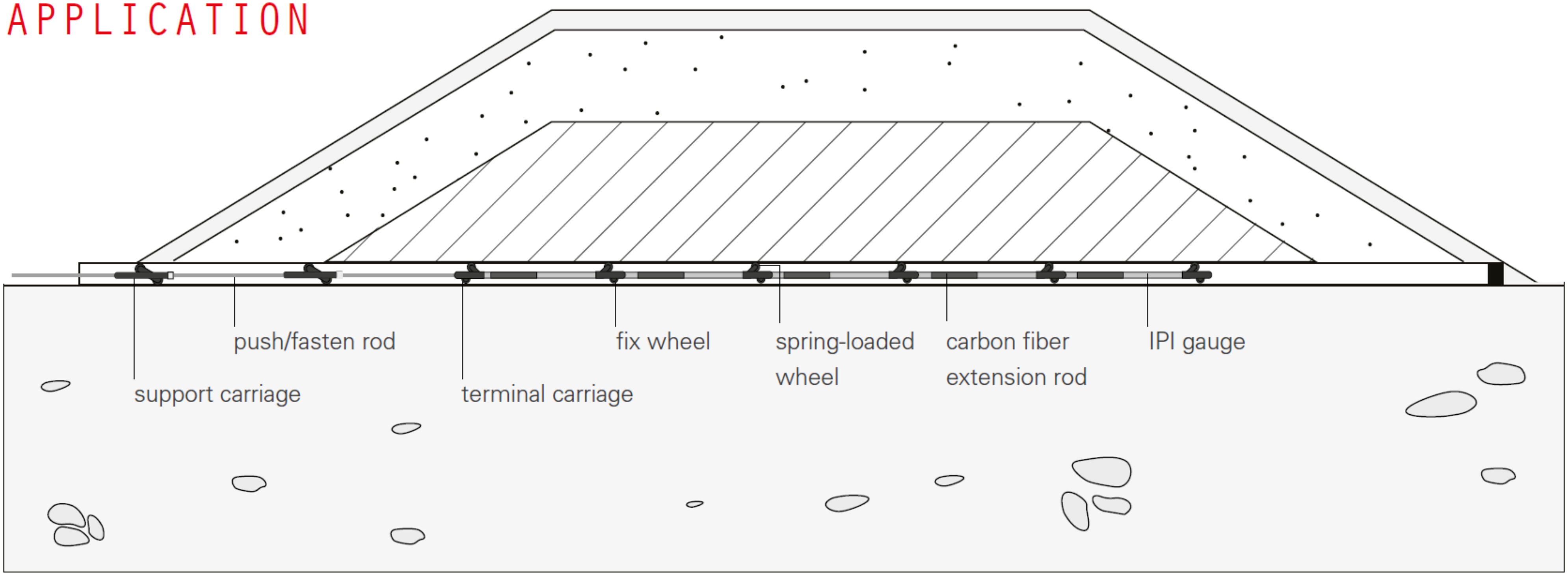
IPI ARE INSTALLED AT DIFFERENT DEPTHS IN THE BOREHOLE TO MONITOR DISPLACEMENT AT <u>SPECIFIC DEPTHS</u>, NOT COMPLETE BOREHOLE PROFILE I.E. 30M BOREHOLE WITH 5 IPI PROBES, ONE EVERY 5 M)



— HORIZONTAL BH-PROFILE

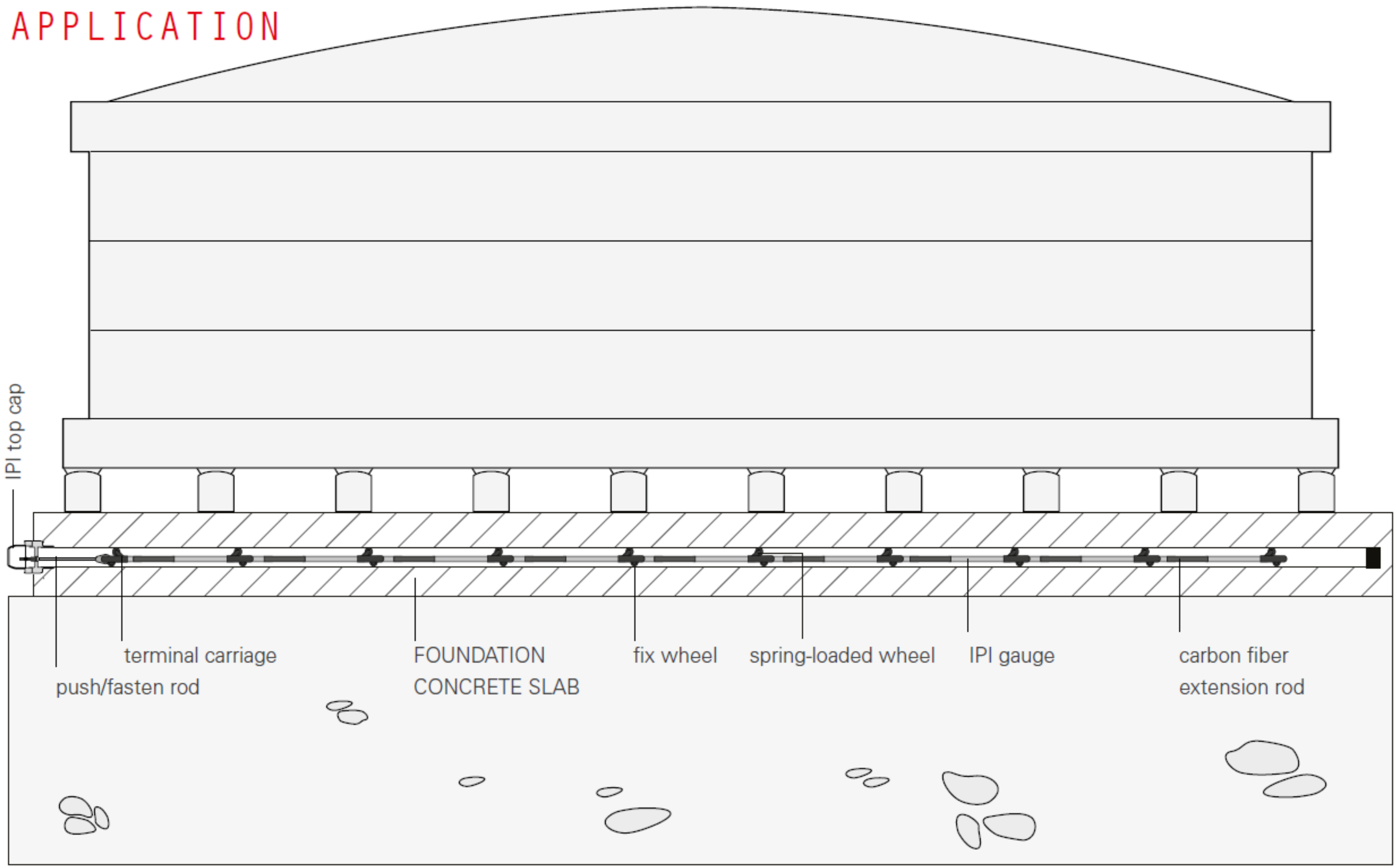
HORIZONTAL IN-PLACE INCLINOMETERS ARE ONLY UNIAXIAL BH-PROFILE MODEL.

