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INFLUENCE OF THE GEOMETRIC CHARACTERISTICS OF WEDGES ON THE SAFETY OF VRASNA TUNNEL IN EGNATIA HIGHWAY, N. GREECE

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Abstract

The present paper concerns the influence of the geometric characteristics of the potential wedges on tunnels safety, which are supported by shotcrete and rock bolts, during the excavation of poor and medium quality rock mass, in accordance to RMR classification system. The geological and tectonic data which were used in our estimations were collected in situ during the excavation of Vrasna's tunnel. According to shear test along discontinuities planes, friction angle was considered 21^o on schistosity planes and 35^o on joint planes. Furthermore, no cohesion was taken into account, as the fractures were, more or less, opened. The orientation and spacing of discontinuities were taken into account for estimating tunnel stability, given that they affect the strength and the quality of the rock mass during the construction. The collected data and the obtained, after elaboration, results were correlated statistically and power regressions were determined.

***Key words:** Shotcrete, rock bolts, rock mass quality.*

Περίληψη

Η παρούσα εργασία αναφέρεται στην επιρροή των γεωμετρικών χαρακτηριστικών των δυνητικών βραχοσφηνών στην ευστάθεια σηράγγων που διανοίγονται σε πτωχής και μέτριας ποιότητας βραχομάζες, σύμφωνα με το σύστημα ταξινόμησης RMR, και υποστηρίζονται με εκτοξευόμενο σκυρόδεμα και αγκύρια. Τα γεωλογικά και τεκτονικά στοιχεία που χρησιμοποιήθηκαν, προέρχονται από την εκσκαφή της σήραγγας Βρασνών. Σύμφωνα με τις δοκιμές διάτμησης, η γωνία τριβής των επιπέδων των ασυνεχειών θεωρήθηκε 21^o για τα επίπεδα της σχιστότητας και 35^o για τα επίπεδα των διακλάσεων. Επιπλέον, η συνοχή θεωρήθηκε μηδενικ,ή καθώς τα τοιχώματα των ασυνεχειών ήταν, λίγο ή πολύ, ανοικτά. Ο προσανατολισμός και η απόσταση των ασυνεχειών λήφθηκαν υπόψη κατά την εκτίμηση της ευστάθειας της σήραγγας, αφού επηρεάζουν τη συνοχή και συνεπώς και την ποιότητα της βραχομάζας κατά την εκσκαφή. Σύμφωνα με τις εκτιμήσεις των στοιχείων, η πλειοψηφία των βραχοσφηνών που δημιουργήθηκαν κατά την εκσκαφή της σήραγγας, υποστηρίζεται με εκτοξευόμενο σκυρόδεμα μέγιστου πάχους 3cm. Η εφαρμογή του εκτοξευόμενου σκυροδέματος αυξάνει τον συντελεστή ασφάλειας των βραχοσφηνών μέχρι 9,48. Τα αγκύρια μέγιστου μήκους 3m υποστηρίζουν την πλειοψηφία των βραχοσφηνών αυξάνοντας τον συντελεστή ασφάλειας μέχρι και 9,43. Παρ΄όλα αυτά, πολλές βραχοσφήνες υποστηρίζονται με α-

