(FMGM 2007: Seventh International Symposium on Field Measurements in Geomechanics © 2007 ASCE)

Trivec and Sliding Micrometer: fully digital instruments for geotechnical displacement and deformation measurement

Heribert Frodl[1], Daniel Naterop[1]

[1]Solexperts AG, Mettlenbachstr. 25, 8825 Mönchaltorf, Switzerland,
PH +41-448062929, FAX +41 448062930; info@solexperts.com

ABSTRACT: Since more then 25 years the Sliding Micrometer and the TRIVEC borehole instruments have been very successfully used for different applications in geotechnical engineering projects to measure profiles of deformation and displacement in soil, rock and in concrete structural elements. The wide range of applications covers landslide projects, foundation engineering, projects with retaining walls, deep excavations, soil consolidation, dam and dam foundation and also tunneling and caverns engineering. One application is the monitoring of the behavior of the Emosson double arch dam foundation since more then 20 years by TRIVEC. Another example are large scale static pile load tests for a new football stadium in Zürich including deformation measurement along the pile but also in the soil under and next to the piles. Recently, the Sliding Micrometer and the TRIVEC were redeveloped with new characteristics including digital sensors, new data acquisition system and new hardware.

INTRODUCTION

In the 1970's, the Sliding Micrometer and the TRIVEC measuring systems were developed at the Swiss Federal Institute of Technology in Zurich, Switzerland. The idea of Prof K. Kovari, at this time director of the Department of Rock Engineering and Tunneling, was to enable measurement of strain profiles in soil, rock and also in concrete structural elements as piles, diaphragm walls and other foundations. Many examples, especially of tunneling projects that included systematic measurements, showed that these readings serve as valuable feedback signals for constructional decision making and for monitoring of adjacent buildings.

In this context, one main purpose is to optimize design and construction of underground structures. Systematic measurements, e.g. strain measurement along profiles, provided valuable information whether the underground structure or parts of it reached stable equilibrium and whether large deformations were to be expected.

To obtain indications on the material behavior and on the overall rock and soil quality, systematic measurement of strain and deformation profiles during excavation of underground structures in combination with suitable computational methods (back analysis) were and are successfully applied.

A dam and its foundation form a structural unit. Behavior and safety of the dam are linked inseparably to the performance of the foundation. But behavior of the foundation can include a relevant source of uncertainty. Deformation measurement along profiles within the dam and the foundation, also often combined with numerical methods, has been an important part to check structural and long term behavior. Early recognition of unexpected deviations of the behavior their cause and source are a result of systematically measuring deformation profiles.

MEASURING PRINCIPLES

The quantitative distribution of deformation along a line is detected by measuring profiles of strain and lateral displacements. Therefore, the line-wise measuring system was developed that consist of the instrument and the measuring casing (corresponding to the line) installed in the borehole or the structural element (e.g. pile or diaphragm wall). So, relative displacements of adjacent reference points at constant distance to each other can be measured. The basic criteria applied to the systems were:

- Portable instruments, which can be used for different instrumentation projects and can be calibrated at any time
- High precision of the results
- Suitability for application in soil, rock and structural elements used in geotechnical engineering

The Sliding Micrometer is a portable strain meter and the TRIVEC is a combination of a portable strain meter with a biaxial accelerometer measuring the angle of the probe axis to direction of gravity. With the Sliding Micrometer one component of the displacement vector is measured. With the TRIVEC all three components of the displacement vector are measured (Figure 1).

The measuring casing is installed in the borehole and the space between the borehole wall and the casing is filled with a suitable grout. The grout usually consists of water, clay powder and cement powder. The amount of clay, cement and water is selected to match strain-stress behavior of the equipped borehole with the surrounding rock or soil. Special precautions have to be taken if loss of grout or water overpressure from the borehole is to be expected and also if horizontal or upwards directed boreholes are equipped. In piles and diaphragm walls, the measuring casing is concreted in the process of construction.

