Geotechnology · Hydrogeology · Monitoring

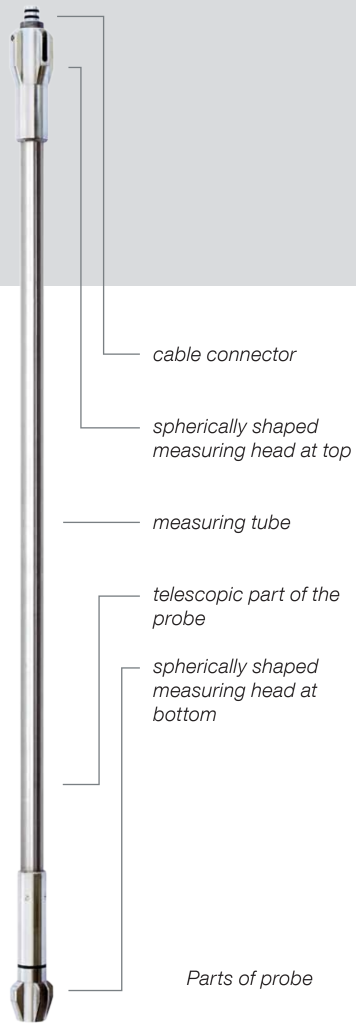
SOLEXPERTS

Swiss Precision Geomonitoring

Trivec · Sliding Micrometer · Sliding Deformeter

Linewise measurement of displacement and deformation profiles in geotechnical engineering

Linewise measurement of displacement vectors along measuring lines gives information on the behaviour of a monitored site in rock and soil or of the structure as well as of the interaction between the structure and the ground. With the Trivec, the Sliding Micrometer and the Sliding Deformeter, displacement and deformation profiles can be measured very accurately metre-by-metre in soil or rock and in foundations, diaphragm walls and other geotechnical structures.



Parts of probe

The measuring system:

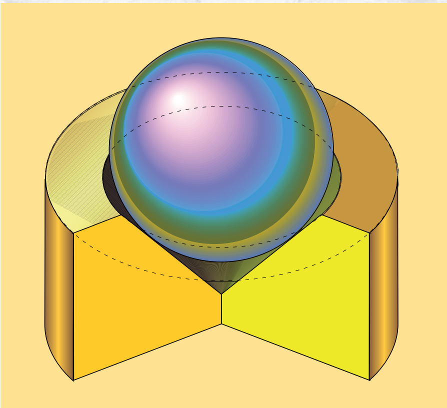
The mobile and modular measuring system consists of the probe, cable, rod, readout unit, data-processing unit and calibration device. The modular structure of the system allows an optimal combination of all components.

The probe uses the ball-and-cone positioning principle in the measuring marks of the measuring tube, and thus with high-precision sensors and regular calibration before and after each series of measurements, a very high accuracy of measurement and long-term stability is achieved. Ball-and-cone positioning principle: the spherically shaped heads of the probe and the circular cone shaped measuring marks ensure a precise positioning of the 1 m long probe during measurement.

The Trivec measures the three orthogonal components Δx, Δy and Δz of the displacement vectors along vertical measuring lines. The accuracy of measurement in Δx and Δy is ± 0.04 mm/m and in Δz it is ± 0.002 mm/m.
The Sliding Micrometer and the Sliding Deformeter measure the displacements Δz along the axes of the measuring lines that can have any arbitrary direction. The accuracy of measurement of the Sliding Micrometer is better than ± 0.002 mm/m and that of the Sliding Deformeter is better than ± 0.02 mm/m.

Planning installation of measuring system

Ball-and-cone positioning principle



Installation of Sliding Micrometer in a pile

Transjura Motorway A16, construction of the section Roches-Moutier, Canton Berne. Trivec measurements in a pile wall

GEOTECHNOLOGY — PRODUCT OVERVIEW – LINEWISE DISPLACEMENT MEASUREMENT

PROBE

- **Trivec Digital TRD** · **Sliding Micrometer Digital GMD** · **Sliding Deformeter Digital GDD**
- **Sliding Deformeter Analogue GDA**
- Inclinometer Vertical Digital · Inclinometer Horizontal Digital · Inclinometer Vertical Analogue · Inclinometer Horizontal Analogue

