



Monitoring of the “Razanj” Landslide in Serbia

Svetozar Milenkovic, Branko Jelisavac, Vladeta Vujanic, and Milovan Jotic

Abstract

Serbia is quite known for its conspicuous number of landslides. Unstable slopes with great number of landslides capture very large areas. Detailed engineering-geological investigations of these slides were carried out in the previous period meant for repair works. Unfortunately, the works thereof were carried out within the budgetary constraints, so that the majority of landslides are still active. Highly precise data on the mechanism and depth of sliding processes and cause and effect links of soil water-saturation and landslide activity level have been obtained through long-standing monitoring of landslides.

Keywords

Road network • Landslide • Monitoring

Introduction

Serbia is well known for its conspicuous number of various landslides, formed prevalingly in the weathering crust, of neogene age, wherein the clays, marls, and sands alternate each other. Unstable slopes created along the river banks of Danube and Sava are particularly known, with great number of landslides which capture very large areas. Basic cause of such numerous occurrences, most frequently spacious and deep landslides, is attributed to complex geological and morphological evolution of the terrain.

Immediate pretext, however, in our time is quite often the consequence of human building and economic activity such as construction of E-75 motorway within the corridor 10. The most complex landslides are as follows: Beska, Begaljicko Brdo, Kolari, Bracin, and Razanj (Fig. 1). These landslides were a calm phenomenon until the construction of motorway. From then and onwards their activity was growing gradually, and thus causing more and more complex problems which were often culminating even

with overall traffic break-down along motorway. The most significant example for such activities is Razanj landslide.

This paper presents the results of the most recent, essential monitoring results, which among other things included as well the inclinometers, piezometers, survey points and triaxes deformeters. Highly precise data on the mechanism and depth of sliding processes and cause-effect links of soil water-saturation and landslide activity level have been obtained through long-lasting monitoring. More objective assessment of hazards and risks has been made possible by this operation, along with the establishment of rating and prioritization for repairs. Moreover, certain stages of repair implementation are being checked-up by monitoring.

Engineering Geological Review of the Landslide Razanj

The area of the “Razanj” landslide is made of deluvial and deluvial-proluvial quaternary clayey-silty sediments, of thickness being 2–6 m in the wider zone. Landslide body is prevalingly made of silty and marly clay, covered with a 5–10 m of filling material (motorway embankment). The thickness of the mass set in motion is the greatest within the landslide peak, in motorway zone (landslide head scarp)

