The Concept of Monitoring Landslides Along the Railway Track Located in the Carpathian Flysch

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Abstract

In the paper, the problem of monitoring of landslides located along the railway track is considered. Railway tracks lying along the slope are exposed to the risk of soil mass movements, especially in areas with a relatively steep slopes and a specific subgrade such as Carpathian flysch. Developing the railway infrastructure on such a slope requires sometimes the cutting of the slope. As a consequence of the change in the shape of the slope surface the subsidence of part of the soil may result in the loss of stability. Based on the numerical analysis the critical stage values applied in the monitoring system have been computed.

Keywords: *landslides, railway, flysch, numerical model, monitoring*

1. Introduction - Problem specification

The landslides constitute a natural danger to urbanized areas and pose a real threat both to the human lives and property. Hence, the landslides should be classified as a high-risk danger. That is why it is so important to identify and monitor landslide movements.

In Poland, the largest number of landslides occurs in southern part, especially in the Carpathian region. It is estimated that in the Polish Carpathians there is on average one landslide per 10 km of railway track and one landslide per 5 km of road. Landslides in the Carpathian flysch are particularly susceptible to activation due to the geological structure of subgrade. In flysch formations, the risk of a landslide is related to the alternating layers of sandstone and easily soaked clay shales and long-term hydration of these formations [1].

Another characteristic feature of the geological structure of the Carpathian flysch is the existence of a weathered zones under the soil layers, which are characterized by large fragmentation of the rock. Such a layer of the weathered material laid on the bedrock and also has a high susceptibility to sliding, while creating the sliding surface between the weathered material and the bedrock.

In most cases, landslides on railway routes do not occur as a result of the natural structure of the subgrade. The very common factor causing landslide movements is connected to the human activity. The occurrence of these landslides is related to changes in ground conditions during the construction of transportation routes [2]. Another cause of these landslides are technical errors made during the construction of the local infrastructure.

2. Landslide monitoring

The main reason for the high financial losses occurring in the landslide areas of Poland is that the locating of construction and transportation infrastructure on vulnerable or active slopes is not well considered by investors [1]. In the paper, the problem of monitoring of landslides located along the railway track is considered. Railway tracks lying along the slope are exposed to the risk of landslides, especially in areas with a relatively steep slopes. Developing the railway infrastructure on such a slope requires sometimes the cutting of the slope. As a consequence of the change in the shape of the slope surface the subsidence of part of the soil may result in the loss of stability. The most vulnerable are slopes that have a natural predisposition to landslides. The cause of a slope sliding may also be a change in geological and hydrogeological conditions. Landslides may occur both above and below the constructed railway track, partially burying it or causing it to collapse.

Landslide monitoring involves conducting regular observations of areas where typical landslide movements have occurred or where there is a risk of typical landslide movements.

The basic classification of methods for observing mass movements can be made according to the type of monitoring. Landslide monitoring methods may simply be divided into in-depth and surface methods. Landslide monitoring should be carried out using the latest, usually wireless methods. The main purpose of observing and controlling these areas is to determine the critical state. After exceeding the critical state, the friction forces in the ground might not support the mass of the earth and the ground slides. The critical state is determined on the basis of subsoil in-situ measurements and laboratory tests of the samples obtained in the analysed cross-sections and the numerical modelling. The results of the modelling are implemented into measurement system as the limit values for inclinometers and piezometers as well as the surface surveying points. The idealized displacement against time may be characterized by the initial deformation stage, the constant speed deformation stage, the accelerated deformation stage, and the critical deformation stage [3].

3. Case Study

The scope of the study includes analysis of the existing soil and water conditions of the subgrade within the modernized Railway Track No. 99 Chabówka-Zakopane along the sections at risk of landslides. The basis of the analyses are ground tests using the CPTU tests, dynamic probing, drilling and boreholes, tests and macroscopic analysis obtained from documentation and the results of macroscopic tests of soil material collected from the spot during an on-site inspection and tested in the Soil Mechanics Laboratory of the Division of Geotechnics and Strength of Materials [4]. In this task, the adopted ground parameters have been taken into account. Moreover, numerical modelling of the behaviour of the subsoil has been performed in selected cross-sections leading through the railway line and active landslide zones. The study also includes an analysis of the computations performed in terms of remote monitoring in specific sections, along with providing threshold values. These calculations have been made for the serviceability limit state using Midas FEM code. Figure 1 presents the map of the analysed cross-section at 7+225 km of the railway track.

