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ENGINEERING-GEOLOGICAL CHARACTERISTICS OF THE LANDSLIDE MLIJA AND THEIR IMPACT ON ENGINEERING STRUCTURES (OMIŠ, SOUTHERN CROATIA)

Slobodan ŠESTANOVIĆ[1] & Duško BARČOT[2]

[1]*Faculty of Civil Engineering, University of Split, Matice hrvatske 15, HR-21000 Split, Croatia*
[2]*Civil Engineering Institute of Croatia, Business Centre Split, Matice hrvatske 15, HR-21000 Split, Croatia*

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In order to design the by-pass road of the city of Omiš which will partially be founded on the landslide Mlija and for the safety of foundations of houses, detail subsurface exploration especially engineering-geological surveys, geophysical surveys, boring and laboratory tests of the sliding material were conducted. Obtained results are presented in this paper. Due to numerous damages of roads, walls and houses built in the area of Mlija and Borak, the possibility of construction in the area was discussed and the foundation method proposed. In order to obtain an overview of circumstances, constant monitoring of variations of the water table level and velocity of the moving material has been proposed.

Ključne riječi: Klizište Mlija, Inženjerskogeološke značajke, Fliš, Eluvij, Deluvij, Građevine, Omiš, Južna Hrvatska

Za potrebe projektiranja obilaznice Omiša koja će dijelom biti temeljena na klizištu Mlija te za sigurna temeljenja obiteljskih kuća na toj padini, provedena su detaljna istraživanja, posebice inženjerskogeološko kartiranje, geofizička istraživanja, istraživačko bušenje i laboratorijska ispitivanja materijala koji klizi. U ovom radu prikazani su postignuti rezultati, a zbog brojnih oštećenja na prometnicama, zidovima i stambenim zgradama izvedenim na području Mlija i Borak, raspravljena je mogućnost gradnje na odnosnom terenu s prijedlogom načina temeljenja. Uz to, za dobivanje cjelovite slike stanja, predloženo je stalno praćenje kolebanja razine podzemne vode i brzine kretanja materijala.

Introduction

Natural slope Mlija is situated southeast from the old centre of Omiš (Fig. 1). Geologicaly speaking, a wider area of the slope has been marked as recent landslide. Due to engineering activities (construction of family houses in the middle part and close to the foot of the slope), a relative stability of the area has been endangered, especially of its middle part.

Engineering-geological, geophysical and geomechanical surveys were conducted during the period 1986–1991 for purposes of the construction of the by-pass road of the city of Omiš. For the most part, the documentation on engineering-geological and geomechanical surveys can be found in archives of Faculty of Civil Engineering of the University of Split and Civil Engineering Institute of Croatia – Business Centre Split. The relevant reports for the area of Mlija were made by Roje-Bonacci et al. (1986) and Šestanović & Barčot (1991). Information on geophysical surveys were elaborated by Dujmić (1991). Results of engineering-geological and geophysical surveys of the Omiš by-pass road, which contain some data on the Mlija landslide were published by Kapelj et al. (1994). Since 1991 there were only occasional subsurface explorations in order to obtain a geotechnical opinion on the possibility and conditions of foundation for family houses. A recent knowledge on the subject has been presented in this paper.

The objective of this paper is to describe geological structure of the slope, geomorphologic and engineering-geological characteristics of sliding upthrow and downthrow beddings and a sliding mechanism and their impact on structures in the area.

Basic geological and geomorphologic data

Surveyed area consists of Eocene flysch beddings (Marinčić et al., 1975, and Marinčić et. al., 1977) eluvial deposits (cohesive soil) formed from the weathering of marl from the base and deluvial deposits (non-cohesive and cohesive soil).

