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Geotechnical properties in relation to grain-size and mineral composition: The Grohovo landslide case study (Croatia)

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ABSTRACT

The Grohovo landslide is the largest active slope movement along the Croatian coast, situated on the north-eastern slope in the central part of the Rječina River Valley (north-eastern coastal part of Adriatic Sea, Croatia). Slopes in this valley are formed of siliciclastic rocks (i.e., flysch), while the limestone rock mass is visible on the cliffs around the top of the river valley. The slopes are at the limit of a stable equilibrium state, and slope movement phenomena have been recorded since the 19th century.

Samples for laboratory testing were taken from the flysch bedrock, weathered zone and slope deposits to provide specimens for determination of their mineralogical, physical and geotechnical properties. Correlation between mineralogical and geotechnical properties and their influence on sliding processes are presented here. The clay fraction in samples ranges from 17 % to 38 %. Clay activity of the tested samples is from 0.45 to 0.89, and the residual friction angle varies from 13.0° to 17.7°. These results correspond to the presence of kaolinite and illite groups of clay mineral. Both the mineral composition and decrease in strength of fine-grained soil materials, due to the increase of pore water pressures, contributes to slope movements.

Keywords: Grohovo landslide, flysch, clay, geotechnical properties, mineral composition, grain size

1. INTRODUCTION

Due to their geological complexity, flysch formations are difficult to characterize from a geotechnical behaviour point of view. Some attempts at applying rock mass classification systems to these complex rock masses have been carried out (HOEK & MARINOS, 2001).

Weathering processes significantly influence changes of strength properties of the flysch rock mass. In the first stage of weathering, characteristic grey-bluishcolour changes to yellow-brownish. The cause of this change is the oxidation of dispersed pyrite that expands in volume and destructs the original structure of the bedrock. The content of the clay fraction in the weathered zone is increased by the alteration of silicate minerals in clay (ATTEWELL & FARMER, 1979). The infiltration of vadose water and increase of inter-particle and inter-aggregate pore water causes swelling of the montmorillonite and illite groups of clay minerals. These processes cause the flysch rock massto gradually increase in volume and soften while the clay content as well as the clay fraction increases. The mineral composition is a key factor controlling the value of residual friction angle ϕ_r for soils (SKEMPTON, 1985).The shear strength of soil greatly depends on the type of clay minerals present and the quantity of inter-particle and inter-aggregate pore water (SELBY, 2005).

The Palaeogene flysch of the Adriatic part of Croatia is characterized by the alternation of fine-grained sedimentary rocks including shale, marl, silt and sandstone (MARINČIĆ, 1981).The ratio of each of these fine grained rocks within

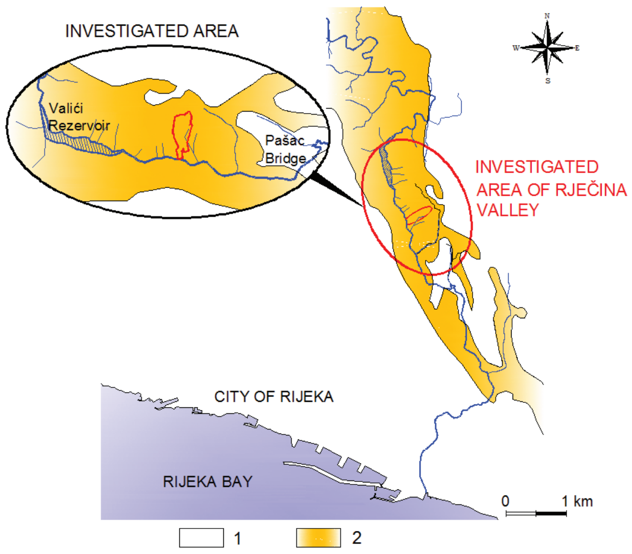

Figure 1: A simplified geological map of the investigated area according to BENAC et al. (2009): 1 – Upper Cretaceous and Palaeogene carbonate rocks, 2 – Palaeogene siliciclastic rocks-flysch.

this rocky complex, varies greatly even in nearby locations. The flysch rock complex in the Adriatic part has in the past been exposed to stresses of different intensity and direction (KORBAR, 2009).

The investigated area is situated on the north-eastern slope of the Rječina Valley. This valley is a part of a dominant morphostructural unit which strikes in the direction of the Klana – Rječina River Valley – Sušačka Draga Valley – Bakar Bay – Vinodol Valley (Fig. 1). The geological structure could be considered to be a Palaeogene flysch syncline limited by faults, analogous with the tectonic style of the Vinodol Valley (BLAŠKOVIĆ, 1999; BENAC et al., 2009).

The unstable phenomenon studied here known as the Grohovo landslide, is the biggest known active landslide on the Adriatic coast and is located in the wider unstable zone with numerous features of dormant historical landslides. The slopes are at the limit of a stable equilibrium state, and several slope movement phenomena have been recorded since the end of the 19th century (VIVODA et al., 2012). The dynamics and complexity of the whole phenomenon was presented in several papers (BENAC et al., 1999; BENAC et al., 2002; BENAC et al., 2005; BENAC et al., 2006).

Remediation works on landslide locations were never performed due to the huge displacement mass and relatively stable equilibrium state of the lower parts of the Grohovo landslide body. Measurements of benchmark movements and changes of groundwater level were provided periodically, every two to three months from 1998 until 2010. Maximum displacements were determined in the upper part of the slope (BENAC et al., 2011).

