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Stages of Geological Documentation on the Example of Landslides Located on the Slopes of the Dam Reservoir “Swinna Poreba” (Poland)

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Abstract. In the Polish part of the Carpathians there are 14 retention reservoirs that accumulate around 1200 million m3 of water. The last larger hydrotechnical structure is the Świnna Poręba reservoir, capacity: 160 million m3, built on the Skawa river. The reservoir has a very varied coastline, within which there are many landslide areas (including the Ostałowa landslide region). Hydropower disasters are known from the history of hydrotechnical objects, the reason for which was the insufficient identification of the geological structure of the reservoir bowl. Documentation of landslide in such areas is therefore an issue of great importance for the safety of not only the hydrotechnical object itself, but also people inhabiting the area of the water reservoir. At particular stages of documenting landslide areas, it is important to: recognize the mechanism that activates the landslide, assess the possibility of securing a slope or escarpment, indicate the optimal method of stabilizing the landslide, determine the geotechnical parameters necessary to develop a landslide protection project and its monitoring. In the article, the key elements of the documentation for the protection of the Ostałowa region were presented against the background of the legal regulations in Poland. The content of landslide document sheets, the scope of the geological work project and the scope of geological engineering documentation for the landslide protection project were characterized. The key elements of the geotechnical design are presented, including slope stability calculations and the proposed protections are presented. Surveying monitoring of the Ostałowa area constituting a continuation of geological works is carried out on a network of sixteen benchmarks controlled in relation to four benchmarks of the reference network. This monitoring should also be continued after the protection of the landslide, as it is the basic measurable way of determining land displacements. Measurement results indicating soil displacement are the basis for possible prevention actions.

1. Introduction

The last major hydrotechnical building in the Polish part of the Carpathians is the Świnna Poręba reservoir, built on the Skawa river at km 26 + 600 of the river's course. The reservoir has a very diversified coastline and extends from the town of Świnna Poręba to Zembrzyce at the length of about 11 km [1]. Examples of water dam disasters in the world (the Malpasset catastrophe in 1959, the Vaiont disaster in 1963) indicate the necessity of conducting thorough geological surveys of the area of the planned dam, as well as the valley slopes occupied by the proposed reservoir [2]. Risk management should also be continued without interruption during the operation of the tank. In accordance with the regulations in force in Poland [3], at the stage of planning the construction of the

Świnna Poręba dam, as well as during the construction, the investor carried out activities related to the geological and engineering documentation of the soil subsoil in the region of the dam and the reservoir.

2. Characteristics of the research area

The Skawa river flows in the area of the Western Beskids. Its course is entirely on the territory of the Lesser Poland Voivodeship. The area of geological works is located in the basin of a small, unnamed brook, which is the right tributary of the Skawa River (second-order river), flowing into the Vistula River (the first-order river). The ordinate of the unnamed stream in the discussed section of the valley is from 297 m above sea level. in the lower, southern part thereof to about 310 m above sea level - in the central and northern part. The nearest elevations are located north-west and east of the valley and reach heights of 410.9 and 378.1 m above sea level. After launching the Świnna Poręba dam and filling the reservoir, the ordinate of the maximum level of water damming in the reservoir will reach 312 m above sea level.

There are 12 small landslides in the analyzed area, within the analyzed section of the valley of the stream, 9 of which have a documentation card along with an opinion, made by the Polish Geological Institute - National Research Institute (Figure 1). Landslides described in the data sheets have been marked with numbers 1-9, where landslides 1-5 are on the left side of the stream, in the hamlet of Ostałowa Zagórska, and landslide 6-9, on the right side of the stream, in the area of the hamlet Ostałowa Dąbrowska.

