Cracow University of Technology

Faculty of Civil Engineering

PERMANENT SHM FOR HISTORICAL KOSCIUSZKO MOUND IN CRACOW AND THE POSSIBILITY OF ITS IMPROVEMENT

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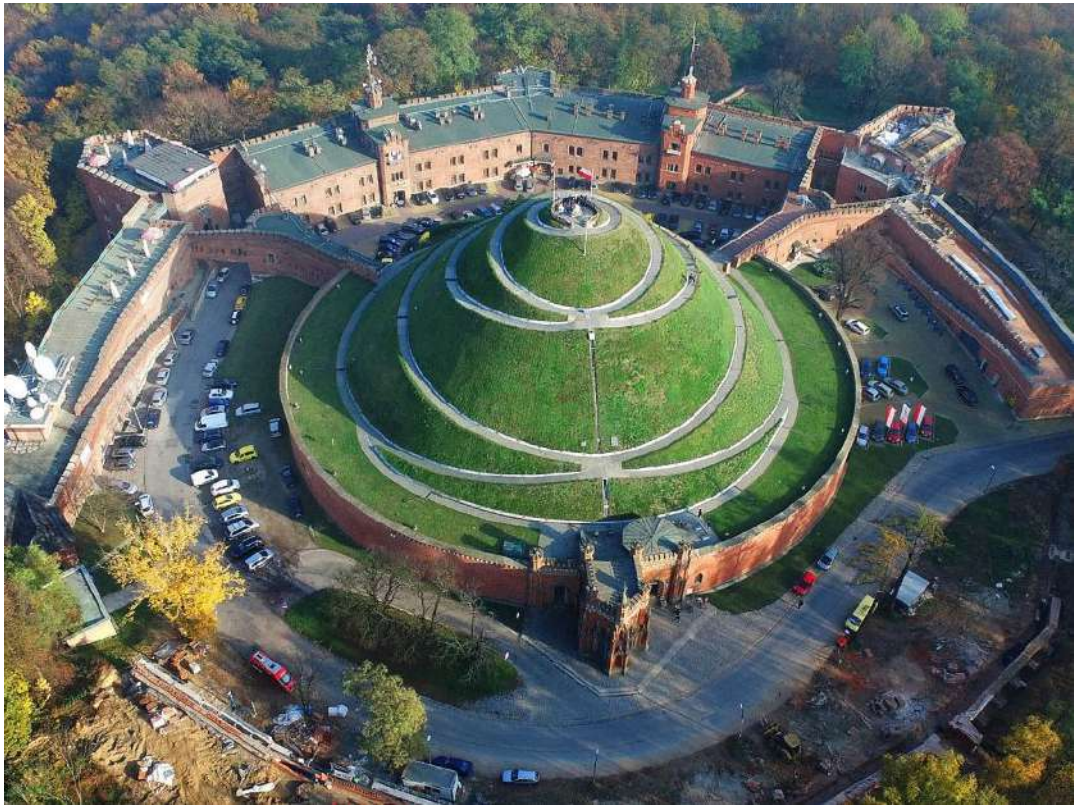
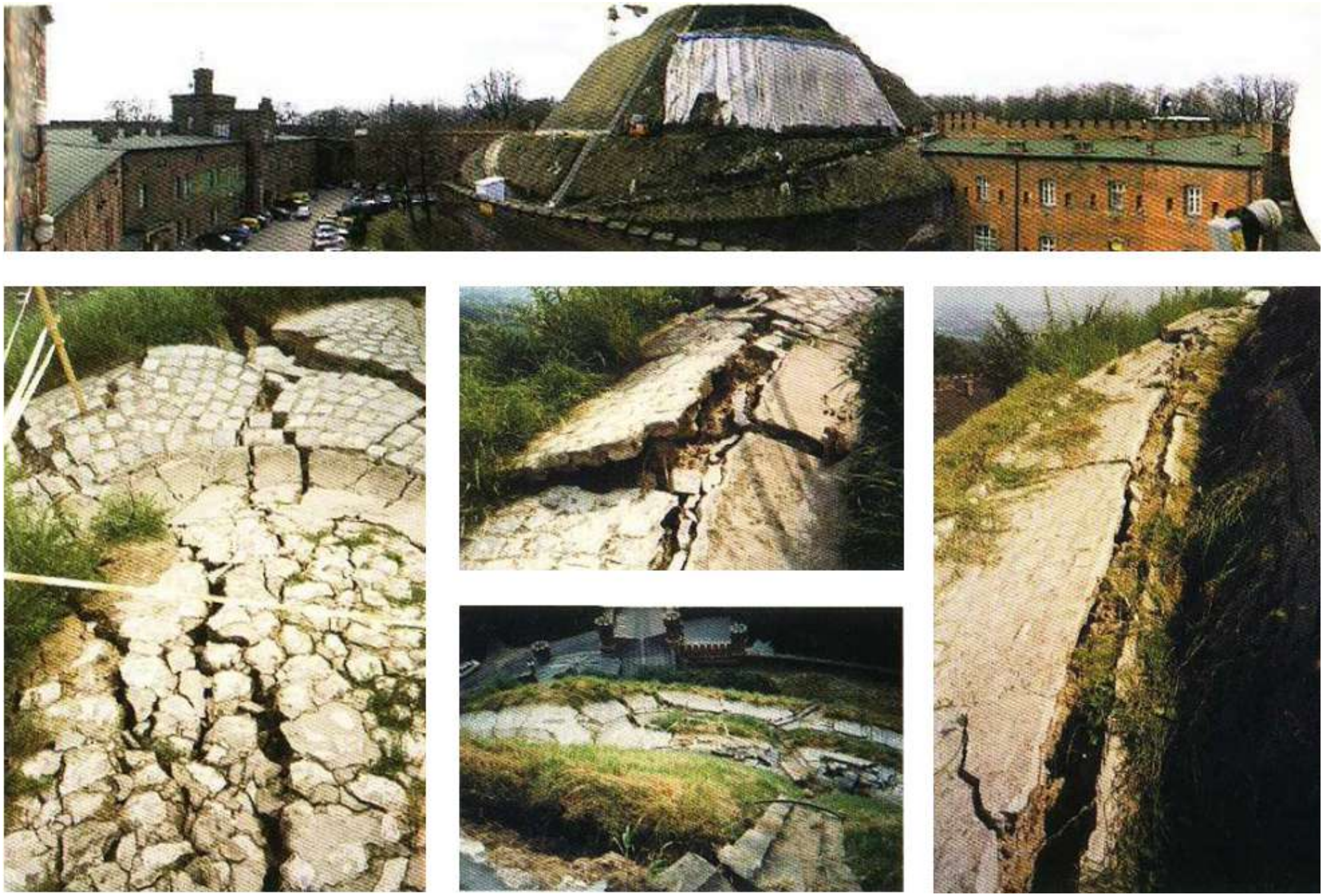
The monumental Kosciuszko Mound in Cracow