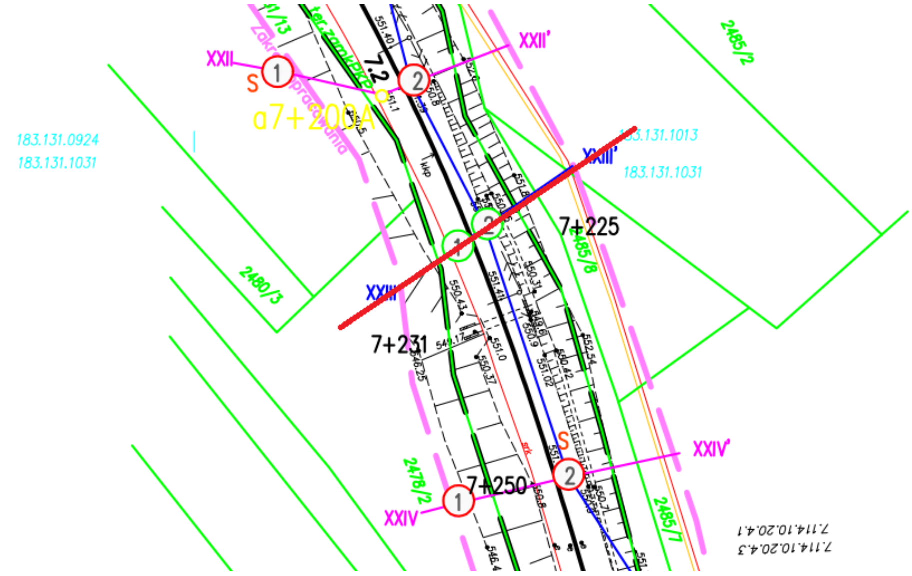

Fig. 1. The map of the analysed cross-section at 7+225 km of the railway track.

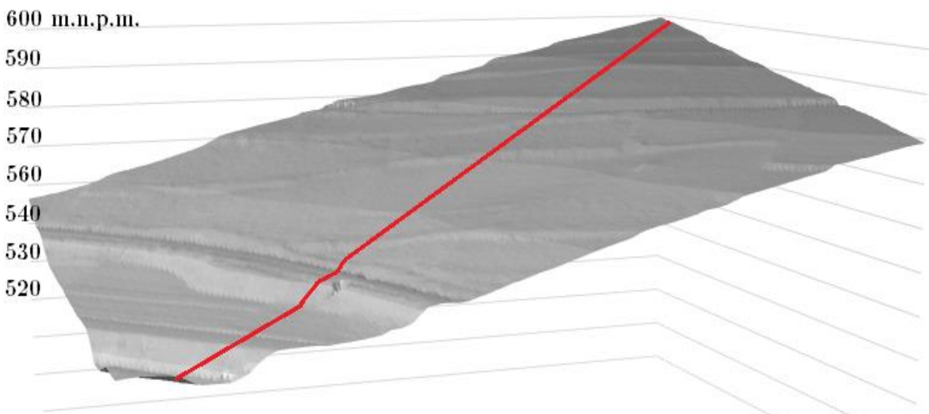

Fig. 2. The local soil surface scan of the analysed cross-section (marked red) at 7+225 km of the railway track

Tab. 1. Geotechnical parameters of individual layers of the subgrade - characteristic values

Soil layer	Soil density γ [kN/m³]	Cohesion c [kPa]	Internal friction ϕ_u [⁰]	Poisson ratio [-]	Deformation Modulus M_0 [kPa]
Earthwork I_D=0.90	19.0	2.0	35.0	0.30	38000
sasiCl I_L=0.35	21.0	12.4	12.3	0.32	21000
Sandstone	26.0	1472.0	32.9	0.20	1758658
Clay Shale I_L=0.15	22.0	12.3	20. 4	0.32	99000

Figure 2 presents local soil surface scan of the terrain along the railway track. For such a cross-section the numerical model has been developed. Table 1 presents the characteristic values of the geotechnical parameters of the subgrade used in the numerical simulations. Figure 3 presents a FEM mesh of the cross-section of the railway track. For such a mesh numerical calculations have been performed using the Strength Reduction Method (SRM). Figure 4 presents a slip surface computed for train load in the dry soil conditions. The value of the factor of safety is equal to FoS = 1.40.

