Review on the applied methods for landslide control in Bulgaria

Revue des méthodes appliquées pour le contrôle des glissements des terrains en Bulgarie

M. Hamova, G. Frangov, H. Zayakova
Higher School of Civil Engineering "L. Karavelov", Sofia, Bulgaria

ABSTRACT
The territory of Bulgaria is characterized by active tectonics, which had determined the formation of hilly and mountain relief. The geological structure is rather diverse and includes both rocks and dispersed soils. Under the effect of the naturally occurring processes thousands of landslides with different volume, mechanism and dynamics are displayed. The construction of various facilities, roads and buildings under these conditions is connected with the performance of excavations and embankments, changes in the groundwater level and dynamic impacts, leading often to slope instability, appearance of new landslides and activation of old existing landslides.

The stabilization of slopes and prevention of landslide appearance occupies an important place in both new construction and exploitation of the already built facilities. The present work gives examples of different methods for landslide stabilization and makes brief analysis of their effectiveness. The more often applied methods include various types of vertical and horizontal drainages, changes of slope inclination, strengthening with reinforced concrete piles, anchors, retention walls, gabions, reinforcement of buttress embankments. Special attention is paid to landslide monitoring as a substantial element for predicting their development and as initial information for selecting a suitable set of preventive and stabilizing measures.

The main conclusion based on the investigated cases is due to the multifactor character of the landslide process the maximum stabilizing effect is achieved when the applied measures are aimed at the factors having the highest weight impact on slope stability.

RÉSUMÉ
Le territoire du pays est caractérisé par une tectonique active, qui détermine la formation d'un relief de collines et de montagnes. La structure géologique est très variée et inclue non seulement des rochers, mais aussi des sols dispersés. Le résultat des processus naturels est la création de milliers de glissements de terrains avec un volume, un méchanisme et une dynamique variables. La construction de différents ouvrages d'art, de routes et de bâtiments dans ces conditions est liée souvent avec la nécessité de faire des excavations et des remblais, de modification des niveaux des eaux souterraines et des impacts dynamiques qui perturbent la stabilité des versants et provoquent la création de nouveaux ou l'activisation des anciens glissements des terrains.

La stabilisation des versants et la prévention contre la création des glissements des terrains ont une importance cruciale non seulement pour les nouvelles constructions, mais aussi pour l'exploitation des ouvrages d'art déjà construits. Dans ce rapport on montre des exemples des différentes méthodes de stabilisation des glissements des terrains et le synthèse d'un analyse de leur efficacité. Les méthodes les plus utilisées sont les différents types de drainages, des déblais, la stabilisation des terrains avec des piliers de béton armé, des ancrages, des murs de soutènement , des gabions, des remblais de contre-forces armés. La supervision, le contrôle préventifs des glissements est un élément important du pronostic de leur développement et c'est une information de base pour le choix des mesures convenables de prévention et de stabilisation des glissements des terrains.

Le processus de glissement dépend de plusieurs facteurs et l'effet maximal de stabilisation des glissements est le résultat de l'application de mesures qui s'adressent aux facteurs qui ont le plus grand poids pour stabiliser les versants.

Keywords: landslide distribution, drainage, anchoring, reinforced embankment, monitoring

1 INTRODUCTION

The complex geological and geomorphological conditions on the territory of Bulgaria predetermine the origin of a rather big number of landslides affecting river banks and sea coasts, mountain slopes, peripheral zones of kettles. Landslide volumes vary from tens of cubic meters to hundreds of millions cubic meters. Only in the settlements there are about one thousand landslides, another thousand affect the infrastructural facilities in the country (Iliev- Brouchev, 1994). Various anti-landslide measures are applied in order to prevent the origin of landslides and their consequences. Their effectiveness depends on the reliability of the initial data about the landslide mechanism, the position of the sliding surface and the physico-mechanical parameters of soils, the selected approach to slope stabilization, the precise and high-quality performance of the project, the monitoring and maintenance of anti-landslide structures.

