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Original scientific paper

GEOLOGICAL AND ENGINEERING-GEOLOGICAL CONDITIONS FOR FORMATION OF LANDSLIDE IN CEMENT MARL AT OPEN PIT "FILIJALA", BEOČIN

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Abstract: Studying of conditions causing occurrence of landslides at the open pit "Filijala" at the cement plant in Beočin is based on geological and engineering geological features of Pannonian marl as basic raw material to be exploited. Morphotectonic and structural relations, lithological composition and the way in which they occur, as well as monitoring of physical and mechanical features both in Pannonian deposits and in floor and roof sediments give an insight into the process of landslide occurrence at open pit.

Key words: geology, engineering geology, land slide, Pannonian marl, Beočin

1. INTRODUCTION

Deposit of cement marl at "Filijala" where open pit with the same name was developed, is the main deposit in exploitation of basic raw material for the cement plant in Beočin today. It was known since 1838, and its usage began since 1969. The deposit consists of three exploitation areas of different size and level of exploitment:

1. "North field" is the largest, the oldest and the most exploited field;
2. "Middle field" and
3. "South field".

The history of studying of geology of the cement marl deposits at Beočin and, as wider region in Fruška Gora, was subject matter of constant interest ever since the first half of the XIX century in various fields of geological disciplines: stratigraphy, paleontology, tectonics, petrology and mineralogy, ore deposits etc. The most complete data from the first stage of explorations of geological features of Fruška Gora can be found in the works of Hörnes (1874), Lentz (1874) and Koch (1896), who were the first to show geological features and tectonics of this area. Shortly afterwards, an eminent group of well-known geologists and geomorphologists, among which Laskarev (1951), Petković et al. (1976), Čičulić et al. (1971), Čičulić (1977), Stevanović & Papp (1985), Stevanović (1990) were engaged in geological features of Fruška Gora. Čongradec (1975), Knežević (2007), Knežević and Lazić (2008),

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Knežević et al. (1997, 2002 and 2008), Simić et al. (2002), Simić (2004, 2006 and 2007), Draško et al. (1998) were engaged in issues of exploration of the reserves and quality of marl as raw material in the deposit "Filijala" and geological features. Recently, Rakijaš (2007), Lazić and Rakijaš (2007) dealt with the issues of engineering geology and hydrogeology in the deposit "Filijala", and especially with the occurrence of landslide.