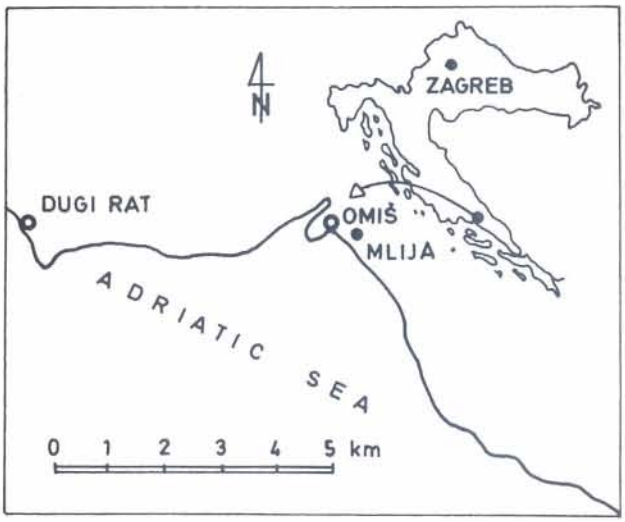

Fig. 1. Geographic situation of the explored location

Eocene flysch beddings ($E_{2,3}$) consist of marls with thin layers of sandstone (arenites). These sediments are the base rock of the slope Mlija. General direction of layer dip of flysch beddings is north-northeast (toward the slope) and the angle of dip is 30°–50°. Layer thickness ranges from few millimeters to several meters, but thin layers are predominant. Sporadical flysch layers, especially marl, occurs in the tectonized (crushed) zone. Sandstone and marl alternate almost regularly and the bedding planes characteristic signs for flysch beddings can be observed (impressions, traces of organism movement, flow marks).

Eluvial sediments (Q_{el}) are the result of weathering of marl from the base rock mass and consist of yellow-brown clay with small percentage of marl and limestone

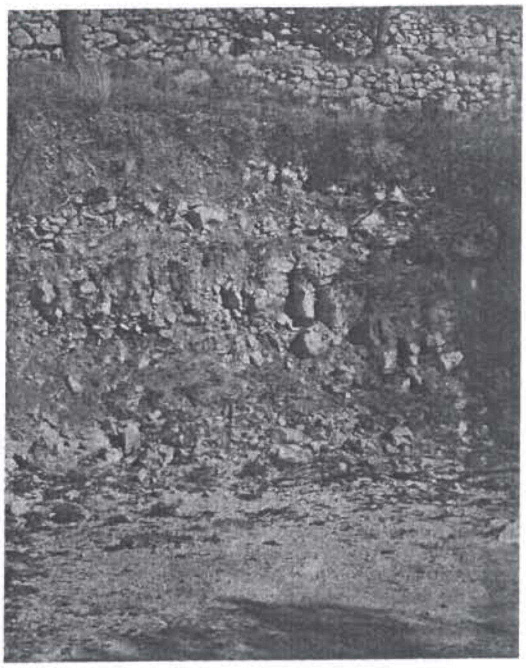

Fig. 2. Deluvial sediments in the cut of the slope

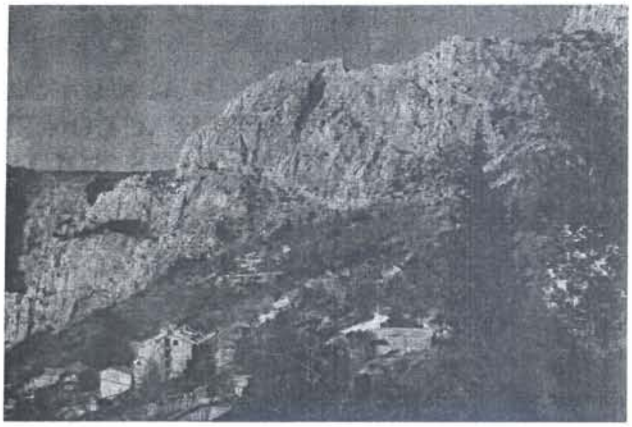

Fig. 3. Thrust Omiška Dinara above the landslide

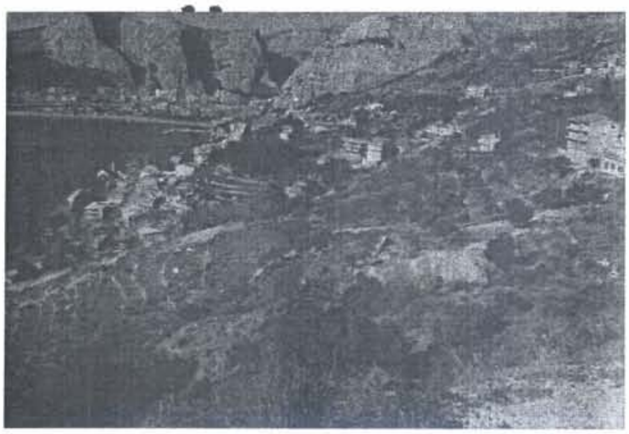

Fig. 4. Landslide Mlija

fragments. In some areas beddings are several meters thick.

