Landslide Brus, translational block sliding in flysch rock mass

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ABSTRACT: Landslide Brus was occurred in April 2005, near Brus village in Istria, Croatia. Landslide is typical block sliding and landslide body consists of practically unique flysch rock mass block, 150 m long and 35 m wide. Sliding was occurred momentary, without previous announcement signs of possible instability. The area of North Istria is composed of flysch deposits of Paleogene age. Superficial deposits are made of considerable thick packages, with alternating layers of siltstones, marls and sandstones. Landslide body is composed of flysch rock mass in thickness of 10 m. Sliding surface is formed through bedding planes of siltstone layers. The sliding was caused by the unfavorable dip orientation of deposit layers in the slope, and additionally by the river erosion in the toe in combination with unfavorable hydrogeological conditions.

1 INTRODUCTION

Landslide Brus is located near the Brus village in central part of Istrian peninsula (Croatia). The initial event of Brus slide occurred on 9th April 2005, at 3.15 pm after period of heavy rainfalls. The sliding was very rapid, without previous announcement signs of possible instability. The most upper part of landslide was developed over the embankment of the local road Cerovlje-Buzet and the traffic was completely disabled.

Landslide is typical block sliding and landslide body consists of practically unique flysch rock mass block, 150 m long and 35 m wide. It is planar failure on continuous bedding surface dipping out of slope face. Thickens of landslide body is 8 to 10 m. The sliding was caused by the unfavorable relative orientation of rock mass layers, and additionally by the river erosion in the toe of the slope in combination with the unfavorable hydrogeological conditions in the slope caused by intensive rainfalls.

This paper presents the results of geotechnical investigation and stability analysis, which includes engineering geological mapping of landslide area, discontinuities data collecting and geotechnical modeling to provide back stability analysis. The paper primarily focuses on geological and geotechnical factors contributing to the initial rockslide event. Results are presented with respect to adopted geotechnical parameters to describe shear strength criteria of slide surface on the contact between slightly weathered and fresh siltstone.

The geological settings inherent to the location of Brus landslide are typical for wider area of North Istria, but activation of this type of landslide is unique recorded event in Istrian flysch deposits.

2 GEOLOGICAL OVERVIEW

The central area of the Istrian peninsula roughly stretches from the Trieste Bay in the west to the Učka Mountain in the east and is called “Grey Istria” according to grey color of Paleogene flysch sediments. The above-mentioned local road Cerovlje-Buzet goes through the hilly areas of the northeastern part of the Paleogene flysch basin.

Figure 1. View on landslide body and lateral scarp from the crown of landslide (August 2005).

Flysch rocks have very diverse physical and mechanical properties, depending of its lithological composition and state of weathering. It mostly consists of claystones, siltstones with intercalated calcareous sandstones and breccio-conglomerates. The lower part of the flysch deposits is composed of marls (Šikić & Polšak 1972). Weathering processes are particularly expressed in the fine grained flysch deposits, such as claystones and siltstones. Contrary, sandstones and breccio-conglomerates are considerably more resistant to the influences of the exogenetic forces (Mihljević & Prelogović 1992). Tectonic deformations of flysch deposits are slightly expressed. Rock layers are mostly undisturbed, with gently inclined or sub-horizontal bedding planes.

2.1 *Site geology*

Engineering geological conditions of landslide area are determined on the basis of engineering geological mapping of the landslide area. The rock units found in the area of Brus slide consist of Paleogene flysch deposit, i.e. series of interbedded sandstone and marls, clearly visible in main as well as lateral scarps, Figure 1. Flysch bedrock is covered by thin superficial deposit of transported soil and residual soil.

Superficial deposits are composed of the yellow-brown to grey-yellow clay of high plasticity with 10-20% of sandstone detritic grains. Consistency of clay is firm to stiff, depending on its moisture content. Thickness of superficial deposit varies from 0.5 to 1.5 m along the slope.