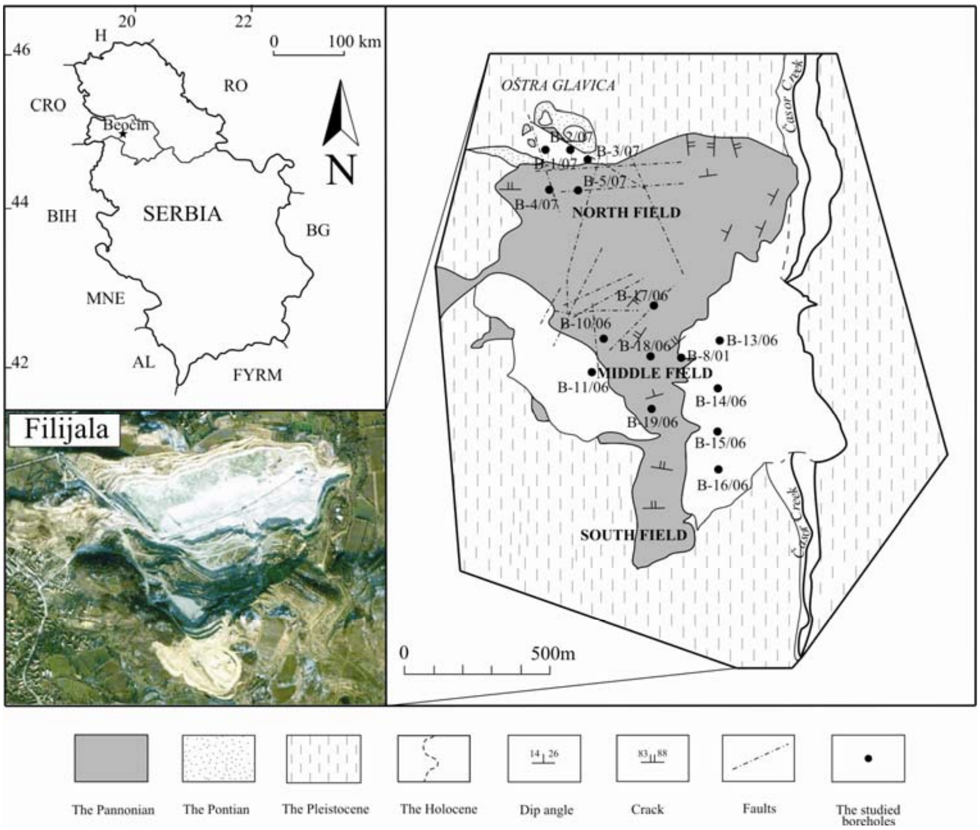

Figure 1 - Geographic and geological sketch of the open pit "Filijala" (Beočin) with position of exploratory boreholes

The open pit "Filijala" encompasses a part of the terrain on northern ranges of Fruška gora, above the right river bank of the Danube near Beočin (Figure 1). The area of open pit itself encompasses hilly area unevenly sloping down the bank of the Danube, so that local heights morphologically break out (Belo brdo 236 m and Oštra glavica 190 m) and coves, and the mean altitude of the terrain is approximately 170 meters. The valley of the Časor creek is located in the eastern part of open pit "Filijala", and to the west of the deposit, the valley of Kozarski creek is developed. Today, due to the exploitation of marl, natural morphology of the terrain is considerably altered. Parts of the former heights were "removed" and the valley of the Časor creek in the area of the deposit and the part of the "Middle field" are mainly backfilled with fill of the former overburden of the pit. Due to mining works, parts of the terrain in the "North field" and partly in the "South field", were almost geometrically profiled by construction of exploitation levels and often they are leveled in form of a plateau, and daily exploitation in the open pit also affects the morphology of the terrain that changes rapidly.

2. GEOLOGICAL FEATURES

In terms of morphotectonics, Fruška Gora represents an elongated horst of the east-west direction, rising above the south zone of Pannonian plain. Cement marl, representing production level at the open pit "Filijala" are of the Pannonian age (Upper Miocene) and they are the most common geological unit especially at the largest exploitation area of "North field". Grey Pannonian marl, as well as the underlying Sarmatian sediments makes the unique structural floor. Overlying is mad by Pontian sands and Quarternary (Pleistocene and Holocene, i.e. Anthropogenic) deposits.

In terms of stratigraphy, Pannonian sediments are divided into two levels: older level – Slavonian substage and younger level - Serbian.

Slavonian is developed in the area of "South field", where grey, compact marls in small layers contain rare and small fossils among which are: *Radix croatica*, *Gyraulus praeponticus*, *Limnocardium praeponticum*, *Paradacna cekusi*, *Undulotheca pancici* and others.

Serbian, which is present in the "North field", in terms of biostratigraphy and paleontology, is marked by the presence of the following mollusk species: *Congeria banatica*, *Paradacna syrmiense*, *Paradacna lenz*i, *Provalenciennessius* sp., *Gyraulus praeponticus* i ostrakoda: *Candona (Caspiola) alasi*, *Candona (Reticulandona) reticulata*, *Amplocypris major* and others (Ganić et al. 2010).

By measuring the elements of marl dip, it was established that:

- in the "South field" they have dip angles of about 20°;
- in the excavated layers of the Pannon in the landslide scarf in the center of "Middle field", dip angle of 18° was established;
- in the northern perimeter of "Middle field" dip is, however, becoming larger by reaching 26°;
- In "North field", by following the azimuth of the strike, the dip angle of marl is gradually decreasing so that at levels of the northern slope of open pit, dip angle of 12-14° is measured.

Regarding the area of the entire deposit, Pannonian marls beginning from the "South field" constantly dip in the direction NNW, so that their thickness is being constantly increased in this direction. Previously, its largest thickness at the peak Oštra glavica was about 200 m. However, after long-term exploitation in the large area of "North field", the thickness of marl bearing deposits is reduced up to the basic level with absolute elevation of 110 m. The largest established thickenss of approximately 109 m was established by newly made boreholes in the "North field" (B-19/06), where drilling was finished in the layer of Pannonian marls (Figure 2).

