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# EXAMPLES OF THE MASS MOVEMENT INVESTIGATIONS IN DIFFERENT TYPES OF DEPOSITS

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**Abstract**. In the paper, examples of geotechnical and geo-environmental mass movement investigations are presented. Research included *in situ* and laboratory tests with monitoring techniques in landslide areas. Projects represented different deposits and types of investigations. Use of the conventional drillings and sampling as well as GPR, GPS and CPTU profiling, inclinometer and piezometer measurements are presented. Field measurements are compared with reference laboratory tests such as index tests, odometer, direct shear tests, uniaxial compression and triaxial tests. Research was based on the investigations of the Carpathian flysch sediments near the city of Gorlice, carried out for local Polish road administration financed by the European Investment Bank inside "The Landslide Counteraction Framework" and is still in progress. Some examples of landslides in Polish open-cast mines are listed. Also investigations in Polish and Norwegian clays are shortly described (project sponsored by the Norwegian Research Council and NATO). The presented data were obtained from the chosen landslide counteraction projects and slope stability calculations.

**Key words**: landslides, monitoring techniques, geotechnical engineering, *in situ* tests, laboratory tests.

**Abstrakt**. W artykule przedstawiono przykłady geotechnicznych i geośrodowiskowych badań powierzchniowych ruchów masowych. Badania z zastosowaniem technik monitoringu obszarów osuwiskowych obejmowały zarówno badania *in situ*, jak i testy laboratoryjne. Przedstawione projekty obejmowały wybrane rodzaje testów w różnych utworach. Stosowano konwencjonalne wiercenia i pobieranie próbek, a także profilowania GPR, GPS i CPTU oraz monitoring inklinometryczny i piezometryczny. Wyniki testów terenowych porównano z badaniami laboratoryjnymi, takimi jak badania podstawowych właściwości fizycznych gruntów, pomiary edometryczne, badania w aparacie bezpośredniego ścinania, badania wytrzymałości na jednoosiowe ściskanie oraz badania trójosiowe. Niniejszy artykuł oparto na badaniach karpackich osadów fliszowych, wykonywanych dla polskiej administracji drogowej (finansowanych przez Europejski Bank Inwestycyjny), w ramach projektu „Osłona przeciwosuwiskowa", które nadal są kontynuowane. Przedstawiono również przykłady osuwisk występujących w polskich kopalniach odkrywkowych. Opisano także badania iłów polskich i norweskich, przeprowadzonych w ramach projektu finansowanego przez Norweską Radę Badań Naukowych i NATO, a także zaprezentowano wyniki wybranych projektów zabezpieczenia osuwisk oraz wyniki obliczeń stabilności zboczy.

**Słowa kluczowe**: osuwiska, techniki monitoringu, geotechnika inżynierska, testy *in situ*, testy laboratoryjne.

## INTRODUCTION

Landslides and other types of mass movements cause many problems in different environments and deposits. Some of them are observed in mountain areas in soft clays, other in open-pit mine excavations, rocks quarries or in thinly layered flysch deposits which represent combination of soils and rocks. Flysch landslides have complicated nature and required effective methods of investigations, monitoring and counteraction. In the paper, some landslide projects and investigations techniques and monitoring methods, used by author in chosen open-cast mines, rock queries and the Carpathians are presented.

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## MASS MOVEMENTS INVESTIGATIONS TECHNIQUES USED IN THE PRESENTED LANDSLIDE PROJECTS

Landslides require effective techniques of investigations. Traditional core drilling is important but time consuming, costly and not always could give answer to the entire list of questions connected with mass movement investigations. Therefore, drillings should always be connected with other types of field measurements and monitoring techniques. They should be chosen depending on the landslide type and its internal structure (Bednarczyk, 1997, 2002, 2004a, b; Bednarczyk, Sandvey, 2004).

Landslide investigations presented in this paper include core drillings and sampling, GPR, GPS, *in situ* static sounding with pore pressure measurements (CPTU), laboratory tests (index tests, odometer, direct shear tests), inclinometer measurements and tree types of groundwater monitoring (standpipe, pneumatic and vented wire piezometers). For better characterisation of the internal landslide body extending between the drilling holes, Ground Penetration Radar scanning (GPR) with different types of antennas (1000 and 500 MHz) was performed. GPR profiles were interpreted, scaled and filtered using core drilling results. GPR allows for performing approximately up to two kilometres of scanning per day. This method, connected with reference drillings, was found as a very effective way of landslide internal structure investigation.

For every type of geodynamic phenomena and/or deposits, different set of investigations should be used. Sometimes, in clay deposits, failure develops as a creep process over periods of months. In contrast, in sandy and rocky deposits, failure could be developed very quickly. A failure often occurs as a combination of different mechanisms. It is well recognised that groundwater regime depends on hydrology, geology and topography. Pore water pressure plays an important role in the stability of slopes. It has one of the most important roles in developing geodynamic processes. In the paper, different types of pore pressure measurements are presented. They include generated pore pressure measured during CPTU test in clays and piezometer measurements performed on the landslide near the city of Gorlice. Pore pressure monitoring connected with inclinometer measurements, laboratory testing, GPR and GPS allowed for effective indication of failure zone and could be used for slope stability calculations. However, not every research method is suitable for each type of the landslide. Caution should be also paid to correct interpretation of the test results.

## MASS MOVEMENTS INVESTIGATIONS IN THE POLISH OPEN-CAST MINES

Landslides in open-cast mines are connected mainly with mine slopes founded in soft clayey deposits. In these types of deposits, in addition to other types of investigations and monitoring methods, CPTU tests could be used. These tests were performed by author in mass movements areas of the Bełchatów and Turów open-cast mines (Fig. 1). One of the largest landslides in the Polish open-cast mines occurred on the southern slope of the Bełchatów open-cast mine, in central Poland and on the external embankments of Turów mine in southwestern Poland, near the border with Czech Republic and Germany (Fig. 2).

Cone penetration tests in Polish open-cast mines had been performed to predict soil mechanical parameters in the potential landslide areas. They represented two types of tests with mechanical cone (CPT) and with piezocone (CPTU) which enabled measurements of cone resistance qc [MPa], sleeve friction fs [MPa] and generated pore pressure. CPTU tests results could be used for interpretation of the soil type and soil design parameters together with reference laboratory tests. These

