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EXCAVATION DATA AND FAILURE INVESTIGATION ALONG TUNNEL OF SYMBOL MOUNTAIN

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Abstract

The tunnel of Symbol Mountain, which is 1160m long, is placed on South-west of Kavala City at Northern Greece. The tunnel consists of two bores with NW-SE direction, which are connected with two small tunnels. The stability of the rock mass was limited, during the excavation, because the rock mass was often changing, the faults are open, and the aquifer is placed above the excavation.

The aim of the present paper is to describe the dangerous geological status of Symbol Mountain and to propose excavation solutions of the unexpected failure conditions.

For the above reasons, the sudden changes of the rock mass quality along the tunnel excavation are described. The causes of the geological failures were investigated and the failures were classified. Furthermore, the efficacy of support measures was tested and a relationship between the apparent face of wedges and the shotcrete thickness was proposed.

Key words: *Tunnels, support measures, wedges, slidings, decollement, anchors, bolts, shotcrete, swellex, excavation.*

1. Introduction

The tunnel of Symbol Mountain is geotechnical located on Rodope mass. The excavation of the tunnel passed through alternations of gneiss, schists and marbles. The quality of the rock formations often changes from sound to weathered. It is, usually, heavily jointed and in many cases is folded. Furthermore, the presence of chloritic schist, lengthen 400m, caused numerous unexpected failures and support problems. So, the excavation needed to be extremely careful, and for this reason a combination of excavation methods were used. The presence of an opened vertical fault, which is just placed at the exit of the tunnel and creates a shear zone about 400m long, increased the stability problems. The water table is placed above the tunnel.

2. Rock mass quality

The beginning of the tunnel, the rock mass consists of fair quality gneiss with pegmatite veins, although there is a part of the tunnel between ch.36+300-ch.36+400 where the quality of a part of gneiss is very poor (Bieniawski, 1989, Hook, 2004). Walking along the tunnel, the rock mass quality becomes poor and or very poor near the schist formation. At the middle of the tunnel (ch. 35+800-ch.36+300), there is a fair quality lens of marble. Walking to the outlet of the tunnel, we met alternations of gneiss and marble medium and poor qualified. Between ch. 36+500-ch. 36+700, there is a formation of chloritic schistolite of poor quality. That geological formation caused numerous problems during the excavation, as it deformated very quickly after it was excavated. The last part of the tunnel is placed along a shear zone of an opened vertical fault 150/70 F (Fig.1).

