Remedial works on landslide in complex geological conditions

Travaux d´assainissement d'un un glissement de terrain dans des conditions géologiques complexes

Ž. Arbanas
Civil Engineering Institute of Croatia, Department of Rijeka, Croatia; University of Rijeka, Faculty of Civil Engineering, Croatia

Č. Benac
University of Rijeka, Faculty of Civil Engineering, Croatia

M. Grošić
Geotech Ltd., Opatija, Croatia

ABSTRACT

During the construction of the Adriatic Highway section near Rijeka, Croatia, a landslide occurred on the slope alongside a highway cut. The affected section of the highway route lies on a flysch slope, in a flysch synclinal valley narrowed by limestone rock mass from the Cretaceous Period. Through lateral expansion, the landslide also affected the partly finished highway cut. The landslide occurred on the site formed in layers of Paleogene flysch, a very complex geological material. Complex geotechnical investigation works were carried out for drafting a landslide remediation project. Based on the results of additional investigation works, a landslide remediation project and a new highway cut construction project were made. The basic rock reinforced structure was replaced by an anchored boring pile-wall structure in the toe of the landslide body. The landslide remediation was based on observational methods. The observational methods show the behavior of designed geotechnical structures and allow 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 des travaux sur l´Autoroute Adriatique près de Rijeka, Croatie, un glissement de terrain s'est produit sur le talus au-dessus du déblai de la route. Ce tronçon de l'autoroute repose sur un versant de flysch, dans un synclinal de flysch avec des flancs dans une masse rocheuse carbonatée du Crétacé. Une propagation latérale du glissement a affecté aussi le déblai de la route, réalisé partiellement. Ce glissement de terrain s'est produit dans des formations de flysch paléogène, dont la composition géologique est très complexe. Des travaux complexes de reconnaissance géotechnique supplémentaires ont été exécutés pour les besoins du projet d´assainissement. Les résultats des travaux de reconnaissance ont permis d'établir un projet d´assainissement du glissement et un nouveau projet du déblai de l´ autoroute. La structure de base de renforcement de la masse rocheuse a été substituée par une structure de pieux forés ancrés au pied du corps du glissement. L´assainissement du glissement de terrain repose sur des méthodes d'observation, qui permettent de déterminer le comportement de la construction géotechnique au cours des travaux et d'y apporter des corrections éventuellement nécessaires. C'est particulièrement utile dans des conditions géologiques complexes, où les reconnaissances sur le terrain ne permettent pas de relever toutes les conditions locales du site.

Keywords : landslide, case history, flysch, site investigations, remedial works, observational methods

1 INTRODUCTION

One of the geotechnical most challenging sections of the Adriatic highway was constructed in the Draga Valley near the City of Rijeka, Croatia in the period from 2004 to 2006. The affected section of the highway route lies on a flysch slope, in a flysch synclinal valley narrowed by limestone rock mass from the Cretaceous Period. During the last stage of construction, a landslide occurred on the slope alongside a highway cut. Through lateral expansion, the landslide also affected the partly finished highway cut. Consequently, the construction works were stopped. The landslide occurred on the site formed in layers of Paleogene flysch, a very complex geological material. The landslide body affected parts of the clayey slope formations formed through the weathering of the flysch rocky mass, and parts of the loosely bound layers of breccia lying on the siltstone layers in the bedrock. The sliding surface was formed at the contact of the cover and the bedrock i.e. layers of breccia and siltstone in the base. A high level of underground water and the hydrogeological properties of the layers so as unfavorable slope of the contact plane in the slope cause sliding. Complex geotechnical investigation works were carried out for drafting a landslide remediation project. The works included core borings works, geophysical works, laboratory testing of soil and rock samples, so as geological, and geotechnical mapping works. Based on the results of these additional investigation works, a landslide remediation project and a new highway cut construction project were made. The basic rock reinforced structure was replaced by an anchored boring pile-wall structure in the toe of the landslide body.

In this paper, we are describing the case history of the occurrence of landslide, the complex geotechnical investigations carried out for determining the site conditions, as well as the complex geological composition of the site. Paper also describes remedial works and the behavior of the landslide and the cut based on the measuring results obtained during the performance of works in phases.

2 GEOLOGICAL AND GEOTECHNICAL PROPERTIES OF FLYSCH FORMATIONS IN DRAGA VALLEY

The geological fabric of steep slopes of Draga Valley is made of limestone rock mass. At the bottom of the valley, there are deposits of Paleogene flysch mainly made of siltstones with rare layers of sand, marl, and breccia. Flysch rock mass is covered with slope formations, which tend to slide and denude (Arbanas et al., 1994). Usual geotechnical profile consists of three layers: clay cover made after disintegration of flysch rock mass (residual soil) or brought by gravitation from hypsometrically

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

doi:10.3233/978-1-60750-031-5-2638

higher parts of the slope, layer of weathered flysch deposits with variable weathered characteristics, which decrease with depth and fresh flysch zone.

