Landslide along the "Asprovalta-Strymonas" part of Egnatia Highway in Northen Greece.

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Abstract

An important landslide, created in an open trench of the under construction Egnatia highway, in Northern Greece, 100 Km to the East of Thessaloniki, was studied regarding to the stabilization of the slope. The area consists of folded gneiss, marble and amphibolite, with pygmatitic intercalations. In this framework, the quality of the rock mass was classified, using RMR and SMR methods. Furthermore, representative wedge failures were analyzed regarding and their safety factors were estimated, in order to organize a new design of the slope. A sliding of a wedge activated a new sliding along the direction of gneiss schistosity in the neighbor part so as the excavation was interrupted for a long time and a new design of cover and cut was chosen to restore the failure.

Introduction

Asprovalta-Strymonas area is located, in Northern Greece, 100 Km to the East of Thessaloniki. The open trench in study was planed to be constructed at the southern part of the Asprovalta tunnel II in order to replace the right bore of the tunnel. The excavation was performed from the upper parts to down slope. The geological investigation took place during the excavation of three upper benches, as the excavation of the "1st" lower bench was not completed because the landslide, under study, occurred (Fig. 1).

Fig. 1. *The landslide in study*

The geological formations, which were uncovered during the excavation, were;

- Folded gneiss with joints of north and southeast directions.
- Folded marble with joints of west and southeast directions.
- Folded amphibolite. The schistosity is oriented to northeast and southeast. The joints are of south and west directions.

The gneiss and marble are co-folded and cut by three faults with NW, NE and SE directions (Fig.2).

Geotechnical investigation along the benches

The upper part of the trench (4th bench) consists of soil. It is a brown colored material deriving from the weathering of gneiss. It contains blocks of gneiss. The tectonic data were measured only on ch.10+530 and ch.10+600 (Chatziangelou & Christaras, 2004) because the material is totally weathered. Three major planes were recognized; i) Joints 215/84J with brown colored infilling soil material, 0,1mm thick; the spacing is about 15cm, ii) completely closed joints 84/72J with spacing of 3cm, iii) completely closed joints 318/68J with spacing of 15-20cm, iv) schistosity surfaces 81/31S with spacing of 7-10cm (Table 1).

Table 1: *Major planes during the excavation of 4th bench*

Joints	**J1**	**J2**	**J3**
Major planes	215/84	84/72	318/68
Schistosity	**S**		
Major planes	81/31		

The 3rd bench has been divided in six areas regarding to theis geotechnical properties. Between ch.10+505 and ch.10+542, gneiss is highly weathered (IV category). The rock quality designation (RQD) is 40-56%. Two discontinuity sets were determined: a) the schistosity; its direction is 213/35 and the inner surfaces are completely closed and slightly rough; the spacing is 6-15cm and b) joints of 355/50 direction, with infilling material consisting of sand and gravels 0,5m thick; the spacing is 6-8cm. Between ch.10+542 and ch.10+556, the gneiss is highly weathered (IV category). The RQD is about 10%. Two discontinuity sets were recognized; a) schistosity 213/35 with separation surface spacing of 6-15 cm; the separation surfaces are completely closed and slightly rough surfaces, b) joints 341/50 with planar smooth surfaces and spacing 3cm. Between ch.10+556 and ch.10+597, the marble is moderately or highly weathered (III-IV category). The RQD is about 10%. Two tectonic sets were recognized; schistosity 31/50 with completely closed, slightly rough surfaces and spacing 5-10cm, c) joints 172/47 with planar smooth surfaces and spacing 6-8cm. The contact between marble and gneiss is characterized by completely weathered rockmass, so as the tectonic data collection was impossible. The amphibolite is highly weathered (IV category), between ch.10+597 and ch.10+638. The RQD is about 56%. Two discontinuity sets were recognized; a) schistosity 182/10 with completely closed and slightly rough surfaces and spacing 10cm, b) pegmatite intercalations 198/60 0,2mm thick. Between ch.10+638 and ch.10+685, amphibolite, which is placed at the lower part of the 3rd bench, is highly weathered (IV category). The RQD is about 22%. Two discontinuity sets were recognized; a) schistosity 201/9 with complete closed slightly rough surfaces and spacing 10-20cm, b) pegmatite intercalations 161/77 having a thickness of 7cm and spacing 5-10cm. The formation of marble, which is placed at the upper part of the 3rd bench, is moderately and highly weathered (III-IV category). The RQD is about 42-59%. Three discontinuity sets were recognized; a) schistosity 207/32 with completely closed slightly rough surfaces and spacing about 10-20cm, b) very closed joints 203/75 and 167/82 with slightly rough surfaces and spacing 20cm and 10cm. The tectonic contact between marble and amphibolite, with infilling sandy material 0,5mm thick, was measured 107/11 (Table 2).