Figure 2 - Borehole B-19/06 with excavated Pannonian marl within the depth interval 96 – 104 m

During field works in the pit, in the northern part of "North field", faults were noticed, affecting the morphostructural configuration of the terrain. Here, around the discordant contact Pannon/Pontian several faults appear which had significant impact on the formation of very specific structural configuration. More detailed studies on open profiles surrounding northern slope of "North field" and in boreholes executed within small morphological cove between most prominent peaks on the Oštra glavica hill (Knežević, 2007), have pointed out the presence of several faults in this area. Some of them close a small, but relatively deep rift valley. The rift valley is, at the south side, limited by the fault in the direction ENE-WNW, than with the fault NNW-SSE from the west and by the fauld in the direction ESE-WNW in the eastern part of this terrain. Those faults form the rift, which in the layout looks like scalene elongated triangle (Ganić et al. 2010).

Genetically speaking, Pannonian marls on northern slopes of Fruška Gora have been formed at early stage of the evolution of Pannonian lake, when due to the isolation and fresh water inflow from the mainland, a salty lake was formed, i.e. mesohaline to oligohaline aquatic environment (Ganić et al. 2010). Under such conditions, principall mass of calcium carbonates that form marls was formed through chemical processes of carbonate precipitation in the warm, mildly agitated aquatic environment saturated by bicarbonate solution. Although Pannonian marls have seemingly the appearance of unified sediments in wide area, they, when layers are considered, nevertheless differ by time of formation within the geological column.

Lower marls in the "South field" are primarily platy, than bedded and relatively harder, locally sandy with occurences of hard layers of carbonate sandstone and marly siltstone. The average amount of $CaCO_3$ in those marls of the "South field" is approximately 62.55%.

Marl containing deposits of the upper Pannon form layers with larger thickness, they are more banked and they are averagely less indurated than lower Pannonian deposits. The average content of $CaCO_3$ (in "North field") is approximately

64.42%. However, there are interbeds and lenses entirely different from the enclosing rocks included in the Pannonian marls in "North field" as well. In the exposed parts of the pit in "North field", the presence of interbeds of ferruginous silty sand thinner than 10 cm was established as well. In the borehole B-6 ("North field") at the depth of 61.0–61.1 m a layer of sand-marl conglomerates with pebbles of quartz, hornstones, serpentinites, Cretaceous sandstones etc. (Ganić et al. 2010) was found and in the borehole B-8 (Figure 3) at the depth of 51.2-53.0 m a layer of marly sand succeeding gravelly-sandy marl was found. Those minor occurences of gravelly-sandy interbeds within marly rocks are of local character and they wedge out in lense-like manner within the area, however, being water permeable environments, ground waters can infiltrate through them and they could impact mining works while exploiting and they represent, under certain circumstances, active factors in formation of a landslide.