CABLE

- **Cable Reel KAR** · **Cable Reel on Winch KAH** · **Cable (Loose) KAL**

ROD

- **Guide Rod MB2 with bayonet connection 2 m** · **Guide Rod MB1 with bayonet connection 1 m**
- Guide Rod MS2 with screw connection 2 m · Guide Rod MS1with screw connection 1 m

SOLEXPERTS DATA ACQUISITION

- **Power Communication Device (PCD)**

SOLLINE-APP

- **Software for field data acquisition on Android Device**

TRICAL SOFTWARE

- **Software for evaluation of the measurement results**

CALIBRATION UNIT

- **Sliding Micrometer Calibration Unit for Z direction KLM** · **Sliding Deformeter Calibration Unit for Z direction KLD**
- calibration device for the X, Y and Z directions (KLT)

Grey: Parts of the measuring equipment that are described in the overview but not in the leaflet

The measuring line:

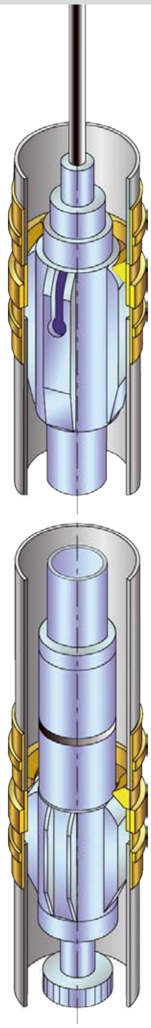
The measuring line is a linkage of measuring tubes, which are connected by «telescopic» moveable connections, the so called «telescope couplings». The conical precision measuring stop is located within the telescope coupling. For the taking of measurements, the probes are placed tightly between two neighbouring measuring stops. The measuring tubes are cemented into boreholes in the soil or rock. Regarding compressibility, the cementation is adjusted to the properties of the surrounding soil or rock. In piles, diaphragm walls and retaining walls the measuring tubes are inserted within the reinforcement and concreted into place. In geotechnical structures like landfill linings or reinforced earth, the measuring tubes are installed by means of mounting plates.

The calibration:

Every measuring system has a calibration device as a reference and to control the zero reading - in the case of the Sliding Deformeter also to check the calibration factor. The calibration of the probe is carried out before and after each series of measurements. In this way a stable measuring accuracy and continuity are ensured.

The measuring procedure:

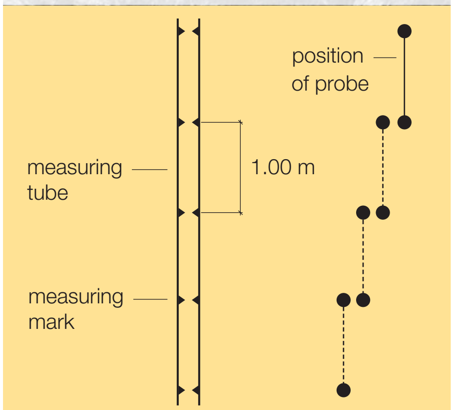
With this measuring system the measuring line is surveyed in successive metre sections. As a result, the relative distance Z – and, with the Trivec, in addition the inclination X and Y of two neighbouring precision measurement stops – can be measured to a very high accuracy without interruption over the whole measuring stretch. With the help of the orientation pin of the Trivec measuring tube, the Trivec can be rotated into the measuring direction. The probe is introduced into the measuring tube using a measuring rod, and it is tightened in steps between two neighbouring measuring stops. Thanks to the geometry of the probe's head and the telescope coupling, the probes can be pushed through the measuring tube in the sliding position and rotated into the measuring position with the aid of the rod.



