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"The Interplay between Geotechnical Engineering and Engineering Geology"

Behaviour of the Votonosi formation in Pindos mountain (Greece)

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SYNOPSIS: The Votonosi formation is exposed in Metsovo area (NW Greece). This formation was investigated regaring its physical and mechanical behaviour in order to determine the stability of the construction of the Egnatia highway, in the part that crosses this formation. Votonossi formation belongs to the Pindos flysch that extends throughout the area. It is a strongly tectonized formation, consisting a chaotic mass of clay, sandstones and silts, which affects the stability of every construction.

The mechanical behaviour of this formation depends almost exclusively on its moisture content and varies between a blocky rockmass condition to a very disturbed soil condition.

The object of the investigation is focused on the transition of the mechanical behaviour of the formation material, from a more or less stable condition (dry material) to a very unstable condition (wet material).

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 Ioannina - Metsovo part of this road, 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 landslides. Very important landslides were occured almost from the beginnin of the road construction not only in the flysch but also in the tectonic formation that was determined between the Pindos and Ionian flysh presenting a significant extension in Votonosi area.

In the present investigation this tectonic formation was studied geologically and geomechanically in order to determine the mechanism of sliding of the slopes along the highway.

2. GEOLOGICAL SETTING

The study area is located in eastern Epirus, in northern Pindos mountain range, near the city of Metsovo. 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.

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.

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 he Pindos nappe, within the tectonic formation (Fig.1). This formation is widely extended throughout the study area (Fig. 2).

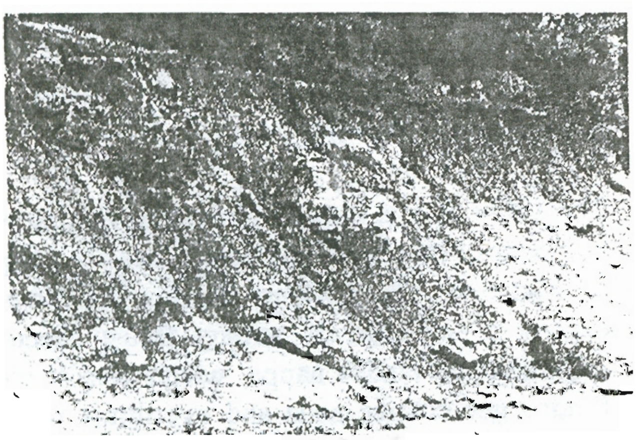

Figure 1. *The material of the tectonic formation*

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

3. TECTONIC ANALYSIS

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 compressional event caused NW-SE to NNW-SSE trending inverse faults which 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 sinistral 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.

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 and the emplacement of the ophiolites over the Pindos flysch.

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).