An advanced comprehensive monitoring system was installed on the Grohovo landslide in 2011. It includes geodetic monitoring with an automatic total station measuring 25 geodetic benchmarks, a GPS master unit and nine GPS receivers, as well as geotechnical monitoring equipment including vertical inclinometers, long-span extensometers, pore pressure gauges, seismographs and rain gauges (ARBANAS et al., 2012). Yet, earlier papers do not contain analyses of the relationships between the mineral composition and geotechnical properties of silty clay from colluvial and weathering zone materials. Due to the low strength parameters, a major part of the sliding surface was formed in these materials (BENAC et al., 2005).

The aim of this paper is to analyse the relationship between the geotechnical properties of the finegrained materials taken from the Grohovo landslide location, with the grain size distribution and mineral composition. Laboratory investigations performed in 2000 and considered in this research (IGH, 2000), were supplemented with new specific mineralogical and geotechnical analyses to obtain more reliable results. Consequently there are no uniform analyses performed on all 22 samples, which has aggravated interpretation of the results.

2. GEOLOGICAL SETTING OF THE STUDY AREA

The unstable phenomenon on the north-eastern slope of the Rječina Valley is situated between the Valići Reservoir and the Pašac Bridge. The bottom of the valley is 150 to 200 m above sea level, and the peaks in the north-eastern side reach

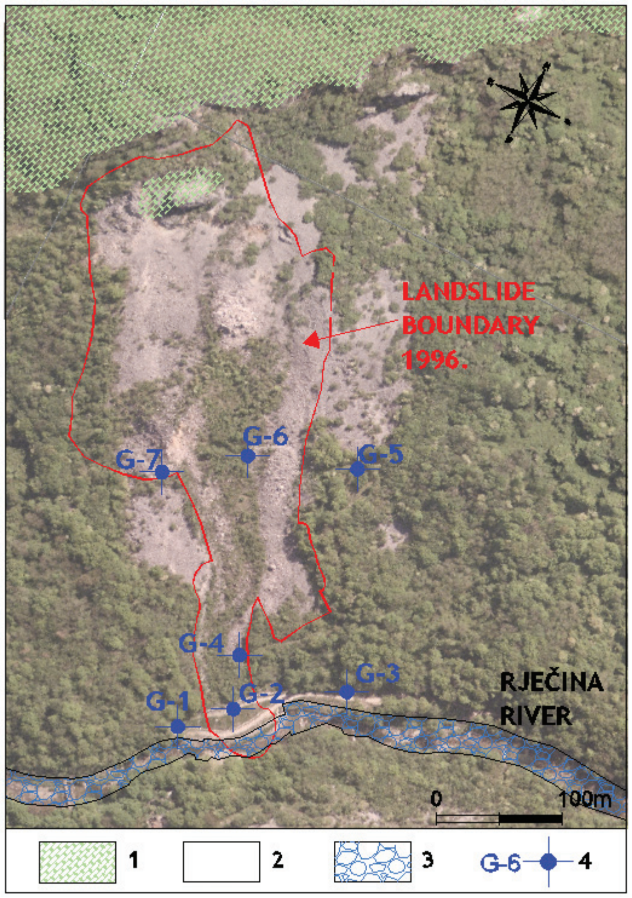

Figure 2: Geological map of the Grohovo landslide area: 1-Palaeogene limestones, 2-Palaeogene flysch rock mass mostly covered by colluvium, 3-alluvial sediments, 4-position of boreholes.

a height of 412 m.The Cretaceous and Palaeogene limestones are situated on the top of the slopes, while the Palaeogene siliciclastic rocks or flysch are located on the lower slopes, including the bottom of the valley (Fig. 2).

During neo-tectonic and recent tectonic movements the limestone rock mass was repeatedly faulted and fractured. Such tectonic movements and weathering processes enabled the separation of limestone blocks and their gravitational sliding over the flysch bedrock, disintegration of the rock mass, as well as accumulation of talus deposits at the foot of the rock cliffs (BENAC et al., 2006).

Siliciclastic or flysch bedrock is characterized by great lithological heterogeneity, because of the frequent vertical and lateral alternation of different lithological sequences. Microscopic petrological analysis of the bedrock has shown the presence of silty marl, laminated silt to silty shale, as well as fine-grained sandstones. Unlike the limestones, the flysch rock mass is more prone to weathering, which results in a clayey weathering zone on the flysch bedrock. Over time, coarse grained fragments of limestone, originating from the rock falls were mixed with clay from the weathered flysch zone forming several metre thick slope deposits (BENAC et al., 2005) (Fig. 3).

The Grohovo landslide has the form of a complex landslide with 13 landslide bodies. According to the WP/WLI Suggested Nomenclature for Landslides (IAEG, 1990), the length of the displaced mass is L_d = 420 m, width is W_d = 200 m, and depth is D_d = 6–20 m. The estimated total volume of the displaced mass is 850.000 m^3. The total displacement of the landslide to eis more than 20 m in the initial state of slope movement (BENAC et al., 1999).

