Polish Geological Institute Special Papers, 24 (2008): 9–14
Proceedings of the Conference “The abiotic environment – evaluation of changes and hazards – case studies”

MONITORING AND INSTRUMENTATION FOR THE SÊKOWA LANDSLIDE STABILIZATION PROJECT (CARPATHIAN MOUNTAINS)

Zbigniew BEDNARCZYK[1]

Abstract. The paper is based on mass movement investigations in Beskid Niski (the Carpathians, Poland), performed inside the “Landslide Counteraction Framework” component “A”, financed by European Investment Bank for Gorlice Road Authority. The Sękowa landslide is formed in soft clayey (Oligocene) flysch deposits with shallow groundwater level. Project represents different types of investigations such as conventional drillings and sampling, ground penetration radar (GPR), laboratory tests (index, oedometer, direct shear tests), GPS-RTK profiling and landslide instrumentation. Monitoring networks consist of inclinometer casings installed in a borehole, pneumatic and standpipe piezometers. Landslide instrumentation and monitoring allowed to integrate landslide geology and to update reference model presented in geological documentation. The most important finding was a precise localization of the sliding zone which was found to be shallow than estimated by the drillings. Inclinometer monitoring, water level and pore pressure measurements were found to be very useful for predicting the geodynamic activity which was used for landslide stabilization project. It also allowed to reduce estimated landslide stabilization costs. Data received from monitoring measurements was the base for slope stability calculation including revised stabilization method.

Key words: landslides, monitoring, landslides counteraction, engineering geology.

Abstrakt. W artykule przedstawiono badania osuwisk w Beskidzie Niskim (Karpaty, Polska) wykonywane w ramach projektu „Osłona przeciwosuwiskowa” finansowanego przez Europejski Bank Inwestycyjny dla Rejonowego Zarządu Drogowego w Gorlicach. Osuwisko w Sękowej powstało w miękkoplastycznych fliszowych gruntach ilastych (oligocen), charakteryzujących się płytkim występowaniem wód gruntowych. W ramach projektu wykonano różnego rodzaju badania, takie jak konwencjonalne wiercenia i pobieranie próbek NNS, profilowania georadarowe (GPR), badania laboratoryjne (pomiary podstawowych cech fizycznych gruntów, testy edometryczne i w aparacie bezpośredniego ścinania), profilowania GPS-RTK oraz instrumentację osuwisk (Bednarczyk *et al*., 2005). System monitoringu składa się z rur inklinometrycznych zainstalowanych w otworach wiertniczych oraz pneumatycznych i standardowych piezometrów. Instrumentacja i pomiary monitoringowe osuwisk pozwoliły na korektę początkowo określonego modelu budowy geologicznej, przedstawionego w dokumentacji geologiczno-inżynierskiej. Najważniejszym wynikiem projektu było precyzyjne określenie powierzchni poślizgu, która okazała się być płycej niż stwierdzona na podstawie wierceń. Pomiary inklinometryczne, monitoring poziomu i ciśnienia porowego wód gruntowych były bardzo przydatne dla określenia stopnia aktywności geodynamicznej osuwiska i zostały wykorzystane w projekcie zabezpieczenia. Pozwoliły one także na zmniejszenie kosztów stabilizacji. Dane otrzymane z pomiarów monitoringowych stanowiły podstawę do analiz stateczności i zostały zawarte w skorygowanej metodzie stabilizacji osuwiska.

S³owa kluczowe: osuwiska, monitoring, stabilizacja osuwisk, geologia inżynierska.

RESEARCH ELEMENTS

Principal geotechnical questions in the project were:
1. What are initial site conditions?
2. How much ground is moving?
3. What are geotechnical parameters at the sliding zone?

[1] Open-Cast Mining Institute, the Poltegor-Institute (Poland), Parkowa 25, 51-616 Wrocław; e:mail: zbigniew.bednarczyk@igo.wroc.pl

4. How much groundwater condition affecting the sliding zone?
5. Will it be possible and effective to improve ground condition and how?