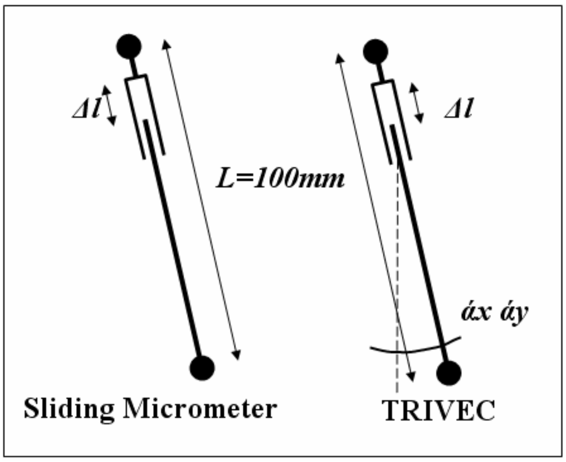

Figure 1: Principles of the Sliding Micrometer and the TRIVEC-probe.

The measuring casing consists of reference points, each at a distance of 1m, and the casing to interconnect the reference points. The reference points with the cone-shaped measuring mark are constructed as telescopic couplings to enable axial movements along the measuring casing (Figure 2). To obtain high precision during the reading, the two sphere-shaped measuring heads of the probe are in contact with the two adjacent cone-shaped reference points. When the sphere is in contact with a cone-shaped surface, the centre of the sphere is uniquely defined. To be able to move the probe along the borehole from one position to the next, the spherical heads of the probe and the cone of the measuring mark are specially designed. In sliding position the probe is moved along the borehole until it is located at the reference points. Then, the probe is rotated by 45° and brought into measuring position.

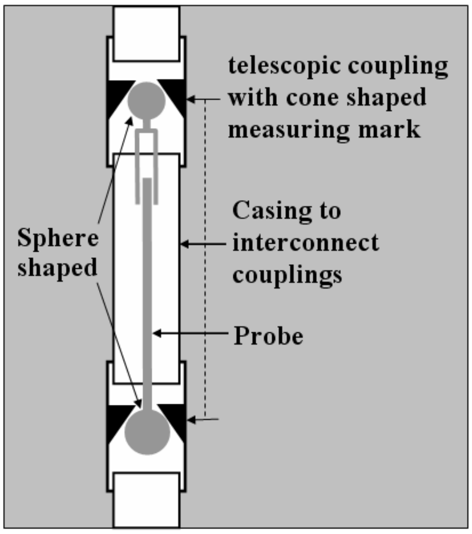

Figure 2: Schematic technical layout, principle of the measuring casing with the probe.

The accuracy obtained with the Sliding Micrometer and the TRIVEC is remarkably high. The relative displacement between two adjacent measuring marks can be measured axial to the measuring casing accurate between +/-0.002 to 0.003mm/m and lateral to the measuring casing accurate to +/-0.05mm/m. This is essential for measurement in concrete and stiff rock but also in soil or soft rock, if early information on the behavior of the formation is required.

EMOSSON DOUBLE ARCH CONCRETE DAM - 20 YEARS OF MONITORING WITH TRIVEC

Typically installed monitoring systems for concrete dams provide rather limited information for numerical methods. Standard monitoring normally includes instrumentation to measure a few displacement vector components at selected points in structure and foundation supplemented by strain and displacement measurements at isolated locations of the dam body and rarely in the rock foundation. This is referred to as “point-wise observations”. If an exceptional behavior requires the knowledge of more details as particular joints, shear zones, weak layers and propagation of cracks, measurements of strain and deformation profiles are essential. In several concrete dams and their foundation, line-wise deformation measurement provided relevant information on the location of such deficiencies and their performance at different reservoir levels over a long period of time (e.g. Kölnbrein-Dam Austria, Albigna dam, Zervreila dam and Garichte dam in Switzerland).

For the 190 m high Emosson concrete double arch dam in Switzerland, the aim is to confirm normal behavior and to check validity of the design assumptions. From the lowest inspection gallery two 30 m deep vertical boreholes through approx. 5 m concrete and 25 m rock have been equipped with TRIVEC-casings (Figure 3). Since 1987 readings of the displacement profiles in vertical (z), upstream/downstream (x) and left/right (y) direction along the two boreholes have been taken. After annual measurements at the beginning, readings are taken now at intervals of about 4 years.

