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Slope stability phenomena along the Egnatia highway: The part Ioannina-Metsovo, in Pindos mountain chain, Greece

Phénomènes de stabilité des pentes le long de l'autoroute Egnatia: La partie Ioannina-Metsovo dans la chaîne de Pindos, Grèce

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ABSTRACT: The Egnatia highway, will connect eastern with western Greece, by crossing Pindos mountain-chain. The presence of flysch in the area creates serious geotechnical problems related to the stability of the slopes. In the present investigation the geotectonic and geomechanical conditions of the area were studied by means of geological mapping and determination of probable unstable zones along the road axis. Furthermore an attempt has been made to interpret failure and sliding phenomena, in relation to the general geotectonic frame of the area.

RESUMÉ: L' autoroute Egnatia en construction, unit la Grèce de l' Est et de l' Ouest,en traversant la chaîne de Pindos. La présence du flysch dans la région provoque de problèmes géotecniques importants liés à la stabilité des pentes. Dans cet étude les conditions géotectoniques et géotecniques de la région ont été étudiées par cartographie géologique et caracterisation de zones de stabilité basse le long de l' axe de la route. L' interpretation des phénomènes de rupture et de glissement de pentes a été essayée dans le cadre géotectonique de la région.

1. INTRODUCTION

The Egnatia highway which is presently under construction, aside from being one of the most important traffic arteries in Greece. It is also the main artery linking trade and commerce from West Europe to the Middle East. The construction of the tunnels of Katara and Anilio (Metsovo area), in relation to the new tracing of the road signify the importance of the road axis especially after the division of Former Yugoslavia.

The area in study belongs to Pindos mountain range and consists mainly of flysch formations carbonate and ophiolitic rocks. The presence of flysch in the area create conditions that disturb the stability equilibrium of the hillsides along the road and triggers slope movements that vary from creep to landsliding. The problems arising from these phenomena, have been affecting the road since the early days of its construction.

The instability phenomena in the area started almost from the beginning of the road construction. Landslides occured on the cut slopes as well as on the the road itself, along the tracing axis, even in sites where the intersection of discontinuities didn't daylight on the cut slopes.

The purpose of the present study was to investigate the cause of the creation of these landslides and to propose confronting measures for the problem.

2. THE EGNATIA HIGHWAY

The construction of the Egnatia highway was decided so as to connect the western Greek port of Igoumenitsa with Constantinople, via Thessaloniki (fig. 1). The Ioannina - Metsovo road,

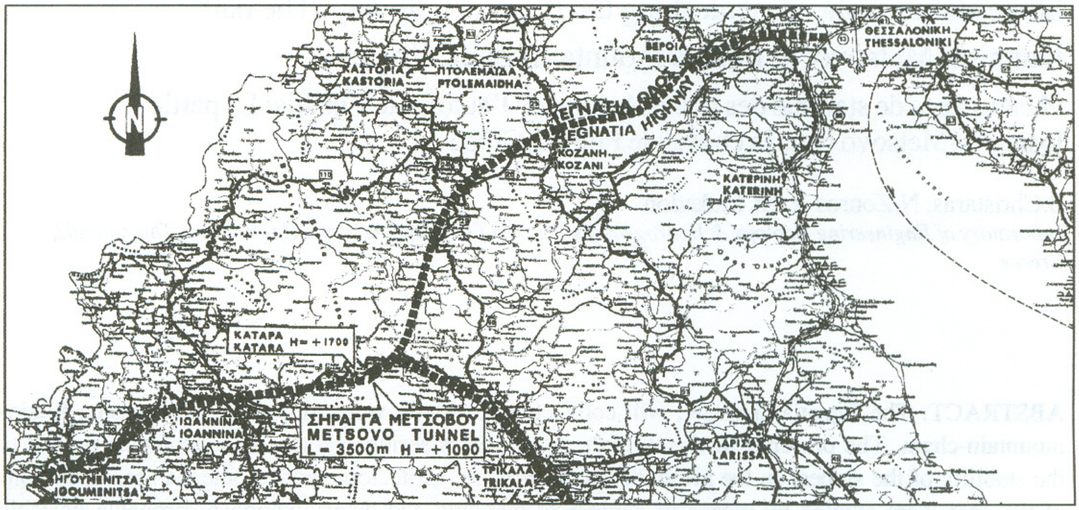

Fig. 1. Indicative tracing of the axis of the Egnatia highway, in the part of Igoumenitsa - Thessaloniki.

