

The problem of stabilization of landslides in glaciotectonically disturbed areas. Case study: road engineering structure

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Abstract. The process of the construction of engineering structures situated within glaciotectonically disturbed areas cause the necessity to link engineering operation with knowledge of geological processes. One of the examples of such a structure was the construction of the west bypass of Zielona Góra. The roadworks were connected with the necessity of deep excavations into glaciotectonically disturbed soil structures. This caused intense changes in the soil mass and - as a consequence – loss of slope stability and the construction of landslides. At the construction stage numerous landslides were already active, which additionally increased during intensive road use. In spite of technical stabilization, there was a risk of loss of slope stability, which is a consequence of stresses in soil mass and engineering activity. This article presents the results of the monitoring of the slope stability during intensive road exploitation.

1 Introduction

The problem of the stability of engineering structures is a challenge for designers, contractors and scientists [1, 2, 3]. In engineering practice there are significant differences in the way that engineering structures respond to geological constraints, which mainly depends on the type of engineering structures. The behavior of cubature structures is different from the behavior of linear structures such as road or bridge structures. In the case of flyovers, viaducts and bridges, strong structural elements such as a bridge supporting structure are built above ground level, which directly intensifies geological impacts. Moreover, in the case of large span linear objects, where the structure support areas are located far from one another, the surface deformation of the subsoil has a strong impact on the stability of the main supporting elements.

While designing infrastructure objects such as bridges in particular, it is worth paying attention to two basic aspects: the kinematics of solids and their strength and stability. The best method of protecting a bridge, a viaduct or a flyover is to ensure the free mutual displacement of the construction solids of which the object is built.

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At present, designers can avoid the occurrence of negative effects such as landslides, depressions or phenomena caused by mining, or they can minimize them by using special technical solutions. In this case, it is necessary to take into account a wide range of available technical solutions, including the latest achievements in soil stabilization such as the use of ground reinforcing composite materials and the more and more popular geosynthetics [4, 5].

The construction of engineering structures located on glacitectonically disturbed soils makes it necessary to combine engineering activities with a knowledge of geological processes [6]. The problem becomes more complex when there are additional difficulties caused by the presence of lignite and damage resulting from lignite mining [7, 8].

The glacitectonic disturbances in the region of Zielona Góra have a complex origin, since they were most probably formed by two glaciations: the San River Glaciation 1 and the Oder River Glaciation, and remodeled by later processes. In areas so highly deformed, even a thick network of research drillings does not make it possible to clearly identify the geological structure.

An example of a road object located on glacitectonically disturbed soils and in an area of mining damage is the western bypass of Zielona Góra, located on the DK 27 national road, called the Wilkanowo bypass. The construction of the object involved making deep excavations and building up steep slopes. This caused significant changes in the rock mass, and resulted in the development of numerous landslides. Landslide processes occurred as early as during road construction, and they occurred again a number of times when the road was used.

2 Characteristics of the research area

The latest section of the Zielona Góra bypass, with a length of 4.97 km, called the western bypass or the Wilkanowo bypass (Fig. 1), was put into service on February 27, 2006.

According to the geographical division of Poland by J. Kondracki, this area belongs to the macroregion of the Zielona Góra elevation (315.7) and the mesoregion of the Zielona Góra embankment (315.74). The Zielona Góra embankment is an area of approximately 240 km² and a maximum height of 221 m above sea level, located latitudinally between the Warsaw – Berlin glacial valley in the north and the Głogów – Baruth glacial valley in the south. The Zielona Góra embankment is a glacitectonic elevation with a relative height of about 100 m and a length of about 30 km. It consists of three distinct parts, the highest of which is the central part, where the town of Zielona Góra is located. The DK 27 section analysed in the paper passes through the main area of the embankment.

The construction of the Wilkanowo bypass encountered a number of geological and engineering problems. A 1.3 km section of the road passes through an area damaged by mining, where there are numerous elongated pits left in the nearby shafts of the "Consolidierte Grünberger Gruben" mine after underground brown coal mining at the turn of the 19th and 20th centuries. Moreover, during pre-work, i.e. rescue research excavations, a small settlement (campsite) of the Corded Ware culture was detected, which dated back to 1900 BC. This discovery was regarded as one of the most important archaeological discoveries of 2003 in the Lubusz Voivodship.

Another problem was related to designing a road in an area with glacitectonic disturbances characteristic of the Zielona Góra region, which turned out to be the most serious problem during the construction and use of the road.