EMBANKMENT APPLICATION



— HORIZONTAL BH-PROFILE

LNG TANK APPLICATION



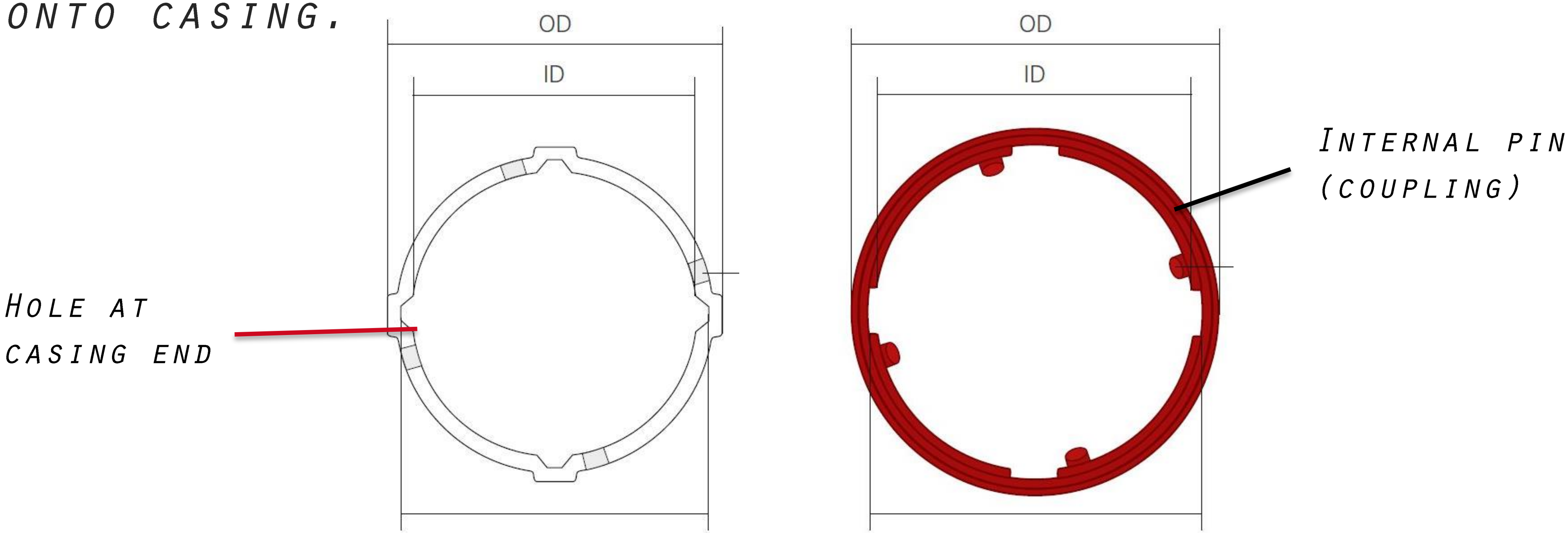
— RED STRIPE INCLINOMETER CASING

Inclinometer casings are special grooved tubes, generally installed into drilled holes, used in conjunction with inclinometer system or in-place inclinometers to determine sub-surface ground displacements.

Red stripe casings are made with virgin ABS and inclinometer tube assembly require drill, rivets, glue and tape.

_ RED STRIPE SELF COUPLING (SC) INCLINOMETER CASING

SELF COUPLING (SC) CASINGS HAVE SPECIAL COUPLINGS WITH INTERNAL PINS, AND CASING MACHINED AT THE ENDS (4 HOLES) TO FIT THE PINS. THIS SOLUTION ELIMINATES DRILLING AND RIVETING: JUST ALIGN AND PUSH COUPLING ONTO CASING.