Upper and lower details of the Trivec

Installation of measuring tube in borehole

Measuring principle



Measuring with a cable reel on winch

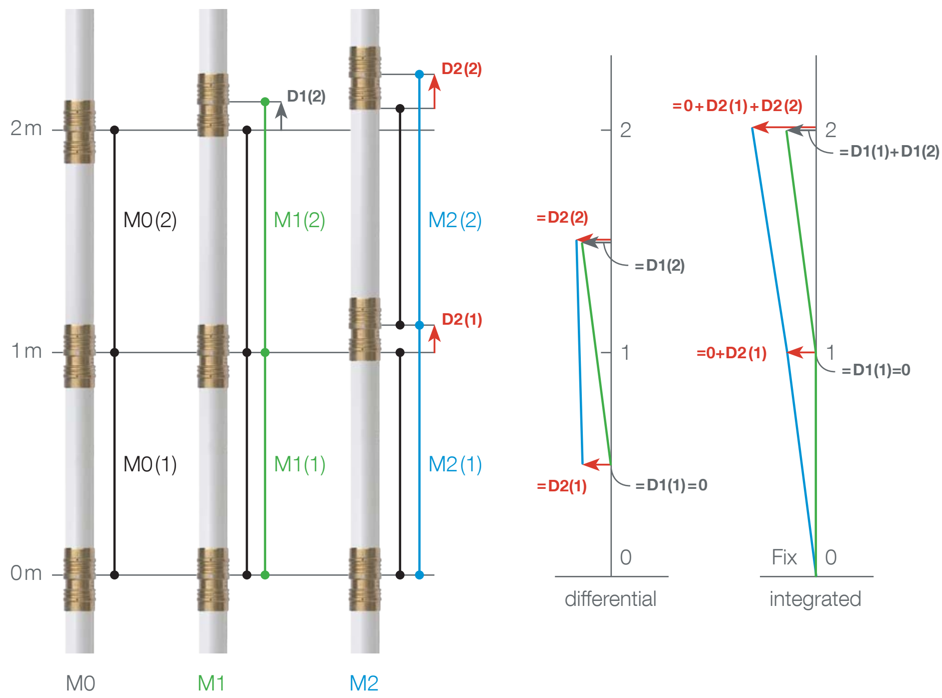
Val di Lei Dam, Sliding Micrometer measurements in the dam foundation

MEASURING PRINCIPLE

The actual measuring series is conducted after carrying out the zero measurement. The selected time intervals between the measurements are based on construction progress or the current loading state. The differential displacements are obtained from the values of the zero measurement and the successive measurements and, using the Trical software, the integrated displacements are calculated by summing these values. If Sliding Micrometer and Sliding Deformeter measurements are combined with Borehole Inclinometer measurements along vertical or horizontal measuring lines, three dimensional displacement profiles can be determined.

Figure right: Sketch of the axial displacement measurements with the reference measurement MO and the subsequent measurements M1 and M2. Presented are the differential and integrated displacements in the Z direction.

LINEWISE DISPLACEMENT PRINCIPLE - MEASURING EXAMPLE



The choice of probe is based on the geotechnical aims, the arrangement of the measuring lines and the required measurement accuracy.

TRD

GMD

GDD

Trivec TRD for high-precision, to the measuring line, axial and radial displacement measurements for vertical boreholes and measuring lines in rock, concrete or soil.

Sliding Micrometer GMD for high-precision, to the measuring line, axial displacement measurements for boreholes and measuring lines in rock, concrete or soil in any arbitrary direction.

Sliding Deformeter GDD for precision, to the measuring line, axial displacement measurements for boreholes and measuring lines in rock, concrete or soil in any arbitrary direction.

Sliding Deformeter in its case with probe guide

PROBE	
Base length	
Sensor for measurements in axial direction	
Measuring range	
System accuracy	
Linearity	
Resolution	
Temperature effect	
Sensor for measurements in radial direction	
Measuring range	
System accuracy	
Linearity	
Resolution	
Temperature effect	
Operating temperature	
Water tightness at high pressure	
Weight	
Probe guide	
Probe guide	
Calibration device	
Base length	
Measuring sections	
Operating temperature	
Thermal coefficient	
Typical applications	
Soil conditions	
Ranges of application	




