GEODYNAMIC CONDITIONS OF THE LANDSLIDE AT THE VILLAGE OF SIPEY, KARDZHALI MUNICIPALITY

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ABSTRACT. The geomorphology and the geological structure of Eastern Rhodopes contribute to the development of landslide processes. Most frequently they are related to the extended areas built up by tuffs and bentonite clays. On the territory of Kardzhali municipality only, more than 30 landslides have been registered. In the spring of 2015, due to the intensive rainfall and snow melting, 8 new landslides were triggered. The landslide in the village of Sipey is one of the largest in the region – with an area of about 20 dka. Its activation resulted in the complete destruction of living houses, roads, water electricity supply lines. The landslide is developed in the tuffs that build up the geological section in the region. The article analyses the actual geodynamic conditions of the landslide, its mechanism and development, and the triggering factors. Based on the results from the stability calculations, landslide forces are obtained and recommendations for reinforcement are made.

Keywords: landslides, stability, reinforcement

ГЕОДИНАМИЧНИ УСЛОВИЯ НА СВЛАЧИЩЕТО В СЕЛО СИПЕЙ, ОБЩИНА КЪРДЖАЛИ

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РЕЗЮМЕ. Геоморфологията и геоложкият строеж на Източните Родопи благоприятстват развитието на свлачищни процеси. Най-често те са привързани към разпространението на туфите и бентонитовите глини, които изграждат геоложкия разрез на значителни територии. Само на територията на община Кърджали са регистрирани повече от 30 броя свлачища, а в резултат на интензивните валежи и снеготопенето през пролетта на 2015 година се активизираха 8 броя свлачищни циркуса. Свлачището в село Сипей е едно от най-големите по обхват свлачища в района – около 20 dka. В резултат от активизацията на свлачищните процеси са напълно разрушени жилищни сгради, пътната и ВиК инфраструктура и е прекъснато ел. захранване. Свлачищните процеси са свързани с разпространението на туфите и туфобрекчите, които изграждат геоложкия разрез в района. В статията е направен анализ на съвременното геодинамично състояние на свлачището, механизма и динамиката на развитие на свлачищните процеси и причините, които са обусловили развитието им. Въз основа на резултатите от стабилитетните изчисления са направени препоръки за укрепване и са оразмерени противосвлачищните съоръжения.

Ключови думи: свлачища, устойчивост, укрепване

Introduction

The area of the Eastern Rhodope is affected by numerous landslides, associated with the highly dismembered relief and the wide affiliation of the tuffs and bentonite clays in the geological section. On the territory of Kardzhali municipality only, more than 30 landslides have been registered. In the spring of 2015, due to the intensive rainfall and snow melting, 8 new landslides were triggered. The landslide in the village of Sipey is one of the largest in the region – with an area of about 20 dka (Fig.1). The first signs of landslide processes in this area were detected in 2014. Subsequently, their range significantly expanded. The landslide processes resulted in the destruction of a section of about 150 meters from "Georgi Popmarinov" Str. (one of the inletting streets in the village), water supply and sewage facilities, high electricity network poles, and four living houses. The landslide processes are currently active and their future development can affect more living houses and widen the destroyed part of the road.

Geomorphological characteristics and geological structure

The village of Sipey is located north-east from the town of Kardzhali. The relief is of low-mountain to hilly type. It is part of the Eastern Rhodope massif. The altitude is between 300 and 325 m. The Paleogene terrigenous and volcanic sediments which fill up the Eastern Rhodope Paleogene depression form smooth relief forms. Only the lava flows keep a sharper relief, forming protruding hills or plates. The gullies and rivers are mainly erosional, with V-shaped valley profiles. The village of Sipey is located at the top of the right valley slope of the Arda River, just below the ridge of its watershed.

In a geological and structural aspect, the region refers to the Eastern Rhodope Paleogene depression. Its filling includes two rock complexes. Continental sediments (calcareous-sandstone complex) and marine sediments (marl-limestone complex) are specific for the lower complex. It refers to the late Eocene.The second complex is represented by the alternation of medium acidic and acidic volcanites, with reef limestone bands and large sandstone bodies (eg. the Dzhebel complex). A triple alternation of medium acidic (andesite) and acidic (rhyolite) complexes is observed in the entire section of this complex. The thickness of the Paleogene deposits is over 2000 m.