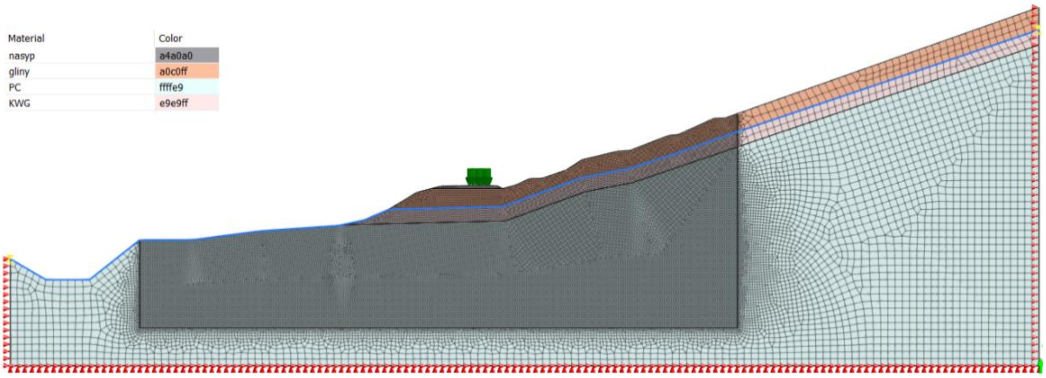

Fig. 3. FEM mesh of the cross-section used in the numerical model at 7+225 km of the railway track.

As far as the monitoring system is concerned the values of the displacements at the specific points are needed. The local coordinate system has been established then in order to monitor the cross-sections along the slip surface.

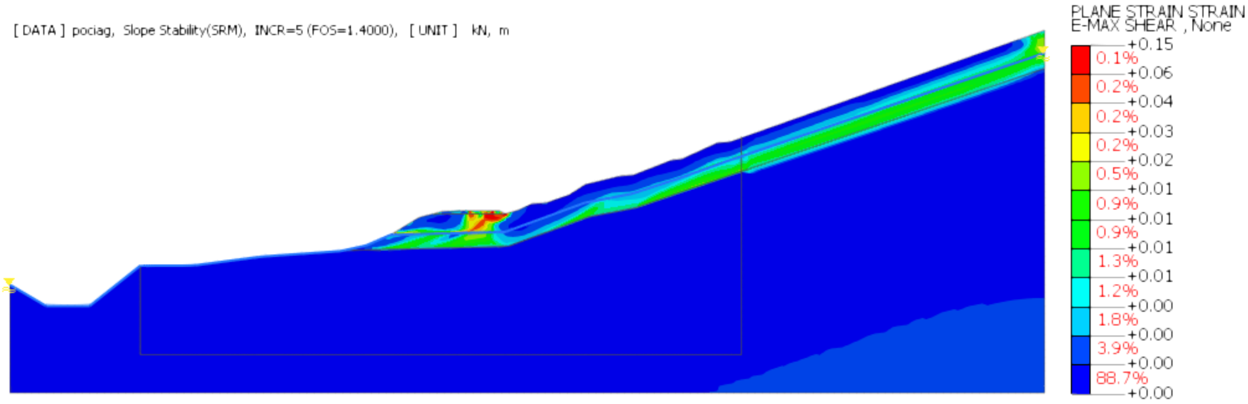

Fig. 4. Slip surface for train load in dry soil conditions with FoS = 1.40.

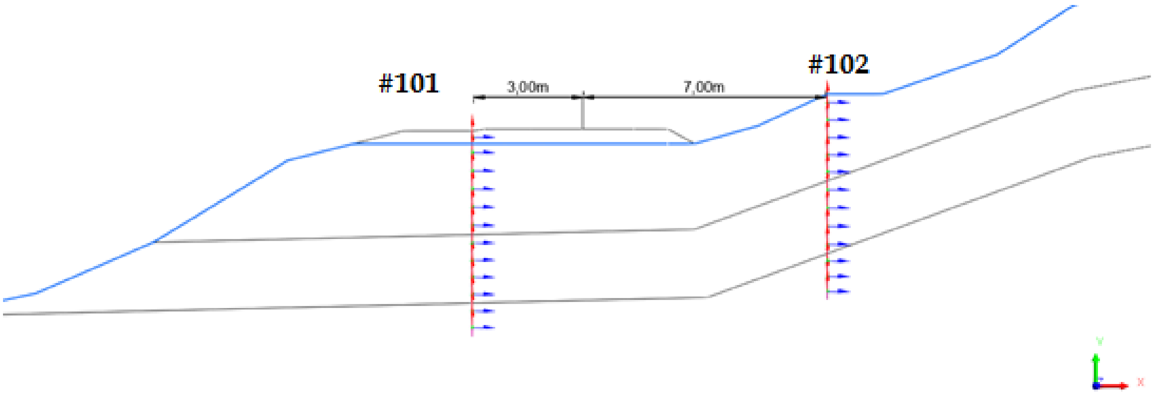

Fig. 5. Local coordinate system of inclinometers with a depth of 6 m in the cross-section at km 7+225. Inclinometer markings: #101 on the left hand side, #102 on the right hand side.