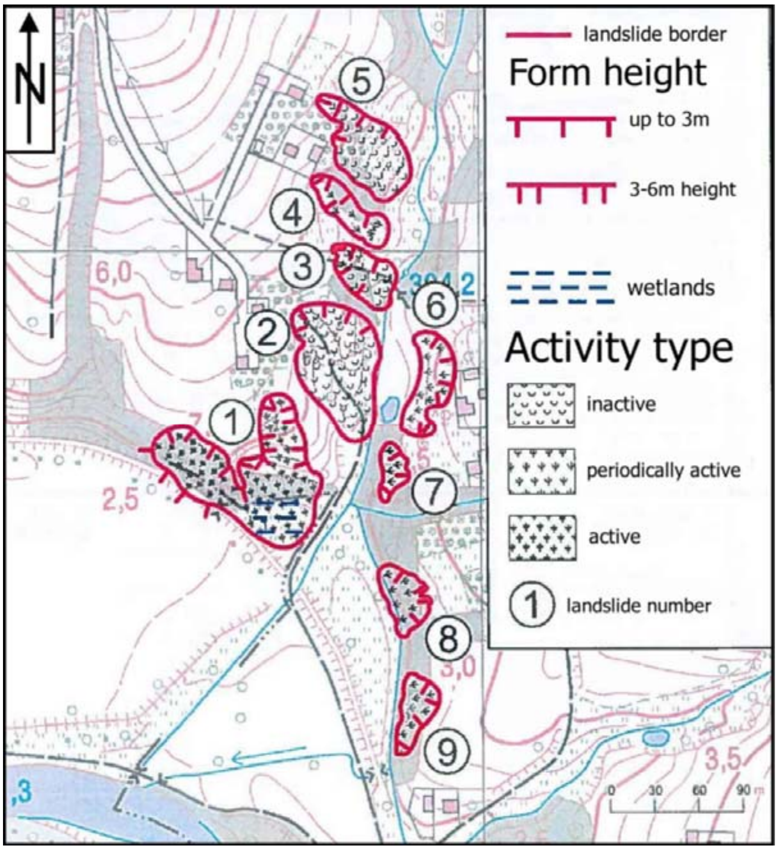

Figure 1. Topographic map with landslide areas (on the basis of the [4])

Landslides are characterized by different degrees of activity from inactive, periodically active to active, and are found both on the right and left side of the stream. A paved road runs along the northern side of the Skawa River, which crosses the lower part of the valley of the unnamed stream.

The majority of the research area and the surrounding area are wasteland overgrown with trees and shrubs stretching along the stream, as well as the surrounding arable lands, in the form of arable lands, meadows and pastures. Directly on the eastern and western sides of the studied valley, over landslides, there are additionally small clusters of single-family and commercial housing buildings to which access roads and ground and underground technical networks lead. The slopes of the whole part of the valley under investigation are currently covered or threatened by mass movements, and traces of landslide movements were also observed in the upper part of the valley located to the north.

The example of this region presents individual elements of the collected documentation for the purpose of preparing a construction project for landslide protection.

2.1. Landslide hazard

The analyzed landslides are characterized by various levels of activity from active to periodically active to inactive, with distinct landslide movements currently occurring within the landslide No. 1 (active landslide) with an area of about 0.7 ha, located in the lower part of the valley in question, where it connects with the valley of the river Skawa. The landslide was activated after heavy rainfall in May 2010. It has a rock-dusty character, is active and starts with a fresh, very distinct main slope with a significant slope and height of about 4-6 m. There are numerous irregularities in its area, including bulging and wetlands. The individual parts of the landslide, such as the main escarpment, side slopes, tongue and landslide face are also clearly visible. Well visible individual parts of landslides and morphological forms are also characterized by landslide 6, with an area of 0.3 hectares, currently considered to be periodically active. Other landslides recognized on the studied area begin with main slopes of the order of 0.5-1.5 m, and end with headwaters with a height not exceeding 0.5 m and usually characterized by less clear traces of landslide movements, mainly in the form of inequalities (depressions and swellings) of the area. Most landslides located on the eastern side of the stream - landslides 7, 8 and are very small, periodically active and inactive, with a maximum area of 0.24 ha (landslide 9), characterized by education in the form of small plumes within the valley or creek valley Skawa formed as a result of undercutting the erosive slope and infiltration of rainwater. Landslides 2, 3, 4 and 5 - located on the western side of the stream, are larger forms with an area of 0.23 to 0.68 ha with little visible, sometimes blurred as a result of erosion and / or human activity of morphological forms. Within most landslides, as well as directly below them, in the place of river deposits, there are also wetlands and / or ground water exudates to the surface and periodic watercourses. Groundwater on the land surface is also observed locally on the slopes of the valley, apart from landslides.