Trivec TRD (digital instrument)	Sliding Micrometer GMD (digital instrument)	Sliding Deformeter GDD (digital instrument) / GDA (analogue instrument)
1000 mm	1000 mm	1000 mm
Digital displacement transducer +/- 10 mm +/- 0.002 mm < 0.02 % FS 0.001 mm < 0.01 % FS / °C	Digital displacement transducer +/- 10 mm +/- 0.002 mm < 0.02 % FS 0.001 mm < 0.01 % FS / °C	GDD: linear potentiometer with digitalisation GDA: linear potentiometer +/- 50 mm +/- 0.02 mm < 0.2 % FS 0.002 mm < 0.01 % FS / °C
Capacitance digital inclination sensor +/- 180 mm/m (+/- 10º) +/- 0.04 mm/m < 0.02 % FS 0.001 mm < 0.005 % FS / °C	no sensor	no sensor
-20 °C to +60 °C up to 15 bar 3.4 kg	-20 °C to +60 °C up to 15 bar 3.2 kg	-20 °C to +60 °C up to 15 bar 1.9 kg
Optional synthetical probe guide	synthetical probe guide above the probe	PA probe guide below the probe
1000 mm 997.5 mm / 1002.5 mm +20 °C +/- 2 °C < 0.0015 mm / °C	1000 mm 997.5 mm / 1002.5 mm +20 °C +/- 2 °C < 0.0015 mm / °C	1000 mm 975 mm / 1025 mm +20 °C +/- 1 °C < 0.0015 mm / °C
in soil, rock and concrete	in soil, rock and concrete	in soil and soft rock
Tunnelling, swelling rock, squeezing rock, excavations, foundations, dams, slopes prone to slide, unstable slopes, rock slides, rock slopes, pile walls, diaphragm walls, piles, pile loading tests		Earth masses, excavations for consolidation tests and test fills, foundations, tunnelling, grouting, soil improvement, earth dams, and slopes prone to slide

ACCESSORIES – Probe Guide, Measuring Cable, Measuring Rod, Carrying Bag, Calibration Device,

Probe Guide

Probe Guide for Sliding Micrometer

The probe guide serves to rotate the probe in the measuring tubes. For this purpose it has a swivel joint to rotate the probe from the sliding position to the measuring position. The probe guide is inserted above the probe as the first guide rod.

- base length 1.20 m, with central measuring rod and synthetical guide elements
- swivel joint 45°

Probe Guide for Sliding Deformeter

- base length 1 m, made of flexible polyamide rod with 45° swivel joint

Measuring Cable

The cable serves the purpose of transferring measurements between the probe and the readout unit as well as to produce a tight fit for the probe between the measuring marks.

- 6-wire with external and internal Kevlar steel reinforcing (tensile strength 500 kg)
- PUR cable sheathing D = 7 mm
- waterproof (up to 15 bar) 6-pin plug on probe with connection joint for the guide rod

Cable (Loose) KAL

For measurements at shallow depths with the Sliding Micrometer and the Sliding Deformeter and for horizontal measuring lines. At one end the probe plug and at the other the connecting plug for the readout unit.

Cable Reel KAR

With 6-fold slip ring for up to 100 m of cable: Weight 1.8 kg with an additional 1.2 kg per 10 m of cable, dimensions 40 x 30 x 20 cm.
With 6-fold slip ring for up to 200 m of cable: Weight 2 kg with an additional 1.2 kg per 10 m of cable, dimensions 50 x 40 x 20 cm.

Cable Reel on Winch KAH

With 6-fold slip ring for up to 200 m of cable: Weight 9 kg with an additional 1.2 kg per 10 m of cable, dimensions 120 x 40 x 20 cm.

- optional trolley for cable reel on winch
- optional aluminium bracket attached to the cable reel, for URD and field data acquisition unit

Measuring Rod, Carrying Bag

Measuring rod with bayonet connection and carrying bag

Measuring rods made of anodized aluminium with connectors made of stainless steel; lateral drill holes to position the probe every 1.0 m. D = 20 mm; weight per 2 m rod 0.42 kg; weight per 1 m rod 0.26 kg. Red markings for alignment of the probe.

- measuring rod with bayonet connection L = 2 m MB2 or L = 1 m MB1
- optional: measuring rod with screw connection L = 2 m MS2 or L = 1 m MS1

Carrying bag for up to 50 rod elements.

Calibration device

Calibration device with telescopic rod for calibration in the Z direction

The calibration devices serve to calibrate the zero reading and check the calibration factor in the Z direction of the probes.

Comment: Since the dAvnclination sensors in the Trivec probe measure in two opposite directions, a calibration of these sensors is not necessary. As an option for the calibration of the Trivec inclination sensors, however, a calibration device for the X, Y and Z directions (KLT) can be supplied or a periodic calibration of the probe carried out by Solexperts can be arranged.

