

Assessment of slope stability

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Abstract. The paper deals with the assessment of slope stability on the road II/595 near the village Zlatno before and after the landslide caused by floods in 2010. The calculation of factor of safety was made using GEO 5 software. For proposal comprehensive assessment and possible remedial work is necessary to know the geological conditions and choose the appropriate method for assessing slope stability. The critical factors of safety have been determined by Petterson, Bishop and Sarma Methods. After finding the most unfavorable slip surface a proposal of remediation measures has been made. The paper presents various solutions to ensure slope stability of the road. The most appropriate remedial action is Variant III - reinforced slope due to its greater factor of safety.

1 Introduction

Currently, frequent flood events are taking place in our area. Floods are associated with rapid erosion processes, which involve the destruction of land resources and consequently may lead to landslides of drenched soil. In 2010, severe floods hit most of the territory of the Slovak Republic. It was the biggest flooding in the last 50 years.

Climatic factors combined with the erosion activity watercourses and groundwater are major causes of slope deformations. In 2010, a result of exceptional rainfall and flood situation increased the number of slope deformations. Continuous rain caused significant elevations in almost all watercourses and floods. Slope that becomes saturated with water might be unstable and prone to landslide.

2 Landslide on the road II/595

The penetration of rainwater on the right embankment slope of the road body was the consequence of a landslide on the road II/595 near the village Zlatno. The main cause of the landslide was primarily long-term rainfall in the months of May and June, when daily rainfall was 25-50 mm throughout Slovakia, but in the north and east of Slovakia was up to 80 mm. Slope saturation by water is a primary cause of landslides.

The area of interest is located in the village Zlatno. Road section is guided in a slope. In 2010 a landslide occurred in this area (from 24.886 to 24.932 km). Asphalt layer of road was broken and slide down after the landslide activity (Fig. 1). Landslide narrowed the width of the roadway, thereby reducing the security of vehicle passages in this section [1].

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According to the geomorphological division of Slovakia the territory is located in the Western Carpathians, in the Slovak Ore Mountains. The territory belongs to the Banská Bystrica region of the district Poltár. In hydrological terms, this territory belongs to the basin of the Ipeľ River and is drained by a tributary of the Poltarica River. Climatically the area is evaluated as moderately warm and moderately wet [2].



Fig. 1. Situation and photo documentation of landslide.

From a geological point of view, subsoil is formed by Paleozoic rocks – granitoids, which are unevenly cover deluvial sediments. They are sandy clays and clayey sands with

fragments of rocks. Two boreholes JZ-1 and JZ-2 have been used for geotechnical investigation [2]. Geological profiles are shown in Fig. 2.

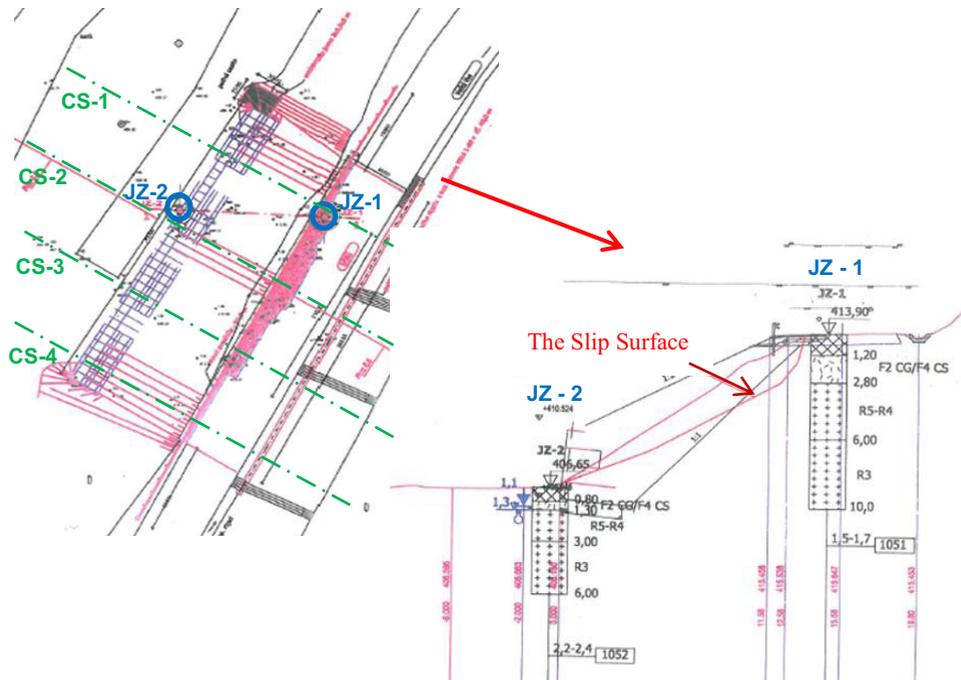


Fig. 2. The location of boreholes and geological profile of boreholes JZ-1 and JZ-2.

Soil classification was made according to STN 72 1001 [8] and in accordance with EN 1997-1 [7]. The values of the geotechnical characteristics are given in the Table 1 and 2 [2].