Deluvial sediments (Q_d) are the result of the weathering of carbonate and flysch beddings in the hinterland which were transported to a short distance mostly by gravitation (Fig. 2) to the foot of the slope and accumulated over older beddings. They consist of silty clay of low to intermediate plasticity and compactness with small percentage of angular limestone fragments. According to the results of exploration, thickness of deluvial deposits in the area of Mlija ranges between 2 and max. 8 m (mostly 2 to 5 m).

Slope movements occur in deluvial and partially in eluvial deposits.

Investigated area is too small to evaluate global tectonic relations. According to the Legend of the generalised geological map of the sheet Omiš (Marinčić et al, 1977) explored location is situated within tectonic unit Tertiary sinclinore which comprises coastal belt to the front of thrusts Kozjak, Mosor and Biokovo. Thrust Omiška Dinara is one of the most significant in the wider area of the explored location. A basic type of structural deformation is thrusty structure where Senonian limestone beddings lie over Eocene flysch.

A tectonic activity locally breaks physical-mechanical features of the rock mass. However, general condition of autochtonous beddings of the Mlija slope point at a simple structure without pronounced deformations. Locally more pronounced decomposition and crushing of the flysch sediments is due to faulting and thursting of Senonian limestones of Omiška Dinara over flysch beddings (Fig. 3).

Morphologically speaking explored location is a slope cascadely shaped by small stone walls. General direction of dip is southwest and the observed dip angle 20°, locally to 35° (Fig. 4). Slope is covered with deluvial sediments (Q_d). A rocky steep carbonate massif of Omiška Dinara, of height 565 m above sea level, rises above the slope.

The main geological feature of the explored area is the occurrence of two lithogenetic base complexes that are flysch formations overlain by the Upper Cretaceous limestone beddings (K_2^3). Therefore two contrasted and by elevation dissectable natural basis of the slope profile can be distinguished:

- flysch and
- carbonate complex.

The flysch rock mass is heterogeneous in structure and condition as well as physical-mechanical parameters and geotechnical features primarily due to genesis of flysch as specific formation and extremely pronounced tectonics.

Flysch slope has been formed during the Quaternary; its morphogenetic evolution altered the base rock mass and weathering products were accumulated.

Hydrogeology

Hydrogeological relations are defined with the permeable rock mass of the carbonate complex and slightly permeable to impermeable flysch. With regard to engineering-geology, a ground water which is retained in the surface area and influences the condition of the soil and the rock mass as well as slope stability is very important. Subsurface ground water is occasionally obtained by wells.

Deluvial deposits have intergranular porosity so precipitation percolates faster or slower depending on the clay content to beddings of degraded flysch (eluvium) which are slightly permeable. Precipitation is also dispersed by occasional runoff as torrents through gullies. At the contact of carbonate and flysch complex there are also periodical springs of low capacity.

Ground water percolates to the contact of deluvium and eluvium depending on preferred filtration courses.