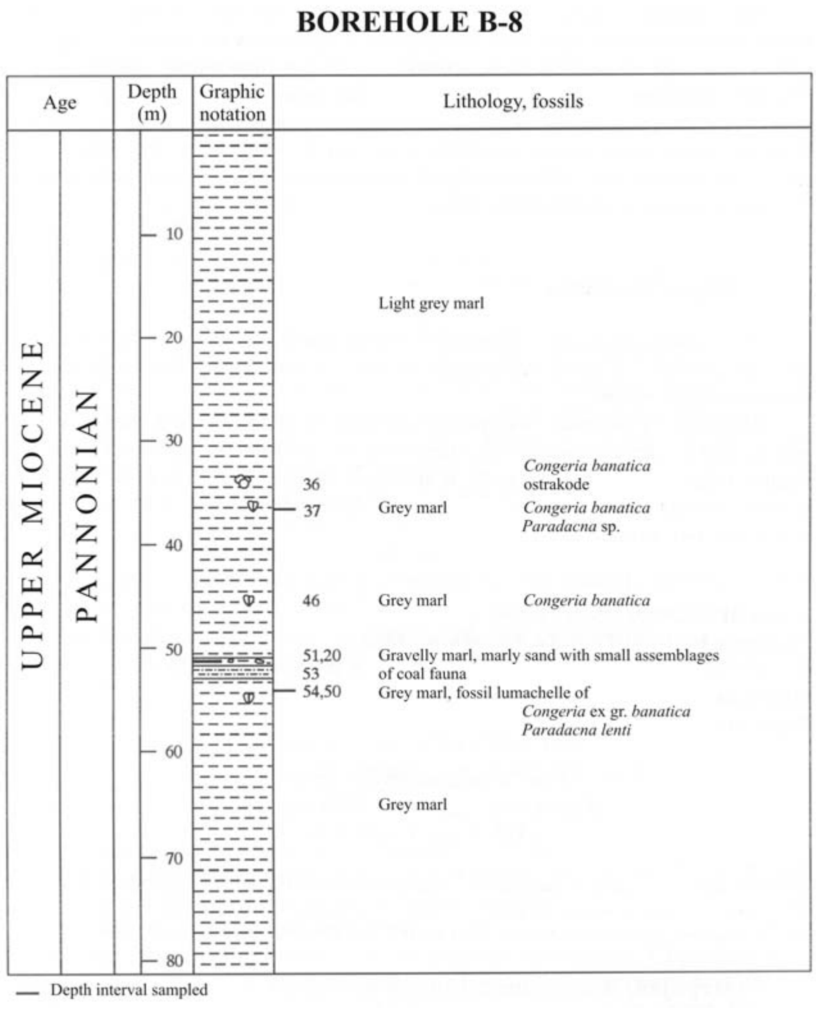

Figure 3 - Stratigraphic profile of borehole B-8, deposit "Filijala - North field"

3. FEATURES IN TERMS OF ENGINEERING GEOLOGY

Engineering and geological studies include Neogene complex and Quartarian deposits in the open pit "Filijala", however, as Pannonian marls represent fundamental raw material for exploitation, special attention is given to the marly sediment complex.

Marly sediment complex is represented through:

- marl weathering crust;
- pale-yellow marls and
- grey marls.

Marl weathering crust is averagely 0.5 to 2.0 m thick with gradual transformation into preserved, unaltered rocks of yellow and grey marls. In this zone, rocks are severely fissured and crushed, partialy up to tiny debris, mixed with clay-marly weathering crust. Degraded zone gradually develops into deeper parts of the terrain under the influence of water infiltrated from upper layers and within a long period of time it is retarded over marls. For this reason, this zone is formed only in those parts of the terrain that are under larger impact of water from upper, more water permeable horizons and it was established in almost all exploring boreholes within the "Časor" dump, and in central part of the terrain it was established by exploratory drillings (B-11/06, B-18/06 and B-19/06) (Figure 1). Due to the bad physical and mechanical as well as engineering-geological features, this zone also represents suitable environment for periodical retaining of minor quantities of water infiltrated from upper parts, as well as for further degradation and development of landslides. Measured vales of basic parameters of physical and mechanical features (bulk density, angle of shearing resistance and cohesion) of the marl weathering crust are as follows: $\gamma_w = 18.00$ kN/m^3, $\varphi = 16°$, $c = 15$ kN/m^2.

Pale-yellow marls lie beneath the clayey-clastic set, and above grey marls. Yellow marls contain clayey admixtures, and they are bedded into thick banks with thickness of 0.6-1.2 m and they dip toward northwest at the angle smaller than 15°. Their established thickness is approximately 9 m, but in certain parts of the terrain they do not exist, which indicates that they are unevenly spread. They are predominant in the southern part of exploratory area (deposit "South field"). Basically, they are degraded marls, whose were transformed due to the impact of water along fissures, so that its thickness becomes larger in the more degraded zone, in coves. In the zone up to 3 m, yellow marls are heavily fissured with the system of fissures along the stratification plane and perpendicular to the stratification. Fissures along the stratification plane are tight and those who are perpendicular to the stratification are filled with clayey-marly and carbonate detritus. Fissures are easily spread on the open profile, whereby larger rock blocks are splintered and caved in. Along fissures, floess and manganese films were established, and in certain parts traces of movement of rock mass (B-10/06, B-11/06, PIB-13/06, B-14/06, PB-17/06, B-18/06) were noticed (Figures 1 and 5b). Rock mass is poorly permeable ($K_f < 10^{-8}$ m/s), while minor quantities of water, infiltrated from upper layers, are temporarily retained within more fissured rock mass. Measured vales of basic parameters of physical and mechanical features of pale-yellow marls are as follows: $\gamma_w = 23$ KN/m^3, $\varphi > 25°$, $c > 30$ KN/m^2. Compressive strength is $\sigma_c = 6.57$ MPa, tensile strength is $\sigma_t = 1.25$ MPa, while the shearing strength within the compact rock mass is relatively good: $\varphi > 25^0$, $c > 40$ KN/m^2.