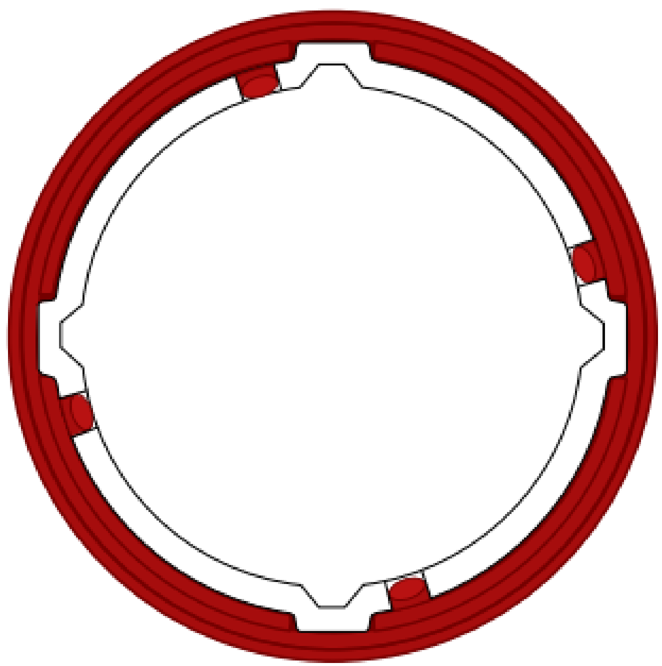


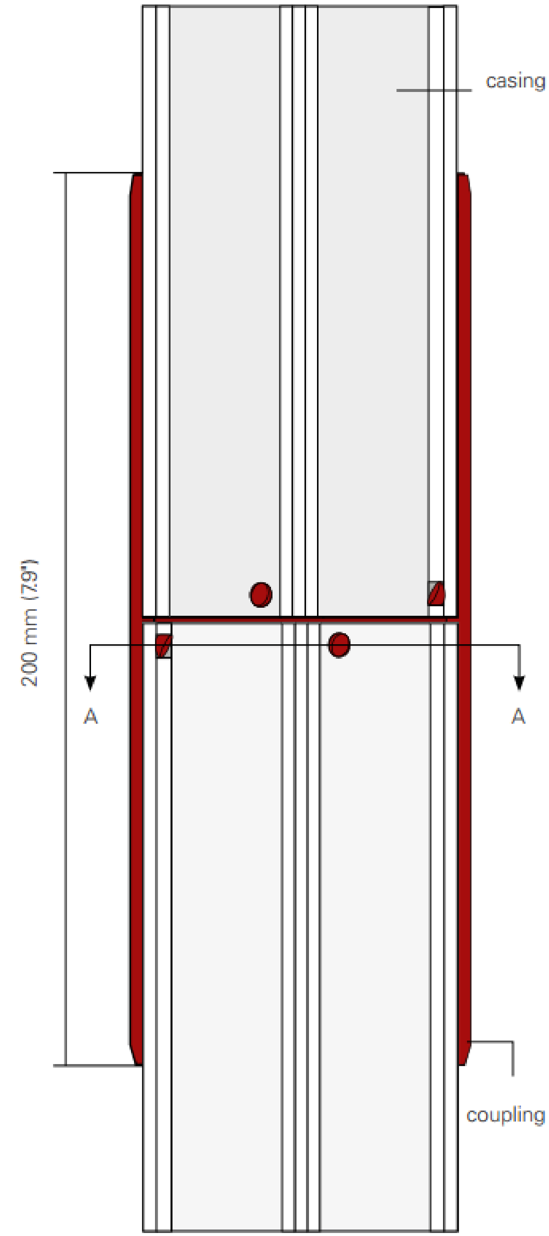
SECTION AA CASING ONLY

SECTION AA COUPLING ONLY

— RED STRIPE SELF COUPLING (SC) INCLINOMETER CASING

Red stripe Self Coupling tube after jointing

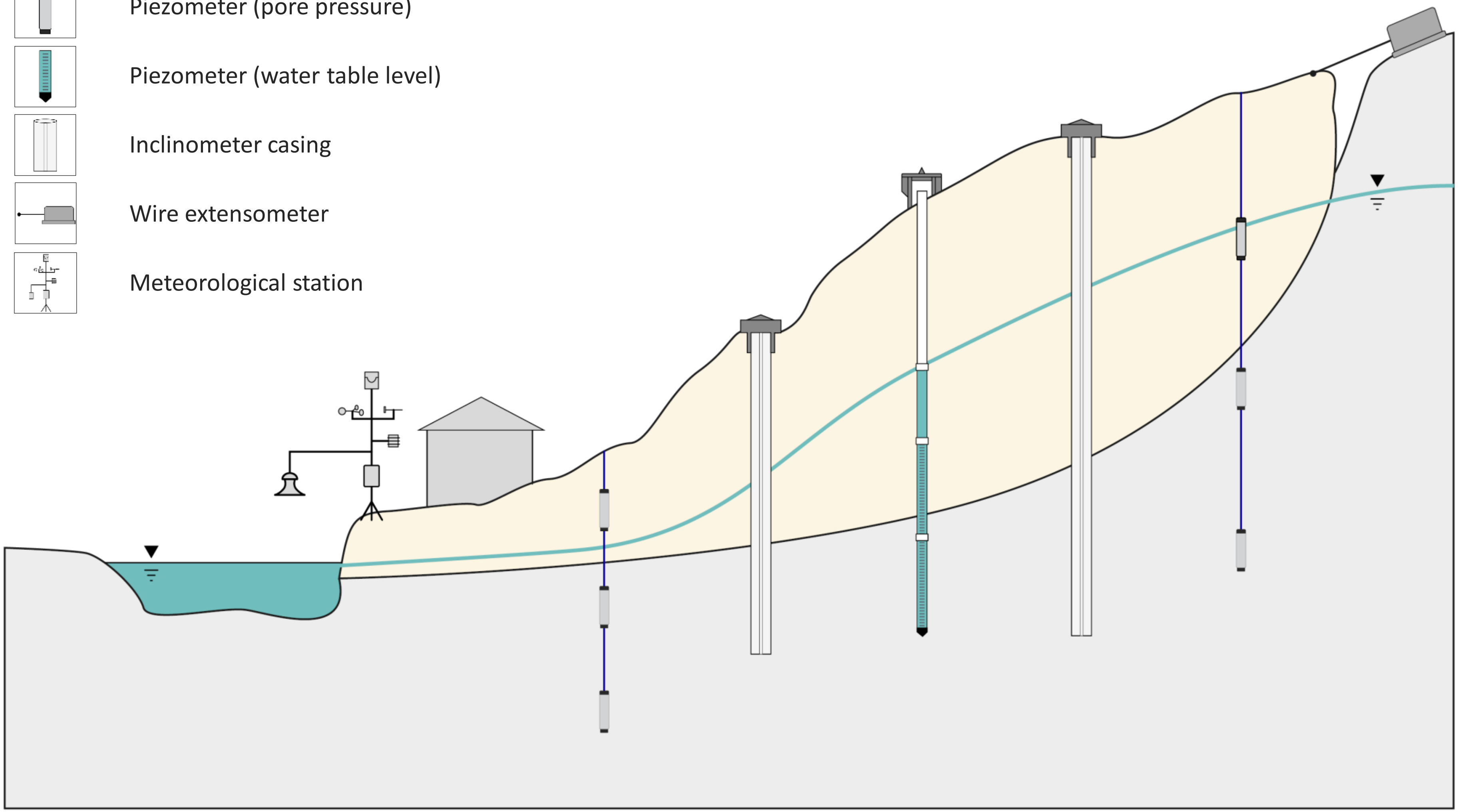




TYPICAL INSTALLATION: ROTATIONAL LANDSLIDE

— ROTATIONAL LANDSLIDE

- Piezometer (pore pressure)
- Piezometer (water table level)
- Inclinometer casing
- Wire extensometer
- Meteorological station



__ INCLINOMETER CASING FOR HORIZONTAL DISPLACEMENTS

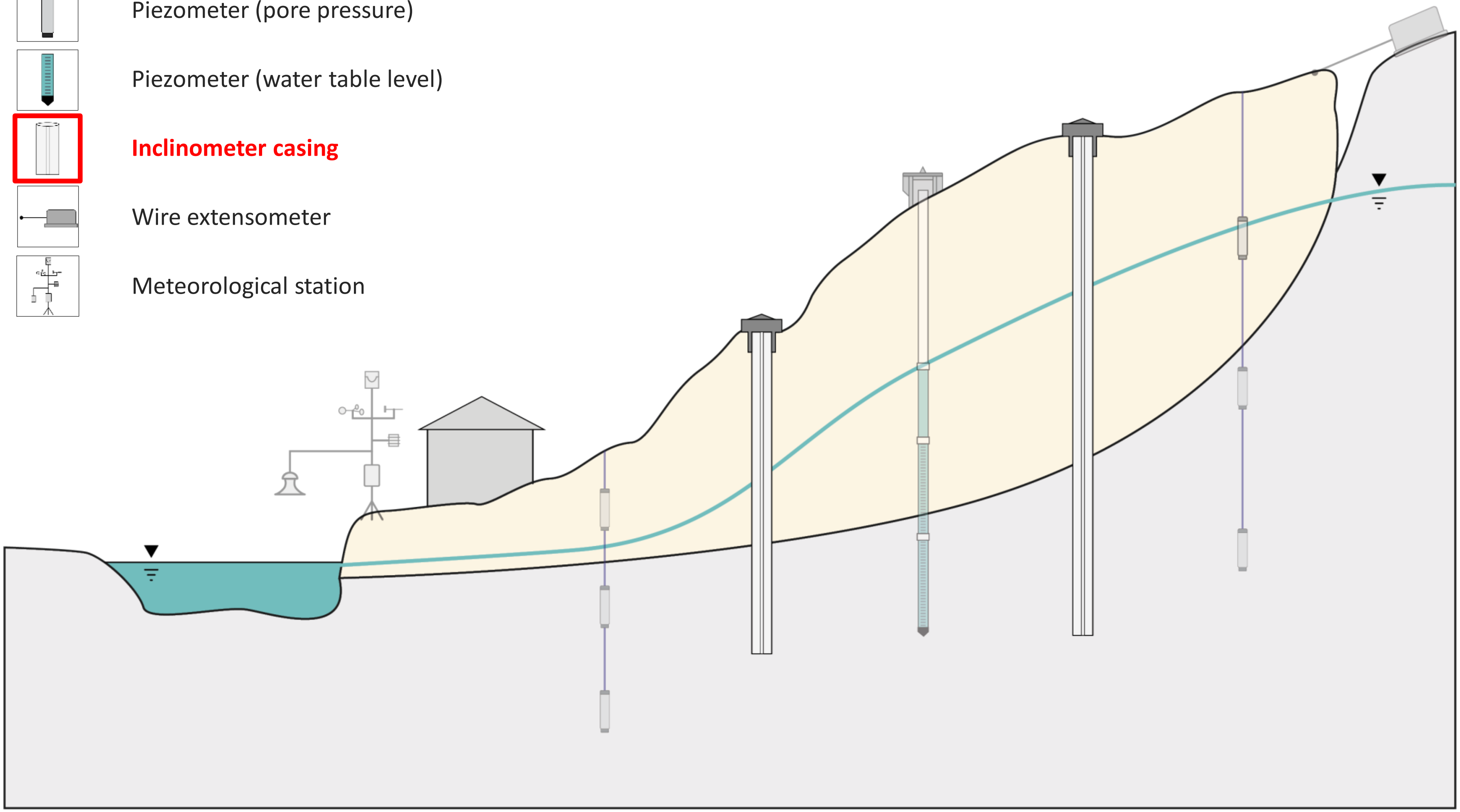
Piezometer (pore pressure)

Piezometer (water table level)