that crosses Pindos mountain-range, can be characterized as one of the most difficult parts for the construction, because the altitude is high, the mountain slopes are very steep and the flysch which is the dominating geological formation in the area causes important geotechnical problems. The existing mountainous national road of Trikala - Igoumenitsa, cannot serve the traffic demand of today any more, because it is narrow and passes through areas of high elevation. The bypass of Katara col, with two tunnels, in Metsovo (3.516 m long) and Anilio (about 700 m long), is a part of this future hifgway, which sortens significantly the existing route and lowers its elevation from +1700 m to +1090 m.

The benefits of the above project, as mentioned by the General Secretariat of Public Works, are: a) the fund-saving which results from the shortening of the above mentioned route, b) the impovement of communication (without the danger of being blocked during winter) between Epirus Thessaly and Macedonia, c) the essential improvement of traffic conditions along the international transportation axis connecting Western and North Europe with Middle East and d) the improvement of the explotation and transportation of the products of the region.

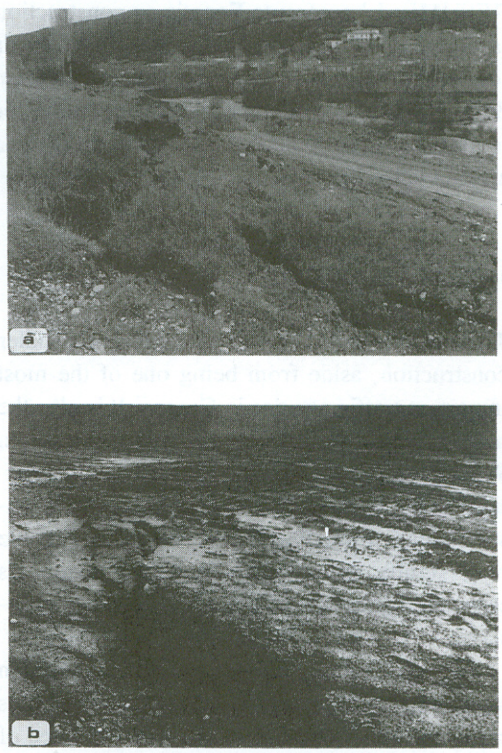

Fig. 2. Landslides are occuring a) on the cut slopes and b) the road itself, along the axis of the highway.

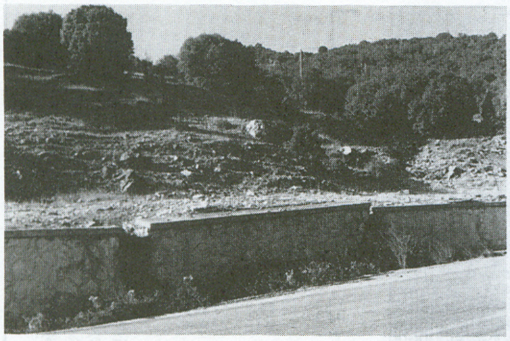

Fig. 3. The landslide has broken the retaining wall in the existing national road, near Mikro Peristeri village.

The construction of the highway in the flysch formations causes important stability problems, related to the nature of these formations. The alternation of silts and clays with sandstones creates sliding conditions especially during rain periods, when the water content in the formation is high.

The landslides occured either on the cut slopes (fitg. 2a) or the roaad itself (fig. 2b) along the road axis almost from the beginning of the road construction. Some tension cracks, occured in the early stages of the phenomenon developing quickly in very important landslides. Similar slope stability problems were also determined along the old national road, in the area of Mikro Peristeri village, near Metsovo (fig. 3), on the northern bank of Metsovitikos river.

3. GEOLOGICAL SETTING

The study area is located in eastern Epirus, in northern Pindos mountain range, near the city of Metsovo (FIG. 4). The northern Pindos mountains expose a sequence of tertiary thrust sheets, including the Pindos nappe, which consist the Pindos geotectonic zone and overthrust westwards the flysch of the Gavrovo and Ionian zones. Further to the east the Pindos ophiolite sequence, a part of the Subpelagonian ophiolites, thrusts towards WSW over the Pindos zone flysch.