γκύρια μήκους 1 m. Συγκρίνοντας την αποτελεσματικότητα εφαρμογής των αγκυρίων και του εκτοξευόμενου σκυροδέματος, η εφαρμογή του εκτοξευόμενου σκυροδέματος, μέγιστου πάχους 10cm, σύμφωνα με τη μέθοδο RMR, αυξάνει τον συντελεστή ασφάλειας δέκα φορές, ενώ η τοποθέτηση των αγκυρίων μήκους 6 m, σύμφωνα με τη μέθοδο RMR, δεν μεταβάλλει τον συντελεστή ασφάλειας. Συνεπώς, η εφαρμογή του εκτοξευόμενου σκυροδέματος είναι πιο αποτελεσματική για την ευστάθεια των ασταθών βραχοσφηνών. Τα στοιχεία πεδίου και τα εξαγόμενα αποτελέσματα συγκρίθηκαν στατιστικά και προσδιορίστηκαν δυναμικές σχέσεις μεταξύ τους. Σύμφωνα με τις σχέσεις αυτές, η μικρή αύξηση της φαινόμενης επιφάνειας των βραχοσφηνών μέχρι $58m^2$ δημιουργεί σημαντική μείωση του συντελεστή ασφάλειας όταν οι βραχοσφήνες υποστηρίζονται με το ελάχιστο απαιτούμενο πάχος εκτοξευόμενου σκυροδέματος. Απ΄την άλλη μεριά, όταν η φαινόμενη επιφάνεια των βραχοσφηνών αυξάνεται περισσότερο από $58m^2$, η μείωση που παρατηρείται στους συντελεστές ασφάλειας είναι μικρή. Επιπλέον, μια μικρή αύξηση στο βάρος ελαφρών βραχοσφηνών (μέγιστου βάρους 15 tns) είναι δυνατό να προκαλέσει σημαντική μείωση του συντελεστή ασφάλειας κατά την εφαρμογή των ελάχιστων απαιτούμενων μέτρων υποστήριξης. Όσον αφορά τις βαρύτερες βραχοσφήνες (βάρους άνω των 15 tns), η αύξηση του βάρους των βραχοσφηνών δεν προκαλεί τόσο σημαντική μείωση του συντελεστή ασφάλειας. Επιπλέον, μια αύξηση στον όγκο των βραχοσφηνών (μέχρι $85m^3$) ή στο ύψος των βραχοσφηνών (μέχρι 10 m) φέρει σημαντική μείωση του συντελεστή ασφάλειας κατά την εφαρμογή αγκυρίων ελάχιστου απαιτούμενου μήκους. Μια ελαφριά αύξηση τον όγκο των βραχοσφηνών (μέχρι $80\ m^3$) δημιουργεί σημαντική μείωση του συντελεστή ασφάλειας κατά την εφαρμογή εκτοξευόμενου σκυροδέματος ελάχιστου απαιτούμενου πάχους.
Λέξεις κλειδιά: Ευστάθεια σηράγγων, βραχοσφήνες, εκτοξευόμενο σκυρόδεμα, αγκύρια.

1. Introduction

The geological and tectonic data which were used in our elaboration were collected in situ, during Vrasna's tunnel excavation. The Vrasna's tunnel is located in northern Greece, 80km to the east of Thessaloniki City. It belongs to the Nymphopetra – Redina's part of Egnatia highway. The tunnel (Fig. 1), which is about 12 m high, consists of two parallel bores, 140 m long each, being oriented from the west to the east. A cavern, which is called Drakopetra, is located at the northern part of the tunnel.

Figure 1 - Medium to poor quality gneiss and good quality marble

2. Geological settings

The area is geologically located in Serbomacedonian mass, consisting of metamorphic rocks. The wedges in study are placed in cracked rock mass of weathered, brown colored gneiss and karstified marble (Fig. 2) with pegmatitic veins.

The quality of gneiss, which is closely jointed, is generally characterized as poor (IV), changing to very poor (V), near tectonic contacts. The quality of marble, which is widely jointed and less weathered than gneiss, is characterized as good (III) and near tectonic surfaces as poor (IV) (Table 1). The presence of karst phenomena, like the small cavern of Drakopetra, which were observed in marbles, during the excavation, is also taken into ccount on the estimations.

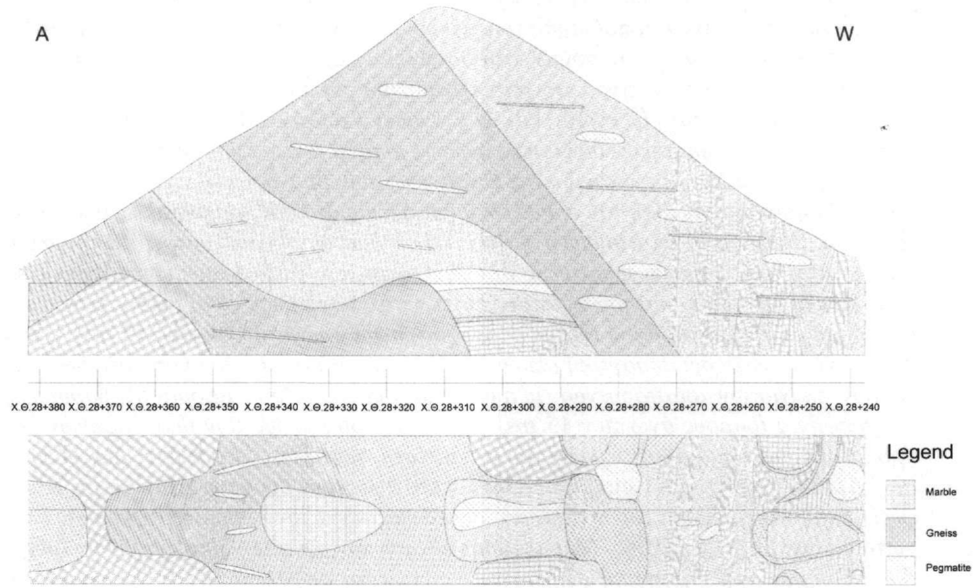

Figure 2 - Geological section along Vrasna tunnel

3. Support measures

According to the RMR system, the Vrasna's Tunnel excavation was performed in two stages. Steel ribs, grouted rockbolts and shotcrete were mainly used for the temporary support of the tunnel. The support measures were placed in accordance with RMR system.