Table 2: *Major plane during the excavation of 3rd bench*

Joints	***GNEISS***	**J**	***MARBLE***	**J1**	**J2**	**J3**	***AMPHIBOLITE***	**J**
Major planes		348/50		250/69	203/75	156/66		191/9
Schistosity		**S**		**S1**	**S2**			**S**
Major planes		213/35		226/14	31/50			178/67
Faults		**F1**				**F2**		
Major planes		360/70				107/11		

The 2nd bench has been divided in seven areas having different geotechnical data. Gneiss is highly weathered (IV category), between ch.10+490 and ch.10+510. The RQD is 29%. Five discontinuity sets were recognized; a) smooth planar joint surfaces of 202/77 with infilling clayey material 10cm thick, b) joints of 266/59 and 336/84 having slightly rough surfaces and spacing 30cm, with infilling sandy and kaolinite material 3mm thick, c) pegmatite intercalations of 144/29, 6mm thick, d) very closed and slightly rough schistosity surfaces 94/35. Between ch.10+510 and ch.10+520, gneiss is completely weathered (V category). The RQD is 46%. Three discontinuity sets were recognized; a) rough joint surfaces of 22/52, b) slightly rough schistosity surfaces of 246/42 with infilling sandy material 3mm thick and spacing 5-10cm, c) slightly rough joint surfaces of 143/40 with infilling clayey material 6mm thick being come from completely weathered gneiss, spacing 40cm. Between ch.10+520 and ch.10+560, the folded gneiss is highly weathered (IV category). The RQD is 10%. The schistosity surfaces, of 42/29 direction, are very closed and slightly rough with spacing 3mm. The schistosity surfaces 105/20 are smooth and planar, with infilling clayey material 4mm thick and spacing 6cm. The contact between gneiss and amphibolite was formed by two faults 282/20 and 333/70. The rock mass near the contact is completely weathered. Kaolinitic material, 4-10cm thick, was observed along the fault 282/20. Pegmatite intercalations were developed parallel to the fault 333/70. The spacing of pegmatite intercalations is 6-20cm. The amphibolite is moderately weathered (III category), between ch.10+560 and ch.10+600. The RQD is 36%. Three discontinuity sets were recognized; pegmatite intercalations (8-12cm thick) of 14/47 direction and spacing 20-25 cm, very closed and rough joint surfaces of 148/39 with spacing 3cm, and schistosity of 70/46 having very closed slightly rough surfaces with spacing 3cm. Between ch.10+600 and ch.10+670, the contact of marble and amphibolite is oriented to northeast (65/47).