Rock masses of Paleogene flysch is heterogeneous complex of clastic sedimentary rocks composed of interbedded siltstones, marls, and calcareous sandstones in alteration. Thicknesses of siltstone and marl layers vary from 10 to 70 cm, thicknesses of sandstone beds vary from 3 to 20 cm. These litological components of flysch rock mass are differently weathered. Weathering stage vary from completely (WC) and highly (WH) weathered through moderately (WM) and slightly weathered (WS) to the fresh or intact rock mass (FR) (ISRM 1978). The marls are grey to bluish grey in color and are highly susceptible to weathering. The relative strength of sandstones makes them more resistant to weathering. They appear brown in color when weathered and grey when fresh. Different stages of weathering are also visible in particular siltstone layers between two sandstone beds. Weathering zone thicknesses slightly varies along the lateral margin of the landslide, Figure 2. In the slide area the bedding layers dip to the southwest and are cross-cut by near-orthogonal joint sets. These joints, together with bedding planes, play a major role in promoting instability.

Figure 2. View thru the northwest lateral scarp (January 2010).

2.2 *Site hydrology*

Surface outflow in the landslide area runs southwest to south draining into the creek placed in the toe of the slope. The geological profile is typically composed of relatively thin superficial deposits (engineering soil) and jointed flysch rock mass. The infiltration of water occurs in the upper part of the slope in the zones characterized by opened joints in flysch rock complex. Systems of vertical fissures and joints in marls and sandstones allow easy infiltration and flow of groundwater. Deeper slightly weathered and fresh siltstone layers act as watertight zones. These impermeable zones cause the draining of groundwater along the fissure-joint system dipping down the slope. After the long-term rainy periods the joint system can not drain entire infiltrated water resulting in rising of groundwater level in vertical joints and also increasing subsequent pore pressures.

3 DESCRIPTION OF THE LANDSLIDE

Landslide Brus presents the typical translational block sliding (Skempton & Hutchinson 1969, Antoine & Giraud 1995) with landslide body consisting of almost unique flysch rock mass block. Single movement of displaced material was extremely rapid because sliding was occurred momentary. The rock mass block, 150 m length and ordinary 30 m width, was moved 33 m down the slope. Sliding mass displaced along a planar surface of rupture (i.e. bedding plane) sliding out over the original ground surface in the lower portions of valley. Upper part of landslide is developed near the top of the slope with main scarp which damaged local road between villages Boljun and Cerovlje.

Landslide dimensions can be precisely defined, regarding the fact that the slide body, as a whole, is clearly expressed, Figure 3. Dimensions of Brus landslide are listed in Table 1 (IAEG 1990).