Grey marls lie in underlying stratum of yellow marls or beneath clayey-clastic Neogene sediments and they are partially established direct under Quarternary sediments or on the surface of the terrain. Grey marls are very good raw material for cement industry, and their established thickness is 80-100 m. They are bedded into banks with thickness of 0.6-1.2 m and, generally, they have direction of a dip towards northwest. In the upper zone, up to approximately 3 m, rock mass is fissured (Figure 5a), while in deeper parts it is compact. However, fissures are tight, so that only due to inadequate cut and alteration of stress condition, they spread and rock blocks splinter on them and by means of gravity they slide down the slope. The anisotropy of rocks is very noticeable with fissure systems along the stratification plane and perpendicular to stratification (Figure 5b). Splintering and sliding of rocks is taking place along fissures perpendicular to the stratification plane and rarely upon beddings of rock mass that are at slight gradient towards northwest. In this connection, on the northern slope of open pit "Filijala - North field", marl layers dip into the hill, while on the south one they have slight dip down the slope (dip angle of layers is 12-15°). This leads to conclusion that the spatial position of primary structures was the basic prerequisite for the occurrence of instability of the hill-side on the southern slope of the pit, and that the stability of slopes on the northern perimeter of the pit "North field" is much better.

Measured basic parameter values of physical and mechanical features of grey marls are as follows: $\gamma_w = 26$ kN/m^3, $\varphi > 30°$, $c > 30$ kN/m^3. In deeper parts, grey marls are compact, slightly fissured and relatively hard ($\sigma_c = 6.57$ MPa, $\sigma_t = 1.25$ MPa). Rock mass is slightly permeable ($K_f < 10^{-8}$ m/s), with minor water filtering along fissures in upper zone that is being infiltrated from overlying strata. Influenced by water, marls gradually soften whereby their compressive strength decreases and the shearing strength as well. The presumption is that generalized stability coefficient of marl (due to openness of rock mass by excavations) is larger than 0.25 which means that their strength decreases so that they are subject to further decay.

The occurrence of fissures in marls was examined on open profiles as well as in the area of borehole locations. In marls and in clayey environment, dumps are separate zones, which are characterized by fracture anisotropy (taking into account spatial orienataion, density and character of fractures, as well as morphogenetic conditions of open profile terrain).

1. The degree of fissureness in marls was analyzed on frontal scarf of active landslide on southern slope of open pit "Filijala - North field". In this zone, two basic fissure systems were detected, as follows:
   - Fissures along stratification, planes EP = 350/10-15°, closed and tight, being activated by way of gravity, when marl blocks are splintered and caved in towards the bottom of the pit. The degree of fissureness of rock mass $S_i > 10\%$, which means that the **rock mass is significantly fissured**;
   - Fissures perpendicular to stratification planes, tension fractures, along which marl blocks are being splintered and caved in towards the bottom of the pit. Statistical EP = 80/85-90°. The degree of fissureness of rock mass $S_i > 10\%$, which means that the **rock mass is very heavy fissured**.

2. The degree of fissureness in marls was also analyzed in the core of exploratory boreholes B-10/06, B-11/06, PB-13/06, B-14/06, PB-15/06, PB-16/06, PB-17/06, B-18/06, B-4/07, B-5/07, B-3 /07, PB-2 /07 and B-1/ 07 (Figure 1). The majority of fissures display movement marks, whose surfaces are coated with loess and manganese, which indicates water circulation along fissures. Fissures are at angles of different inclination, from 45-90°. According to the indicator of fissureness in rock mass, it was established that this is mean to heavy fissured rock mass. Uneven fissureness of rock mass is caused by morphogenetic characteristics, as well as by the proximity of wide mine excavations, so that marls are heavily fissured both on the southern and on the northern perimeter of the pit "Filijala - North field".