The affected slope has distinctive filtration anisotropy. Groundwater flow in cohesionless talus material is very rapid, in contrast to cohesive talus material, where infiltration and water flow are very slow. Subsurface groundwater can be accumulated locally in clayey to silty slope material and in the weathered bedrock zone. This water originates either from direct infiltration of precipitation, or from the karst aquifer on the top and behind the slope. The groundwater level changed less than 10 cm in the upper boreholes (G-5 and G-7), but varied up to several metres in the lower boreholes (G-1, G-2 and G-3) (Fig. 2) (BENAC et al., 2005).

3. METHODS

Material samples have been recovered to provide specimens for laboratory testing to obtain data on their mineralogical, physical and geotechnical properties.The 22 representative samples were selected and taken from the flysch bedrock, weathering zone and from slope deposits- colluvium. From a total of 22 samples, 18 were taken from borehole cores (Fig. 3). The boreholes were drilled during the second phase of field investigation in 1999 (IGH, 2000). The other 4 samples were taken from the surface during 2006 (Fig. 2, 3 and 4, Table 1).

Table 1 summarizes the results of all the performed tests. On 12 samples selected from borehole cores, quantitative and semi-quantitative mineralogical analyses were performed (No. 1-4, No. 6-9 and No. 13-16). For the purpose of mineralogical analysis, grain size distribution of the fine-grained fraction (up to 1 mm) was also determined. This analysis will be referred to as sedimentological methods of grain size analysis in the following text. In this way, the finer fraction percentage is additionally increased. One additional mineralogical analysis was performed on sample from the surface (No. 22).

Figure 3: Photo of the core from borehole G-2: boring interval 0.0-4.0 m (photo: Č. Benac, 1999). Borehole location is shown in Fig. 2.

Table 1: Summarized results of analyzed samples.

Sample No.	Borehole /depth (m)	Grain size analysis Sedi-ment.	Geo-tech.	CF	W_0 (%)	W_L (%)	W_p (%)	I_p (%)	A= I_p/CF	I_m	Ring shear	Direct shear	c (kPa)	ϕ (°)
1	G-1/ 5.0 m	+								1.09				
2	G-2/ 1.0 m	+	+	19						1.30				
3	G-2/ 2.5 m	+	+	27	19.41	42.6	20.53	22.07	0.82	1.23	+		16.67	16.1
4	G-2/ 4.5 m	+	+	37						1.37				
5	G-3/ 2.0 m		+	23										
6	G-3/ 3.0 m	+								1.31				
7	G-3/ 3.4 m	+	+	33						1.38				
8	G-3/ 7.0 m	+								1.02				
9	G-3/ 10.3 m	+								0.23				
10	G-4/ 2.5 m		+	20	14.19	32.22	18	14.22	0.71			+	9.5	23.7
11	G-4/ 4.3 m		+	36	19.2	33.97	17.73	16.24	0.45			+	1.0	26.1
12	G-4/ 5.5 m		+	35	16.32	33.01	17.28	15.73	0.45			+	7.5	25.1
13	G-4/ 14.0 m	+								0.68				
14	G-5/ 1.0 m	+	+	31						1.54				
15	G-5/ 4.5 m	+	+	17						0.68				
16	G-5/ 8.5 m	+	+	26						1.14				
17	G-6/ 11.0 m		+	32										
18	G-7/ 20.0 m		+	18										
19	G-1/ 0 m		+	28		41.14	23.75	17.4	0.62		+		0	13.0
20	G-2/ 0 m		+	27		37.41	21.72	15.69	0.58		+		0	14.5
21	G-3/ 0 m		+	27		37.38	22.5	14.88	0.55		+		0	17.7
22	G-4/ 0 m	+	+	19				16.99	0.89	2.14	+		0	15.0

Standard geotechnical laboratory tests were performed on 13 borehole samples (No. 2-5, 7, 10-12, 14-22) and on 4 surface samples (No. 19-22 in Table 1). Grain size analysis (sieving and hydrometry) were performed on all samples, according to ASTM standard (IGH, 2000). On some of those samples, Atterberg limits, plasticity index and water content were determined. Results of sedimentological and geotechnical methods grain size distribution analysis are shown in Fig. 5.

The clay fraction (CF) refers to the percentage of particles <0.002 mm, as determined by geotechnical grain size analysis. Most of the authors recognized that the use of CF as an indicator of platy shaped particles did not give real insight into the soil composition. Measurement of the clay content (CC) proportion in total clay minerals indicates soil characteristics more comprehensively than CF (TIWARI & MARUI, 2005). However, for practical reasons, the use of CF for the description of soil behaviour is still more widely used (LUPINI et al., 1981; SKEMPTON, 1985). The CF in Fig. 5B ranges from 17 % (No. 15) to 38 % (No. 14) (Table 1).

The sample (No. 20) has been analysed using a scanning electron microscope (Philips XL-30). The minerals were identified by the habitus of crystallographic shapes and identification picks in the energy spectrum of x-rays (EDAX).

Shear strength tests were also performed on samples from borehole cores: three direct shear tests (No. 10-12) and one ring shear test (No. 3). Additional ring shear tests were performed on surface samples (No. 19-22). Direct shear tests were performed for normal stress of 50, 100 and 200 kPa to determine peak shear strength and ring shear tests for normal stress of 100, 200 and 300 kPa to determine residual shear strength (Table 1). A remoulded specimen was used in ring shear tests in which the first shear surface was formed after consolidation and before shearing.

