Slope stability structures for road landslide

Structures de stabilité de pentes pour glissement de terrain

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ABSTRACT: Landslide had appeared on main road affecting more than half of the roadway and caused traffic difficulties. The landslide had a width in the top 55 m, length - 38 m and maximum depth of 8-9 m. Groundwater table rising, river erosion undermining the slope and the dynamic effects of transport were defined as key factors for slope instability. Cantilever retaining wall on driven pile's foundation, in addition with trailing plate and drainage facilities for landslide stabilization were designed and constructed. The monitoring of strengthened road section during the period 2006 - 2012, shows that the landslide was successfully stabilized and new landslide deformations have not been established.

RÉSUMÉ : Un glissement de terrain est apparu sur une route principale affectant plus de la moitié de la chaussée et perturbant terriblement le trafic. La surface de glissement avait les dimensions suivantes: largeur dans la partie supérieure - 55 m, longueur - 38 m sur une profondeur maximale de 8 à 9 m. On a considéré que l'instabilité de la pente était le résultat des facteurs suivants : nappe phréatique, érosion croissante provoquée par la rivière, effets dynamiques du trafic. Un mur de soutènement fondé sur des pieux, un sol renforcé par inclusion et des drainages ont été conçus et construits pour stabiliser l'ensemble. L'analyse du profil en travers de la route entre 2006 et 2012 montre que le glissement a été stabilisé et qu'aucun nouveau déplacement n'a été observé.

KEYWORDS: Landslide, slope instability, stabilization, cantilever retaining wall, driven piles, drainage facilities.

1 INTRODUCTION

Many landslides have appeared every year on the roads of Bulgaria triggering by various factors and causing serious traffic problems (Ivanov & Dobrev, 2006). Such landslide had occurred on the main road Ruse - Veliko Tarnovo in October, 2005. The landslide had affected more than half of the roadway and it had a width at the top 55 m. This part of the road for a few days had slide up to 70 cm. Wide open cracks had been clear observed on the roadway (fig. 1).

Tension cracks were hardly noticed without vertical escarp at the beginning of sliding. The impression was that only horizontal movement of the landslide had occurred toward the rest of the terrain. The appearance of the landslide was preceded by anomalously high precipitation. Overall it was a wet year, and the annual rainfall amounted to 163% compared to the norm. Rainfalls had formed significant surface runoff, increasing water levels in the river Yantra and the related increase in the levels of groundwater. The subsequent rapid drop in the river water levels had caused reverse filtration and occurrence of high groundwater gradient toward the river.

2 GEOLOGY AND CLIMATE

2.1. Geomorphology

The studied area represents a system of low hills with well-defined crests with west-east direction. More expressive heights are Tarnovo Hils with oversea levels - 300 to 400 m. Main artery Yantra River cuts through the Turnovo mountain forming pictorial Dervish Gorge. Belyakovo and Arbanasi Plateaus are located to the west and the east of the gorge. The northern slopes of Turnovo Hills are steep and there the Danube plain border is marked. The survey landslide is on the highway Ruse - Veliko Tarnovo on the left slope of the Yantra River. The slope is too steep to vertical at the top and low-grade - at the bottom.