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 (ISRM 1981a). The layer of fresh siltstone rock has no visible weathering marks, except color change on the main discontinuity surfaces. During decomposition of singular weathering zones of the flysch rock mass, along with visual check of the material from test drills, significant contribution came from results from geophysical measurements with surface seismic refraction methods and down-hole method (Arbanas et al. 2007a).

The rock mass is mainly made of siltstones which exhibit visual transfer from completely weathered (CW) zone with yellow color through highly weathered (HW), moderately weathered (MW) and slightly weathered (SW) deposits all the way to fresh rock mass (F) colored grey to blue, according ISRM (ISRM, 1981a). In the zone of the completely weathered siltstones, the rock mass is completely disintegrated, but original structure of the rock mass stayed intact (ISRM, 1981a, b). The layers of fresh siltstones have no visible weathering marks, except color change on the main discontinuity surfaces.

In some part of the Draga Valley a wider zone of breccia deposits are present directly on the siltstone flysch bedrock. The breccia deposits are formed from talus formation from limestone slopes and clay from flysch formations. Breccias are consisting of limestone fragments matrix bonded with red colored clayey binder. In some parts of deposits the breccias are completely cemented but in other parts binder completely absent. These breccia formations can be define as group of disintegrated rock mass according Geological Strength Index classification.

3 DESCRIPTION OF LANDSLIDE

During the last stage of construction of the cut on the middle part of the highway section thru Draga Valley, a landslide occurred on the slope alongside a highway cut. Through lateral expansion of the landslide, sliding also affected the partly finished highway cut. The support constructions consist of rockbolts reinforcement in upper part and reinforced concrete grid construction with ground anchors in the nodes in the lower part of the slope. Consequently, the construction works were stopped.

The landslide occurred on the site formed in layers of Paleogene flysch, a very complex geological material. The landslide body affected parts of the clayey slope formations formed through the weathering of the flysch rocky mass, and parts of the loosely bound layers of breccia lying on the siltstone layers in the bedrock. The sliding surface was formed at the contact of the cover and the bedrock i.e. layers of breccia and siltstone in the base. A high level of underground water and the hydrogeological properties of the layers so as unfavorable slope of the contact plane in the slope cause sliding on the slope.

Complex geotechnical investigation works were carried out for drafting a landslide remediation project. The works included core borings works, geophysical works, laboratory testing of soil and rock samples, so as geological, and geotechnical mapping works. Boring works were included boring 18 holes 12 to 30 m depth with sampling soil and rock core samples. Geophysical works were included surface seismic refraction and electrical resistivity methods. Performed geophysical measurements in combination with results of boring enabled detailed reconstruction of geological layers spread on the wider location of landslide. Geological surface mapping were updating the information obtained by field investigation, resulting with adequate geological map (Figure 1) so as geological cross-section to restore competent geotechnical model (Figure 2).

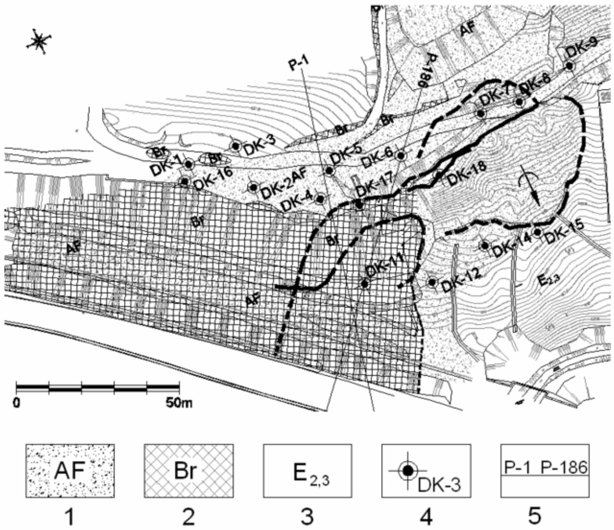

Figure 1. Schematic engineering-geological map of the landslide (1.Fill; 2.Breccia deposit; 3.Flysch deposit; 4.Borehole position; 5.Trace of cross-section).