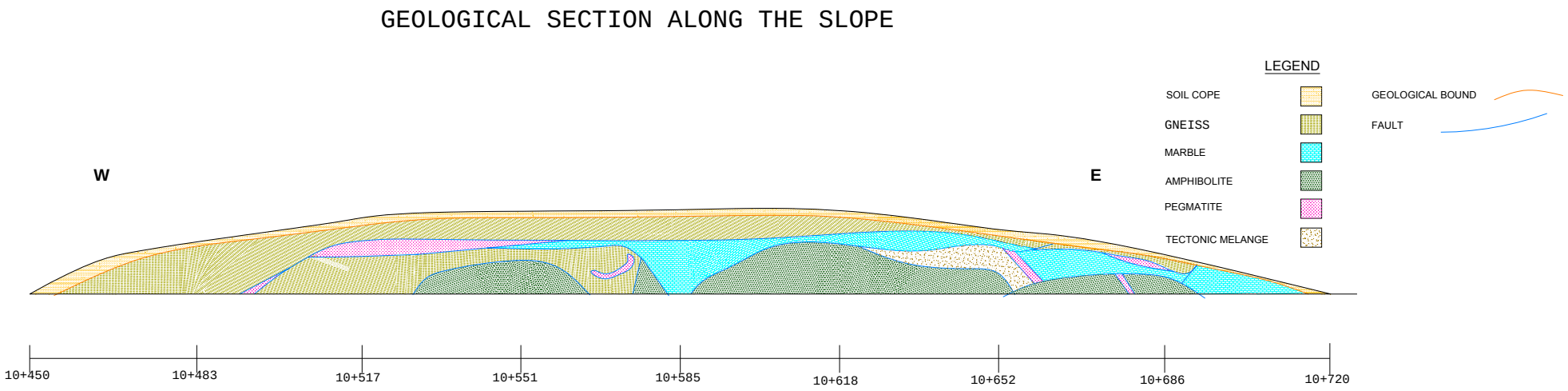

Fig. 2: *Geological section along the slope*

The upper marble formation extends from ch.10+600 to ch.10+640 and the lower amphibolite formation extends from ch.10+600 to ch.10+670. The tectonic mélange (ch.10+600 – ch.10+660) consists of weathered marble and amphibolitic pieces. The RQD is 32%. Three tectonic sets were recognized; a) pegmatite intercalations of 192/77 with thickness of 0,5-40cm and spacing 40cm, b) completely weathered, rough joint surfaces of 250/44 with spacing 4-10cm, and c) joints 126/52, with infilling clayey material 2mm thick and spacing 3m. The formation of marble is slightly to moderately weathered (II and II category). Four discontinuity sets were recognized; a) very closed and slightly rough joint surfaces 73/51 with spacing 2,7cm, b) very closed and rough joint surfaces 196/71 with spacing 3cm, c) schistosity of marble directed to 195/39 and d) very closed and slightly rough joint surfaces 278/76 with spacing 6mm. The formation of amphibolite is very weathered (IV category) having a 22% RQD. Two tectonic sets were recognized; a) Very closed and slightly rough surfaces 259/56 with spacing 9cm and b) pegmatite intercalations 166/73, 10cm thick with spacing 1m. The tectonic surfaces are covered by clayey material 0,5mm thick, deriving from weathered amphibolite. Between ch.10+670 and ch.10+680, gneiss is completely weathered (V category) at the upper part of bench and moderately weathered (III category) at the lower part of bench. There is a fault (328/33), which lies northwest, that separates the completely and the moderately weathered gneiss. Four discontinuity sets were recognized on the rockmass of completely weathered gneiss; a) eroded pegmatite veins 169/53, 25cm thick, which are placed between smooth surfaces of gneiss with spacing 1m, b) schistosity surfaces 229/48 with spacing 4-8cm, c) aplitic intercalations 125/85 located between smooth surfaces 5mm thick with spacing 1m, d) pegmatite intercalations 37/26 placed between rough surfaces having a thickness of 5cm and spacing 16cm. Two tectonic sets were recognized on the rockmass of moderately weathered gneiss; a) completely closed joint set 217/24 having slightly rough surfaces with spacing 16cm, and b) pegmatite veins 191/83 placed between smooth surfaces having major thickness of 70cm and spacing 1m. There is the tectonic contact 312/56 of completely weathered marble (RQD=82%) and gneiss, between ch.10+680 and ch.10+695. The contact is full of pegmatite intercalations 4cm thick. Two major tectonic sets were recognized; a) pegmatite intercalations 115/75 having a thickness of 3mm and spacing 30cm, and b) very closed joints 209/58 with spacing 15cm (Table 3).

Table 3: *Major planes during the excavation of 2nd bench*

Joints	***GNEISS***	**J1**	**J2**	***MARBLE***	**J1**	**J2**	**J3**	***AMPHIBOLITE***	**J1**	**J2**
Major planes		355/86	164/34		205/61	278/76	115/75		159/56	276/44
Schistosity		**S1**	**S2**		**S1**	**S2**			**S**	
Major planes		248/49	75/26		182/38	79/43			70/46	
Faults		**F1**			**F2**				**F3**	
Major planes		112/40			322/44				65/47	

Geotechnical classification

Two classification systems were used in order to classify the rockmass of the slope; RMR (Bieniawski,1989) and SMR (Romana, 1985).

According to RMR classification system, the rockmass quality was characterized as poor (RMR_{bas} = 22-40) (Christaras et al, 2001). There is a part of slope between ch.10+570 and ch.10+640 consisting of amphibolite and marble formations with better rock mass quality (RMR_{bas} = 42-49) than the rest part of the slope. Taking into account the orientation of tectonic data, rock mass quality is characterized as very poor (RMR=3-17), and only between ch.10+550 and ch.10+640 the rockmass quality is characterized as poor (RMR=24-35).

Table 4: *Rock mass geotechnical classification*

CH.-CH.	RMR_{bas}	Rock mass quality	RMR	Rock mass quality using orientations of tectonic data	SMR	Stability
4th bench						
10+540-10+555	-	Soil	-	-	-	-
10+555-10+625 (gneiss)	37	IV (poor quality)	12	V (very poor quality)	J1: 34,5 J2:48 J3:48 S:46	Unstable (IV)
10+625-10+675	-	Soil	-	-	-	-
3rd bench						
10+500-10+505	-	Soil	-	-	-	-
10+505-10+542 (gneiss)	35	IV (poor quality)	5	V (very poor quality)	S: 12,5 J:30	Very unstable (V)
10+542-10+556 (gneiss)	36	IV (poor quality)	5	V (very poor quality)	S: 15 J: 43	Very unstable (V)
10+556-10+577 (marble)	36	IV (poor quality)	31	IV (poor quality)	S: 16 J:31	Very unstable (V)
10+577-10+638 (amphibolite)	49	III (moderately quality)	24	IV (poor quality)	S: 58 J: 58	Stable(II)
10+638-10+685 (amphibolite)	28	IV (poor quality)	3	V (very poor quality)	S: 35,5 F: 40 J: 39	Unstable (IV)
10+638-10+685 (marble)	40	IV (poor quality)	15	V (very poor quality)	S: 13 F: 54 J1: 30 J2: 51	Very unstable (V)
10+646-10+695 (marble)	40	IV (poor quality)	15	V (very poor quality)	S: 54 F1: 37 F2: 50 J1: 51 J2: 51	Unstable (IV)
10+695-10+700	-	Soil	-	-	-	-
2nd bench						
10+488-10+490	-	Soil	-	-	-	-
10+490-10+510 (gneiss)	30	IV (poor quality)	5	V (very poor quality)	J1: 20 J2:44,1 J3:45 J4:45	Very unstable (V)
10+510-10+520 (gneiss)	28	IV (poor quality)	5	V (very poor quality)	J1=43 S=43 J2=43	Moderately stable (III)
10+520-10+560 (gneiss)	22	IV (poor quality)	5	V (very poor quality)	S1=37 F1=37 S2=37 F2=33,25	Unstable (IV)
10+560-10+600 (amphibolite)	40	IV (poor quality)	35	IV (poor quality)	J1=47,5 J2=55 S=47,5	Moderately stable (III)
10+600-10+640 (marble)	42	III (moderately quality)	17	V (very poor quality)	J1=57 J2=32 S=6 J3=57	Very unstable (V)