Pindos zone is composed of mesozoic carbonate and silisiclastic rocks and the tertiary flysch. Spesifically Pindos zone consists of clastic and deep sea sediments (Middle Triassic), Micritic limestones with chert and siltstone (Late Karnian-Liass), Radiolarites of pure chert and mudstone (Early Doggerian-Tithonian), Calpionellid thin-beded limestone (Tithonian - Berriassian), flyschoid formation composed of clastic material, intercalated by mudstone and marlstone (Albian-Turonian), Platty limestone (Coniasian-Early Maestrichtian), Transition beds from limestone to flysch (Maestrichtian) and Tertiary flysch consisting of pelites, siltstones, marls and sandstones (Palaeocene-Late Eocene).

Three lithostratigraphic groups of flysh sendiments have been distinghuished in the study area. Politses group is very well exposed in the area, represents the nappe of the Pindos flysch and overthrusts the Zagori group sendiments. The last one represents the younger sendiments of the flysch of the Ionian zone. The Metsovon group appears as a tectonic window under the thrust-sheets of the Pindos Flysch nappe and the Subpelagonian ophiolite nappe.

Pindos flysch (Politses group) is divided into four formations, from base to top these are: the "red flysch", alternation of red shales, pelites and sandstones with maximum thickness 100 m, the second formation comprises thin grey micaceous sandstones alternating with grey shales and marls with an average thickness 70 m, the third formation comprises thick massive sandstones and interbedded grey shales and marls with an maximum thickness 350 m and the last one characterized as "wild flysch" composed of strongly tectonized grey siltstones and sandstones.

Beneath the Pindos nappe, along the thrust front appears a "tectonic formation" consisting a melange of strongly tectonized rocks, pelites, sandstones and blocks of limestones (Zouros and Mountrakis 1990). Different thrusting planes have been distinguished along the thrust front of