4. RESULTS

Both methods of grain size analysis, (sedimentological (Fig. 5A) and geotechnical (Fig. 5B)) show that the silt and clay fractions prevail in all samples. Consequently, material can

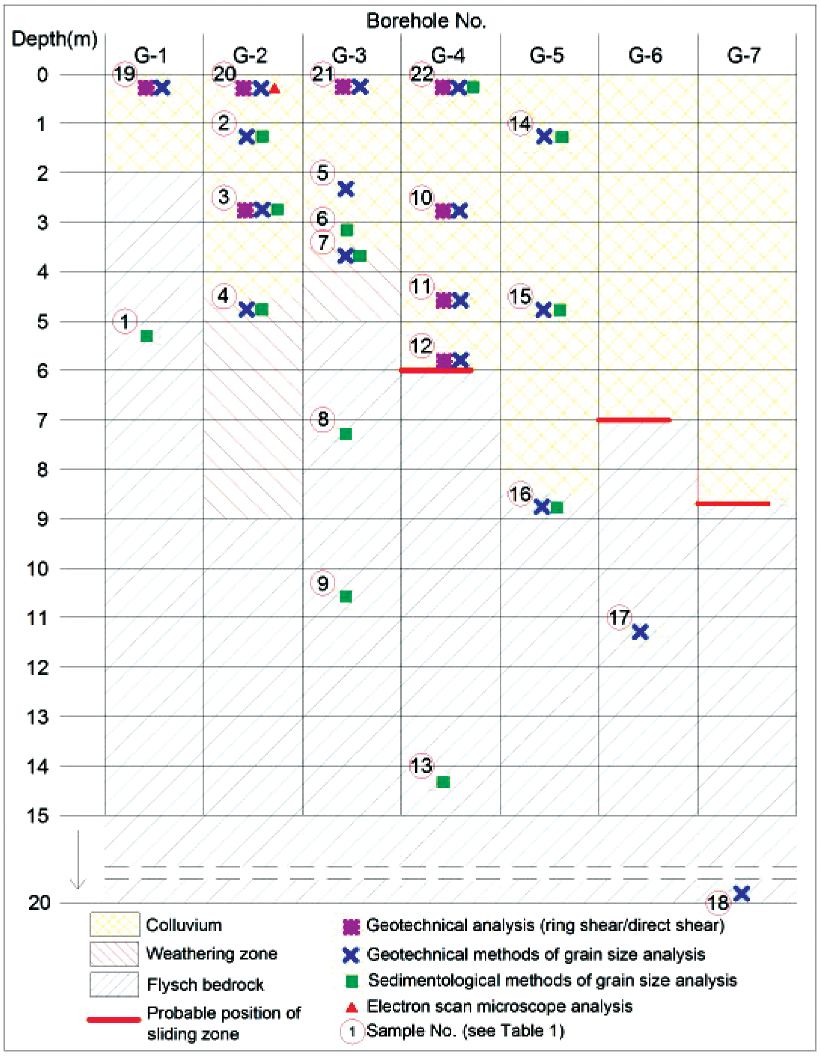

Figure 4: Schematic borehole cross-sections with locations of the analyzed samples.

be considered clayey silt or silty clay. Fig. 5B shows that the average particle size (D_{50}) according to geotechnical methods of analysis ranges from 0.004 to 0.042 mm. Fig. 5A shows a much wider range of D_{50} according to sedimentological methods analysis from 0.0028 to 0.056 mm.

Results of Atterberg limit testing and plasticity indices are given in Table 1 and are presented in Fig. 6. Besides showing consistency limits (liquid limit and index of plasticity) in Fig. 6, areas of the main clay minerals: kaolinite and illite groups are also shown. The tested materials have low to medium plasticity according to the plasticity index (I_p = 14–22 %), and liquid limit (w_l = 32–43 %) respectively.

Clay activity is defined as the ratio of plasticity index (I_p) and clay fraction (CF). This simple index gives the in-

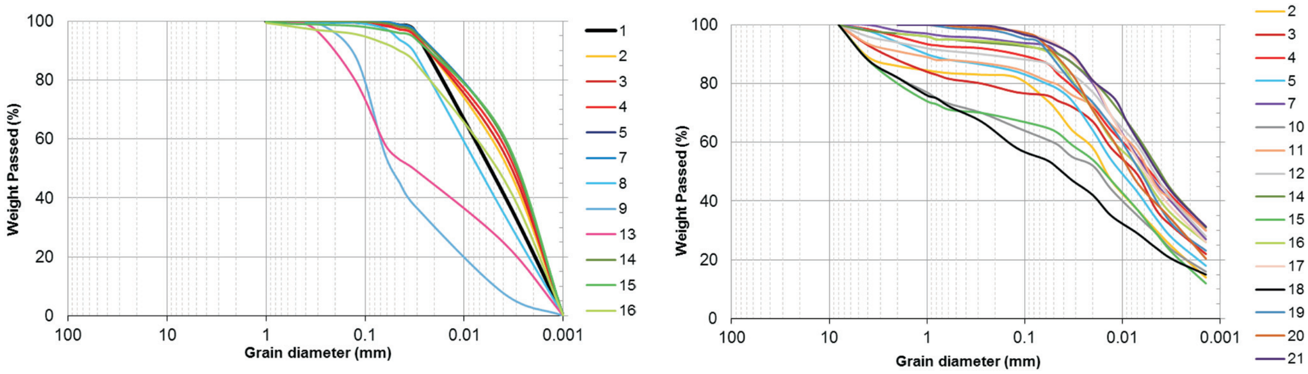

Figure 5: Results of grain-size analysis: a-sedimentological method, b-geotechnical method.