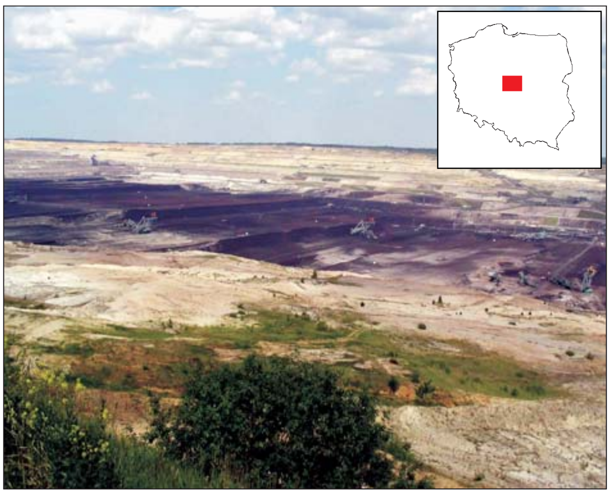

**Fig. 1. Landslide on southern slope of Bełchatów open-cast mine (2 mln $m^3$)**

**Fig. 2. Landslide on external embankments of Turów open-cast mine (6 mln $m^3$)**

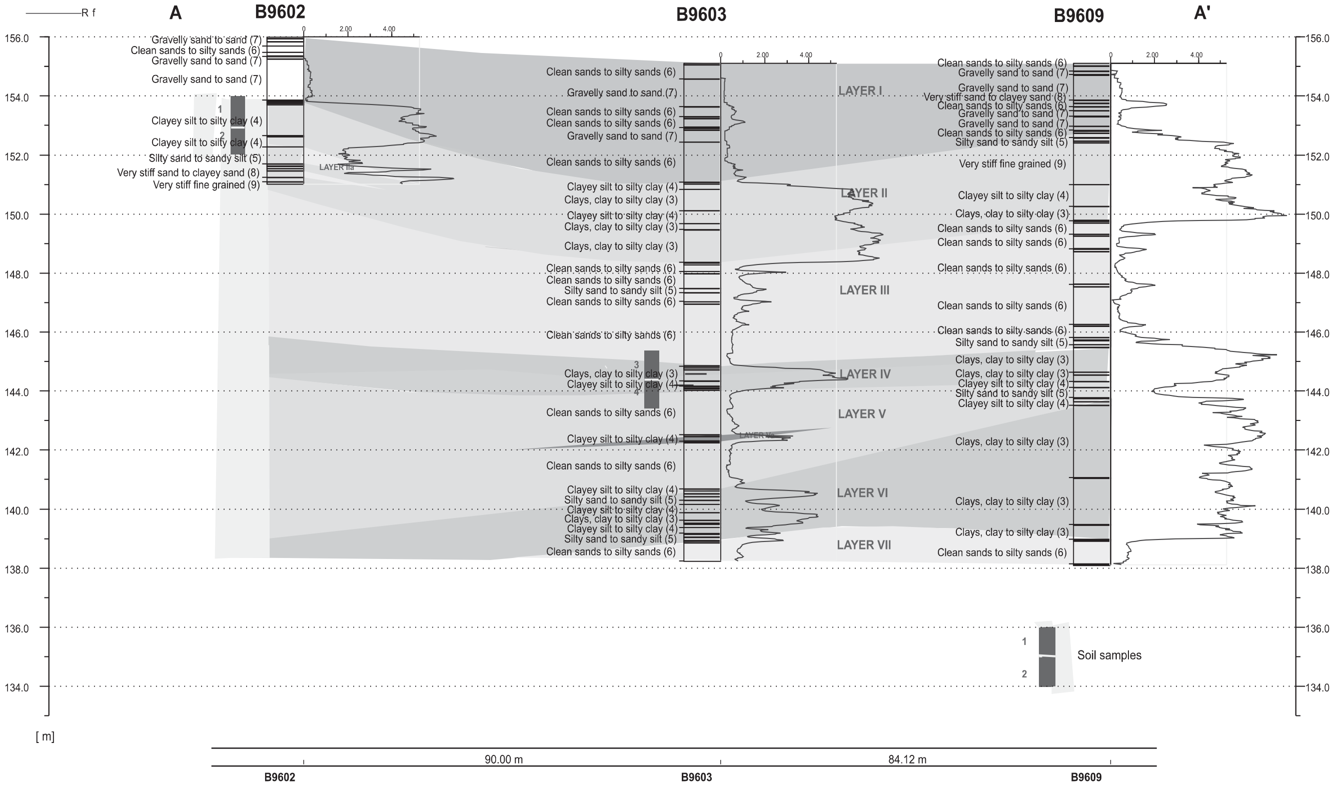


**Fig. 3. Geotechnical cross-section across the potential landslide area in the Bełchatów open-cast mine; Rf [%] diagram indicating soil type and soil parameters (higher values — clay deposits)**

tests methods are suitable for landslides formed in clayey soils mainly and have limitations connected with heavily cemented, consolidated soils or rocky soils.

Landslides in open-cast mines are often formed on external embankments or inside the mines. Landslide in Turów mine on its external embankment (Fig. 2) was caused by ineffective base drainage. Landslides have caused many geotechnical problems in this mine and were the reason of building drainage system together with monitoring system which included inclinometers, variation measurements and pore pressure monitoring system. In the Bełchatów mine. Landslides are connected with clay deposits on the southern slope of the mine localised on a palaeolandslide in Kleszczów Rift Valley, over a brown coal deposits. It occurred also on the northern slope of the mine within thinly layered clay deposits.

Methods of CPTU tests in clays interpretation were studied by author during the research visit at geotechnical Division NTNU (Bednarczyk, 1997, 2002, 2004a, b; Bednarczyk, Sandven, 2004). Project was made possible due to the NATO Advanced Fellowship Programme support. The research basis was the slope stability evaluations of the open-cast Bełchatów mine in Poland where CPTU tests have been performed down to 200 m below the natural terrain level (Fig. 3). During the study, interpretation of the designed Polish and Norwegian clays parameters was performed on the base of piezocone and laboratory tests. Laboratory tests program on the selected clay samples from Poland was performed at the Department of Geotechnical Engineering of the Norwegian University of Science and Technology. CPTU interpretation for Polish and Norwegian clays included different mechanical parameters, such as total and effective shear strength, compression module and stress history, using the interpretation method developed at NTNU.

## MASS MOVEMENTS INVESTIGATIONS IN POLISH ROCK QUARRIES

Mass movements in rock quarries have different nature comparing to landslide formed in clayey soils. They are often caused by erosion processes or by blasting exploitation method (Fig. 4). Failure in rock landslides could also occur in a joined stratum where movement is a consequence of sliding on bedding planes. Layers direction, inclination angle and occurrence of cracks or joints are very important for rocks stability.

In rock formations, the Morh-Couloumb criterion could not be used for shear strength calculations. The Hoeck and Brown (1980) calculation of slope stability was used in the presented project. Using this criterion, rock friction angle φ and cohesion acting along the defined sliding surface could be described by the following equations:

**Fig. 4. Weathering processes in marl quarry, partin Opole (Poland)**

$$\mathrm{tg}\varphi = AB\,(\sigma'/\sigma_c - T)^{B-1} \quad [1]$$

$$c = A\sigma_c\,(\sigma'/\sigma_c - T)^{B} - \sigma'\,\mathrm{tg}\varphi \quad [2]$$

where:

$\sigma_c$ — uniaxial compression strength [kPa],

$\sigma'$ — force acting on the base of every potential sliding surface [kPa],

A, B, T — rock type correlation factors.

An example of slope stability calculations in marl quarry is presented below. For characterisation of the rock mechanical parameters, uniaxial compression laboratory tests on dry and saturated rock specimens were performed using Fellenius, Bishop, Janbu, Morgenstern-Price and Discrete Elements Methods (DEM). Exemplary Janbu method calculation in the Opole marl quarry is presented on Figure 5. It included an influence of exploitation method on the slope stability.