The landslide rounds usually include both quaternary ashtray cover and flysch formations. The weathering cover is formed in the form of cohesive silty clayey rocks with ground rock crumbs, the number of which increases with depth, as well as sandstone, mudstone and slate rubble with a variable (usually significant) fraction of smaller fractions. The total thickness of landslide slide is from 3.0-4.0 m - on a landslide No. 6 to 17.2 m below the level of the landslide No. 2.

The whole area of the slope of the described valley of the stream without a name, outside landslides, is currently undergoing processes of fulfillment, as evidenced by the occurrence of the so-called "drunken forest effect" and can be considered as threatened by mass movements.

The causes of landslide processes in the studied region should be seen in:

- influence of rainwater (soil irrigation after long-lasting precipitation and spring thaw),
- erosional properties of the stream,
- geological structure (presence of cohesive soils that are sticky to plasticizing and other weathering of ground rocks and weathered sandstones and shales),
- favorable slope of the valley slopes - western slope - about 8-15°, eastern slope - about 15-35°.

3. The scope of work carried out

Geological and engineering documentation is a result of a geological survey carried out on the basis of a geological work project. In 2015, within the framework of the "Geotechnical opinion together with the documentation of the ground plot of the water reservoir in the vicinity of the landslide slope of Ostałowa", ground-water conditions were initially recognized. To this end, 15 geotechnical holes were drilled in the landslide with a depth of 6-10 m. under the surface. For the described region, laboratory analyzes of representative soil samples were also carried out then [5].

The works and examinations carried out as part of the documentation included:

- working on the situation and altitude map,
- execution of geological engineering mapping,
- reconstruction of twenty geological engineering holes,
- macroscopic description of the ground drilled,
- installation of 3 inclinometers,
- execution of laboratory tests of soil, rock and water samples collected,
- measurements in inclinometers,
- designing geological engineering documentation.

The geological engineering documentation was made in accordance with the provisions of the Act [3] and Regulation [6]. Recognized and documented ground and water conditions were the basis for designing engineering solutions for the purpose of securing the landslide area.

The area of geological works is owned by the Regional Water Management Board in Kraków and private persons, and geological engineering holes were drilled on parcels no .: 1024/18, 1160/1, 1664, 2223/20, 2224/11, 2593/2, 2542 / 2, 2544.

3.1. Surveying works

Geodetic works included updating the situation and elevation map of the landslide area on a scale of 1: 500, as well as setting out and leveling holes in the field. To the geological engineering documentation, due to its large size, the above map has been reduced to scale 1: 1000 and posted as a documentation and geological-engineering map. The scale of the map is sufficient for the content presented. The ordinates were determined using the method of direct geodetic measurements in the field, using the GPS system, referring to the state system and based on the situation and elevation map.

3.2. Geological and engineering mapping

The mapping was carried out on the surface of landslides and in their immediate vicinity. During the mapping, morphological forms and elements indicating the manifestations of mass movements in the studied area, such as landslides (including the main scarp) and thresholds were applied to the map. Particular attention was also paid to the manifestations of groundwater occurrence on the surface, such as: wetlands, effusions or periodic watercourses. In addition, the spatial distribution of lands and rocks lying near the surface were indicated. The boundaries of landslides were detailed and the nature of their activity was determined.