The profiles of vertical (z-) and horizontal (x-) displacements are given in Figures 4 and 5 respectively. At the contact between concrete and rock foundation, slightly increased extensions and horizontal deformations have been observed. At the end of the borehole, at 30 m depth, vertical extensions of up to maximum 0.15 mm/m are clearly measured. In the horizontal direction (down-/upstream) integrated displacements of maximum up to 12.5 mm over the 30 m borehole have been measured. The displacements in x- and z- direction correlates well with reservoir levels (Figure 6). The results of the readings taken at the Emosson dam clearly show that line wise observation with the TRIVEC provides high quality data for long term behavior control of the dam foundation.

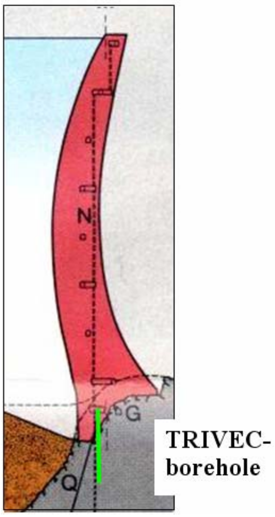

Figure 3: Cross section of the Emosson dam with TRIVEC-boreholes

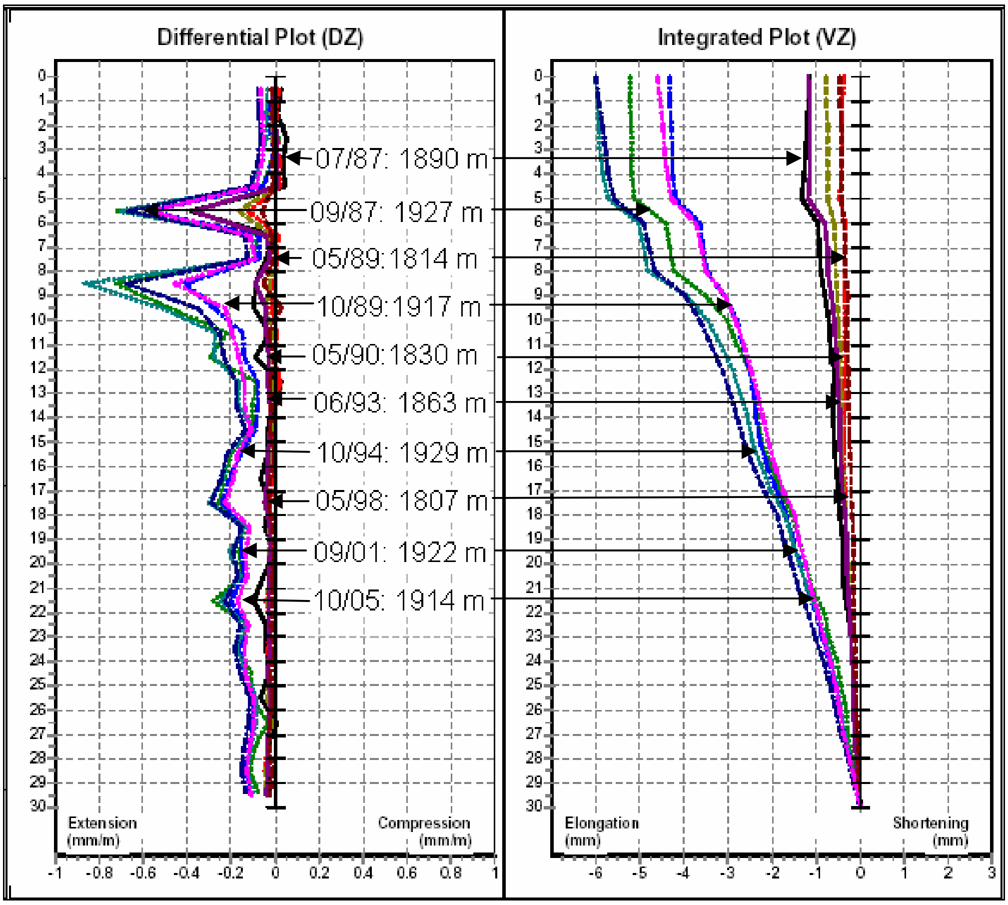

Figure 4: Displacements profiles in vertical direction at different reservoir levels