Based on results of provided complex field investigations the layers in geotechnical cross-section were determined:

- Fill, anthropogenic mixture of clay, silt, sand and stone fragments so as waste buildings materials;
- Talus breccia, consist of limestone fragments <5 cm bonded with red colored clay, partially completely cemented, partially without binder;
- Flysch bedrock, predominantly consist of homogeny siltstone, yellow to grey to blue colored. The completely weathered zone (CW) of yellow colored siltstone is present on overall location. The moderately weathered (MW), slightly weathered (SW) to fresh siltstone (F) is presented deeper.

The thickness of different layers in geological cross-section significantly vary lateral without rules.

The presence of steady state of ground water was identified on overall location. Fill so s a talus breccia is layers with very high permeability but siltstone formation in the bedrock can be considered as watertight.

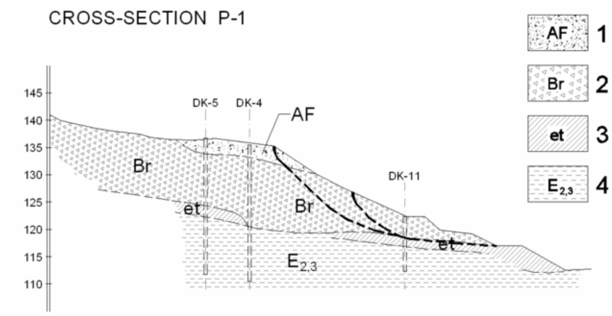

Figure 2. Geological cross-section P-1 (1.Fill; 2.Breccia deposit; 3.Wheathered flysch zone; 4.Fresh flysch deposit).

The geometry of the landslide is described below, following the WP/WLI Suggested Nomenclature for Landslides (IAEG 1990):

- total length L =85 m;
- length of the displaced mass L_d = 80 m;
- length of the rupture surface L_r =80 m;
- width of the displaced mass W_d = 110 m;

- depth of the rupture surface: Δr = 3–8 m;
- total height: ΔH = 18 m.

Because of irregular and uneven contact between breccia deposit and flysch bedrock the reconstruction of authentic cross-section was hard and based on results of geophysical measurements. The geophysical methods were especially helpful to identify contact between different layers so as the better bonded zone in breccia deposits (Figure 3).

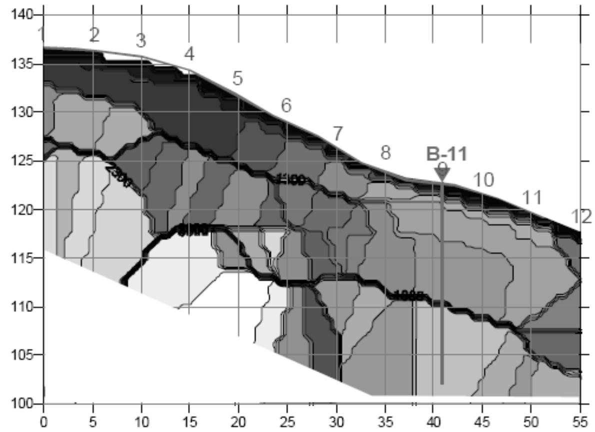

Figure 3. Geophysical seismic refraction cross-section P-1.

4 GEOTECHNICAL MODEL

The samples from boring holes were submitted to laboratory test to determine geotechnical properties of soils and rocks in geotechnical cross-section in landslide body. Because of heterogeneity of rock mass, the results of laboratory testing weren't to productive to identify the real behavior of rock mass. During boring, it was difficult to get undisturbed samples, because of rock weakness in breccia so as rock mass disintegration in highly (HW) to moderate weathered (MW) siltstones. The significant is also a sudden degradation and disintegration of slightly weathered (SW) to fresh (F) siltstones after removing of geostatic loads and exposing to air and water during boring. The consequence of these processes in fresh (F) siltstones was very small number of undisturbed samples for laboratory uniaxial strength tests. Obtaining of the undisturbed samples in completely (CW) to moderately weathered (MW) was not possible. The main test comprised of was Point Load Test (PLT), where samples, obtained by boring, were used without further processing and almost immediately after sampling (ISRM, 1985), but with known disadvantages (Arbanas et al. 2008).

Determination of the shear strength criteria and deformation modulus of flysch rock mass was based on the Geological Strength Index (GSI) concept (Hoek, 1994; Hoek et al., 1995; Hoek et al., 1998; Marinos and Hoek, 2000; Marinos and Hoek, 2001, Marinos et al., 2005). Based on recommendations from Marinos and Hoek (2001), fresh (F) siltstone flysch rock mass is placed in group E to H, with GSI values from 30 to 10 (Arbanas et al. 2007; 2008).