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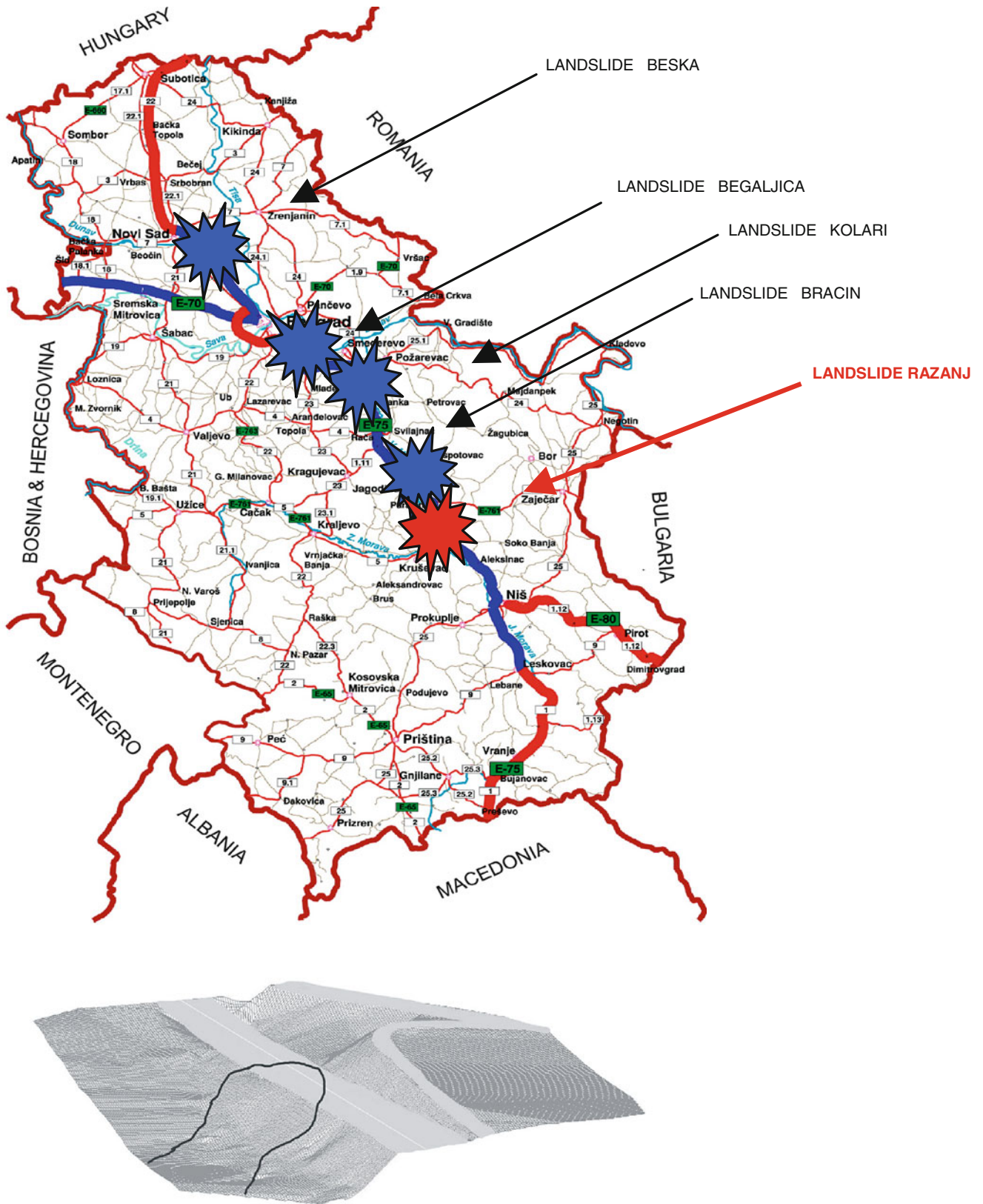


Fig. 1 Geographic location of the major landslides on corridor 10 through Serbia with 3D terrain model of the landslide Razanj

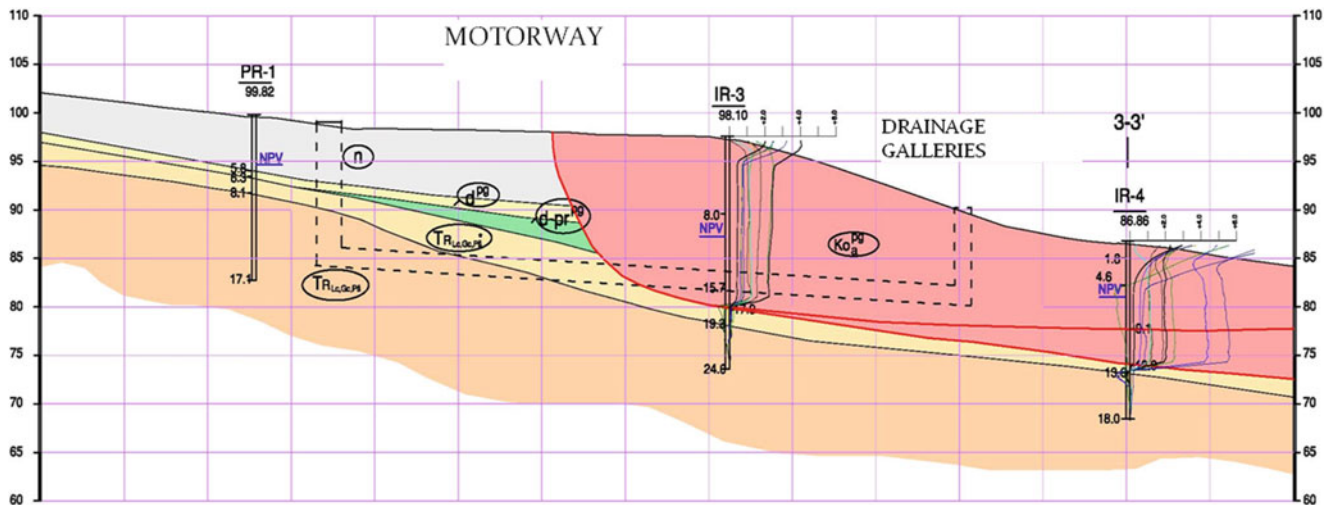


Fig. 2 Engineering geological cross section

and amounts to 16–17 m. Within the motorway embankment toe the landslide depth in the central part is about 10 m. Residual values of the shear strength, as defined under direct shear test are $\varphi = 8.5\text{--}10.0$ with $C = 0$ kPa. Other values of physical characteristics are: natural moisture content $w = 14\text{--}22\%$, consistency features $W_p = 19\text{--}35\%$, $W_I = 39\text{--}70\%$, $I_p = 19\text{--}30\%$, and $I_c = 1.0\text{--}1.3$.