2 DISTRIBUTION AND ACTIVITY OF LANDSLIDES

A considerable part of the riparian Danubian bank is occupied by ancient and contemporary landslides, which are activated during different time periods (Figure 1). Catastrophic landslides occur rather frequently – their consequences are very serious and the measures for ensuring counter-effects against their destructive impact are rather difficult, expensive and not always effective. More than 15 catastrophic slides were displayed along the Danubian bank during the period 1950-2000. They are irregularly distributed. Concentration of high-velocity sliding is

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-1646

Figure 1. Distribution of unstable slopes on the territory of Bulgaria

observed within the range of the Lom depression, in the region of the towns Tutrakan and Nikopol.

The distribution of landslides is irregular with time. Certain cyclicity is observed, which is more clearly expressed in landslides with broader range – with a depth of sliding surface H>20 m or volume V>1 million m^3. Activation is observed at every 8-10 years. The more shallow slidings occur more often – usually every 4 years. Shallow consistent slidings with low movement velocity are displayed almost every year in Oryahovo, Svishtov and Tutrakan. According to their seasonal distribution the shallow catastrophic landslides are concentrated in the periods March-April and October-November. The bigger number of slidings in spring compared to these in the autumn is related with the additional impact of precipitation and snow thawing. The occurrence of deep landslides in time is within a broader range – from February till May and from October till December. Their monthly distribution is almost regular and shows that the reasons for their display are related not only with the water saturation of the slopes but also with results from the impact of various factors.

The landslides along the Black Sea coast originated during the Quaternary (Kamenov et al, 1973). The greater part of them is temporarily stabilized at the present moment. The big landslides are developed mainly in younger geological formations. Their origin and multiple activation depend on the natural conditions, the naturally occurring processes and technogenic factors. The landslides are situated in the zone between the seacoast and the coastal plateaus and plateau-like flat areas. The depth range of ancient landslides reaches up to 80-100 m in the zone of the main landslide slope and up to 10-15 m below the sea level in the landslide tongue (Stoykov, Evstatiev, 1983). Once subjected to landslide deformation and displacement, the rocks and soils strongly diminish their strength parameters and are transformed into a suitable medium for repeated reactivation of the landslide process (Stakev et al, 1994). The distribution of the landslides with time shows the existence of certain cyclicity, which is more clearly expressed in the landslides with broader range. The periods of enhanced landslide activity are repeated every 10-15 years. The seasonal distribution shows concentration of slidings in the periods March-May, which is related with the spring maximum of precipitation and snow thawing in combination with other destabilizing factors – strongly expressed erosion and abrasion, technogenic activity and earthquakes. More than 30 relatively small landslide activations were manifested in the range of these ancient landslides during the last 50-60 years (Koleva-Rekalova et al, 1996).

A significant number of landslides have been recorded in mountain massifs too. Some of them affect considerable areas and the landslide movements are realized at big depths. The more important landslides in the Rhodope Mt. occur to the south of the town of Kardzhali – the so-called "Schupenata planina" (the Broken Mountain), near the villages of Lebed, Ustren and General Geshevo (Nenov, 1968). The landslide near the General Geshevo village was activated in the spring of 1999. A prism of active earth pressure emerged in the zone to the south of the "Karaboruntepe" elevation with width (in north-south direction) of 70-100 m and length (east-west direction) of about 600-800 m. The landslide movements exert impact on a mountain massif built predominantly of Paleogenic pyroclastic materials – tuffs. A mirror sliding surface is formed in them at some places with vertical displacement of about 6-8 m. The collapse of the terrain is within the range between 5-8 m and 15-17 m at some places, the maximum values being observed in the western part. The landslide is of the detrusive type with lateral thrusting of the earth masses. Its dimensions are – width of 1300-1500 m and length of 1900-2000 m. The maximum depth of sliding is about 90-120 m. The approximate volume of the slid earth masses amounts to 150 000 000 m^3. This is the biggest active landslide at present in Bulgaria. The regions with medium degree of hazard are the peripheral parts of the kettles, river-valley slopes, hilly lands in the Fore-Balkan, parts of the Central and East Rhodopes. The basic destabilizing factors here are earthquakes, groundwater and anthropogenic activity.

