Proceedings of the 15th European Conference on Soil Mechanics and Geotechnical Engineering
A. Anagnostopoulos et al. (Eds.)
IOS Press, 2011

doi:10.3233/978-1-60750-801-4-1319

Landslide affected with an open pit excavation in flysch deposit

Glissement de terrain causé par l'excavation d'une fouille dans les couches de flysch

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ABSTRACT

During the excavation of pit of Nautical High School Sport Hall in the City of Bakar, Croatia, a landslide is occurred on the slope upper of the executed excavation in autumn 1999. Through the landslide movement, the great part of landslide body was sliding in the pit and consequently the construction works were stopped. The landslide body are formed in the clayey slope deposits formed through the weathering of the flysch rocky mass. The slip surface was developed at the contact of the cover and the bedrock i.e. layers of clayey residual soils and siltstone in the bedrock. A high level of underground water and unfavorable hydrogeological properties in the slope also affected on the sliding occur. Complex geotechnical investigation works were carried out for the purpose of drafting a landslide remediation project. Based on the results of investigation works, a landslide remediation project and the new cut construction design were made. The basic reinforced wall structure was replaced by an anchored boring pile-wall structure. The landslide remediation was based on observational methods. The paper describes the remedial works and the behavior of the landslide based on the measuring results obtained during the performance of works in phases. Results obtained from observations of geotechnical structures indicate on the behavior of geotechnical structures and allows for potential corrections. This is especially useful in complex geological conditions where site investigation works are not enough to determine the condition of all site features.

RÉSUMÉ

Lors de la réalisation de la fouille pour la construction de la salle de sport du lycée maritime à Bakar, Croatie, en automne 1999, un glissement de terrain est survenu sur la pente au-dessus de l'excavation. Suite à ce glissement, la fouille s'est remplie de la masse du sol glissé et les travaux ont été arrêtés. Le corps glissant s'est formé dans les formations argileuses dans la pente, elles-mêmes formées par l'érosion de la masse rocheuse de flysch. Le plan de glissement s'est formé à l'interface entre le sol et la base rocheuse, c'est à dire entre le sol résiduel argileux et le grès fin de la roche mère. Le niveau élevé des eaux souterraines et des mauvaises conditions hydrogéologiques ont également favorisé le phénomène de glissement. Des travaux géotechniques complexes ont été entrepris pour l'assainissement du terrain glissé. Les résultats des travaux de recherche ont servi de base dans l'élaboration d'un projet de travaux d'assainissement, ainsi que d'un nouveau projet de stabilisation du talus. La construction porteuse prévue dans le projet initial a été remplacée par un rideau ancré de pieux sécants. L'assainissement du glissement de terrain a été basé à une méthode observationnelle. En outre, dans le présent article, sont décrits les travaux d'assainissement ainsi que le comportement du glissement de terrain quant aux résultats de mesures diverses effectuées à chaque étape de réalisation des travaux. Les résultats obtenus par l'observation de la construction géotechnique ont donné des indications sur le comportement de la construction elle-même et d'éventuelles corrections. C'est surtout utile dans des conditions géotechniques complexes où les travaux de recherche ne suffisent pas pour déterminer toutes les conditions sur le site étudié.

Keywords: Flysch, landslide, excavation, remedial works, pile wall, analysis

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INTRODUCTION

The City of Bakar is old small town situated on the northwest part of Bakar Bay on Northeaster n part of the Adriatic coast, Croatia. Whole area of Bakar Bay has complex geological structure: the Cretaceous and the Paleogene limestone are situated on the top of the slope, while the Paleogene siliciclastic sedimentary rocks or flysch outcrops at the lower slope, and in the bottom of the bay. The flysch rock mass is characterized by lithological heterogeneity, because of frequent vertical and lateral alternation of different lithological sequences. Medieval core of the City of Bakar was constructed on the most stable part of the terrain, and remaining seemingly favorable locations around the City are potentially unstable [1]. Anyhow, before designing and construction of local Nautical High School sport hall, unsuited and insufficient geotechnical field investigations were done and geological settings on the location could not be established, and, consequently, the adequate open pit construction was not predicted.

During the construction of the open pit for the sport hall, the landslide on the slope above the pit occurred, and the sliding mass buried excavated pit and broken built-up parts of construction. Consequently, the construction works were stopped.