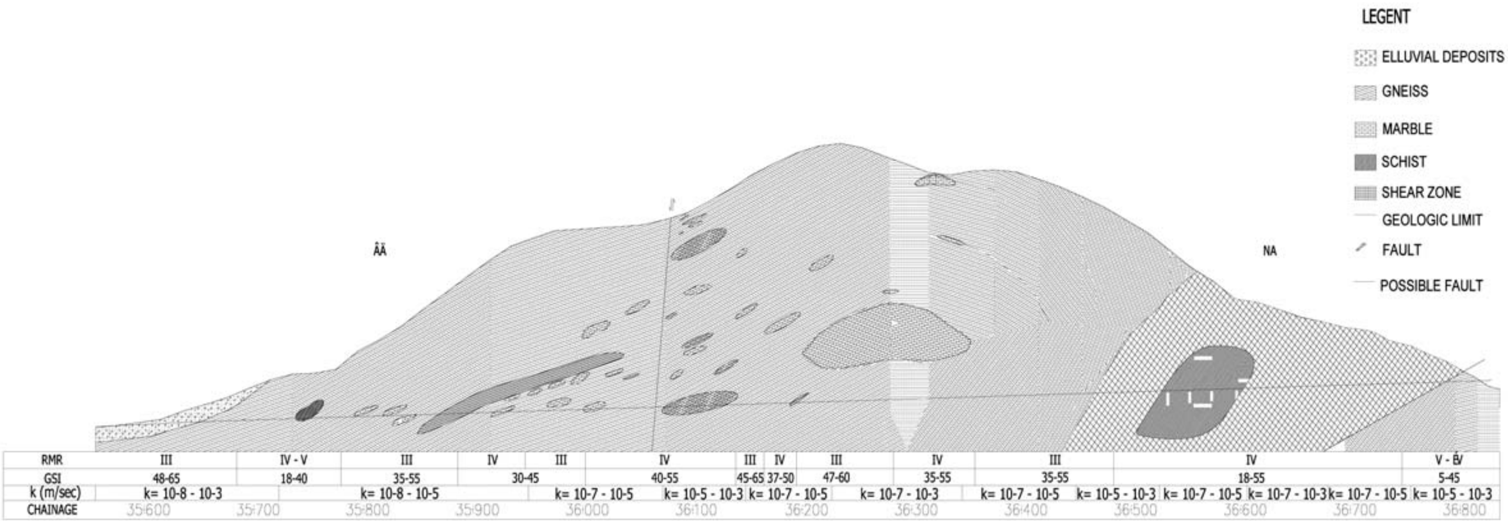

Fig. 1: Geological section along the right bore of the tunnel.

Table 1. Slidings and dècollemens along the tunnel

Chainage	Geological formations	Sliding	Dècollement	J1	J2	J3	J4	J5
35677,1 - 35680,70	Gneiss with pegmatitic intercalations	239/38 S		173/38 S	239/38 S			
35684,3 - 5695,10	Gneiss with pegmatitic intercalations	235/54 F		235/54 F	360/32 S			
35697,5 - 35706	Gneiss with pegmatitic intercalations	224/58		224/58	146/4 S	174/72	145/38	
35716,5 - 35724	Gneiss with pegmatitic intercalations	249/41, 153/67		153/67	249/41	100/6 S		
35728,8 - 35733,3	Gneiss with pegmatitic intercalations	308/59, 212/47		212/47	308/59	97/12 S		
35733,3 - 35741,4	Gneiss with pegmatitic intercalations and schist	272/54		33/18 S	206/46	272/54		
35741,9 - 35744,7	Schist	71/51		343/19 S	71/51	119/31		
35744,7 - 35749,4	Schist and gneiss with pegmatitic intercalations	31/73, 238/45 S		154/25	238/45 S	20/18	31/73	
35749,4 - 35765,2	Gneiss with pegmatitic intercalations	64/53, 275/52		275/52	344/30 S	64/53		
35765,2 - 35774,2	Gneiss with pegmatitic intercalations and schist	285/63 F		181/26 F	285/63 F	339/28 S	56/65	
35774,4 - 35776	Gneiss and schist	226/46		226/46	351/18 S			
35776 - 35785	Marble and gneiss	238/61		174/69	238/61	4/12 S		
35785 - 35790,4	Gneiss	252/59		252/59	110/79	8/22 S		
35790,4 - 35802,9	Marble and gneiss	204/65	161/77	161/77	204/65	247/31	5/30 S	
35802,9 - 35864,4	Gneiss	54/60 S		54/60 S	243/43	10/24F		
35864,4 - 35880	Gneiss and marble	275/40 S, 71/77	Flow of weathered material, fall of soiled material	71/77	275/40 S	65/41	150/15 S	200/75
35880 - 35882	Marble	100/64	Soil material	258/29 F	358/68	100/64		
35882 - 35906,6	Gneiss and marble and chlorite	112/63, 175/67, 9/62 S	Soil material	237/34 F	9/62 S	112/63	175/67	
35906,6 - 35934,626	Marble	204/62 F		155/64	204/62 F	258/19 S		
35934,626 - 35941,635	Gneiss, marble, pegmatite and quarzite	55/62, 198/72	283/12 S	55/62	198/72	250/70	283/12 S	
35941,63535948,349	Marble	66/56		100/68	66/56	288/8 S		
35948,349 - 35957,379	Gneiss and marble	191/62, 313/36 S	313/36 S	313/36 S	191/60			
36008,125 - 082,468	Gneiss and marble	34/73, 267/29 S	267/29 S	267/29 S	151/60	34/73		
36082,468 - 36114,909	Marble	191/59, 270/58	318/16 S	66/88	191/59	270/58	318/16 S	