3.3. Geological and engineering drilling

As part of geological works, 20 geological and engineering boreholes were drilled with a depth of 10.0 to 23.0 m below the surface area, marked with symbols from O-1 to O-20, including 3 inclinometer holes, whose names were distinguished by the letter I : O-5I , O-14I and O-18I. The total length of all drilled holes was 289.0 meters, and the total area of inclinometer holes was 61 meters. The drillings were carried out to determine the types of colluvial soils and surrounding soils and their parameters, as well as to indicate the depth of occurrence of landslide slip. O-I-O-14I boreholes were made on the eastern side of the analyzed valley, in the landslides No. 1, 2, 3, 4 and 5, and boreholes O-15-O-20 - on the western side of the valley, in the area of landslides No. 6 and 8. During the drilling, a detailed macroscopic description of the encountered soils was carried out, paying attention to the type of soil, its color, humidity, state of consistency and content of organic parts. Attention was also paid to the occurrence of interbedding, lamination, admixtures, etc. In addition, a detailed description of the drilled rocks was carried out, which consisted in defining their name, color, degree of weathering and cracking and compactness, as well as indicating the locations of the surface of the gaps. The depth of the slip area found in the openings made in the landslide No. 1 is 5.5 and 3.0 m under the surface. Described landslides colluvium usually consists of the quaternary cover of the weathering as well as the flysch formations. The weathering cover is formed in the form of cohesive clay-silty works with crumbs of ground rocks, the number of which increases with depth, as well as sandstone rubble and shale with a variable (usually significant) share of smaller fractions. The total area of landslide slide found in the holes made is 2.5 to 6.8 m below the surface area and the largest is on the landslide marked with number 2.

3.4. Installation of inclinometers and measurements

In order to recognize mass movements that occur in the analyzed landslide area and precisely determine the pace, direction and depth of the landslides No. 2, 5 and 6 of the displacements in the holes O-5I, O-14I and O-18I, with a depth of 23.0, 18.0 and 20 m under the surface and diameter of 132 millimeters, columns of inclinometer tubes with a diameter of 80 millimeters, in sections of 3 meters, were drilled.

The correct test was carried out with an inclinometer. The measurement was made every 0.5 meters. The meter registers a deviation from the vertical in the sine of an angle or in millimeters. Based on the measurements, documentation sheets of inclinometer holes were made, showing their profile and structure. A description of the results of measurements made in individual inclinometers is listed below:

Inclinometer O-5I: The calculated average measurement error for the O-5I hole is +/- 0.34 mm. On the basis of 2 previous measurements, it was found that there is no unambiguous possibility to determine the active slip surface. The occurring displacement increments have values well below the measurement error.

Inclinometer O-14I: The calculated mean measurement error for the O-14I hole is +/- 0.25 mm. Changes in this hole do not exceed 1 mm and apply only to the subsurface zone, which probably results from the settlement of the measuring column housing. Other changes (within the limits of measurement error) concern the section from the surface to -14.0 m depth.

Inclinometer O-18I: The calculated average measurement error for the O-18I hole is +/- 0.48 mm. On the basis of 2 previous measurements, it was found that there is no unambiguous possibility to determine the active slip surface. The occurring displacement increments (maximum 0.15 mm) have values well below the measurement error and occur near -6 m m.p.p.

Summing up, on the basis of the inclinometer measurements carried out so far, no movements within the landslides exceeding the values of the measurement error were found.

3.5. Laboratory tests

The borehole cores taken during field work were transferred to the Laboratory of Soil Mechanics of Przedsiębiorstwo Geologiczne SA, where the detailed macroscopic examinations were carried out. Then, in accordance with the design of geological works, samples for laboratory tests were selected for the determination of physical and mechanical properties of the identified soils and rocks. These tests were carried out in accordance with [7].

Laboratory tests included the determination of physical characteristics of soils, such as: granulometric analysis, natural humidity, bulk density, consistency limits and content of organic parts and determination of strength traits, including: the angle of internal friction and cohesion in the triaxial shear apparatus. In addition, rock tests were also carried out in terms of uniaxial compression strength. Basic soil parameters were tested for 37 soil samples, and uniaxial compression strength tests for 48 rock samples.

3.6 Aggressiveness of groundwater

A sample of water for analysis for aggressiveness in relation to concrete and steel constructions was taken from the O-2 borehole selected by the geological survey. Based on the obtained results, the analyzed water should be defined as non-aggressive in relation to Portland cement concrete with the content of 300 kg / m3 and the W-4 water tightness level according to BN-62 / 6738-07. In accordance with the requirements of the EN 206-1: 2000 standard, the results of the tests qualify the water tested for the XA1 class.