The geological section of the landslide is built up of the second Medium acidic volcanic complex, which is lithologically represented by medium-acid tuffs and a reef limestone series. Bentonite clay bands can be found as a result of hydrothermal meta-somatic processes. These are well extended, with a thickness from a few centimeters up to more than 15 m. The bentonites are white to light-colored.

The Quaternary cover is represented by deluvial and deluvial-elluvial silty and silty-sandy clays with a thickness of up to 4.0 - 5.0 m.

Hydrogeological conditions

The groundwater is bound to the tuff horizons. They are hydraulically connected in a single aquifer. Due to the different weathering degree of the tuffs and the presence of bentonite clay interlayers, it is with a rather complex regime. At the upper part of the landslide, the groundwater levels occur at a depth of 12.6-14.5 m getting to 3.5 m down the slope. At the road zone, their depth is from 4.20 to 8.60 m. The aquifer is slightly pressurized (from 0.5 m to 5.3 m) due to the different permeability of tuffs with different weathering degrees, as well as due to the presence of bentonite interlayers that act as local aquitards. The permeability coefficient of the aquifer varies between 0.1 m/d and 2.0 m/d. The average permeability coefficient of the bentonite clays is $0{,}30.10^{-6}$ m/d. In wet seasons, the water levels rise significantly and reach the terrain surface of the negative relief forms. During the study of the landslide in February 2015 (when the slide was activated), the water levels reached the surface of the two wells located in the area.

Landslide description

The landslide has affected terrains with an area of about 20 dka in the western part of the village of Sipey. The first signs of landslide processes in this area were detected in the end of 2014. Subsequently, their range widened significantly. The areas affected by the landslide processes are characterized by an undulating relief, clearly marked main landslide scarps with a height of 1.5-2.5 m, toe elevation, numerous inside scarps, and open cracks. The electric poles within its range were inclined and the living houses located were with serious constructive damages that made them uninhabitable. The landslide processes are in an active stage of development. There is an actual danger that they will increase their area (observed in the summer months of 2015), which will lead to the destruction of more living houses and infrastructural facilities in the area, and an increase of the range of the destroyed part of the road. The landslide is developed in highly weathered tuffs and the sliding surface is located along the contact with the base from bentonite clays. It has a linear shape, with an average inclination of about 11° and at depth between 4.50 and 6.50 meters from the surface. The landslide itself has a circular contour.

It is triggered mainly by the massive saturation of the clays from the weathering crust of the Paleogene tuffs due to the heavy rainfall in the area by the end of 2014 and the beginning of 2015. As a result, groundwater level reached the terrain surface in the negative relief forms leading to a considerable decrease of strength properties. The uncontrolled water leakage from the artificial water basin located in the north part above the landslide had an additional unfavorable influence over the stability of the terrains in the area. Household water was discharged in the low relief parts, due to the lack of sewerage network, and also contributed for the saturation of the landslide materials.

Engineering geological characteristics

The following layers (engineering soil types) are divided in the geological section (Fig. 2):

- *Layer 1* – Gravel embankment (crusted stone). It was executed during the building of the road and has limited area distribution. Its width varies between 1.0 and 1.30 meters.
- *Layer 1b* – Clay, grey-black, organic. The clay builds the top part of the natural Quaternary covering. Its average thickness is 1.20 – 1.50 meters.
- *Layer 2* – Highly weathered tuffs, yellow-green to rusty, silty to silty-sandy with gravel. The layer builds up the top level of the Oligocene tuff and materials. The weathering processes have changed the tuffs to clays and gravely clays. Their thickness varies from 7.0–9.0 m in the top part of the landslide to 3.0 – 5.0 m in its lower part. The layer is subjected to the landslide processes and the sliding surface is developed in its base.
- *Layer 3* – Bentonite clay, grey-green to beige, hard. The clays occur as continuous interlayers in the tuffs with thickness from 5.5–9.0 m down slope to 8.0–15.0 m in the middle and top parts of the slope. The clays are fissured and crushed in some areas. The strong sensitivity during the interaction with water is typical for the bentonite clays. They swell significantly and their strength properties present a thixotropic behaviour.
- *Layer 4* – Tuffs, weathered. They build the weathering crust of the second horizon of tuffs under the bentonite clays at a depth from 8.0–9.0 m in the toe and middle part of the landslide up to 12,0–15,0 m in its top part. The layer thickness is 0.5–2.0 m. The tuffs and tufts are highly weathered to hard gravely clays and to gravel with clayey-sandy filling.
- *Layer 5* – Tuffs, slightly weathered gray. They build the basic part of the geological section. The tuffs are slightly weathered, irregularly interlayered by thin clay bands (up to 0.10 m thick). They are sensitive to interaction with water up to complete disintegration.