Within the interaction zone, lower sediments consists of miocene clay and marly clay with thin interlayers and lenticular sand.

These deposits are quite degraded (weathering crust), with thickness being 5–10 m, and are located directly below the landslide main body. They represent the product of surface physical-chemical alterations of miocene marls, which are found in the underlying stratum.

Basically they feature considerable weakness of specific physical-chemical properties, and as such prone to sliding. Laboratory testing on representative samples established residual values of the shear strength are $\varphi = 8\text{--}14$ along with $C = 0$ kPa. Besides, these samples had specific consistence features $W_p = 24\text{--}38\%$, $W_I = 37\text{--}85\%$, $I_p = 18\text{--}58\%$, and $I_c = 0.9\text{--}1.2$. Natural moisture content $w = 20\text{--}32\%$.

Miocene marls are located below the complex of clays and marly clays and are sandy here and there with thickness reaching several tens of meters (The Highway Institute documentation 2008–2010).

Recent Investigations and Previous Remedial Works

In order to point to overall complexity of this landslide, it is worth stressing that the investigations as regards the origins of appearance, depth, mechanism and dynamics of sliding were carried out by various specialized institutions in the

period from 1979 till 1997. Previous geotechnical and design documentation has limited possibilities of utilization and application due to differing investigation approaches to the issue of deformation causes.

In view of the threat of traffic break-down on the right carriageway of motorway Belgrade – Nis due to the sliding process, the Highway Institute carried out additional geotechnical investigations of soils involved in the sliding zone and prepared the Project of risk mitigation control works during 1989–1990. In order to prevent further movements of landslide, by the above mentioned Project, two drainage galleries (Fig. 2) were made (about 100 and 60 m long). Since then, landslide displacement rates are in the trend of decreasing, but as one can observe from further text, certainly not completely stopped. A great contribution in the perception of causes, dynamics, geometry and particularly future activity of the landslide was given by systematic observations from year 2002 till nowadays as follows: geodetic, inclinometric, hydrogeological and deformation measurements in drainage galleries.

Additional geotechnical works were carried out in order to define mechanism and dynamics of sliding (Hunt 1984; Leonards et al. 1993; Lollino & Wasowski 1994; Leroueil et al. 1996; Baldassarre et al. 1996; DeGraff 2002; Haberler-Weber 2005). They encompassed: detailed engineering-geological mapping of terrain on a very narrow location around the landslide; nine exploratory holes were drilled with overall length of 150 m and besides the mapping, the sampling was done as well; within the framework of four exploratory hole four inclinometers were set in total length of 58 m; within five exploratory holes piezometers were set in total length of about 16 m; observations as regards ground water level were performed (total of 30 measuring cycles); observations were carried out within the four installed inclinometers (also 12 measuring cycles); 10 surveying marks were set and

