International Conference on Case Histories in Geotechnical Engineering
(2008) - Sixth International Conference on Case Histories in Geotechnical Engineering

15 Aug 2008, 1:30 pm - 3:00 pm

Landslides in Balchik –The Biggest Nature Experiment for Shore Protection in Bulgaria

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LANDSLIDES IN BALCHIK – THE BIGGEST NATURE EXPERIMENT FOR SHORE PROTECTION IN BULGARIA

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ABSTRACT

The nice ancient Bulgarian town Balchik is situated on deep (70m) landslide on the Bulgarian Black Sea cost. The genesis of this enormous landslide is supposed in last geological periods when the Black Sea level had changed around 300m. The geologic structure is a celebrated combination of Sarmat limestone, marl and sensitive clay. The mechanics of failure reminds the landslides of Ankoridge (Alyaska) from 1962 even without tsunami. Through 80-th and 90-th years of the last century the landslide has been protected by the complex of, maybe, all known means for Cost protection and the aim has attained. The complex includes general precautions (ruble groins, spur dykes, drainage gallery…), many local precautions (pre-stressed anchors, drilling drainages, buttresses, walls…), additional precautions (rehabilitation of canals, reconstruction of buildings…) etc. In the report are presented the erected protection complex, some studies results of the monitoring. The study of the landslide had started from the beginning of the last century and the monitoring and analysis of the protection is from the end of the last century.

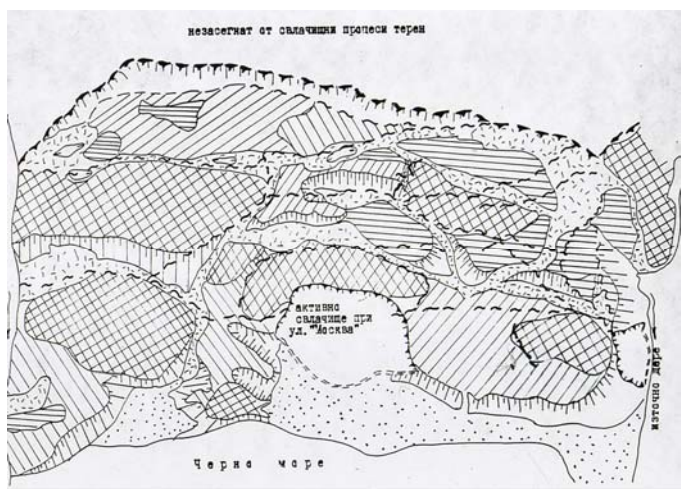
INTRODUCTION

Bulgaria is located on the Balkan Peninsula where landslides are a typical geological phenomenon. To the East the county borders with the Black Sea. The beautiful ancient town of Balchik is located on the Black Sea Coast and is situated upon a deep (70m) landslide.

I. LOCATION AND TOPOGRAPHY

The town of Balchik is located in the northern part of Bulgarian Black Sea coast. The first records about sliding of earth masses in this region date as far back as Roman times. However, landslides have been subject of observation, description and investigation only for 70-80 years.

Landslide phenomena have spread all over a large part of the steep coastal slope. The width of the main zones of depletion reaches up to 500-600m, and length varies within the range 1-2 to 4-5 km. the landslide scarp of the main zone of depletion of ten reaches 40-50m height, and the landslide tip can be traced in the shallow coastal part of the Black Sea basin, down to elevation of about-6,0m. Active landslide processes are reflected in the specific relief with plenty of negative and positive forms. The elevation difference between landslide crest and landslide tip measures up to 160-180m.



II. GEOLOGICAL CONDITIONS

Fig.1. Geomorphologic plan of Balchic

The area under investigation is a build up sedimentary rocks dated as Sarmatian. Three horizons of Sarmatian have been distinguished (*Fig.1*):

- Upper, Limestone horizon, made of organogenesis limestones, of thickness 15-20m;

- Middle, limestone-marl horizon, which can be subdivided into two complexes: Upper complex, consisting of marls and thin intercalated beige calcareous clays about 30m thick, and Lower complex, composed by marls, darker colored calcareous clays, alternating with limestones and calcareous sandstones. The thickness of the Lower complex reaches approximately 50-70m.

- Lower, clay-marl horizon, made of silt clays, slightly cemented sandstones and clay marls. This horizon is characterized by high plasticity of the clayey materials.