Figure 5 presents the local coordinate system of inclinometers with a depth of 6 m in the cross-section at km 7+225 of the railway track. Two inclinometers positions are marked as #101 on the left hand side, and #102 on the right hand side of the cross-section. And then the computations have been repeated until the value of the critical state (i.e. Fos = 1.00) is reached. Table 2 presents the values of generalized displacements in the conditions of limit equilibrium of the railway track at the critical state. Both horizontal and vertical displacements values are shown for the surface of the soil, where the maximum values are reached, while the maximum rotations are reached inside.

Figure 6 presents the horizontal displacements at the positions of inclinometers for FoS=1.00 (critical state).

Tab. 2. Values of generalized displacements in the conditions of limit equilibrium at 7+225 km of the railway track (the critical state).

Inclinometer	**Horizontal displacements** [cm]	**Vertical displacements** [cm]	**Rotation angles** [rad]
#101	1.16	1.59	0.00575
#102	3.02	0.85	0.01163

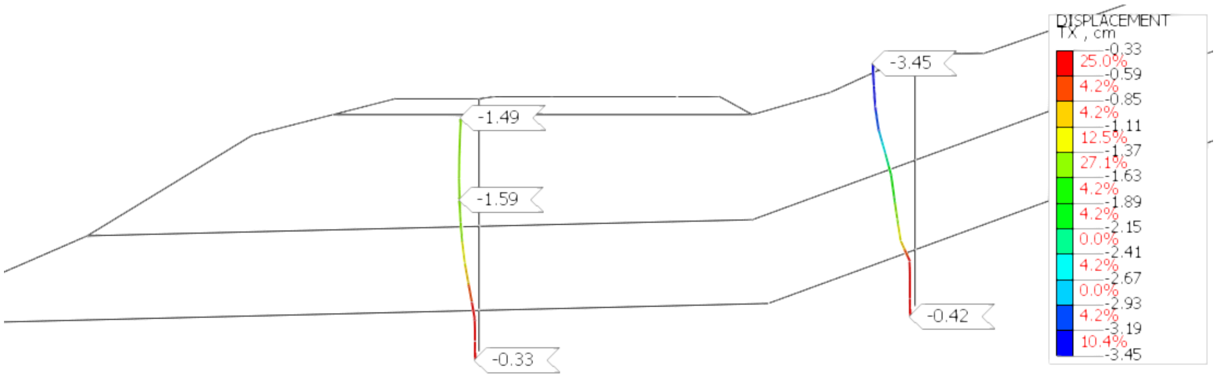

Fig. 6. Horizontal displacements at the positions of inclinometers for FoS=1.00 (critical state).

Tab. 3. Values of permissible horizontal displacements at 7+225 km of the railway track

Inclinometer	**Warning values-** Accelerated stage [cm]	**Alarm values –** Critical stage [cm]
#101	0.5	1.1
#102	1.5	3.0

As far as horizontal displacements are concerned two types of the permissible values are defined, namely the warning values and the alarm values. The warning values are liming the accelerated stage, while the alarm values limit the critical stage. Table 3 presents the values of permissible horizontal displacements at 7+225 km of the railway track. All of them are referred to the soil surface and may be easily measured.

Figure 7 presents the vertical displacements at the positions of inclinometers for FoS=1,00 (critical state).