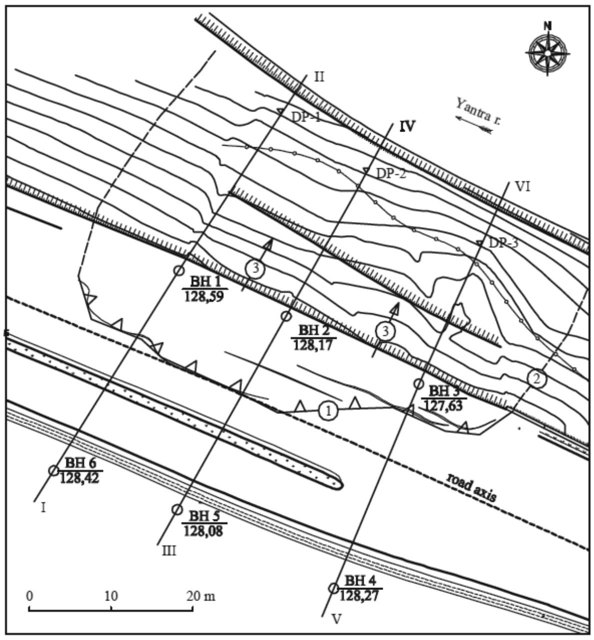

Figure 1. Location map of landslide: 1 - main scarp; 2 - lateral boundary; 3 - movement direction; BH 2 - borehole No 2; DP 1 - dynamic probing No 1; I - II - engineering geological cross-section

2.2. Geology

Territory in close vicinity of the site is made up of different by genesis and composition rock complexes (Chrischev, 1990):

Gornooryahovska Formation (gK1h-a). The Formation outcrops have wide area. The unit builds lower parts of the terrain and slopes of hills, crowned by a strong sandstone and limestone cliffs on its cover. It consists mainly of gray-blue to dove-gray clayey marl altered with some rare and thin layers of solid calcareous sandstones and softer unsorted clayey sandstones.

Balgarenska Terrigenous Formation (bnK1b-a). In the eligible area this formation consists of calcareous sandstones, silty clays and marls, which in places pass into lime-clay siltstones.

Emen Limestone Formation (eK1b). In Veliko Tarnovo region the lower parts of Emen Limestone Formation are presented. It is made of bio-detritus fine limestone, which are revealed in the ridge parts of the landscape. The thickness of the Formation is up to 200 m.

Quaternary diluvial and alluvial deposits are presented above rocky basement. Deluvial deposits are composed of sandy clays, coarse gravels and boulders. They are presented at the foot of the slopes. In some places deluvial clays have considerable thickness. Alluvial deposits build up fragments of first and second terrace above the Yantra River. Alluvial sediments include well graded gravels and sands and sandy clays.

The region belongs to the transitional zone between the Moesian platform and Fore Balkan. Southern boundary of the transition zone is traced unambiguously from Turnovo-Zlatarishky fault. On the surface, it is marked by longitudinal beam fractures, tearing sediments of Balvanska syncline. Northern border passes along the most significant gradient of facial changes and transitions sediment thickness formed during Middle Alpine stage. The transitional nature of the area is expressed in fold-block structure dominated by faults. The study area falls within the scope of the Tarnovo anticline.

2.3. Climate

Investigated area characterized by moderate continental climate. The average January temperature is -1 to -3,0° C and the average July temperature 23-24° C. The annual rainfall is 550-650 mm, with a minimum in February and a maximum in June. The west and northwest winds predominate. In 2005, significant rainfall exceeded the average monthly and annual rate (Table 1).

Table 1. Rainfall in the region before landslide (2005) (www.stringmeteo.com)

Month	Monthly Rainfall, mm	Compared Rate, %
05	113,3	138
06	148,7	179
07	212,2	322
08	90,0	141
09	236,6	538
10	47,8	126
Sum, 2005	1132,2	163

Precipitation in September was more than five times the average monthly rainfall. This reflected in the runoff, increase groundwater levels and the development of physical and geological processes and phenomena.

2.4. Geo-dynamical phenomena and processes

Landslides, weathering, erosion and karst are developed in the region. The presence of clayey sediments, very rugged terrain, tectonic structures and hydro geological characteristics determine the appropriate conditions for development of different type landslides. Their appearance and activation is caused by river erosion, increase groundwater levels, earthquakes, undercutting the slopes by excavations and overloaded the slopes with large embankments (Glavcheva & Dobrev, 2012).

The basic rocks are cracked and disintegrated at a depth of 5-7 m under the action of weathering agents. The weathered rocks are susceptible to sliding and erosion during high precipitation and runoff. Karst is highly developed in the limestone cliffs of Emen Formation and different caverns and caves are formed.