- an artificial hill of 34.1m relative height, heaped up by Poles in the years 1820-1823 in order to commemorate the national hero – Tadeusz Kosciuszko, in recognition of his merits,

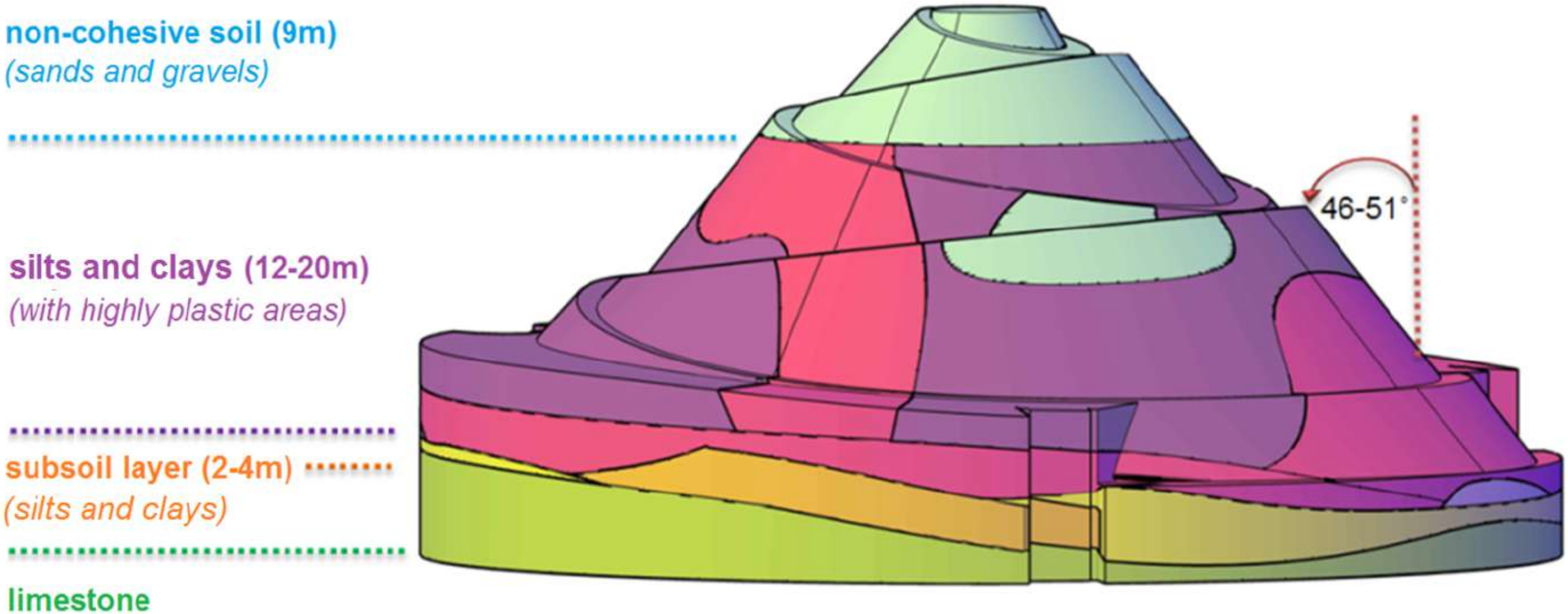
- a geotechnical structure especially sensitive to deformation, mainly due to the unfavourable structural material and very steep slopes,



- in the past it failed several Times - the most significant structural failure occurred after the flood of 1997.