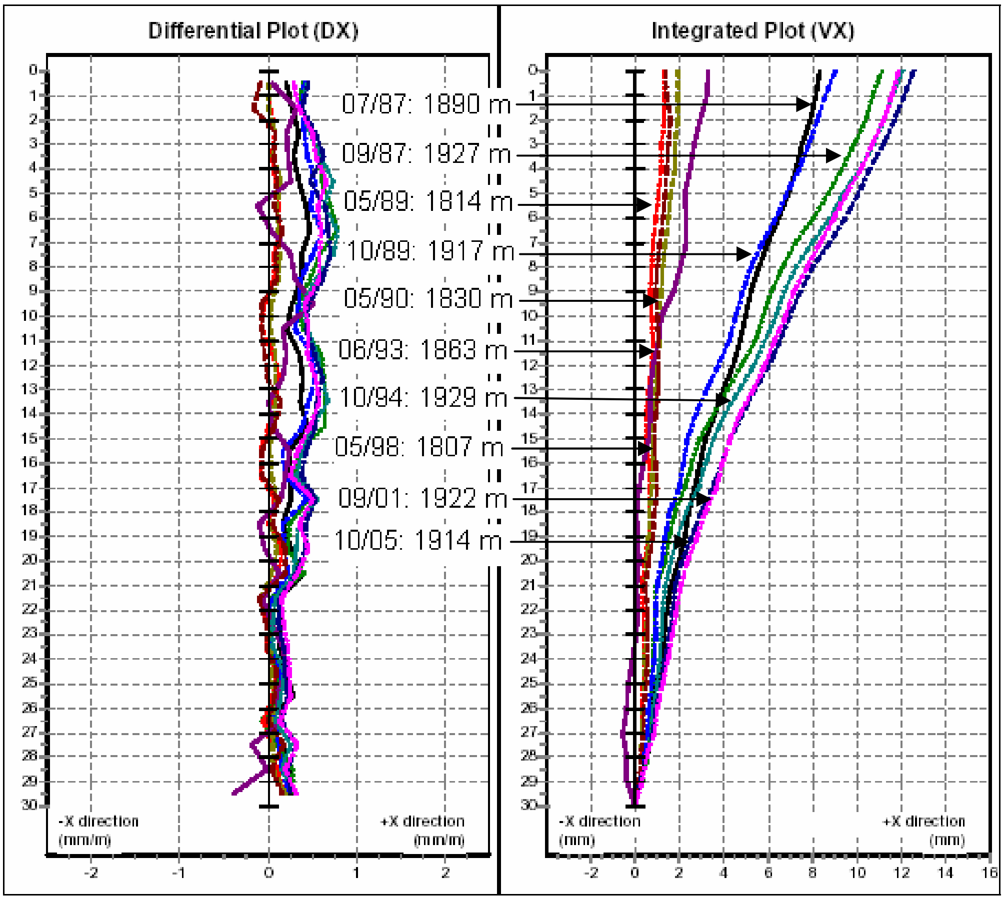

Figure 5: Displacements profiles in horizontal direction at different reservoir levels