Table 1. The geotechnical parameters of soils.

Properties	Group F2 – CG (Gravelly Clay) Group F4 – CS (Sandy Clay)	Group S5 – SC (Clayey Sand)
Poisson's ratio ν [-]	0.35	0.35
Unit weight γ [kN.m^{-3}]	19.0	18.5
Deformation modulus E_{def} [MPa]	6	9
Total stress parameters – cohesion c_u [kPa]	55	-
Total stress parameters – angle of friction ϕ_u [°]	0	-
Effective stress parameters – cohesion c_{ef} [kPa]	13	8
Effective stress parameters – angle of friction ϕ_{ef} [°]	25	27

Table 2. The geotechnical parameters of rocks.

Properties	Weathered rock layers Group R5-R4	Weathered rock layers Group R3
Poisson's ratio ν [-]	0.35	0.35
Deformation modulus E_{def} [MPa]	6	9

3 Assessment of slope stability on the road II/595

Currently, there are several methods of calculating slope stability [3-5]. Most often there are the methods based on the assumption that failure occurs towards slip surface. The shape of slip surface depends mainly on the physical and mechanical properties of soils or their arrangement in the profile. The stability analysis in question takes into account two basic principles. The first is an assumption that the slip surface developed will be circular (Pettersen and Bishop Methods) and the second principle is that the slip surface will be polygonal (Sarma Method) [6, 10, 11].

The slopes of the road are made up of fine-grained soils and rocks. That is the reason why Pettersen, Bishop and Sarma Methods were selected for calculation and assessment of slope stability of the road. Calculation and assessment of slope stability on the road II/595 near the village Zlatno was carried out by using program "Slope stability", which is a sub-program of GEO 5 by company FINE Ltd [9].

The slope stability analysis was carried out in compliance with STN EN 1997-1, Design Approach 3 [7]. According to EN 1997-1 [7] was assessed stability of slopes according to the "limit states theory". A factor of safety was calculated as the ratio of the forces resisting movement (thus ensuring the slope stability) to those driving movement (thus threatening the slope stability), i.e. the ratio between the passive and active forces. In general, if the factor of safety of a slope is within the interval between 0 and 1.0, the slope is actively unstable. The value over 1.0 indicates that the slope is considered stable. The calculated factor of safety has been compared to limit value of stability degree.

Assessment of slope stability on the road II/595 near the village Zlatno was made on the landslide place, in four cross-sections CS-1, CS-2, CS-3, and CS-4 (from 24.886 to 24.932 km). The load on the construction of the road was 16.8 kN/m² and the axle load was 115 kN. Calculation of slope stability was realized in several variants.

VARIANT I - The original condition, the dry state (i.e. before the landslide). In this variant, the groundwater level was considered as in geological profile (JZ-1 a JZ-2).

VARIANT II – Condition after landslide, the saturated state (i.e. after the flood). In this variant with maximum groundwater level was considered, i.e. situation that caused the landslide.

Whereas the landslide has large dimensions, it is possible as a remedial measure to propose anchoring of reinforcing elements into the body of the slope. As a first method of remediation measures to slope stability of the road reinforcement of slope with geosynthetics materials was proposed.

VARIANT III - Reinforced slope, i.e. the slope reinforcement with geogrid. For remediation of slope, geogrid with tensile strength 173 kN/m was used. By static calculation in the GEO 5 program, the required length and number of geogrids has been determined.

For comparison as another method of remediation of slope stability of roads a **Variant IV** – Reinforced slope with ground anchors was chosen. Ground anchors can be used to improve the stability of a slope for road applications. Ground anchors can be used also as a remedial measure for landslide slope. The proposal was made by calculating in the GEO 5 program. Length of ground anchor is 10 m, bond length of ground anchor is 1.5 m and anchorage strength is 150 kN.

The calculated factors of safety (F_s) for these variants are shown in Table 3.

Table 3. Calculated factors of safety for Variant I - Variant IV.

The cross-section	Variant I Factor of safety F_s and Evaluation			Variant II Factor of safety F_s and Evaluation		
	Petterson Methods	Bishop Methods	Sarma Method	Petterson Methods	Bishop Methods	Sarma Method
CS-1	0.88	0.97	1.04	0.60	0.77	0.81
CS-2	0.97	1.06	1.24	0.65	0.79	0.89
CS-3	0.89	0.99	1.12	0.61	0.77	0.85
CS-4	0.86	0.96	1.04	0.58	0.74	0.80
The cross-section	Variant III Factor of safety F_s and Evaluation			Variant IV Factor of safety F_s and Evaluation		
	Petterson Methods	Bishop Methods	Sarma Method	Petterson Methods	Bishop Methods	Sarma Method
CS-1	1.42	1.98	2.14	1.12	1.69	1.83
CS-2	1.46	1.99	2.18	1.09	1.54	1.63
CS-3	1.37	1.86	1.97	1.17	1.69	1.78
CS-4	1.53	2.01	2.14	1.06	1.56	1.67

Based on the calculations and the results listed in Table 3 it can be seen that the stability of slopes did not satisfy the assessment of slope stability before the flood situation (Variant I – Petterson Method).

