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DESCRIPTION AND EVALUATION OF THE LANDSLIDE HAZARD. A CASE STUDY IN A LANDSLIDE IN RADZISZOW

1. Introduction

A series of records concerning the issue of mass movements were accumulated at the beginning of the twenty-first century [8–11, 13]. They were mainly caused by catastrophic precipitation and floods, which triggered the landslide processes and resulted in monetary losses estimated in hundreds of millions of zloty.

In the first half of 2010, nature's fury struck again, as intense and sustained rainfall caused a series of geodynamic processes in the area of Skawina and its urban-rural commune. In the aftermath, this re-activated old landslides and gave rise to new ones. It has been estimated that there are currently about 275 various types of landslide movements, more or less active, registered in the area of the urban-rural commune of Skawina (last updated, the end of 2011) [7]. One of the largest landslides, which was almost 100 ha, in Radziszow, is located 3.5 km south from Skawina. It is a piece of land where about 30 dwelling houses and more than 15 utility buildings stretch. Preliminary research, conducted in the summer of 2011, led to determining the causes and the methods of protecting and monitoring the landslide movements [1].

2. General characteristics of the study area

The landslide area is located in the north-western part of Radziszow, in the Malopolskie province, in the urban-rural commune of Skawina, about 3.5 km south of the centre of Skawina. It is one of 275 landslides registered in the area of Skawina and its urban-rural commune [7], and it stretches out for 100 ha. The first contemporary notes about the landslide in

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Radziszow were recorded in the 1980s [6] and it was marked in the attachments to explanatory notes for a detailed geological map — Myslenice sheet (1997) [4]. In May 2010, as a consequence of intense and sustained precipitation, the landslide movements in the area renewed, which created cracks in the ground, water seeps and surface soil movements in the northern and middle part of the landslide.

In terms of morphology, the study area is on a slope of the local mountain Wyczyszczek, which is inclined westward at the angle of about 8° and north-westward at about 5,5°. It has been deformed by geodynamic processes which have been occurring for many hundreds of years and is characterised by specific undulation. The height coordinates of the area range from about 215.0 m to about 344.3 m asl at Wyczyszczek Mountain culmination. The height coordinates of the landslide range from about 219.0 m to 338.0 m asl. In its lower part, the scarp is