Chainage	Geological formations	Sliding	Dècollement	J1	J2	J3	J4	J5
36114,909 - 36124,729	Marble	310/5 S		240/38	310/5 S			
36134,729 - 36139,41	Marble and schistolite	254/64, 349/26 S		254/64	349/26 S			
36139,41 - 36176,222	Marble	224/60, 33/68	348/13 F	224/60	140/68	33/68	348/13 F	
36176,222 - 36188,494	Marble and gneiss	65/67		240/71	312/33 S	65/67		
36188,494 - 36240,379	Gneiss	310/11 S, 43/78, 233/66	310/11 S	233/66	332/68	43/78	310/11 S	
36240,379 - 36312,44	Gneiss and marble	224/72		224/72	247/3 F			
36312,44 - 36+327,74	Gneiss and marble	210/37	10/10 S	210/37	10/10 S			
36327,74 - 36350,746	Gneiss and marble		358/22 S	232/43	152/32 F	358/22 S		
36425,28 - 36387,1	Gneiss	137/52 S, 227/78	19/27 S, 137/52 S	227/78	137/52 S	238/39	19/27 S	
36387,1-36481,783	Chloritic schist and gneiss	123/70 S		123/70 S				
36481,783 - 36443,87	Gneiss	80/55, 197/55 F		197/55 F	80/55	03 / 015 S		
36443,87 - 36499,58	Chloritic schist and gneiss	221/72, 26/74		221/72	26/74	137/16 S	147/60	
36499,58 - 36537,046	Chloritic schist	219/72	cracked material, 138/44 S	219/72	212/11 S	138/44 S	04/016 S	
36537,46 - 36659,4	Gneiss	28/75, 149/74, 252/74	155/20 S, cracked material	246/74	155/20 S	149/74	28/75	
36659,4 - 36717,5	Gneiss and granite	220/63, 135/37		135/37	220/63	49/75	267/6 S	
36717,5 - 36740,9	Gneiss and marble	30/58 S, 120/70		140/52	265/82	30/58 S		
36+740,9 - 36746	Gneiss	38/85		61/15 S	333/90	38/85		
36746 - 36749	Melange of granite, gneiss and marble	221/59, 128/68 F		128/68 F	221/59			
36749 - 36763,1	Granite and kaolinite	117/70 F		48/16 S	117/70 F	210/19	26/84	
36765,73 - 36766,7	Gneiss	15/60 F		45/84	348/38 S	108/46 S	158/60 F	
36766,7 - 36771,5	Gneiss	132/74 F, 117/43 S		132/74 F	117/43 S			
36771,5 - 36777,5	Gneiss	100/43		90/10 S	100/43			
36777,5 - 36779,5	Gneiss and marble	124/40 S		188/70 F	287/63	35/63	120/70 F	124/40 S
36779,5 - 36789	Gneiss			36/83	81/89	153/68 S	171/36	

Table 2. Geometrical characteristics of most importand wedges along the tunnel of Symbol Mountain

Chainage	Geological formations	Distance of the roof from the surface (m)	J1	J2	J3	J4	J5	Type of failure	Position of the wedge	F.S.	Volume (m3)	Weight (tns)	z-length (m)	Apparent face (m2)	Height (m)
335675,9-35677,10	Gneiss	0	300/49	166/43	40/20			Collapse	Upper left wedge	0	201,825	544,928	20,26	72,54	9,53
								Collapse	Lower right wedge	0	208,672	563,414	16,12	66,51	9,85
35698,8 - 35707,2	Gneiss with pegmatitic intercalations	15	224/58	146/4 S	174/72	145/38		Collapse	Upper left wedge	0	778,222	2101,198	40,39	210,56	12,68
								Collapse	Upper right wedge	0	187,967	507,51	13,17	80,02	8,66
35707,2 - 35710,1	Gneiss and granite	15	158/48	226/52	80/5 S			Collapse	Upper left wedge	0	620,66	1675,781	45,56	221,48	9,34
35710,1 - 35718	Gneiss with pegmatitic intercalations	15	146/46	199/13 S	236/53	330/58		Collapse	Upper left wedge	0	1646,741	446,2	40,72	276,07	22,14
								Collapse	Upper right wedge	0	1036,954	2799,776	18,51	121,47	35,26
35718 - 35725,8	Gneiss with pegmatitic intercalations	15	153/67	249/41	100/6 S			Collapse	Upper left wedge	0	428,827	1157,833	25,85	124,25	11,71
5725,8 - 35730,3	Gneiss with pegmatitic intercalations	15	234/32	108/17 S	350/58			Collapse	Upper left wedge	0	232,963	629	23,27	99,42	7,5
35730,3 - 35734,8	Gneiss with pegmatitic intercalations	15	212/47	308/59	97/12 S			Collapse	Upper left wedge	0	967,241	2611,551	59,67	326,68	9,71
35734,8 - 35742,9	Gneiss with pegmatitic intercalations and schist	18	33/18 S	206/46	272/54			Collapse	Upper left wedge	0	1004,184	2711,296	147,98	577,23	6,4
35746,2 - 35749,4	Gneiss with pegmatitic intercalations and schist	18	154/25	238/45 S	20/18	31/73		Collapse	Upper right wedge	0	1009,331	2725,194	26,31	141,8	22,61
								Collapse	Lower right wedge	0	591,184	1596,196	23,67	112,33	18,47
35768,8 - 35774,2	Gneiss with pegmatitic intercalations and schist	34	181/26 F	285/63 F	339/28 S	56/65		Collapse	Upper right wedge	0	1236,274	3337,941	15	108,57	38,52

