CZASOPISMO INŻYNIERII LĄDOWEJ, ŚRODOWISKA I ARCHITEKTURY
JOURNAL OF CIVIL ENGINEERING, ENVIRONMENT AND ARCHITECTURE
JCEEA, t. XXXV, z. 65 (3/18), lipiec-wrzesień 2018, s. 119-126, DOI:10.7862/rb.2018.49

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ANALYSIS OF SLOPE STABILITY USING CONVENTIONAL METHODS

The paper deals with the assessment of slope stability on the road II / 595 near the village Zlatno. The assessment of slope stability was made before and after the landslide caused by floods in 2010. For proposal for a comprehensive assessment and possible remedial action is necessary to know the geological conditions and choose the appropriate method to assess slope stability. The calculation of factor of safety was made using GEO 5 software. The critical factors of safety have been determined by Petterson, Bishop and Sarma Methods. We analyzed possibilities to using these methods for assessment of slope stability. The Sarma Method is more appropriate for this calculation.

Keywords: assessment of slope stability, landslide, factor of safety, road

1. Introduction

Currently, the main cause of the extremely large landslides is primarily long-term rainfall. Continuous rain cause significant elevations in almost all water courses and floods. Slopes ground mass saturated with water are prone to landslide. Climatic factors combined with the erosion activity water courses and groundwater are major causes of slope deformations.

The overall stability of slopes including existing, affected or planned structures shall be verified in ultimate limit states (GEO and STR) [5] with

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design values of actions, resistances and strengths, where the partial factors defined in [5] shall be used. In analyzing the overall stability of the ground, of soil or rock, all relevant modes of failure shall be taken into account. When choosing a calculation method, the following should be considered:
- soil layering,
- occurrence and inclination of discontinuities,
- seepage and pore-water pressure distribution,
- short- and long-term stability,
- creep deformations due to shear,
- type of failure (circular or non-circular surface; toppling; flow),
- use of numerical methods.

2. Conventional methods for analysis of slope stability

There are several methods currently employed in slope stability analyses based on the equilibrium of forces, moments or the energetic equilibrium. Most frequently, it is assumed in the calculations that failure occurs along a particular slip surface. The mass of soil or rock bounded by the failure surface should normally be treated as a rigid body or as several rigid bodies moving simultaneously. Failure surfaces or interfaces between rigid bodies may have a variety of shapes including planar, circular and more complicated shapes. 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 both basic principles. The first is an assumption that the slip surface developed will be circular (Petterson and Bishop Methods) and the second principle is that the slip surface will be polygonal (Sarma Method) [3].

Petterson Method is the oldest and simplest method of analysing slope stability. It is the method of slices not considering the action of neighbouring elements, i.e. the sliding mass above a circular slip surface is divided into a number of vertical slices and the forces acting on each slice are obtained, given by their self-weight and the weight of other facilities (Figure 1). If the slip surface is not known, it is necessary to determine it by the gradual optimizing calculation, i.e. by changing its parameters – locations of the centres of slip circle and the circle diameter [1].

Bishop Method is a modified and extended version of Petterson Method (Figure 2). Horizontal actions of neighbouring slices are incorporate into the calculation as well as the neutral stress on the slip surface, most commonly by means of empirically determined pore pressure coefficients [1].