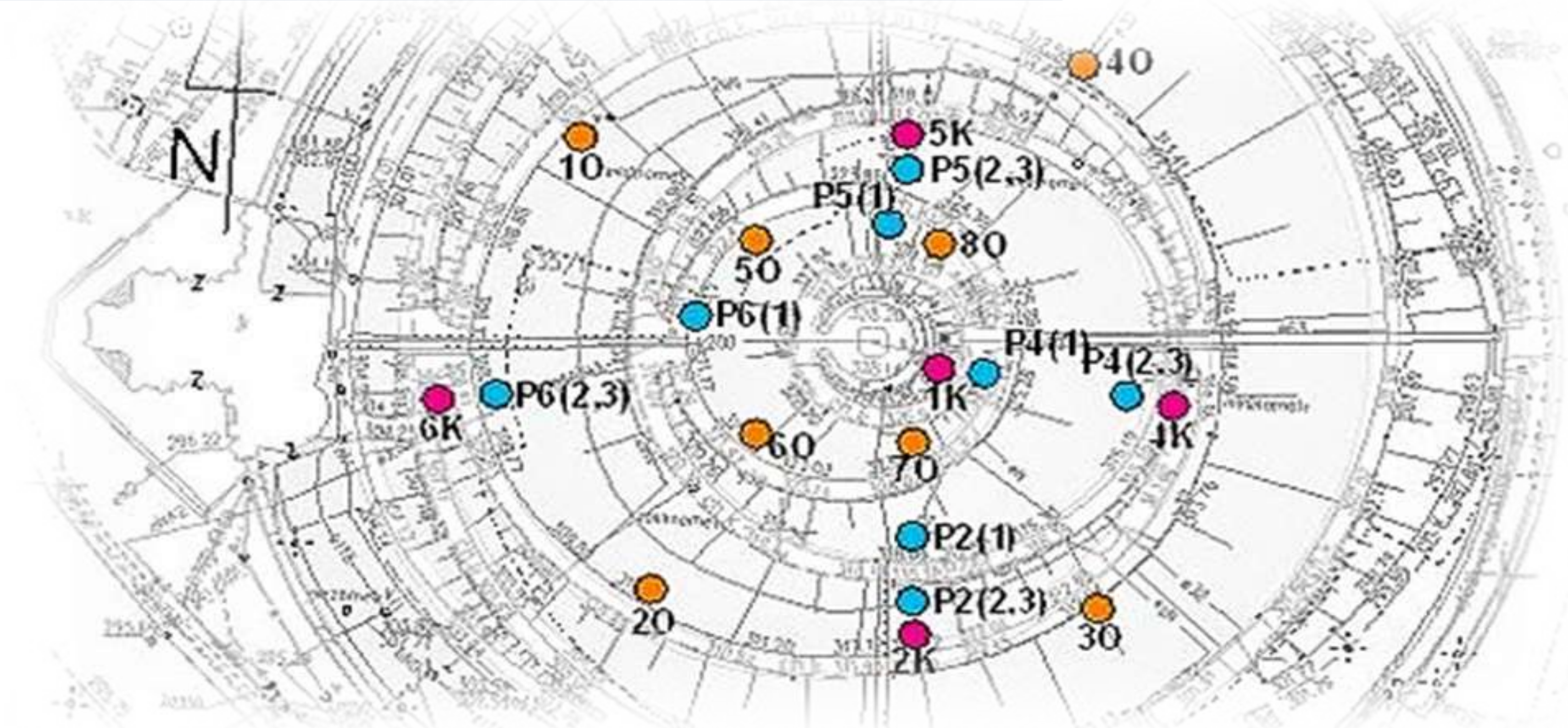


Destruction of the mound in the year 1997

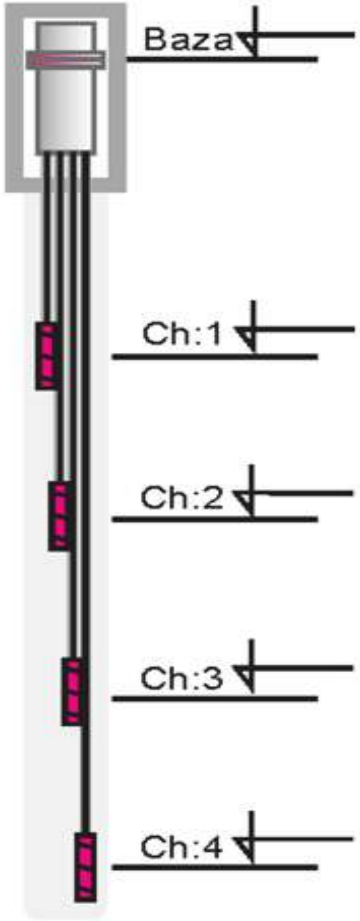


Internal soil structure of the Kosciuszko Mound.

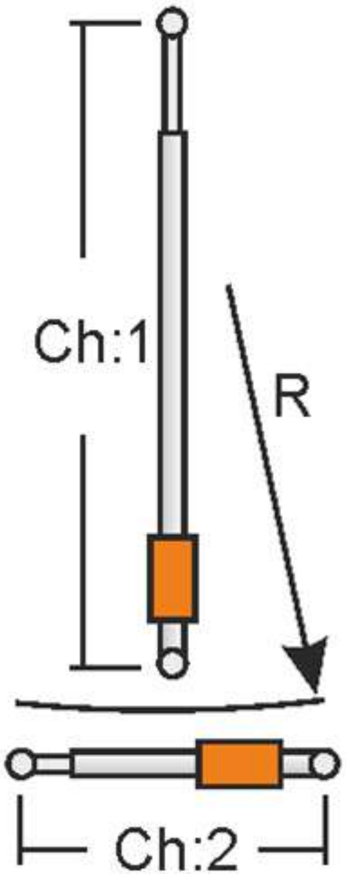
Description of the SHM system applied on the mound

