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The influence of foundation for the initiation and growth of the landslidein the Carpathian flysch

Wpływ warunków posadowienia na inicjację i rozwój strefy osuwiskowej we fliszu karpackim

Abstract

The southern part of Poland is mostly covered by Carpathian mountains. Carpathian Flysch is especially predisposed for the landslides type of the subsoil. Around 98% of all occurring in the country landslides are located in Carpathians. Many of them became active in May 2010, when periodically dormant landslides and new landslide were activated after intensive rainfall. In addition to the main causes of landslides such as rainwater and its infiltration into the ground layers also the Carpathian Flysch tectonic construction (rock layers collapsing in one direction, with numerous jumps and discontinuity) and some anthropogenic influences (loading, slopes undercutting, improper dehydration, etc.) are typical triggering factors. Landslide activity contributes not only to a significant progress of the relief to which occur, but it also carries devastating consequences for the population living nearby. Landslides are a natural threat for economic activities and people's lives. They are the cause of the damage not only residential buildings but also road and railways and other infrastructure. The landslide analysed here is located in Tymbark, Limanowa district. This article discusses the influence of the building foundation for initiation and growth of the landslide zone in the Carpathian Flysch. Two types of foundations are analysed – base plate foundation and a continuous footing. In both cases, there is a high risk to occur slip zones (FoS < 1.5). Base plate turns out to be more favorable foundation in this subgrade conditions. Although the displacements are relatively larger than in the other case, slip zone is located quite shallow. In the case of the continuous footing, landslide may form deeper reaching the bedrock.

Keywords: landslides, Carpathian flysh, numerical model, stability analysis, MIDAS

Streszczenie

Szczególnie predysponowanym obszarem na terenie Polski do powstawania osuwisk są Karpaty fliszowe. Właśnie na tym obszarze zlokalizowanych jest ok 95% wszystkich osuwisk występujących w kraju. Wzmożona aktywizacja osuwisk na tym terenie miała miejsce w maju 2010 roku, kiedy po intensywnych opadach atmosferycznych doszło do aktywizacji wielu okresowo nieaktywnych osuwisk oraz do inicjacji nowych stref osuwiskowych. Oprócz głównej przyczyny powstawania osuwisk jaką jest woda opadowa oraz jej infiltracją wgłąb warstw gruntowych wyróżnić możemy również budowę tektoniczną Karpat fliszowych (warstwy skalne zapadające się w jednym kierunku, liczne uskoki i nieciągłości) oraz wpływy antropogeniczne (obciążenie, podcinanie skarp, błędne odwodnienie itp). Aktywność osuwisk przyczynia się nie tylko do znacznego rozwoju rzeźby terenu w jakim występują, ale również niesie za sobą katastrofalne skutki dla ludności zamieszkującej pobliskie tereny. Osuwiska są naturalnym zagrożeniem dla działalności gospodarczej oraz życia ludzi. Są przyczyną uszkodzeń nie tylko budynków mieszkalnych ale również m.in. elementów infrastruktury drogowej i kolejowej. Analizowane osuwisko zlokalizowane jest w Tymbarku, w powiecie limanowskim. W artykule omówiono wpływ warunków posadowienia na inicjację i rozwój strefy osuwiskowej we fliszu karpackim. Przeanalizowano dwa przypadki posadowienia obiektu budowlanego – posadowienie na płycie fundamentowej oraz na ławach fundamentowych. W obu przypadkach istnieje duże ryzyko wystąpienia stref poślizgu (FoS < 1,5). Korzystniejszym warunkiem posadowienia okazuje się płyta fundamentowa. Pomimo, że występujące przemieszczenia są stosunkowo większe od przemieszczeń w przypadku posadowienia na ławach fundamentowych mamy do czynienia ze strefą osuwiskową zlokalizowaną dość płytko. W przypadku posadowienia na ławach fundamentowych może dojść do wystąpienia głębokiego, strukturalnego osuwiska sięgającego warstw skalnych.