Research elements included site conditions documentation. It presented interpretation of landslide localization, size, depth, lithology, failure mechanism, geotechnical conditions landslide instrumentation and preliminary landslide stabilization project performed inside component "A" of the project, between May and July 2005. Monitoring control measurements in the year 2006 allowed to precise localization of the sliding surface under the public road. It also allowed correction in landslide stabilization project with significant cost reduction, however, finance support for this type of measurements inside Component "B" of the project has not started yet. To avoid possible damage of casings without control measurements, monitoring was financed by Poltegor-Institute. Measurements will be also performed till the end of 2006 in one month periods.

LANDSLIDE LOCALIZATION AND CHARACTERIZATION

The Sękowa landslide is formed in the Carpathians near the Sękowa village. It is an active landslide along the Męcinka River, causing Sękowa–Rozdziele road subsidence at the distance of 30.0 m. Landslide is founded in flysch claystone deposits. Its size is 400 × 50 m with sliding surface depth 2.7–8.0 m. For landslide characterization, different types of investigation methods were used (Larsen, 2002; Rączkowski, Mrozek, 2002; Bednarczyk, 2004a, b; Bednarczyk, Sandven, 2004).

LANDSLIDE DOCUMENTATION

For landslide geological and geotechnical internal structure recognition seven diamond impregnated, 132 mm diameter core drillings, total depth of 65 metres were be performed. They allowed to establish geological profiles and cross-sections and gaved samples for laboratory tests. Drilling was also used for comparison with GPR six profiles made with 100 and 250 MHz antennas at the total distance of 1260 metres. Geotechnical tests performed in the laboratory included index tests (grain size, moisture content, liquid and plastic limits, unit weight, soil particles unit weight), incrementally loaded (I_L) odometer tests and direct shear tests. Soils used for these tests represented silty loams, silty clays to claystones (rock). Soils inside the sliding surface had very high moisture content to 36%, liquidity index up to 0.50, apparent cohesion 6.5 kPa, angle of shearing resistance 11° and modulus of liner deformation 11,000 kPa. The highest values of moisture content and plasticity index were observed at depth 2–5 metres below natural terrain level.

MASS MOVEMENTS MONITORING

Monitoring measurements had been continuously performed between January and September 2006. Inclination of 70 mm ABS casings was measured in two A and B surfaces in 0.5 m steps (Fig. 1). Subsequent surveys indicated changes in profile during the ground movement. Inclination measurements converted to lateral deviations are presented in figure. Displacement profile is useful for determining the magnitude, depth, direction, and rate of ground movement (Figs. 2, 3).