- measuring sections made of Invar steel, the casing of aluminium
- temperature sensitivity 0.0015 mm /°C, recommended operating temperature 20 °C ± 1 °C
- base length 1 m
- dimensions 170 x 11 x 10 cm, weight 12 kg
- calibration device Sliding Micrometer and Trivec (KLM): calibration sections E1=997.5 mm / E2=1002.5 mm
- calibration device Sliding Deformeter (KLD): calibration sections E1=975 mm / E2=1025 mm
- accessories: telescopic rod and separate digital temperature measuring device

ACCESSORIES – Solexperts Data Acquisition Set, PCD SolLine-App, Data Evaluation

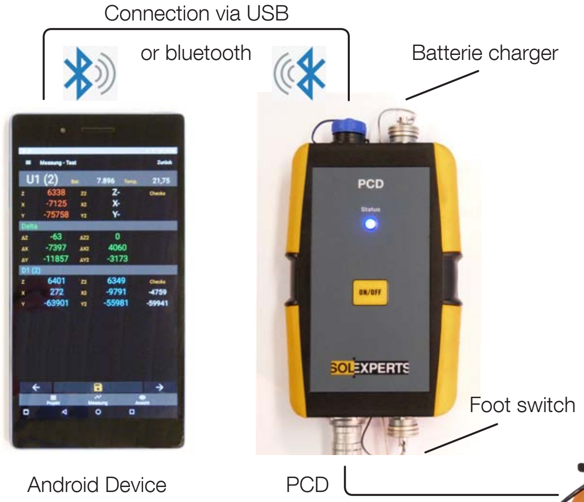
Solexperts Data Acquisition Set

Power Communication Devise (PCD) and SolLine-App for Android Devices

Solexperts Data Acquisition Set will be used to measure the following digital probes:
- Trivec
- Sliding Micrometer
- Sliding Deformeter
- Borehole Inclinometer, horizontal and vertical (type Glötzl)

PCD:
The PCD receives the signal from the probe and sends it to an Android Device with the SolLine-App. There is no display on PCD.
Accessories:
- External charger
- Foot switch for data storage

Overview connection

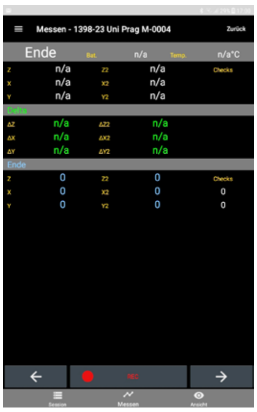


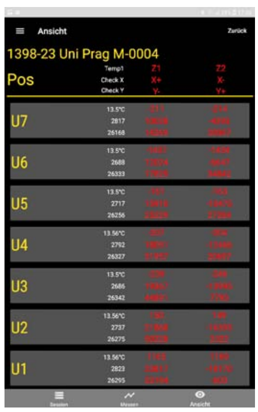
SolLine-App
Live view of measuring data.
The most important functions are:
- displaying the difference between down and up measurements
- displaying the reference values from both positions of inclinometer measurements
- data transfer to PC for evaluation with Trical software

Data storage:
- Internal drive
- send data by mail
- send data to cloud

Accessories:
- External charger
- Try to support Android Device
- Solexperts provides rugged style tablets for the use of SolLine App. Software is pre-installed