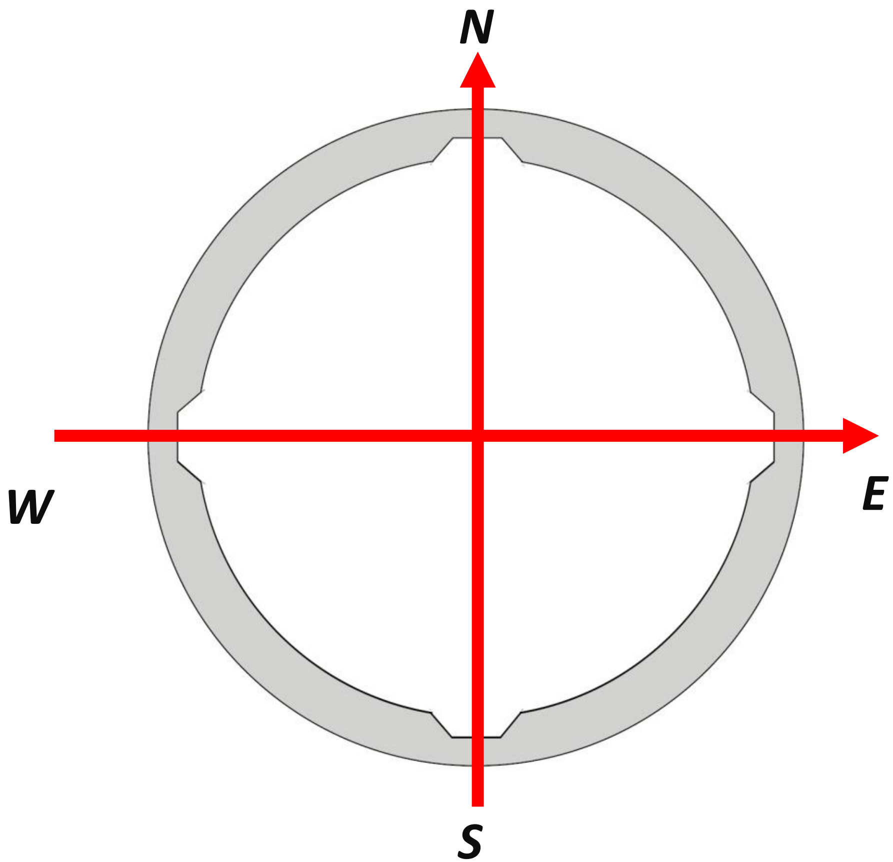
Inclinometer casing

Wire extensometer

Meteorological station



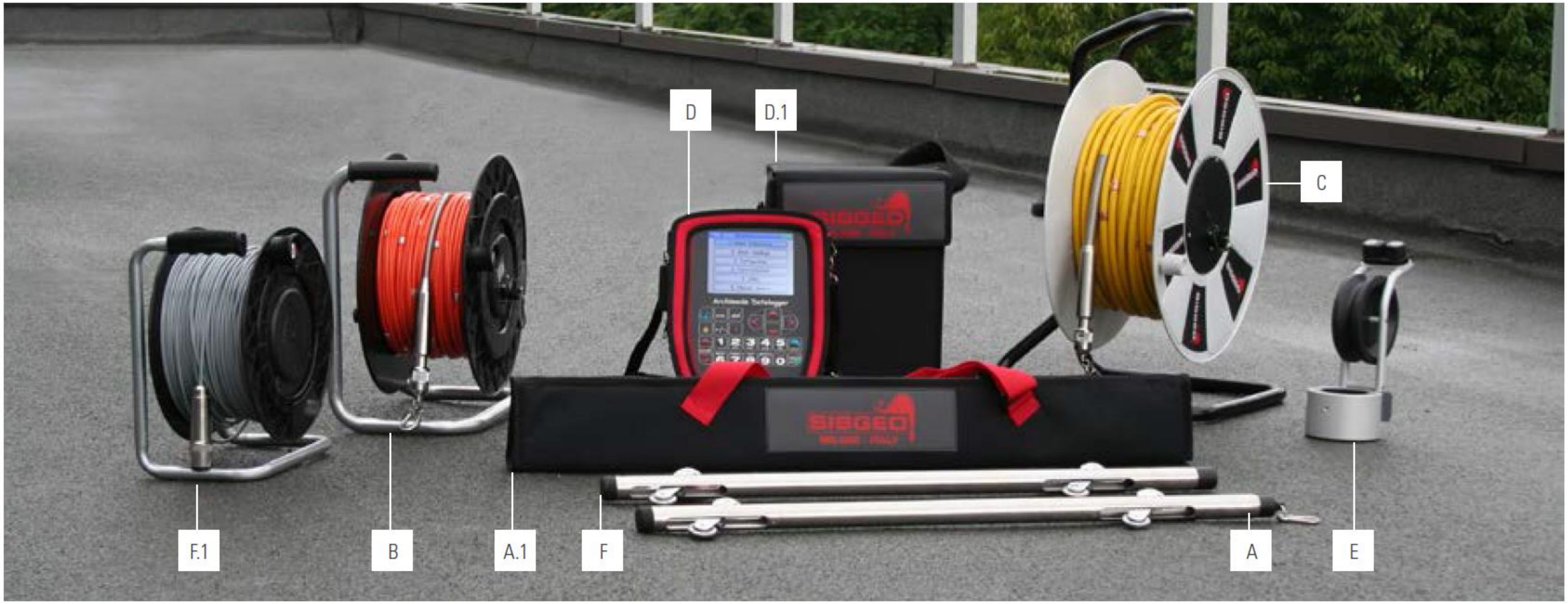
__ INCLINOMETER CASING FOR HORIZONTAL DISPLACEMENTS



Inclinometer casing section:

4 grooves to guide the probe in the tube without twisting

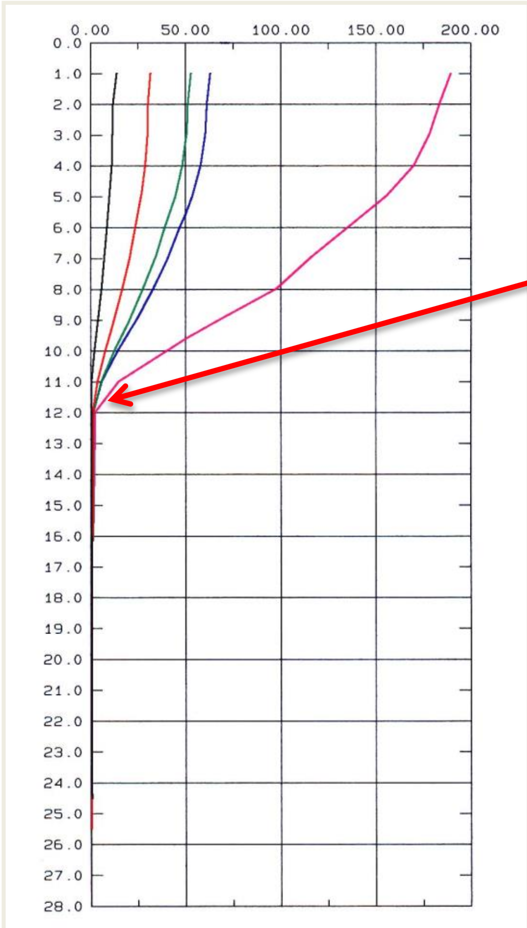
— REMOVABLE INCLINOMETER SYSTEM FOR INCLINOMETER CASING SURVEYING



A Digital inclinometer probe
A.1 Travel bag for both inclinometer and dummy probes
B Light inclinometer cable reel
C Heavy-Duty cable
D Archimede readout
D.1 Archimede carrying case
E. Pulley assembly
F. Dummy probe
F.1 Cable for dummy probe