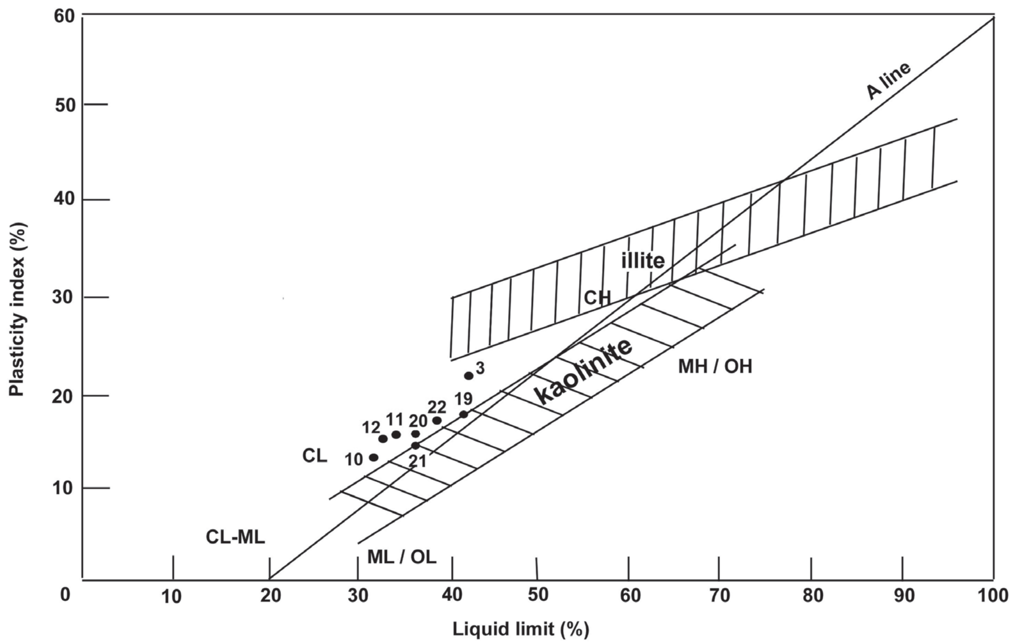

Figure 6: Diagram of Atterberg limits and plasticity indexes (according to GRIM, 1968). Numbers refer to analyzed samples (Table 1).

sight into the mineral composition of materials (Fig. 6 and 7). Water quantity that can be absorbed within soil particles depends on the quantity and type of clay minerals. The highest clay activity occurs in the montmorillonite group, then illite and the lowest in the kaolinite group. Active clays provide the most potential for expansion. Activity of the tested samples ranges from A = 0.45 (No. 12) to A = 0.89 (No. 22). Accordingly, samples for non-active clays (A < 0.75), include samples No. 10-12 and No. 19-21, and normally active clays (A = 0.75–1.25), for samples No. 3 and No. 22 (Table 1).

X-ray diffraction analysis was performed and the following minerals were identified: quartz, calcite, plagioclase, K-feldspar and phyllosilicates (Fig. 8). Quantitative mineralogical analysis detected the presence of the following clay

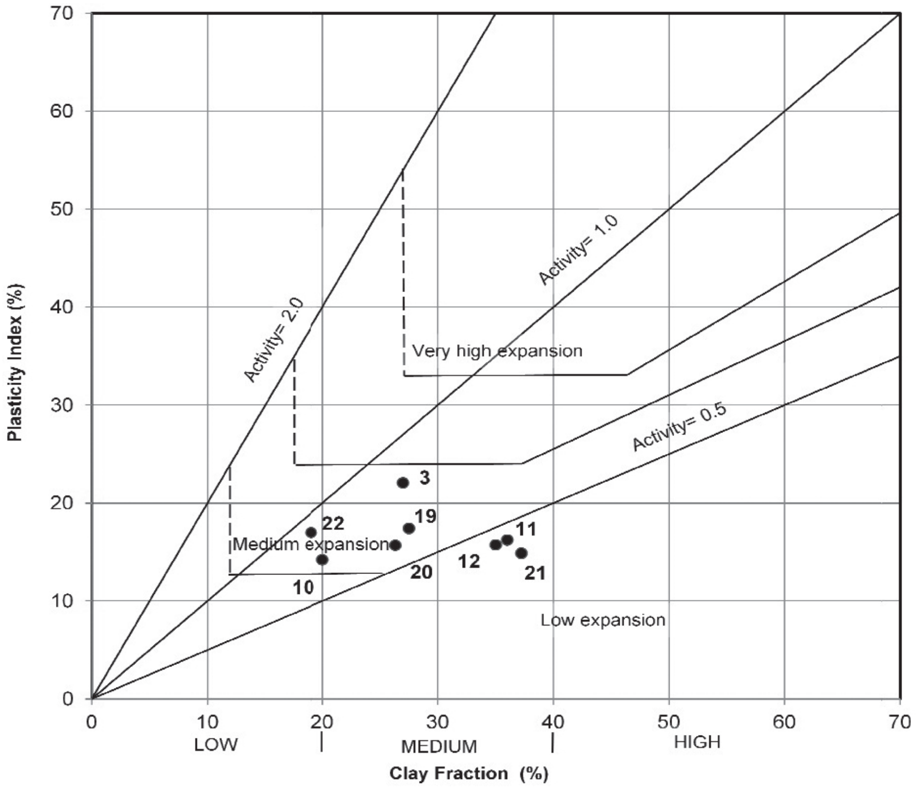

Figure 7: Estimation of expansiveness of clay in analyzed samples (according: BELL, 1993): numbers refer to analyzed samples (Table 1).