The landslide processes have developed mainly in the Middle and Lower Sarmatian horizons (*Fig.2*).

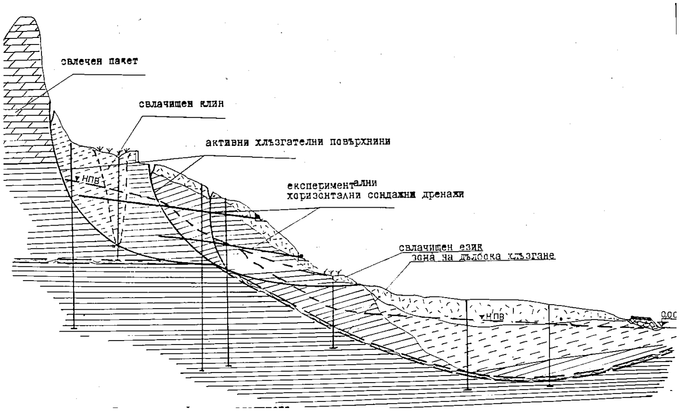


Fig.2. Cross geological section through Balchik's landslide

III. HYDROLOGICAL CONDITIONS

Four aquifers have been found in the landslide area. The first aquifer is formed in the Upper Sarmatian limestones. They are jointed, with highly developed karstification and represent an appropriate structure for significant groundwater accumulations. Groundwater flow is directed towards the landslide zones of depletion, where great quantities of water come from that aquifer. Dynamic flow rate is $1800 \div 1900 m^3$/day in water abundant seasons.

The second aquifer is found in Middle Sarmatian calcareous clays and clay marls. It has a low storativity and is characterized by low values of the coefficient of permeability, ranging from 0,5 to 2,0m/day. The recharge of this horizon is realized predominantly by water, flowing down from the upper aquifer through lithogenetic joints.

The third aquifer was found in the Lower Sarmatian sediments. It is attached to single lenses and intercalated beds of weakly cemented sands. It is characterized by artesian water, the piezometric level being fixed at about elevations of +3,00 and +5,00m. The coefficient of permeability is approximately 12,0m/day.

The fourth aquifer is set up in the landslide materials. Negative relief forms in the landslide body (landslide grabens) are the main water-bearing structures. The recharge of this aquifer is realized by water flowing down from the first and second water-bearing layers, as well as by sewage.

IV. CAUSES FOR THE MASS MOVEMENTS

The local slope geometry (steep to nearly vertical) contributes significantly to the formation of overstressed zones in the massif.

Individual layers from lower Sarmatian complex, composed by clays with high plasticity index, liable to creep, with low shear strength, are not able to resist the high shear stresses caused by the specific slope geometry and undergo deformations. Together with deformations of layers, located at the base of the slope, tensile stresses occur in the zone of landslide crest. Characteristic joints appear in this zone and huge blocks break away from the massif. This process is probably accelerated by seismic impact, because the area is of IX grade of seismicity, according to MSK scale.

Sliding takes places in slip zones, built up of highly plastic clays, located in the Lower Sarmatian. Primary landslides formed in this manner classified according to Skempton-Hutchinson as compound landslides, and according to Kamenov-Demirev (1965)-as deep step-shaped linear landslide.

Different human activities, leading to undercutting of the slopes, overloading of the landslide scarps, as well as increase of water content of the earth masses, give to secondary landslides. The survey of a reference point network, carried out for 20 years, has shown that the primary landslides move at a rate of 0,03 to 0,7m/year. The general direction of the movement is towards the sea coast. Secondary landslides move 25 times quicker that primary ones. They are particularly dangerous getting activated in a very short period of time and about great damages.

V. SOIL CONDITIONS

On the basis of a large number of tested samples, taken from each one of the lithological horizons, the index properties as well as the strength and strain parameters of the soil in each layer have been determined.

It has been found out that single layers Lower Sarmatian are characteristic with lowest density, high plasticity and low shear strength. The material is classified as clay, according to the plasticity index.

For the reason of impossibility landslide zones to be drained in natural conditions, the residual shear strength was determined by undrained shear test. The values of the shear strength components, characteristic for the zones of deep landslides (primary landslides), obtained in this way are for the angle of internal friction 7° and for the cohesion 6 kN/m^2.