Stability of the terrain made of marl was evaluated on the basis of detailed engineering-geological mapping of the terrain, as well as on the basis of movement fissures established by exploratory drilling. By detailed mapping the boundary of active landslide on the southern slope of open pit "Filijala - North field" was defined, as well as the upper limit of potential instability of the terrain both on the southern and on the northern slope of the pit (Figure 4). By surveying and analyzing of fissures of rock mass movement the upper limit of potential instability of the terrain within the marl deposit of "Filijala - North field" was confirmed.

Apart from parameters concerning physical and mechanical features of cement marls, the evaluation of marl rock mass with regard to execution of mining works and their stability was made. Apart from engineering-geological and physically-mechanical indicators, for the evaluation of marl rock mass strength in the "Filijala" deposit the following indirect analysis data were used:

- petrographic and chemical fetures of rock mass: composition of diagenetic consolidation of rocks (consolidation of rock mass), content of $CaCO_3$ etc.,
- stratigraphic position of rock mass (geological units) within the terrain.

Based on those reseaches, analysis and correlative connection of those results, data on relative strength of Pannonial marls with regard to the conditions of their exploitation as mineral raw material were obtained.

Marls of the "North field" and "Middle field" deposits are compact and with relative medium strength, they represent good exploiting raw material due to: small bulk density ($\gamma_w = 19$ kN/m^3, $\gamma_d = 13\text{-}16$ kN/m^3), small compressive strength ($\sigma_c = 5.02$ MPa), small coefficient of elasticity ($E_e = 4.20$ Mpa), cohesion ($c = 65$ kN/m^2), angle of shearing resistance ($\varphi = 49^{\circ}$), modulus of compressibility ($M_v = 30000$ kN/m^2). Those sediments are regarded as relatively medium hard rock mass (in terms of comparison with the total massif in this area), with monotonous values of parameters for compressive strength and scearing strength. In certain parts of the terrain, in the surface zone (up to the depth of 10.0 m), considerably softer parts of rock mass are present, which is caused by its secondary alterations.

Softening coefficient K_r of marls is high because rock mass rapidly receives large quantities of water (it becomes waterlogged) and its strength becomes reduced under the influence of water.

Consistency coefficient K_p is also high (> 0.25), which indicates that marl, under conditions of exposure and dip during a certain time period, loses considerable share of its initial strength.