In this paper will be described case history of the landslide occurrence, the geotechnical properties of the materials in the slope so as analyses and remedial works necessary to stop the sliding, and enabling undisturbed constructing of the pile wall and sport hall construction. Back analysis to determine the strength parameters of the soil on slip surface, and stability analysis for the remediation measures were carried out with GEO Slope Slope/W software [2]. First stage of remediation work was conducted to stop further sliding and to increase general stability of the slope. For these reason the clayey saturated material in excavated pit was removed and replaced by crushed rocky material to increase the loads in the toe of the slope and lowering the groundwater level in the lower part of slope.

GEOTECHNICAL PROPERTIES OF THE LANDSLIDE BODY

To determine the geological settings, landslide dimensions and the position of the slip surface geotechnical investigation works were performed. After the sliding occurrence geodetic survey of the broad landslide location, and engineering geological mapping were done, where the contours and cracks were instrumentally recorded. Six investigation boreholes depth were done and disturbed and undisturbed soil samples for laboratory testing were taken. In boreholes were installed piesometers for ground water level monitoring and inclinometers for further landslide body movements' observations.

Geological setting and morphogenesis of the slope

The Bakar Bay is a part of a dominant geomorphological unit which strikes the direction: the Rječina Valley –the Sušačka Draga Valley – the Bakar Bay – the Vinodol Valley. The structure was considered as a flysch syncline confined by faults. The Cretaceous and the Paleogene limestone are situated on the top of the slope, while the Paleogene siliciclastic sedimentary rocks or flysch outcrops at the lower slope of the valley, and in the bottom of the Bakar Bay. Limestone rock mass is strongly fractured and karstified. The flysch rock mass is characterized by lithological heterogeneity, because of frequent vertical and lateral alternation of different lithological sequences: mostly marls, siltstones, shales and sandstones [3].

Unlike the limestone, some components of flysch rock mass is more subject to weathering. That particularly refers to calcitic silts and shales which prevail in flysch. That caused formation of a residual clayey cover on the flysch bedrock. During the time, coarse grained fragments originating from the rock falls were mixed with clay from flysch weathered zone and few meters thick slope deposits were formed [1,4,5,6]. Therefore, the flysch rock mass in investigated area is almost completely covered by weathering zone and slope.

Engineering-geological properties of the slope

In the wider area of the landslide the slope is slightly inclined toward the northeast with inclination of 12^0 to 20^0. Before the construction the location was completely covered with fill, so that the geological fabric could be established from the the borehole core overwiev, and partly by inspection of the excavation material. It was assessed that the geological cross-section consists of fill, slope deposits (deluvial and talus) and flysch bedrock in the basis.

The fill consists of mixture of the blocks originally from carbonate rocks and brown clay. Thickness of the fill varies from 1.5 m to 2.0 m.

Deluvium layer is by composition brown to yellow, low plasticity, clayey dust (ML) and contains from 5 to 30% of limestone rock particles. In the southeast part of the slope, an interbed of bonded talus breccias with significantly different structure was located. Those are the rock blocks of limestone mixed with 5 to 10% of sandy red colored binder.

The flysch bedrock is from Paleogene to Eocene age. Flysch rock complex on the slope is relatively homogeneous: clayey siltstones to laminated shales. The rock mass is mainly made of siltstones which exhibit visual transfer from completely weathered zone with yellow color through highly weathered, moderately weathered and slightly weathered deposits all the way to completely fresh rock mass colored gray and blue. With completely weathered siltstones, the rock mass is completely disintegrated, but original structure of the rock mass stayed intact [7, 8]. The layer of fresh siltstone rock has no visible weathering marks, except color change on the main discontinuity surfaces.

Description of the landslide

During the morphological evolution of the slope in previously formed depression, accumulated material was formed by physical and chemical weathering and was partly brought by gravitation from hypsometrically higher parts of the slope. Regarding the different intensity of erosion, that was the consequence of the variable climate conditions and energy of the relief, deluvial deposits in the cover are lithologically heterogeneous. The consequence of that is the filtration anisotropy and different shear strength [1].

Anthropogenic actions (excavation works for construction pit and regulation of the agricultural slope terraces) caused disturbance of the established natural balance in the slope. The greatest influence had the excavation of the construction pit in the toe. The soil material from the passive landslide zone was removed, and that considerably influenced on reduction of the effective shear strength on the slope surface, and caused sliding in the cover of the upper part of the slope [9]. Sliding was also affected as result of the unfavorable hydrogeological conditions and high ground water level.

This occurred landslide was multiple regressive types [10] and the sliding process was developing from the bottom to the top of the slope causing further retrogressive sliding on the slope. The new sliding and retrogressive widening doesn't happen immediately, movements started with creep process with consequently reducing of the shear strength and finally lead to the failure.