Chainage	Geological formations	Distance of the roof from the surface (m)	J1	J2	J3	J4	J5	Type of failure	Position of the wedge	F.S.	Volume (m3)	Weight (tns)	z-length (m)	Apparent face (m2)	Height (m)
35792,5 - 35802,9	Gneiss and marble	22	161/77	204/65	247/31	5/30 S		Collapse	Upper left wedge	0	1596,816	4311,403	31,37	212,72	26,18
								Collapse	Roof wedge	0	109,254	294,986	26,56	69,1	5,41
35908,4 - 35934,626	Marble	85	155/64	204/62 F	258/19 S	35908,4 - 35934,626		Collapse	Upper left wedge	0	1539,353	4156,252	59,53	422,28	14,27
35934,626 - 35948,349	Gneiss, marble, pegmatite, quarzite	105	55/62	198/72	250/70	283/12 S		Collapse	Upper right wedge	0	1449,127	3912,462	17,44	118,23	41,21
35948,349 - 35955,63	Marble	105	100/68	66/56	288/8 S			Collapse	Upper right wedge	0	786,449	2123,411	49,36	269,86	9,69
36144,19 - 36188,494	Marble	158	224/60	140/68	33/68	348/13 F		Collapse	Upper right wedge	0	19244,169	51959,257	36,12	274,99	237,49
36215,595 - 36240,379	Gneiss	170	233/66	332/68	43/78	310/11S		Collapse	Roof wedge	0	243,995	658,786	40,22	91,62	9,02
								Collapse	Upper right wedge	0	4390,322	11853,87	34,02	262,22	57,48
36350,746 - 36425,28	Gneiss	130	227/78	137/52 S	238/39	19/27 S		Collapse	Upper right wedge	0	370,929	1001,508	71,82	178,32	7,11
36481,783 - 36529,937	Chloritic schist and gneiss	99	221/72	26/74	137/16 S	147/60		Collapse	Roof wedge	0	704,133	1901,158	41,42	214,13	11,69
36359,4 - 36717,5	Gneiss and chloritic schist	32	246/74	155/20 S	149/74	28/75		Collapse	Roof wedge	0	280,457	757,235	15,51	86,46	11,72
36717,5-36740,9	Gneiss and granite	26	135/37	220/63	49/75	267/6 S		Collapse	Uper left wedge	0	435,204	1175,05	32,9	129,55	12,59
36749 - 36763,1	Granite and kaolinite	20	48/16 S	117/70 F	210/19	26/84		Collapse	Lower right wedge	0	467,882	1263,282	105,6	295,25	4,95
								Collapse	Upper left wedge	0	362,944	980,039	38,51	207,03	6,21
36765,73 - 36766,7	Gneiss	15	45/84	348/38 S	108/46 S	158/60 F		Collapse	Roof wedge	0	451,866	1220,39	14,83	57,62	26,9
36777,5 - 36781,9	Gneiss and marble	8	188/70 F	287/63	35/63	120/70 F		Collapse	Roof wedge	0	506,556	1367,7	20,86	124,35	13,8
								Collapse	Upper right wedge	0	659,163	1779,739	8,3	31,97	67,29
36+781,9 - 36789	Gneiss	7	36/83	81/89	153/68 S	171/36		Collapse		0	1057,986	2856,561	21,09	182,01	28,21