For determination of flysch rock mass strength, the Hoek-Brown failure criterion is used (Hoek et al., 2002) with uniaxial strength value (σ_c) of fresh (F) siltstone rock mass of 10 MPa and disturbance factor (D) of 0.7, which corresponds to machine excavation. In completely weathered (CW) flysch rock mass on the contact with clayey cover the Mohr-Coulomb criterion is adopted with strength parameters equal the parameters in the colluvial deposits and residuals soils (ϕ=26^o, c=6 kPa).

Similar problem was to determine strength criteria for breccia deposits. The uniaxial strength was determined on the samples representative for the best quality parts of deposit because impossible obtaining the samples from weathered zones or zones with low quality of bonding.

Because of described reasons, to determine appropriate strength parameters for breccia deposit the back analyses was conducted. As a representative cross-section the profile P186 (Figure 5) was chosen. Based on back analyses using limit state slope stability analyses (GEO-Slope 1998) the following average Mohr-Coulomb's strength parameters are adopted for further analyses:

- Internal friction angle ϕ=26^o
- Cohesion c=3 kPa.

5 REMEDIAL WORKS ON LANDSLIDE

Before the sliding occurs, the designed cut support construction was including rockbolts reinforcement in upper part and reinforced concrete grid construction with ground anchors in the nodes in the lower part of the slope. After sliding, designed support system couldn't be applied without remarkable modifications.

The first step after sliding was to form a stabilizing berm in the toe of the cut. The second phase of slope stabilization was to remove unstable material from the upper part of the slope. After conduction of these measures to stop further sliding, the formed geometry of the cut was modified, and old design couldn't be applied as final support construction.

As an adequate support construction to ensure stability of the highway cut on landslide location the anchored pile-wall construction was chosen. The pile-wall is 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. Pile-wall is connected with head beam anchored in the bedrock with prestressed anchors in the head of each pile. Capacity of anchors was 1000 kN, 25 to 38 m long with 10 m long bond section in siltstone (Figure 4, 5). Between piles in the pile-wall the selfboring drains were performed to ensure lowering of ground water level. To reinforce the upper part of the slope, the rockbolting was used with applied shotcrete structure on the face to prevent possible erosion processes.

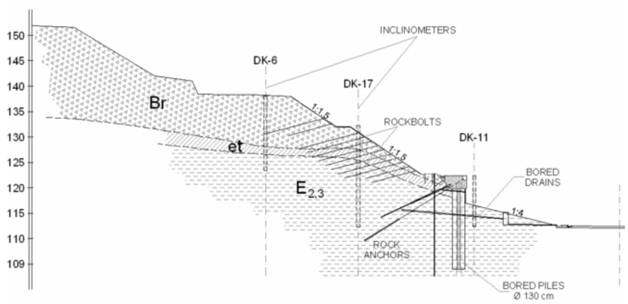

Figure 4. Cross-section of landslide with anchored pile-wall solution.

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

During the pile-wall construction a monitoring system based on observational method (Nicholson et al. 1999; Kovačević 2003) was established. The monitoring system included measuring of deformation in deformeters and inclinometers, ground water level in piezometers and geodetic surveying. The measured data enabled the control stress-strain back analysis. Based on the results of these back analysis an active design procedure was established (Arbanas 2004; Kovačević 2003) which made possible the required changes in the support construction in cut if the observations indicates on unacceptable deformations. Measured strains on installed measurement equipment showed a good match with the predicted calculated strains and construction was successfully finished in the spring 2007 (Figure 6).

Figure 5. Photo of pile-wall during construction.

6 CONCLUSIONS

During the construction of the Adriatic Highway section near Rijeka, Croatia, a landslide occurred on the slope alongside a highway cut. The affected section of the highway route lies on a flysch slope, in a flysch synclinal valley narrowed by limestone rock mass from the Cretaceous Period. Complex geotechnical investigation works were carried out for drafting a landslide remediation project. The works included core borings works, geophysical works, laboratory testing of soil and rock samples, so as geological, and geotechnical mapping works. Based on the results of these additional investigation works, a landslide remediation project and a new highway cut construction project were made. The basic rock reinforced structure was replaced by an anchored boring pile-wall structure in the toe of the landslide body. The landslide remediation was based on observational methods. The measured data enabled the control stress-strain back analysis to confirm parameters for describing the real behaviour of rock mass in the slope. This is especially useful in complex geological conditions where site investigation works are not enough to determine the condition of all site features Based on the results of these back analysis an active design procedure was established which made possible the required changes in the support construction in cut if the observations indicates on unacceptable deformations. Measured strain on installed measurement equipment showed a good match with the predicted calculated strains for all construction stages and construction was successfully finished in the spring 2007.