3 SLOPE STABILIZATION AND PREVENTION OF LANDSLIDES

Diverse methods are applied for slope stabilization and protection of structures against the unfavorable consequences from landslide activation.

The basic method for stabilization of landslide terrains is drainage, which might be surface, depth and most frequently – a combination of both types. The climate of Bulgaria is characterized by four seasons, two of them – winter and spring, being related with significant accumulation of water in the surface layer. The same effect is observed also in summer due to floods, provoked by the considerable amounts of precipitation related to the global warming. In addition, groundwater in a significant part of the territory of the country is situated close to the terrain surface.

The drainage facilities used are horizontal drainage galleries (town of Balchik), vertical shafts with horizontal drainage boreholes, drainage ribs and horizontal drainage of rock material (landslides along the Fore-Balkan, the Danubian plain, the Black Sea coastal area, mountain terrains in South Bulgaria). Facilities as culverts, lined trenches, concrete pipe drainage, Italian catch-drain with concrete gutters, etc., are built for preventing slope erosion.

Slope re-shaping of the terrain is an effective and ecologically friendly method for reducing the weight of the active part of the landslide and increasing the retention forces. The landslide body is frequently shaped as steps with berms (inclination of 2%) allowing surface water to flow away. This method is usually applied in combination with ribs of drainage material, yielding excellent results. The method is effective and is applicable for consistent landslides, situated on terrains, which are state property.

It is extremely difficult to stabilize the deep landslides along the Danube River valley, where vast terrains are occupied by the loess formation, as well as the terrains along the Black Sea coast, built of clayey-carbonate deposits. Numerous settlements are affected here, some of them being of high historical value. The reasons for destabilization of these terrains are not only natural ones due to the typical geological structure and climate features, but ensue also from anthropogenic factors. For example, the fishermen settlements, founded millennia ago, today are towns with thousands of inhabitants, consuming vast quantities of water coming from the interior of the country. A part of this water is spilled on the terrain – for cultivation of the environmental space, irrigation and in some cases – due to lack of sewerage. This additionally increases the risk of terrain destabilization. In these cases the construction of water-tight sewerage is included as an element of the anti-landslide project to prevent flooding of the landslide.

Sometimes the landslides affect entirely the building fund and infrastructure and it is economically more profitable to remove the settlement or the threatened part of the road on strong terrain than to stabilize the whole landslide. In 1979, the whole village of Orsoya, to the west of the Lom town, was moved due to the activation of enormous land sliding. In 1983, it was necessary to build the waste water treatment plant of the Sofia City on a new site. In 2006 another big landslide emerged on the Vidin – Montana road near the town of Dimovo, which necessitated the shifting of the road alignment (Stoynev and Lakov, 2006).

In some cases, when urgent rehabilitation of interrupted roads or railways is necessary, stabilization is performed not of the whole landslide, but only of the slope part, where passes the facility. Rigid structures are preferable – mainly stabilization with borehole-cast in-situ piles. A low retention wall is used as a grid. In deeper landslides the piles and the grid form framework structures. The piles are calculated as cantilever elements, elastically restrained in the soil beneath the landslide surface. For effective stabilization it is usually necessary that the anchoring depth is almost equal to the thickness of the landslide body. Then the calculated piles are deep, with big diameter and significant reinforcement. Certain reduction of dimensions may be achieved by anchoring the grid and taking a part of the landslide force by anchors (Figure 2).

The experience proves that sometimes pile stabilization is not very effective due to the possibility of material flowing between the piles. This happens when stabilizing slid road embankments built of unsuitable soils - silty clays, weathered marls, etc., as well as materials that had not been drained during the embankment construction. In these cases other types of stabilizing structures are preferred: retention walls with slits, filled with coarse rock material on the interior side, inclined anchored beams united by a longitudinal beam in their upper part. The structure of walls-plates, anchored between them-