The soil type geotechnical properties are shown in Table 1.

Landslide stability assessment

According to the characteristics of the landslide, the model of sliding along parallel to the terrain sliding surface was adopted (as in Naredba № 12, or Ordnance№ 12), but taking into account the active earth pressure in the top part of the landslide. The general stability scheme is given in Figure 3.

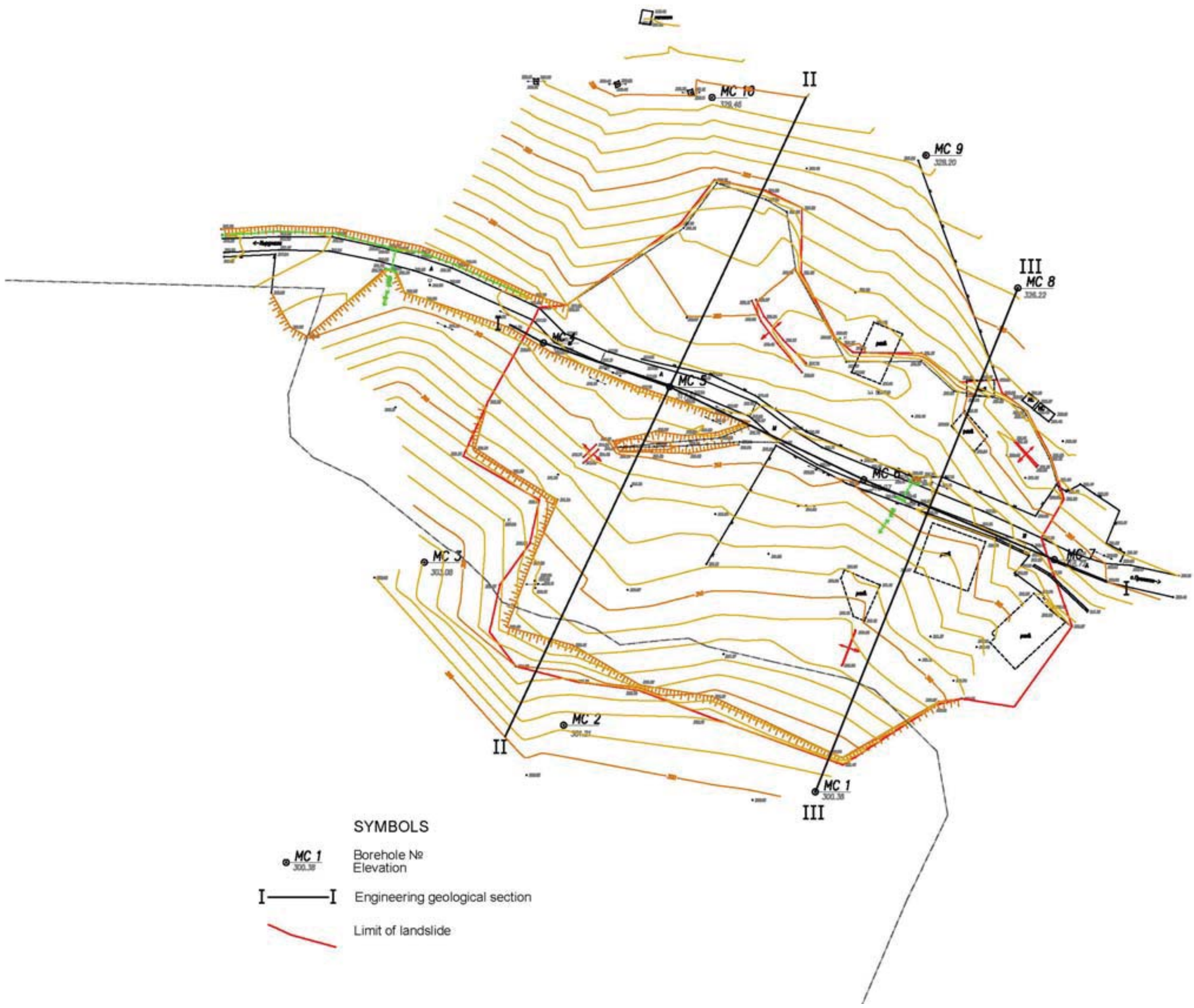
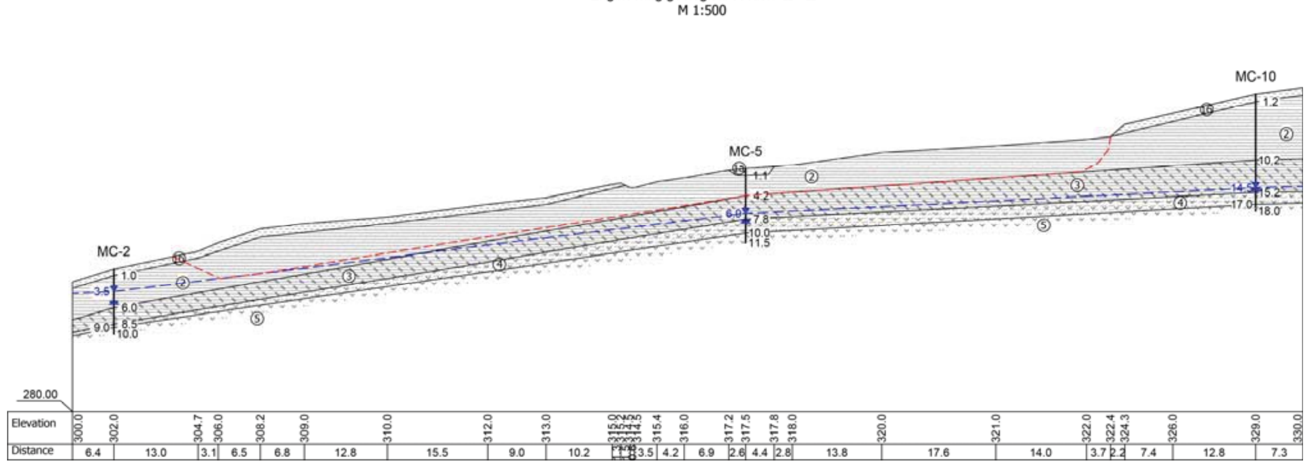