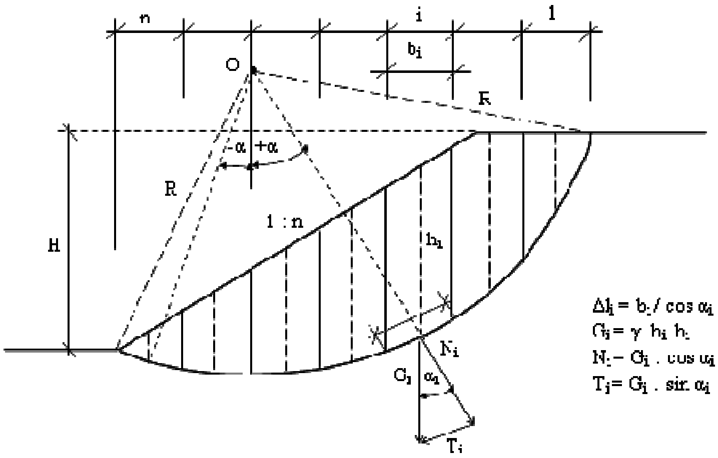

Fig. 1. Petterson Method

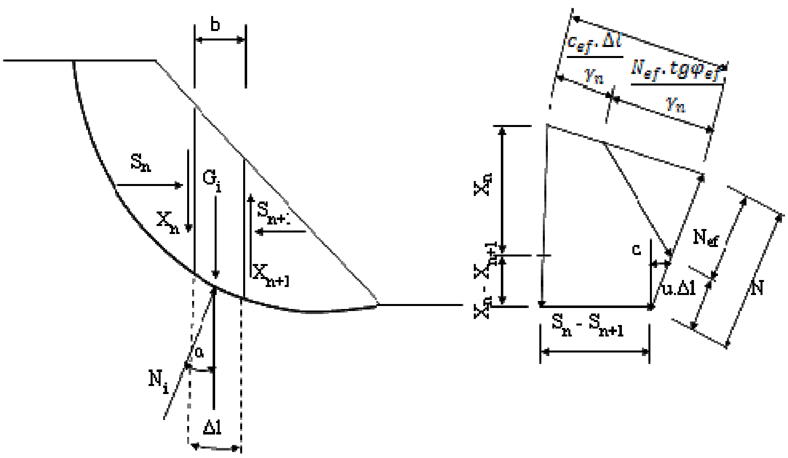

Fig. 2. Bishop Method

Sarma Method is another limit equilibrium technique. This method is based on the equilibrium condition being fulfilled for the forces and moments in the individual wedges [1]. Wedges are created by dividing the soil mass above a polygonal slip surface by planes with various inclinations (Figure 3).

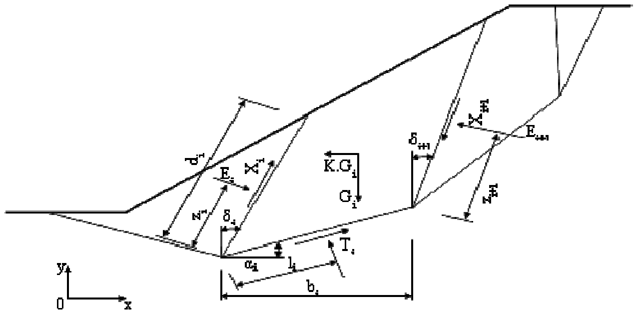

Fig. 3. Sarma Method

3. Analysis of slope stability on the road

The area of interest is located in the village Zlatno on the road II / 595. Road section is guided in a slope in the unilateral notch. In this area occurred in 2010 a landslide from 24.886 to 24.932 kilometers. The consequence of the penetration of rainwater on the right embankment slope of the road body was a landslide. Asphalt layer of roads after the landslide of the slope is broken and slid down. Landslide narrowed width of the carriageway, thereby reducing the security of vehicle passages in this section (Figure 4 and 5).

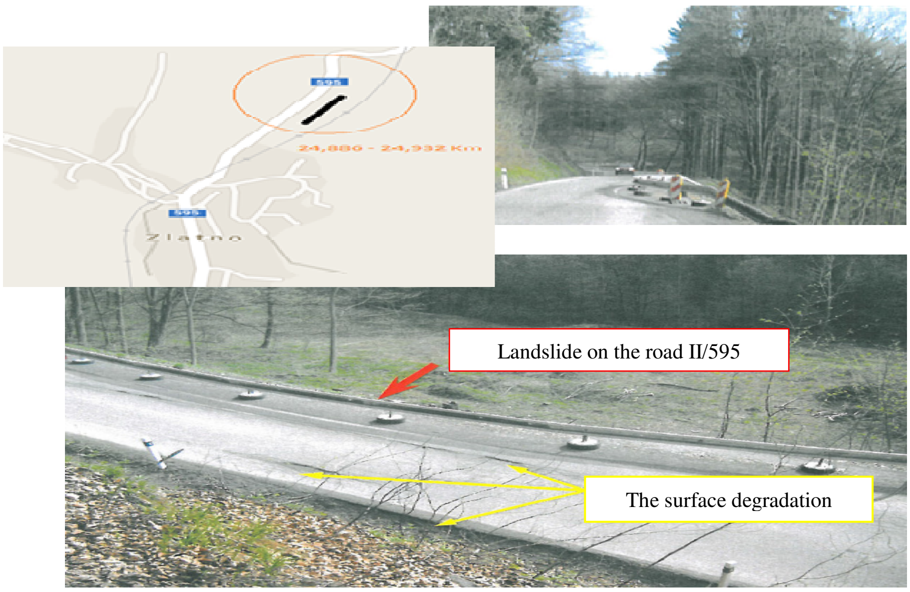

Fig. 4. Situation and photo documentation of landslide, based on [2]

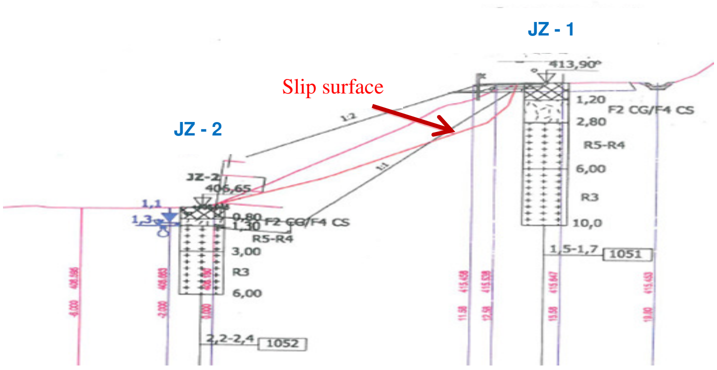

Fig. 5. The location of boreholes and geological profile of boreholes JZ-1 and JZ-2, based on [2]

The slopes of the road are made up of fine-grained soils and rocks. 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 done for geotechnical investigation [2]. Geological profiles are shown in Figure 5. Soil classification was made according to STN 72 1001 [4] and in accordance with EN 1997-1 [5]. The values of the geotechnical characteristics are given in the Table 1 and 2 [2].