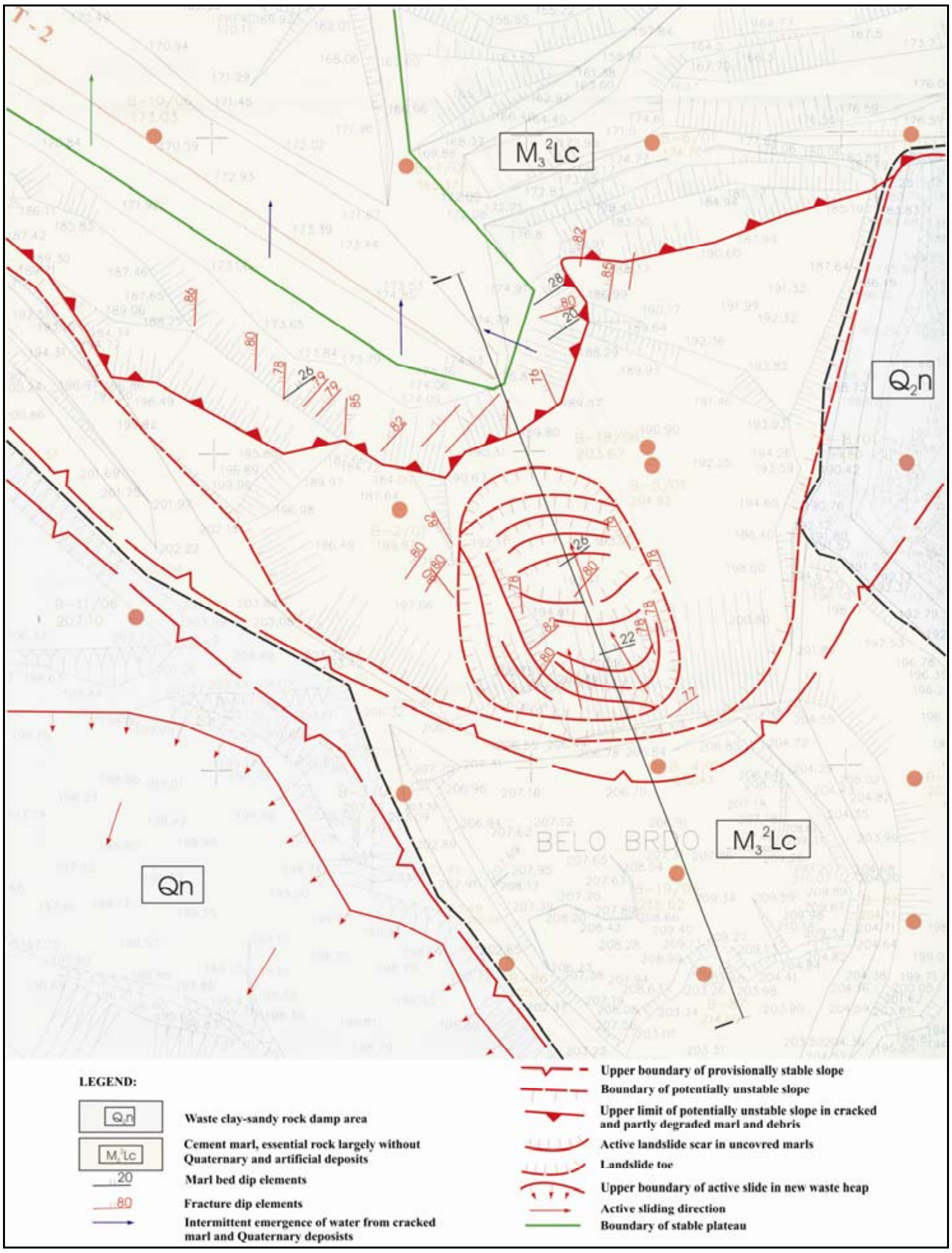

Figure 4 – Engineering-geological map of a part of cement marl deposits at "Filijala - Middle field"

Strength and consistency of marls, together with dip conditions, degree of fractureness and alterations, have a large significance for excavation conditions and exploitation of the deposits, and in connection to excavation, workability and drilling; they belong to the category of semi-hard rocks.

a) b)

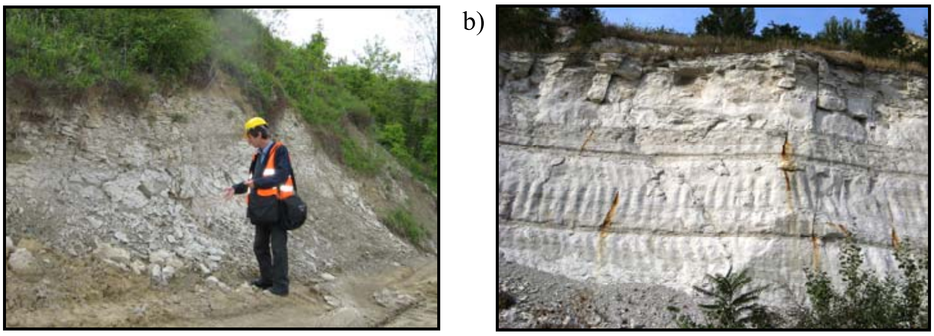

Figure 5 - a) Small-fissured Pannonian marls on the slope of the "Filijala - North field " deposit (photo: M. Lazić); b) Profile of marl dissected by vertical fissures in the open pit "Filijala - North field " deposit (photo: Lj. Rundić)

4. DISCUSSION

The largest occurrences in the open pit "Filijala" deposit have Upper Miocene sediments of the Pannonian age. They are deposited conformable over Sarmatian sediments and together with them they form the unique structural unit.