Sarma Method is more appropriate for this calculation, because the slope is formed of rock. The calculated factors of safety by Bishop and Sarma Methods point to the fact that at any overrun load is an increased risk of landslide (Variant I).

Due to rain and infiltration of rainwater into the slope (Variant II), there was a landslide, as confirmed by the calculated factors of safety for all cross-sections.

Both the proposed remedial measures (Variant III and Variant IV) improve the stability of the slope. Variant III is more appropriate than Variant IV, because it has a greater factor of safety. In terms of the factor of safety it is preferable Variant III.

In Fig. 3 you can see the arrangement of geogrid in the slope (Variant III). Variant IV is shown in Fig. 4.

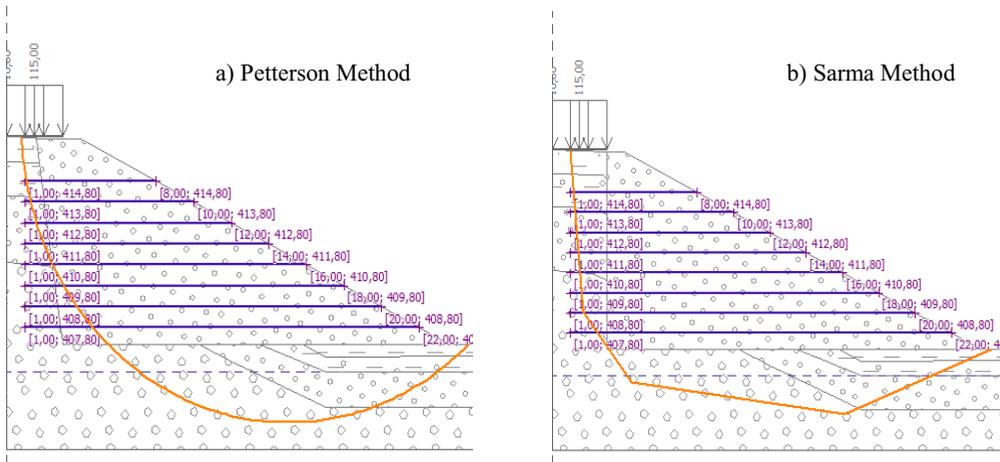


Fig. 3. Variant III - Reinforced slope.

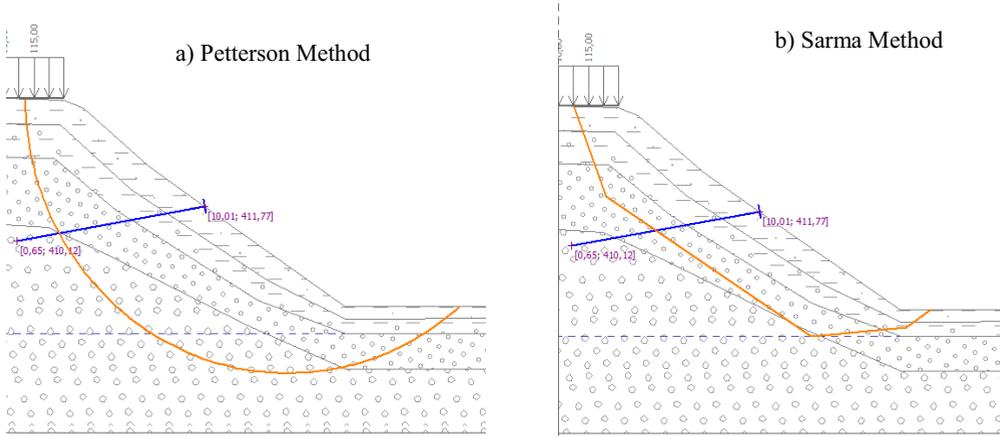


Fig. 4. Variant IV - Reinforced of slope with ground anchors.

4 Conclusion

Calculation of slope stability of road body was realized in four variants, in which we analysed possibilities to solve and improve the stability slope after the flood. Assessment of slope stability on the road II / 595 has been done before and after the landslide, caused by the flood (Variant I - The dry state and Variant II - The saturated state). In view of the fact that the body of the road is formed of rocks groups R3 to R5, it is more appropriate for calculation of factor of safety to use Sarma Method.

The calculated factors of safety by Sarma Method (Variant I) confirmed that any overrun load is an increased risk of landslide. As confirmed by the calculated factors of

safety for Variant II, due to rain and infiltration of rainwater into the slope there was a landslide.

The proposal of remediation measures (Variant III and Variant IV) have been made after finding the most unfavorable slip surface. Variant III was proposed as a reinforced of slope with geogrid and Variant IV was proposed as a reinforced of slope with ground anchors. By comparison of the factors of safety, Variant III is the best one.

Roads are considered as significant structures and therefore it is necessary to pay high attention to the design and assessment of these constructions. Because of their importance, security and reliability throughout their lifetime remains the top priority.

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