The initial sliding body was occurred in the January 2000, and buried excavated pit with sliding material. Two secondary sliding bodies incurred up the slope in March 2000. The final landslide body by retrogressive widening was attained in June 2000 (Fig. 1).

The geometry of the landslide following the WP/WLI Suggested Nomenclature for Landslides [11] is described below:

- total length of the landslide, L =85m;
- length of the displaced mass, L_d = 78m;
- length of the rupture surface L_r =70m;
- width of the displaced mass W_d = 50m;
- width of the slope surface W_r = 50m;
- thickness of the displaces mass D_d=6m
- max. depth of the slip surface D_r= 7m.

Regarding the results of investigation works, it was estimated that the incurred movements of landslide body are a consequence of sliding of relatively thin cover over siltstones in flysch bedrock. Slip surface was formed trough clayey cover layers or on the contact of the cover and the flysch bedrock (Fig. 2).

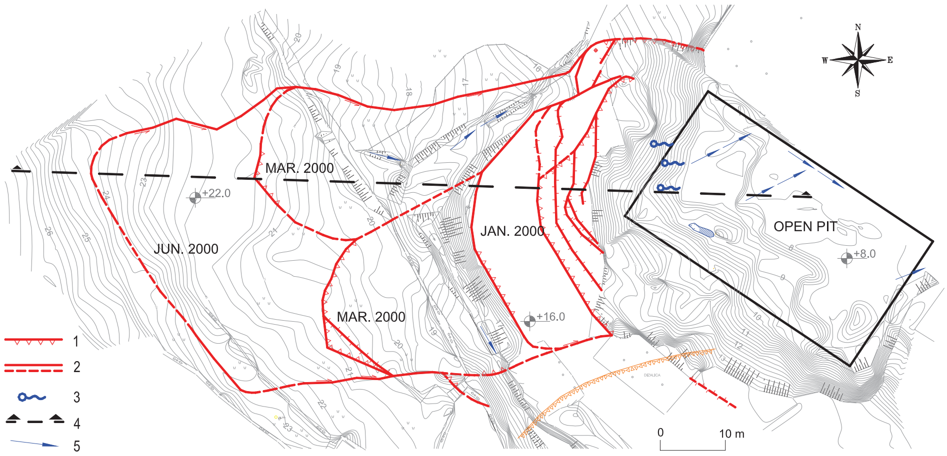

Figure 1. Schematic engineering-geological map of landslide (1.Open scarps; 2.Landslide borders; 3.Springs; 4.Trace of cross-section; 5.Temporary surface flows).

The basic triggering mechanism was uncontrolled excavation in the toe of the slope in combination with unfavorable hydro geological conditions and rising of groundwater level caused by period of heavy rains.

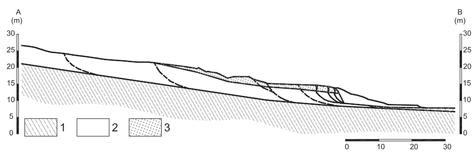

Figure 2. Landslide cross-section (1.Flysch bedrock; 2.Deluvium; 3.Fill).

REMEDIAL WORKS ON THE LANDSLIDE

Remedial works on occurred landslides was divided in two different stages:

- Stabilization of the occurred sliding, dewatering of slope and lowering ground water table;
- Construction of retaining structure as a final part of slope stabilization to enable further construction of sport hall.

First stage was constructed in autumn 2000. As appropriate stabilization method buttressing technique was chosen. Semi liquid clayey material from accumulation zone was removed and replaced by crushed rocky material to increase the loads in the toe of the slope. Rocky material allows drainage of the groundwater from landslide body and lowering of water level in lower part of the slope is enabled. To speed up dewatering of the slope, drain trenches down the slope was constructed with bottom below slip surface. Combination of these types of remediation methods stopped further movements of landslide body and ensured conditions for further construction.

To enable further construction of planned sport hall, as an adequate retaining construction anchored pile wall in the toe of the landslide was chosen. The pile-wall consisting of bored piles with 1.50 m diameters, length of 18 m, and 10 m bored in siltstone flysch bedrock below future toe of the cut was designed. Head beam was designed to connect piles in firm unit construction. To ensure additional horizontal forces on construction, pile wall construction was supported by ground anchors. Capacity of anchors was 600 kN, 16 to 20 m long with 8 m long bond section in siltstone. Drains between the piles were predicted to ensure dewatering from the drain trenches behind the wall. To ensure ground water lowering in upper zone of the slopes, drilling of bored drains was predicted (Fig. 3).