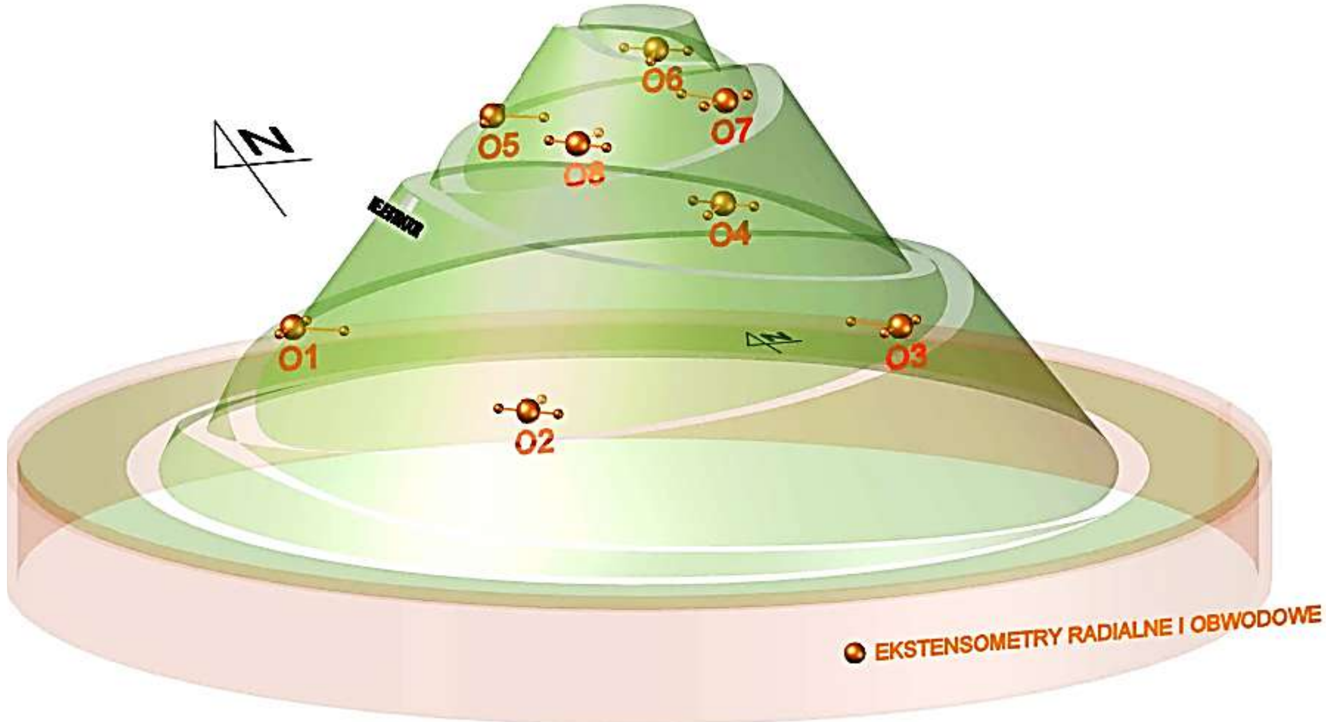


Horizontal projection of the mound with indicated locations of measurement stations (denotations: K - sensors measuring vertical displacements, O - sensors measuring horizontal displacements (radial and circumferential) and soil humidity, P - sensors measuring pore water pressure and humidity of the external soil layer.

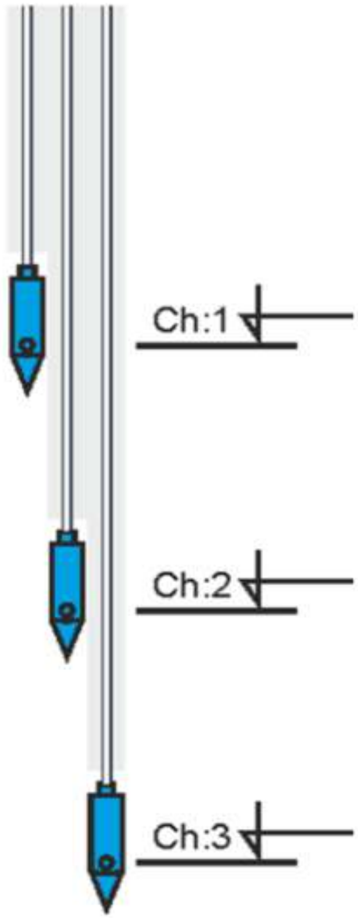


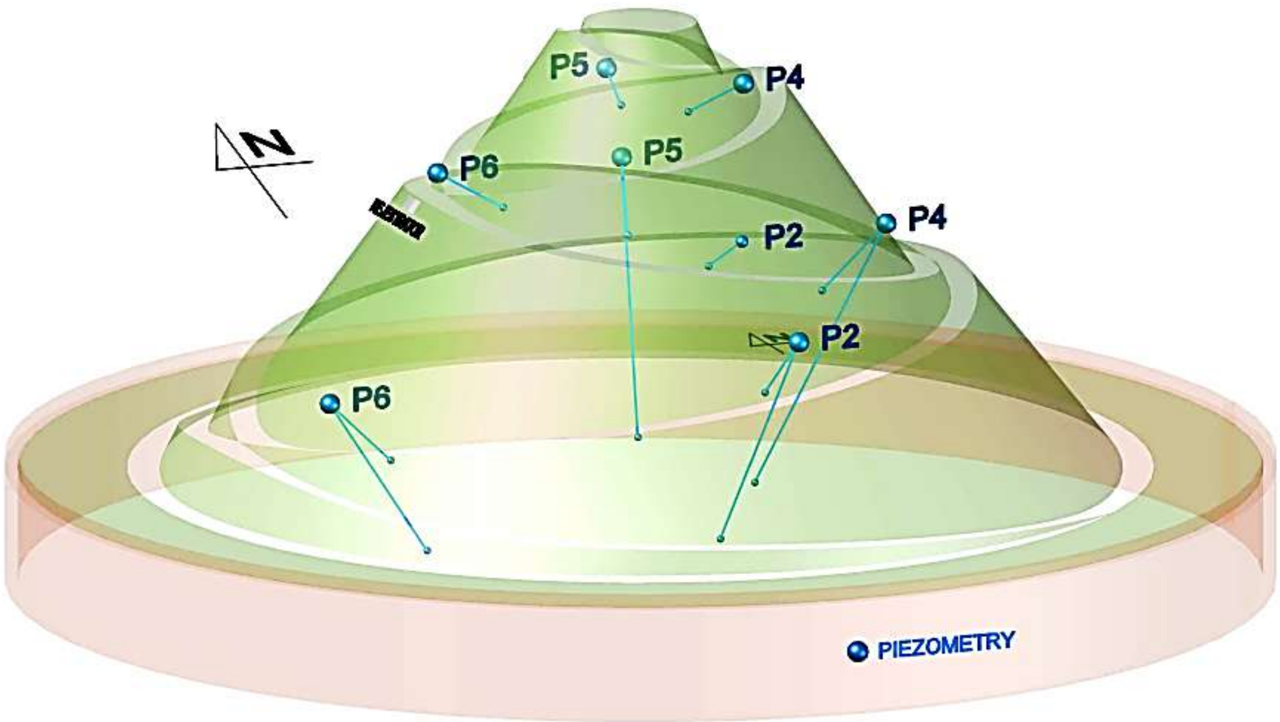
Details of vertical displacement measurements.