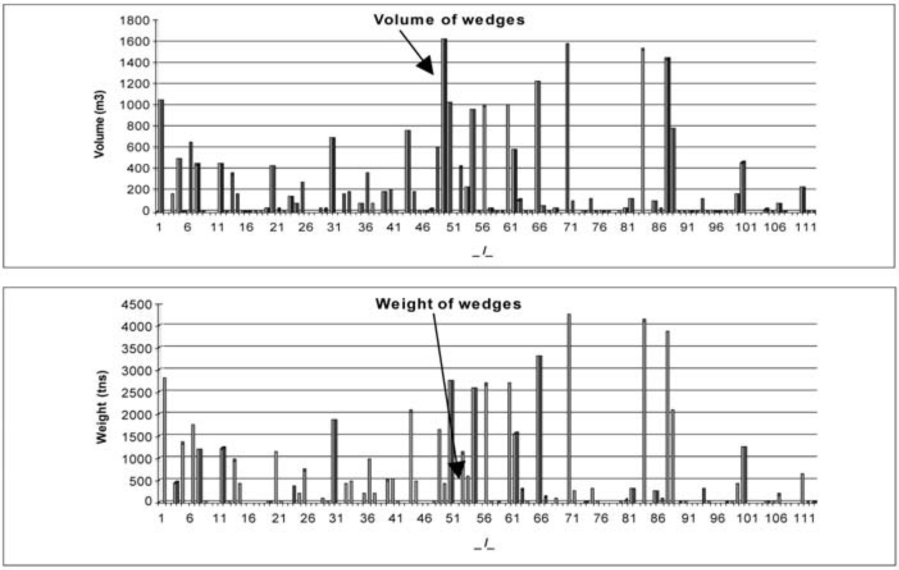

Fig. 2: Comparison between volume and weight of wedges. The arrow shows the position of wedge with volume of 1646,741m^3, and weight of 446,2 tns.

3. Excavation methods

The rock mass along the tunnel differs from one place to another. Hard gneiss rock fair qualified of marble of granite was alternated with fractured and deformated rock mass of gneiss and marble. Furthermore, the presence of chloritic schist and the shear zone, minimize the safety of the excavation using the simple mechanical means. So, in order to excavate the tunnel safety, we ought to apply different excavated methods, taking into account rock mass behaviour (Marinos et al, 2005).

Near the outlets and where the rock mass was very poor, the tunnel was excavated mechanically, using the NATM method of excavation. The use of explosive measures was preferred on poor and fair quality of hard rock mass. The excavation of chloritic schist and the shear zone was very dangerous. Although the chloritic schist was very hard and it was very difficult to be excavated with mechanical means, it was deformated very quickly, when it was in conduct with the atmosphere. So, before the removal of excavation material to be completed, pieces of chloritic schist were felled down. The SCL method of excavation was preferred on that case in order to support small parts of the face before the excavation be completed. Furthermore, light explosion used in order to crack the hard rock mass helping the excavation.The sudden change of rock mass quality created the necessity of fore polling.

4. Tunnel stability

The sliding along a plane, the décollement from the roof and the fall of wedges (Chatziangelou et all, 2001) were the common failure causes. Sliding took place along a tectonic surface from the walls of the tunnel. On the other hand, the dècollement of a plate is due to its smooth surface in addition with the influence of gravity (Table 1).

One hundred and eleven wedges were measured along the tunnel (Table 2). All the wedges were to be collapsed, so the calculated safety factor, before the application of support was zero. From ch.36+139,41 to ch.36+176,222 a wedge with volume of 19244,17 m^3 had been observed on the