Table 1. The geotechnical parameters of soils

Properties	**CG (gravelly clay) CS (sandy clay)**	**SC (clayey sand)**
Poisson's ratio υ (-)	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 υ (-)	0.35	0.35
Deformation modulus E_{def} (MPa)	6	9

Existing failed slopes, which can potentially be reactivated, should be analysed considering circula, as well as non-circular failure surfaces. That is a reason why Petterson, 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.

The GEO 5 program is designed for the stability analysis of slopes, which suits the purpose of heterogeneous slope analyses [6]. Bishop, Petterson, and Sarma methods were employed for calculating the stability of slopes in the article. All three methods are so-called limit equilibrium techniques, i.e. based on the equilibrium principle of moments above a selected slip surface. They are derived from the existence of stress condition in the surrounding environment, while the surface where slip may occur is sought (so-called the critical slip surface). The result is a factor of safety determining the ratio between the active and passive forces. The slope stability analysis was carried out in compliance with STN EN 1997-1, Design Approach 3 [5]. According to EN 1997-1 [5] was assessed stability of slopes according to the "limit states theory". A factor of safety is defined 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 active and passive forces. In general, if the factor of safety of a slope is within the interval between 0 and 1, the slope is actively unstable. The value over 1.0 indicates that the slope is considered stable.

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 kNm-2 and the axle load was 115 kN. Calculation of slope stability was realized in two variants. The calculated factor of safety has been compared to limit value of stability degree.

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

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

In Figure 6 the slip surface for Variant I and Variant II (Petterson and Sarma Methods) can be seen. The calculated factors of safety (Fs) for these variants are shown in Table 3.

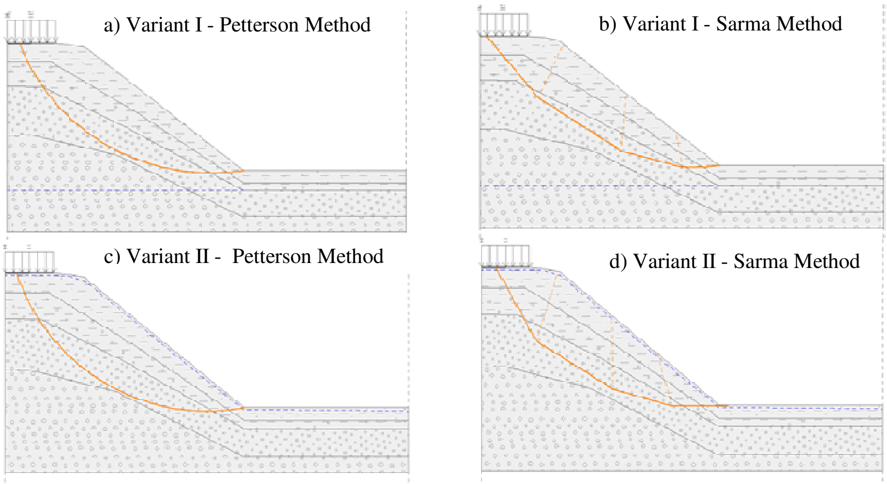

Fig. 6. Variant I and Variant II – The shape of slip surface for cross-sections CS-1

Table 3. Calculated factors of safety for Variant I and Variant II

Variant	The cross-section	Methods	Factor of safety F_s	Evaluation (F_s > 1.0)
Variant I	CS-1	Petterson	0.88	NO*
		Bishop	0.97	NO
		Sarma	**1.04**	**OK****
	CS-2	Petterson	0.97	NO
		Bishop	**1.06**	**OK**
		Sarma	**1.24**	**OK**
	CS-3	Petterson	0.89	NO
		Bishop	0.99	NO
		Sarma	**1.12**	**OK**
	CS-4	Petterson	0.86	NO
		Bishop	0.96	NO
		Sarma	**1.04**	**OK**
Variant II	CS-1	Petterson	0.60	NO
		Bishop	0.77	NO
		Sarma	0.81	NO
	CS-2	Petterson	0.65	NO
		Bishop	0.79	NO
		Sarma	0.89	NO
	CS-3	Petterson	0.61	NO
		Bishop	0.77	NO
		Sarma	0.85	NO
	CS-4	Petterson	0.58	NO
		Bishop	0.74	NO
		Sarma	0.80	NO

*NO = unstable, **OK = stable

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). 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).

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.

4. Conclusion

Calculation of slope stability of road body was realized in two variants, in which we analyzed possibilities to using conventional methods. 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, is more appropriate for calculation of factor of safety 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. Roads are considered as significant structures and therefore it is needed to pay high attention the design and assessment of these constructions. Because of their importance, security and reliability throughout their lifetime remains the top priority.

Acknowledgements: *This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences under Project VEGA 1/0477/15.*

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Przesłano do redakcji: 02.10.2017 r.
Przyjęto do druku: 27.09.2018 r.