Słowa kluczowe: osuwiska, flisz karpacki, model numeryczny, analiza stateczności, MIDAS

1. Introduction

Carpathians, due to the complicated geological structure, is an area in Poland where the most active landslide zones are located. It is estimated that in the Carpathians, with the surface just 6% of the country, approximately 95% of all landslides occurring in Poland is located [4]. Alternating stacked layers of permeable sandstone and poorly permeable shales, claystone's and marls, as well as the presence of steep slopes, increase the risk of landslides. Many landslides were triggered in May and June 2010. A number of buildings, including residential houses, industrial facilities, road infrastructure and railways were destroyed as a result of terential rainfall.

2. Significant causes of mass movements

One of the main factors influencing the activity of mass movements is undoubtedly detrimental effects of water flow. The occurrence of landslides in the area of the Carpathian Flysch is associated with complicated meteorological and hydrological conditions. Violent rain, spring thaw and long, wet and cold periods lasting several months are particularly dangerous. Water, which is then stored in weathered caverns and bedrock, contributes to the formation of a deep structural landslides [1]. Therefore, infiltration of rainwater is considered as the main cause of deterioration of the strength properties of soil and initialization of landslide movements. The slope stability is also influenced by factors such as frost and thawing of soil, undercutting slopes (eg. abrasion), shock (eg. earthquake), as well as the propagation of cracks and crevices, suffosion or weathering.

One should also pay attention to the anthropogenic factors. Direct and indirect human activities are equally important factors in the analysis of mass movements, which is often ignored. Load on steep slopes by constructing buildings and undercutting the slopes by conducted operational and engineering works are the most dangerous factors. The influence of dynamic loading is also significant. It can be triggered by e.g. work heavy machinery or blasting.

Complicated structure of the Carpathian Flysch has also undoubtedly the influence on the occurrence of landslides. Rock-layers collapsing at the same angle in one direction and the discontinuities of any size favour the formation of the gravitational mass movements. As a measure of stability in view of the equilibrium limit is considered the general Factor of Safety – FoS. The value of FoS is calculated as the ratio of the maximum shear strength of the soil to the strength guaranteeing the balance of the slope.

3. Landslide in Tymbark

3.1. Location

The landslide analysed here has its SOPO (System Protection Against Landslides) number (8358) and it is located in the north-west part of Tymbark (Fig. 1). The Łososina river is flows on the west side of the landslide and there is a local road in the southern part. Several residential, commercial and service buildings are constructed in the vicinity of the landslide.

The landslide covers an area of about 4.5 ha. The dimensions are about 120 m in length and about 360 m in width at its base. The inclination of the slope varies from 10° to 18° in a north-western direction. The central part of the landslide is still active. The south-west part is threatened by the further soil movements.

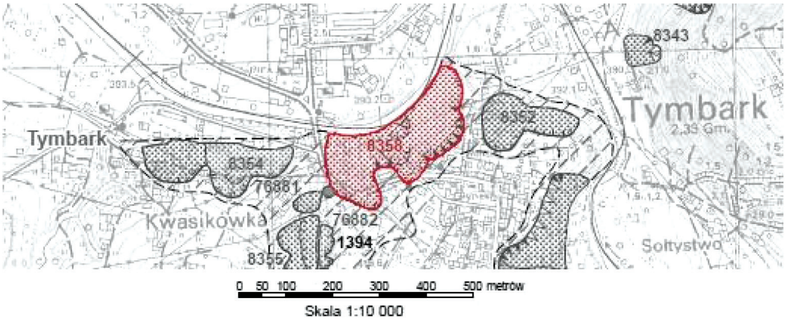

Fig. 1. Tymbark landslide location [5]

3.2. Geological structure

There are tertiary and quaternary layers here. The subsoil consists of eocene shale flysch, which is mainly slates flysch, interbedded with fine-grained sandstones and clay stones (Fig. 2).