Figure 6. Photo of pile-wall construction in the toe of the landslide.

REFERENCES

Arbanas, Ž., Benac, Č., Andrić, M. & Jardas, B. 1994. Geotechnical Properties of Flysch on The Adriatic Motorway from Orehovica to St. Kuzam. *Proceedings of the Symposium on Geotechnical Engineering in Transportation Projects*, Novigrad, Croatia, October 5-8, 1994:181-190, Zagreb: Croatian Geotechnical Society. (in Croatian)

Arbanas, Ž. 2004. *Prediction of supported rock mass behaviour by analysing results of monitoring of constructed structures, PhD Thesis*. Zagreb: Faculty of Civil Engineering, University of Zagreb. (in Croatian)

Arbanas, Ž., Grošić, M. & Jurić-Kaćunić, D. 2007. Experiences on flysch rock mass reinforcing in engineered slopes. In L. Riberio e Sousa, C. Ollala & N.F. Grossmann (eds), *The Second Half Century of Rock Mechanics; Proceedings 11th Congress of the Int. Society for Rock Mechanics*, Lisbon, Portugal, July 9-13, 2007: 597-600. London: Taylor and Francis Group.

Arbanas, Ž., Grošić, M. & Briški, G. 2008. Behaviour of Engineered Slopes in Flysch Rock Mass. In Y. Potvin, J. Carter, A. Dyskin & R. Jeffrey (eds), *SHIRMS 2008; Proceedings 1st Southern Hemisphere Int. Rock Mechanics Symposium,* Perth, Australia, September 12-14, 2008: 493-504. Perth: Australian Centre for Geomechanics.

GEO-Slope Int. Ltd. 1998. *User's Guide GEO-Slope Analysis, Version 4*, Calgary: Geo-Slope.

Hoek, E. 1994. Strength of Rock and Rock Masses. *ISRM News Journal* 2: 4-16.

Hoek, E., Carranza-Torres, C.T. & Corkum, B. 2002. Hoek-Brown Failure Criterion-2002 Edition. In *Proceedings 5th North American Rock Mechanics Symposium*, Toronto, Canada, 2002: 267-273. Toronto: Dept. Civ. Engineering, University of Toronto.

Hoek, E., Kaiser, P.K. & Bawden, W.F. 1995. *Support of Underground Excavations in Hard Rock*. Roterdam: Balkema.

Hoek, E., Marinos, P. & Benissi, M. 1998. Applicability of the Geological Strength Index (GSI) Classification for Very Weak and Sheared Rock Masses. The Case of the Athens Shist Formation. *Bulletin of Engineering Geology and Environment* 57: 151-160.

IAEG 1990. Suggested nomenclature for landslides. *Bulletin of Engineering Geology and Environment* 41:13–16.

ISRM, Commission on Standardization of Laboratory and Field Test 1981a. *Suggested Methods for the Rock Characterization, Testing and Monitoring*. Oxford: Pergamon Press.

ISRM, Commission on Standardization of Laboratory and Field Test 1981b. *Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses*. Oxford: Pergamon Press..

ISRM, Commission on Standardization of Laboratory and Field Test, 1985. Suggested Methods for Determining Point Load Strength. *Int. Jour. Rock Mech. Min. Sci. & Geomech. Abstr.* 22: 51-60.

Kovačević, M.-S. 2003. The Observational Method and the Use of Geotechnical Measurements. In *Geotechnical problems with man–made and man influenced grounds, Proceedings 13th European. Conference on Soil Mechanics and Geotechnical Engineering*, Prague, Czech Republic, August 25-28, 2003: 575-582.

Marinos, P. & Hoek, E. 2000. GSI: A geologically friendly tool for rock mass strength estimation. In *Proceedings GeoEng 2000 at the International Conference on Geotechnical and Geological Engineering*, Melbourne, Australia, 2000: 1422-1446. Lanacaster: Technomic Publishers.

Marinos, P. & Hoek, E. 2001. Estimating the Geotechnical Properties of Heterogeneous Rock Masses such as Flysch. *Bulletin of Engineering Geology and Environment* 60: 85-92.

Marinos, V, Marinos, P. & Hoek, E. 2005. The geological strength index: applications and limitations. *Bulletin of Engineering Geology and Environment* 64: 55–65.

Nicholson, D.P., Tse, C.M. & Penny, C. 1999. *The Observational Method in Ground Engineering: Principles and Applications, Report 185*. London: CIRIA.