Magnetic connection PCD to cable frame
Android Device on try





Example of measurement with SolLine-App

Data Evaluation

Trical 4 data evaluation

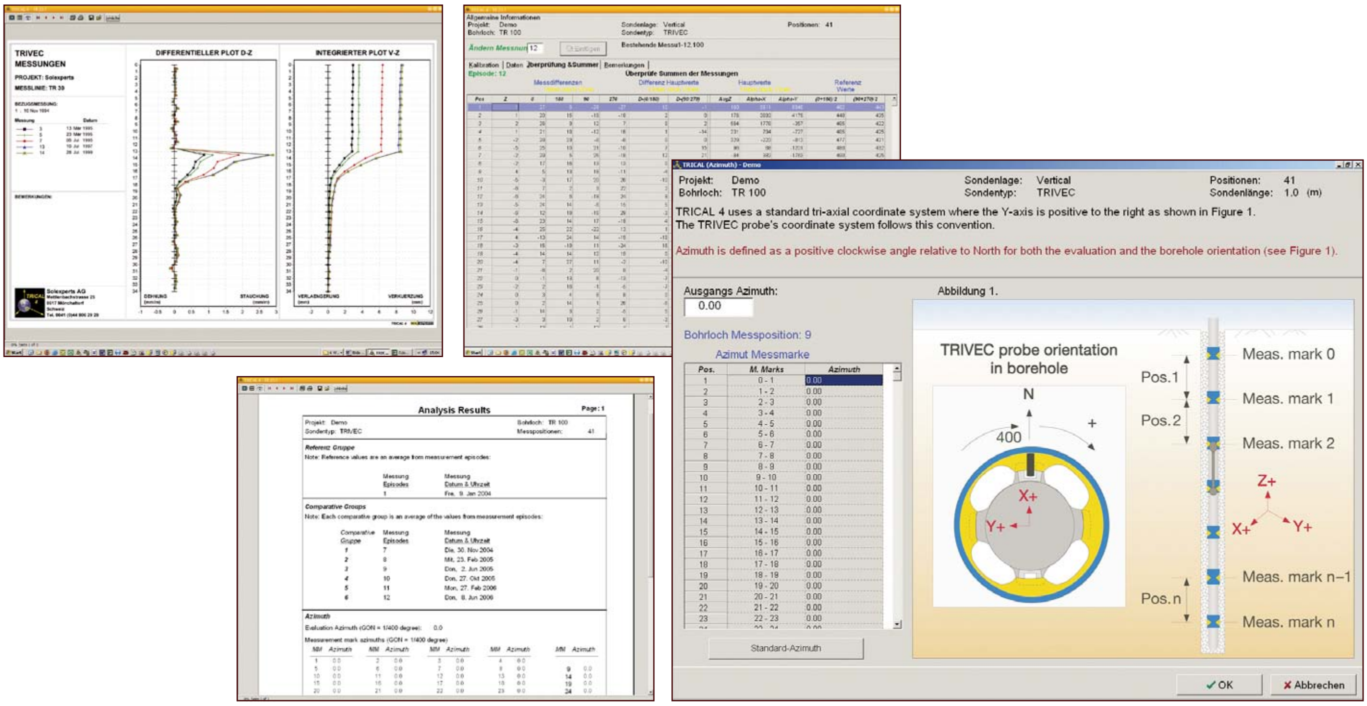
Solexperts Trical 4 software is used for the processing and evaluation of data measurements from the measuring systems Trivec, Sliding Micrometer and Sliding Deformeter and the Borehole Inclinometer.

Trical 4 is efficient and easy to use. The data import, the analysis of the measurements and their evaluation is performed in a few clearly structured steps. Trical includes all necessary functions to be able to evaluate the measurements made with borehole instruments.

Further, more detailed information can be found under http:/www.solexperts.com/LMS/software

Screen photos clockwise
1. Graphics options
2. Data Editor
3. Transformation of the evaluation direction and rotation of the measuring tube
4. Numerical results of measurements

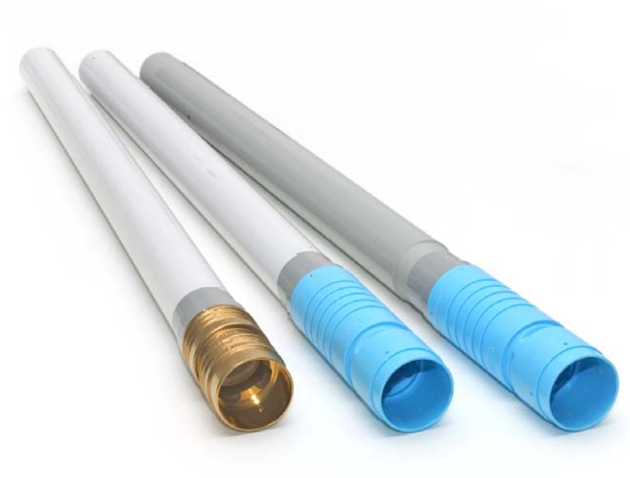
- data transfer from field acquisition unit (e.g. TDS-Recon) or manual input of measured values
- editor for input of project and borehole information as well as of the calibration values
- editor to compare and process the field measurements
- calculation of the X, XY or XYZ displacement profiles (depending on the instrument used); comparison of the measured values, taking into account fixed and end points; measuring lines can be divided into two sections (e.g. if the measuring line is interrupted by tunnelling operations); possibility of shortening a measuring line (e.g. due to excavation of the instrumented section) or lengthening it (e.g. by increasing the height of an instrumented fill or a retaining wall)
- transformation of the calculated displacement vectors taking into account the absolute and relative rotation of the measuring tube
- numerical evaluation with borehole and project information, measured values, differential measured values and reference values of both inclinometer measuring positions, table with the calculated differential and integrated displacements
- graphical evaluation with selected combinations of the differential or integrated displacement profiles with a user-specified graphics scale and line type, inclusion of firm's logo and a text box for comments
- export of the data and results of measurements for WebDAVIS, the Web-based Solexperts data management system
- choice of software language: operation and evaluation of results in German, English, French or Spanish
- editor for any arbitrary output language for the evaluations