Fig. 2. The Carpathian Flysch strata sample [2]

About 20% up to 30% of flysch layers contains the sandstones. There are quaternary, weathered layers of mainly silty clays with veined sandstones and clay stones. There are also the colluvium layers as clays, rubbles, clay stones, silty clays and clays in the bedrock. Alluvia such as pebbles, clays, and sandstones occur in the valley of the Łososina river [3].

4. Tymbark landslide stability analysis

4.1. Landslide modeling

The Tymbark landslide has been modeled using Finite Element Method (FEM) package MIDAS GTS NX (Figs. 3–4). The total number of nodes in the FEM model reached 87 904, while the number of elements is equal to 86 838. Table 1 summarizes the material characteristics of each layer of geotechnical model.

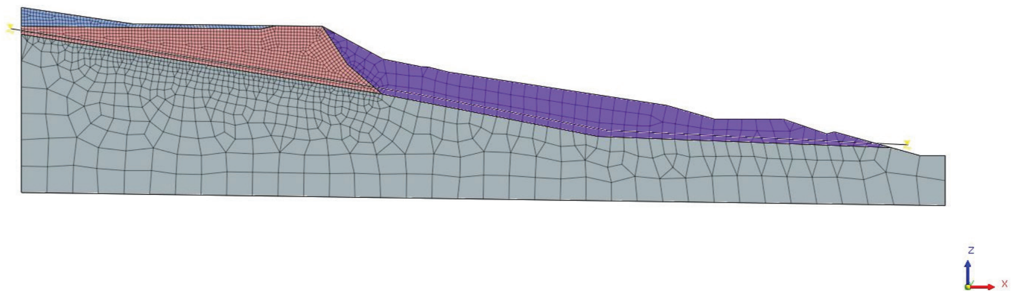

Fig. 3. Computer model of the landslide – 2D view of the mesh and soil layering. Water table level is also visible

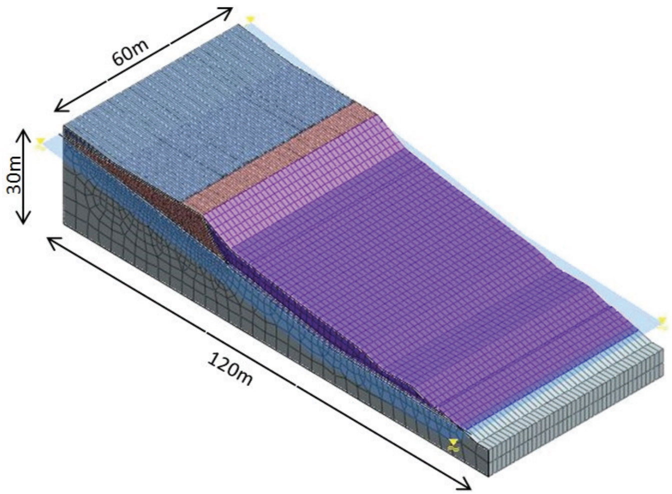

Fig. 4. Computer model of the landslide – 3D view of the mesh and soil layering and water table

Table 1. Geotechnical parameters of the layers in a calculation model

Marking	Soil symbol	Material model	Layer symbol	Poisson's ratio [–]	Water content [%]	Volumetric density [t/m³]	Cohesion [kPa]	Internal friction angle [ ]	Young modulus [kPa]
(blue)	nN	Mohr-Coulomb	**N**	0.2	16.2	2.00	10	11	25 000
(pink)	G	Mohr-Coulomb	**Ia**	0.2	18.1	2.08	10	11	40 000
(purple)	Gp	Mohr-Coulomb	**Ib**	0.2	14.5	2.25	7	10	40 000
(grey)	Iłk/PC	Mohr-Coulomb	**IV**	0.2	13.8	2.35	85	10	40 000