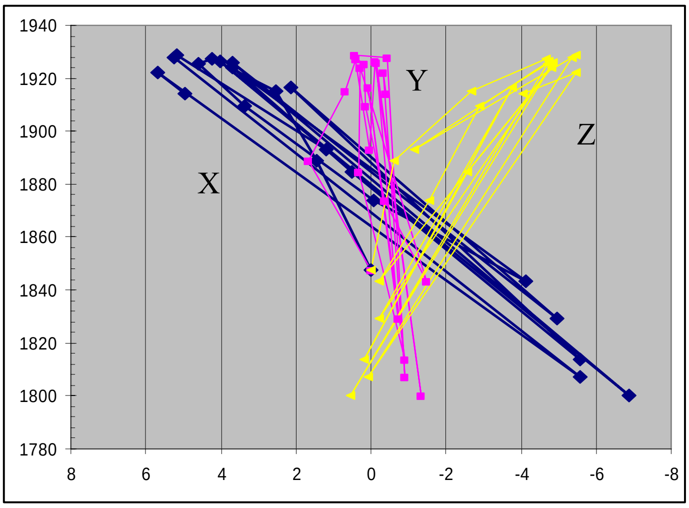

Figure 6: Integrated displacements in relation to reservoir level

ZÜRICH, NEW HARDTURM SOCCER STADIUM, PILE LOAD TESTS WITH SLIDING MICROMETER

Foundation of columns of the new soccer stadium in Zürich, some of them will have a maximum load up to 150 MN, will be on concrete piles. To optimize pile length and to verify design of the foundation, three test piles were constructed to perform static pile load tests. The length of the piles varies between 11 and 17 m and the pile diameter is 0.9 m. Location, length and instrumentation of the test piles was selected to investigate, in addition to the pile load capacity in different soil layers, long term behavior monitoring of the pile foundation. The load of up to 12 MN on every pile was applied with 12 soil anchors, each 38 m long (Figures 7 and 8). Instrumentation included:

- Automatic precise leveling at 4 points around the pile head with a motorized digital level
- Load measurement and load control with calibrated load cells and precisely regulated hydraulic jacks
- Tilt measurement at the top of the pile
- Line-wise deformation measurement with the Sliding Micrometer in and under the pile and in the surrounding soil
- Temperature measurement of the concrete to compensate for thermal influences
- GeoMonitor system for automatic and remote operation of pile load test and automatic data acquisition of load, settlement and tilt.
- WEB-Davis, data visualisation of all test results on an Internet site

In each pile a steel casing of 150 mm diameter was installed. After the pile was concreted, a borehole was drilled through the steel casing down to 10m below the foot of the pile. Then, the Sliding-Micrometer casing was installed in the borehole. By grouting with a soft grout in the soil and a stiff grout in the pile, the Sliding-Micrometer casing was connected to the surrounding medium to meet its stress-strain characteristics.

Next to the pile, at a distance of approx. 0.5 m to 1 m, a borehole was drilled to 40 m depth and equipped with Sliding Micrometer casing to measure displacements nearby the pile.

The results for pile no. 3 are given in Figure 9, 10 and 11. Rather big compression up to 24 mm/m was measured directly at the foot of the pile. To avoid any skin friction at the top 5 m of the pile, a membrane was applied isolating the concrete pile from the soil. From the applied load and the deformation measured in the isolated section at the top of the pile, the modulus of elasticity of the concrete pile was determined.

Line wise deformation measurement with the Sliding Micrometer provided very useful information to back calculate skin friction along the pile and to determine the bearing capacity of the highly loaded piles.

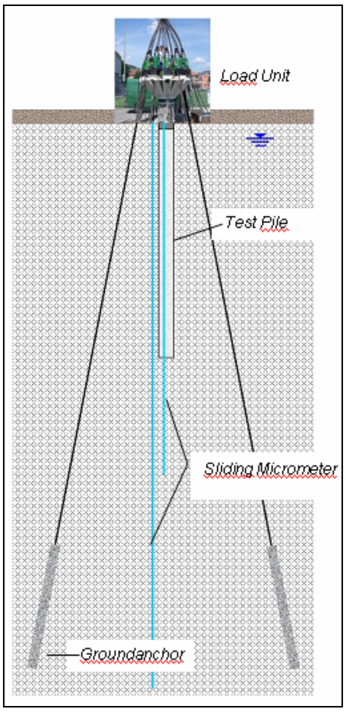

Figure 7: Schematic layout of the test pile and the instrumentation

Figure 8: Installation of the pile reinforcement (left) and the top of the pile (right*)*