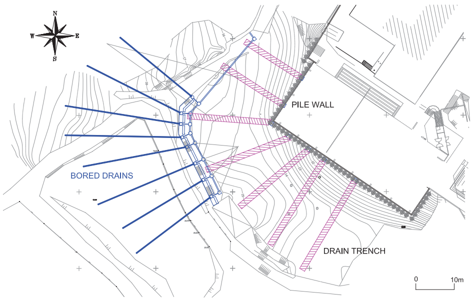

Figure 3. Schematic map of landslide position of pile wall, drain trenches and bored drains.

Construction of second stage started in the winter 2006. During the cut construction a monitoring system was established. The monitoring system included measuring of deformation in horizontal deformeters and vertical inclinometers, geodetic surveying. Based on the results of these back analysis an active design procedure was established [12] that made possible the required changes in the support system if the observations indicates on unacceptable deformations.

SLOPE STABILITY ANALYSES

To confirm this solution, the stability analyses were performed using parameters of soil and rock masses in geotechnical model obtained from back analyses so as usual values for support construction (Fig. 4).

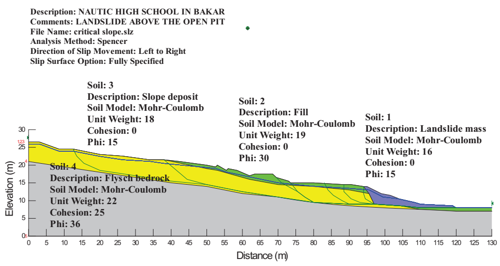

Figure 4. Geotechnical model of the slope.

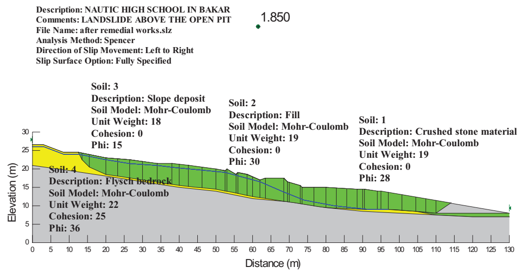

Figure 5. Critical slip surface after buttressing.

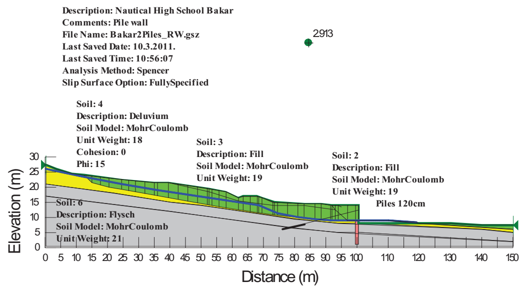

Figure 6. Critical slip surface after pile wall construction.

Stability analyses on competent geotechnical cross-section were done in order to define satisfying stability of the slope after constructing the first stage of remedial works: buttressing in the toe of the slope and deep drain trenches. For those conditions of slope, factor of safety for the whole slope provides satisfying value of 1.85 (Fig. 5). In analyses for final stage of remediation works in geotechnical model was included anchored pile wall construction and additional water level lowering in upper part of the slope due to boring drain system installation. Analyses were conducted in combination of stress-strain analyses of anchored pile wall behavior during excavation ahead of wall and limit equilibrium slope stability analyses using GEO-Slope Sigma/W and Slope/W software package [2]. The final factor of safety for the whole slope after second stage of remediation works offered satisfying value of 2.91 (Fig. 6).

CONCLUSIONS

During the construction of the open pit for the Sport Hall in Bakar, Croatia, the landslide on the slope above the pit occurred, and the sliding mass buried excavated pit and broken built-up parts of construction. Complex geotechnical investigation works were carried out for drafting a landslide remediation project. Based on the results of these investigation works, a two stage landslide remediation design was made. Stabilization of the occurred sliding and dewatering of slope were designed as the first stage. In the second stage was predicted construction of anchored retaining pile wall structure. The first stage of remediation was successfully finished in January 2001. The second stage of landslide remediation works started in the winter 2006. The design of anchored pile wall was based on observational method. The measured data on installed monitoring equipment enabled the control stress-strain back analysis to confirm parameters for describing the real behavior of construction. Based on the results of these back analysis, an active design procedure was established that made possible the required changes in the pile wall construction during excavation ahead of wall if the observations indicates on unacceptable deformations. Measured strain on installed monitoring equipment showed relatively good match with the predicted calculated strains and construction was successfully finished without significantly construction changes in summer 2007 (Fig. 7).

Figure 7. Drains drilling trough pile wall construction.

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