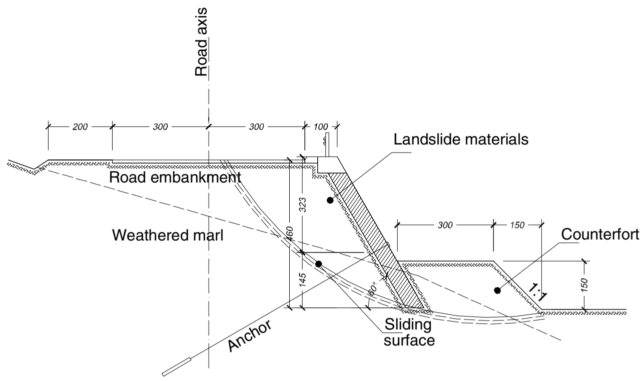

Figure 2. Anchored reinforced concrete beams

selves by a rigid anchor rod, turned to be especially effective for road embankments (Figure 3). The above mentioned structures were used for stabilizing landslides along the road infrastructure in combination with measures for effective surface and deep drainage by drains.

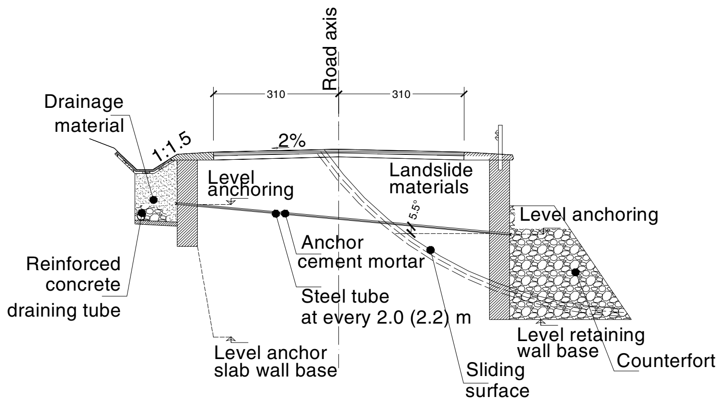

Figure 3. Anchored walls- plates

Effective stabilization of landslide terrains is achieved in Bulgaria by strengthening with flexible facilities of reinforced soil using geotextile, geo-cells, gabions and gabions with extensions for reinforcement of the embankment behind them. The above mentioned materials provide the possibility for effective drainage through the supporting structure's body, which leads to stabilization of the terrain (town of Svoge). The performance of a landslide stabilization project with gabions with extension is impending in the town of Tsarevo (southern Black Sea coast) (Figure 4). The retention walls of gabions are combined with drainage ribs made of drainage materials. The front part of the gabions will be made of dry stone masonry, which will protect the embankment from carrying away the soil by stormy sea waves.

4 MONITORING OF LANDSLIDES

Since landslide activation represents a cyclic process, special attention is paid to the monitoring, especially in cases when the sliding process is temporarily attenuated. The monitoring allows

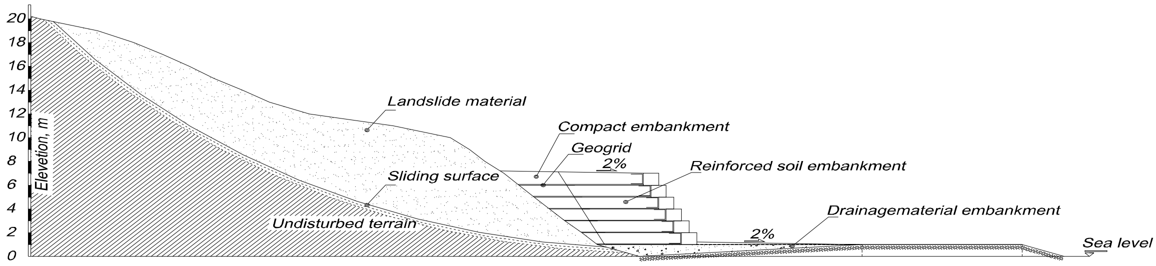

Figure 4. Reinforced soil embankment

to establish the moment of landslide activation and to select in due time the stabilization measures.

Geodetic and inclinometric measurements are most often used for recording the movement of the landslide body, as well as measurements of pore pressure and landslide water level. Most often the soil mass movement is recorded by means of geodetic measurements from several permanent benchmarks outside the landslide towards observed benchmarks along the landslide body. The geodetic measurements give the possibility of determining the velocity and direction of movement of the observed benchmarks, the zones of attenuation and activation, as well as of the mechanism of movement of the landslide as a whole. The "Ezerishte" landslide near the town of Svoge is observed at present using geodetic measurements.

