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LANDSLIDE INVESTIGATION ASPECTS

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Landslide processes are a distinct phenomenon with a huge impact on human way of life. Those gravitational movements in the upper layers of the crust can have a dramatic effect in river valleys, coastal regions and mountainous terrains. The reasons for their existence and development lie in naturally occurring processes in the lithosphere and the atmosphere and large-scale human activity. Investigating various natural and anthropogenic phenomena is vital, with attention to climate change processes. In the report of the European Commission (2012) an alarming level of erosion and abrasion is observed, with more than 630 000 areas with landslide processes. According to MRRB in Bulgaria there are near 2000 zones with active movements. The current investigation focuses on a fragment of the Bulgarian coast prone to landslide that was researched in 2017. The first registered movements date back to 2010. Characterizing for this case is the relatively quick developments of the movements, which affect urban areas. This publication revolves around a complex engineering investigation, which provides an understanding how and why activation processes in the researched zone form, while using well-known proven methods. The used techniques for investigation focus on usability issues, as well as on the opportunity to corelate different sets of data, gather important information and reinforce it with monitoring. The focus here is on these three combined steps: information, prediction, monitoring.

Keywords: Philosophy of engineering observations, Methods of predictions, Landslide fragment, Inclinometric monitoring.

1 INTRODUCTION

Landslides, as a natural manifestation of the lithosphere, adversely affect human activity. It is this particular feature that deeply excites people, and these processes have a particularly severe impact on the engineering infrastructure. The problem is exacerbated when movements also affect urbanized territories because their impact directly affects human activity.

Investigating these processes, related to a large empirical dataset, is one of the well-known practices and, at the same time, a necessary activity to be carried out by national services. That's why this activity is a major goal in complex large-scale research into the problem (CORDIS 2012). Here, given the established practice in Bulgaria, emphasis should also be placed on the sufficiency of publicly available information that generates general public awareness.

In common practice, preliminary engineering studies of these processes involve a complex of directions, including:

- General engineering studies - topography, surface water runoff, erosion, abrasion, available engineering infrastructure and its impact on landslides; micro seismic studies, etc.

- Geological engineering studies - the structure of the geological formation and its changes in past periods; petrographic and mineral composition, physical and mechanical characteristics of the individual structural units.
- Engineering and hydrogeological studies - water movement in the aeration zone, nature of migration in the underground horizons, mineral composition, etc.
- Hydrological engineering studies - scope and characteristics of the catchment area, soil cover and vegetation, rainfall quantities and periods of their study.
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Following these concepts, the authors share their experience of preliminary exploration of a fragment of the seashore (nearshore and hinterland), which, through the results obtained, draw attention to some aspects of landslide slopes which manifesting as slow movements (mainly in hinterland). These movements are characterized by their most unpleasant features, they are difficult to model and as a result - for prediction. These are the main reasons a priority to the analytic-observational approach to be given in the similar situations.

2 FEATURES OF THE SITUATION

The written records of the observations in the area under consideration date from January 2000. Active movements with significant impacts on the urbanized territories developed after June 2014 and January - February 2015. The only records for the landslide slope behavior before 2014 come from inhabitants of the area and from them it is hard to determine both a chronological order and to make an estimation of the speed of these processes. One important detail of these fragmentary records suggests that all higher-speed movements are activated during heavy rainfall.

Until the beginning of 2015 there are no data on studies, measurements and mapping of the landslide. According to the testimony of the property owners, movements in the massif were manifested in 2000-2002, provoked by an accident in a street water supply system. After this period, there was a certain lull.

Second, the broader activation begins in early spring 2010 after heavy snowfall. After reasonable settling, active movements were detected in the beginning of June 2014 with a range of 4-5 m from conditionally “healthy” terrain. In the time period boggification of the landslide base occurred and in the boundaries of the steep section underneath the landslide body landmasses slid into covering the seawall.

The characteristics of the landslide after in situ inspections and the registered results from movement give us reasons to classified the landslide as "Hanging", which implies the absence of a counterforce part and, as a result, an inability to stabilize naturally. General view of landslide toe can be seen in Figure 1.

Surveys conducted in August, September and October 2017 revealed some significant marks in the following aspects:

A landslide (main scarp) has been formed with a change in elevation of the terrain surfaces of 5-6 m. in the minor scarp the Cracking systems up to 20-30 cm wide can be observed and with numerous breaches in the buildings and road infrastructure nearby. More than 20 single-family buildings have been destroyed.