Fig. 1. Terrain situation with landslide boundaries and exploratory work location



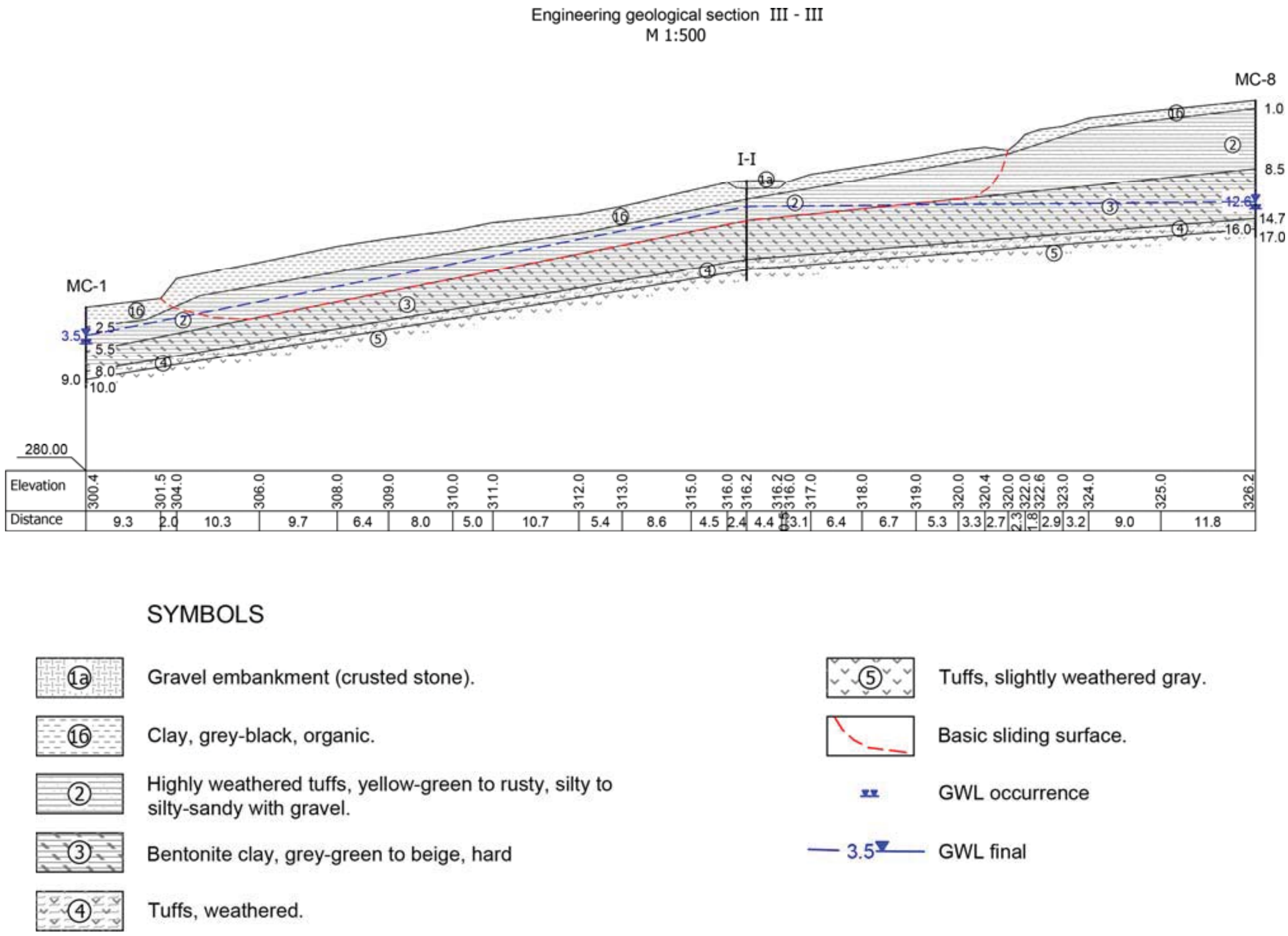


Fig. 2. Engineering geological sections. (The layer indices are given below)

Table 1.
Geotechnical properties of the soil types

SOIL PARAMETERS		Layers №					
		1	1б	2	3	4	5
Bulk density	ρ_n, g/cm^3	1.90	1.69	1.70	1.62	1.64	210
Plasticity index	Ip, %	-	-	22.0	54.3	19.4	-
Consistency index	Ic	-	-	0.65	0.87	1.04	-
Peak shear strength (characteristics)							
Angle of internal friction	ϕ_k, °	-	-	14.2	13	18	23
Cohesion кPa	C_k, kPa	-	-	25.1	25.8	37.9	49.6
Residual shear strength (characteristics)							
Angle of internal friction	ϕ_k, °	-	-	12.0	12.0	-	-
Cohesion кPa	C_k, kPa	-	-	16.1	19.3	-	-

Remark: The characteristic values of the friction angle and the cohesion are obtained through statistical processing of the results from plane shear tests in aTaylor type apparatus in a consolidated-drained state.

For profiles II-II and III-III with lengths of 100 m and 145 m, an average depth of the sliding surface of 5.5 m and average slope of about 11 degrees were estimated.

Since the landslide surface is attached to the base of layer 2, the corresponding average density values γ=17.0 kN/m^3 and the characteristic values of the residual shear strength are used in the stability calculations. The maximum water saturation of the massif ($h=h_w$) is considered.

The calculated safety factors for both profiles are F=1.55 and F=1.30, respectively. These values do not correspond to the actual active state of the landslide. Back calculations are made in order to establish a more realistic value for the cohesion, corresponding to a safety factor of F=1.00. The obtained values for both profiles are respectively C = 12.2 kPa for F=0.997 (along profile II-II) and C = 12.0 kPa for F=1.003 (along profile III-III), the lower is considered to be characteristic for the landslide.

The slope stability defined by the above mentioned shear parameters, without the presence of groundwater, results in safety factors of F=1.48 and F=1.51, respectively. This shows that the groundwater is the basic factor for triggering the landslide processes. So, for a major approach for its stabilization, we should consider the construction of a trench fishbone drainage system inside the landslide body. Considering the fact that the excavation works will be carried out in an active landslide, it is technologically appropriate for the depth of the trenches to be limited to 3.0 m. Assuming a curvilinear depression line between the drainage members, the average design decrease of the groundwater level in the slope is estimated to be 2.5 m from the surface corresponding in the calculations to h_w = 3.0 m.