3.7 Geotechnical drilling, macroscopic and laboratory research of soils

Directly on the site of the research, in the valley of the unnamed stream, there is a thin layer of river land of this stream, and on the slopes of the valley - a layer of weathered tracks. Both alluvial and dusty soils and, in some cases, some of the rocky deposits of the older subsoil, take part in massive movements and constitute colluvial formations of numerous landslips. Works made in the southern part of the valley of the stream are, however, plated on river Skawa river ridges. Quaternary occurs in the form of river, dusty and colluvial deposits in the studied area. In the investigated area during geotechnical drilling, intense, shallowly occurring water filtrations were drilled within the organic and cohesive clayey and clayey and sandy soils in the soft plastic state of the valley of the stream without a name and the Skawa valley, as well as few exudations within the clayey silty primeval lands occurring on the slopes of the stream valleys. The depths of this filtration range from 0.2 to 2.6 meters. The amount and intensity of ground water sands occurring in the studied area, as well as the depth of the first groundwater table in the Skawa river valley are strictly dependent on hydrometeorological conditions and will change during periods of increased rainfall, spring thaw and drought.

3.8. Analysis and engineering calculations

Four geotechnical layers were separated in the substrate, the genesis of which was the criterion of separation. These are:

- geotechnical layer I - colluvial formations,
- geotechnical layer II -river land,
- geotechnical layer III-dust,
- geotechnical layer IV - flysch rocks. (see table 1)

Table 1. Parameters characterizing geotechnical layers.

Parameter	Geotechnical layer I	Geotechnical layer II	Geotechnical layer III	Geotechnical layer IV
natural humidity w_n	32%	35%	18%	
bulk density ρ	1,990 g/cm^3	1,935 g/cm^3	2,000 g/cm^3	2,400 g/cm^3
degree of plasticity IL	0,55	0,80	0,35	
internal friction angle ϕu	9,0°	6,0°	12,0°	
cohesion Cu	9,0 kPa	7,0 kPa	30,0 kPa	
soil organic matter SOM		6,8%		
compressive strength				Łi-Rc=1-2 MPa Pc-Rc=20 MPa

Values of internal friction and soil cohesion were determined in the triaxial shear apparatus. A detailed description of the drilled land in individual wells is provided on the hole document sheets. The spatial layout of geotechnical layers is illustrated by geotechnical sections (an exemplary cross-section is shown in Figure 2), and the aggregate results of laboratory studies of soils and rocks are presented in tabular formulas see Table 1.