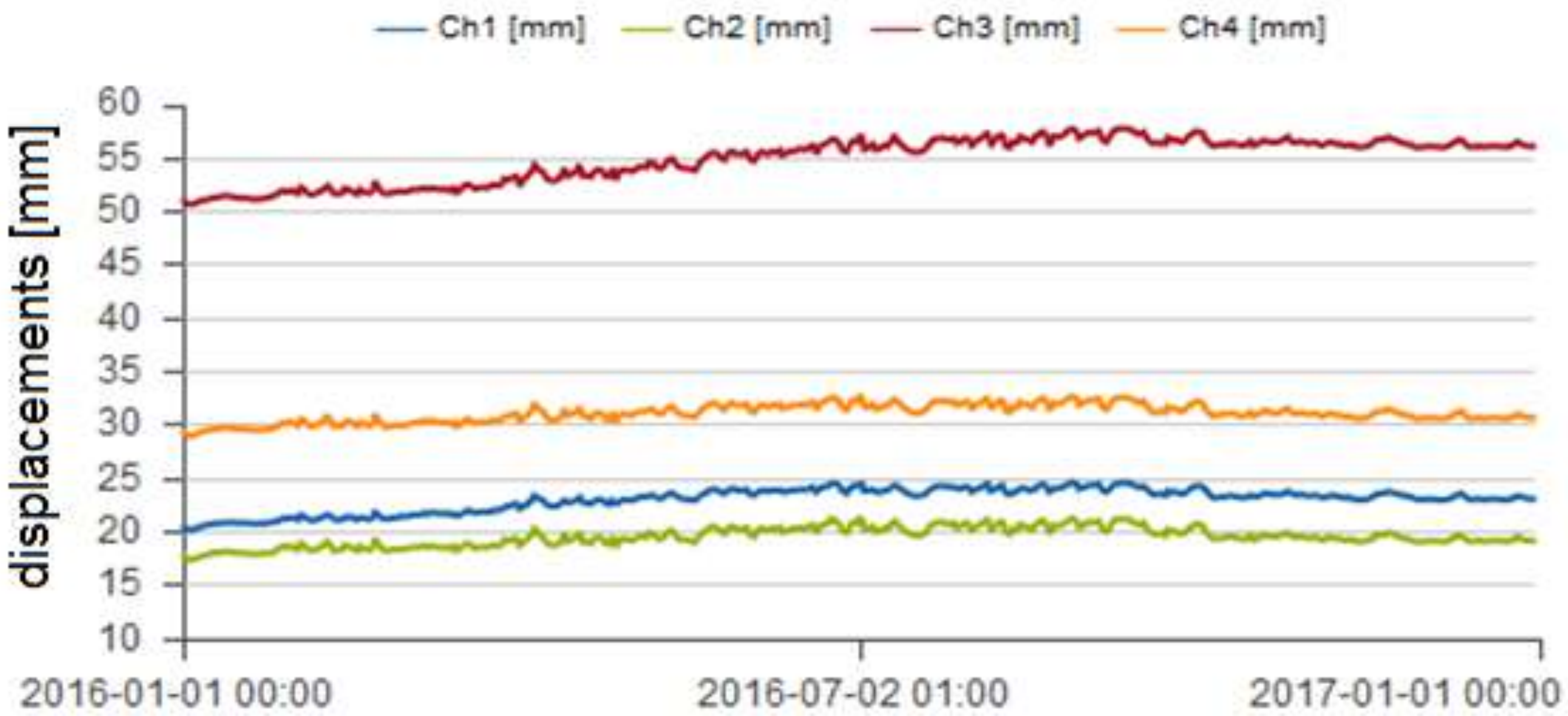


Details of horizontal deformation measurements (along the radius and circumference).