Pannonian sediments are here present at the marl facies representing the basic raw material in cement production. On the basis of fossil fauna as well as some lithological and structural features, sediments of Lower Pannon (Slavonian subage) present in the area of "South field" have been isolated, while more prevailing sediments of Upper Pannon (Serbiana) were detected in the area of "Middle field" and "North field". Layers of Pannonian marls here spread in the length of approximately 1.5 km; they sink toward NNW at the angle of 12-26° and have thickness larger than 200 m.

Sandy Pontian sediments are transgressively and unconformably deposited over Pannonian marls and they form upper structural unit with smaller dip angles (mainly 5-10°). Quartarian, Pleistocene and Holocene sediments (especially anthropogenic deposits) were deposited over them.

In the area of the deposit, elements of radial tectonics in form of a complex rupture configuration are present, primarily in form of a system of fissures and small faults (with minor movements along fault surfaces). In the northern part of the deposit, at the Oštra glavica peak and at its foot, larger faults with stronger differential movements of separated blocs are also present as well as occurences of rift structures. Folding shapes, so called monoclines and flexures were presumably formed at the moment when marls were still young unsolidified rocks (probably during Early Pontian when sedimentation ceased due to the uplifting of the part of Fruška Gora) (Ganić et al. 2010). Those structural forms represent initial prerequisite for landslide formation in the open pit.

By examining the results of engineering-geological researches it can be noticed, that thefractureness and incoherence of marls, which was monitored within weathering crust of yellow and grey marl, affects badly their physical and mechanical features. This fractureness is followed by infiltration of surface water into deeper parts of the deposit, shearing strength of deposits, especially in the dump area, is reduced. By taking into account all physical and mechanical parameters, it was established that the degree of fractureness in the "North field" of the "Filijala" open pit and their dependency on the position of fissures in relation to stratification fall under the category of heavily fissured and very heavily fissured rock mass. Under the category of heavy fractureness fall fissures formed along the stratification planes, activated by gravitational sliding towards the bottom of the pit. On the other hand, under the category of very heavy fractureness fall fissures formed perpendicular to the stratification (tension fractures), forming marl blocks and enabling their caving in (movement) (Figure 6a, 6b).

Apart from that, due to the small bulk density, small compressive strength, small coefficient of elasticity, cohesion, angle of shearing resistance and modulus of compressibility, marls of the "North field" and "Middle field" are considered to be semi-hard rock mass. However, due to the infiltration of surface water along fissures, it comes to the increase in values of softening coefficient and consistency coefficient. This leads to the decrease in hardness of marls and in that way, they become more susceptible to deformations, which enables the occurrence of sliding process.

a)

b)

Figure 6 - a) Landslide with blocks formed along fissures parallel to the stratification planes and perpendicular to them; b) Profile dissected by fissure system within grey marls (photo: Lj. Rundić)

5. CONCLUSION

Based on the results of the researches at the "Filijala" open pit, it was established that, in geological and engineering-geological terms, the following factors affect the occurrence of landslide and instability of working slopes:

- structural and geological relations in the terrain, i.e. dip of Pannonian marl layers at the "Filijala" open pit, which are constantly sinking towards NNW with variable dip angle of 10°–26° and which are forming the flexure;

- considerable fractureness of Pannonian marls, with distinct system of fissures perpendicular to the stratification plane, as well as with the system of interstratal fissures often filled with clayey backfill;
- deteoration of rock mass in the upper zone, through which precipitation water is periodically infiltrated;
- susceptibility of marl rock to softening under the influence of water and frost, whereby its parameters of compressive strength and shearing strength are considerably reduced;
- coverage of marl rocks, in certain parts of the terrain, by the deposits of Quarternary sediments subject to further movement down the hill-side, i.e. down the slope;
- alteration of tension within marl rock due to the construction of open cuts;
- when removing the gangue, marl rocks with inconsistent physical and mechanical features are being exposed, whereby this rock mass is exposed to the influence of external agents with further deteoration;
- in the dump, landslides emerge due to bad solidification of rock mass with oftenly uneven lithological composition, as well as due to subsequent water inflow in this environment.

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