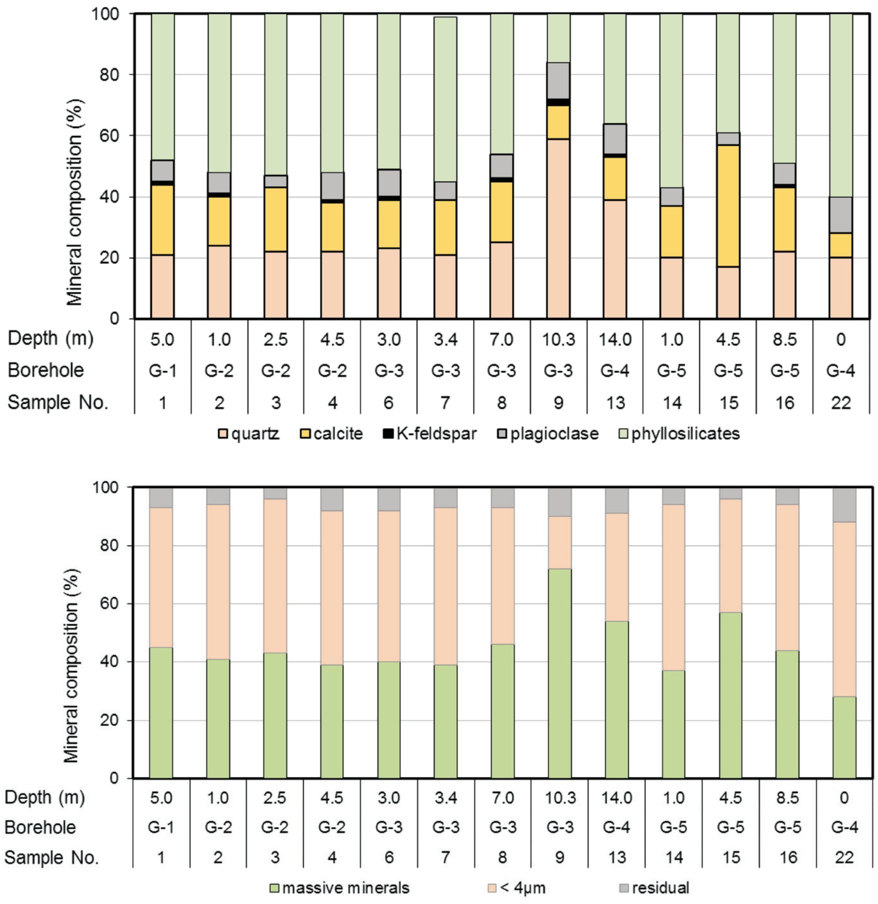

Figure 8: Mineral composition of samples (Table 1): a-content of minerals, b- content of massive and fine-grained particles.

minerals: kaolinite, illite, chlorite, mixed-layer clay minerals, and in some samples vermiculite (not detected in sample No. 9) and smectite (not detected in sample No. 5-9 and No. 14-16) (IGH, 2000).

Phyllosilicates in tested samples are prevalent and are represented by micaceous minerals, kaolinite, vermiculite, smectite and chlorite groups, and mixed-layer clay minerals. From the mineral composition of the fractions <4 μm, it is clear that the main clay minerals are illite and kaolinite and sporadic ones are vermiculite, smectite and mixed-layer clay minerals. Sample No. 22 consists of illite-smectite minerals (Fig. 8).

Quartz, calcite and phyllosilicates constitute 86–96 % of the mineral composition (Fig. 8). Quartz, calcite, and feldspar are the commonly observed massive minerals, while the most common types of clay minerals include: kaolinite, illite, smectite, halloysite, chlorite and micaceous minerals.

Grains of partially dolomitized calcite are observed in sample No. 20 using the scanning electron microscope. Clay minerals from chlorite or chlorite-illite groups have dimensions between 5–15 m. The particles of albite (plagioclase group) have dimensions around 40 m. Micaceous minerals are visible only sporadically. Individual crystals of quartz have dimensions between 5–10 m. Skeletal principal microstructural types prevail in analyzed material (Fig. 9).