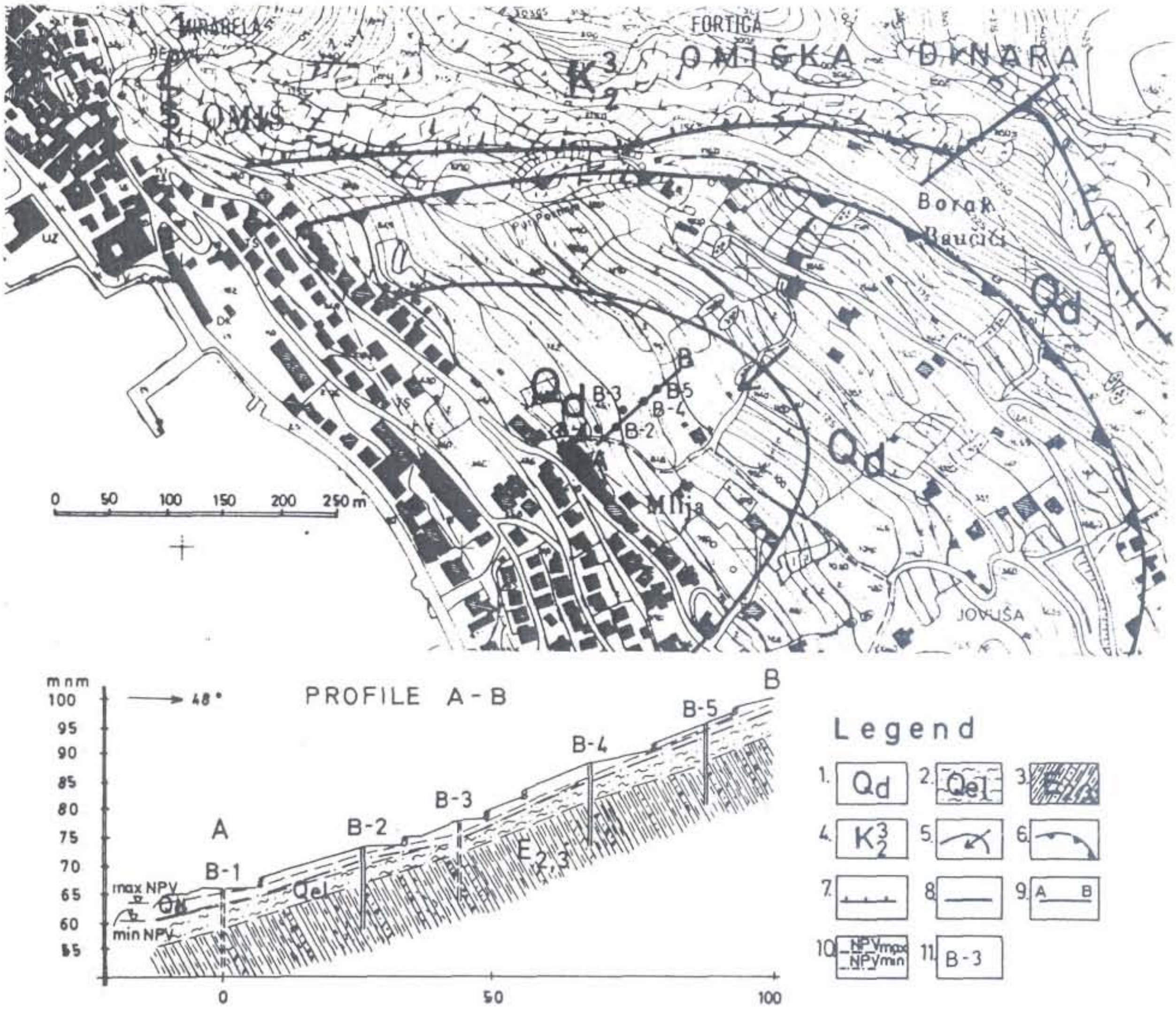

Fig. 5. Engineering-geological map and profile.
Legend
1 – Deluvium, 2 – Eluvium, 3 – Flysch, 4 – Upper Cretaceous limestones (Senonian), 5 – Landslide, 6 – Unstable slope boundary, 7 – Thrust Omiška Dinara, 8 – Fault, 9 – Profile A–B, 10 – Ground water level (max. and min.), 11 – Boring

Ground water level was monitored during three winter moths of 1986 and minimal levels in five boreholes, from –1.80 m to –4.10 m from the ground surface, were measured as shown in Fig. 5. Maximal water levels ranged from –2.70 m to –0.65 m. In a well situated near the upper part of the landslide ground water level of –1.60 from the ground surface was measured.

Generally speaking, the entire area is an aquifer which can be confirmed by numerous wells, percolation of water in building pits in the body of the landslide and a notch close to the foot of the sope as well as periodical wells in the Borak area which is situated east from Mlija. Test boreholes were used to determine the thickness of Quaternary sediments which ranges between 6.0 m and 7.40 m in the inspected profile.

Engineering-geological model of the slope

Two basic engineering-geological elements are: Upper Cretaceous carbonate complex (K_2^3) and clastic Eocene flysch ($E_{2,3}$). The former is well cemented and well petrified rock mass while the latter can be described as poorly petrified marl beddings (»soft rock«). Well cemented and well petrified but jointed sandstones (arenites) in the form of intercalations can be sporadically observed in marls.

Engineering-geological map and characteristic profile obtain by boring is shown in Fig. 5. The surface area is formed from deluvial deposits (I) which is covering degraded flysch-Eluvium (II) and the base rock mass – flysch (III).

There are two boudary planes between mentioned elements. One of them is at the contact of deluvium and eluvium and it should be considered as potential slope failure plane. Another negative factor is the ground water level mainly in the contat zone.