So, steel ribs were placed where the rock mass was very poor. Rockbolts were placed, at the very poor parts, mainly around the excavation, in order to strengthen the rock mass. Rockbolts were also used for the support of steel ribs creating more safe conditions. Rockbolts were also placed in good quality rock mass at selected positions, in order to avert the fall of heavy blocks. Thin flexible shotcrete lining was installed to take only a part of the load (Chatziangelou and Christaras 2003).

It is well known that the failure of a rock mass around an underground opening depends upon the in situ stress level and the geotechnical characteristics of the rock mass. In highly stressed rock masses the failure, around the opening, progresses from brittle spalling and slabbing, in the case of massif rocks with few joints, to a more ductile type of failure for heavily jointed rock masses. The presence of many discontinuities provides considerable freedom for individual rock pieces to slide or rotate within the rock mass (Hoek *et al.* 1995). Failure, involving slip along intersecting discontinuities in a heavily jointed rock mass, is assumed to occur with zero plastic volume change. For this purpose, in shallow tunnels, as the Vrasna tunnel is, the geometry of the discontinuities is considered to be the main instability cause (Christaras *et al.* 2002), taking also into account that no groundwater is present higher than the construction floor. The stability of the potential wedges in shallow tunnels, and the efficacy of rock bolts and shotcrete, were studied along the Vrasna's tunnel.

4. Calculation methodology

The dip and dip direction of the major joint sets were in situ measured. So, the unsafe potential wedges were determined and the safety factors were calculated resolving the sliding and resistance forces along the sliding surface.

The geometrical characteristics of the wedges were calculated using geometrical analysis, taking into account that the dips between wedges' sides were estimated by the stereo diagram and the length of discontinuities, which is equal to the length of a wedge's edge, was in situ measured.

For our calculations, the strength of marble was estimated as 2,67 Mpa, using point load test. The strength of moderately weathered gneiss was also estimated as 4,34 Mpa and the strength of very weathered parts of gneiss was estimated 0,62 MPa. The strength of pegmatite veins was also estimated as 4,45 Mpa, using point load test. Friction angle was considered 21^{o} on schistosity planes and 35^{o} on joint planes. Furthermore, it was considered that there is no cohesion between discontinuity planes.

Having found out the unsafe potential wedges around the tunnel, the minimum support measures were determined. The estimations concern the length of rock bolts and the shotcrete thickness, as shotcrete and rock bolts can be placed easier and more quickly than other support measures as still ribs are. Actually, the safety factors, of the above wedges being supported by the minimum support measures, were calculated, resolving the sliding and resistance forces along the sliding surface. For our calculations, theoretical thickness of shotcrete usually of 1cm, 2cm or 3cm and length of rock bolts of 1m, 2m or 3m were used. The software "UNWEDGE" (Hoek 2000) helped our calculations.

5. Estimations

Thirty-seven unstable wedges, heavier than 5 ns, were estimated (Tables 2-5). At the beginning, the position of unstable wedges, the direction and the type of the failure (sliding or falling) were defined around the opening. The mechanical characteristics of the wedges were estimated; weight, volume, apparent face area on the surface excavation.

After that, the increase of safety using the proposed by RMR support measures was calculated. For this reason, the thickness of shotcrete was considered 10cm and the length of rock bolts was considered 6 m. The quality of the rock mass, the mechanical characteristics and the geometry of the wedges, the minimum support measures and the related safety factors, are given in Tables 2-5. Taking into account the orientation and the spacing of discontinuities, and the overall ground conditions, the rock bolt spacing was considered to be varied from 1.5mx1.5m to 1.5mx1m (Bieniawski 1989).