VI. HYPOTHESIS FOR THE PROVENANCE AND ANALOGY WITH SIMILAR CASES

Several times the level of the Black Sea lowered and rose substantially during the Glacial Period and the melting of the glaciers. It is no coincidence that the legends about the Flood are deemed to refer to it. Some authors even assume the possibility that there was a tsunami as a result of a strong earthquake, but this presupposes a much larger area of the sea. Given its location on a steep sea coast, geological structure and the large landslide, Balchik resembles to a large extent the town of Anchorage in Alaska. The difference is that the landslide in Anchorage was caused by a tsunami after a strong earthquake in 1962.

VII. CARED OUT INVESTIGATIONS AND MONITORING

Exploration of the landslides in the region of Balchik started at the beginning of the 20th century. A number of articles have been publishes, containing results obtained by Bulgarian, Russian and Italian scientists. The largest number of studies was conducted during the second half of the 20th century, when the landslides in the region were most active. The scientific and applied studies are in the area of geotechnics, geodesy, geology, hydrogeology, hydrology, seismology, and hydraulics.

VIII. COMPREHENSIVE SYSTEM FOR THE LANDSLIDE PROTECTION

The integral approach to the waterside reinforcement in Bulgaria has been most widely applied in the town of Balchik. Different aspects of the problems have been surveyed for the last 70 years, which lead to the accumulation of a solid basis for the emergence of design ideas.

The appearances of landslides of a different type, as well as the abrasion and erosion have been tracked in detail historically. Regime observations of many years have been conducted on different natural factors: winds, temperature and rainfalls, water motion, abrasion and alluvium movement, river flow, "geodynamic" processes, tectonic and seismic movements, etc. Former attempts for reinforcement served as examples for exploring their positive or negative effect.

The principle profile of the landslides in Balchik (*Fig.2*) corresponds completely to the theoretical profile presented above: there is a deep active sliding surface at a depth of 70 m from the terrain with a minimum below the sea level and with a sliding tong along the sea bottom. The eyebrow of the landslide is located at the border of the limestone Dobrudzhansko Plateau. Along the body of the landslide (within the boundaries of the old town) there are a number of more shallow local landslides of a different size and genesis, very often anthropogenic. While in the past the deep landslide was most likely caused by the sudden withdrawal of the sea, currently the waters of the karst limestone of the plateau mainly feed the slope and support its slow movement towards the sea (*Fig.1*) and (*Fig.2*). An integral approach of reinforcement was applied to this generally presented picture.

The general measures undertaken at the highest level include the construction of a drainage gallery behind the landslide, which would reduce substantially the feeding up with underground waters. For this purpose 150 vertical drainages were drilled in the gallery, each deep 35 m and at a distance of 6 m from the terrain of the plateau. As a result, the total drained water quantity varied between 15 and 28 *l/sec*. The construction of the gallery is part of the so called "safety measures" within the meaning of the classification presented above. A reinforcement stone levee was constructed in the zone of the sliding tong, with artificial beach behind it, which supported the passive area of the landslide profile and at the same time prevented any further abrasion of the coast and the formation of new local landslides.

In addition, a new jetty and breakwater were constructed as a result of the finding that no sufficient alluvium is retained in this area, with the southeast winds taking it away (*Fig.3*).

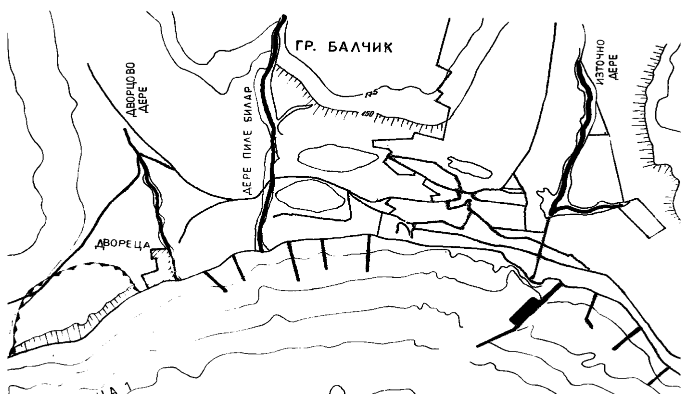


Fig.3. Plan of old cost protection structures in front of Balchik

The *second level* of general measures includes the complete replacement of the water supply network with cast-iron and high density polyethylene (HDPE) pipes with flexible connections. The sewerage network was also reconstructed. The street surface and sidewalk pavement were repaired in order to ensure the fast drainage of water and reduction of the infiltration to the minimum.