2.5. Methods of exploration works

The landslide was studied with 6 motor boreholes located in three longitudinal profiles (fig. 2). Drilling depths were 9.20 m to 12.00 m, depending on specific conditions. Dynamic probing in 3 points was carried out to determine the thickness of the Quaternary cover and landslide masses and for extending the profiles.

Core drilling was performed, without casing, on dry and short trips. This technology was applied in order to obtain the most reliable information about the boundaries of engineering geological layers and determining slip surface of the landslide. To characterize the physical and mechanical properties of soils 12 samples were taken.

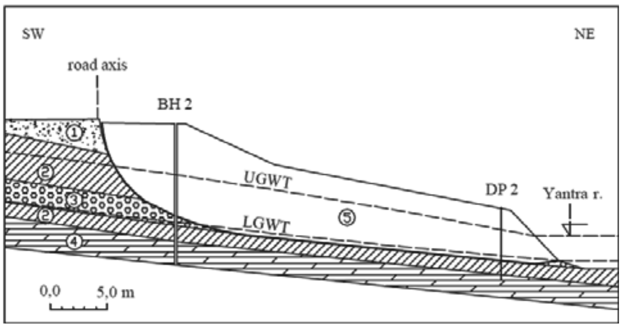

Figure 2. Engineering geological cross-section I - II

1 - road embankment; 2 - Quaternary diluvial clay; 3 - Quaternary gravels with sandy-clayey filler; 4 - Lower Cretaceous marls; 5 - Landslide masses; LGUT - lower ground water table; UGWT - upper ground water table

2.6. Engineering geological layers

According to Genesis, lithological characteristics and physico-mechanical properties of soils established in exploratory boreholes, five layers were separated (Table 2).

Layer 1 - Embankment. The layer builds the road bed. Its thickness is amended widely due to the slope of the natural terrain. The layer is composed of medium to coarse well graded gravel with a maximum thickness of 1.50 m on the coarse rounded gravel with a sandy-clayey filler.

Layer 2 - Quaternary diluvial clay. The layer is located below a layer 1, reveals the at the terrain surface or alternating with layer 3. It is represented by brown, tan to variegated stiff to firm clays with fine gravels. Large boulders up to 0.5 to 1.5 m diameter are found in some places. The thickness of the layer is between 4.70 m in borehole 5 (BH 5) to 9.20 m in BH 1.

Layer 3 - Quaternary gravels with sandy-clayey filler. The layer is set below the layer 1 in BH 1 or alternating layer 2 at different depths in the other boreholes. It is represented by medium to coarse angular to semi rounded gravels with soft sandy-clayey filler. Its thickness varies from 0.50 m in BH 1 to 2.30 m in BH 3.

Table 2. Physical and mechanical properties of the layers

Layer No	Unit wt. γ, кN/m³	Angle of internal friction, φ	Cohesion, c кN/m²
1	23,0	35°	0,00
2	20,5	14,9°	13,3
3	22,7	16,3°	15,8
4	21,6	12,1°	14,5
5	19,3	9,8°	10,2

Layer 4 - Lower Cretaceous marls. Layer 4 is established under the Quaternary cover at various depths below the surface of the terrain - from 3.90 m in dynamic probing 1 (DP 1) to 10.80 m in BH 2. The whole thickness of marls is not exceeded in exploratory drillings. According to visual macroscopic description marl is gray with a brownish tint. The texture is layered and it is built by calcite and clay minerals with some single quartz grains.

Layer 5 - Landslide masses. Landslide body is made of highly mixed clays with some gravels. The landslide movement caused violation of soil structure, changing natural water content and consistency. For the purposes of slope stability calculations three soil samples from slip surface were tested.

2.7. Hydro geological conditions

The region characterizes by middle ground water abundance. The presence of cracked karst limestone creates appropriate conditions for the formation of fissure-karst groundwater. They are drained underground in the Yantra river alluvium or by springs in contact zone between limestone and marl.