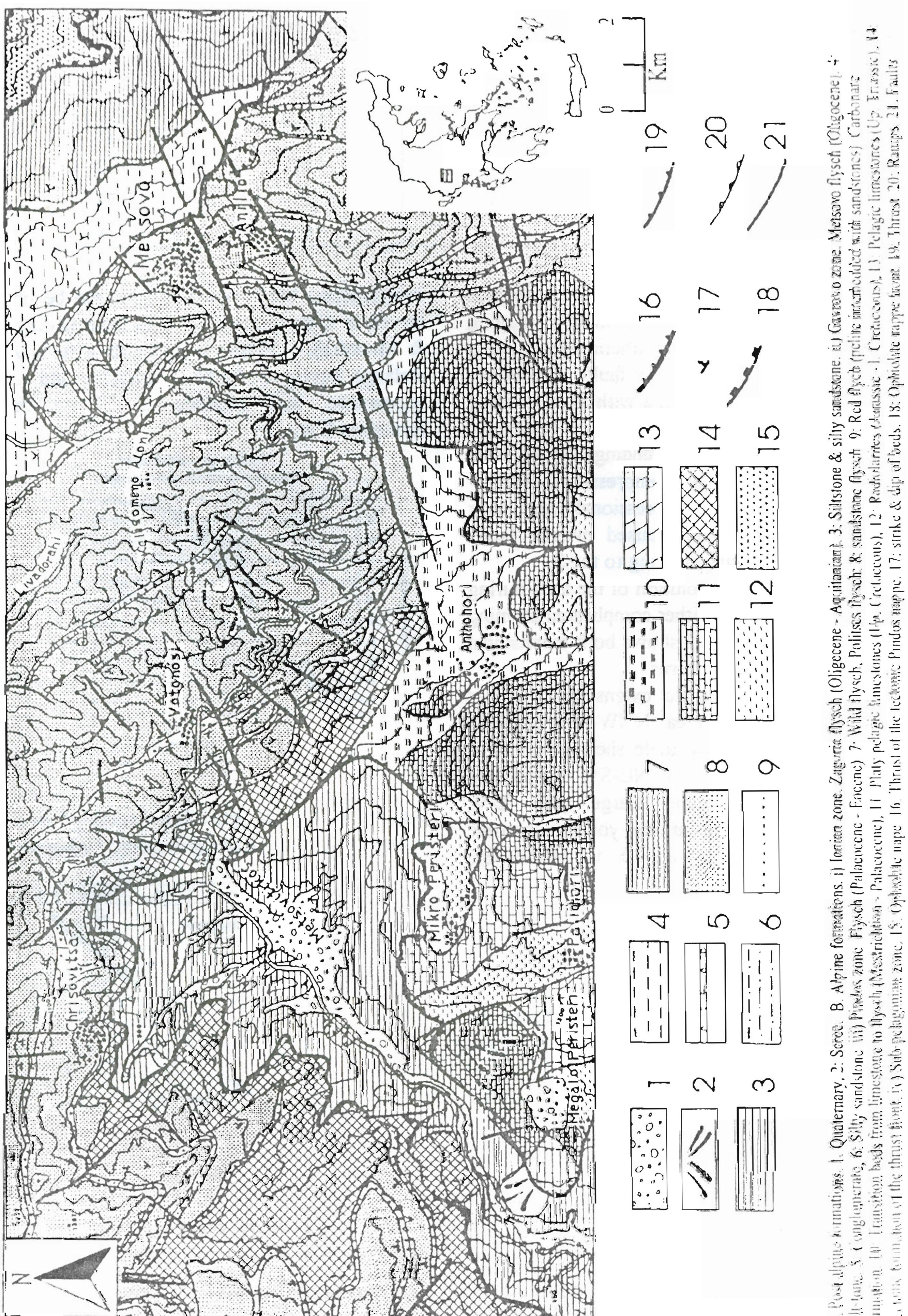

Figure 2 *Geological map of the study area (Zouros, 1993)*

Table 1. *Physical characteristics of three representative samples from the tectonic formation.*

Property	TF1	TF2	TF3
Liquid limit (LL, %)	36	39	38
Plastic limit (PL, %)	25	25	25
Plasticity index (PI, %)	11	14	13
Pass No 200 sieve (%)	58	78	73
Group Index (I_G)	5	11	9

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.

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.

4. THE VOTONOSI FORMATION

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 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 (Fig. 1).

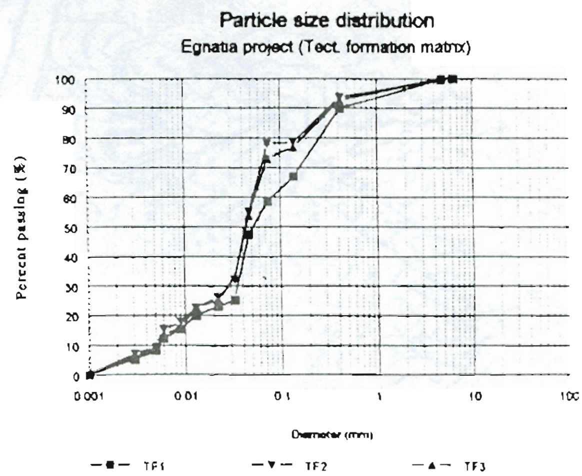

Figure 3. *Particle size distribution of three samples collected from the tectonic formation*

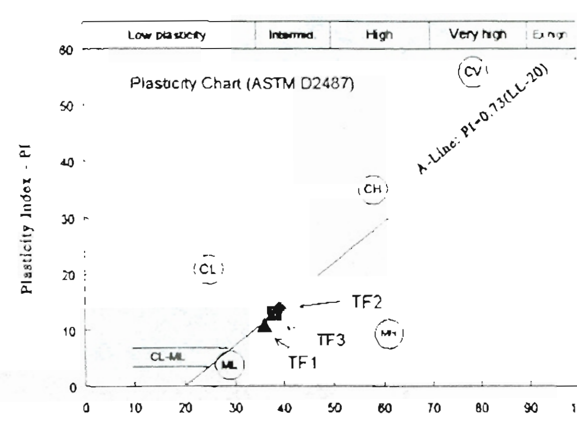

Figure 4. *Plasticity chart of three samples collected from the tectonic formation*