The index parameter I_m (mineralogical index) was introduced in Table 1. It is defined as a ratio of the mass fraction of phyllosilicates and the sum of quartz and calcite. From among the different indices and parameters, I_m was used to define the proportion of platy (clay) to rotund (massive) particles. The value of I_m ranges from 0.23 (No. 9) to 2.14 (No. 22). The lowest I_m is the result of the smallest frac-

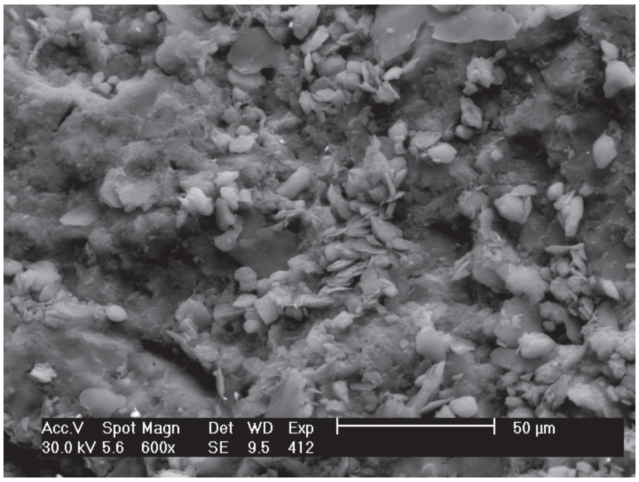

Figure 9: Electron micrographs of sample No. 20 (position of sample is presented in Fig. 4).

tion of phyllosilicates (16 %). In contrast, sample No. 22 has the highest value of I_m due to the highest fraction of phyllosilicates (60 %).

Results of eight shear strength analyses are given in Table 1. Peak values determined by direct shear are in the range of 23.7°<ϕ<26.1° for peak friction angle and 1<c<9.5 kPa for cohesion. Samples were sheared until shear displacement reached 8 mm at each normal stress of 50, 100 and 150 kPa. For the ring shear test, one borehole sample was used and sheared up to 150–200 mm of shear displacement for each normal stress applied (100, 200 and 200 kPa). Parameters of residual strength obtained at a cumulative displacement of 450 mm were c_r = 16.7 kPa and ϕ_r = 16.1°. Additional ring shear tests performed on surface samples (No. 19-22) had the following residual strength parameters: c_r = 0 kPa and ϕ_r = 13.0° – 17.7°.

5. DISCUSSION

The content of the fine grained fraction increases during rock mass weathering processes. The content of the clay fraction (CF) in the weathered zone also increases by alteration of silicate minerals to clay (SELBY, 2005).The increase of the CF is clearly visible in samples from colluvium and the weathering zone, where the clay fraction prevails, while in the flysch bedrock, the silt fraction prevails (Table 1). The oxidation of dispersed pyrite that expands in volume and destructs the original structure of the bedrock is usual during weathering processes in rock mass like flysch (ATTEWELL & FARMER, 1979). Furthermore, the Palaeogene flysch rock mass in the Croatian coast contains a high proportion of the $CaCO_3$ component. This component is dissolved during weathering processes and the matrix is destroyed which probably causes an increase in the fine grained fractions. In the neighbouring area of the Sušačka Draga Valley, siltstone-from the flysch bedrock has up to 25 % $CaCO_3$, while in the weathering zone, the $CaCO_3$ component decreases to 10–15 % (BENAC, 1994).

Results of both methods of grain-size analysis showed that in all the tested samples, fine grained materials prevail, and the CF index ranges between 17–38 %. Direct comparison of grain-size fractions is not possible, due to the different methods of analysis. In the sedimentological method of analysis, particles <1 mm are used, and then $CaCO_3$ is dissolved. Therefore, the proportion of the fine fraction (clay and silt) is much higher than in the geotechnical method of analysis (Fig. 5).

According to the Unified Soil Classification System (USCS), materials are low plasticity clays (CL). Results of analysis categorize samples in the zone between kaolinite and illite, which is in accordance with their mineral composition (Fig. 6). The uniform relationships between the Atterberg limits (which represent the total quantity of pore water and the adsorbed water onto the external and internal surfaces of clay minerals) and other physical properties does not exist in many cases (DOLINAR & ŠKRABL, 2013).

Tested samples fall into the area of low (No. 11, 12 and 21) and medium expansion (No. 3, 10, 19, 20 and 22). All of the tested samples have a CF in the range between 17–40% with most of them having clay activity in the range A = 0.5–1 (medium expansion) and some A < 0.5 (low expansion). Active clays provide the most potential for expansion. Typical values of activities for the three principal clay mineral groups are as follows: A = 0.4 for kaolinite, A = 0.9 for illite and A>1.25 for montmorillonite groups (BELL, 1993). Therefore, according to activity, the tested samples are in the group of illite and kaolinite (Fig. 7).The quantity of adsorbed water on the external surfaces of the clay minerals greatly depends on their size and clay fraction content. The interlayer water quantity depends mostly on the quantity and the type of the swelling clay minerals in the soil composition and their exchangeable cations (GRIM, 1968).

The prevailing gravitational type of sediment transport, which is usual during the sliding process, has a strong influence on the orientation of fine grained particles (LAMBE & WHITMAN, 1979). According to morphogenesis of slope deposits (BENAC et al., 2005) the preferred orientation of platy particles and laminar microstructural type could not be expected. The results of analysis using scanning electron microscope illustrate the chaotic texture of particles (Fig. 9).

Grain-size and mineral composition were correlated to geotechnical properties. Geotechnical properties of fine-grained materials which prevail in the lower part of the landslide are mostly unfavourable and often determined by clay minerals (Fig. 8).The values of the peak and residual friction angles ϕ_r obtained from direct shear apparatus (average 25°) and ring shear apparatus (average 15°) show a difference of 10°. Parameters of residual strength obtained for borehole sample (No. 3) and surface samples (No. 19-22) were in the same range regarding the residual friction angle (13.0°< ϕ_r<17.7°), but they differed greatly with regard to the value of cohesion. The cohesion determined in ring shear testson samples taken from the surface (for a cumulative displacement of 300–350 mm) was c = 0 kPa, while the borehole sample (No. 3) had an unusually high value of c_r = 16.7 kPa (Fig. 4, Table 1).