Groundwater is accumulated in the Lower Cretaceous karst and cracked limestone and Quaternary sand and gravel layers and lenses. Deep drainage of groundwater has been determined by highly dissected topography. The aquifer is confined with low to medium water pressure at the bottom of the slope depending on the position of ground water table. Groundwater flow is directed northeast to the Yantra.The feeding of ground water is performed by infiltration of precipitation in areas of outcropping of rocks. Groundwater levels are strongly influenced by the seasonal distribution of precipitation and levels of Yantra River. At high river water levels the groundwater upraise, where a sharp drop in river flow creates high-gradient groundwater and hence hydrostatic and hydrodynamic pressure in the slope.

3 SLOPE STABILIZATION

3.1. Overall stability of the slope

To compile a design model for determination of actual stability stage and its alternation due to different destabilizing factors have been reviewed geological and geomorphologic characteristics of the slope, physical and mechanical soil's parameters, sliding mechanism, etc. Main factors in landslide activation have been River Yantra's erosion, increasing of the water table levels and dynamic impact of the vehicles on the road. Additionally the slope stability is influenced from the restraining of gravitational movement of surface and ground waters due to the positioning of road embankment, the lack of effective drainage in the foot of the slope, weathering of the down part of the slope with high river levels, deterioration of shear strength of soils due to vibrations from heavy vehicles.

Position of the most unfavorable sliding surfaces is determined as following boundary conditions have been accepted: obtained main slope of the landslide, swelling on the landslide terrain and established sliding surfaces in drilling boreholes. The form of the sliding surfaces is circular. Janbu's "effective stresses" method is applied under consideration of following conditions: slope stability in natural and dry state and under a dynamic loading.

Table 3. Alternation of Factor of safety (Fs,min) for a different design states and for all of investigated geological profiles

Design state	Fs,min
After landslide activation, in natural state of the slope	0,94 - 1,04
Dynamic impact of the road traffic	0,91 – 0,99
Lower ground water level	1,05 – 1,20

Main conclusions from slope stability analyses can be generalized as follow:

- During the active stage at the time of in – situ investigations of landslide, the slope is in the state of limit equilibrium, near to the further movement.
- Under dynamic loading from the road traffic, the slope exhibits additional decrease of stability measured by the minimum coefficient of safety less than 1.
- Lowering of the ground water levels leads to the increase of its stability.

Analyses of slope stability show that the design of effective drainage system shall not be enough for ensuring the minimum values of factor of safety through all testing profiles, prescribed in national standard for construction in unstable slopes, including the value of Fs,min=1.1 set in National annex of EC7. To achieving the standard overall stability prescriptions the landslide should be strengthened by a retaining structure set in an upper part of slope near to the road (Kolev, 2006).

3.2. Landslide strengthening and drainage works

For recovering of the damaged road section, cantilever reinforced retaining wall on driving pile foundation and additional trailing plate has been designed (fig. 3). The retaining wall has a length of 60 m and it is divided into 12 sections long 5 m each with 2 cm gap between them. The height of retaining wall above the foundation is 4 m. Each section's foundation is composed by 8 driving piles 30/30/900 cm. Due to large horizontal loading from landslides materials at the foundation level the additional "trailing" plate has been designed (fig. 4). The transverse limit state design of pile group has to be done considering of the weight of the backfill above the plate and the activated friction beneath the plate and ground base. The width of trailing plate is 3.5 m and its height is 0.3 m. The piles are designed as end – bearing and embedded into a strong soil layer.

The drainage of landslide has been performed by deep horizontal interception drainage toward the slope. From the bottom of drainage have been constructed drainage shafts 2 m deep, in 10 m from each other. The shafts cross the impermeable soil layer and embedded into lower layer with high seepage capacity. The drainage of high ground water decreases the hydrostatic pressure on the landslide materials. Through the shafts water flows in drainage concrete pipes and then in concrete culvert beneath the road.