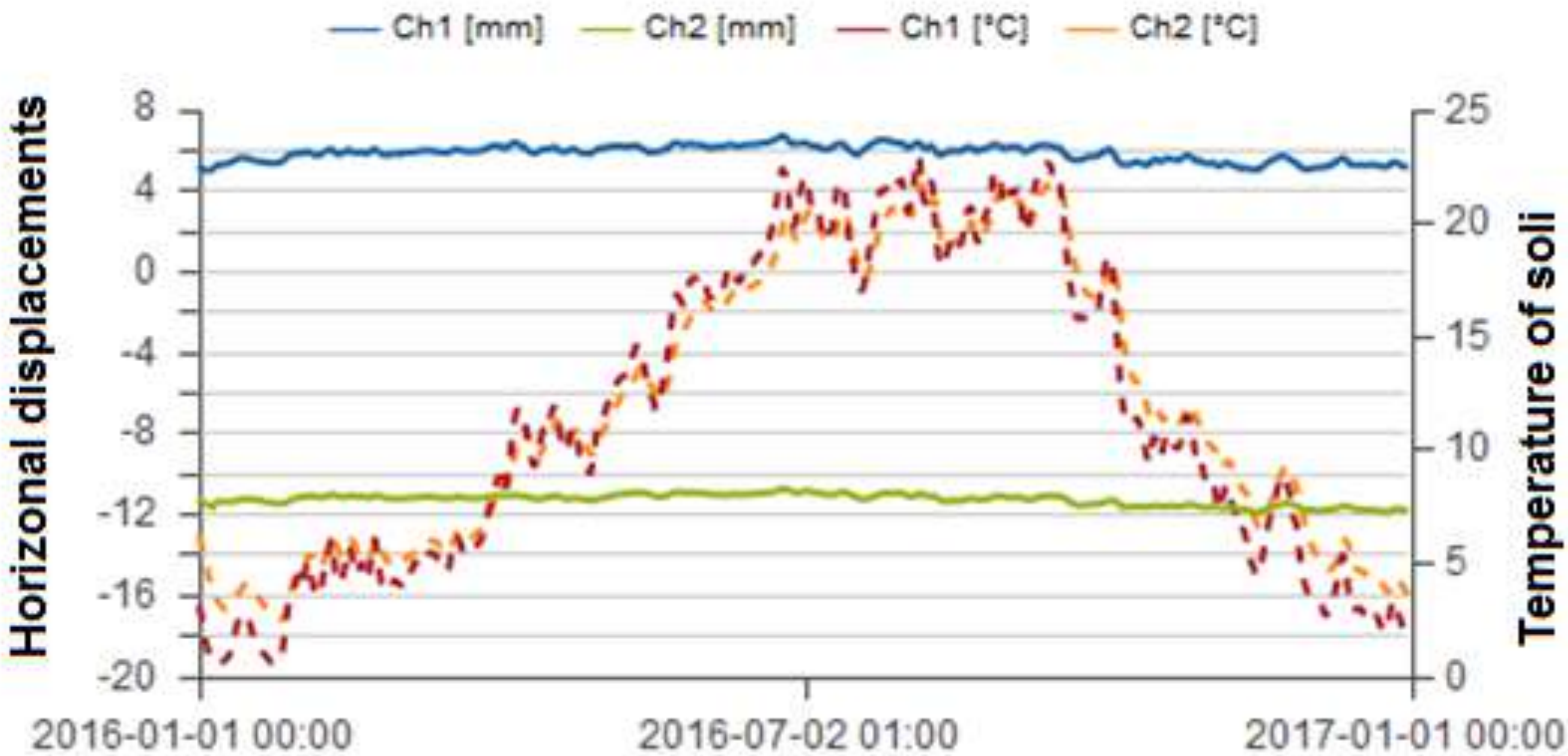




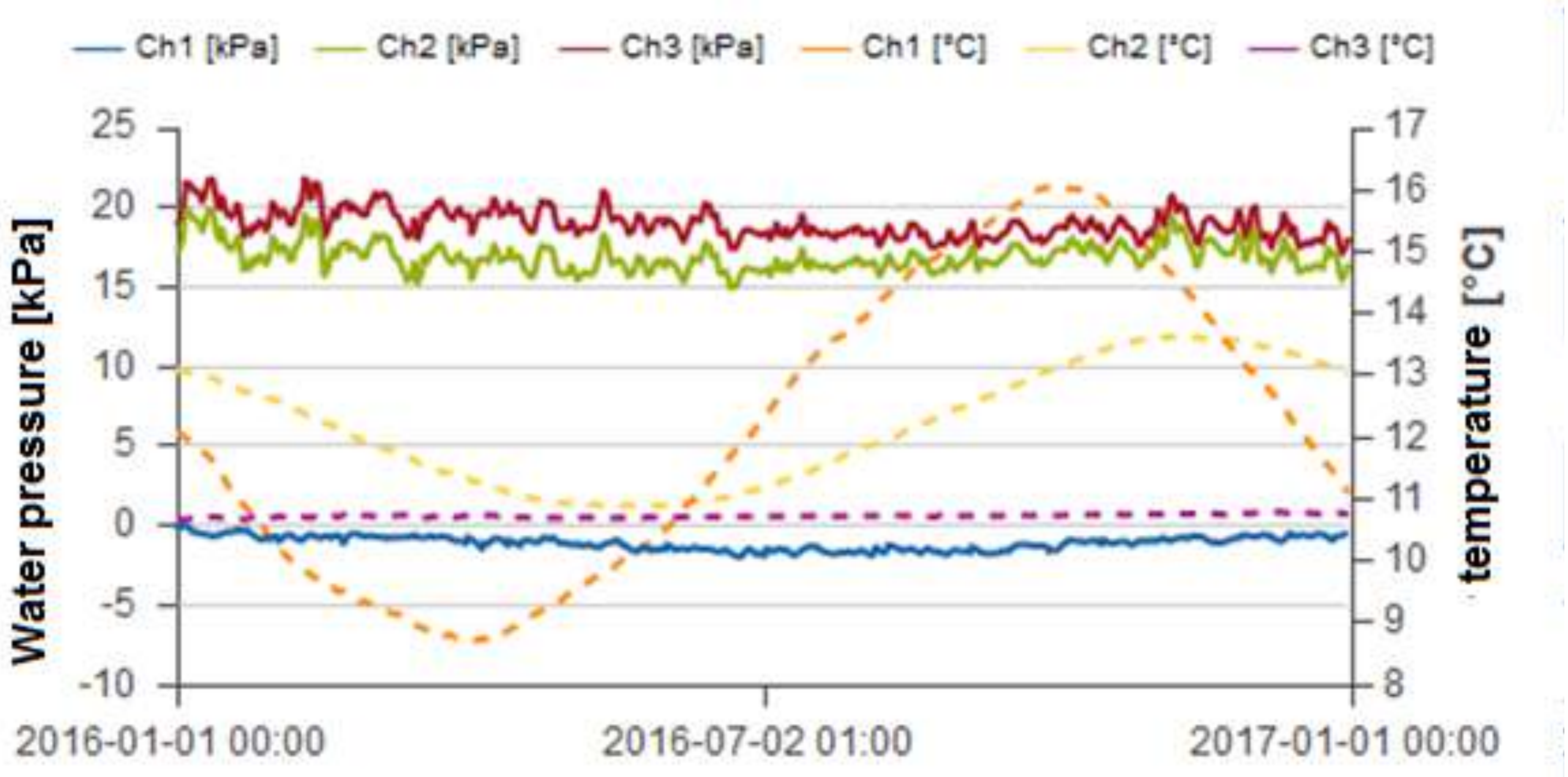
Details of the pore water pressure and external layer humidity measurement stations.