4.2. Loading

The slope stability is performed using the shear strength reduction method (SRM). Such a method of analysis is versatile and popular. The soil is burdened by the stress caused by the building structure located above. The existing building is 20 m in width and 40 m in length. Two cases of building foundation are considered. The first assumed the base plate foundation (Fig. 5a). It allows locate buildings of different types and in different soil conditions. The main advantage of the base plate is the ease and speed of their accomplishment. The object founded on the base plate passes self weight on the subsoil in a uniformly distributed manner. The stress acting on the ground takes the same value on the entire surface of the foundation. Stress value due to the dead weight and permanent loading is assumed equal to 28.7 kPa for the purpose of the slope stability analysis. The second case assumed the implementation of the continuous footing with a width of 100 cm for the same loading of building as in the first case (Fig. 5b). In this case, the weight of the building is transferred to the subsoil only over the width of the foundation. It has been estimated that the loading of the building is equal to 287 kN/m.

In both cases, the load is applied at a depth of the frost penetration i.e. 1.2 m below the ground level.

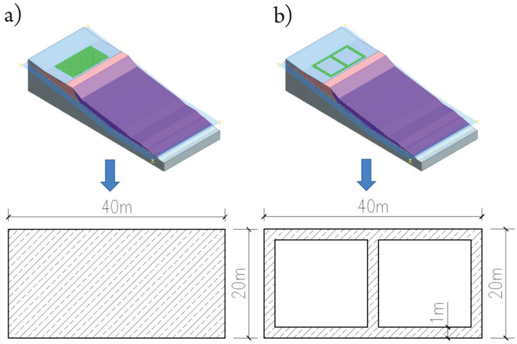

Fig. 5. Foundation: a) on the base plate, b) on the continuous footing

5. Analysis results

The aim of the calculations is to determine the maximum displacement of the slope and the location of the possible slip surface. There are also designated the maximum shear strains and maximum shear stresses of groundwater layers. Based on the obtained results, the difference between the influence of foundation on the base plate and foundation on the continuous footing has been shown. Factors of stability are also determined for analysed cases.

The minimum value of FoS based on the finite element method, using geometry of the landslide, boundary conditions and loading is determined applying the shear strength reduction method (SSR). Calculations are performed on the basis of reducing the internal friction angle and cohesion until the lack of convergence. FoS is determined at the time of loss the convergence of the calculation.

Foundations on the base plate – FoS = 1.3

The maximum displacement of the slope in both cases is approximately equal to 1.5 m (Figs. 6, 7, 10, 11). The most vulnerable to landslide movements in case where the building is founded on the base plate are shallow layers of sandy clays with crushed sandstones and shales around the building. Also in these layers the slip surface is located. In the rest of the slope, the displacement decreases to zero. These may be confirmed by the maps of maximum shear strains (Fig. 8) and maximum shear stress (Fig. 9).

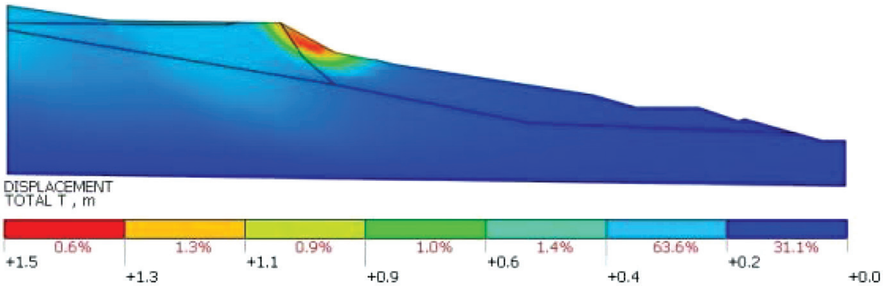

Fig. 6. Total displacement [m]