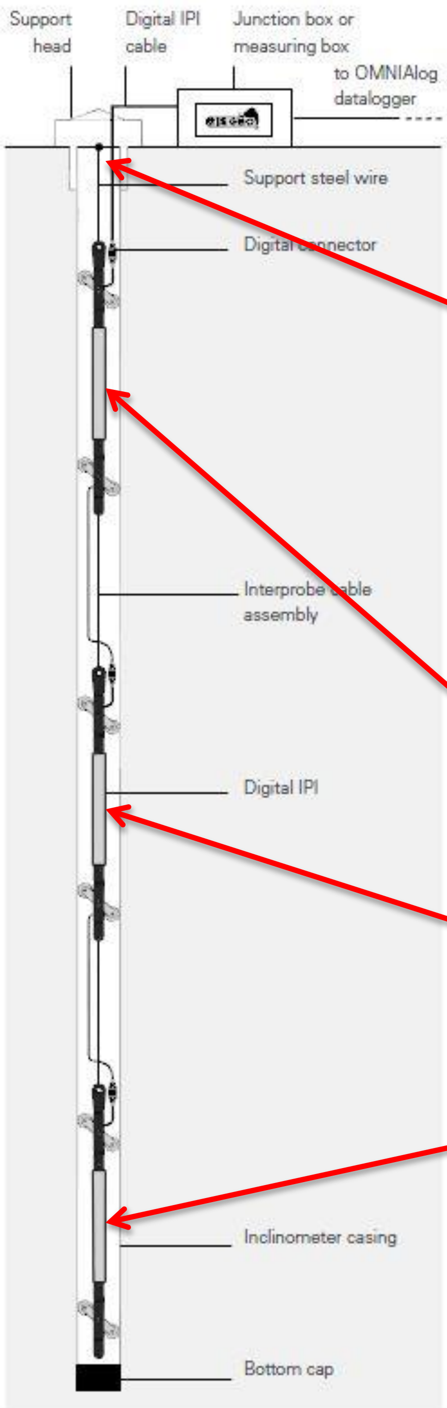
— REMOVABLE INCLINOMETER SYSTEM FOR INCINOMETER CASING SURVEYING

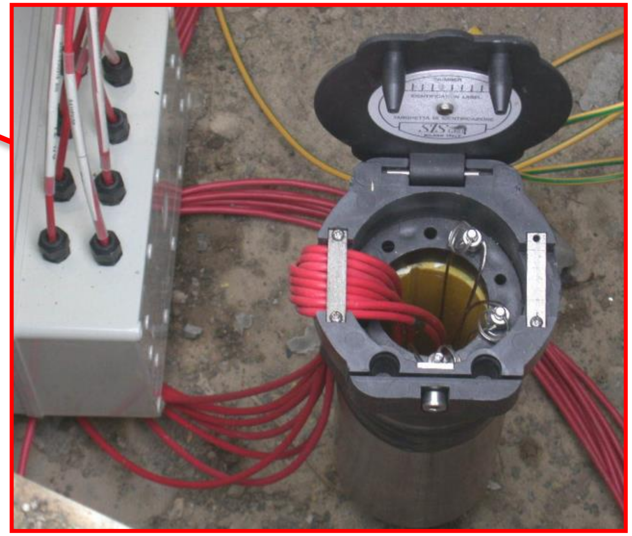
— REMOVABLE INCLINOMETER SYSTEM FOR INCINOMETER CASING SURVEYING



IN THIS LANDSLIDE EXAMPLE IS CLEAR THAT AT DEPTH -12.0M THERE IS A SLIPING SURFACE

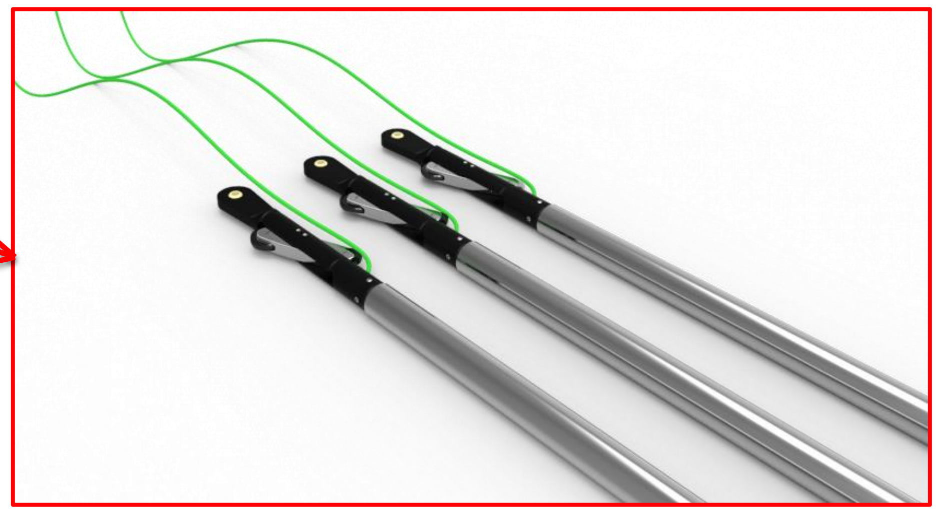
IN-PLACE INCLINOMETERS (IPI) FOR AUTOMATIC INCLINOMETER MONITORING





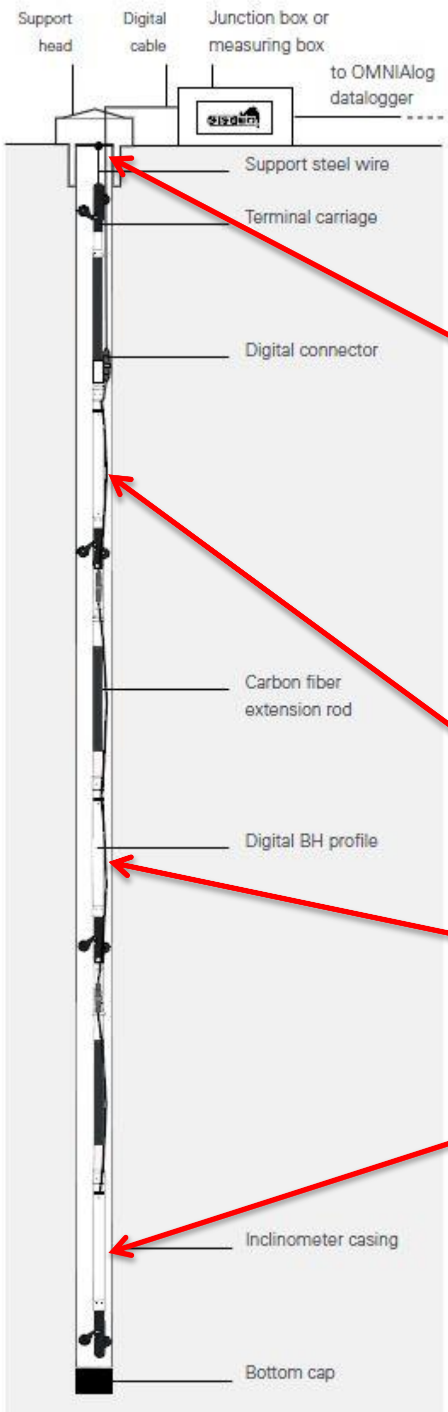
SUPPORT TOP CAP AFTER INSTALLATION

IPI PROBES



TYPICAL INSTALLATION: ROTATIONAL LANDSLIDE

BH PROFILE INCLINOMETERS FOR CONTINUOUS BOREHOLE PROFILING



SUPPORT TOP CAP AFTER INSTALLATION

DIGITAL BH PROFILE INCLINOMETERS WITH CARBON FIBER EXTENSION ROD

— LANDSLIDE MONITORING: DATA ACQUISITION SYSTEM

Instruments installed for landslide monitoring provide automatic real-time monitoring by means of OMNIAlog datalogger.

Usually in landslide DAS are powered by solar panel package.

With an internet router, OMNIAlog can provide remote system management, data pushing on a server and alarms.

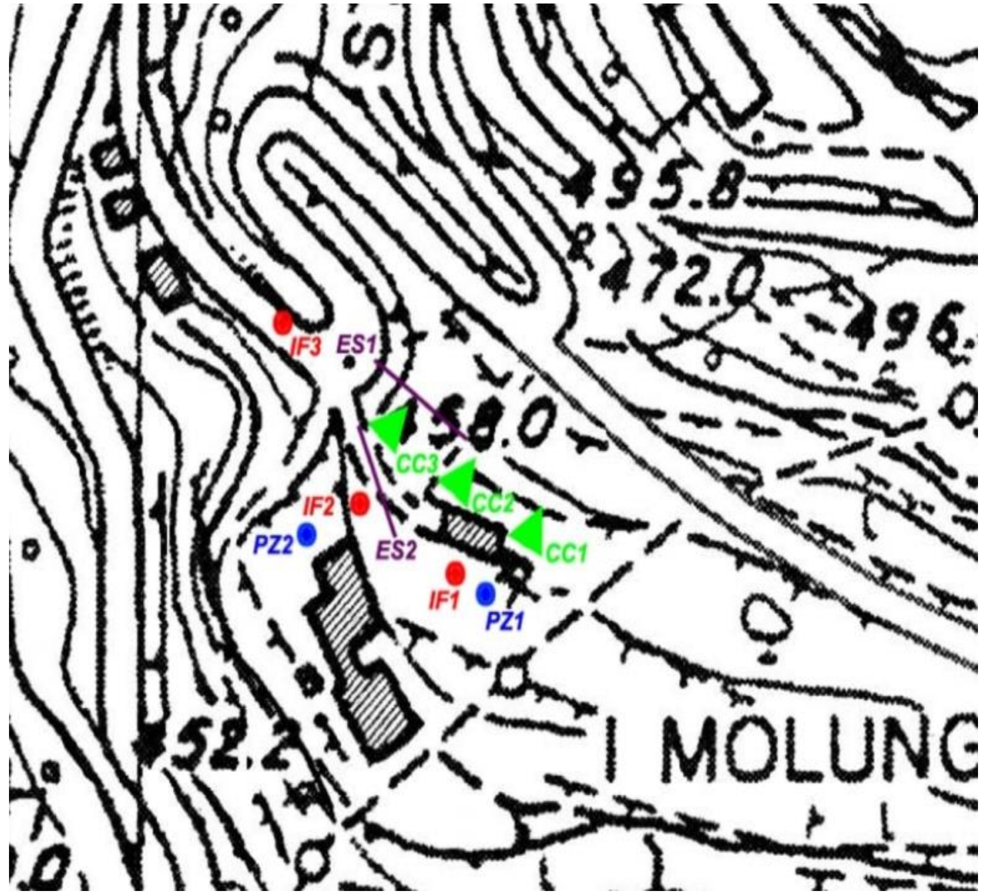
Case History

- Molunghi Landslide –Italy
- Petacciato landslide –Italy
- Fenice Bridge Over Strait of Messina -Italy
- Turin Passante Railway -Torino
- Salonicco Subway-line -Greece
- Brisbane Bridge –Australia
- Tel Aviv Red line –Israel