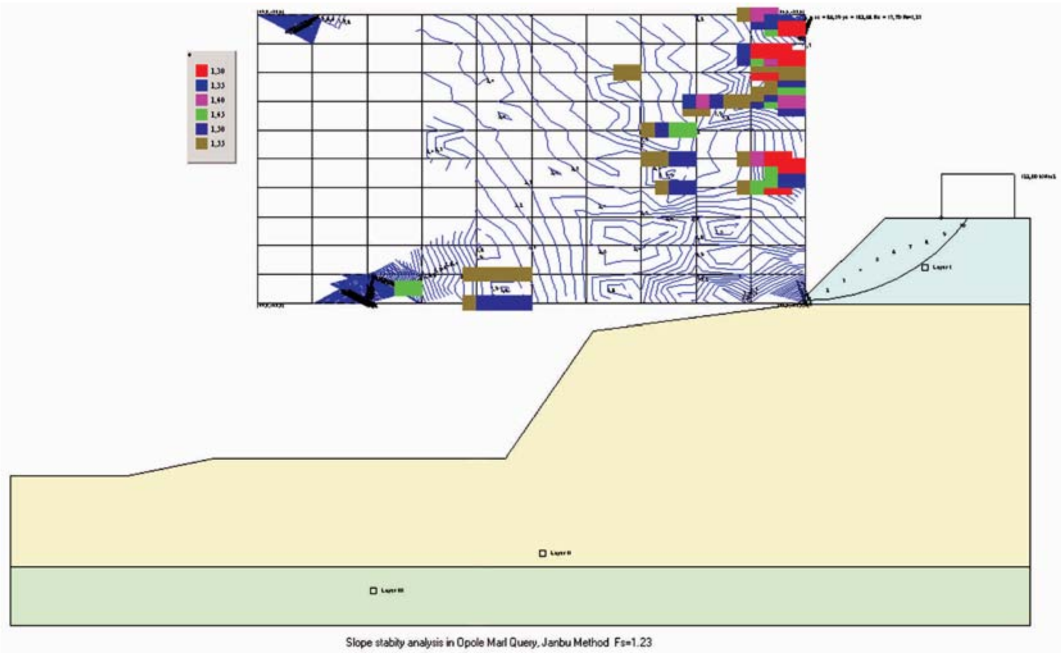


**Fig. 5. Slope stability calculations in the Opole marl quarry**

## LANDSLIDE INVESTIGATIONS IN CARPATHIAN FLYSCH DEPOSITS IN SOUTHERN POLAND, GORLICE REGION

Gorlice region is localised in southeastern Poland. Landslides are formed in Tertiary (Oligocene) flysch deposits. They are mainly developed on slopes built of soft clay deposits with shallow groundwater level. They represent layers of marine sedimentation, folded, elevated and displaced in Gorlice region by 40 km to the north during the Alpine orogenesis, when the Carpathians were formed. Landslides depth is changing, from few to dozens metres. The presented research was conducted and is still in progress, in the Carpathians on two landslides localised in Wapienne and Sękowa and on 15 landslides above the public road Szymbark–Szalowa. Project included core drilling together with sampling and laboratory testing, GPR profiling, GPS precise mapping, installing monitoring system including inclinometers and monitoring system for pore pressure parameters. It used two types of pore pressure transducers: VW wire piezometers with fully automatic data acquisition and hydraulic piezometers. Drillings and installation of monitoring equipment together with initial monitoring

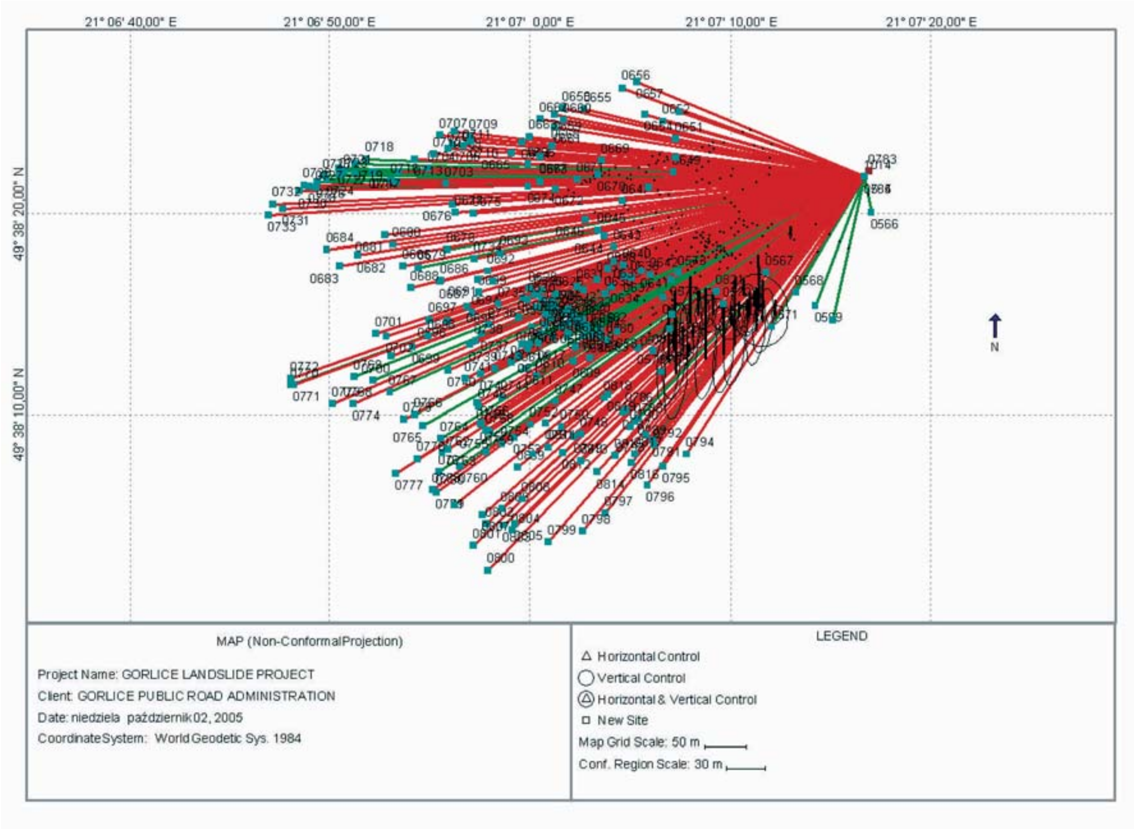


**Fig. 6. Bystrzyca landslide morphology modelling using GPS measurements**

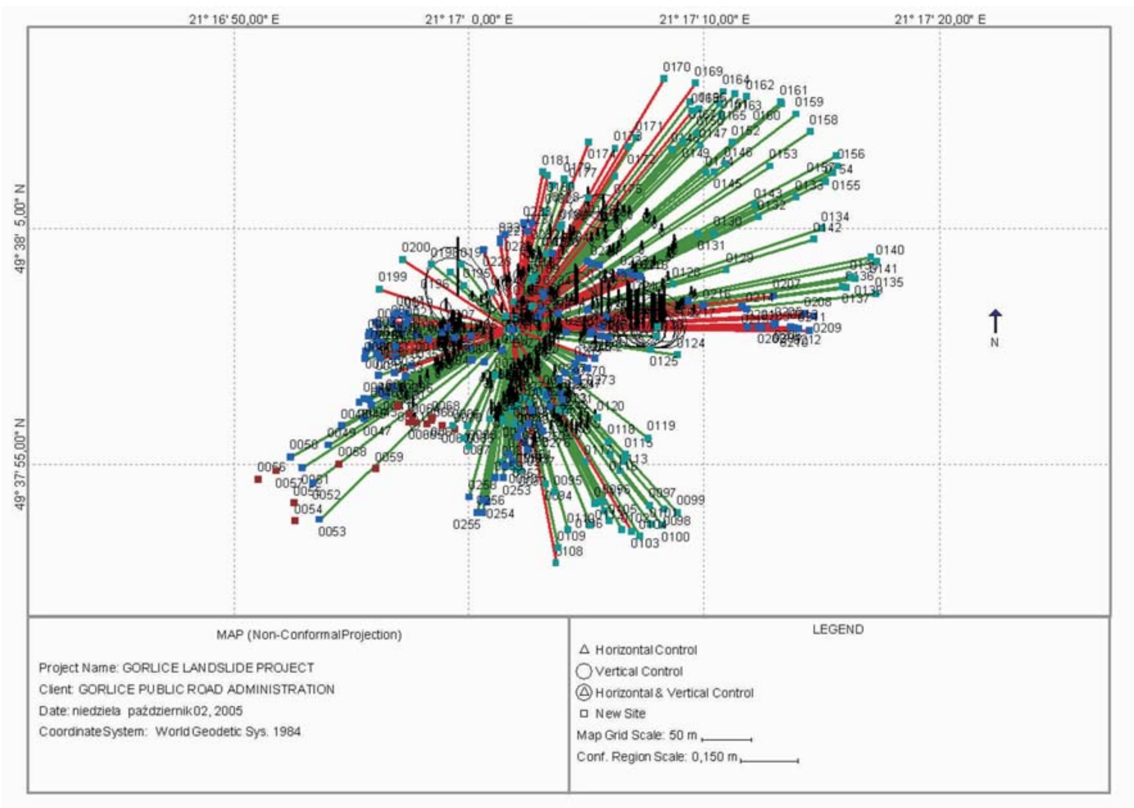


**Fig. 7. Wapienne landslide morphology modelling using GPS measurements**

measurements as well as GPS and GPR profiling are now completed on three landslides and are still in progress on 14 landslides developed on public roads, along the distance of about 15 km. Geological documentations on the two landslides projects have already been finished and the results of these studies are presented in the paper.