In accordance to our estimations, shotcrete, up to 3 m thick, can support the majority of the wedges, increasing the safety factor up to 9,88. Although some of wedges are very heavy, they are effectively supported by 2 cm or 1cm shotcrete as the rockmass is cracked and separated into pieces. Also, the face area of the heavy wedges is too extensive, and the weight is uniformly divided, so as the wedge weight on a significant point is small enough in order to be supported by 2 cm or 1 cm shotcrete. The maxinum thickness of shotcrete, which can support successfully the wedges, is 8 cm, although in the most cases, shotcrete 1 cm thick can effectively support the most wedges. Rockbolts, up to 3 m long, can also support the most wedges, increasing the safety factor up to 9,43. Rock bolts 1 m long, can support the most of these wedges. In some cases of cracked wedges, the rock bolts do not restrain the wedges from sliding, but they are embodied in the rock mass increasing the cohesion. In that cases the length of rock bolts needs to be small, smaller than the wedges apex height, so as not to increase the sliding forces. Five wedges cannot be effectively

Table 1 - Rock mass quality classification along the excavation of the tunnel

Ch. - Ch.	RMR	Class	RQD	Spacing of discontinuities (m)	Discontinuity length (m)	Separation (aperture) (mm)	Roughness	Infilling (gouge)	Weathering
Right bore									
28+238,50-28+242,50	44-47	III	75-90	0,2-0,8	3-10	>5	Slightly rough or slickensided	Soft filling<5 or or hard filling>5	Moderately weathered
28+242,50-28+248,50	38	IV	50-75	0,06-0,2	3-10	>5	Slickensided	Hard filling>5	Moderately weathered
28+248,50-28+263,76	43-47	III	50-90	0,06-0,8	3-20	>5	Slightly rough, smooth or slickensided	Hard filling>6	Slightly or moderately weathered
28+263,76-28+339,40	22-40	IV	<90	<0,2	3-20	>0,01	Slightly rough, smooth or slickensided	Soft filling<5 or or hard filling>5	Highly or moderately weathered
28+339,40-28+373,40	21-39	IV	25-90	<0,2	3-20	>5	Slightly rough or slickensided	Soft of hard filling >5	Highly or moderately weathered
28+373,40-28+380	43-53	III	75-100	0,06-0,8	10-20	>5	Smooth or slickensided	Soft filling<5 or hard filling>5	Slightly or moderately weathered
Left bore									
Ch. - Ch.	RMR	Class	RQD	Spacing of discontinuities (m)	Discontinuity length (m)	Separation (aperture) (mm)	Roughness	Infilling (gouge)	Weathering
28+262-28+272,95	41-47	III	75-100	0,06-0,8	10-20	>5	Slightly rough or slickensided	Soft filling<5 or or hard filling>5	Slightly or moderately weathered
28+272,95-28+339,21	26-40	IV	25-90	<0,2	3-20	>5	Slickensided	Soft filling<5 or or hard filling>5	Slightly, moderately or highly weathered
28+339,21-28+356,60	41-46	III	75-100	0,06-0,2	3-20	>5 or no separation	Slightly rough, smooth or slickensided	Hard filling>5 or none	Slightly or moderately weathered
28+356,60-28+399	23-39	IV	25-90	<0,2	3-20	>5	Slightly rough or slickensided	Hard filling>5 or soft filling	Highly or moderately weathered

Table 2 - Geometrical characteristics of possible wedges along the left bore of the tunnel

Ch. - Ch.	A/A	Position	J1	J2	J3	Sliding	Weight (tns)	Face area (m^2)	Volume (m^3)	Height (m)
28+262 - 28+272,95	1	roof	204/42F	143/41S	182/77J	J3	137	39,97	50,67	4,38
28+262 - 28+272,95	2	l/h wall	204/42F	143/41S	182/77J	J2	9,2	9,54	3,39	1,13
28+262 - 28+272,95	3	roof	204/42F	143/41S	340/50J	FALL	19	19,19	7,04	1,26
28+262 - 28+272,95	4	l/h wall	204/42F	143/41S	340/50J	J1/J2	51	31	19,05	2,12
28+262 - 28+272,95	5	r/h wall	204/42F	143/41S	340/50J	J3	99	52,17	36,7	2,49
28+262 - 28+272,95	6	roof	143/41S	182/77J	340/50J	FALL	97	48,74	35,77	2,49
28+262 - 28+272,95	7	l/h wall	143/41S	182/77J	340/50J	J1/J2	30	27,43	11,06	1,29
28+262 - 28+272,95	8	r/h wall	143/41S	182/77J	340/50J	J3	34	31,2	12,6	1,46
28+272,95 - 28+339,21	9	l/h wall	166/48F	65/44J	338/45F	J2	651	86,33	241,15	9,94
28+272,95 - 28+339,21	10	r/h wall	166/48F	65/44J	338/45F	J3/J1	214	51,84	79,43	7,07
28+272,95 - 28+339,21	11	roof	166/48F	65/44J	228/61S	FALL	286	79,91	105,84	5,36
28+272,95 - 28+339,21	12	l/h wall	166/48F	65/44J	228/61S	J1/J2	11	10,17	4,02	1,23
28+272,95 - 28+339,21	13	r/h wall	166/48F	65/44J	228/61S	J3	24	23,92	8,73	1,44
28+272,95 - 28+339,21	14	roof	338/45F	65/44J	228/61S	FALL	80	47,84	29,55	2,54
28+272,95 - 28+339,21	15	l/h wall	338/45F	65/44J	228/61S	J2	131	51,64	48,36	3,1
28+272,95 - 28+339,21	16	r/h wall	338/45F	65/44J	228/61S	J1/J3	144	65,92	53,3	3,11
28+339,21 - 28+356,6	17	r/h wall	314/51S	174/47F	117/58F	FALL	133	27,73	49,43	6,01
28+339,21 - 28+356,6	18	r/h wall	314/51S	256/40S	117/58F	J2	83	20,39	30,85	5,11
28+356,6 - 28+399	19	l/h roof	102/9S	161/66J	95/71J	J3	31	16,13	11,33	2,68
28+356,6 - 28+399	20	r/h roof	102/9S	161/66J	95/71J	J2	18	12,06	6,48	2,09