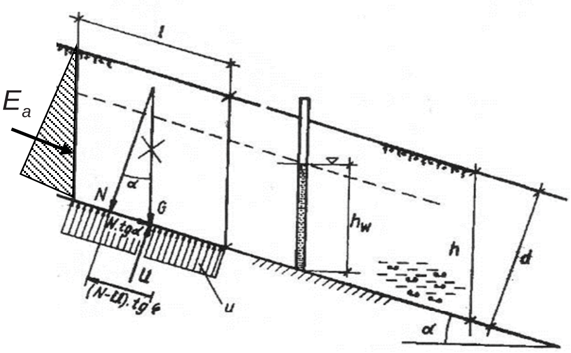


Fig. 3. General calculation scheme for parallel sliding

$$F = \frac{(1-r_u)\gamma.h.cos^2\alpha.tg\,\phi.l + c.l}{\gamma.h.sin\,\alpha.cos^2\alpha.l + E_a}$$

където :

$$r_u = \frac{\gamma_w h_w}{\gamma_n h};$$

$$E_a = \frac{\gamma.h^2}{2}K_a;\ K_a = \frac{cos^2\alpha}{\left[cos^2\alpha + cos(\varphi+\alpha)\,cos(\varphi-\alpha)\right]}$$

The design stability calculations were performed according to the requirements of Eurocode 7 and National Annex EN 1997-1: 2005 / NA Amendment 1. DA3 design approach is applied using a partial resistance coefficient γR = 1.0. For a basic load combination in accordance with the National Annex EN 1997-1 / NA, the following partial factors to the soil parameters are applied – $\gamma\gamma$ = 1.0, $\gamma\varphi$ = 1.25, and γC = 1.25.

The obtained results for the stability factors for profile II-II and profile III-III are F=0.975 and F=0.992, respectively. These values are close to but still lower than the limit value for F=1.00 and they show that the slopes in both sections are still unstable under the specified conditions.

Since the main purpose of the landslide stabilization is to restore the road and limit the development of the landslide process, it was accepted to construct an anchored pile wall located at the up-slope side shoulder of the road.

The necessary anti-landslide forces R along the two profiles are determined through back calculations to achieve a minimum safety factor of F=1.00. For lengths of the landslide blocks above the line of the support structure 37.0 m and 62.0 m, the obtained values are R = 116 kN/m and R = 94 kN/m.

Calculations for earthquake conditions are performed in a serviceability state with partial factors on the soil parameters $\gamma\gamma$ = $\gamma\varphi$ = γC = 1.0. The seismic coefficient for the stability calculations is obtained by the formula:

$$K_C = 0{,}5.\ aR\ .\ \gamma I\ .\ S = 0{,}5\ .\ 0{,}11\ .\ 1{,}0\ .\ 1{,}2 = 0{,}066,$$

where: aR is the reference seismic acceleration for the region, according to the National seismic zoning; γI is the coefficient of significance, equal to 1.0; S is the amplification coefficient that, according to Eurocode 8 and National Annex EN 1998-1 / NA1 for the established Soil Ground C, is S=1.2.

For these conditions, the obtained values of the anti-landslide force for profile II-II is R=167 kN/m, and for profile III-III it is R=184 kN/m. As far as they are higher than the determined for a basic load combination, the maximum value R=184 kN/m is accepted as a design value for the whole landslide.

Conclusions

The analysis of the slope stability conditions in the studied area, including the road section passing through and the results from the landslide stability calculations, shows that it must be stabilized. In particular, the stability of the road and the limiting of the landslide development towards the buildings in the eastern boundary of the landslide should be assured. Based on the established engineering-geological conditions and the stability calculations, the following are recommended as most efficient anti-sliding measures:

- Construction of a 3 m deep buried trench fish bone drainage system inside the landslide body;
- Construction of a reinforcement anchored pile wall along the up-slope side road shoulder. It should be designed to counteract a force of 184 KN/m. The wall will ensure the

protection of the road, and limit the development of the down-slope landslide process;

- Construction of an overloading embankment from coarse-grained aggregates just above the pile wall with a height of 1.5 m in order to prevent the danger of the landslide overflowing over the wall;
- Repairing the water basin in the area above the landslide to stop water leakage in the landslide body;
- Inspection of the sewers of the living houses in the area and eliminating their discharge into the landslide body;
- Construction of a ditch with bottom drainage along the road and leading the surface waters outside the landslide area;
- Restoring of the drain-pipe in the eastern part of the landslide;
- Performing a vertical planning for grouting the opened cracks and regenerating a gentle surface slope that will allow the quick down-slope flow of the surface waters.

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The article is reviewed by Prof. Stefan Dimovski, DSc. and Prof. Dr. Radoslav Varbanov.