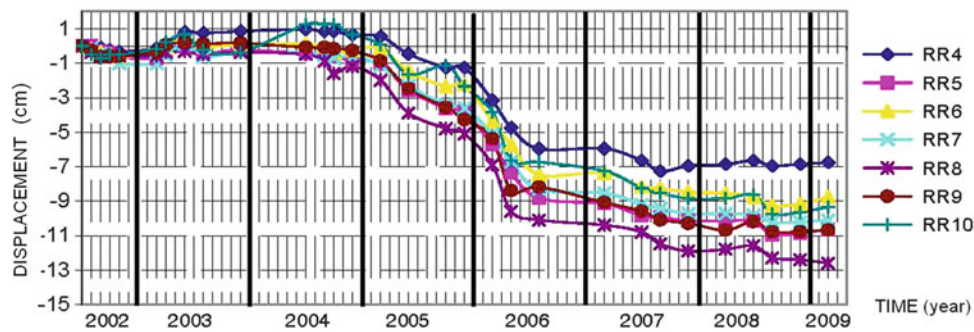


Fig. 3 Overall downhill displacement of landslide

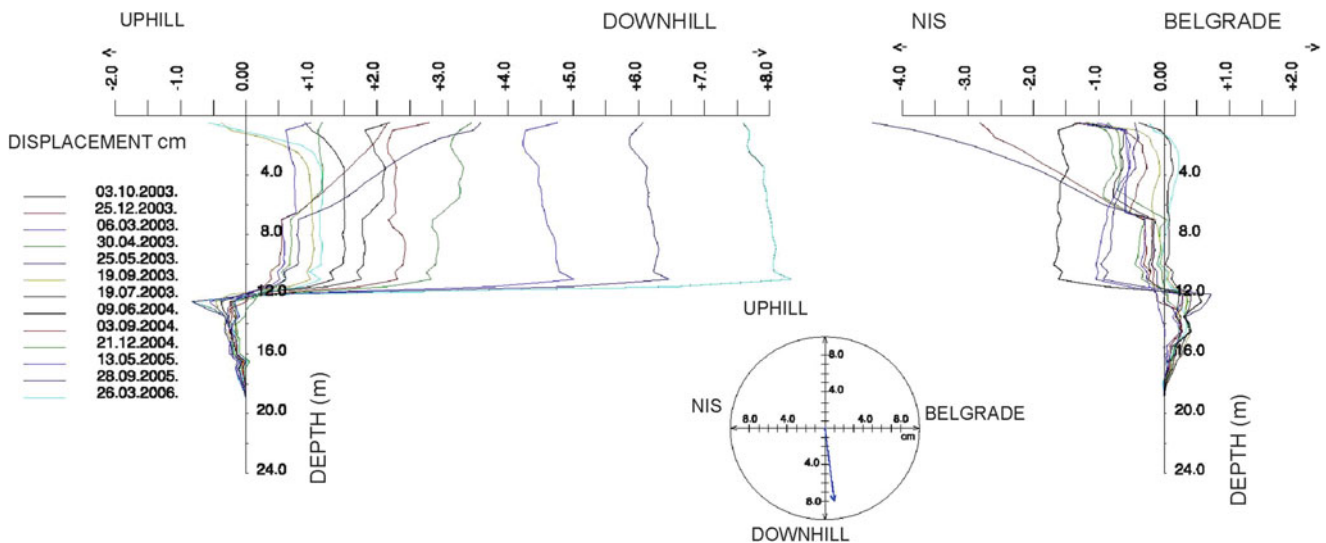


Fig. 4 Displacement profiles and vector of overall inclination (BI-2)

observations of their shifting were carried out on the supporting structure set in motion; various laboratory soil mechanics investigations were carried out on 12 samples from the slide main body. Also, observations of eight triaxial mechanical deformaters, installed in drainage galleries were carried out.

expect that after longer observations these displacements will be more pronounced.

Monitoring of the Landslide

Geodetic Data

Geodetic survey was carried out on the net of 19 survey points established on July 2002, and during 32 measuring cycles, surface displacements in the range of centimeters were recorded within the sliding body.

All of the points which are situated within the sliding body are shifted vertically from a range 0.5 to 1.0 cm, and horizontally from 7.0 to 13.0 cm (Fig. 3). In comparison with displacements observed during previous stages of investigations, general tendency of displacement rates decreasing is significant. In spite of that fact, and one may

Installation and Monitoring of Inclinometers

After the installation and protection, the initial measurement has been carried out in two orthogonal planes defined by the position of internal grooves: one normal onto the motorway (AB) and the other one parallel to the motorway (CD). Other measurements have been carried out as relation to zero point, so disregarding the original position of the structure within spatial considerations, each landslide motion is recorded as the discrepancy from upright vertical. A total of seven series of measurements have been carried out, whereas the monitoring results have been presented as diagrams of differences of cumulative displacements for two measuring planes and vectors of overall displacements (Fig. 4).

In the period from July 2002 till nowadays, a series of 32 measurements in both measuring planes have been

carried out on seven installed inclinometers within the landslide body.

Measurement results are presented in diagrams of overall motions whereby one was in a position to define the depth of sliding, landslide body motion dynamics, as well as the vectors of overall motions. Maximum displacement is carried out within the zone of weathered tertiary sediments, and within its scope during the mapping procedure one was able to record clear and numerous shearing cracks. Overall shifting of the landslide body within AB plane, i.e. along the embankment towards the stream amounts to 8 cm.