Following these initial findings, a series of studies were conducted in the fall of 2017 to determine the causes and design the measures to temporarily and permanently stabilize the array.

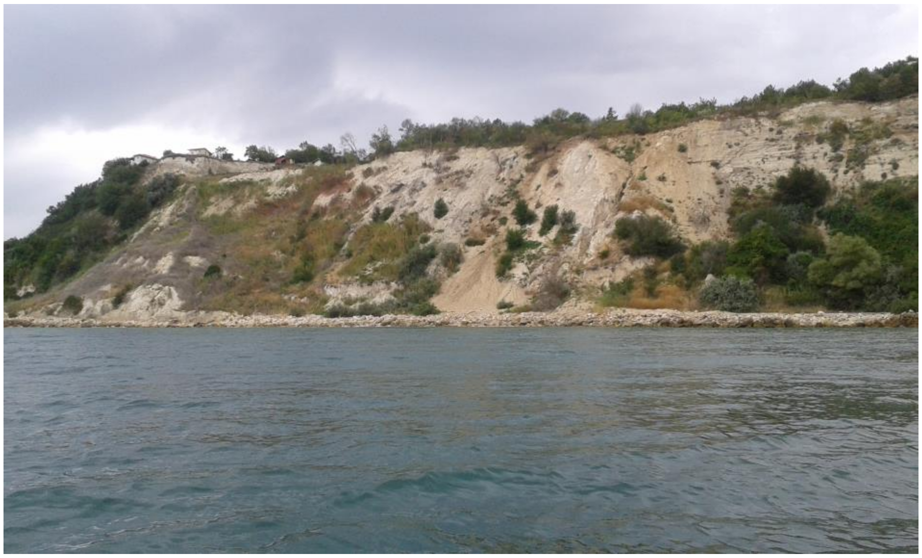

Figure 1. General view of landslide toe.

3 SCOPE OF THE RESEARCH

In the initial phase of this project, large-scale geodetic measurements were developed, including mapping of visible slope elements. These measurements, also made for the underwater coastal slope, created the conditions for determining the structure of the geometric model of the landslide.

Climate research for the purposes of the project includes summarized data from a 25 year period of observations of climate factors relevant to the problem. The geological and hydrogeological studies have been developed with the execution of drilling workings up to 100 m deep, and for the purposes of analytical models, in situ data have been collected and laboratory tests of standard type have been conducted.

Hydrological surveys cover an area of 50 ha and determine the directions and water quantities from all drainage areas in the zone.

As a result of the interdisciplinary engineering studies, the type and geometrical situation of the engineering infrastructure were identified and a qualitative assessment of its influence over the landslide was carried out.

In the final phase of the survey, studies were carried out on almost every element of the environment, because it was established during the study that each of them had a cumulative effect on the movements. The scale and volume of the research and the deterministic forecast created are dictated by the fact that another 50 buildings are at risk of landslides.

Detailed studies comprise the following components of the medium:

- General engineering studies - topography, engineering infrastructure, type of construction, impact on the anthropogenic environment.
- Climatic factors.
- Engineering geological and hydrogeological studies. Construction of the elements of geological monitoring.
- Hydrological studies with assessment of erosion and abrasion factors.

The survey and the subsequent analysis identified several key factors that played a crucial role in activating movements in massif. These factors turn out to be mainly of natural origin i.e.

the inappropriate situation and elements of transport infrastructure create conditions for the negative impact of natural processes. The construction of the road (embankment body) in the late 1970s blocked the way for natural runoff of surface water. For the past 30 – 40 years this creates conditions for water to be redirected in the direction of the horst part of the massif, which process reached the bottom of the silty-clay materials that slid there during the Pleistocene.

The results of the climate data analysis sharpen the attention to the rainfall situation in the area. Figure 2 summarizes the results for the annual precipitation amounts for the twenty-five year period.