GPS measurements are effective, quick and precise methods for mapping a sliding area. GPS equipment and Microstation software were used to landslide mapping and morphology modelling. Equipment used in Gorlice project has horizontal post-processing precision of 5 mm. During the dynamic sessions, up to 300 measurements were performed on one landslide (Figs. 6–7). Using this technique 17 maps have already been finished in Gorlice project.

At that time, over 400 m of core drillings and 6000 m of GPR profiling were already completed, 20 monitoring devices to the depths over 20 m were installed and numerous laboratory tests were performed. It also included preparation of Sękowa landslide stabilisation project and conception of Wapienne landslide counteraction. Wapienne landslide 3D schematic model is shown on Figure 8.

Laboratory tests included index tests such as grain size, moisture content, liquidity and plasticity limits, unit weight, IL odometer tests and direct shear tests. These tests results are presented in Table 1. Results of drillings and laboratory tests indicate that sliding areas are built mainly of clays, other types of cohesive soils, claystones and sandstones. Clays on sliding surfaces have had high plasticity ($I_L = 0.5$), very high moisture content, low friction angle $\varphi^{(n)} = 6.50°$) and cohesion ($c_u^{(n)} = 11$ kPa).

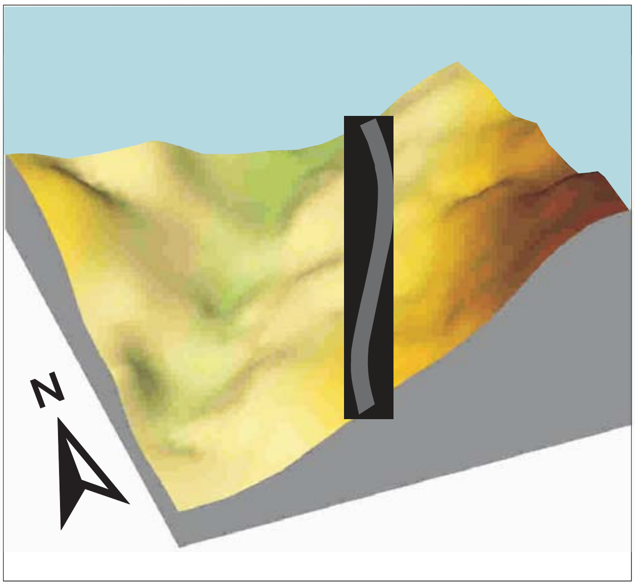


**Fig. 8. Wapienne landslide 3D schematic model**

In Sękowa landslide, sliding surface probably is located between 4.7 to 5.0 m below the surface. In Wapienne, it is probably between 7.2 and 9.0 m below the natural terrain level.

Results of drillings and GPR profiling (Figs. 9–11) indicate that there is not only one sliding surface but rather complicated system of sliding surfaces with some detected faults inside the deeper parts of flysch sediments. Soils with very low geo-