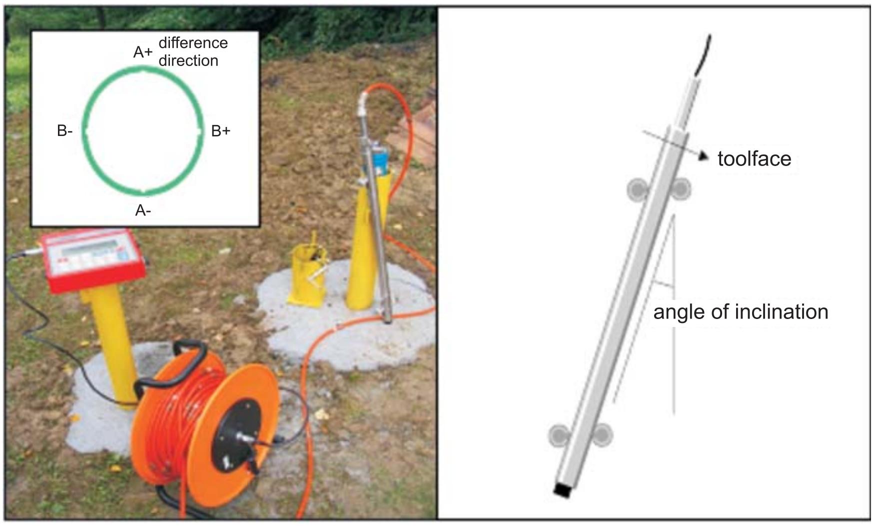


Fig. 1. Mass movement monitoring

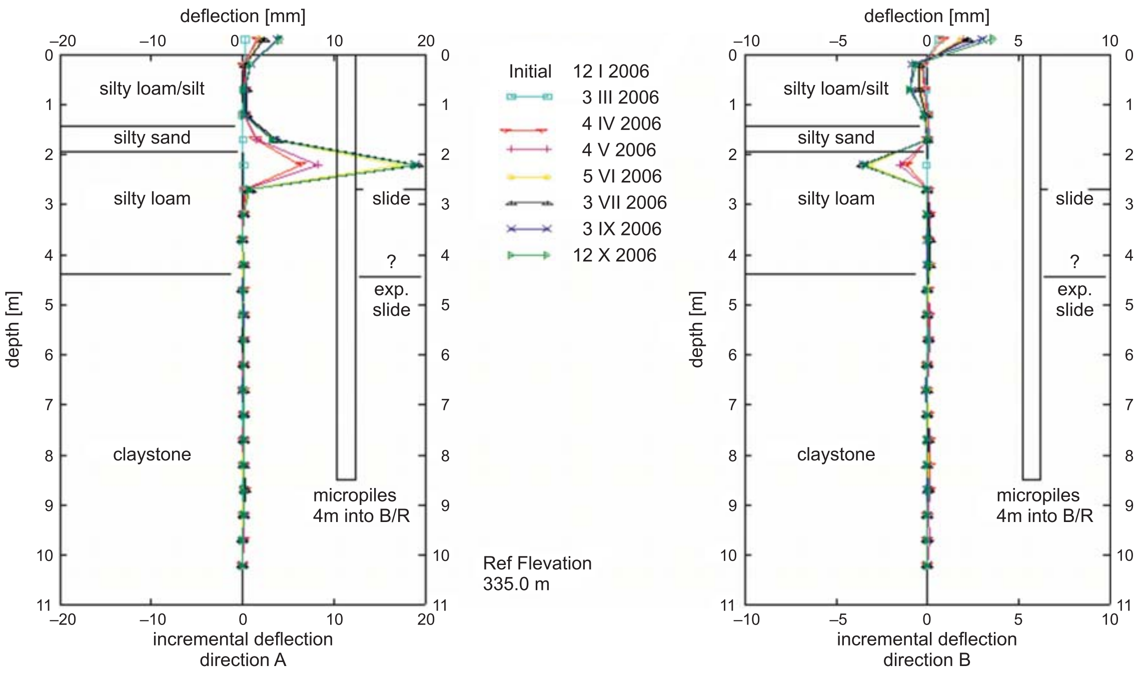


Fig. 2. Results of ground movement measurements

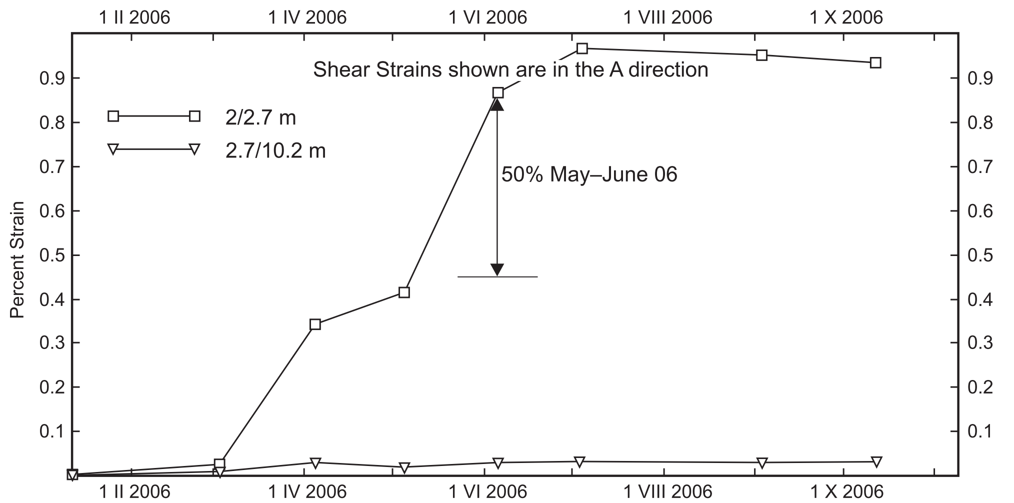


Fig. 3. Interpretation of mass movements measurements, displacement/shear strain plots

GROUNDWATER AND PORE PRESSURE MONITORING

Within the presented project two types of piezometers were installed. There were stand-pipe piezometer and pneumatic pore pressure transducer. Pneumatic piezometer measured groundwater pressures *in situ*. It allowed observing the variation of pore pressure and landslide effective stress stability analyses. Piezometer was embedded in a borehole within sandy filter, covered by bentonite-cement seal at expected sliding surface depth. Using gas transmission tubes and compressed nitrogen gas reading was obtained by the special digital pressure gauge indicator. Two types of pore pressure measurement (with gas flow and after gas shut of) were made between June 2005 and September 2006. Results indicated that the highest values of pore water pressure were observed in April and June 2006 which correspond to the highest mean monthly precipitation values in this region (measured by Polish Academy of Sciences – courtesy PAN Szymbark) presented on Figure 4.

Groundwater level had been also measured in observation well localizated in the upper part of the landslide. Obtained readings (Fig. 5) indicated that the shallowest level of groundwater level was in autumn and spring periods, however record precipitation in June 2006 has no such a respond as measured pore pressure values (Fig. 4).