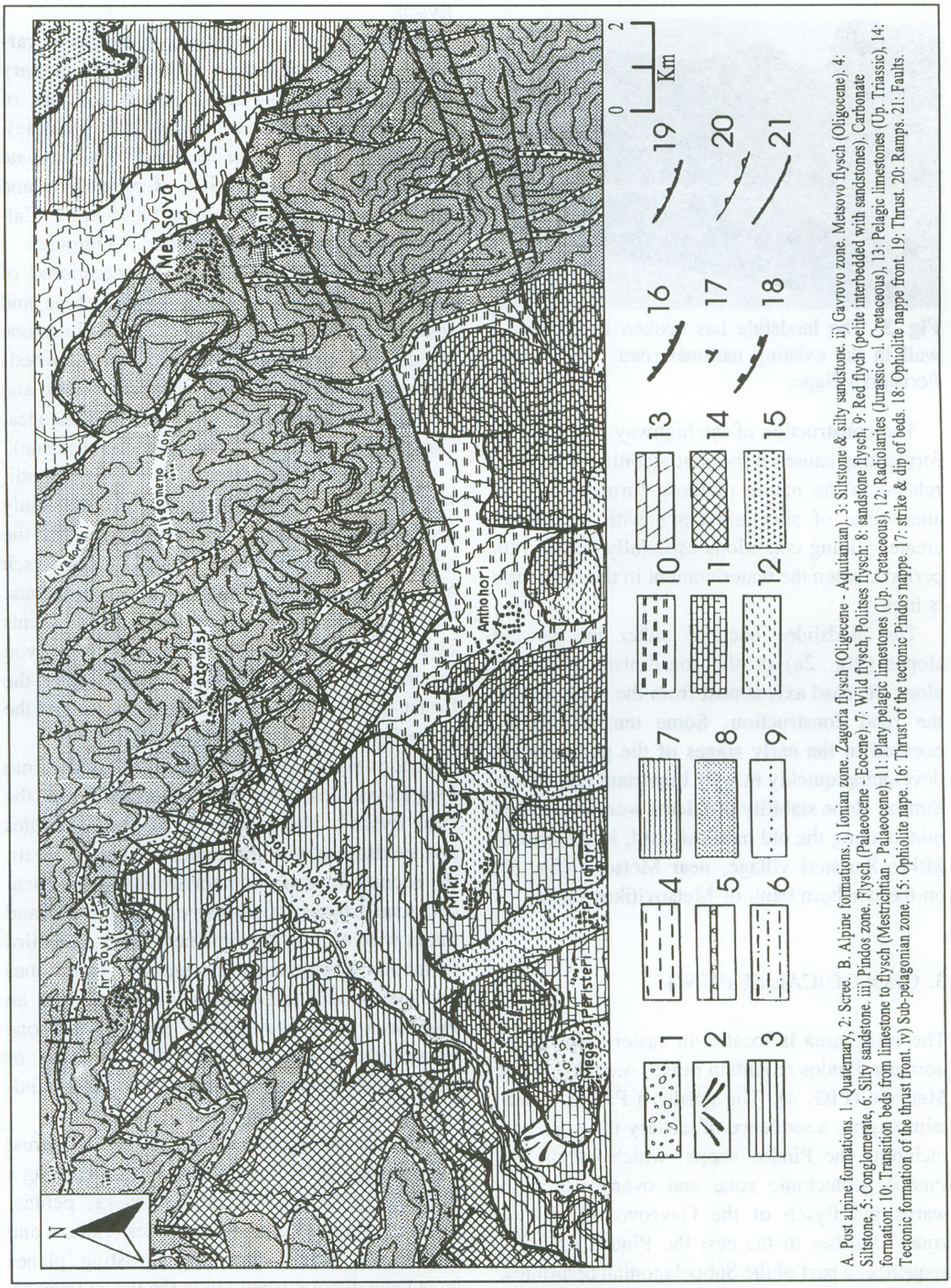

Fig. 4. Geological map of the study area (Zouros, 1993).

the Pindos nappe, within the tectonic formation.

Tectonic windows of the Ionian and Gavrovo zones (Zagori and Metsovon groups respectively) has been established by regional mapping under the Pindos nappe. Zagori and Metsovon groups consist of silty-marls and interbedded fine-grained sandstones as well as conglomerates, mainly in the Metsovon group.

4. TECTONIC ANALYSIS

NW-SE to NNW-SSE trending inverse faults are the dominant tectonic features in the area and bound the tectonic slices with a movement direction towards SW. Strike slip faults with remarkable displacements of the deformational front of the Pindos nappe along them, are closely related with the above mentioned compressional features. These faults are either dextral or sinistral1 The largest exists along Metsovitikos river. It is a major transverse fracture zone, known as Kastaniotikos fault (Lyberis et al., 1982) that interrupts the continuation of the Pindos zone.

Successive tectonic events arise from the structural analysis in the area. The sense of movement was established by using shear criteria and kinematic indicators. Using the methods of quantitative analysis it was possible to provide a quantitative interpretation in terms of strain from the striations observed on the fault planes (Zouros, 1993).

Tertiary evolution started in Late Eocene times with a D_0 compressional event (maximum stress σ_1 axes ENE-WSW) which caused detachment, folding and thrusting of the Pindos flysch before the emplacement of the ophiolite over the flysch.

D_0 event was followed by an important D_1 extensional event (minimum σ_3 axes ENE-WSW) in Early Oligocene times, which caused a semi-ductile to brittle deformation in the area i.e. major extensional features in both ophiolites and flysch, the emplacement of the ophiolites over the Pindos flysch and certainly the formation of the Meso-Hellenic Trough.

Two younger successive compressional events D_2 and D_3 are responsible for the refolding, imbrication and final shape of the Pindos nappe, with the maximum stress axes trending E-W and N-S respectively, took place during the Middle-Late Miocene (the second probably evolutionary to the first).

D_2 compressional event, caused inverse faults trending NNW-SSE, mainly dipping towards ENE as well as antithetic ones dipping towards WSW. The inverse faults usually accompanied by kink-banding with axes trending NW-SE. Additionally, some very important sinistral strike-slip faults trending NW-SE have also been caused by this compressional event.

Subsequently, D_3 compressional event took place in the area and caused inverse faults trending E-W, mainly dipping to the S. It also caused major dextral strike-slip faults trending WNW-ESE. These features are common particularly in the serpentinized peridotites.

The post-alpine evolution of the area during neotectonic times is rather complicated forming a transitional zone that shows both extensional and compressional patterns.

Large and mesoscale extensional features are observed in the area. NNW-SSE trending normal faults and low angle shear zones have been observed due to a NE-SW extentional event during Pleiocene. Large scale E-W trending normal faults are the younger tectonic structures coused by a N-S to NNW-SSE extention.