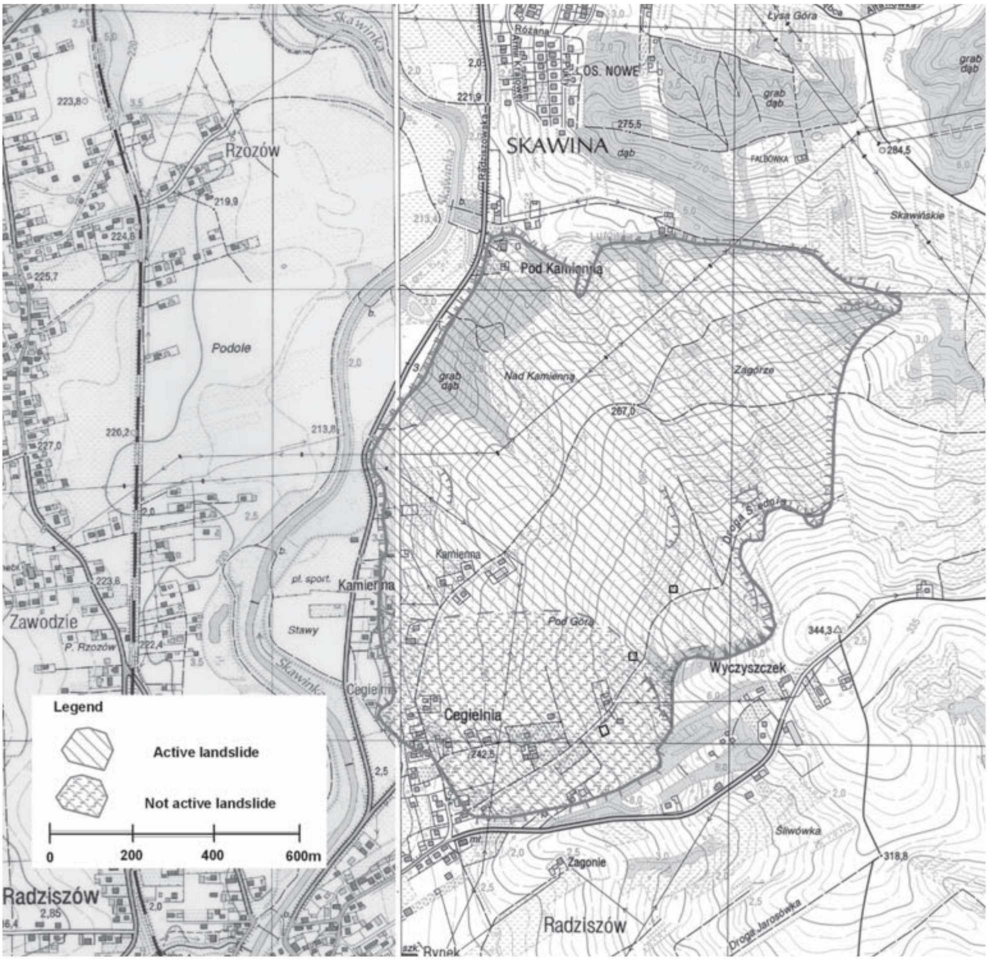

Fig. 1. The location of the landslide in RadziszowM-34-76-B-a-4 (Bukow), M-34-76-B-a-3 (Radziszow) [1]

incline at a considerable angle, which is the reason for the height difference of approximately 2 to 5 metres (Fig. 1.) The study area on the site planning is marked as a terrain for: a single--family and homestead building development (MNR), agricultural area (R), green wastelands areas (ZR) and, a small part, belongs to woodlands (ZL) [14]. The piece of land was heavily exploited as an agricultural area until the 1990s. Currently, it is idle land, covered with grass, bushes and trees. There are about 30 dwelling houses and more than 15 utility buildings in the study area. It is bordered by the valley of the Skawinka river from the west and by Lutowka Creek, which is the right-bank tributary of Skawinka. Its southern side, is adjacent to a valley where a local road from Radziszow to Bukow runs through. On its eastern side, it adjoins another landslide form. Hydrographically, it belongs to the Vistula basin, whose bed is about 5 km away north-westward. The surface runoff flows in a western and north-western direction.

The study area lies in the Outer (Flysch) Carpathians. The slope shape of the land is a reflection of its geological structure. It belongs to the Wielickie Foothill [3]. It constitutes a fragment of the flysch formations of Subsilesian and Silesian Nappe [4]. The oldest bedrock is formed of the Early Cretaceous layers of medium- and coarse-grained Grodzisk sandstones interbedded with Cieszyn and Wierzbica shale. The Cieszyn Shale is dark grey, almost black, marly shale. The Wierzbica Shale is represented by dark grey, slightly limy or siliceous shale and thin-bedded, fine-grained, brittle and limy sandstones. There might be some pieces of gaize is mixed with shale and marly beds. A considerable part of the area is covered with the Palaeogene spotted red and green argillaceous schist as well as the Neogene clays of the Skawina layers. The entire area is coated with Pleistocene formations of the northern Poland glaciations represented by residual and alluvial clays and loess and loess-like formations in the shape of powdered clays in the lower layers mixed with the chippings of the older bedrock. The presence of underground waters in the study area is connected with the occurrence of the shallow quaternary waters, which take shape of a seepage in the layer of powdered clays, and fissure waters in the sediments of a flysch series. The waters in the flysch are mainly interstitial waters. They are in the form of discontinuous levels. Water-bearing layers are topped up with rainwater, which is filtered through layers of detritus or rock outcrop [1, 2, 5].

3. Landslide in Radziszow

The landslide in Radziszow is a large and complex landslip, which occupies the whole length of the slope from its ridge to foot. It is localized on the western and north-western slope of the hill and it is almost 100ha in area. Its starting point is a distinct main scarp, which is about 8 m high and inclined at an angle of 450, (Fig. 2). Downwards, the scarp is distinguished with recurrent slopes, namely, Wyczyszczek, but it is difficult to localize due to thick flora, such as, trees, bushes. There is a landslide ditch, below the scarp, which is filled with water (Fig. 3), originating from the main scarp's water seepages and precipitation. The inter--landslide relief is diversified (Fig. 4). There are numerous humps, step-like and flattening forms, and hollows, which are sometimes filled with water (marshes, bog spring) (Fig. 5). Their biggest centre was observed in the northern part.