MEASURING TUBES

The measuring line for a Trivec, Sliding Micrometer or Sliding Deformeter is given by the measuring tubes that are installed in soil, rock or concrete. Each individual measuring tube consists of a 1 m long connecting tube and the telescope coupling with the conically shaped precision measuring stop. The probe measures the displacements at the telescope couplings, which are firmly connected to the ground or the structure by means of cement or concrete.

Depending on the application and the selected probe, different measuring tubes are available. For high-precision measurements with the Trivec and the Sliding Micrometer brass telescope couplings are used, while for the Sliding Deformeter plastic (ABS) couplings are used. In the case of the measuring tubes with internal longitudinal grooves, Borehole Inclinometer measurements can be performed in addition to the Sliding Micrometer or the Sliding Deformeter measurements.



The bottom end piece consists of a 0.5 m long measuring tube with a telescope coupling and a closure plug. For the top of the measuring tube a closure flange, on which the cable reel on winch can be mounted, a tube with a screwed cover plate or a cap can be used.

MEASURING TUBE	
Accuracy of measurement axially	
Diameter of connecting tube	
Diameter of telescope coupling	
Weight per unit metre	
Photo of measuring tube	

CLOSURE PIECE OF MEASURING TUBE	
Weight	
Photo of measuring tube closure piece	

Special types of measuring tubes:
- steel casing (black, galvanized or stainless steel) for installation in piles, diaphragm walls and retaining walls
- casings with double O-ring sealing at both ends for waterproof tubes
- Sliding Deformeter measuring tube for large settlements/compression: 80 mm/m shortening and 20 mm/m extension
- Sliding Deformeter measuring tube for large heave/extension: 20 mm/m compression and 80 mm/m extension

Accessories for measuring tubes:
- grout packer with opening for measuring tube, grouting tube and vent tube
- geotextile sock for installation in jointed rock (prevents loss of grout)

Further more detailed information on the measuring tubes can be found under http://www.solexperts.com/LMS/casing

Trivec	Sliding Micrometer	Sliding Micrometer / Borehole Inclinometer	Sliding Deformeter	Sliding Deformeter / Borehole Inclinometer
+/- 0.002 mm/m	+/- 0.002 mm/m	+/- 0.002 mm/m	+/- 0.01 mm/m	+/- 0.01 mm/m
60 mm	60 mm	62 mm	60 mm	62 mm
68 mm	68 mm	68 mm	68 mm	68 mm
1.85 kg	1.85 kg	1.95 kg	1.24 kg	1.34 kg
				

Bottom end piece: Trivec	Bottom end piece: Sliding Micrometer	Bottom end piece: Sliding Micrometer / Inclinometer	Top end piece: Flange D = 150 mm	Top end piece: Steel Tube D (tube/cap) = 60/70 mm
1.4 kg	1.4 kg	1.5 kg	1.6 kg	2.6 kg
				

With the Trivec, the Sliding Micrometer and the Sliding Deformeter, displacement profiles can be determined in hard to soft rocks as well as in firm to very soft soils. The Sliding Micrometer and the Sliding Deformeter are often combined with the Borehole Inclinometer.