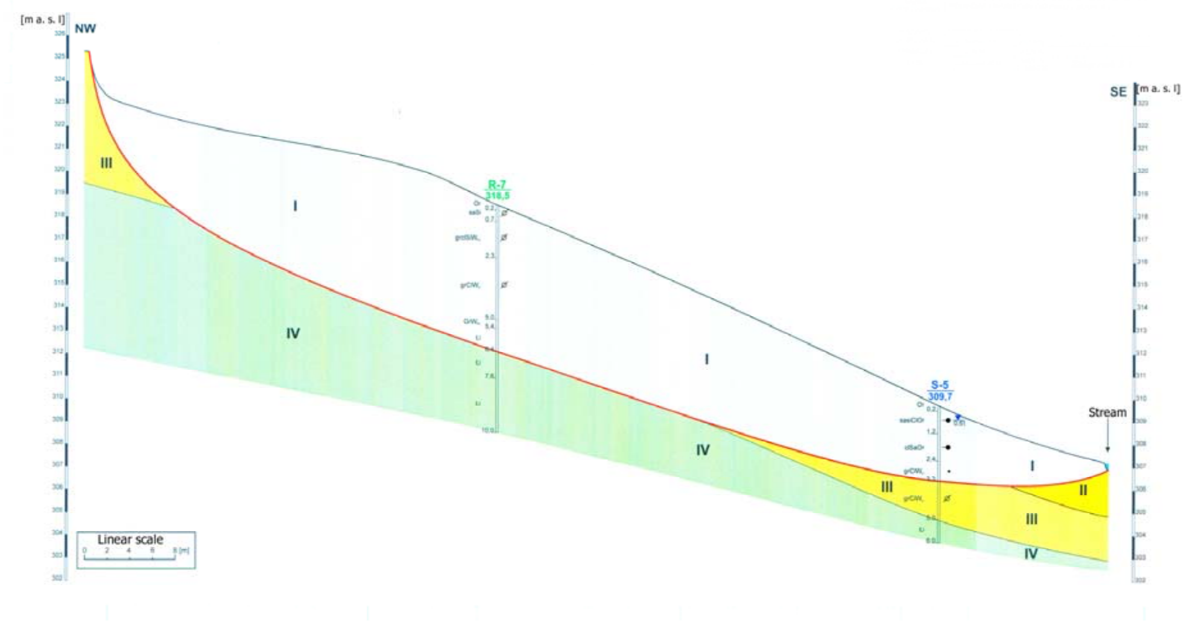

Figure 2. An example geotechnical cross-section

4. Assessment of the scope of field and laboratory tests carried out to determine the geological and engineering conditions, taking into account the geotechnical category of the designed buildings

The recognition made on the basis of mapping the area, made headings, laboratory tests and inclinometer measurements is sufficient to determine the geological and engineering conditions present in the area of the landslide area. The elements of protection planned for future in the entire length of the landslide area within the valley belong to the third geotechnical category due to the occurrence of geodynamic processes.

5. A stabilization project for the landslide area

As part of the protection of the landslide, a linear concrete palisade with a diameter of 80 cm, a height of 8.50-16.50 m (depending on the depth of the bearing soil) is predicted, a spacing of 1.60 m and a total length of 467.28 m. The piles will be topped with a reinforced concrete cap . A steel handrail with a height of 1.10 m will be mounted on the tap. On the face of the palisade, a reinforced concrete coat with a minimum thickness of 15cm is designed. The slope from the palisade towards the valley floor will be covered with stone wedge, 80 cm thick. The lands above the palisade will be drained using drainage pipes with a diameter of 100mm.

In relation to the original security concept, the course of individual pleats has been changed. Their geometry was more adapted to the existing situational and altitude conditions. However, it should be noted that despite the maximum possible shifting of the proposed palisade to higher parts of the slope, in areas of landslides No. 2,3,4,6 and 7 above the barrier, there will still be a risk of displacement activation. This should be kept in mind, especially during earthmoving during construction, and be especially careful. Therefore, all earthworks are suggested to be carried out in dry periods.

6. Calculation of the stability index

On the basis of data contained in geological cross-sections, a landslide analysis was made in the geological-engineering documentation to determine the values of the stability index. The values of the stability index were determined for the original landslide condition (unprotected) in five profiles, yielding 0.86 stability factors; 0.94; 1.07; 1.19 indicating a large and very high probability of a landslide and 1.57 indicating a very low probability of a landslide. With the protection designed, the stability indicators for four landslides have risen to 1.73; 1.83; 1.61 and 1.58, which means that the probability of a landslide is very small.

7. Conducting geodetic monitoring of slope stability.

Site area deformation monitoring is carried out on four points of the reference network and on sixteen benchmarks of the control network with the use of leveling technology. So far, seven measurement series have been carried out in about 1 month periods, on the basis of which no significant surface movements were found. Conducting this monitoring should be continued at least twice a year in order to ensure the safety of the dam's functioning.

8. Summary

The progress of mass movements in the current landslides and the entire section of the Skawa River can be caused or accelerated in the future by cycles related to the rise and fall of the water level in the Świnna Poręba Reservoir during alternating dry and wet periods that will affect the parameters strength of soils and rocks. The flooding of the reservoir in the investigated region will also cause additional infiltration of water into the soil, leading to plasticization of cohesive lands and excessive loading of the valley slopes.

Progressive landslide movements occurring in the area may in future threaten the functioning of the reservoir, especially due to the negative impact of water on the slope stability (deterioration of land parameters and the load on the slopes). For this reason, securing the entire slopes of the stream in the region of landslides and their threatened mass movements of the area is necessary so that they do not adversely affect the functioning of the Świnna Poręba reservoir.

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