Table 4 (Continues)

CH.-CH.	RMR_{bas}	Rock mass quality	RMR	Rock mass quality using orientations of tectonic data	SMR	Stability
10+600-10+660 (tectonic melange)	28	IV (poor quality)	3	V (very poor quality)	J1=21,75 S=43 F=43 J2=35,5	Unstable (IV)
10+650-10+670 (amphibolite)	40	IV (poor quality)	15	V (very poor quality)	J1=55 J2=18,1	Very unstable (V)
10+670-10+680 (completely weathered gneiss)	28	IV (poor quality)	5	V (very poor quality)	J1=31,5 S=23 J2=39,25 J3=43	Unstable (IV)
10+670-10+680 (moderately weathered gneiss)	31	IV (poor quality)	6	V (very poor quality)	J1=29,2 F=46 J2=24,75	Unstable (IV)
10+680-10+695 (completely weathered marble)	39	IV (poor quality)	14	V (very poor quality)	J1=50,25 F=53,1 J2=48,9	Moderately stable (III)
10+695-10+697	-	Soil	-	-	-	-

According to SMR classification system, the 4th bench is unstable. The 3rd bench from ch.10+505 to ch.10+577 and from ch.10+638 to ch.10+685 is very unstable and it needs to be transformed. The 3rd bench from ch.10+638 to ch.10+685 and from ch.10+646 to ch.10+695 is unstable. There is a part of 3rd bench between ch.10+577 and ch.10+638 being stable. The 2nd bench from ch.10+490 to ch.10+510, from ch.10+600 to ch.10+640 and from ch.10+650 to ch.10+670 is very unstable. The 2nd bench from ch.10+520 to ch.10+560, from ch.10+600 to ch.10+660 and from ch.10+670 to ch.10+680 is unstable. The 2nd bench from ch.10+510 to ch.10+520, from ch.10+560 to ch.10+600 and from ch.10+680 to ch.10+695 is moderately stable. Taking into account all the above results, the excavation of the slope is very unstable and extensive failures are expected.

Slope stability

Stability was estimated at different parts of slope using Markland test (1972) – Hocking improvement (1976).

Gneiss formation, being placed between ch.10+505 and ch.10+556 of the 3rd bench, may slide along the direction of schistosity 213/35. The same formation, being placed between ch.10+510 and ch.10+520 of the 2nd bench, may slide along the direction of schistosity 246/42. There is a part of completely weathered gneiss, being placed between ch.10+670 and ch.10+680 of the 2nd bench, which may slide along the direction of the section being formed by schistosity 229/48 and joints 169/53 or 125/85. Marble formation, being placed between ch.10+600 and ch.10+640 of the 2nd bench, may slide along the direction of the section being formed by schistosity 195/39 and joints 278/76 (Fig.3-20).

Landslide along the open trench

The formation of the upper three benches (4th, 3rd and 2nd) had just completed when an extensive landslide took place. The landslide was placed between ch.10+533 and ch.10+620. The sliding of wedge between ch.10+600 and ch.10+620, located in the marble of the 2nd bench, caused the beginning of landslide. The sliding was performed toward to the section of the schistosity 195/39 and joints 278/76. The sliding of the wedge activated new sliding in the neighbor part between ch.10+533 and ch.10+600. The new sliding took place along the direction of gneiss schistosity 213/35 (Chatziangelou & Christaras, 2003). The excavation was interrupted for a long time and a new design of cover and cut was chosen to restore the failure.