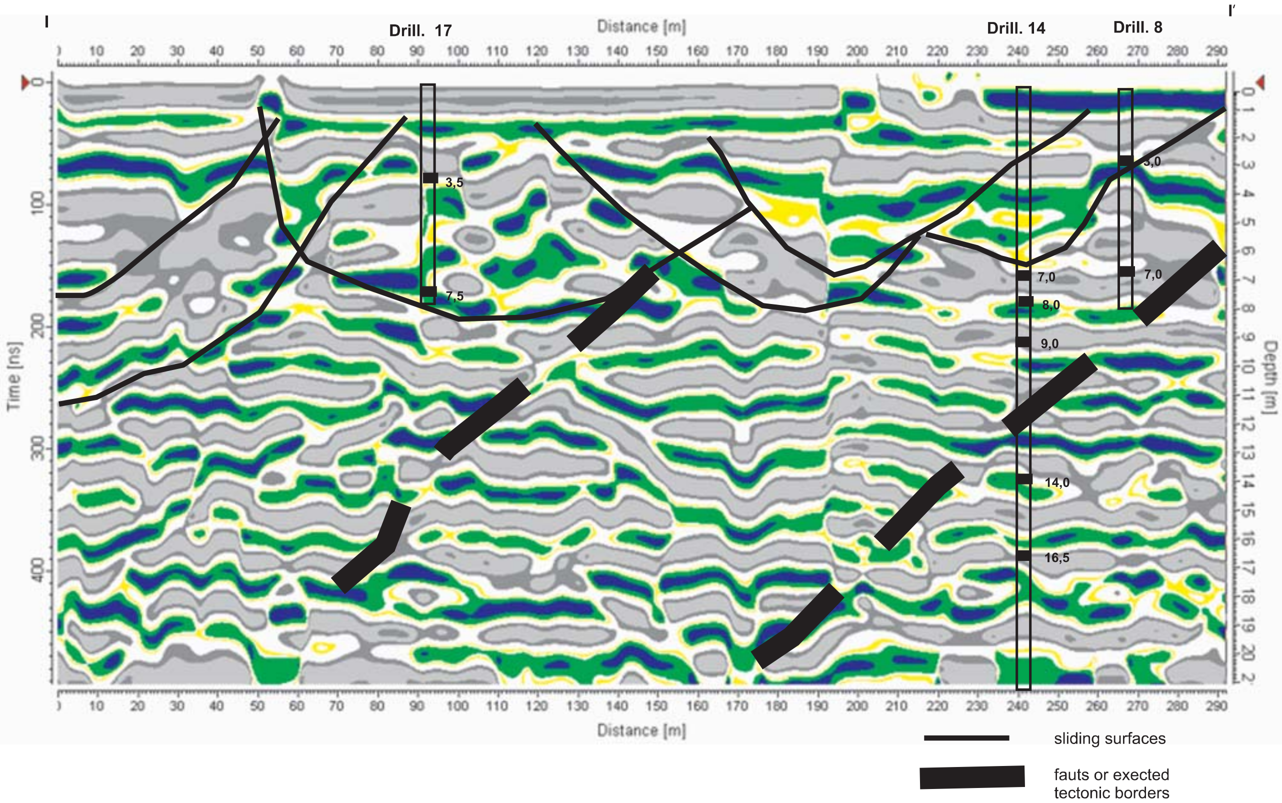


**Fig. 9. GPR I–I’ longitudinal scanning profile, Wapienne landslide**

**T a b l e 1**

**Laboratory tests results, Wapienne and Sękowa landslide**

| Soil sample* | Depth | Moisture content Wn [%] | ρs [g/cm$^3$] | Unit weight ρ [g/cm$^3$] | ρd [g/cm$^3$] | Wp [%] | WL [%] | IL | IP [%] | Cohesion c [kPa] | Friction angle ϕ [°] | Soil type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W7/1 | 1.00–1.40 | 35.35 | 2.70 | 1.981 | 1.464 | 23.61 | 60.17 | 0.32 | 36.56 | 12.40 | 14.00 | clay |
| W7/2 | 1.40–1.60 | 26.74 | 2.70 | 2.029 | 1.601 | 22.23 | 56.82 | 0.13 | 34.59 | 28.00 | 14.00 | clay |
| W7/3 | 4.10–4.30 | 23.62 | 2.65 | 2.062 | 1.668 | | | | | | | clay + clayston |
| W7/4 | 6.50–7.00 | 19.39 | 2.65 | 2.062 | 1.668 | | | | | | | clay + clayston |
| W7/5 | 12.00–12.10 | 6.42 | 2.65 | 1.986 | 1.866 | | | | | | | gravel |
| W8/1 | 4.00–4.20 | 27.58 | 2.65 | 2.001 | 1.568 | | | | | | | clay + clayston |
| W10/1 | 0.20–0.80 | 28.64 | 2.65 | 2.112 | 1.642 | 25.33 | 36.88 | 0.29 | 11.35 | | | clay + clayston |
| W10/2 | 2.00–2.50 | 18.33 | 2.65 | 1.974 | 1.668 | | | | | | | clay + clayston |
| W12/1 | | 16.22 | 2.76 | 2.103 | 1.809 | 12.11 | 26.05 | 0.29 | 13.94 | 23.10 | 17.00 | sandy loam |
| W12/2 | | 18.41 | 2.71 | 2.001 | 1.690 | 18.41 | 40.86 | 0.00 | 22.45 | 31.00 | 18.00 | silty loam |
| W14/1 | 4.40– 4.55 | 17.77 | 2.65 | 2.10 | 1.783 | | | | | | | clay + clayston |
| W14/2 | 9.70–10.00 | 16.34 | 2.76 | 2.138 | 1.838 | 16.34 | 27.74 | 0.00 | 11.40 | | | sandy loam |
| W14/3 | 19.00–19.30 | 14.77 | 2.70 | 2.178 | 1.898 | 13.26 | 59.93 | 0.03 | 46.67 | 31.00 | 12.50 | clay |
| W15/1 | 3.00–3.20 | 28.15 | 2.67 | 2.031 | 1.585 | 20.71 | 38.18 | 0.42 | 17.74 | | | loam |
| W15/2 | 5.00–6.00 | 22.60 | 2.65 | 2.002 | 1.632 | 20.90 | | | | | | clay + clayston |
| W16/1 | 2.00–2.30 | 43.01 | 2.70 | 2.134 | 1.492 | 15.33 | 61.16 | 0.60 | 45.83 | 14.26 | 20.30 | clay |
| W16/2 | 2.00–2.30 | 28.12 | 2.65 | 1.911 | 1.494 | | | | | 20.10 | 29.10 | clay + clayston |
| W16/3 | 4.50–5.00 | 23.70 | 2.65 | 2.039 | 1.649 | | | | | | | clay + clayston |
| W17/1 | 3.00–3.20 | 16.71 | 2.67 | 2.132 | 1.826 | 15.21 | 28.13 | 0.12 | 12.92 | 24.10 | | loam |
| W17/2 | 3.74–3.85 | 20.31 | 2.65 | 2.080 | 1.729 | | | | | | | clay + claystones |
| W17/3 | 5.70–5.85 | 26.31 | 2.65 | 1.967 | 1.557 | 22.38 | | | | | | clay + clayston |
| W18/1 | 1.80–1.90 | 18.01 | 2.67 | 2.131 | 1.806 | | | | | | | |
| S2/1 | 2.20–2.35 | 30.77 | 2.68 | 1.920 | 1.468 | 18.15 | 56.17 | 0.32 | 38.02 | 29.00 | 14.00 | silty loam |
| S2/2 | 2.20–3.00 | 21.78 | 2.68 | 1.957 | 1.607 | 16.67 | 51.03 | 0.15 | 34.36 | 33.40 | 19.10 | silty loam |
| S2/3 | 4.10–4.30 | 16.36 | 2.71 | 2.091 | 1.787 | 13.23 | 46.12 | 0.09 | 32.89 | 35.11 | 20.20 | silty loam |
| S2/4 | 7.00–8.00 | 10.68 | 2.67 | 2.286 | 2.066 | 9.83 | 25.16 | 0.06 | 15.33 | 21.71 | 22.20 | |
| S3/1 | 2.60–2.70 | 32.08 | 2.65 | 1.952 | 1.478 | | | | | 19.40 | 29.7 | clay + clayston |
| S3/2 | 2.50–2.60 | 36.13 | 2.70 | 1.883 | 1.348 | 15.46 | 57.58 | 0.49 | 42.12 | 6.54 | 16.28 | clay |
| S3/3 | 4.00–4.10 | 32.44 | 2.65 | 1.967 | 1.485 | | | | | 20.12 | 23.10 | clay + clayston |
| S3/3a | 4.20–4.30 | 28.29 | 2.69 | 1.893 | 1.475 | 19.05 | 39.14 | 0.46 | 20.08 | 30.11 | 15.00 | loam |
| S3/4 | 5.10–5.40 | 10.78 | 2.65 | 2.250 | 2.031 | | | | | 18.92 | 27.10 | clay + clayston |
| S3/5 | 9.60–9.80 | 15.92 | 2.65 | 2.182 | 1.883 | | | | | | | clay + clayston |
| S4/1 | 1.50–1.70 | 24.86 | 2..65 | 2.002 | 1.603 | | | | | | | clay + clayston |
| S4/2 | 1.70–3.00 | 23.52 | 2.65 | 2.108 | 1.707 | | | | | | | clay + clayston |
| S5/1 | 0.80–0.90 | 20.51 | 2.65 | 2.143 | 1.778 | | | | | | | clay + clayston |
| S5/2 | 2.00–2.50 | 13.20 | 2.65 | 2.091 | 1.847 | | | | | | | clay + clayston |
| S5/3 | 2.60–2.90 | 16.90 | 2.65 | 2.076 | 1.776 | | | | | | | clay + clayston |
| S5/4 | 4.80–5.20 | 11.16 | 2.65 | 2.203 | 1.982 | | | | | | | clay + clayston |
| S5/5 | 3.80–4.70 | 11.66 | 2.65 | 2.207 | 1.976 | | | | | | | clay + clayston |
| S5/6 | 5.35–5.45 | 12.33 | 2.65 | 2.235 | 1.990 | 11.07 | 36.65 | 0.05 | 25.58 | 17.10 | 29.00 | clay + clayston |