The *local measures* can be presented in two hierarchical levels:

The *first level of local measures* includes the reinforcement of the small residential complexes or the zones around more significant sites, such as the zones around the town hospital and bus station, the slope underneath the largest school in the town, the area around Moscow Street (*Fig.4*) and Tymok.

Street, the whole East gully, etc. In most cases, the reinforcement systems which were applied represent a combined action of horizontal drilling drainages and pre-strained anchors (*Fig.5*).

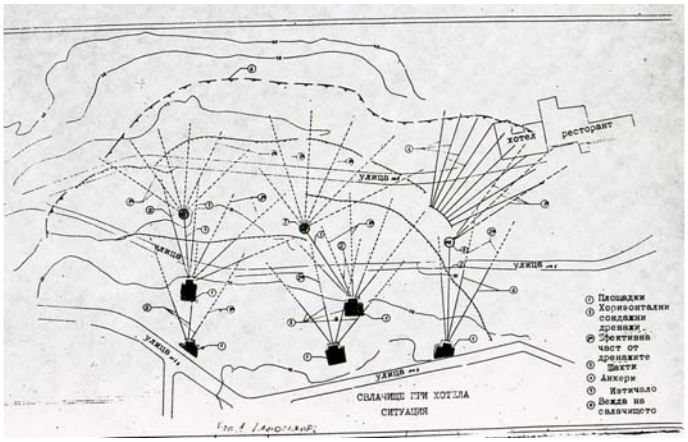


Fig.4. Plan of the protection system under Moskow Str.

The *second level of local measures* includes the reinforcement of the land base under individual buildings, some of which are cultural monuments.

Fig.5. Construction of pre-strained anchors in Balchik (1988)

The regular precise geodesic measures indicate that the reinforcement systems constructed in the old city have a positive effect. The local landslides have been reinforced completely. The movement along the 70 m deep sliding surface has been reduced to below 55 mm per year.

The processes outside the area of the old town, i.e. to the south of Balchik, continued to develop. The analogical complex reinforcement schemes that were prepared for this area were not implemented in time due to the lack of sufficient funds. Later the works proceeded directly to the construction of the first level of local measures (for example, the reinforcement of the zone above the area "Ovcharov Plazh" and around "Sviloza" hotel), but the final effect has not been reached yet.

It is true that the category of significance of the terrain decreases for the zone to the south of the town of Balchik and it is difficult to prove a fair value of the direct economic effect of the construction of a drainage gallery as a highest level of general measures. Instead, the emphasis is placed on the second level of general measures such as the reconstruction of the water pipes and sewages, leveling and drainage, as well as on the local measures such as the reinforcement and drainage of the individual zones and buildings.

As compensation it would be reasonable to look for a technology for deep drainage of the landslide body in the zone of the landslide wedges under the eyebrow, even with the cost of seasonal work of the drainage pumping station.

The lack of reinforcement equipment at the heel of the landslides to the south of Balchik also presents an unresolved problem, whose impact will always be felt. Environmental considerations also have a determinant influence and, all things considered, we could make the conclusion that the complex scheme for the reinforcement of the old town could no be replicated for the reinforcement of the landslides to the south of Balchik. In the general context it is reasonable to implement a solution, which includes a different type of reinforcement. In order to reinforce the surf area and the tong, an underwater breakwater could be constructed for the protection of a large artificial sand beach, at the rear of which there is a natural construction for reinforcement and passive protection of the steep slope.

IX. CONCLUSIONS FROM THE INVESTIGATIONS AND LANDSLIDE PROTECTION

The large deep landslides, such as the one in Balchik, could be reinforced with a complex of diverse and mutually related technological measures, which would effectively counteract the powerful cutting efforts in the soil and the sea abrasion. These measures are subordinate to a certain structural and technological order, without which the final effect could not be easily attained.

The experience of reinforcing this large landslide and the restoration of the beautiful sea town represents a valuable natural experiment, which could serve as an analogue for other similar cases.