Geophysical surveys (Dujmić, 1991, and Kapelj et al., 1994) provided the minimum velocity of propagation of longitudinal seismic waves in surface beddings as: 660 m/s in deluvium, and up to 1250 m/s in eluvium. Velocities to 2000 m/s were registered in medium to well jointed and weathered flysch while greater velocities were registered in non-degraded flysch (approx. 3000 m/s). In areas with more sandstones (arenites) velocities greater than 3800 m/s were registered. Laboratory tests (Roje-Bonacci et al., 1986) were used to obtain soil parameters of the slope surface: c=22 kN/m^2, fric-

Fig. 6. Particle size distribution curve of the deluvium from the boring B-3

tion angle $\varphi = 21{,}3^{\circ}$ and unit weight $\gamma = 20\ kN/m^3$. These parameters were used for slope stability analyses for maximal and lowered ground water level using personal computer.

Characteristical grain size distribution curve of the deluvial material from the boring B-3 is shown in Fig. 6 while the subsurface exploration log of the boring B-3 is shown in Fig. 7. Standard penetration test (SPT) using the cone and cutter shoe obtained results between 13 and 21 blow for the same material shown in grain size distribution diagram

According to the Seismic Map of the Yugoslavia (1987) investigated location is situated in the zone for which for the recurrene period of 200 years and probability 63% maximum earthquake intensity of 8° of MSC Scale can be expected while for the recurrence period of 500 years 9° of MSC Scale can be expected.

In order to determine seismic impact on engineering structures of the Ist category, it is necessary, according to the »Regulations on technical normatives for the construction of buildings in seismic areas« (Anon., 1981) to determine the impact of local soil condition. With regard to the slope structure, investigated area belongs to the third category (poorly compacted and soft soil, semi solid clays, medium compacted sand etc. with thickness greather than 10.0 m). Due to engineering-geological features of the slope, it is necessary to use intensity of 9° of MSC Scale for structural analyses, and to build foundations in the ground of the first category, that is non-degraded flysch which occurs at the average depth of 6 to 7 m.

Discussion and conclusion

The Mlija slope is situated within tectonic unit Tertiary sinclinore and is limited with the thurst Omiška Dinara, which is elevated and lies over the Eocene flysch which is the base rock mass of the slope. Final form of the slope is a result of subsequent physical-geological processes in the ground.

Conducted explorations enabled to define engineering-geological model of the slope that consists of three units: flysch–eluvium–deluvium.

Generally speaking the entire slope is an aquifer. Sporadically tensile cracks can be observed. They are not widespread but it is obvious that the slope is unstable due to slow movements – creeping. There is also a possibility of the sudden slope failure especially in places where natural equilibrium was deranged due to cutting into the slope. As it could have been observed by field visits, all cuttings for purposes of preparation works for the construction have caused slope failure of a greater extent.

In the area of Borak the following can be observed: deformations of new stone walls (Fig. 8), creeping of blocks and deluvial breccias (Fig. 9) and cracks in asphalt pavement (Fig. 10). The most vivid example of inadequate foundations on the Mlija slope, as can be observed in Fig. 11 and Fig. 12, is an family house overturned during the construction. The structure was situated on the top of the slope (south from the local road) and had shallow foundations in deluvium which was the mass that moved.

Based on obtained information, a conslusion can be drawn that the slope is in the state of constant creeping due to the hydrodynamic pressure, with sporadical failures of local character while each intervention as the slope cutting causes landslide and inadequate foundations overturning of houses.

Foundations should be constructed in non-degraded flysch beddings, with deeper strictly controlled excavation if flysch is found on depths less than 3 m. Pilots should be used when non-degraded flysh is found on greater depths. If intervention and construction costs are to high construction should be avoided. Therefore, any action in this slope should be strictly programmed, and preparatory works designed and undertook before any other activity.