* W — samples from Wapienne landslide, S — samples from Sękowa landslide

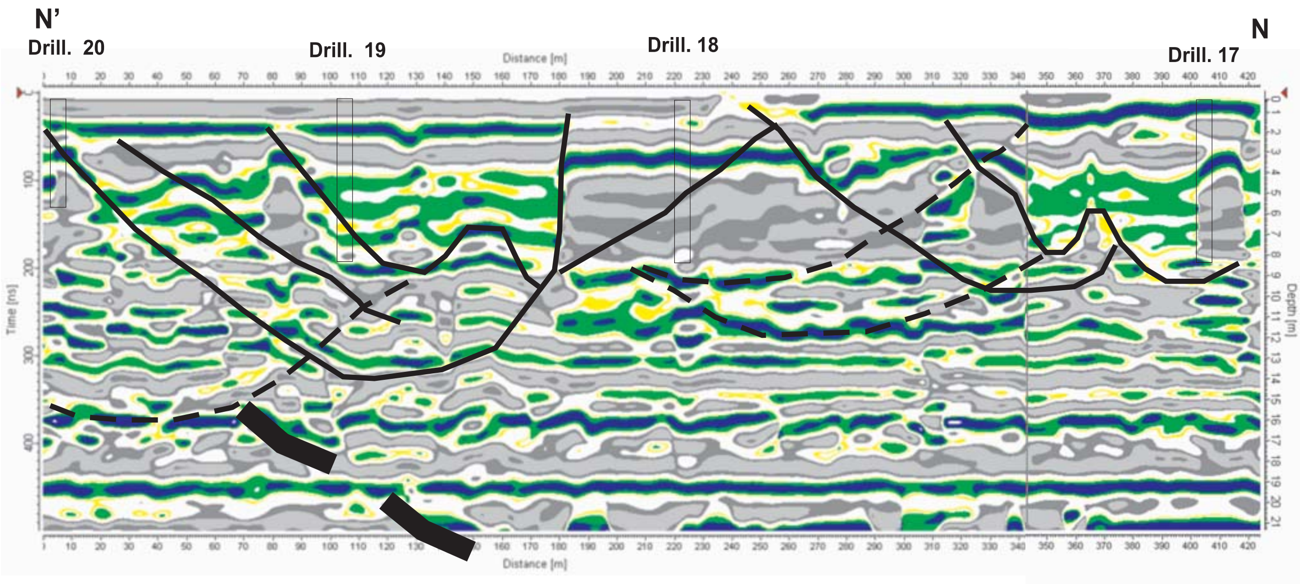


**Fig. 10. GPR N–N' transverse scanning profile, Wapienne landslide**

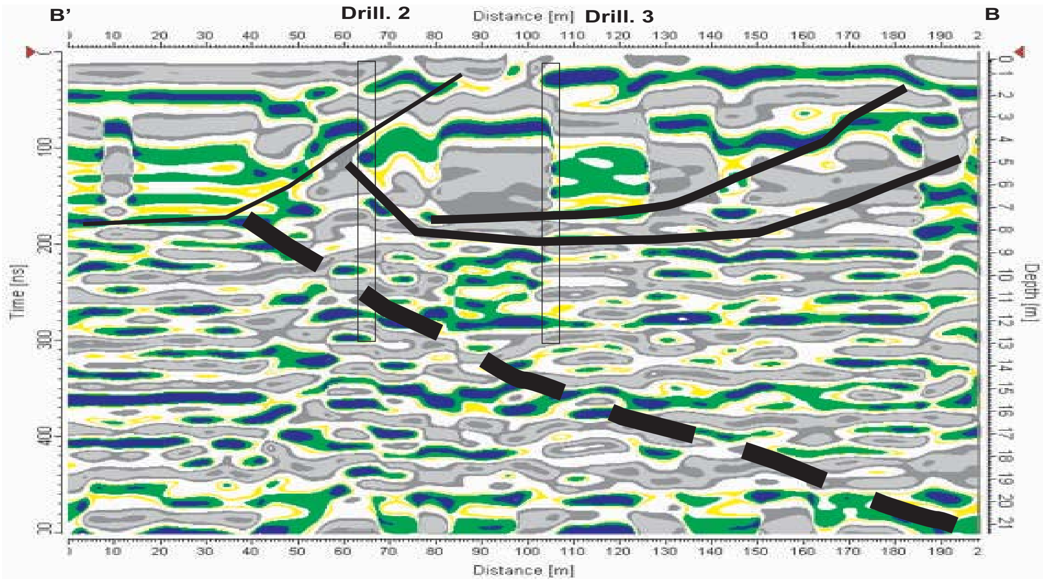


**Fig. 11. GPR B'–B longitudinal scanning profile, Sękowa landslide**

technical parameters are interbeded with medium hard to hard rocks such as claystones or sandstones, with different degree of diagenesis. Main parameters which have influence on the slope stability are: friction angle, cohesion and moisture content. Using results from laboratory tests and slope stability, analysis with Janbu and Morgenstern-Price calculation methods were performed. Results obtained for Sękowa landslide indicate that slope safety factors $F_s$ are fare below 1.3, using Janbu method — 1.2, Morgenstern-Price method — 1.12.

Presented project includes also inclinometer and pore pressure measurements (Fig. 12). Used for the project digital inclinometer probe was constructed by Poltegor-Institute and tested

**Fig. 12. Inclinometer measurements at Wapienne landslide**

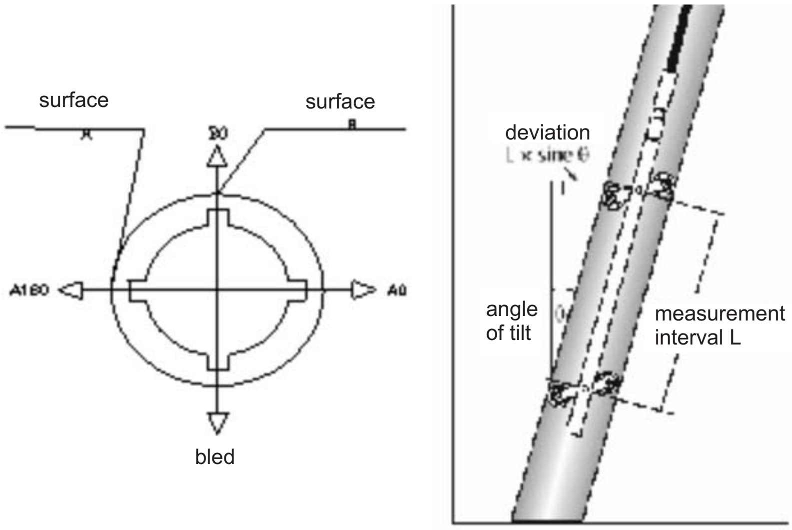


**Fig. 13. ABS inclinometer casings, A and B, 0–180° measuring surfaces**

in Turów Open-Cast Mine over a period of one year together with US produced inclinometer probe. It allowed to measure static and dynamic inclination on two surfaces A and B (Fig. 13) in 0.5 m steps or continuously with automatic depth acquisition to 130 m depth. The first survey established an initial casing profile. Subsequent surveys revealed changes in the profile, if ground movement occurred. During a survey, the probe was drawn upwards from the bottom of the casing to the top, halted at 0.5 m intervals for tilt readings.

The inclination of the inclinometer body was measured by two force-balanced, servo-accelerometers. One accelerometer measured tilt on the plane of the inclinometer wheels, which track the longitudinal grooves of the casing. The other one measured tilt on the plane perpendicular to the wheels. Inclination measurements were converted to lateral deviations (Fig. 14). Changes in deviation, determined by comparison of current and initial surveys, indicated ground movement. Displacement profiles were useful for determining the magnitude, depth, direction and rate of ground movement. Gorlice project monitoring system included installation of the inclinometer monitoring systems in a boreholes with over 200 m of 70 mm diameter ABS inclinometer casings. Installation of this equipment is now in progress. On five monitoring sites initial measurements are already being performed.