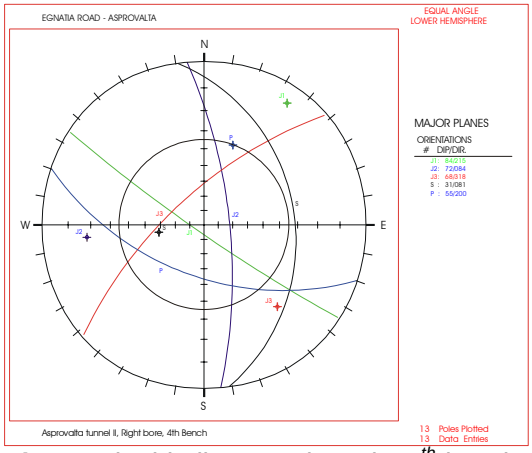

Fig.3: *Schmidt diagram along the 4th bench.*

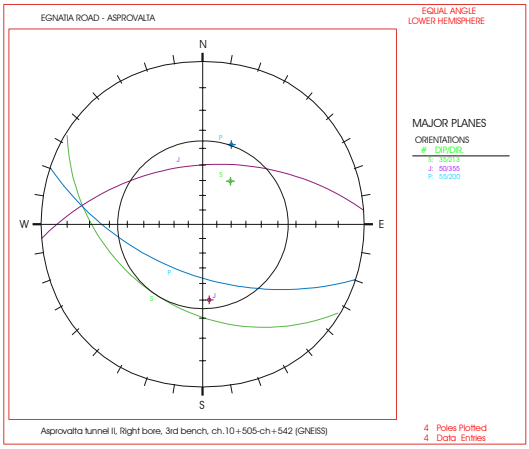

Fig.4: *Schmidt diagram in gneiss along the 3rd bench, between ch.10+505 and ch.10+542.*

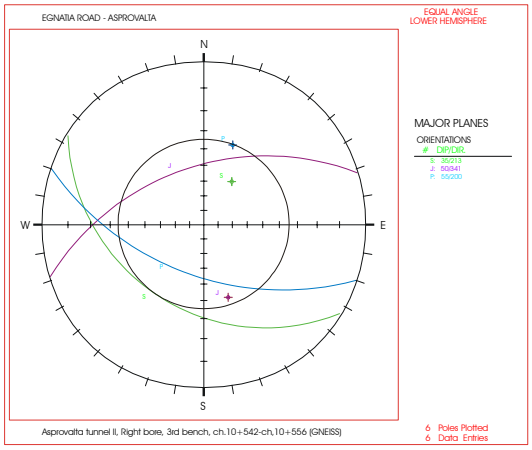

Fig.5: *Schmidt diagram in gneiss along the 3rd bench, between ch.10+542 and ch.10+556*

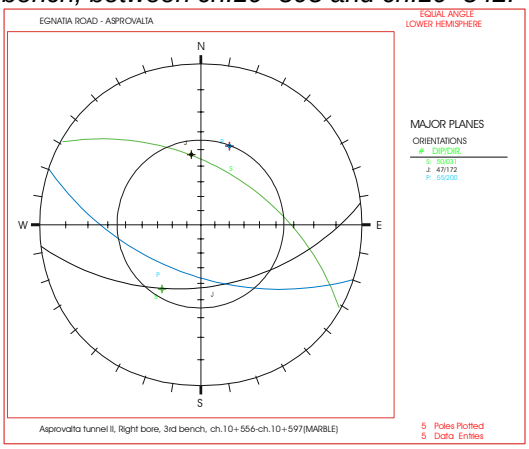

Fig.6: *Schmidt diagram in marble along the 3rd bench, between ch.10+556 and ch.10+597*

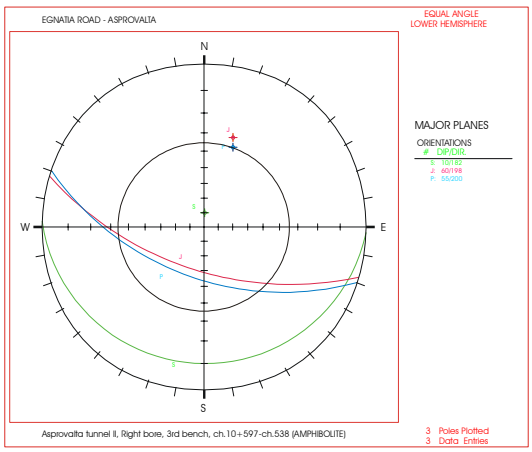

Fig.7: *Schmidt diagram in amphibolites along the 3rd bench, between ch.10+597 and ch.10+638 of*

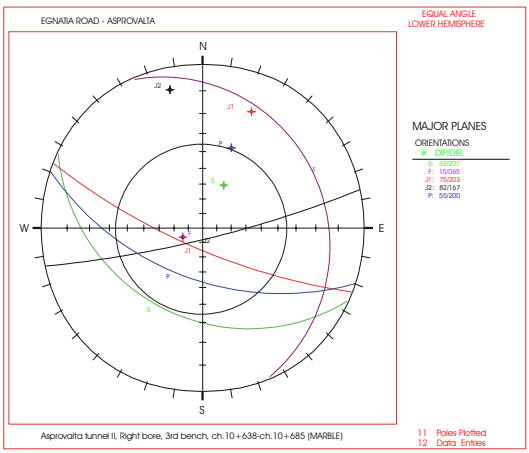

Fig.8: *Schmidt diagram in marble, along the 3rd bench, between ch.10+638 and ch.10+685*