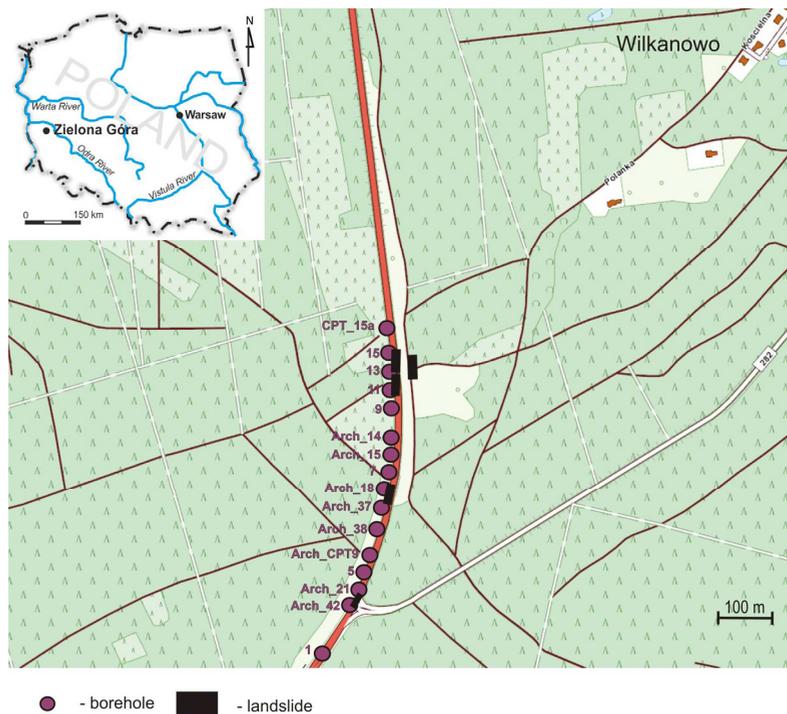


Fig. 1. Site location.

3 Mining damage

The area in the vicinity of the road section described is the place where the first lignite deposit near Zielona Góra was discovered in 1838, which led to the establishment of one of the largest lignite mines in the region of Lubusz (1840 - 1948). Lignite mining in the Consolidierte Grünberger Gruben mine started in the present area of Zielona Góra, and then it systematically moved to the west, towards the villages of Wilkanowo (formerly Wittgenau and Heinrichau) and Słone (Schloin). In the years 1930-1938 the Pohlenz shafts existed in the area through which the road passes. They were 11 shafts of various depths (30-50 m), adapted to highly variable geological conditions [9].

At present, the area over the depleted deposits is covered with wasteland with clearly visible land deformations, and less frequently it is covered with forest. Some of the depressions are filled with water or they are marshes. The underground deposits were mined using the block caving method/the pillar-chamber method, on the spoil tips. The roof collapsed over the chamber almost immediately, causing the appearance of depressions on the surface. Sometimes, mining chambers or transport tunnels that did not collapse and they remained in the ground. The occurrence of land deformations is then postponed. The accidents that occurred several years ago showed that it could happen even after nearly 100 years.

4 Glacitectonic disturbances

The glacitectonic structures found in the area near Zielona Góra, and also those near Wilkanowo, were described by many authors including: Fries [10], Kołodziejczyk [11, 12], Kotowski and Kraiński [13]. They were interpreted on the basis of geological drillings

carried out during exploration for lignite deposits or for construction purposes. That work clearly indicated that the whole of the Zielona Góra embankment should be regarded as a glacitectonically strongly disturbed area, where various continuous deformations (folds, flexures) and non-continuous ones (seismic faults, scales, flocs) are common.

Glacitectonic deformations are connected with the immediate impact of the ice sheet - its movement to the south, the weight and freezing of the ground. The Zielona Góra embankment is one of the areas with the strongest glacitectonic disturbances in Poland. The glacitectonic structures of the Polish Lowland were formed mainly during Glaciation 2 of the San River [14] or Glaciation 2 of the San River and the Glaciation of the Oder River [15, 16], and the later ice sheets might have somewhat remodelled the older structures

While documenting the characteristics of the aggregate deposit present in this gravel pit, 16 drillings were made to a depth of 4.0 to 8.3 m below ground level. The drillings did not reveal the presence of glacitectonic disturbances. It was not until after the access tunnel had been dug and the mining had begun that the area turned out to be glaciectonically disturbed. Among the sandy, raised formations, e.g. in the form of a "chest", moraine clay and silt/mulberry inserts are commonly found, and arched formations are glaciectonically disturbed and covered with a ceiling of flat (undisturbed) deposits developed in the periglacial period. The glaciectonic disturbances occurring in the ceiling part of the deposit resulted from the pile-up effect caused by the ice sheet supporting the older formations.