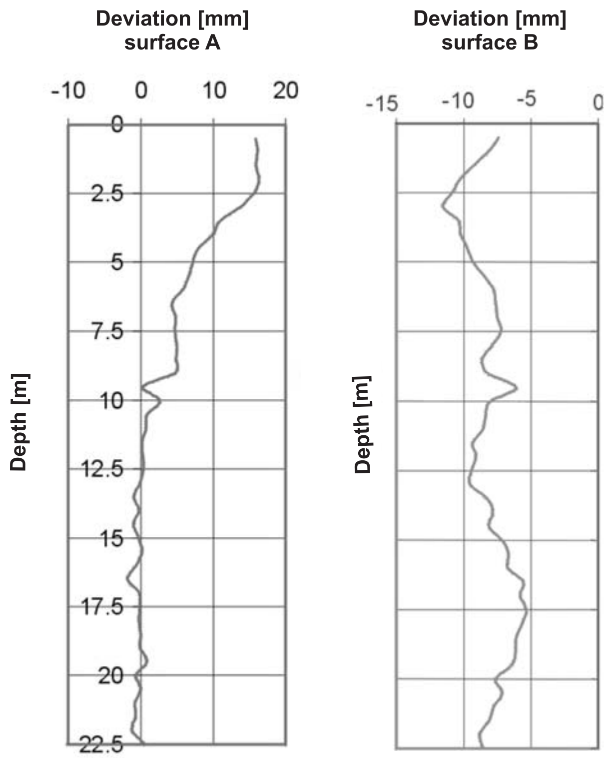


**Fig. 14. Initial measurements at Wapienne landslide to depth of 22.5 m**

**Fig. 15. Installation of Poltegor type standpipe piezometer**

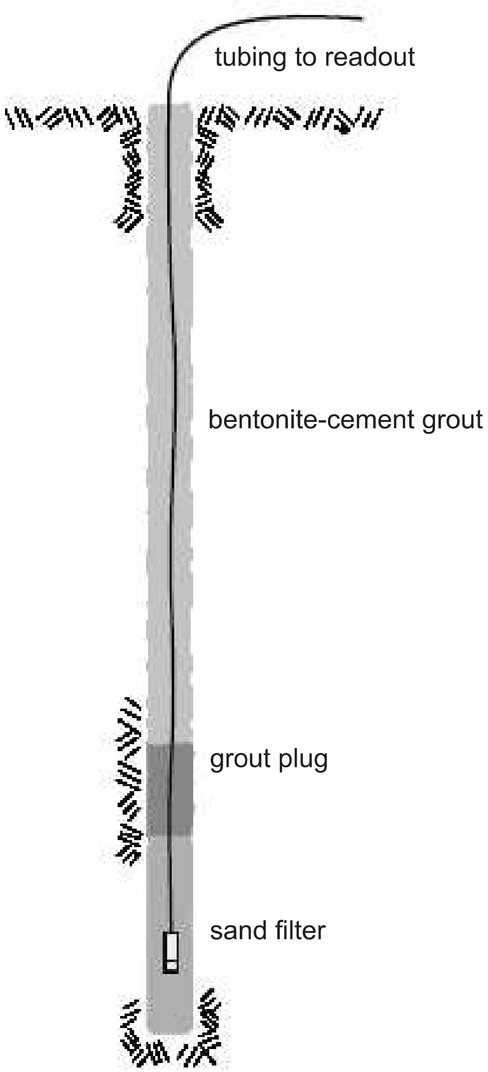


**Fig. 16. Pneumatic piezometer installation**

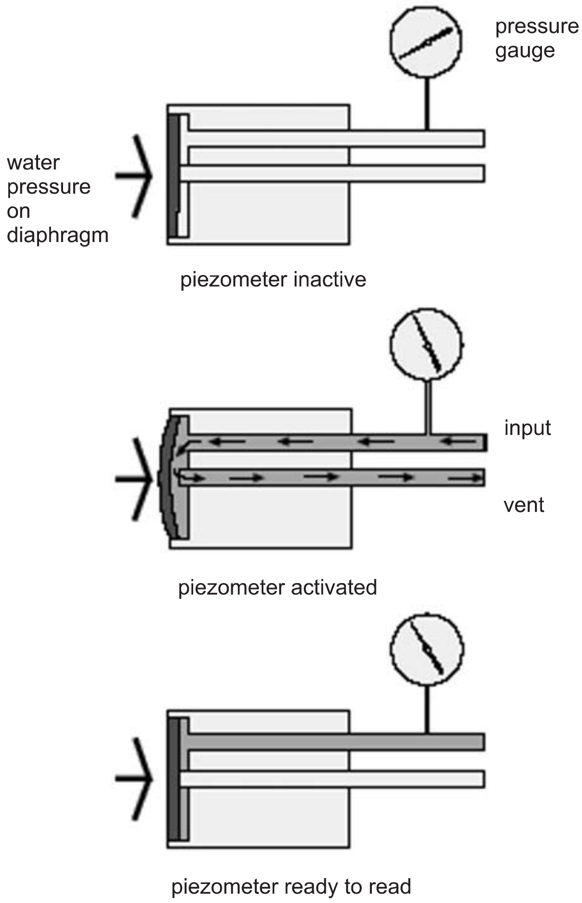


**Fig. 17. Pneumatic piezometer operating principle**

Inclinometer casings usually could bend up to 11 degree without damage. Measurements should be, therefore, repeated every month and start as soon as possible after completing the installation processes. It is especially important in areas where significant mass movements are expected. However, from the practical point of view, the few first measurements might be not representative because of hardening of the bentonite-cement mass around the inclinometer casings.

In the Gorlice project, influence of pore groundwater pressure on slopes stability was predicted through pneumatic and fully automatically vented wire piezometers with special transducers and standpipe piezometers (Figs. 15–20). In that region, pore water pressure plays one of the most important roles in developing landslide processes. Monitoring system included pneumatic piezometers, vented wire piezometers and, additionally, standpipe piezometers.

The details of the implemented monitoring procedures are as follows:

**Fig. 18. Pore pressure measuring equipment**


**Fig. 19. Pneumatic piezometer transducer**

1. Standpipe Poltegor-type piezometers with filters of 70 mm diameter were built of gravel and epoxide. They were embedded in the boreholes to the depth of 5 m and are to be used for monitoring of natural groundwater level.
2. Pneumatic piezometers are used to measure pore water pressure in saturated clayey soils to determine slope stability. On the monitoring sites, pneumatic piezometers were already installed to the depth of 5–10 m and an initial measurement was performed. Piezometers were embedded in a borehole within the 1 m sandy filter and covered by bentonite-cement seal. Twin pneumatic tubes connected the piezometers with a terminal at the surface. Readings were obtained with a digital pneumatic indicator. The piezometer contained a flexible diaphragm. Water pressure acted on one side of the diaphragm and gas pressure on the other. During the measurements, a digital pneumatic indicator was connected to the tubing. Compressed nitrogen gas from the indicator flowed down the input tube to increase gas pressure on the diaphragm. When gas pressure exceeded water pressure, gas escaped via the vent tube. Gas pressure in the piezometer decreased until water pressure forced the diaphragm to its original position. At this point, gas pressure equaled water pressure and a reading could be obtained by the digital pressure gauge on the indicator.

Table 2

**Results of the initial pore pressure measurements on Sękowa and Wapienne landslides**

| Measurement no. | Date | Method A groundwater pore pressure after gas is shut off | Method B groundwater pore pressure with gas flow |
|---|---|---|---|
| | | [kPa] | |
| S1 | 12.06.2005 | 40.86 | 39.15 |
| S2 | | 40.84 | 39.20 |
| S3 | | 40.78 | 39.12 |
| S4 | | 40.29 | 39.10 |
| S1 | 13.06.2005 | 40.90 | 39.22 |
| S2 | | 40.84 | 39.24 |
| S3 | | 40.86 | 39.25 |
| S4 | | 41.15 | 39.20 |
| W1 | 12.06.2005 | 41.15 | 39.92 |
| W2 | | 41.44 | 39.22 |
| W3 | | 41.50 | 39.25 |
| W4 | | 40.40 | 39.92 |