Table 3 - Support of possible wedges along the left bore of the tunnel

Ch. - Ch.	A/A	SF_{before}	min.thickness of shotcrete (cm)	$SF_{shotcrete}$	min. length of bolts (m)	SF_{bolts}	$Sf_{gun=10cm}$	$Sf_{bolts=6m}$
28+262 - 28+272,95	1	0,16	1	1,01	2	1,11	8,67	1,49
28+262 - 28+272,95	2	0,44	1	8,27	1	6,27	65,58	6,27
28+262 - 28+272,95	3	0	1	3,57	1	4,68	36,27	4,06
28+262 - 28+272,95	4	0,28	1	2,89	1	3,31	26,35	5,12
28+262 - 28+272,95	5	0,59	1	2,07	1	3,18	15,41	3,81
28+262 - 28+272,95	6	0	1	1,11	1	1,54	11,12	2,05
28+262 - 28+272,95	7	0,44	1	3,8	1	5,86	34	5,86
28+262 - 28+272,95	8	0,59	1	3,65	1	6,3	31,16	6,29
28+272,95 - 28+339,21	9	0,73	2	1,25	2	1,16	3,15	1,63
28+272,95 - 28+339,21	10	0	1	4,66	1	6,58	41,52	14,72
28+272,95 - 28+339,21	11	0	3	1,18	3	1,18	3,86	1,17
28+272,95 - 28+339,21	12	0,64	1	9,88	1	12,53	92,6	8,58
28+272,95 - 28+339,21	13	0,21	1	3,67	1	5,04	29,81	5,49
28+272,95 - 28+339,21	14	0	1	1,3	1	2,12	11,97	2,74
28+272,95 - 28+339,21	15	0,73	1	1,81	1	2,56	11,59	3,48
28+272,95 - 28+339,21	16	0,26	1	1,24	1	2,35	10,13	3,52
28+339,21 - 28+356,6	17	0	7	1,08	12	0,28	1,54	0,22
28+339,21 - 28+356,6	18	0,46	1	1,25	2	1,21	8,36	1,48
28+356,6 - 28+399	19	0,24	1	2,08	1	3,22	18,66	2,59
28+356,6 - 28+399	20	0,31	1	2,11	1	1,66	18,31	2,5

Table 4 - Geometrical characteristics of possible wedges along the right bore of the tunnel