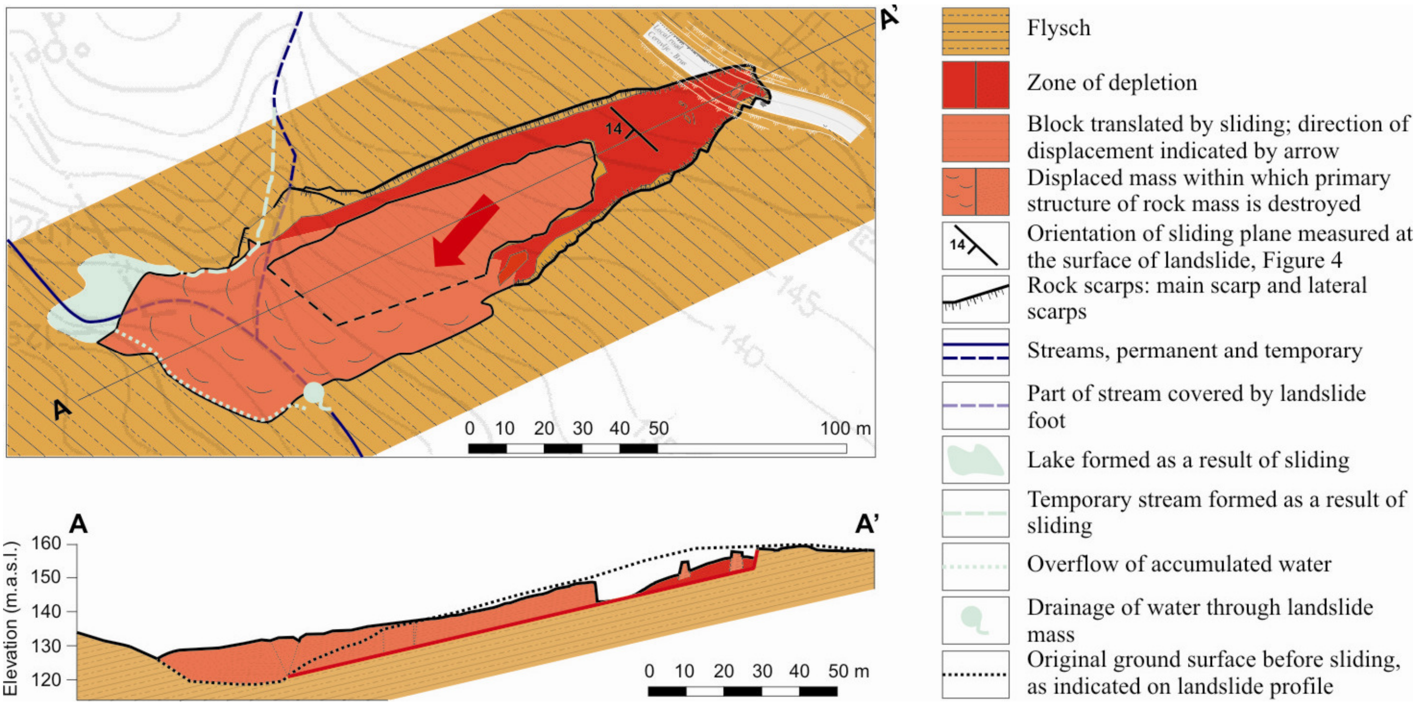

Figure 3. Engineering geological map and cross-section of the Brus Landslide.

Table 1. Dimensions of Brus Landslide.

Dimension	Symbol	(m)
Total length from crown to toe	L	208
Length of displaced mass	Ld	142
Maximum length of sliding surface	Lr	142
Maximum width of displaced mass	Wd	37
Maximum width of slide surface	Wr	37
Thickness of displaced mass	Dd	8-10
Maximum depth of sliding surface	Dr	10
Level difference from crown to toe	ΔH	38

Landslide features are shown in Figure 3. The average inclination of the slope before sliding was approximatlly15^0, while it ranges from 10^0 near the road to 35^0 in the lower parts of the slope. The general orientation of rock mass bedding planes varies from 220/13 to 225/19 with average value of 223/14. Dip directions of bedding planes and slope are similar but not the same.


Figure 4. Picture of the sliding surface (August 2005).

The slide surface was identified on the contact between slightly weathered and fresh siltstone rock mass, Figure 4. The direction of sliding along bedding plane resulted in spreading propagation of northwest lateral scarp and in embedment and shearing of displaced mass along southeast lateral scarp, Figure 3.

The lowest part of displaced mass, i.e. landslide foot, has moved beyond toe of slide surface overlying creek channel and overriding on the opposite slope. Uplifting of the foot mass resulted in squeezing and shearing of material and consequently complete disturbance of integral structure of sliding block.

Landslide foot formed dam and caused formation of lake, Figure 3. The accumulated water drains thru the landslide mass and, in a case of heavy rainfall and rapidly lake level rising, overflow landslide accumulation.

4 ROCK MASS PROPERTIES AND STABILITY ANALYSIS

Investigation of the landslide and pre-slope failure conditions clearly indicates that the sliding was caused with exceeding shear strength in siltstone layers with unfavorable beds orientation along the slope in combination with the unfavorable hydrogeological conditions in the slope.

Of main importance in Brus Landslide slope stability analysis is the model for estimating shear strength criterion on the bedding plane on the contact between slightly weathered and fresh siltstone. The model provides easy and practical procedures to predict the shear strength of rock joint from joint roughness and joint wall strength. The Barton-Bandis shear strength criterion of rock joint peak shear strength is given by the following equation (Barton & Choubey 1977, Barton & Bandis 1990):

$$\tau = \sigma_n \tan\left[JRC \log_{10}\left(\frac{JCS}{\sigma_n}\right) + \phi_r \right] \qquad (1)$$

where τ = peak shear strength; σ_n = effective normal stress on the joint plane; *JRC* = joint roughness coefficient; *JCS* = joint wall compressive strength; and ϕ_r = residual friction angle. The use of ϕ_r is depended on weathering of joints. For fresh (F) unweathered joints $\phi_r = \phi_b$ where ϕ_b = basic friction angle.

Data collection (orientation of bedding planes, joint roughness coefficient and joint wall compressive strength) to obtain Barton-Bandis shear strength criterion for slide surface of Brus Landslide were collected trough engineering geological mapping of the landslide. The asperity amplitudes of joints were measured by use of the profiler and then traces were drawn on the paper. The measurement of asperity amplitudes were done in two directions: parallel to dip direction and parallel to sliding direction. Measurements were provided on the surface of sandstone, slightly weathered and fresh siltstone beds. The asperity amplitudes were converted to *JRC* using comparison with typical roughness profiles (Barton 1973). The joint wall compressive strength was determined using Schmidt hammer and Schmidt hammer rebound values on surface of sandstone, slightly weathered and fresh siltstone beds. Joint properties data collection used in stability analysis of Brus Landslide is presented in Table 2.