The soil beneath the foundation of retaining wall at a depth of 0.5 m is replaced with gravel connected with three deep trench drains with branches. Draining water flows gravitationally into the river.

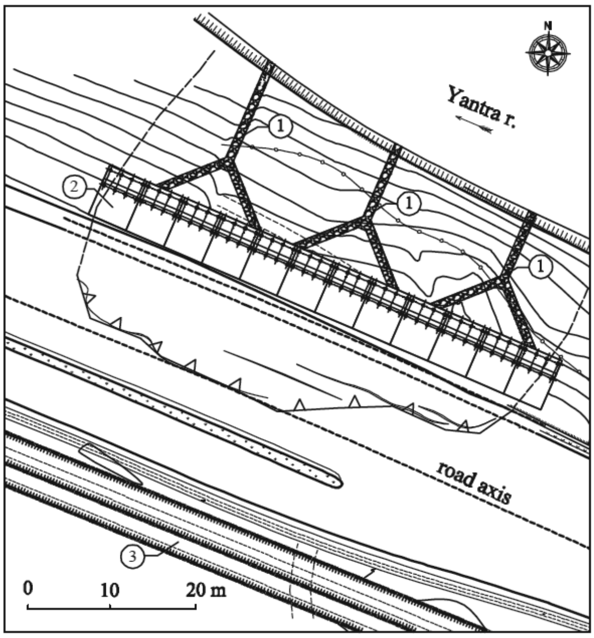

Figure 3. Layout of stabilizing structures

1 - deep trench drains with branches; 2 - retaining wall with trailing plate on driving pile foundation; 3 - deep horizontal interception drainage

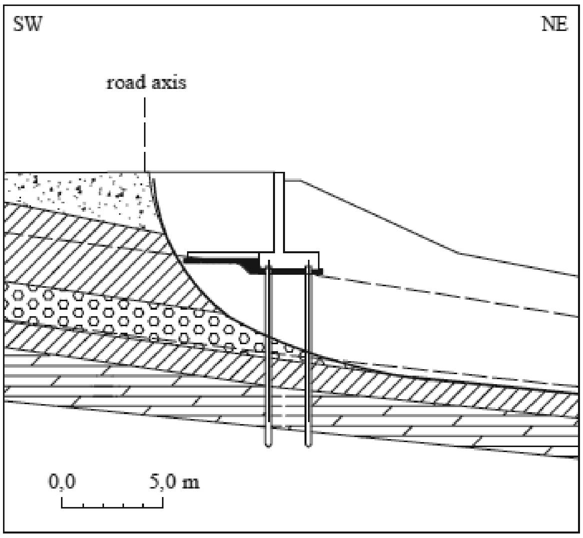

Figure 4. Cross-section through the retaining structure

4 CONCLUSIONS

Conducting investigation of activated landslide leads to following conclusions:

- The investigated slope consists of Quaternary deposits covering Lower Cretaceous marls. Activated landslide is caused by combining influence of river erosion due to high water tables of Yantra River, low strength parameters of quaternary clays, temporary rise of ground water levels from rain water infiltration, static loading from road embankment and dynamic impact of passing vehicles.
- For quality strengthening of road section passed trough activated landslide has been constructed reinforced retaining structure on pile foundation, combined with trailing plate. Piles are embedded in a strong soil layer beneath the sliding surface. The structure has been designed for the pressure from landslide materials and under earthquake condition.
- Drainage system includes interceptor trench drain aligned parallel to the road toward the slope and deep trench drains between the retaining wall and the river. The designed system allows the infiltrated surface water from rains and snow melting to be drawn aside through the culvert to the river without further moistening of landslides materials.
- The installed monitoring system for observation of displacement of stabilized road section shows that constructed retaining structure and drainage system are functioning successfully.

ACKNOWLEDGEMENTS

Present investigation has been funded by Road infrastructure agency part of Ministry of Regional Development and Public Works of Bulgaria.

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