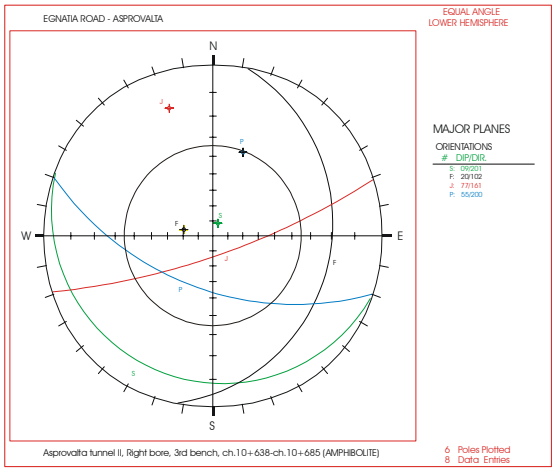

Fig.9: *Schmidt diagram in amphibolites, along the 3rd bench, between ch.10+638 and ch.10+685*

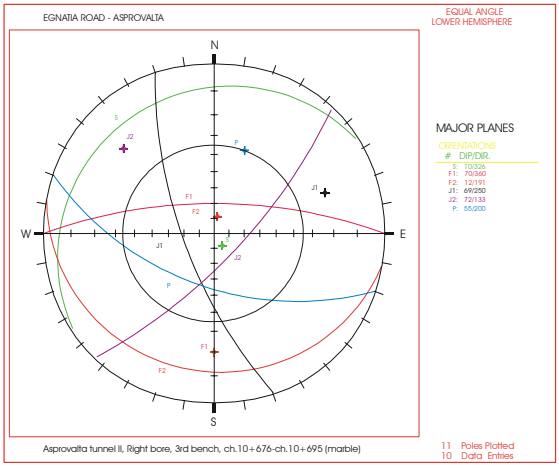

Fig.10: *Schmidt diagram in marble, along the 3rd bench, between ch.10+676 and ch.10+695*

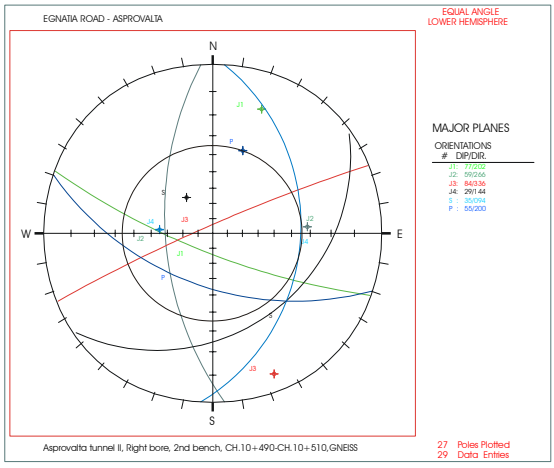

Fig.11: *Schmidt diagram in gneiss, along the 2nd bench, between ch.10+440 and ch.10+510*

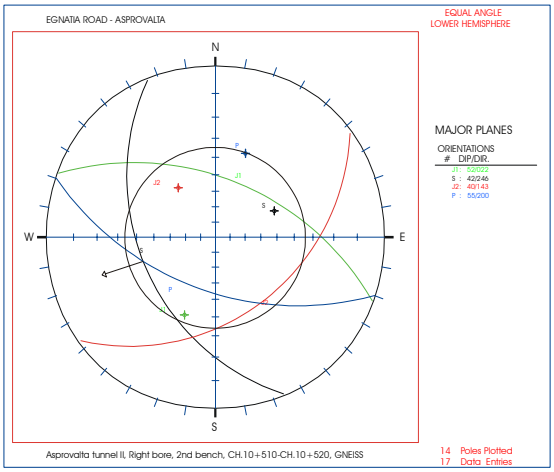

Fig.12: *Schmidt diagram in gneiss along the 2nd bench, between ch.10+510 and ch.10+520*

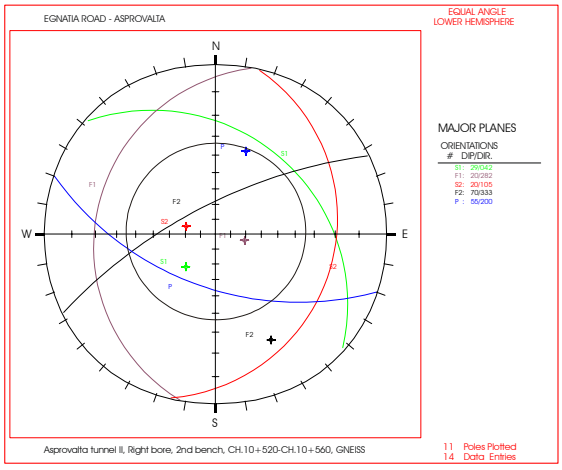

Fig.13: *Schmidt diagram in gneiss, along the 2nd bench, between ch.10+520 and ch.10+560*

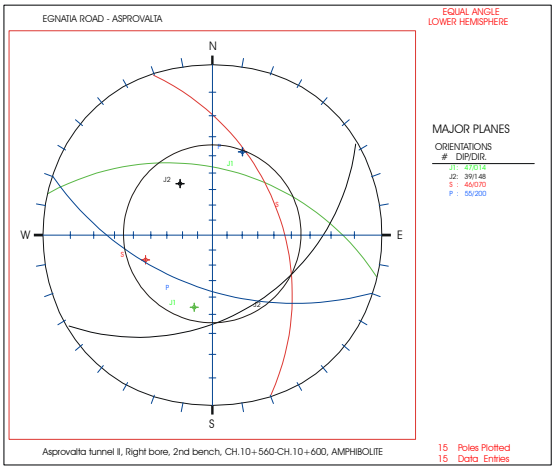

Fig.14: *Schmidt diagram in amphibolites, along the 2nd bench, between ch.10+560 and ch.10+600*