5. THE LANDSLIDES

The more important landslides occuring in the area are not only due to the geometry of the discontinuities of the flysch, in relation to the cut slopes directions, but mainly to the nature of the specific geological formation in which landslides are determined.

After our investigation, the more important

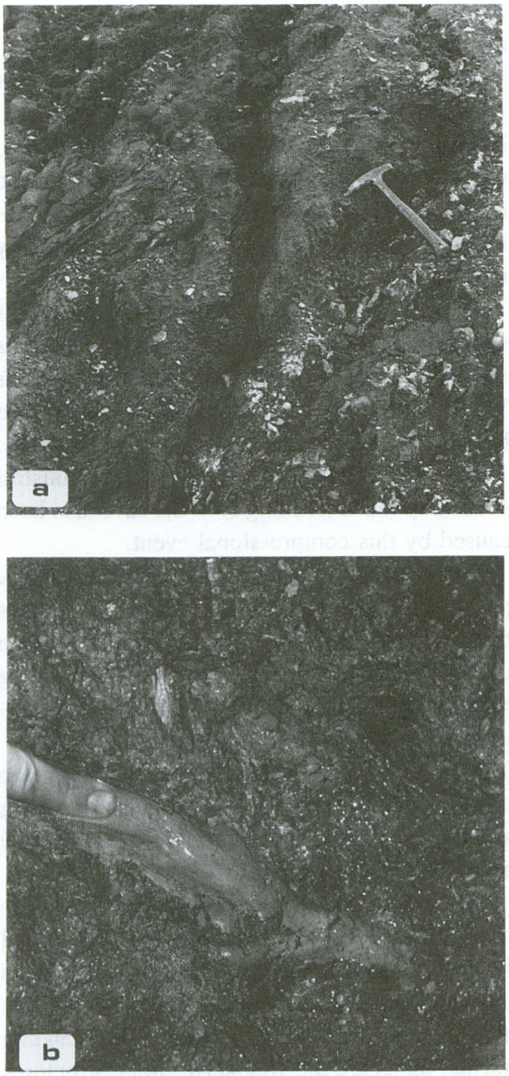

Fig. 5. The material of the tectonic melange. Rain water destroys the initial form (a) and the material behaves like a soil, well satured (b).

geological formation considered to be responsible for landslides creation is the "tectonic formation" that lies under the Pindos nappe overthrusting the Ionian flysch; it can be observed in many places along its front (Zouros & Mountrakis, 1990). It concerns a tectonic melange having a "chaos" structure and an appearance that reminds a "wild-flysch" formation. The matrix of the melange is mainly grey shales and sandstones in most cases completely sheared (fig. 5a). Detached blocks of limestones and deep sea sediments such as thin bedded pelagic limestones, radiolarian cherts, and Late Cretaceous neritic limestones with dimensions from several centimetres up to several hundred meters, are observed within the matrix. The blocks are particularly tectonized and generally fault bounded.

Table 1. Particle size and Atterberg limits results, of the matrix of the tectonic formation and the pelites of Pindos flysch

Propery	Tectonic formation	Pelites
Liquid limit (LL)	36	41
Plastic limit (PL)	25	25
Plasticity index (PI)	11	16
Pass No 200 sieve	58 %	96 %
Group index (I_G)	5	17

Mechanically the material behaves differently way in dry and in wet conditions. In dry it behaves like a rock. In wet it loses rapidly its cohesion and its original structure and behaves like a saturated soil (fig. 5b). The matrix of this formation was characterized as silt to silty fine sand, with low to intermediate plasticity, according to the particle size distribution (fig. 6a) and the data of the plasticity chart (fig. 7) (Johnson & Graff, 1988). The small plastic range between plastic (PL) and liquid limits (LL), given in Table 1, determine the ability of the material to change rapidly from the semi-solid to the liquid state, improving the significant decrease of the cohesion, angle of internal friction and bearing capacity after raining (Lambe & Whitman, 1979). The Group Index (I_G), given in Table 1,