The established velocity of movement and its dimensions qualify this landslide as a potential ecological threat for a vast region surrounding it.

The "Ezerishte" landslide endangers the Iskar River with damming with subsequent flooding of the town of Svoge and interrupting the main Sofia-Varna railway connection, which is of national importance for the economy of the country. It is difficult to stabilize a landslide with such dimensions, but preventive measures may be applied for restricting the consequences of its activation. The authors have launched the idea for the construction of a tunnel for the Iskar River flow with placing a rock material embankment on top of it, playing the role of an abutment.

5 CONCLUSION

The greater part of the Bulgarian territory is occupied by mountainous and hilly terrain. The specific features of the terrain and the climate and the enhanced urbanization contribute to the origin of landslides, which represent a threat for single buildings and facilities, as well as for whole settlements. Their territorial distribution is irregular and most of them are included in already established and known landslide regions – the Rhodope region, open pit coal mines.

The landslides affect mainly young geological formations – Paleogenic and Neogenic sediments and volcanites. The landslides have clearly expressed phases of development – preliminary in the course of many years, active, with duration of hours and days, and attenuating, lasting months and years. The consequences are devastating, catastrophic and difficult to overcome, especially when settlements, infrastructure and transport communications have been affected. It is most difficult to counteract big active landslides.

All known methods are used for landslide stabilization: reshaping of slopes, construction of abutments, drainage – surface and in-depth, applying strong structures, flexible retention walls of reinforced soil, etc. An important direction for reducing the landslide hazard is to enhance the preventive control and prophylactics during the construction of buildings and infrastructure on landslide terrains. This will provide the possibility of undertaking measures in due time for preventing the slides with much lower expenses compared to the case if they have already happened. Relevant attention should be paid to the monitoring of landslides as an important element for establishing their activation and to the selection of appropriate methods for their stabilization.

ACKNOWLEDGEMENT

The present investigation was financially supported by Project VU 12/06 of the "Scientific Investigations" Fund of the Bulgarian Ministry of Education and Science.

REFERENCES

Iliev-Brouchev, Il., 1994. The Geological Hazard in Bulgaria. Explanatory text and a map in scale 1: 500 000. Sofia, Bulg. Acad. of Sci., MTS-Troyan.

Kamenov, B., Iliev, I., Tsvetkov, S., Avramova, E., Simeonova, G. 1973. Influence of the geological structure on the occurrence of different types of landslides along the Bulgarian Black Sea coast. - Geol. Appl. Hydrogeol. Conf., Vol. 8, part 1, pp.209-220.

Koleva-Rekalova, E., N. Dobrev, P. Ivanov. 1996. Earthflows in the Baltchik landslide area, North-eastern Bulgaria. In: Proc. of the 7th Int. Symp. on Landslides, Trondheim, Norway, 473-478.

Milev, G., Pelzer, H., Eds., 1992. Instrumental Methods for Investigation of Hazardous Geodynamic Processes, Bulg. Acad. of Sci., Geotech. Laboratory, pp.508.

Nenov, T. 1968. Landslide phenomena in a part of the East Rhodopes (Kardzhali district). – Bulletin of the Bulg. Geogr. Soc., VIII (XVIII), pp.35-53.

Stakev, M., Frangov, G., Ivanov, P. 1994. Geotechnical status and stabilization of the bigger active Black Sea landslides. - In: Third Scientific-Practical Conference on Protection of Population against disasters and accidents, 8 - 9 XII, Sofia, vol. VI, pp.20-30.

Stoykov, D., Evstatiev, D. 1983. The landslide in the "Panorama" villa zone near Varna. – Eng. Geol. and Hydrol., 13, pp.20-32.

Stoynev, S., Lakov, A. 2006. Mechanism of development and evaluation of the stability of the landslide along the "Vidin – Montana" road near the town of Dimovo. National Scientific-Technical Conference "Condition and Management of Landslide and Erosion Processes in Bulgaria", pp.221-225.