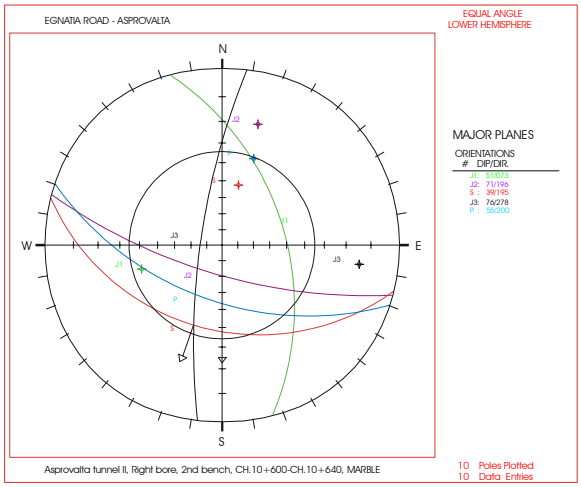

Fig.15: *Schmidt diagram in marble, along the 2nd bench, between ch.10+600 and ch.10+640*

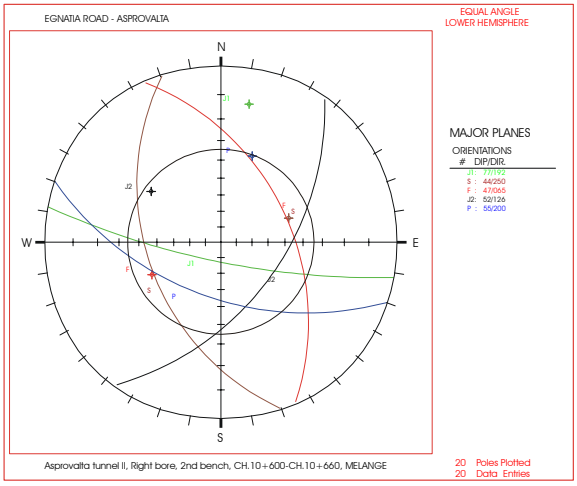

Fig.16: *Schmidt diagram in the mélange, along the 2nd bench, between ch.10+600 and ch.10+660*

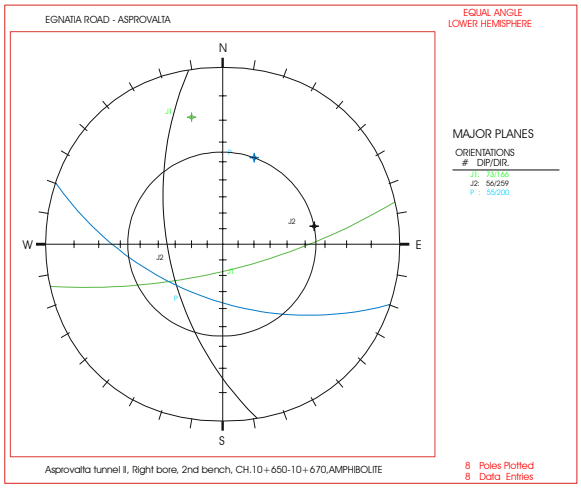

Fig.17: *Schmidt diagram in marble, along the 2nd bench, between ch.10+600 and ch.10+640*

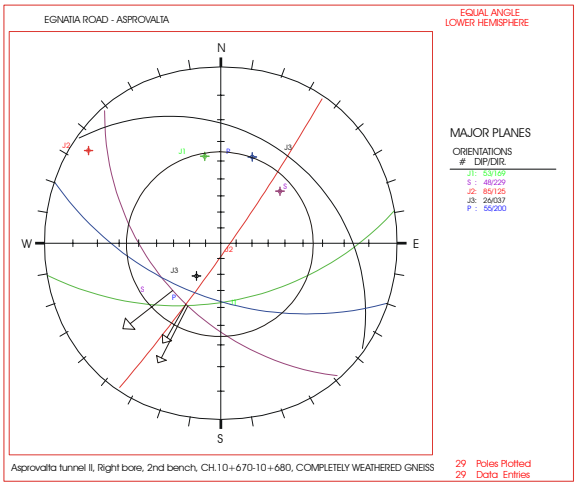

Fig.18: *Schmidt diagram in complete weathered gneiss, along the 2th bench, between ch.10+670 and ch.10+680.*