Preparatory works should consist of drainage of ground water and intake of surface water out of the construction site. Drainage should cover the permeable

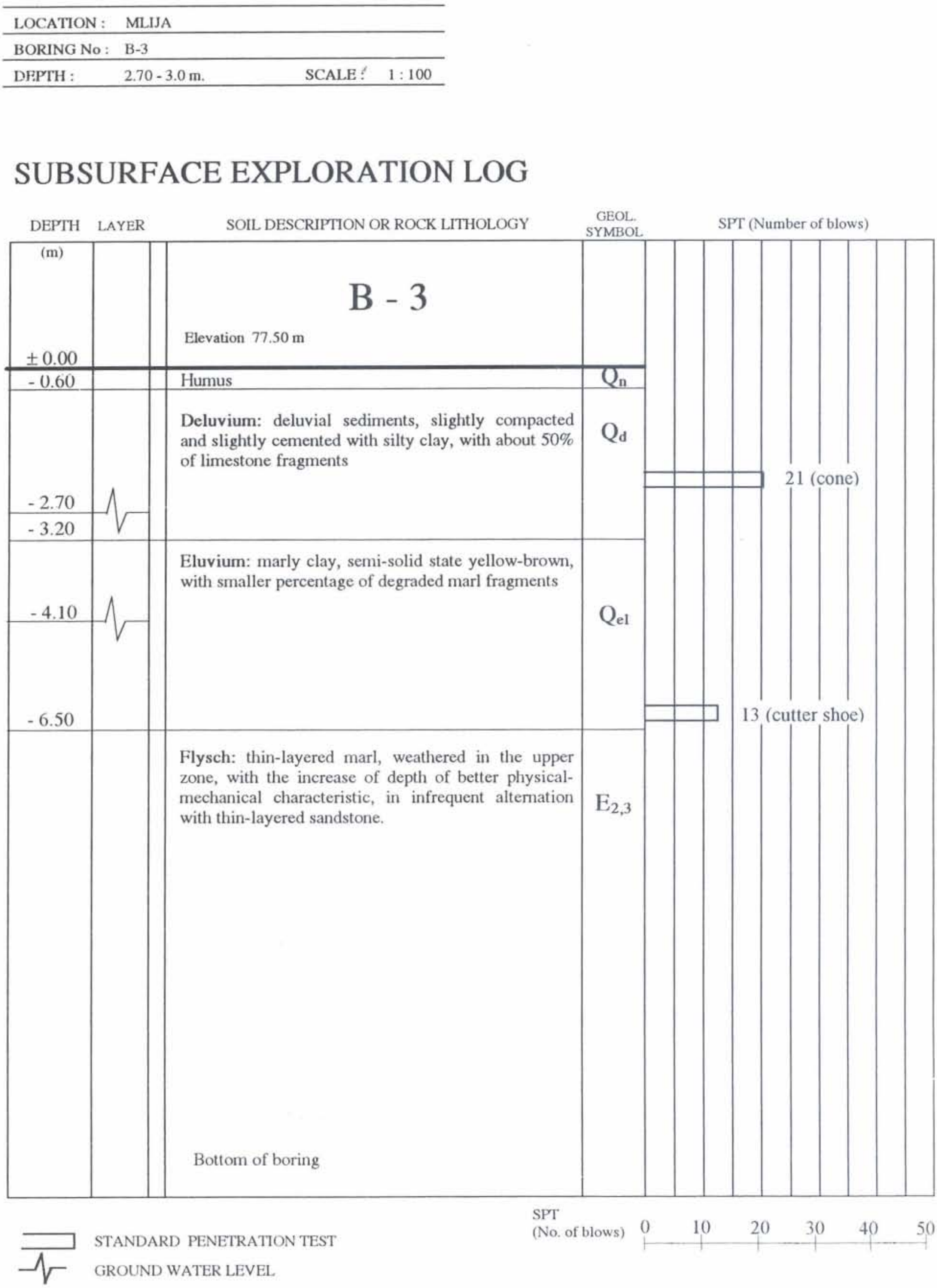

Fig. 7. Subsurface exploration log of the boring B-3

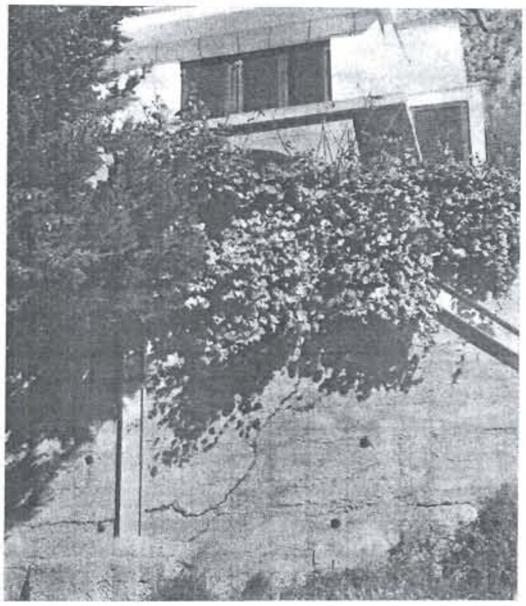

Fig. 8. Crack in the retaining wall of the family house in the area of Borak

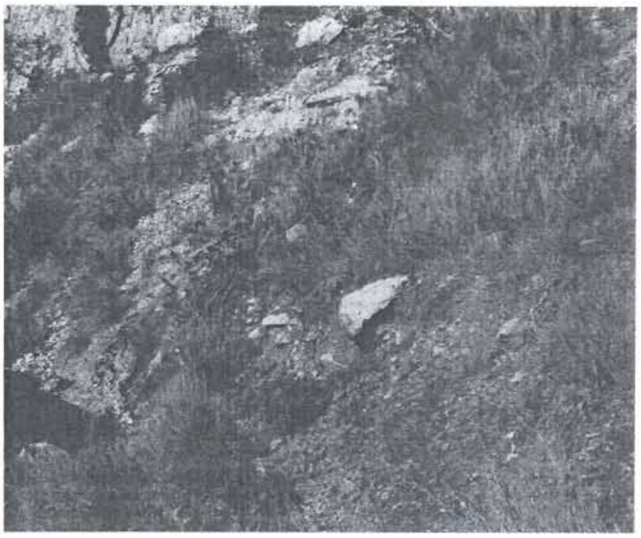

Fig. 9. Creeping of blocks and deluvial breccias in the slope

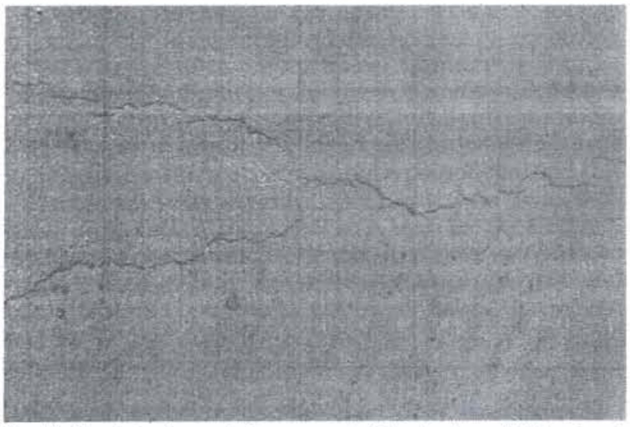

Fig. 10. Cracks in the asphalt pavement of the local road Mlija–Borak

surface area to depth of approx. 4.0 m from the ground surface.

Impact of possible high embankments on the entire slope stability should be considered. Stability analyses

Fig. 11. Overturned house due to the slope movement

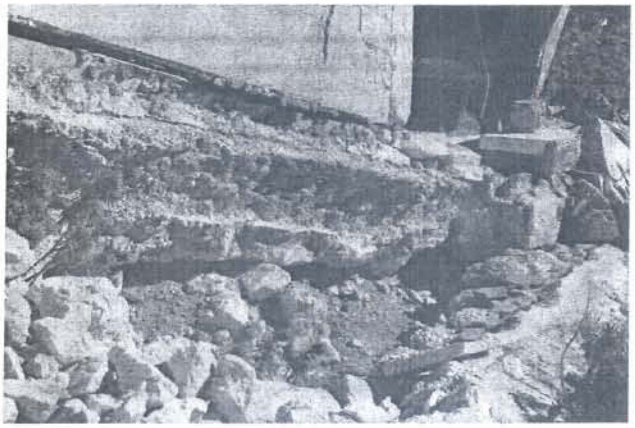

Fig. 12. Shallow foundations in deluvium mass which moved as a cause of overturning

(Roje-Bonacci et al., 1986) determined that surface zone is in a state of constant slow creeping because of the alternation and weakening of shear strength parameters. Cause is the constant process of weathering of marls from flysch due to water activity and deformations of the material because of its movement due to hydrodynamic pressure. According to the results of explorations as well as deformation monitoring of the slope after the cutting, it can be assumed that the shear stress is approaching residual shear strength in the deluvium. Systematical monitoring of the Mlija landslide has not been established. However if Omiš by-pass road is going to be constructed and the construction of family houses will continue, without systematic monitoring of the ground water level variations and velocities of the moving material, it will not be possible to obtain reliable information for interventions in the ground and safe foundations.

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