Table 2. *Test results of shear strength (c_u) and the corresponding moisture (m) contents of three representative samples from the tectonic formation.*

	TF1		TF2		TF3	
Test Repeats	m (%)	c_u (KPa)	m (%)	c_u (KPa)	m (%)	c_u (KPa)
1	26.48	25.0	26.68	27.0	27.83	24.0
2	28.64	14.0	27.32	22.0	28.55	14.0
3	31.10	6.1	28.86	15.0	30.11	9.2
4	28.50	10.0	30.63	10.0	31.29	7.6
5	29.80	3.2	31.85	6.3	32.33	4.3
6	31.89	2.5	32.43	3.3	33.76	2.5
7	33.96	1.2	33.98	2.5	34.38	1.5
8	34.78	0.6	34.53	0.9	35.03	0.7
9	35.81	0.3	35.10	0.6	35.98	0.6
10	27.55	22.0	36.28	0.6	36.55	0.6

The matrix of the melange is mainly grey shales and sandstones in most cases completely sheared. 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. 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 particle size destribution of the matrix of the tectonic formation is given in Figure 3.

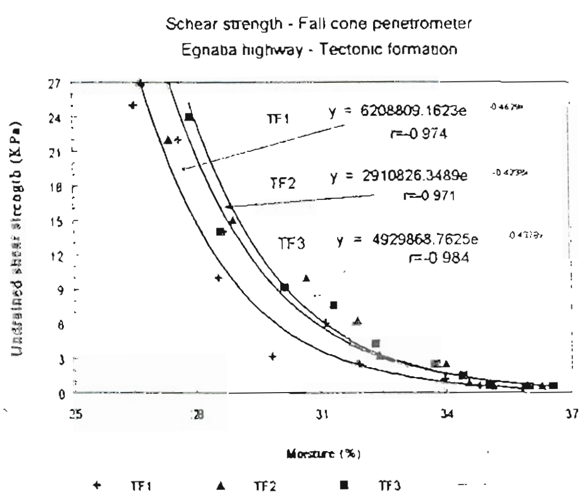

Figure 5. *Correlation diagram betwee the shear strength and the moisture. Samples were collected from the tectonic formation and moisture changes was mad artificially*

Mechanically the material behaves differently in dry and in wet conditions. In dry it behaves like a rock, having a dry density of 2.56 gr/cm^3 and unaxial strength of 350 Kg/cm^2. In wet it loses rapidly its cohesion and its original structure and behaves like a saturated soil. It is a finegraned material of intermediate plasticity (Fig. 4, 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, is rather high determining poor foundation conditions (Dunn et al., 1980).

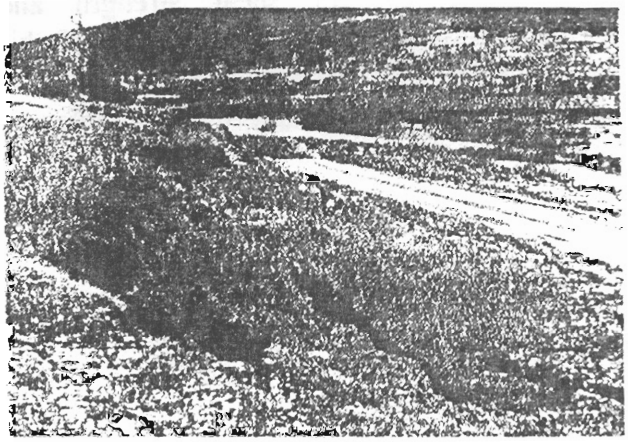

Figure 6. A *Landslide occured in the Votonosi formation, after the rain*

One other important parameter which was was the change of the shear strength in relation to the moisture content. For this purpose three representative samples from the area were investigated using a desk top fall cone penetrometer (Karlsson, 1977, Christaras, 1991). The shear strength was measured for 10 artificially different moisture contents. The water contents in our tests covered almost the whole range of moisture, from the plastic limit to the liquid limit percentage. According to the correlation diagram of Figure 5, an exponential relationship can express the changes of the above properties comfirming that a small quantity of water can cause a significant decrease of the shear strength. This observation can be related to our previous observation, that a small quantity of water can change rapidly this material from the semi-solid to the liquid state, improving that in the humid conditions of Pindos mountain chain a light rain can easily create landslides on the hill-slopes (Fig. 6).

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 Votonosi 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.

According to our shear strength and plasticity tests the fine graned matrix of this formation changes rapidly with rain from a solid and strenght rockmass to an unstable wet soil.

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