Ch. - Ch.	A/A	Position	J1	J2	J3	Sliding	Weight (tns)	Face area (m^2)	Volume (m^3)	Height (m)
28+238,50 - 28+242,50	1	l/h wall	223/49J	353/25S	155/64J	J1/J3	22	16,43	8,21	1,59
28+238,50 - 28+242,50	2	r/h wall	223/49J	353/25S	155/64J	J2	30	22,26	11,28	1,73
28+238,50 - 28+242,50	3	l/h wall	223/49J	353/25S	155/33F	J1/J3	30	19,34	11,27	1,9
28+238,50 - 28+242,50	4	r/h wall	223/49J	353/25S	155/33F	J2	60	33,81	22,14	2,22
28+238,50 - 28+242,50	5	l/h wall	223/49J	353/25S	186/70J	J1/J3	20	17,44	7,29	1,32
28+238,50 - 28+242,50	6	r/h wall	223/49J	353/25S	186/70J	J2	20	18,94	7,57	1,31
28+238,50 - 28+242,50	7	l/h wall	155/64J	353/25S	186/70J	J3	82	32,9	30,3	3,28
28+238,50 - 28+242,50	8	l/h roof	155/64J	223/49J	186/70J	J3	172	23,38	66,37	10
28+242,50 - 28+248,5	9	l/h roof	178/75J	246/26S	134/42F	J1/J3	105	33,38	38,92	3,94
28+248,5 - 28+263,76	10	roof	192/64J	139/32F	356/43S	FALL	79	51,83	29,26	2,12
28+248,5 - 28+263,76	11	l/h wall	192/64J	139/32F	356/43S	J1/J3	156	72,87	57,9	2,76
28+248,5 - 28+263,76	12	r/h wall	192/64J	139/32F	356/43S	J3	179	74,63	66,27	2,97
28+263,76 - 28+339,40	13	r/h wall	190/39F	121/50S	359/46J	FALL	22	12,29	8,17	2,31
28+263,76 - 28+339,40	14	r/h wall	190/39F	121/50S	225/8J	J1/J3	204	49,95	75,51	5,99
28+263,76 - 28+339,40	15	r/h roof	179/63F	121/50S	225/8J	J1/J3	11	10,39	4,14	1,85
28+263,76 - 28+339,40	16	l/h wall	179/63F	121/50S	225/8J	J2	103	34,38	38,11	4,44
28+339,40 - 28+373,40	17	l/h wall	153/39S	63/31F	160/72F	J3/J2	992	53,56	367,31	23,19

Table 5 - Support of possible wedges along the right bore of the tunnel

Ch. - Ch.	A/A	SF_{before}	min.thickness of shotcrete (cm)	$SF_{shotcrete}$	min. length of bolts (m)	SF_{bolts}	$Sf_{gun=10cm}$	$Sf_{bolts=6m}$
28+238,50 - 28+242,50	1	0,66	1	6,62	1	5,1	60,95	5,84
28+238,50 - 28+242,50	2	0,82	1	6,67	1	6,54	59,26	7,98
28+238,50 - 28+242,50	3	0,17	1	7,09	1	4,79	69,41	7,17
28+238,50 - 28+242,50	4	0,82	1	4,35	1	5,11	36,08	6,58
28+238,50 - 28+242,50	5	0,61	1	6,67	1	7,17	61,25	7,17
28+238,50 - 28+242,50	6	0,82	1	9,17	1	9,43	84,34	9,38
28+238,50 - 28+242,50	7	0,25	1	1,35	1	1,59	11,23	2,05
28+238,50 - 28+242,50	8	0,25	3	1,25	6	0,89	3,57	0,89
28+242,50 - 28+248,5	9	0,19	1	1,12	1	1,22	8,65	1,89
28+248,5 - 28+263,76	10	0	1	1,48	1	2,08	13,84	3,04
28+248,5 - 28+263,76	11	0,34	1	1,49	1	2,31	11,06	2,86
28+248,5 - 28+263,76	12	0,41	1	1,38	1	1,87	10,11	2,96
28+263,76 - 28+339,40	13	0	2	1,22	3	0,48	6,08	0,48
28+263,76 - 28+339,40	14	0	3	1,46	4	0,76	4,85	0,76
28+263,76 - 28+339,40	15	0	1	3,38	1	1,8	33,83	1,8
28+263,76 - 28+339,40	16	0,32	2	1,61	1	1,25	6,77	1,71
28+339,40 - 28+373,40	17	0	8	1,11	12	0,38	1,41	0,36

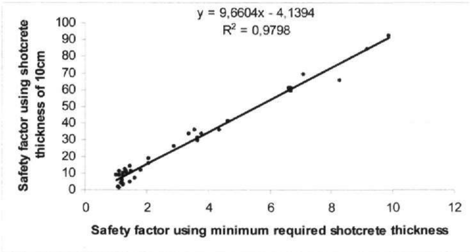

Figure 3 - Correlation between safety factor using the minimum required shotcrete thickness and shotcrete thickness of 10 cm

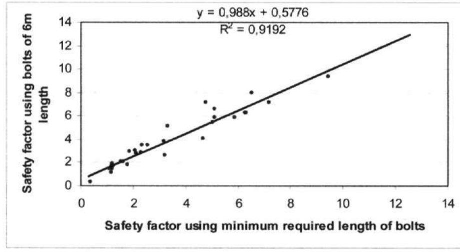

Figure 4 - Correlation between safety factor using the minimum required length of bolts and bolts of 6 m length