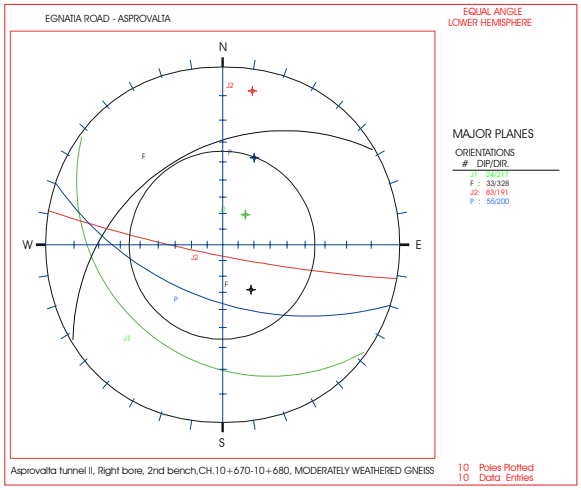

Fig.19: *Schmidt diagram in moderately weathered gneiss, along the 2nd bench, between ch.10+670 and ch.10+680*

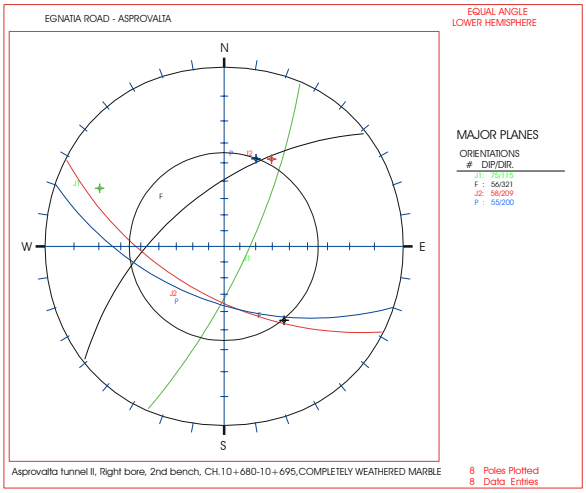

Fig.20: *Schmidt diagram in completed weathered gneiss, along the 2nd bench, between ch.10+680 and ch.10+695*

Conclusions

The open trench was excavated in four benches. According to RMR classification system (Bieniawski, 1989), the qualities of rock mass, which was estimated during the excavation of benches, without considering the influence of discontinuities orientation, was characterized as poor (RMR_{bas} = 22-40). There was only a part of 70m, between ch.10+570 and ch.10+640, that rockmass was of medium quality (RMR_{bas} = 42-49). Considering the influence of the orientation of discontinuities, the rock mass was characterized as very poor (RMR = 3-17). There was also a part of 90m, between ch.10+550 and ch.10+640, that rockmass was of poor quality (RMR = 24-35). According to SMR classification system (ROMANA, 1985), the excavation of the open trench was unstable, expecting extensive failures.

Studying the probable failure, potential sliding observed between ch.10+505 and ch.10+556, during 3rd bench's excavation, in the direction of schistosity of gneiss 213/35. Potential sliding was estimated, during 2nd bench's excavation; i) between ch.10+510 and ch.10+520 along schistosity of gneiss, ii) between ch.10+600 and ch.10+640 in the direction of the section of schistosity of marble 195/39 and joints surfaces 278/76 and iii) between ch.10+670 and ch.10+680 in the directions of the section of schistosity of gneiss 229/48 and joints surfaces 169/53 or 125/85.

The construction of three benches had just been completed when the landslide took place between ch.10+533 and ch.10+620. A wedge failure was observed in marble formation between ch.10+600 and ch.10+620 (2nd bench) in the direction of the section of schistosity of marble 195/39 and joints surfaces 278/76. The above failure caused rockmass sliding along schistosity of gneiss 213/35 at neighbor area from ch.10+533 to ch.10+600.

REFERENCES

BIENIAWSKI, Z.T., 1989. Engineering rock mass classification. New York: Wiley.

CHATZIANGELOU M., CHRISTARAS B., 2003. Rainwater influences on the instability of a high slope at the Asprovalta-Strymonas part of Egnatia highway (chainage 9+700), 5th Euromech Solid Mechanics Conference ESMC-5, Thessaloniki.

CHATZIANGELOU M., CHRISTARAS B., 2004. Comparative stability study of high slopes in wet and dry atmospheric conditions. The case of the Egnatia Highway in Eastern Greece (chainage 9+700). 32nd International Geological Congress (IGC), Florence.

CHRISTARAS B., CHATZIANGELOU M., MALLIAROUDAKIS EM., MERKOS S., 2001. Support capacity of wedges and RMR classification along the Asprovalta tunnel of Egnatia Highway, in N. Greece. 9th Congress of Engineering Geology for Developing Countries, Durban.

HOKING, G., 1976. A method for distinguishing between single and double plane sliding of tetrahedral wedges. Int. J. Roc Mech.&Mining Sci., 13, pp.225-226.

MARKLAND, J.T., 1972. A useful technique for estimating the stability of rock slopes when the rigid wedge sliding type of failure is expected. Imperial College Rock Mechanics Research Report, 19, pp.1-10.

ROMANA, M., 1985. New adjustment ratings for application of Bieniawski classificaton to slopes. Proc. Int. Symp. Rock Mech. Excav. Min. Civ. Works, ISRM, Mexico city, pp.59-68.