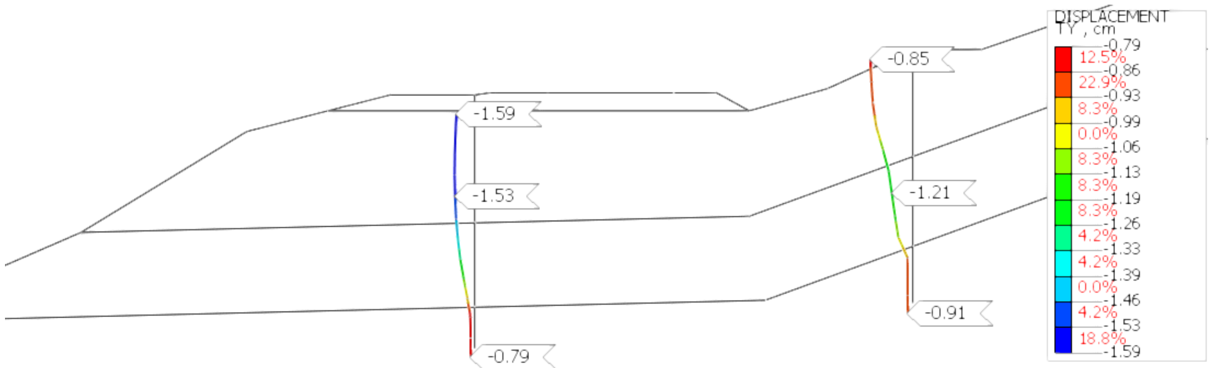

Fig. 7. Vertical displacements at the positions of inclinometers for FoS=1.00 (critical state).

Tab. 4. Values of permissible vertical displacements at 7+225 km of the railway track

Inclinometer	**Warning values -** Accelerated stage [cm]	**Alarm values –** Critical stage [cm]
#101	0,7	1,5
#102	0,4	0,8

As far as vertical displacements are concerned two types of the permissible values are defined, namely the warning values and the alarm values. The warning values are liming the accelerated stage, while the alarm values limit the critical stage. Table 4 presents the values of permissible vertical displacements at 7+225 km of the railway track. All of them are referred to the soil surface and may be easily measured.

Figure 8 presents the rotation angles at the positions of inclinometers for FoS=1.00 (critical state).

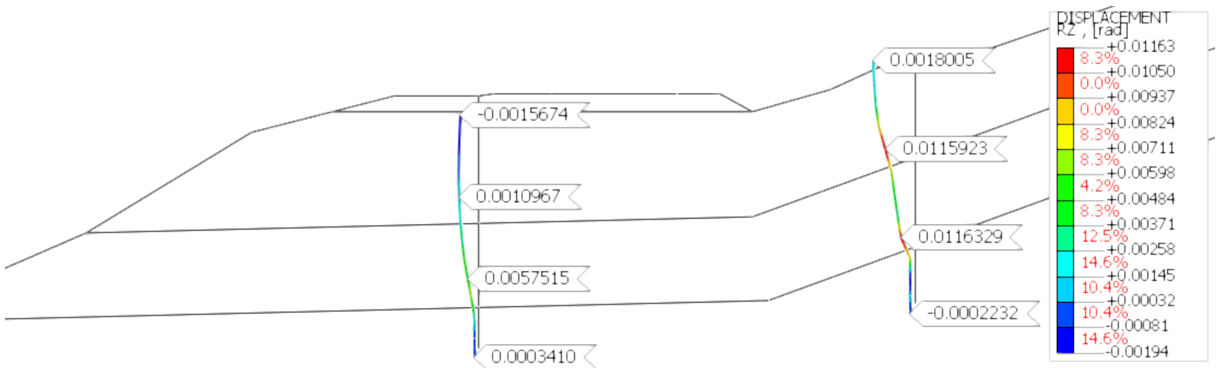

Fig. 10. Rotation angles at the positions along the inclinometers for FoS=1.00 (critical state).

Tab. 5. Values of permissible rotations at 7+225 km of the railway track

Inclinometer	**Warning values -** Accelerated stage [rad]	**Alarm values –** Critical stage [rad]
#101	0.002	0.005
#102	0.005	0.011

As far as rotation angles are concerned two types of the permissible values are defined, namely the warning values and the alarm values. The warning values are liming the accelerated stage, while the alarm values limit the critical stage. Table 5 presents the values of permissible vertical displacements at 7+225 km of the railway track.

4. Conclusions

In the paper, the problem of monitoring of landslides located along the railway track is considered. Railway tracks lying along the slope are exposed to the risk of landslides, especially in areas with a relatively steep slopes and a specific subgrade such as Carpathian flysch.

Based on the calculations made in this work, an analysis of the reliable values that will be namely the warning values and the alarm values during the monitoring of the landslide zone at km 7+225 on the railway track No. 99 Chabówka-Zakopane have been performed.

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