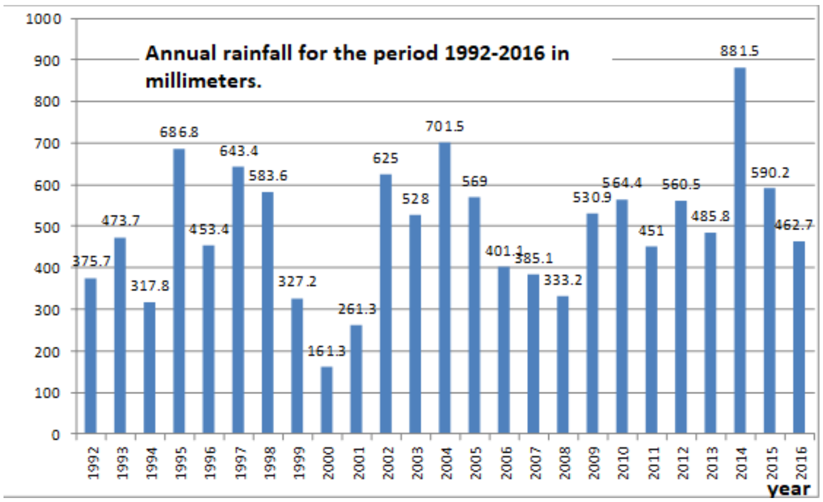

Figure 2. Annual precipitation amounts for a 25 years period.

These conclusions are confirmed by the drilling work performed, the electro-profiling of the slope, subsequently followed by the piezometer system. The conducted survey found, and it was confirmed with the two-years monitoring period that changes in groundwater levels are significantly more affected by annual seasonal cycles than by anthropogenic activity.

With the data of the conducted researches, three-dimensional model (Figure 3) was developed for predictive analysis of:

- Topographical features.
- Hydrological processes.
- Geotechnical behavior of the massif.
- Hydrogeological processes.

For each of the model groups, a series of model predictions were investigated, which were defined for continuous verification of the monitoring data.

The models and research methodology used are subject to a verification procedure that is still under development. It is important to note that the overall process modeling is started with the established characteristics and factors in the viewing area and, based on the monitoring data, has been tracked and further developed so far. Geotechnical deterministic analyzes have been developed in two directions - internal bearing capacity using usual models (Fellenius-Terzaghi, Bishop, Morgenstern-Price) and using methods, based on constitutive soil models (Laide 2005), taking into account consolidation and creep. The forecast with regard to the long-term deformability of the massif is verified (Todorov 2017) at the moment with measurements from the inclinometric monitoring system.

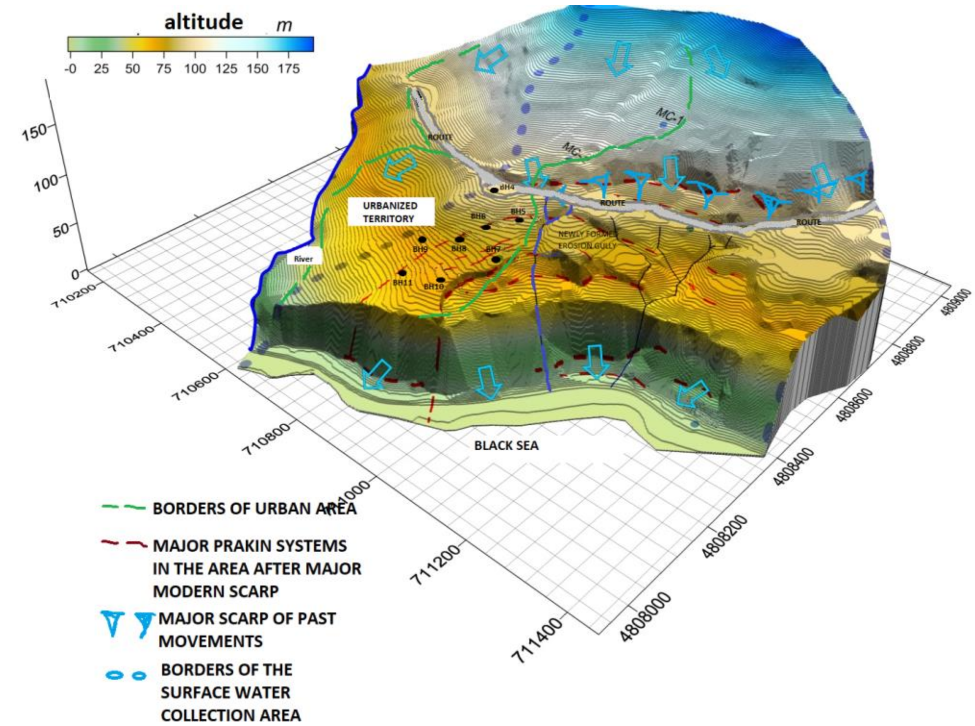

Figure 3. Three-dimensional topographic and hydrological model.