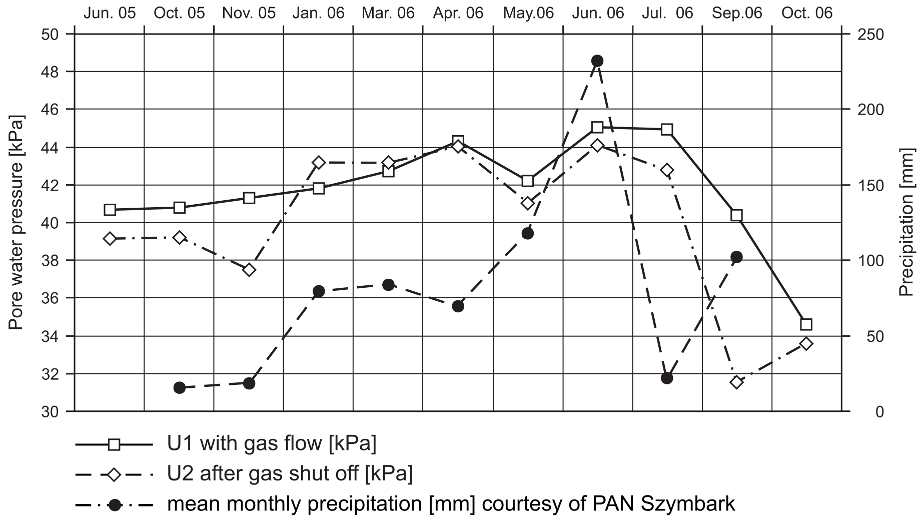


Fig. 4. Pore water pressures and precipitation monitoring

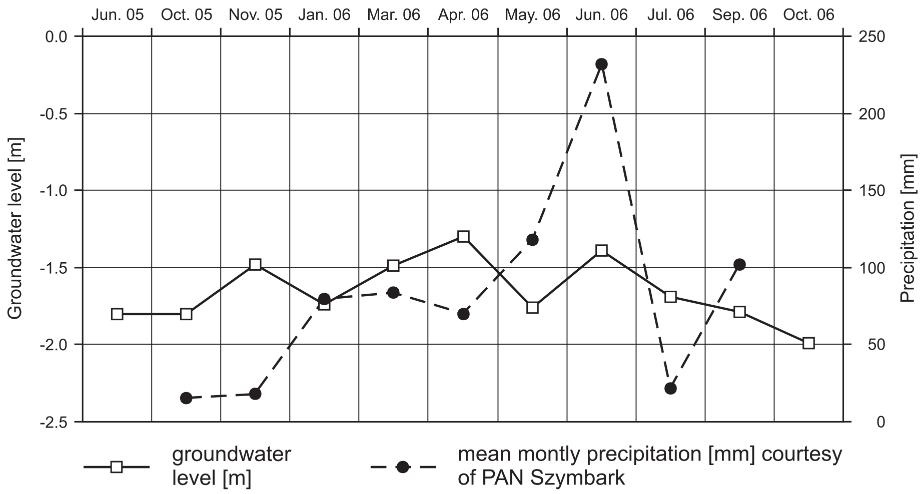


Fig. 5. Groundwater level and precipitation measurements

LANDSLIDE COUNTERACTION PROJECT

The landslide counteraction project included construction of the landslide drainage system. Stabilization works will include rebuilding of the road, building of reinforced ground retaining wall (200 × 3 m) along the river. It will be built on the 300 mm diameter micropiles foundation (2 rows, first row incline at 22 deg., to 3 m depth). Second part of the stabilization project including micropiles over the road to depth of 8.5 in 2 rows connected by a special concrete supporting construction at the surface. It is planned that during and after construction works control monitoring measurements will be performed.

LANDSLIDE STABILITY ANALYSIS

Calculation of landslide slope stability was performed using Finite Elements Flex software and by classical Janbu, Morgenstern-Price and Bishop Method. Results of stress analysis using FEM analysis are presented in Figure 6. These analyses included cumulative ground movements and pore pressures monitoring measurements for the sliding surface. Obtained final mesh indicated that the landslide is still very active and could damage the road. Proposed counteraction was checked using classical methods which are based on relative factor of safety (F_s). Obtained values of F_s at the time before stabilization were slightly above $F_s = 1.0$ (which represents point of failing, when resistance is in exact balance with the destabilizing force). In Bishop Method relative factor of safety was equal 1.13 before counteraction and 1.58 after proposed stabilization (Figs. 7, 8).