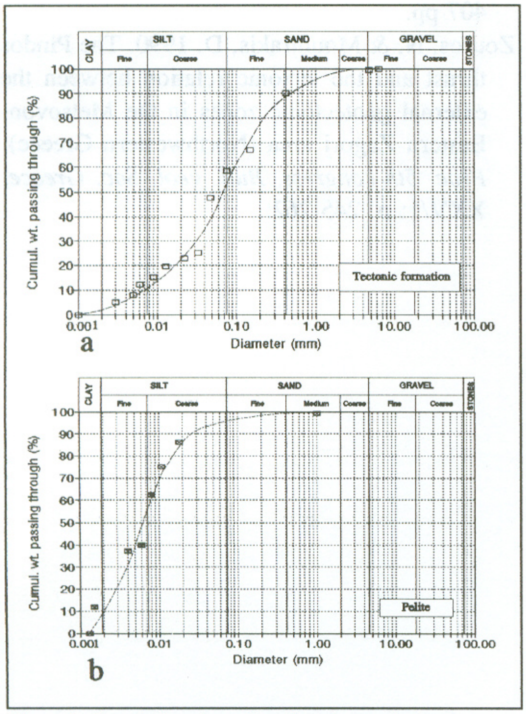

Fig. 6. Particle size distribution of a) the tectonic formation matrix and b) the pelites.

is not extremely high but is not also near to "0", however it determines rather poor or intermediate foundation conditions (Dunn et al., 1980).

The formation has a significant thickness of 20 to nearly 80 m, depending on the site, and extends under Pindos flysch, creating important foundation problems. The presence of important tectonic structures in relation to the bedding and the alternation of silts and clays with sandstones in the red Pindos flysch, strengthens the instability conditions in the area. It is mentioned that the most of the important landslides in the broader area are related to this formation, regardless of the slope face. In this framework the area corresponding with the tectonic formation should be excluded, for road construction. Furthermore the lower parts of Pindos flysch should also be excluded regardless of possibly stable local conditions because the sum of the overlying strata could be sliding along the tectonic formation itself.

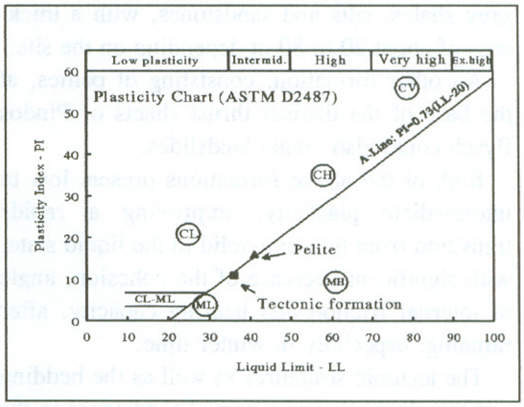

Fig. 7. Plasticity chart according to ASTM D 2487.

Another formation that could create important sliding phenomena is the pelites of the "red flysch" formation. Pelites are in alternation with sandstones at the base of the distinct thrust sheets of the Pindos flysch nappe. According to the particle size analysis (fig. 6b) and the data of the plasticity chart (fig. 7) the matrix of this material can be characterized as silt and clay with intermediate plasticity. The plasticity measured (Table 1) determines a rapid transition from solid to liquid state with significant decrease of the cohesion and angle of internal friction, during rain periods. The Group index (I_G), given in Table 1, is very high indicating a poor subgrade material with low bearing capacity. The thickness of the pelites is small, compared to the one of the tectonic formation; however the interbedding with sandstones creates serious unstable conditions.

6. CONCLUSIONS

Our investigation has shown the following:

The tectonic formation lying under the nappes of the red Pindos flysch, overthrusting the Ionian flysch, could be considered as mainly responsible for the creation of landslides along the

Egnatia highway, in the study area. This formation has a "chaotic" structure consisting of grey shales, silts and sandstones, with a thickness of about 20 to 80 m depending on the site.

An other formation, consisting of pelites, at the base of the distinct thrust sheets of Pindos flysch could also create landslides.

Both of the above formations present low to intermediate plasticity, improving a rapide transition from the semi-solid to the liquid state, with significant decrease of the cohesion, angle of internal friction and bearing capacity, after rainning, especially in winter time.

The tectonic structures as well as the bedding and the alternation of silts and sandstones in the above Pindos flysch, aggravate the instability phenomena.

According to the above observations we believe that the tectonic formation and the lower parts of the red flysch should be excluded from the tracing of the axis of the Egnatia highway.

We mention that the research of the geotechnical problems in the area is in evolution, with *in situ* investigation and laboratorial tests, so as more completed results will be presented in the future.

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