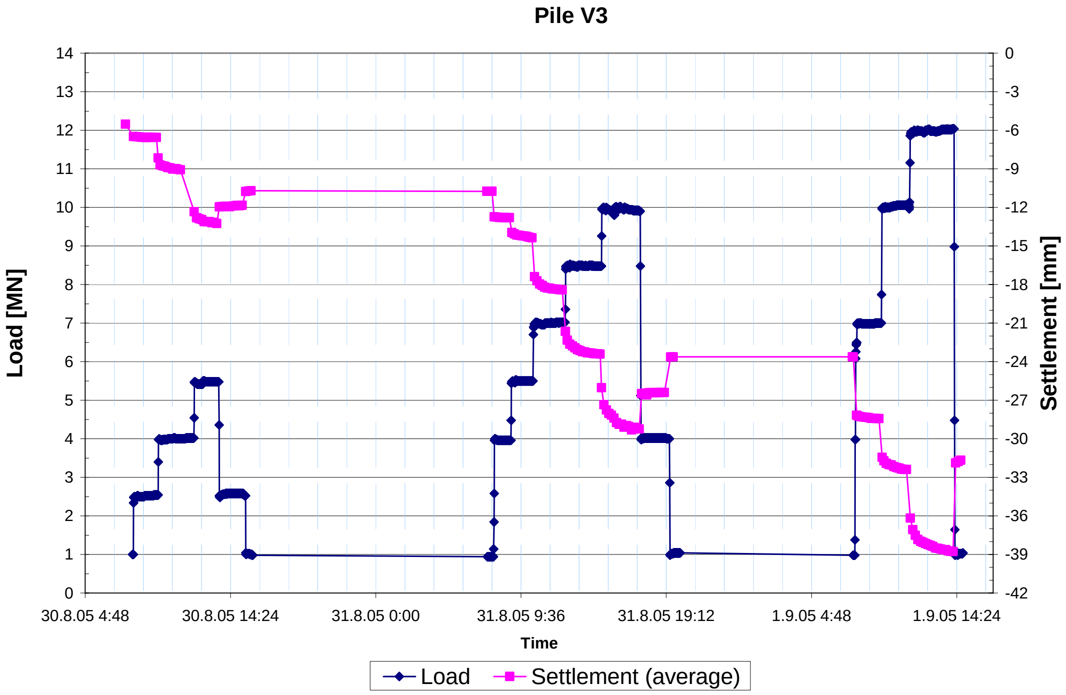

Figure 10: Load and settlement in pile no. 3 over time

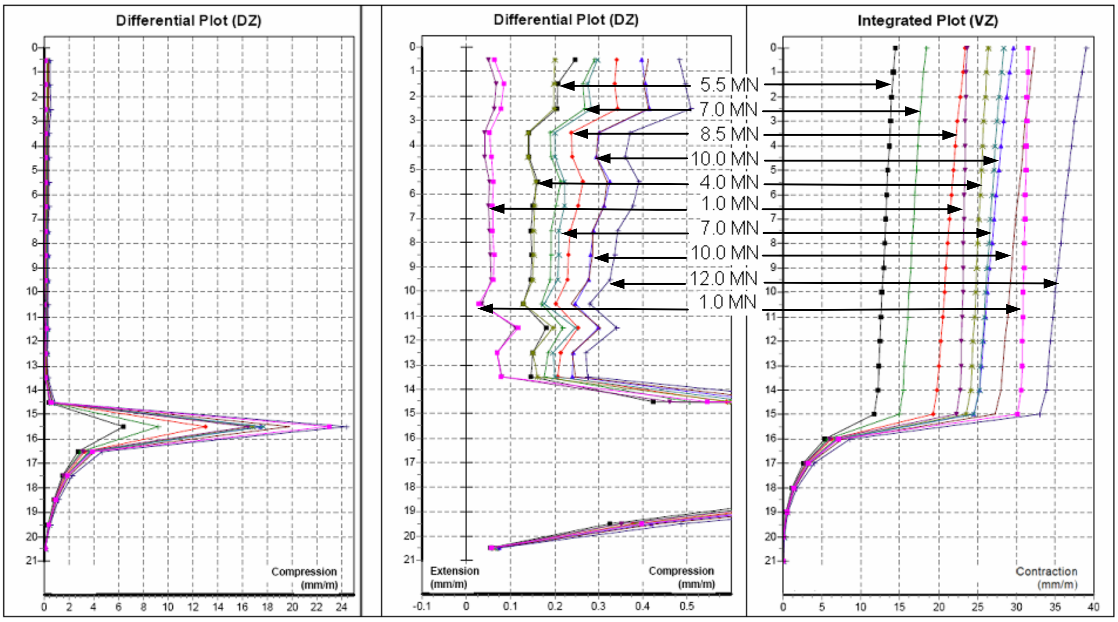

Figure 11: Strain profiles measured in and below the pile with applied loads (center graph magnified from left graph)