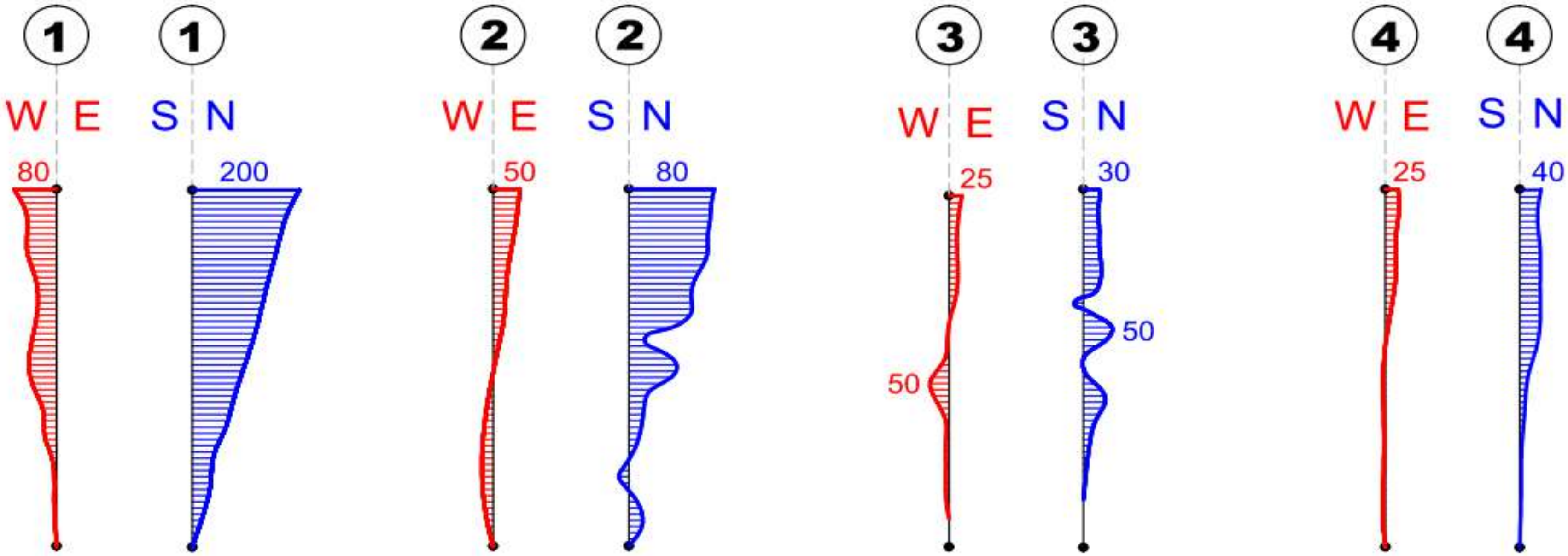
A segment of the graph depicting monitored vertical displacements in the 1K measurement station at the boundaries of subsequent soil layers.



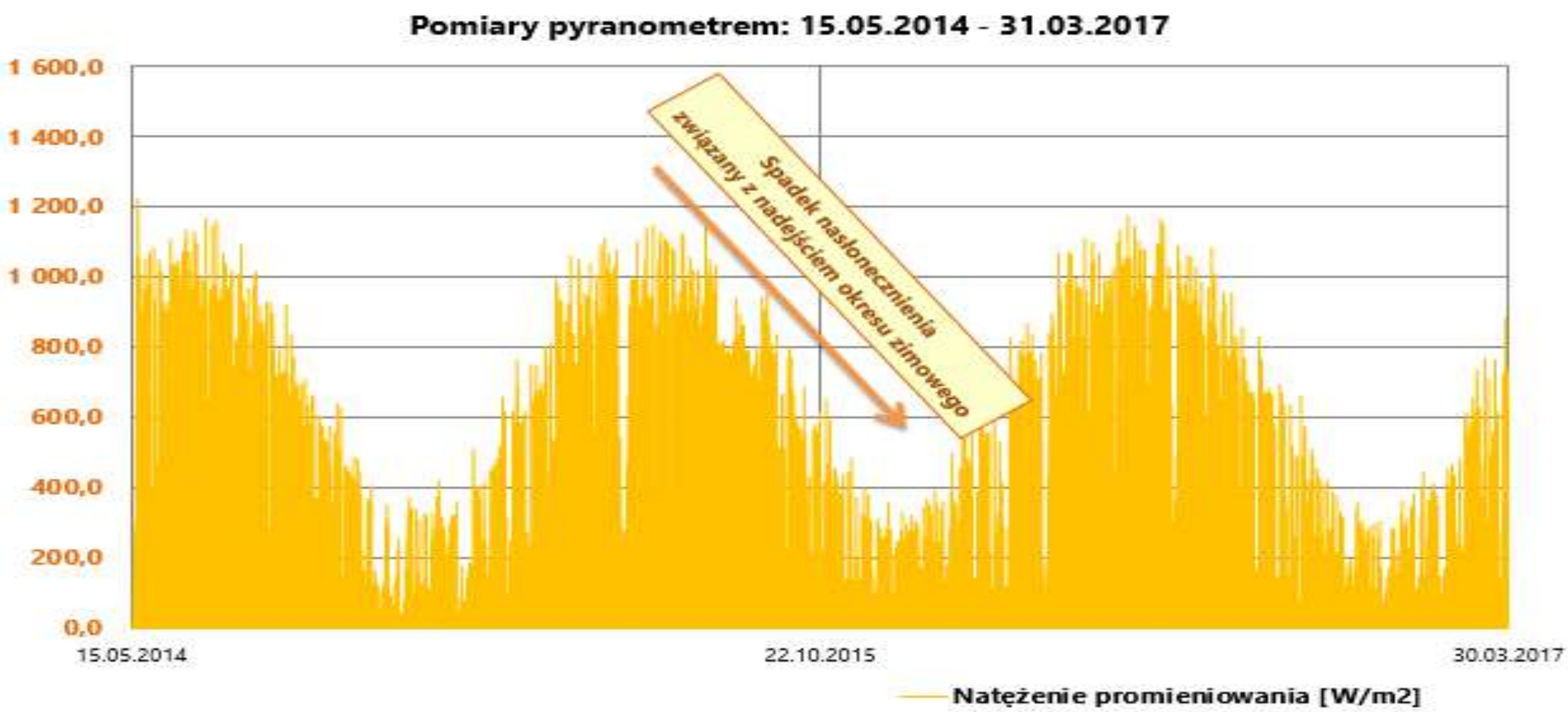
A segment of the graph depicting monitored horizontal displacements in the 2O measurement station at the boundaries of subsequent soil layers accompanied by the soil temperature graph (yearly fluctuations of the soil temperature are clearly visible).