Fig. 2. The main scarp of the landslide.
(Photo by A. Borecka)

Fig. 3. The landslide ditch filled with water below the main scarp of the landslide.
(Photo by A. Borecka)

Fig. 4. A view over the central part of the landslide with characteristic undulating surface, such as, step-like forms, hollows.
(Photo by A. Borecka)

Fig. 5. Bog springs in the area of the landslide.
(Photo by A. Borecka)

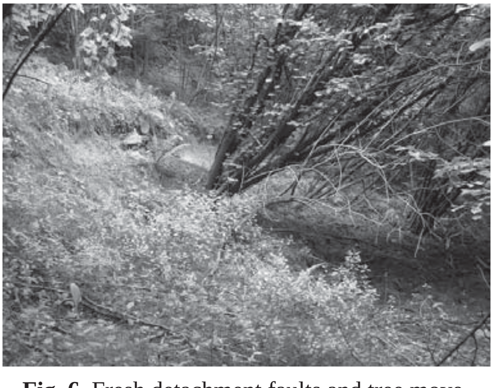

Fig. 6. Fresh detachment faults and tree movements in the crown zone in its northern part.
(Photo by A. Borecka)

Fig. 7. Water seeps from the crown of the landslide in its western part near Skawinska street.
(Photo by A. Borecka)

Fig. 8. The crown of the landslide and its deformation and soil ripples, with characteristic steps, hollows and interstices, which are the result of the colluvial masses movement in the western part of the landslide near Skawinska street. (Photo by A. Borecka)

Fig. 9. The crown of the landslide with fresh detachment faults in its northern part, near Lutowka water-course, which shows that there is a very dynamic slip of colluvial masses in the area. There are visible water seepages from the crown of the landslide. (Photo by A. Borecka)

At present, the area is wasteland, covered with trees, bushes, grass and very often hydrophilic plants, such as, horsetails. The crown of the landslide coincides with the fluvial terrace of the Skawinka watercourse to the west and with the surface watercourse of Lutowka Creek to the north. Its height is varied and ranges from 0,5 m to even 8 m. There are fresh cracks, detachment faults and water leaks from the crown of the landslide visible in its northern and west-northern part (Fig. 6–10). The landslide is divided into two parts, active and inactive (Fig. 1). The active part constitutes about 60–70% of its area.

Fig. 10. The crown of the landslide with fresh detachment faults in its northern part, near Lutowka water-course. Fallen tress prove that there is a very dynamic slip of colluvial masses in the area. (Photo by A. Borecka)

Fig. 11. Cracked concrete pavement near a utility building, Skawinska street, which is a consequence of the landslide's crown pressing forward. (Photo by A. Borecka)

As a result of the intense rainfall in May 2010, numerous cracks occurred in soil and its movements in the northern and the middle part of the landslide, where dwelling houses and utility buildings are located (Kamienna street and the slope below and Pod Gora street in its upper part). There is current observation of the cracks on the buildings and its foundations, cracked concrete pavements surrounding the buildings, damaged property fencing and tilted pylons with taut wires (Fig. 11–15). It shows the effect of the long-term activity of the landslide, chiefly, a creep.

Fig. 12. Cracked concrete pavement near a utility building, Kamienna street, which is a consequence of the colluvial masses movement. (Photo by A. Borecka)

Fig. 13. Cracked walls a utility building, Kamienna street, which is a consequence of the colluvial masses movement. (Photo by A. Borecka)

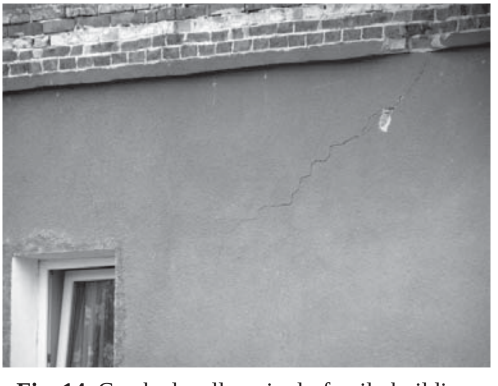

Fig. 14. Cracked walls a single-family building, Kamienna street, which is a consequence of the colluvial masses movement. (Photo by A. Borecka)

Fig. 15. Tilted pylons near Kamienna street, which is a consequence of the colluvial masses movement. (Photo by A. Borecka)

The landslide can be classified as deep, as the surface area of its slide in the middle part exceeds 10 metres. The slide probably occurs in two zones. The first is near the surface at a depth of 2–6 m, where looss formations and bedrock of Neogene clays meet, which take on the nature of a translational slide and creep. The second one is deeper, in the area of the flysch formations [1, 2]. The geological structure of the landslide, particularly, the occurrence of the thrust zone and soils of various parameters, namely, loess (silts, loams), clay formations, spotted shale and layers of sandstones and clay in the bedrock, creates favourable conditions for its expansion. Surface water movement in the upper part of the slope were changed as a result of construction work, which now creates a hazard of flooding for the lower-lying buildings. The occurrence of leaky local water pipes in the substrate causes continuous saturation of the soil with water and may be one of the factors which trigger the reactivation of landslide movements. Long-term intense rainfall and the spring thaw may accelerate the landslide processes. Recurring landslide activation will pose a threat to people and infrastructure near the area of the landslide.