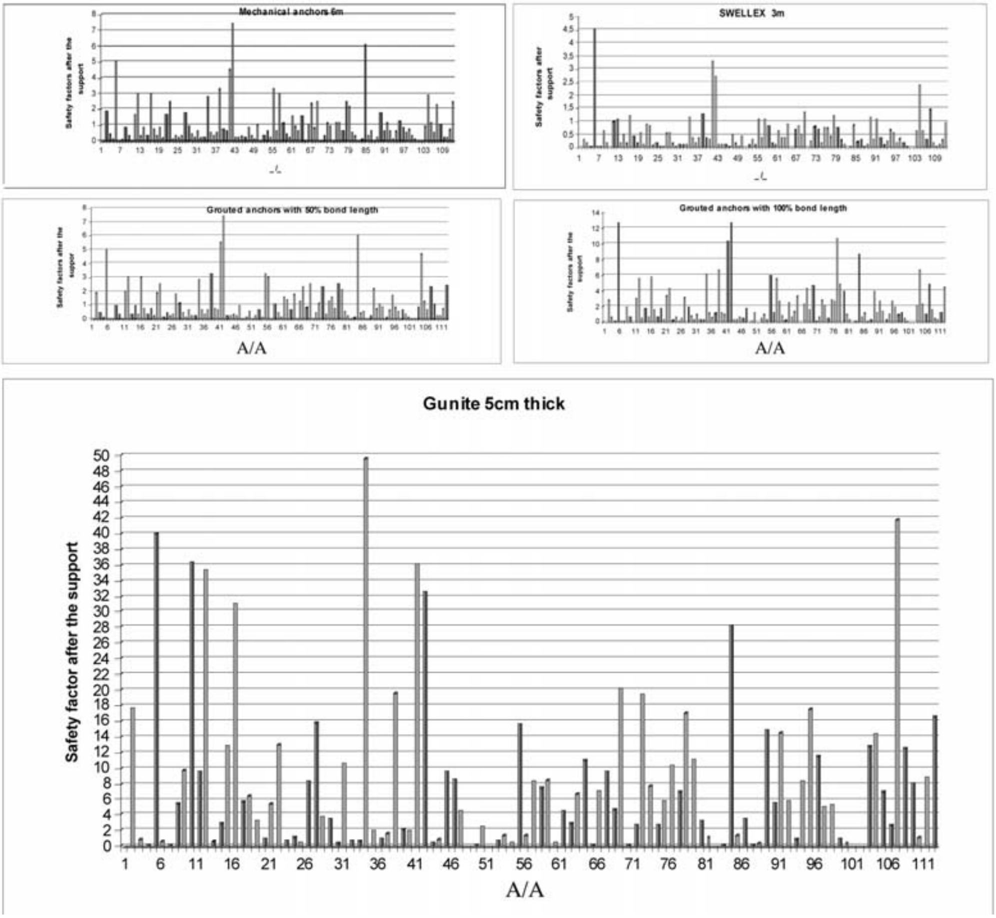

Fig. 3: Safety factors of the wedges after the support of different measures.

upper right part of the tunnel. The failure of that wedge could cause the collapse or all the overlying formations up to the surface. That wedge didn't take into account on our estimations. Another one big wedge, with volume of 4390,22 m^3 (from ch.36+215.595 to ch.36+240,379), which was also formed on the upper right part of the tunnel didn't take into account on our estimations.

Usually, there is a relation between the weight and the volume of the wedges. It is common place, the wedges with big volume to be also heavy. But an exception of the above, was observed between ch.35+710 and ch.35+716,5, where there is a wedge with the one of the biggest volumes (1646,741m^3), but one of the slightest ones (weighted 446,2 tns) (Fig.2) That is due to the very poor quality of the rock mass, in addition to fractrure and deformation. The deformation reduced the apparent weight of the rock mass. Also, the numerous of discontinuities, as they are crossed, they cause empty space at the cross point, so the weight of the wedge does not increase so much as the volume increase.

5. Comparing different support measures

The rock mass quality methods, RMR and GSI, were used for determining the efficacious support measures of the slopes and the tunnels in the area (Christaras et al, 2002). According to the geotechnical

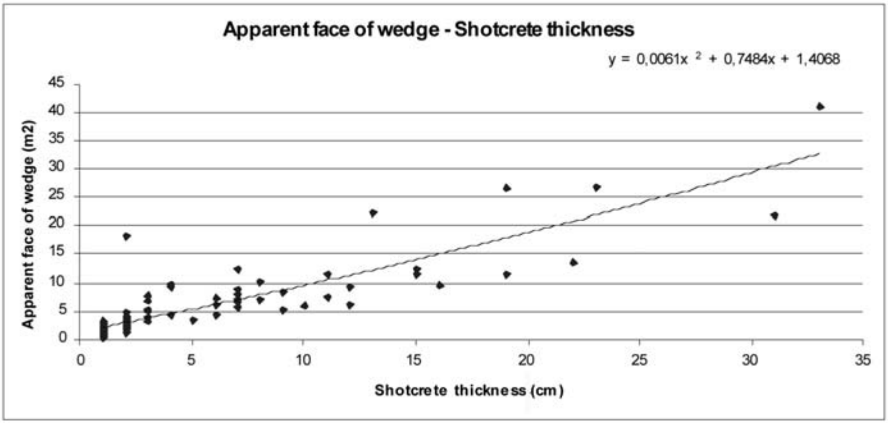

Fig. 4: Relationship between apparent face of wedge and shotcrete thickness.