During the construction of the Wilkanowo bypass, the Geoprojekt company from Poznań prepared documents in 2005 [17], which indicated that the geological structure of the area consisted of Pleistocene sandy-clay sediments of glacial (gQp) and fluvioglacial (fgQp) origin and Tertiary (LLTr) cohesive formations, and that the area under research was characterized by strong glaciectonic disturbances. They were formed as continuous deformations, including anticlines or diapirs elevated over 20 m, as well as numerous discontinuous deformations, such as scales and seismic faults.

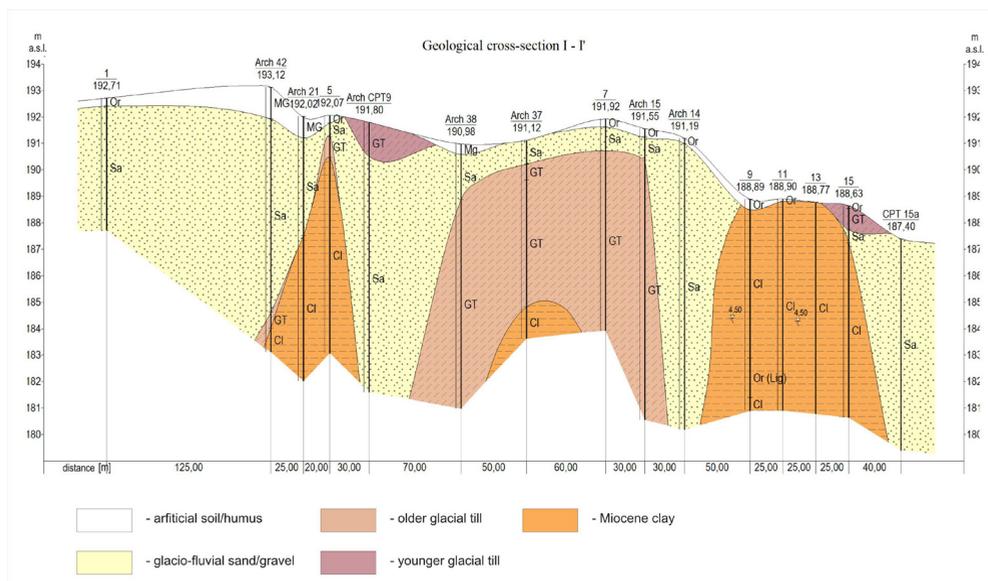


Fig. 2. Geological and engineering cross-section of the Wilkanowo bypass.

In 2014, detailed geological surveys were carried out in the area of the Wilkanowo bypass [18], including: 23 drillings to a depth of 9.0 m below ground level, 20 dynamic penetration tests and 4 cone penetration tests. The authors distinguished as many as 29

geotechnical layers in the section of the road under research, which may indicate the degree of complexity of the geological structure.

The hydrogeological conditions of the area analysed are very complicated and determined by glacitectonic disturbances. Underground water was found in only 4 archival drillings, mainly in the form of oozes. The geological structure of the area was presented in a geological and engineering cross-section (Fig. 2).

5 Landslide processes

Despite the known, complicated soil conditions, the Wilkanowo bypass was designed and built with high (up to 8.0 m) and very steep slopes (up to 45°). As early as during the road excavations, strong erosion processes caused by the migration of rainwater into the rock mass and glacitectonic deformations were revealed (Photo 1).

The cohesive soils were much brecciated, which indicated intense glacitectonic deformations in this area and changes in soil stresses caused by multiple ice sheet pressure, and also by relieving the soil after the excavations. This phenomenon was particularly intensified in the areas where hydrated sands slipped over the clay substrate.

After the road was put into service, there were surface movements almost everywhere. On the slopes and escarpments there were different types of displacements of soil masses, including: debris flows, earthflows, rockfalls, pulls, slides and landslides.



Photo 1. Glacitectonic structures revealed during the road excavations (U. Kołodziejczyk, 2005).