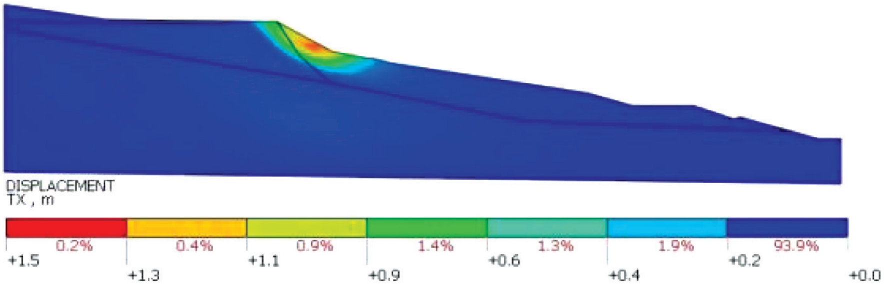

Fig. 7. Horizontal displacement [m]

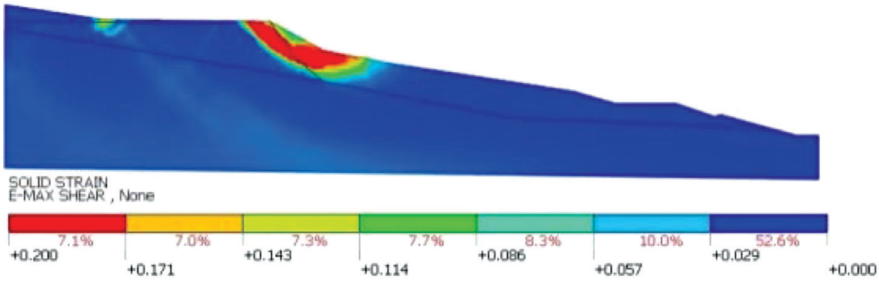

Fig. 8. Maximum shear strains [–]

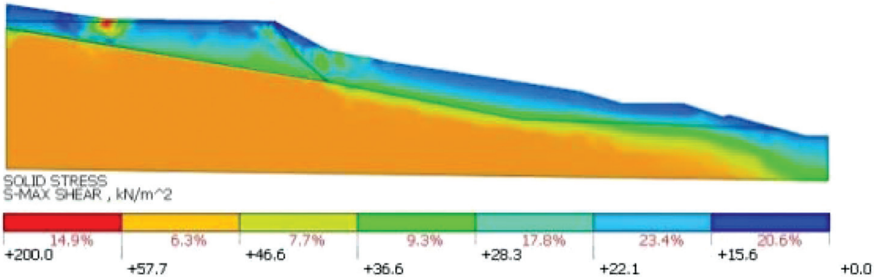

Fig. 9. Maximum shear stress [kN/m^2]

Foundations on the continuous footing – FoS = 1.1

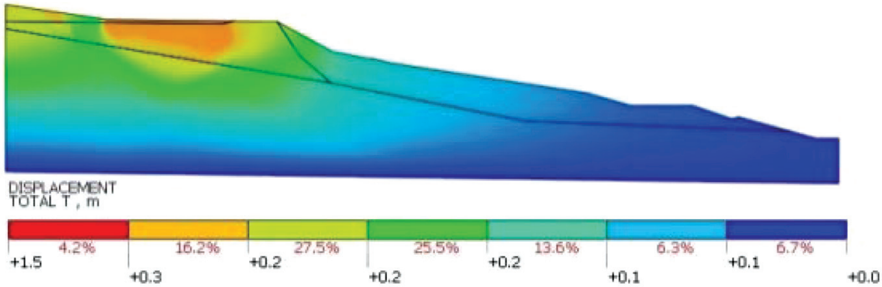

Fig. 10. Total displacement [m]