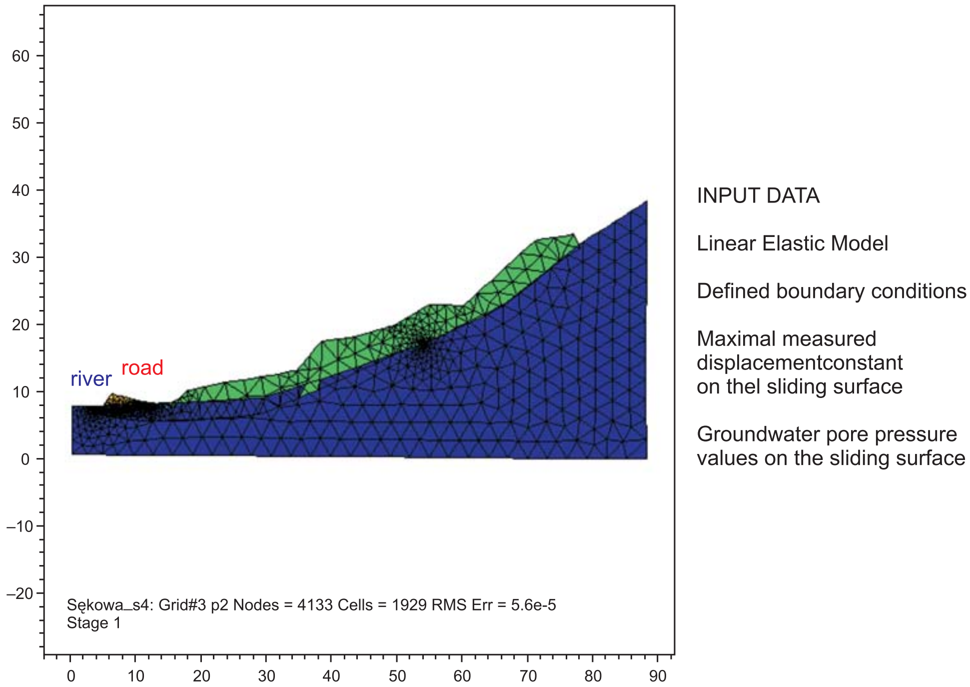
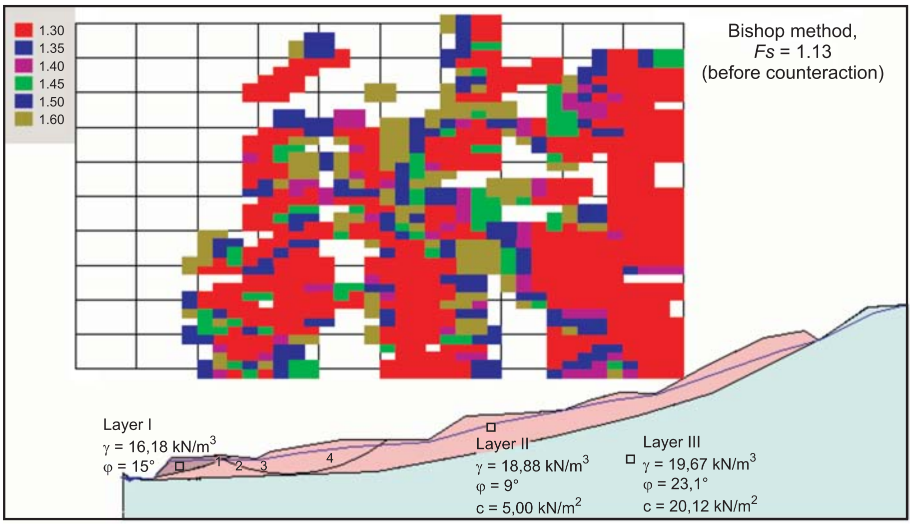