TRIVEC AND SLIDING MICROMETER ▷ LA ROCHE

La Roche, Transjurane

The pile wall serves to stabilize the creep slope Combe Chopin. The technical monitoring involves the determination and checking of the structural behaviour of the pile wall. Sliding Micrometer and Trivec instruments have been installed in 7 piles. The strain and displacement profiles were measured during construction and subsequent use.

Pile wall: La Roche

Trivec: Shaft for Linthal Power Station

Trivec: Measurements in St. German

TRIVEC ▷ LINTHAL AND ST. GERMAN

Shaft for Linthal Power Station

In the 70 m deep and 20 m diameter shaft to house the power station unit there is a pump turbine, which pumps water from a lower equalising reservoir to the 1046 m higher Limmern reservoir, and when there is a high demand the water is released through the turbines. 4 Trivec measuring tubes for geotechnical monitoring have been installed beneath the shaft and in the wall of the shaft. Rock deformations are measured by means of Trivec measurements in the shaft wall and beneath the shaft and thereby the position of the foundation support for the pump turbine can be monitored.

St. German, Alp Transit Lötschberg

Trivec measurements up to depths of 71 m provide the displacement vectors beneath the village of St. German in relation to depth, direction, inclination and magnitude. Groundwater drawdown caused by the tunnelling work resulted in large settlements.

SOLEXPERTS

SLIDING MICROMETER — ZURICH AND BELCHEN TUNNEL

Zurich Hardturm Stadium
To assess pile bearing capacity and serviceability three static pile-loading tests were carried out. The instrumentation of each test site with Sliding Micrometers included a measuring line in the pile, which was extended by means of a drill hole to 8 m below the pile, as well as a measuring line alongside the pile to a depth of 38 m.

Belchen Tunnel / Chienberg Tunnel
To assess the swelling mechanisms in the Gipskeuper of the Belchen and Chienberg tunnels Sliding Micrometer measurements are being carried out. For this purpose special measuring tubes made of stainless steel with O-ring sealing were installed. They withstand the high swelling pressures and the O-rings prevent the ingress of water into the rock strata with swelling potential.

SLIDING DEFORMETER — VENICE AND RATICOSA TUNNEL

Venice, Bocca di Lido
Consolidation Test: M.O.S.E. Project.
To investigate the consolidation behaviour of new flood embankments an in situ consolidation test was carried out.
The settlements in the underlying ground were obtained using the Sliding Deformeter. Sliding Deformeter measuring tubes with measuring ranges of 80 mm/m compression and 20 mm/m extension were installed to a depth of up to 60 m in the middle of the earth structure and eccentric to it. Displacement profiles were measured continuously during the heightening of the embankment.

Raticosa Tunnel
The displacement measurements ahead of the tunnel face, executed with either the Sliding Micrometer or the Sliding Deformeter, serve to optimize the tunnel face anchors and to assess and safeguard its stability. These measurements could also be carried out with Modular Reverse-Head Extensometers.


Pile loading tests: Zurich, Hardturm Stadium


Consolidation test: Venice, Bocca di Lido


Sliding Micrometer measurements: Belchen Tunnel

More information on the choice of measuring system and the measuring tubes can be found on the following web pages:

For measuring systems:
www.solexperts.com/LMS/instruments

For measuring tubes:
www.solexperts.com/LMS/casing

For software:
www.solexperts.com/LMS/software

For manuals:
www.solexperts.com/LMS/manuals

We reserve the right to make technical modifications

SOLEXPERTS
Swiss Precision Geomonitoring

Measuring systems and professional services in the fields of geotechnology and hydrogeology.

Solexperts AG
Mettlenbachstrasse 25
Postfach 81
8617 Mönchaltorf
Switzerland

Tel +41 (0) 44 806 29 29
Fax +41 (0) 44 806 29 30

info@solexperts.com
www.solexperts.com

Solexperts France SARL
Technopôle Nancy-Brabois
10 allée de la Forêt de la Reine
54500 Vandœuvre-lès-Nancy
France

Tel +33 (0) 3 83 94 04 55
Fax +33 (0) 3 83 94 03 58

info@solexperts.fr
www.solexperts.com

MeSy-Solexperts GmbH
Meesmannstrasse 49
44807 Bochum
Deutschland

Tel +49 (0) 234 904 47 11
Fax +49 (0) 234 904 47 33

info@mesy-solexperts.com
www.mesy-solexperts.com