Installation and Monitoring of Triaxial Orthogonal Deformometer

Mechanical displacement measuring device – triaxial orthogonal deformometer (Fig. 5) is used to measure relative motions of cracks within three orthogonal directions. These are practically installed in concrete or masonry structures, or even to follow-up the discontinuity in hard rock masses.

It is composed of two crank type profiles which are bifurcating in three parts under a right angle. Profiles are made of stainless metal, with consistent thermal properties. Every profile thereof has three reference bolts each being utilized to measure relative motions within three orthogonal directions. Measurements are facilitated by micrometer. Eight triaxial measuring devices have been installed four each in both drainage galleries (Fig. 6), and one inch within the stable terrain. By analyzing the motions measured by triaxial deformometer one is obtaining the data on spatial motions of concrete centerings which make the structural foundation of drainage galleries.

Deformation devices are installed in both galleries, on the spots where one can observe visually the largest deformations of structure, i.e. the cracks with the width ranging from 3 to 7 cm, which appeared in previous 20 years. Total motions measured during 8 years amount to 6 cm. Displacement vectors reflect actual motion intensity, while their spatial position is relative one. The rationale for this is the impossibility of installing the deformation devices in a position which is coinciding with the absolute orientation of spatial axes.

Installation and Monitoring of Piezometers

In order to perceive the conditions and regime of ground waters within the terrain, a monitoring network of piezometers was established in June 2002. Five standard piezometers have been installed, out of which one within the stable backing, while four within the landslide body.

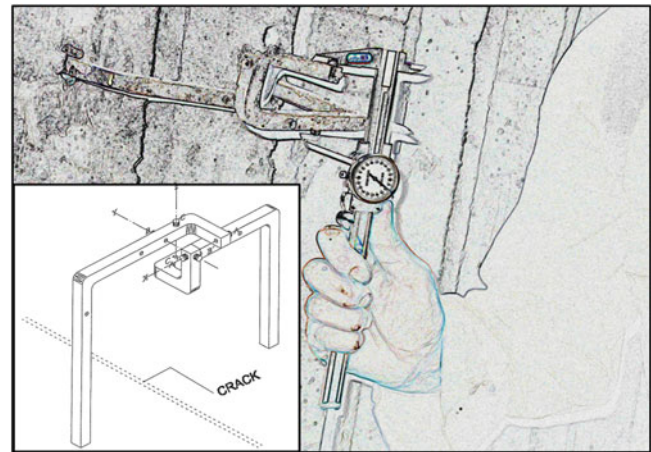


Fig. 5 Triaxial measuring device



Fig. 6 Drainage gallery

The analysis of results arising from systematic monitoring with piezometers network provided for the conclusion pertaining the ground waters in the area under study.

Fourteen series of measurements for ground waters level on all installed piezometers and inclinometers have been carried out in the course of monitoring period (July 2002 – March 2005). The results indicate onto the seasonal variations with somewhat more pronounced maximums in the spring months, i.e. the minimums by the end of autumn. These variations are within the range of 1 m, which are obviously below the anticipated values. This fact can be corroborated by the functionality of constructed drainage system, whereby the entire surplus of infiltrated water from precipitations is brought down to rather uniform level.

By interpolation of results regarding the ground waters measured level, one may draw a conclusion that within the sliding body an aquifer has been formed with relatively stable static level. This aquifer is inclined along the slope