THE NEW DEVELOPED DIGITAL SLIDING MICROMETER AND TRIVEC

Recently, new digital Sliding Micrometer and TRIVEC measuring systems extended from the old systems were developed (Figure 12). The probe of the new system includes a digital displacement sensor with a range of 25 mm/m and a resolution of 0.0005 mm for axial deformation measurement. Compared to the traditional Sliding Micrometer with the LVDT-type 10 mm-range displacement transducer, the measuring range is remarkably increased and linearity is greatly improved.

The inclination sensor in the digital TRIVEC-probe has a range of +/-10° from direction of gravity. Likewise, this sensor has an improved linearity. Temperature compensation for axial and lateral displacement measurement is included in the probe. To compensate structural temperature effects, the temperature is continuously recorded.

Technical data of the digital Sliding-Micrometer and TRIVEC and accuracies are:

– Axial displacement measurement	range 25mm	resolution 0.0005mm
	linearity ≤ 0.02% FS	
	accuracy +/-0.002mm/m	
– Lateral displacement measurement	range +/-10°	resolution 0.0001mm/m
	linearity ≤ 0.02% FS	
	accuracy +/-0.03mm/m	

Figure 12: The digital TRIVEC- measuring system (left), the digital readout and data recorder in watertight housing (right)

Besides the increased accuracies, the following prominent features of these new systems are:

- Digital data transmission by cable to the readout unit and to the data recorder: This can be a small-size PDA-type pocket computer or a notebook PC. The PDA is normally housed in a robust weather-prove box (Figure 12). The recording with a notebook PC offers some extended numerical and graphical possibilities as the on-line display and the comparison of the actual measurements (down and up-reading) with the previous readings.
- The readout unit supplies the probe with electrical power and enables measurements to be taken also without PDA or PC.
- The items of the measuring systems are mainly standardized. Both systems, the Sliding Micrometer and the TRIVEC, can be operated with the same cable, same measuring rods, same readout unit and with the same computer for data recording together with the software to display and print the results. Thus, the use of hard- and software is largely optimized and the costs can be highly reduced, especially when instruments for several applications and projects are purchased.
- The TRIVEC calibration device is identical to the one used for the Sliding Micrometer. Calibration of the clinometers is only occasionally required.

CONCLUSIONS

The use of the Sliding Micrometer and the TRIVEC in the past 30 years in very different applications of geotechnical engineering projects, e. g. for dam construction, tunneling, excavation and landslide stabilization projects, clearly demonstrated the explanatory power of systematic line-wise deformation measurements.

Before construction starts these measurements are used to identify possible problematic areas and to detect rock and soil parameters of geotechnical structures. To assess deformability of rock, soil and concrete structures at an early stage of construction and during construction, monitoring according to this principle is advisable. After the completion of construction systematic use of line-wise deformation monitoring is recommended to detect long-term deviations from normal behavior. Thus, line-wise deformation measurement with the TRIVEC, the Sliding Micrometer and the Sliding Deformeter provides superior information for decision making in geotechnical engineering.

The new developed digital instruments presented in the paper will, for future geotechnical projects, increase overall performance of the already high accurate instruments used in the past.

REFERENCES

Kovari, K, Amstad, C. (1993). "Decision making in tunneling based on field measurements." *Comprehensive rock engineering*, Vol. 4, Elsevier, Amsterdam: 571-605.

Kovari, K. (1985). "Detection and monitoring of structural deficiencies in the rock foundation of large dams." *15th Int. Congr. Large Dams ICOLD*, Lausanne: 695-719.

Naterop, D., Becker, H.J., Anghern, Ph., (2005). Statische Pfahlbelastungsversuche Hardturmstadion Zürich, *Mitt. der Schweiz. Ges. für Boden- und Felsmechanik*, 151: 119-127.