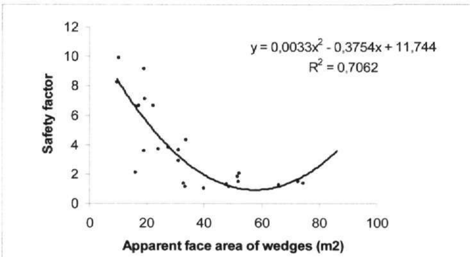

Figure 5 - Correlation between apparent face area of wedges and safety factor of supported wedges with shotcrete of minimum required thickness

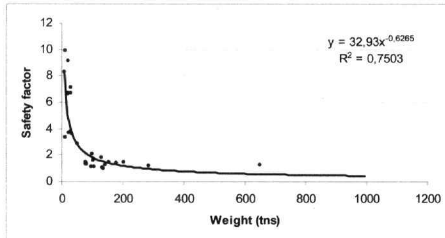

Figure 6 - Correlation between wedges weight and their safety factor after the use of minimum required thickness of shotcrete

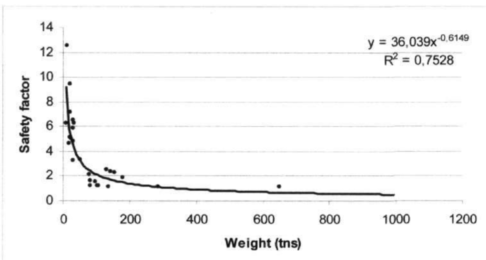

Figure 7 - Correlation between wedges weight and their safety factors after the use of minimum required length of bolts

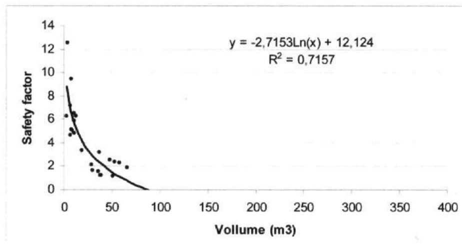

Figure 8 - Correlation between wedge volumes and the safety factors after the use of the minimum required length of bolts

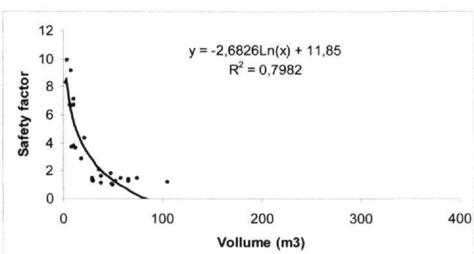

Figure 9 - Correlation between wedge volumes and the safety factors after the use of the minimum required thickness of shotcrete

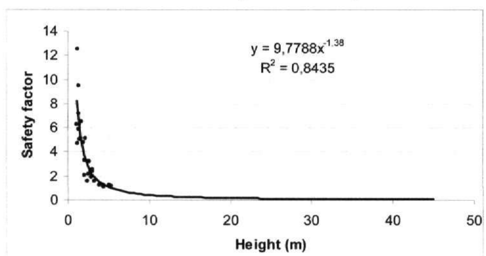

Figure 10 - Correlation between wedge height and the safety factors after the use of the minimum required support with bolts

supported by rockbolts, although they are effectively supported by shotcrete. Consequently, shotcrete can support with efficacy the unstable wedges better than rock bolts.

As it is observed, there is a linear relation between the safety factor of the wedges, supported by shotcrete of 10cm thick and the safety factor of the wedges, supported by shotcrete with the minimum required thickness. According to the above relation, the safety provided by the installation of the proposed by RMR system shotcrete thick, is about ten times the safety provided by the shotcrete with the minimum required thickness installation ($SF_{shot.=10cm} = 9.6604*SF_{shotcrete} - 4.1394$, $R^2 = 0,97$, Fig. 3). Furthermore, as it is observed, according to the linear relation between the safety factor of the wedges being supported by bolts of 6m long and the safety factor of the wedges being supported by bolts, with the minimum required length, the increase of bolts length more than 3m, doesn't increase the safety ($SF_{bolts=6m} = 0.988*SF_{bolts} - 0.5776$, $R^2 = 0,91$, Fig.4).

The geometrical characteristics of the wedges and the safety factors using the minimum required support measures were correlated statistically and power regressions with significant correlation factors (R) were determined (Figs 5-10):

Apparent face area of wedges (F) and their safety factor (SF), when the wedges are supported by shotcrete with the minimum thickness required ($SF=0.0033*F^2 - 0.3754 + 11.3744$, $R^2 = 0,71$).