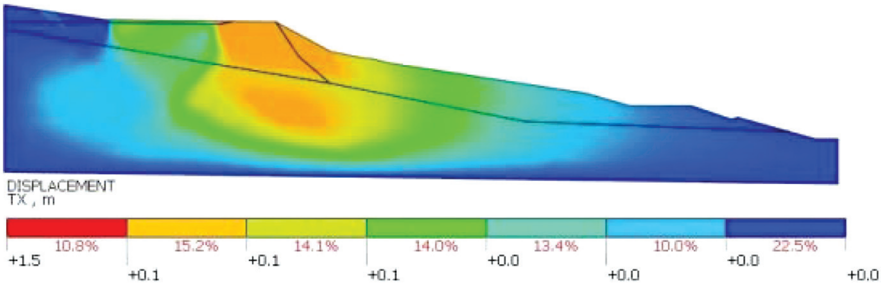

Fig. 11. Horizontal displacement [m]

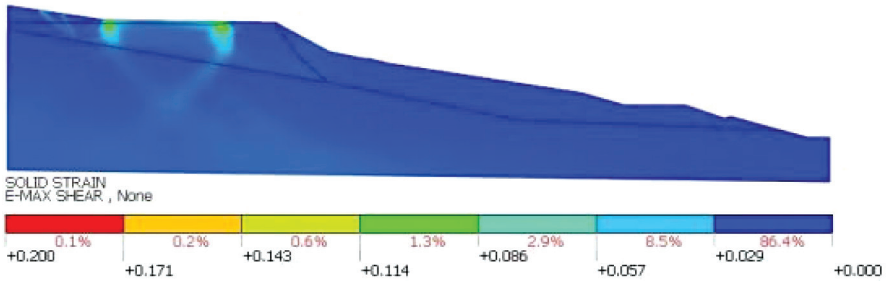

Fig. 12. Maximum shear strains [–]

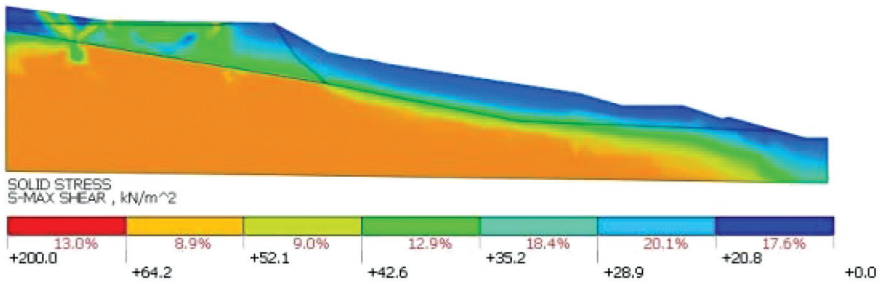

Fig. 13. Maximum shear stress [kN/m^2]

In case of the building founded on the continuous footing the maps of maximum shear strains (Fig. 12) and maximum shear stress (Fig. 13) show that all of the soil layers are at risk of landslide movements. Slip surface is located in the deeper layers of sandstone interbedded with shale.

6. Summary

The analysis of the results clearly shows that losing stability on the test landslide is very probable, regardless of the choice of the foundation method. In the first case (foundation on the base plate) FoS = 1.3. In the second case (foundation on the continuous footings) FoS = 1.1. Wysokiński [8] assumes that the occurrence of the landslide is likely if 1.0 <FoS < 1.3. Kłosiński and Lesniewski [6] relate more strictly to the built-up slopes. They built-up slope deemed stable if 1.33 < FoS < 1.43. The slope that was analysed here does not meet any of the above mentioned criteria and cannot be considered as stable.

Conclusive results based on the maximum shear strains and maximum shear stress of solid show that in case where is assumed the base plate foundation the possible slip surface appears relatively shallow – in layers of sandy clays with crushed sandstones and shales. There is also a high probability of securing such landslides, stopping further mass movements and above all, rescue building located over the potential landslide. The second method of foundation –

continuous footings could be probably much more dangerous for the building and the soil stability. The potential slip surface caused by the landslide movement, will be reached much deeper – the maximum shear stresses of the soil occur in layers of sandstone interbedded with shale. There is a serious possibility of deep, structural landslide in this case.

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