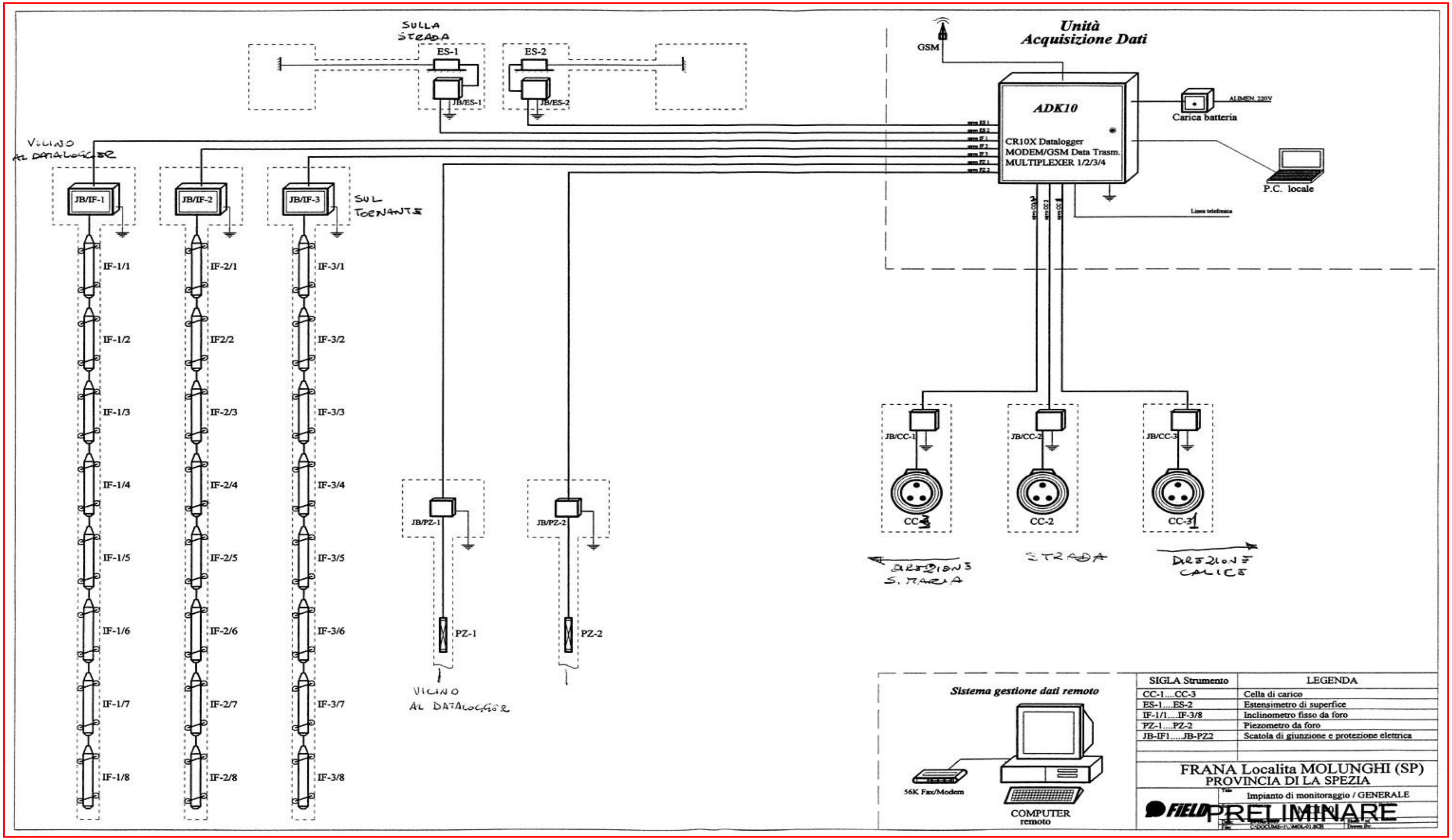
To Mention Just a Few…

Molunghi Landslide

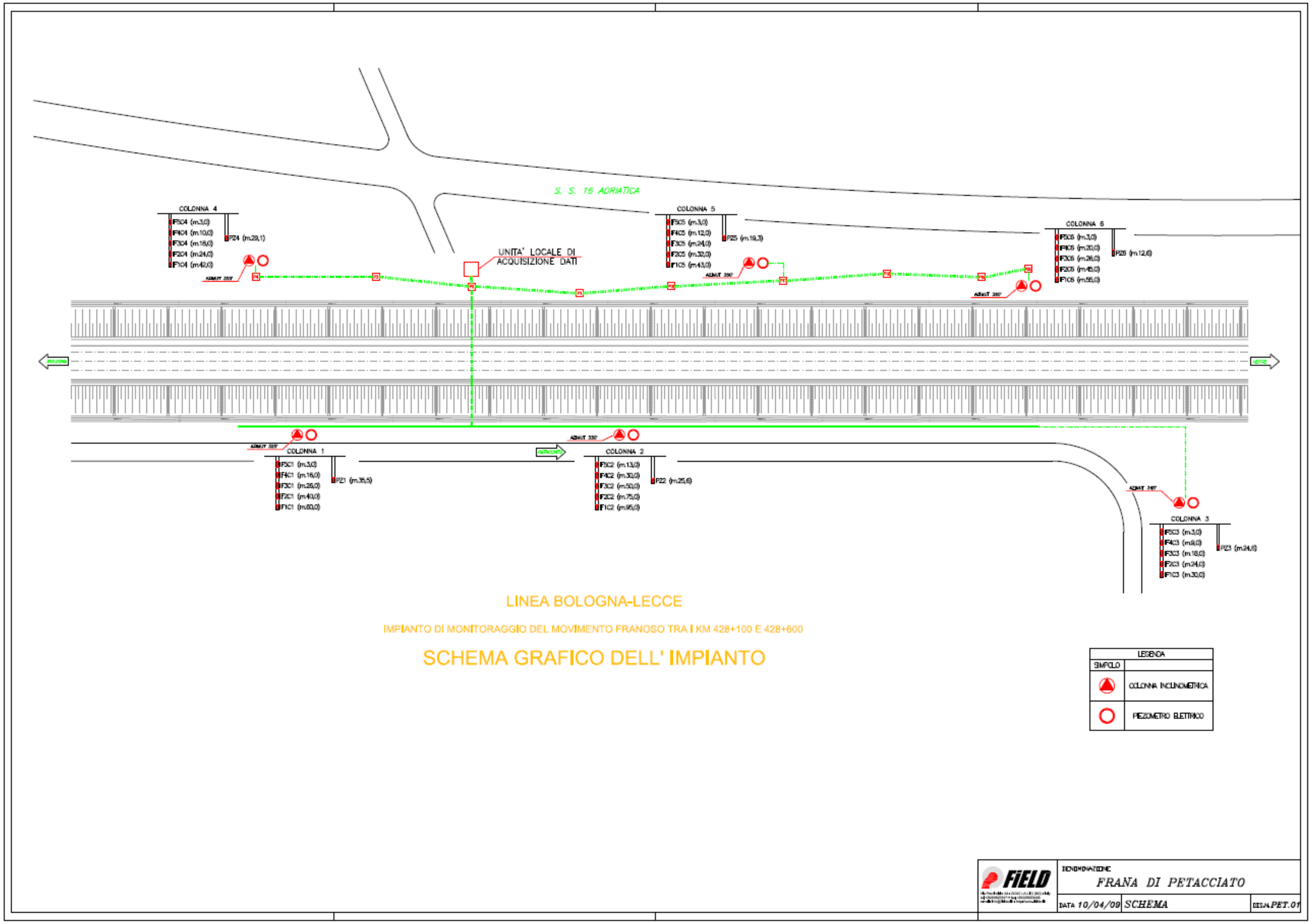
Durante l'evento alluvionale del novembre 2000 si riattivò un antico movimento franoso che coinvolse, interrompendola, la Strada Provinciale n. 27. A seguito degli studi eseguiti dalla Provincia di La Spezia (campagna di carotaggi, indagine geologica e geotecnica) fu ritenuto più sicuro ed economico predisporre una variante al vecchio percorso. Data la diffusa fragilità areale del versante, anche il nuovo progetto andava necessariamente a porsi poco a monte del ciglio di distacco della frana del 2000 oltre che a localizzarsi a margine di una linea tettonica riconosciuta. In conseguenza di ciò ed al fine di ridurre al minimo il rischio per la viabilità, fu deciso di porre in opera un sistema di monitoraggio strumentale convenzionale composto da: inclinometri fissi, piezometri fissi, estensimetri a filo fissi, tre celle di carico fisse; un *datalogger* per la raccolta automatica dei dati (una lettura ogni sei ore), la memorizzazione e la trasmissione via rete dei dati.