Fig. 6. Slope stability analysis FEM Method – final mesh

Fig. 7. Slope stability analysis with Bishop Method before counteraction



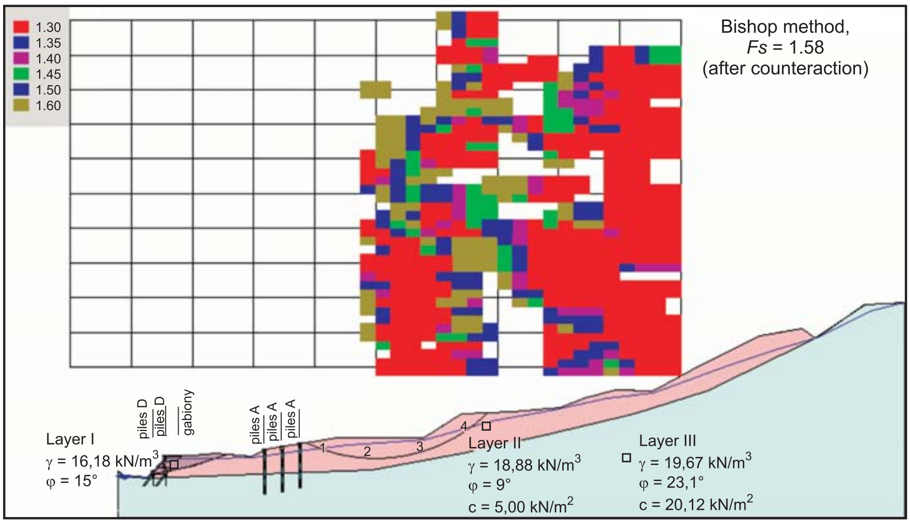


Fig. 8. Slope stability analysis with Bishop Method after proposed counteraction

SUMMARY AND CONCLUSIONS

1. The Sękowa landslide is built from flysch soils with very low geotechnical parameters and high water content which play one the most important roles in developing geodynamic processes.

2. Results of monitoring indicated that sliding surface is 2.7 m below the public road the in lower part of the landslide, where displacement reached 20 mm between Jan.– Sept. 2006. Laboratory tests showed that sliding area is built mainly from silty clays, clays, other types of cohesive soils and claystones. Silty clays at 3 m depth sliding surface had high plasticity *IL* = 0.5, very high moisture content (30%) low friction angle $\varphi u^{(n)} = 6.50$ and cohesion $cu^{(n)} = 11$kPa.

3. The highest values of pore water pressure – 45 kPa was observed in July 2006. It fairly corresponded with the largest monthly mass movements of 12 mm and 232 mm precipitation.

4. Landslide is still very active and could damage the road that was indicated by control inclinometer measurements and FEM analysis. Partly stabilisation of lower area of the landslide seems to be however possible. Proposed landslide stabilisation project included micropiles, drainage and reinforced ground systems along the river.

5. Results of slope stability classical analysis indicated, that before proposed stabilisation, slope safety relative factors were far below safety level *Fs* = 1.3 (*Fs* = 1.13). After proposed stabilisation including micropiles, drainage and reinforced ground system it increased to 1.58.

6. Field instrumentation, monitoring and control stability calculations allowed to lowered approximate stabilisation cost by about 20%, however monitoring should be performed also during and after stabilization works.

REFERENCES

BEDNARCZYK Z., 2004a — Chosen aspects of soil investigations in landslide areas. Proceedings of 62 Conference of Polish Academy of Sciences “Natural Hazards in Mining”, Bełchatow, Poland: 611–623.

BEDNARCZYK Z., 2004b — Landslide investigations by static sounding with pore pressure measurements (CPTU), ground penetration radar techniques (GPR) and other chosen methods. *In*: Proceedings of the Conference “Risks Caused by the Geodynamic Phenomena in Europe” (eds. M. Graniczny *et. al.*). *Polish Geol. Inst. Sp. Papers*, **15**: 19–28.

BEDNARCZYK Z., MAREK A., ŁAWNICZAK M., ŁĘGOSZ A., 2005 — Geotechnical documentation of the landslides in Gorlice region. Landslide Counteraction Framework, comp. “A”. Poltegor-Institute, Wrocław.

BEDNARCZYK Z., SANDVEN R., 2004 — Comparison of CPTU and laboratory tests interpretation for Polish and Norwegian clays. International Site Characterisation Conference ISC-2. International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), International Society of Rock Mechanics (ISRM), International Association Engineering Geology (IAEG), Geo-Institute of the American Society of Civil Engineers (ASCE), Portuguese Association of Engineers (OE) and British Council (BC), Porto, Portugal. Geotechnical and Geophysical Site Characterization. Millpress, Rotterdam, Netherlands.

LARSEN J. O., 2002 — Some aspects of physical weather related slope processes. Ph.D. thesis 2002: 19 NTNU, Department of geotechnical engineering, Trondheim, Norway.

RĄCZKOWSKI W., MROZEK T., 2002 — Activating of landsliding in the Polish Flysch Carpathians by the end of the 20th century. *Studia Geomorph. Carpatho-Balcanica*, **36**: 91–111.