4 CONCLUSIONS

The study of the landslide fragment in this case indicates the appropriate selection of methods, which utilize conventional techniques. It is important to note that their complex consideration is a key factor in identifying the reasons for activating movements today.

The research here proves the importance of considering the actions of the past in building up elements of urbanized territory and drawing conclusions from these as factors for identifying movements of the massif.

The processes of the past are a solid model to follow when creating forecast models and conducting future monitoring. The parameters of their study are conveniently identifiable using field survey techniques.

In this particular solution' approach, it is important for us to formulate computing models, which can reliably predict ultimate limit states both in the process of building and exploitation. Because of the complex character of the massif this can hardly be done with only one model.

The measured displacements through the massif-based inclinometric monitoring system recorded movements at creep speeds (see Figure 4). In different parts, the velocities range from 0.01 to 0.1 mm / day. The usage of the results and the generated consolidation models give us grounds for optimism in the estimation of movements.

The process of choosing the design concept must go through a series of procedures of correction and to be implemented according to verified prognosis. This is the reason for those measures to be conducted one by one, while observing their effect on every single step.

A lot of attention has to be paid to the stabilization concept. In this particular case after all the surveying, prognosis and analysis the following solutions are being proposed:

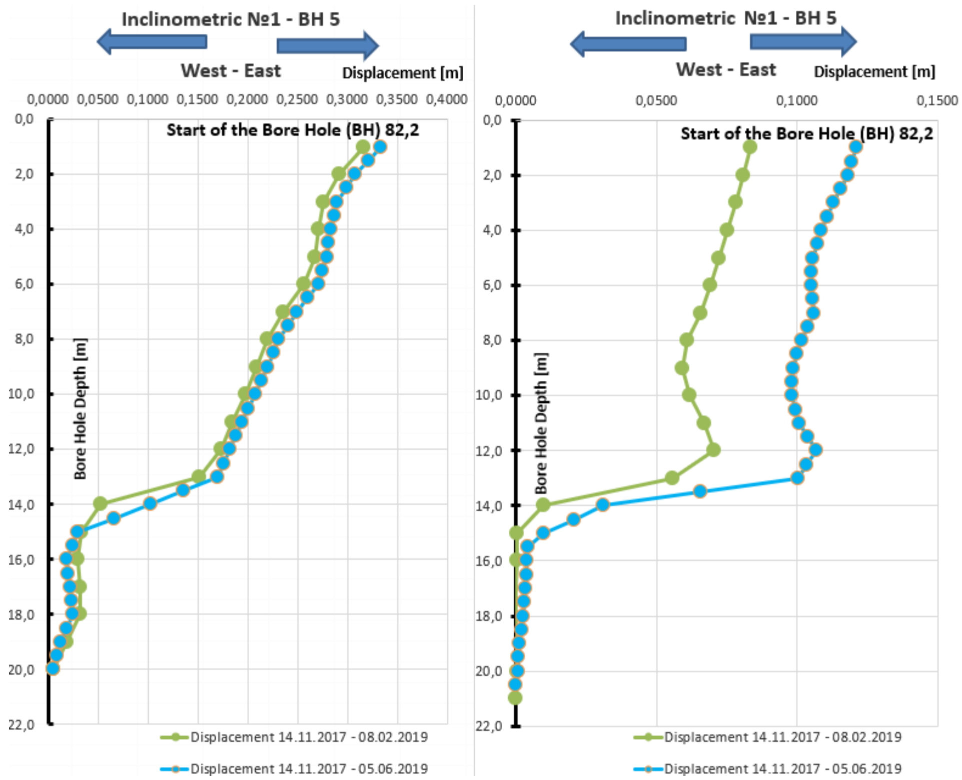

Figure 4. Results from Inclinometric monitoring.

- Amending the outflow forms for the movement of surface water.
- Construction of drainage systems in depth of the damaged part (the massif with cracks after the main contemporary scarp) from the massif.
- Remodeling terrain treatment solutions as the only possible solution for the hanging landslide.

From the conducted analysis we can conclude that in those situations the success can be achieved through the usage of large volumes of information, gathered via past processes and their follow-up theoretically-observational techniques. Those cases require not only the detailed surveying of the parameters of the environment, but a prolonged observation and systematic incorporations of treatment measures, which considering the scope of the works can be quite economically demanding.

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