The specificity of landslides lies in the fact that they are not only caused by local water and soil conditions, but also as often as this - by common technical errors, such as too steep an inclination of the slopes, too much slope undercutting, inadequate construction technology or insufficient dehydration [19]. The risk of activating mass movements becomes greater if the angle of the slope in relation to the angle of the natural slope increases, soil integrity is reduced as a result of relieving part of the slope by removing the overburden, soil erosion increases due to exposing the soil, which increases the speed of water runoff and changes the water and ground conditions. Landslide threats depend not only on land configuration, but also on geological structure. Low values of the angle of internal friction of clay soils, including clays, make it difficult to maintain good slope stability even with an inclination of 1:3. In the abovementioned cases, all kinds of earthflows, rockfalls and landslides occur easily [5].

Self-induced movements of soil masses on slopes and escarpments, commonly referred to as landslides, are considered to be one of the important geological processes in dynamic geology. They most frequently occur on the slopes of river valleys, sea coasts and on

mountain slopes, but they can also occur as a result of deep excavations, which was the case during the construction of the Wilkanowo bypass. The loss of stability of slopes and escarpments, which leads to landslides, occurred in this case as a result of exceeding the shear strength of the soil along the slip surface.

In the case of the Wilkanowo bypass, several factors undoubtedly occurred simultaneously, as is the case with any construction failure. However, a number of them could have been predicted and taken into account as early as at the design stage, which would certainly have prevented the subsequent failures. Meanwhile, the construction of the bypass proved to be very difficult [20, 21]. Due to the occurrence of numerous landslides and strong erosion of the slopes, a number of additional measures were necessary, including construction of new drains and reformation of the slopes, this time already properly compacted. In addition, the surface of the slopes and the escarpments was stabilized in order to prevent further erosion. The surface of the slopes was also strengthened with geosynthetic mats and meshes or with perforated concrete slabs, and with a cover of vegetation by sowing appropriate plant species on the slopes. Despite the enormous amount of effort and resources, those measures were not always successful (Photo 3).

The use of the road caused further landslides. Soil thixotropy and the weight of heavy vehicles led to further landslide movements. Retaining walls and gabions were used for temporary protection, as well as slope and surface drains.

However, such methods as soil exchange and changing hill geometry were not used, despite the lack of objections from the owners of the nearby lands (the Regional Directorate of the State Forests in Zielona Góra) to the purchase of the land adjacent to the road strip. The results were soon to be seen.

Subsequent numerous landslides appeared on the Wilkanowo bypass in 2006 and 2007. In 2008, characteristic humps appeared across the road - probably consistent with the course of the axes of the anticline glacitectonic elevations.

In the years 2011-2012, further modernization work was carried out, including modernization of the slopes and removal of the abovementioned humps. During that work numerous water channels appeared. In 2013 the slope strengthened in 2006 collapsed again (Photo 2).



Photo 2. Damage of the retaining wall structure built in 2006 (U. Kołodziejczyk, 2013).

In 2017, thorough work was done to secure the landslides on the Wilkanowo bypass [22]. The work included: removing the soil from the area of the existing slides and landslides, making steps in the slopes, restoring the damaged sections of the retaining structures with gabions, rebuilding or securing the existing drainage systems of the road

excavation slope, laying out separation and filtration geotextiles, rebuilding the slope with crushed aggregate - crushed stone and adding an external 0.3 m thick layer of the slope façade from crushed aggregate. The results of the work can be seen today (Photo 3). Time will tell how effective they are.



Photo 3. View of reconstructed retaining wall and the slope, damaged in 2013 (M. Hudak, 2017).

6 Conclusions

The location of landslides on the Wilkanow bypass could have been predicted based on geological surveys, let alone after the construction excavations. Because of the type of geological structure that was found during geological surveys, soil conditions in this area should have been regarded as complicated, which was indicated by the presence of glacitectonic processes, mining damage and landslide processes.

The danger of further landslides still exists, which is a sign of struggle between glacitectonic structures and human geoengineering activities. During the construction of slopes in glacitectonically disturbed formations, geological surveys should be carried out close to one another, in addition not only in the axis of the road, but also in the wide belt stretching on both sides. Only such a geological diagnosis will make it possible to properly identify the layer system and predict geological and engineering processes.

A frequent cause of landslides is the impact of water. For this reason, it is necessary to include this factor in all solutions related to slope drainage and water regulation both in the area of a potential landslide and adjacent areas. Therefore, it is necessary to take action aimed at draining the water outside the landslide area and filling up the resulting gaps with impermeable material.

Since the problem addressed in the paper is important both in the economic and scientific aspects, the authors are of the opinion that it is necessary to increase the awareness of designers dealing with objects to be constructed in geologically varied areas where there is a high risk that the phenomena described in the paper might occur.

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