Residual cohesion is often assumed to be c_r = 0 kPa, especially after the sample is sheared at large displacements (SKEMPTON, 1985). There has been some discussion on the accuracy of this assumption, as cohesion values as large as 9.2 kPa have been observed for residual strength envelopes for some soils (TIWARI et al., 2005).

Most previous studies indicated a reduction in the residual friction angle (ϕ_r) with an increase in the clay fraction (CF) (LUPINI, 1981; TIWARI & MARUI, 2005). Many of these studies tried to correlate the residual friction angle of soils with their index parameters. The effect of particle reorientation has an influence only in soils having CF values exceeding 20–25% (SKEMPTON, 1985). According to LUPINI et al. (1981) three modes of shearing have been identified: turbulent (CF < 25 %), sliding (CF > 50%) and one that is transitional between these two. The mineral composition is a key factor controlling the magnitude of ϕ_r for soils that exhibit the sliding shear mode. The angles of residual shearing resistance of the three most commonly occurring clay mineral groups are approximately equal to 15° for kaolinite, 10° for illite and 5° for montmorillonite (SKEMPTON, 1985). Electrostatic bonding has been reported as contributing about 80 % of shear strength for the montmorillonite group, 40–50 % for the illite group and <20 % for the kaolinite group (SELBY, 2005).

The obtained residual friction angles (ϕ_r) are in the range of the illite and kaolinite groups, but values disperse due to the wide range in clay fraction (CF) composition of samples. Regarding the influence of CF on ϕ_r, the data did not show similar trends to those widely reported. Samples with the highest CF (No. 21, CF = 37) had the highest residual friction angle (ϕ_r = 17.7°). Sample No. 22 has the lowest CF value (CF = 19) but the highest fraction of phyllosilicates (Table 1; Fig. 8). This can be explained by the existence of micritic material and aggregated particles in soils originating from flysch rock mass, which makes it difficult to give any precise relationship between ϕ_r and CF (KALTEZIOTIS, 1993).

Soils derived from a rock mass like flysch (marls, mudstones and shales) may generate platy particles by degrading during shearing (LUPINI et al., 1981). Similarly, bonded cohesive soils might exhibit higher residual friction angles than those in the laboratory due to bonding and particle aggregation, which are destroyed when tested in a remoulded state in the laboratory. Decalcification during weathering, reduces the calcite content due to the elimination of medium and coarse silt particles and the increase in clay fraction and plasticity index (HAWKINS & Mc DONALD, 1992). As a result, lower internal friction angle values were obtained in weathered samples compared to the corresponding values in non-weathered samples.

The last large landslide occurred after a longer rainy period (BENAC et al., 1999), and according to historical notes, sliding in the Rječina Valley often appears after heavy rainfall (VIVODA et al., 2012). The stability analyses have indicated that the high water level influences landslide instability (BENAC et al., 2005). Accordingly there are indications that increased saturation of the fine grained particles influences the strength properties on the potential sliding surface. Similar conclusions have been drawn for other terrains formed in a Palaeogene flysch rock mass (FIFER BIZJAK & ZUPANČIČ, 2009; DUGONJIĆ JOVANČEVIĆ & ARBANAS, 2012).

Based on past periodic groundwater measurements and benchmark movements, it was not possible to establish any clear correlation between these two parameters (BENAC et al., 2005; BENAC et al., 2011). The establishment of a new monitoring system could provide continuous measurement data (ARBANAS et al., 2012; MIHALIĆ & ARBANAS, 2013; ARBANAS et al., 2014). More precise data could be taken from installed vertical inclinometers, long-span extensometers, pore pressure gauges and rain gauges. Therefore it will be possible to investigate the influence of water on the strength parameters of fine grained sediments in the investigated slope in the future.

6. CONCLUSIONS

The investigated landside is the biggest known active mass movement in the Adriatic coast and is located in the wider unstable zone with numerous traces of dormant landslides. The slopes are at the limit of a stable equilibrium state, and mass movement phenomena have been recorded since the 19th century.

Quartz, calcite, feldspars and phyllosilicates including micaceous and clay minerals, comprise 86 to 96 % of the mineral composition of the analyzed samples taken from flysch bedrock, the weathering zone and colluvium. The clay fraction ranges from 17 % to 38 % in samples. The most common groups of clay minerals are: kaolinite, illite and chlorite. Smectite and vermiculite were found in some samples. Clay activity of the tested samples is from 0.45 to 0.89. This is in the range of low to normally active clays and corresponds to kaolinite and illite groups. The results of analysis using scanning electron microscope presented the chaotic microstucture of particles that corresponds to the morphogenesis of the investigated slope. The residual friction angle is in the range 13.0°<ϕ_r<17.7° and corresponds to kaolinite and illite groups.

Preformed stability analyses have shown that slope movements were caused by an increase in groundwater level and thereby unfavourable water flow. According to the described laboratory analyses, silty-clayey sediments prevail in the lower part of the colluvium materials in the landside body. Mineral composition and decrease in strength of fine grained soil materials due to increase of pore water quantity, contributes to the slope movements.

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