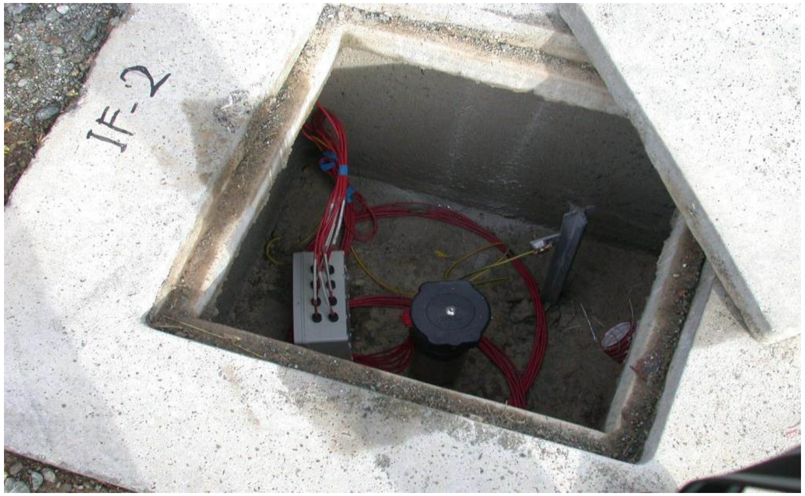
Molunghi Landslide

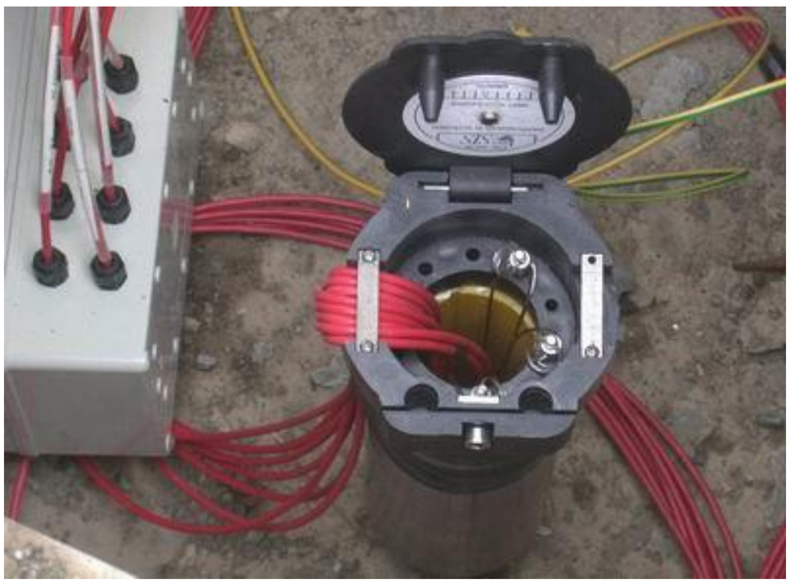


PETACCIATO LANDSLIDE

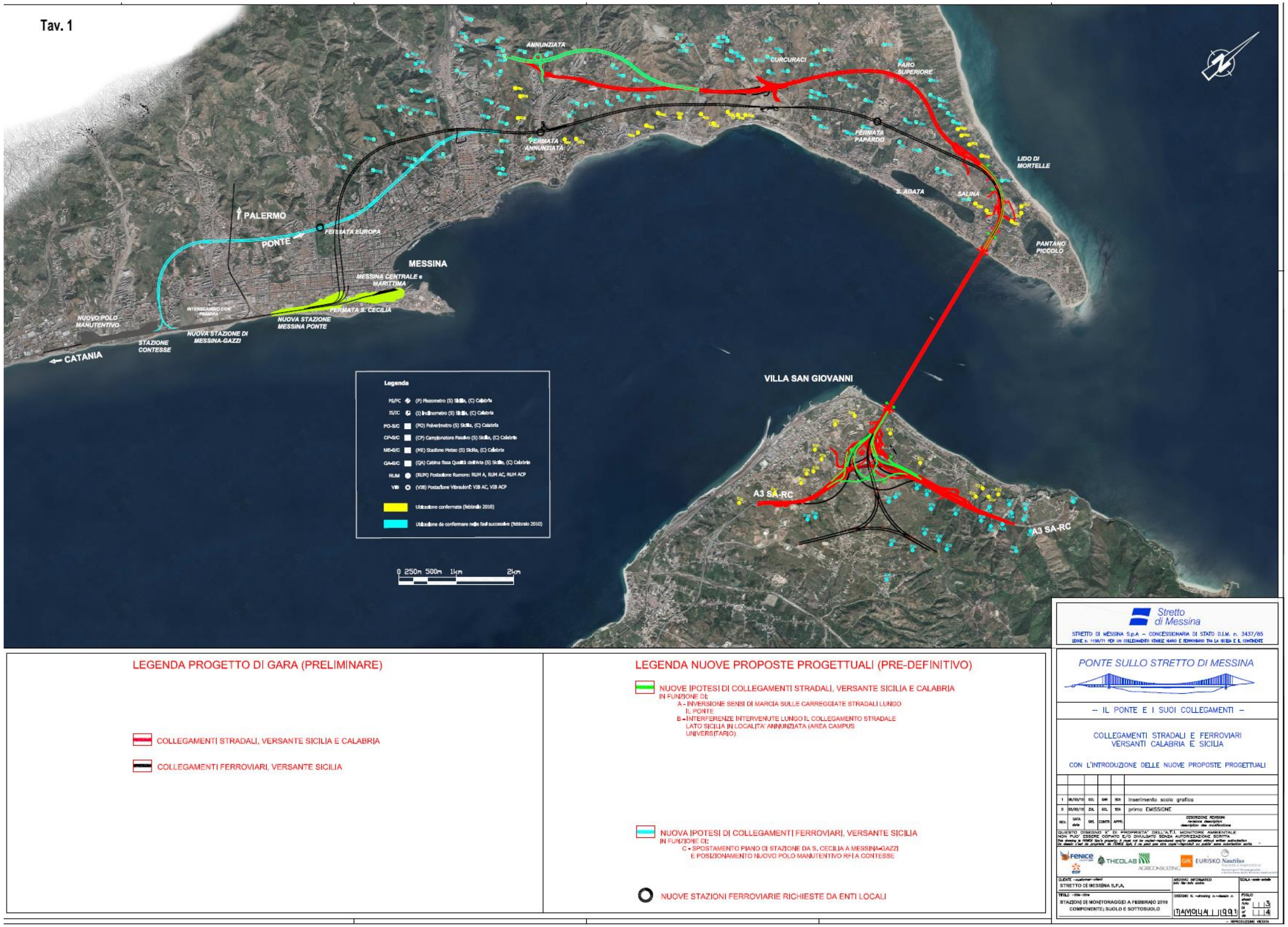


PETACCIATO LANDSLIDE

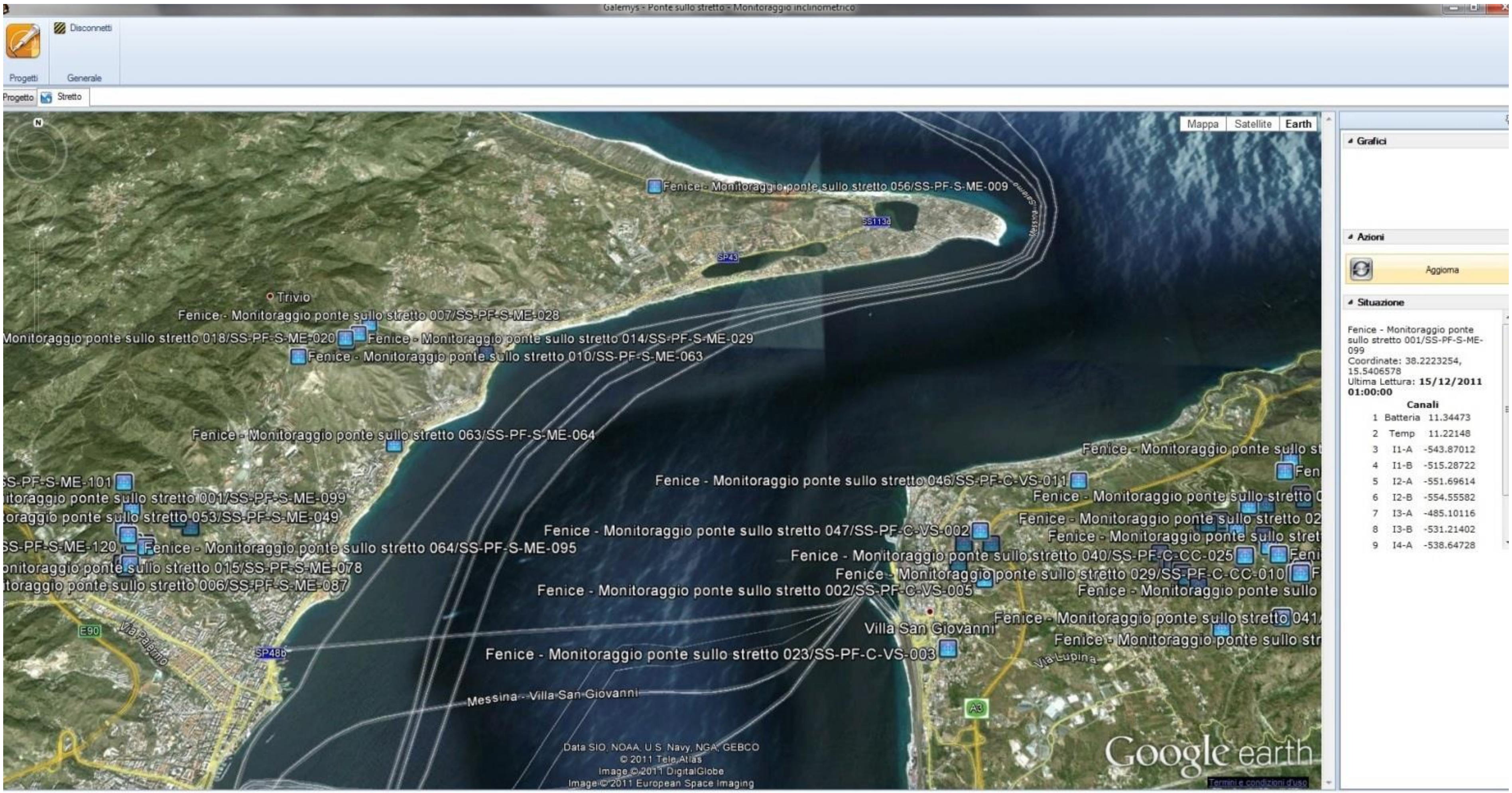




Fenice Bridge Over Strait of Messina



Fenice Bridge Over Strait of Messina



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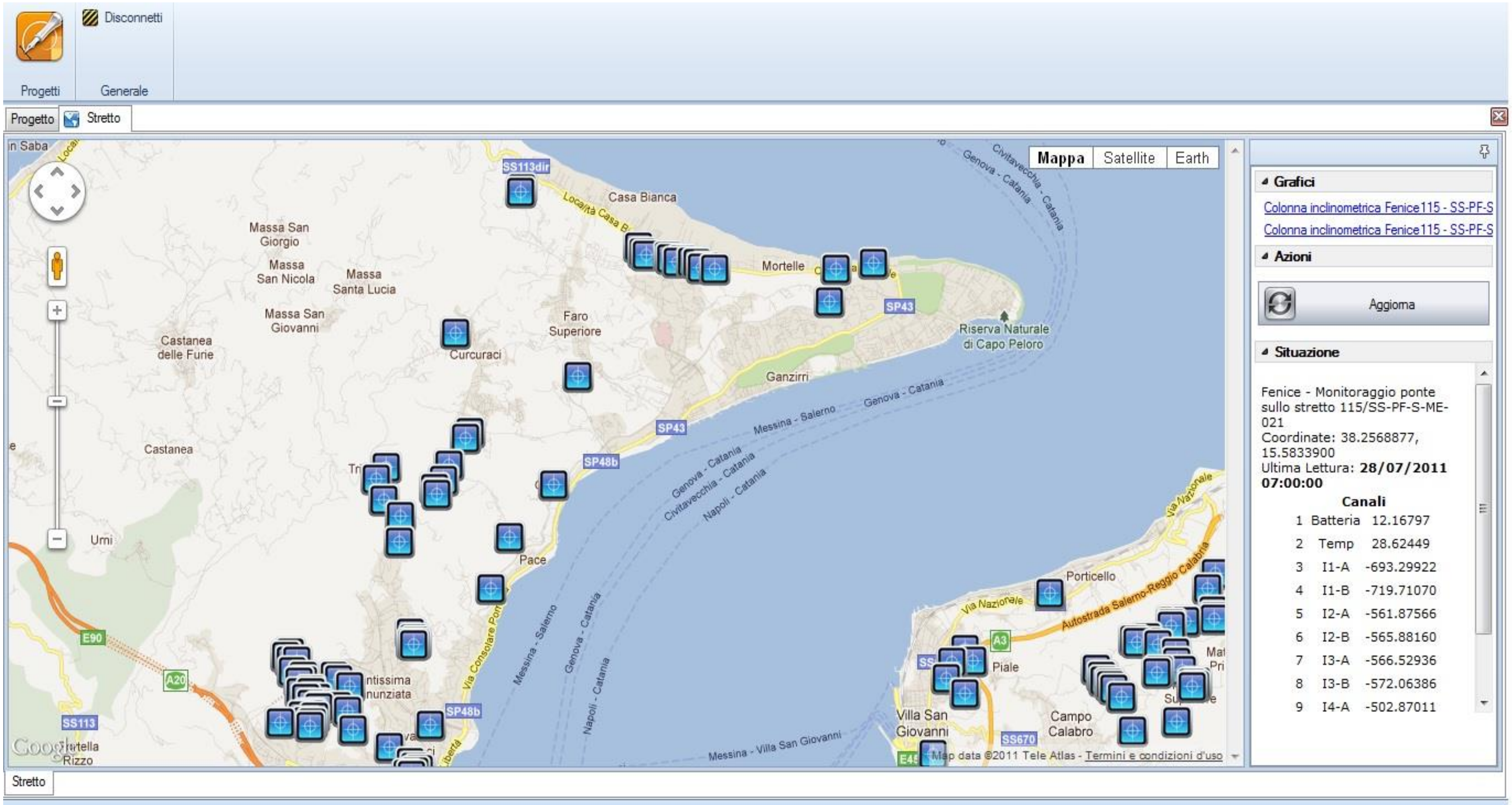
Fenice Bridge Over Strait of Messina



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Fenice Bridge Over Strait of Messina

Turin Passante Railway -Torino

Turin Passante Railway -Torino

Salonicco Subway Line

Salonicco Subway Line

Brisbane Bridge –Australia

Brisbane Bridge –Australia

TEL Aviv Red Line

TEL Aviv Red Line

CONCLUSIONS

- Monitoring could be an important aspect for monitoring management

- Results from monitoring can be the basis for monitoring control

- Data must be carefully analyzed and evaluated

- Monitoring process must include measurements and collection of information

- Safety can be improved by the correct use of monitoring systems

…remembering that

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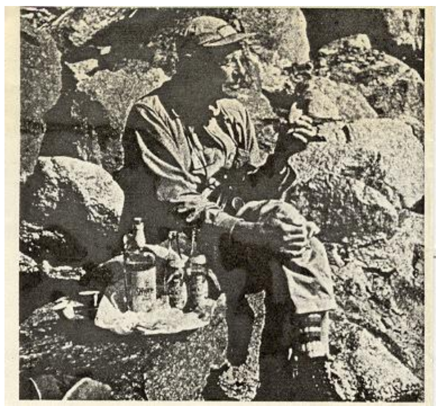
"Every job is a large scale experiment. The information obtained from such experiments cannot be secured by any other means. It is of inestimable value in connection with future construction work of similar nature, provided the observations were reliable and complete enough to permit fairly definite interpretation"



(Karl Terzaghi)

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AIS International Summer School
Orvieto-Todi
20-26 August 2023

Thanks

Alessandro Zampieri M.Sc.

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Todi, Italy, 21 August 2023