Table 2. Data collection of joint properties on Brus Landslide.

Parameter	Sandstone	Siltstone
Joint roughness coefficient	4-6	0-2
Joint compressive strength (MPa)	29-34	16-19
Residual friction angle (^{o})	28	20
Uniaxial compressive strength (MPa)	75-130	15-35
Density (kN/m^3)	26	24

Based on adopted joint properties the back stability analysis using GEO Slope Slope/W software package was carried out. The analyses were conducted using fully defined slide surface, Spencer limit equilibrium method and Barton-Bandis shear strength criterion, Figure 5. The stability analysis was carried out to clarify condition that caused sliding event. It was determined that the sliding was appear with following joint parameters on sliding surface: *JRC* = 0; *JCS* = 18 MPa; and ϕ_r = 20^o. In low ground water level conditions, the sliding is not possible. The decisive triggering factor was rising of ground water level affected by long term heavy rainfall and consequent shear strength decreasing.

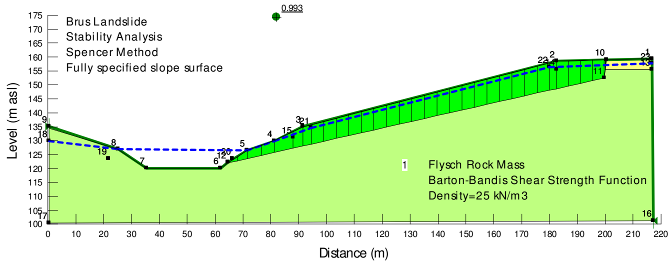

Figure 5. Brus Landslide slope stability analysis.

5 CONCLUSIONS

Landslide Brus presents the typical translational block sliding with landslide body consisting of unique flysch rock mass block. The sliding was caused with exceeding shear strength in siltstone layers with unfavorable beds orientation along the slope in combination with the unfavorable hydrogeological conditions in the slope. To analyze the stability of the landslide the Barton-Bandis shear strength criterion of rock joint peak shear strength is adopted and it was assessed that the sliding was appear with joint parameters on sliding surface as follow: *JRC* = 0; *JCS* = 18 MPa; and ϕ_r = 20^o. The decisive triggering factor was rising of ground water level affected by long term heavy rainfall, and, consequently, increasing of pore pressures so induced decreasing of effective rock joint shear strength.

REFERENCES

Antoine, P. & Giraud, A. 1995. Typologie des Mouvements de Versants dans un Contexte Operationnel. *Bulletin IAEG*, 51: 57-62.

Barton, N. 1973. Review of a new shear strength criteria for rock joints. *Engineering geology*, 7: 287-332.

Barton, N. & Bandis, S. 1990. Review of predictive capabilities of JRC-JCS model in engineering practice. *International conferenceo on rock joints; Proc. intern. symp.* Rotterdam: Balkema.

Barton, N. & Choubey, V. 1977. The shear strength of rock joints in theory and practice. *Rock Mechanics*10: 1-54.

IAEG, Commission on Landslides, 1990. Suggested nomenclature for landslides. *Bulletin IAEG* 41: 13-16.

ISRM, 1978. Quantitative description of discontinuities in rock masses. *International Journal of Rock Mecanics and Mining Sciencies & Geomechanical Abstract* 15, 89-97.

Mihljević, D. & Prelogović, E., 1992. Structural - geomorphological characteristic of the mountain ranges Učka & Ćićarija. *Geomorphology and Sea, Proc. of the Int. Symp.*, Mali Lošinj, Croatia.

Skempton, A.W. & Hutchinson, J.N., 1969. Stability of natural slopes and embankemst foundations. In: *Seventh Int. Conf. On Soil Mechanics and Foundation Engineering. Proc. intern. conf.Mexico 1969.* Mexico City: Sociedad Mexicana de Mecana de Suelos.

Šikić, D. & Polšak, A., 1973. Basic Geological Map 1:100.000, Geology of Labin sheet. Zagreb: Croatian Geological Survey (in Croatian).