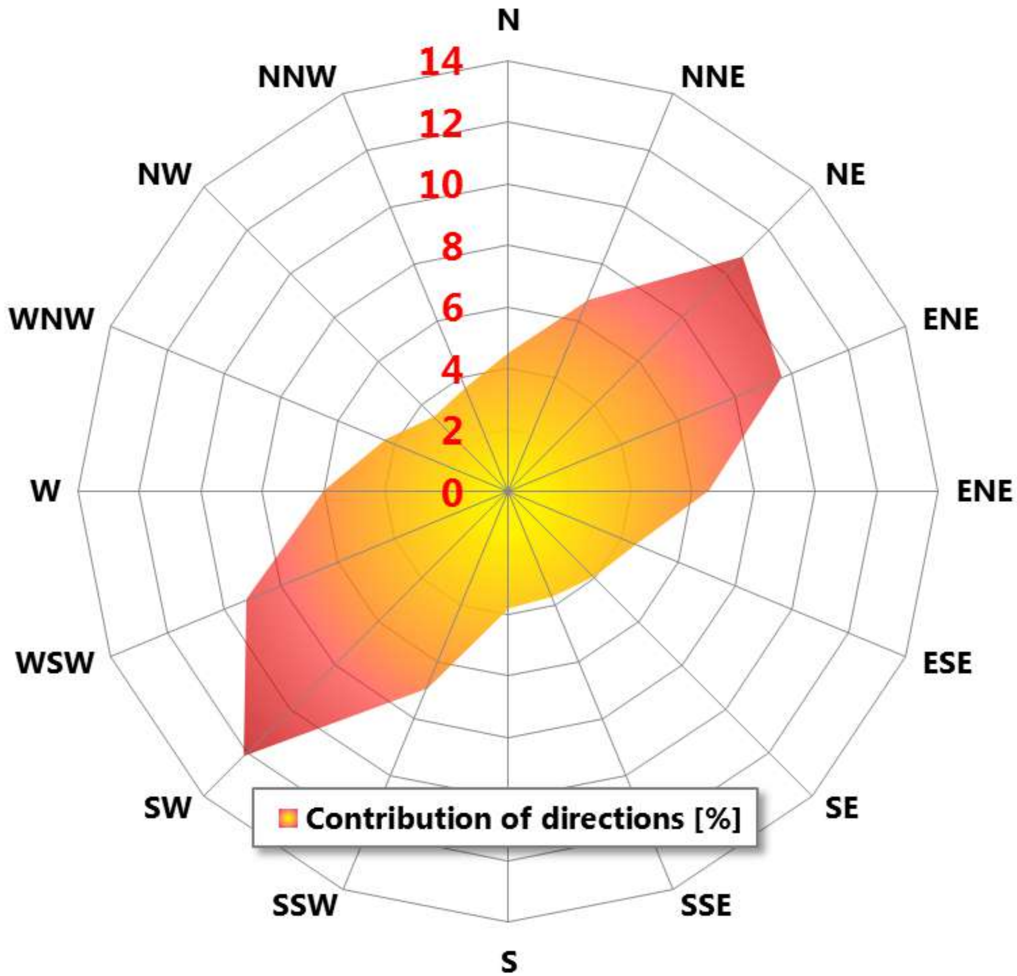
A segment of the graph depicting monitored pore water pressure and corresponding soil temperature values measured at the 2P station (yearly fluctuations of the soil temperature are clearly visible).



Results of the inclination measurements at a given moment in time.



Changes in the mound insolation in a yearly cycle recorded by pyrometer.



Monitoring obtained wind rose for the mound location.

The SHM strategies possible to choose in the future

- **Strategy no 1**: at the determined and relatively low risk level it is suggested not to undertake any remedial actions as long as the monitoring would not indicate the local or global increase of this level to at least the threshold level arbitrarily assumed at a relatively high value. This strategy, if applied, results in the mound owner having to bear relatively high repair costs, but rather infrequently. Failures are infrequent but if do happen are of serious consequences.
- **Strategy no 2**: often initiated remedial actions of limited scope are preferred, i.e. actions are initiated every time the acceptable threshold risk level defined by the owner at relatively low level is identified as reached or exceeded even over a relatively small and insignificant area of the mound.

The future improvement concepts of the existing monitoring system

- The point is that the various data types should be analysed in a complex manner in a single procedure taking into account the inherent intrinsic interactions and correlations present within the whole data set, instead of piecewise analyses performed on chunks of available data.
- It is also postulated, that the results obtained a posteriori, based on the measurements performed by the monitoring system sensors, should be used to improve the a priori assumed theoretical model.
- An extension of the user interface, and especially of the part on system “output”, would also constitute a significant improvement of the system as a whole.
- The objective is to deliver to the evaluator a 3D risk map, showing the risk of soil reaching the ultimate limit state of bearing capacity or the mound slope stability, reproducing the whole volume of the monitored structure and accompanied by the risk level specified for each point on the map coincident with sensor location.

Concluding remarks

- Analysis of a structure of this type combines the problems of classical civil engineering (especially geotechnics), with problems of safety evaluation and systems engineering.
- The data available to the person appraising the technical condition of the structure of this type are characterized by the high variability of not only the statistical type but also due to the daily and yearly changes in the climate and weather conditions.
- The basic source of uncertainty is in this mound the layered structure of the hill, with very heterogeneous soil structure in all layers. Furthermore, the man made ground has its origins in many locations, thus its parameters fluctuate substantially. Finally, the soil properties to a large extent depend on its humidity, and this in turn is affected by the seasonally changing weather conditions. This raises questions about the representativeness and reliability of the data collected.
- The limited accuracy of the measurements, due to the precision of the sensors used and their sensitivity to the weather conditions, is an additional source of uncertainty. The limitation of this type is especially important, as there is a risk of accumulating measurement errors, especially in the case of slope measurements.

- The uncertainty due to the limited credibility and random nature of the measurement data is aggravated by the inference uncertainty, based on the simplified model of analysis applied in practice. So far the inference based on the existing monitoring is supported by the statistical processing of the measured data and the analysis of the random processes describing the temporal evolution of the measured parameters. However, this variability is interpreted only locally in order to identify the possible trends and record the cases when the limit values are exceeded. It seems, that in order to qualitatively and quantitatively describe the deformation and mechanical properties of the mound structure, which change during the service time, it would be desirable to apply the measurement data gathered at discrete locations to develop and calibrate the 4D (three spatial dimensions and the temporal one) random field describing the soil behaviour in the whole volume of the mound. The 3D numerical model should also take into account the climate loads correlated with this field, and having the statistically determined values, based on the measurements supplied by the weather station.

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