Wedge weights (W) and their safety factors (SF) after the use of minimum required thickness of shotcrete ($SF = 32.93\ W^{-0,6265}$, $R^2 = 0,75$).

Wedge weights (W) and their safety factors (SF) after the use of minimum required length of bolts ($SF = 36.039*\ W^{-0,6149}$, $R^2 = 0,75$).

Wedge volumes (V) and the safety factors (SF) after the use of the minimum required length of bolts ($SF = -2.7153\ \ln SF + 12.124$, $R^2 = 0,72$).

Wedge volumes (V) and the safety factors (SF) after the use of the minimum required support by shotcrete ($SF = -2.6826\ \ln SF + 11.85$, $R^2 = 0,8$).

Wedge height (H) and the safety factors (SF) after the use of the minimum required support by bolts ($SF = 9.7788 * SF^{-1.38}$, $R^2 = 0,84$).

6. Conclusions

The aim of this paper was the investigation of the workability of shotcrete and rock bolts on tunnels support being excavated in medium and poor quality rock mass. The data for our estimations were collected during the excavation of Vrasna Tunnel.

The final conclusions were based on the estimation of the support of thirty-seven unstable wedges, heavier than 5 tns, which were identified along the excavation. The majority of these wedges is supported by shotcrete up to 3 cm thick, increasing the safety factor up to 9,88..Rockbolts, up to 3m long, can also support the most wedges, increasing the safety factor up to 9,43. On the other hand, rock bolts with length of 1m, can also support the most of these wedges. Comparing the efficacy of rock bolts and shotcrete, there are some wedges that although they are not supported by rock bolts, they are effectively supported by shotcrete. So, the application of shotcrete is more effective than rock bolts, on unstable wedges' safety. The proposed by RMR system thickness of shotcrete is excessive for the safety, as the safety factor is increased ten times. Furthermore, the proposed by RMR system length of rock bolts is also excessive as, it is proved, the increase of the length of rock bolts up to 3m does not increase the safety factor.

The elaboration of our results gave power regressions with significant correlations between the geometric-characteristics of the potential wedges and the safety factors, obtained with the shotcrete and rock bolts. According to the above-mentioned relationships, a slight increase of the apparent face area of wedges less than 58 m^2 causes a significant decrease of their safety factor (SF) when the wedges are supported by the minimum required shotcrete thickness. On the other hand, the safety factors are slightly decreasing when the apparent face area, of the wedges, is more than 58 m^2. Furthermore, a slight increase of the wedge weight causes a significant decrease of their safety factors (SF) after the use of minimum required support with shotcrete of wedges weight lower than 15 tns. On the other hand, the safety factors don't decrease significantly by increasing the weight, when wedges are heavier than 15 tns. Furthermore, a slight increase of the wedge weight (lower than 15 tns), causes a significant decrease of their safety factors (SF) when the wedges are supported by the minimum required length of bolts. Nevertheless, when wedges are heavier than 15 tns, the safety factors don't decrease significantly by the weight's increase. A slight increase of the wedges volume, which is lower than 85 m^3, causes a significant decrease of the safety factors (SF) after the use of the minimum required length of bolts. Also, a slight increase of the wedges volume which is lower than 80 m^3 causes a significant decrease of the safety factors (SF) after the use of the minimum required thickness of shotcrete. A slight increase of the wedges height, which is less than 10m, causes a significant decrease of the safety factors (SF) after the use of the minimum required length of bolts.

The above estimations show that even if a small strength of support measures, shotcrete or rock bolts, is enough to balance the sliding strength of the wedges in medium and poor rock mass quality having a small percentage of cracking.

7. References

Bieniawski, Z.T., 1989. *Engineering rock mass classifications*, New York: Wiley.

Chatziangelou, M., and Christaras, B., 2003. Shotcrete application effectiveness as support measure at poor quality rock masses, *Proc. International Symposium of Industrial Minerals and Building Stones*, Konstantinoupolis, Turkey, 745-749pp.

Christaras, B., Chatziangelou, M., Malliaroudakis, Em., and Merkos, S., 2002. Support Capacity of wedges and RMR classification along the Asprovalta tunnel of Egnatia Highway, in n. Greece, 9th Congress of the International Association for Engineering Geology and the Environment, *J.L. van Rooy and C.A. Jermy*, ISBN No.0-620-28559-1.

Hoek, E., 2000. Practical Rock Engineering, Rotterdam, *Balkema.*

Hoek, E., Kaiser, P.K., and Bawden, W.E., 1995. Support of underground excavations in hard rocks, *Balkema Pbl.*, Roterdam, 215p.