4. Landslide mitigation and monitoring

The landslide may be difficult to stabilize due to its surface area. The cost of protective work may also be extremely high. Therefore, the possibility of the stabilization of the landslide along its whole length must be excluded. However, it should be pointed out that there are several dozen dwelling houses (more than 30) and a dozen or so utility buildings localized in the area of the landslide. The majority of protective work should therefore be conducted in the inactive zone, directly above it in the area of the main scarp and also in the area of dwelling and farm buildings. The top priority of the protective measures is to drain the study area. A system of surface and underground drainage should be set up to absorb maximum amounts of precipitation and thaw waters then to redirect them away from the area of the landslide hazard. Surface drainage is recommended, namely, roadside ditches and culverts, which should reduce the saturation ratio of the substrate. The surface water relations in the upper part of the landslide were changed due to construction work, which has caused the inundation of the lower-lying buildings. Therefore it is vital to restore the original runoff of the surface waters. It will be possible to absorb and redirect infiltration waters away from the area of the landslide hazard using underground drainage. Other potential protective measures are conditioned by a detailed identification.

Additionally, the local water intakes (local water supply system) should be removed or secured, as they may be another source of irrigating the substrate. In most cases, the pipes are corroded or broken by the previous landslide movements, and more importantly, they may pose a threat of bacteriological contamination for the inhabitants due to farm waste polluting the drinking water (septic tanks).

Water-sewage management should be addressed in the area of the landslide by means of removing leaky septic tanks and replacing them with a sewage system (for example, using elastic and deformable elements) or sealing them.

It would be beneficial to impose a ban on building home sewage treatment systems, where a water channelling system would be based on a leach drain, introduce a ban on discharging waters deep into the substrate and use, if possible, a closed-loop wastewater system, which would redirect waters away from the landslide area.

Building a storm drain is recommended (using elastic, deformable elements) or channelling storm waters through a system of surface drainage taking it away from the landslide.

An essential step towards the more precise identification and more effective measures of preventing the landslide movements will be carried out by introducing a system of surface and in-depth monitoring:

- geodetic monitoring — by means of installing benchmarks on the chosen buildings and transmission poles to determine the pace and directions of the most intense movements of colluvium,
- in-depth monitoring — which will contribute to the identification of the ground-water conditions of the landslide (geological-engineering documentation). Employing inclinometers and piezometres in the axis of the landslide which will make possible to research the in-depth dynamics of the landslide and determine the size and depth of the movements.

Monitoring should also be used as a kind of an alarm for the people living in the landslide area.

The area of active landslide and several-dozen-metres surrounding it should be excluded from the area development plan. In the future, it will be possible to erect buildings in the landslide area only in its inactive zone. But, it applies only to light timber buildings, after conducting detailed research and geological-engineering documentation, not expert evaluation, as often happens, (according to the act of Geological and Mining Law, including the third geotechnical category, which includes structures built on complicated soil conditions [12]) and employing an adequate water-waste treatment system.

It should also be pointed out that there is a considerable hazard of damage to buildings in the active zone of the landslide during successive landslide movements. In the case of their occurrence, which will result in cracks and damage to the buildings, it will be necessary to relocate the inhabitants and move all the transmission poles away from the active zone of the landslide.

5. Summary

Currently, it has been estimated that there are about 275 various types of landslide movements, more or less active, registered in the area of urban-rural commune of Skawina (last updated, the end of 2011). The largest landslide in Radziszow is almost 100 ha in area. It was classified as a partly active landslide, where more than 30 dwelling houses and more than 15 utility buildings are located. Numerous characteristic landslide formations were recorded in the study area, such as cracks, humps, step-like flattening forms, and hollows, which were sometimes filled with water. Cracks on buildings and foundations, fractured concrete and pavements surrounding the buildings, damaged property fencing and tilted pylons with taut wires are an effect of the long-term activity of the landslide. At present, the landslide does not tend to extend up the slope. However, in the future, landslide movements may spread above the main scarp and loose, often saturated, colluvial material may be subject to further mass movements. The landslide is difficult to stabilize due to its size and extremely expensive to conduct protective work, on account of which, it is impossible to stabilize its whole length. Yet, it is crucial to introduce a system of surface and in-depth monitoring, which will make it possible to determine the pace and directions of the most intense movements of the colluvium, research the in-depth dynamics of the landslide and establish the size and depth of the movements.

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