characteristics of the rock mass, the proposed support measures are completed with different types. The present paper examines the effectiveness of different types of anchors and shotcrete on the rock mass of Symbol Unit. For this purpose, the support of the tunnel was tested using mechanical anchors 6m long, swellex 3m long, grouted anchors 3m long with 50% bond length, grouted anchors 3m long with 100% bond length and shotcrete with thickness of 5cm (Fig.3). Actually, the wedges tested to be supported with one of the above measures, without using combination of them. The required safety factor which was used for the comparisons was 1,5.

Twenty five wedges were observed to be supported with mechanical anchors with length of 6m. Five wedges were supported with swellex bolts. So, the mechanical anchors can support more wedges than the swellex bolts can. Also, there is no difference when the bolts are grouted at 50% of their length and are totally not grouted. The safety becomes bigger when the bolts are totally grouted. Forty seven wedges are supported sufficiently. Also, the grouted anchors with 100% bond length give bigger safety factors than the grouted anchors with 50% bond length. The percent of safety increases two times with the use of grouted anchors with 100% bond length. As far as shotcrete concern, seventy four wedges are supported effectively with shotcrete 5cm thick.

6. Calculation of shotcrete thickness using the apparent face of wedge

As the excavation of tunnels and the application of the support measures are dangerous, the quick calculation of shotcrete thickness during the excavation is useful. Comparing the apparent face of the wedges (the surface which is appeared at the inner surface of the tunnel) with the demanded shotcrete thickness (thinner than 40cm), in order the unstable wedges to be supported, a relationship was resulted (Fig.4);

$$F\ (m^2) = 0{,}0061 * [h\ (cm)]^2 + 0{,}7484 * h(cm) + 1{,}4068 \quad (1)$$

where h = shotcrete thickness (cm)

F = apparent face of the wedge (m^2)

The coefficient of the above relationship was calculated 0,877.

The above relationship has the same form with the relationship, which has calculated from the data of Asprovalta tunnels of Egnatia Highway (Chatziangelou, 2008);

$$F\ (m^2) = 0{,}3489 * [h\ (cm)]^2 + 16{,}654 * h(cm) + 14{,}049 \quad (2)$$

Asprovalta tunnels are located at Serbomakedonian mass and the tunnels are passed through gneiss with pegmatitic intercalations, marble and amphibolite. The coefficient of that relationship was calculated 0,082.

7. Conclusions-Results

The tunnel which crosses the Symbol Mountain was excavated dangerously because of the difficult geological status with unexpected failure conditions. The sliding along a plane, the décollement from the roof and the fall of wedges were the common failure causes.

Different methods were used in order to excavate the tunnel safely. The NATM method of excavation was used near the outlets and where the rock mass was very poor. On poor and fair quality of hard rock mass the explosive measures were the most effective. Also, light explosion was used in order to crack the hard rock mass helping the excavation. Chloritic schist formation and the places, where the loose deformed material flowed from the walls and the face, were excavated by the SCL method.

Studying the geometrical characteristics of wedges, we concluded that the weight reduce of the wedges with big volume is due to i) deformation which reduces the apparent weight of the rock mass and ii) the cross of the numerous discontinuities, that they cause empty space at the cross point.

Examining the effectiveness of different types of anchors and shotcrete, we concluded that the mechanical anchors can support more wedges than the swellex bolts can. Also, there is no difference when the bolts are grouted at 50% of their length and are totally not grouted. The safety becomes bigger when the bolts are totally grouted. As far as shotcrete concern, more than 50% of wedges are supported effectively with shotcrete 5cm thick.

Finally, comparing the apparent face of the wedges with the demanded shotcrete thickness (thinner than 40 cm), in order the unsteady wedges be supported, a relationship (1) was resulted. The above relationship has the same form with the relationship (2), which has calculated from the data of Asprovalta tunnels of Egnatia Highway;

Consequently, there is a relation between apparent face of the wedges and the demanded shotcrete thickness being formed;

$$y = a * x^2 + b * x + c \tag{3}$$

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