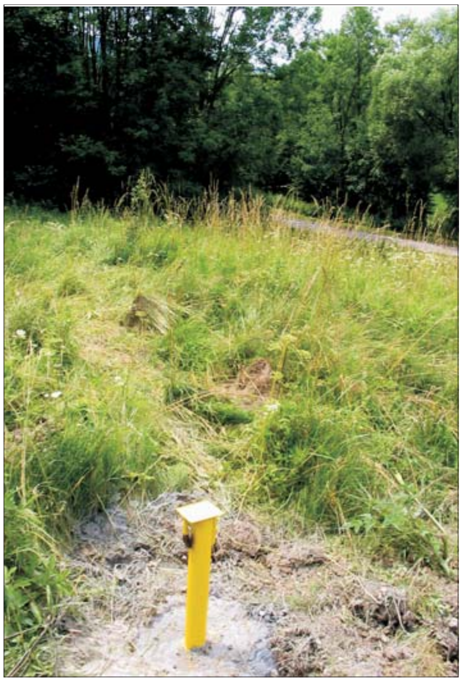

**Fig. 20. Standpipe piezometer, Sękowa**

3. Vented wire piezometer was used on two sites for continuous monitoring of pore water pressures to determine slope stability and effects of dewatering systems used for soil parameters improvement in landslide areas. The vented wire piezometers converts water pressure to a frequency signal via a diaphragm, a tensioned steel wire and an electromagnetic coil. The piezometer is designed in that way that a change of pressure on the diaphragm causes a change in tension of the wire. The vibration of the wire in the proximity of the coil generates a frequency signal that is transmitted to the readout device. A data logger stores the reading in the computer units which is battery-operated and can work over a 3 months period without the need for battery changing, with few measurements made every day. Piezometers respond very quickly to small changes in pore-water pressure. Signals are transmitted to mini logger computer unit and to special interpretation software. Piezometers are measuring temperature continuously. They are also allowing for barometric pressure correction of the obtained pore pressure results.

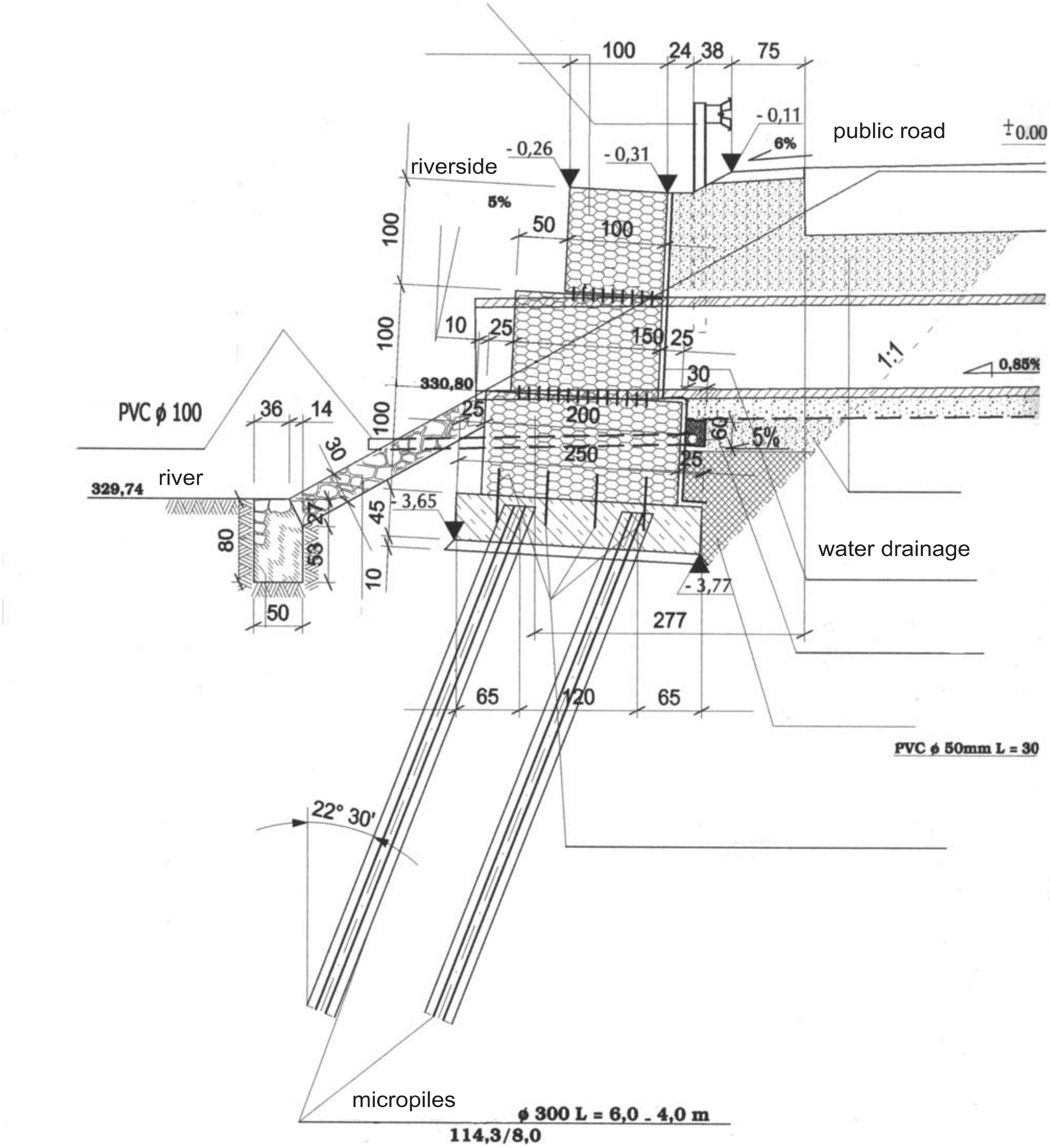


**Fig. 21. Part of the Sękowa landslide counteraction project**

Initial pore pressure measurements were performed on July 13, 2005 using two existing standards of measurements — with gas flow and with shut it off. Measurements were performed four times to receive reliable pore pressure values. In Table 2 there are presented obtained values. Initial measurements S1–S4 have been done at Sękowa landslide on July 12, 2005 and repeated on July 13, 2005. Average values for this two measurements were 40.69 kPa in method A and 39.14 kPa in method B. On Wapienne landslide it was 41.12 and 39.25 kPa. These measurements were performed during the dry weather and it is important to provide continuous measurements every month after installing complete set of the equipment.

For the landslide stabilisation projects, slope stability analyses were performed. They included landslide stabilisation project for Sękowa landslide. Standpipe piezometer measurements on Wapienne and Sękowa landslide on July 13, 2005 indicated very low groundwater level — 0.5 m below the natural terrain level at Wapienne landslide and 0.8 m on the Sękowa landslide. Sękowa landslide road stabilisation project included a natural drainage system and micropiles. Fragment of this project is presented on Figure 21.

## SUMMARY AND CONCLUSSIONS

**1**. Some chosen examples of the mass movements investigations have been presented in the paper.

**2**. The projects represent wide spectrum of landslides investigation techniques with the special attention paid to the flysch landslide project in the Carpathians.

**3**. For each type of geodynamic phenomena and deposits, the different set of investigations should be used. Sometimes, like in clay deposits, failure develops over periods of months as a creep process. In contrast, in sandy and rocky deposits failure could be developed very quickly. Failure often occurs as a combination of different mechanisms and depends on hydrology, geology and topography.

**4**. Pore water pressure plays an important role in the slopes stability. It plays one of the most important roles in developing geodynamic processes. In the paper, different types of pore pressure measurements were presented. They include generated pore pressure measured during CPTU test in clays and different types of piezometer measurements performed on the landslide near the city of Gorlice.

**5**. Landslide monitoring is essential for mass movements prediction and counteraction. Pore pressure monitoring connected with inclinometer measurements, laboratory testing, GPR and GPS allows for effective indication of the failure zone and could be used for slope stability calculations and landslide stabilisation projects. However, not all the research methods are suitable for every type of landslide. Caution should be also paid to the long enough data collection and correct interpretation of the test results.

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