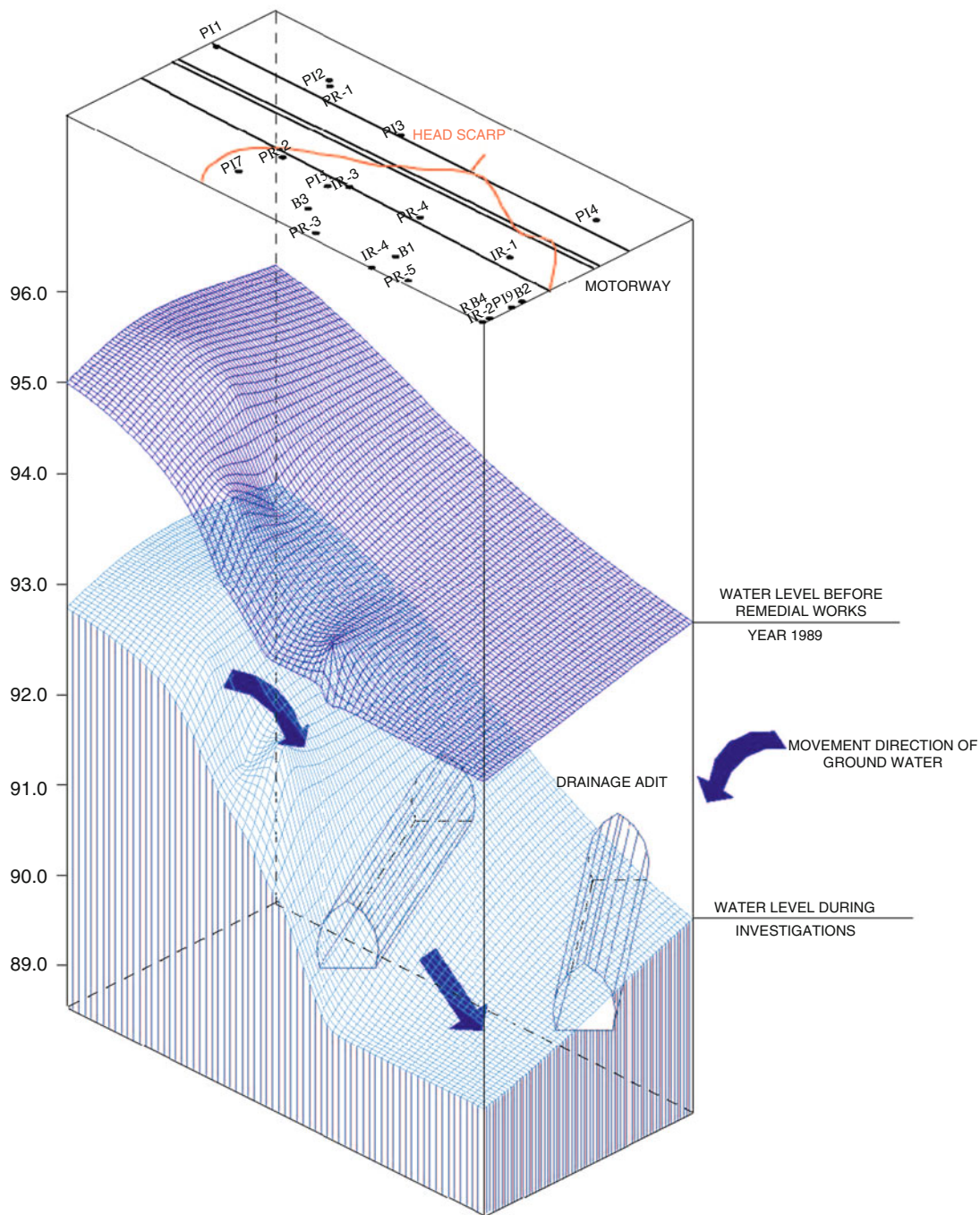


Fig. 7 3D review of ground waters level lowering

towards Nis township, which perfectly matches to the displacement vectors.

These results are of exceptional relevance, since one can compare them with the ground waters levels prior to the construction of drainage galleries/drifts, i.e. to establish the effect of the drainage itself. Namely, Fig. 7 is showing 3D review of ground waters level lowering after putting two drainage galleries into operation. It is obvious that the basic cause of slowing down the sliding process is the fact that ground water level within the short period has been lowered

for 4–5 m and mostly within the zone of activity performed by drainage facilities (Fig. 6).

Conclusion

Terrain deformations caused by the landslide appearance, not only exert the influence directly onto the stability and security of road traffic operations, but also endanger the security of the population living nearby. Road improvement works and reestablishment of previous conditions call for extensive financial funds. That is why it is

necessary to recognize all potential (active and calmed) landslides, at an early stage of appearance, through their recording, investigation and monitoring in order to prevent the sliding processes phenomena of larger proportions.

Since this is the most rational way of investigations, monitoring on the landslide should be continued as it was the case in the past, while the attained results are of high relevance, and thereby the effects of previous repair measures are evaluated and remaining works directed towards further implementation.

The remote location of many landslides has also created an urgent need for systems that can be monitored automatically and remotely in order to provide immediate warnings in the case of failure signs. Due to widely availability of modern electronic instrumentation it is possible to monitor landslides more effectively and economically. This is the direction the monitoring programs in Serbia should evolve to.

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