STABILITY STUDY ALONG VRASNA TUNNEL EXCAVATION

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Abstract

In the present paper a stability investigation was performed during the excavation of Vrasna tunnel, taking into account the mechanical properties of geological formation. For this purpose, the strength of marbles was estimated to 2,67Mpa, using point load test. The strength of the moderately weathered gneiss was estimated to 4,34Mpa and the strength of the very weathered gneiss was estimated to 0,62MPa. The strength, of pegmatite veins, was estimated to 4,45Mpa, also using point load test. According to shear test along schistosity and joint planes, friction angle was considered to 21^o on schistosity planes and 35^o on joint planes. Furthermore, no cohesion was taken into account, as the planes of discontinuities were opened. RMR classification system was used in order to estimate the quality of the rockmass under excavation. The support system was estimated according to the RMR classification system (Bieniawski, 1989) and the obtained results were used for estimating the support capacity of the potential wedges. The orientation and spacing of discontinuities were also taken into account for estimating the stability of the tunnel, given that they affect the rock mass strength and quality influencing its response to construction. The collected data and the obtained, after elaboration, results were correlated statistically and power regressions were determined.

1. Introduction

The tunnel in study is located at north Greece, in Vrasna area, 80km to the east of Thessaloniki City. It belongs to the under construction Redina – Asprovalta 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 is located at the northern part of the tunnel.

The support system along the tunnel was estimated according to the RMR classification system (Bieniawski, 1989). This system was used for estimating the support capacity of the potential wedges taking into account their dimensions, the changes of the rock mass quality and the spacing of the joints.

2. Geological settings

The area is geologically located in Serbomacedonian mass, which consists of metamorphic rocks. The tunnel crosses weathered, brown colored gneiss with schistosity surfaces and karstificated marble (Fig.2). Rockmass is cracked and faulted. Faults with important slip surfaces are also present. The quality of gneiss is generally characterized as poor (IV), which changes to very poor (V), near tectonic contacts. Nevertheless, marble quality is characterized as good (III) and near tectonic surfaces as poor (III) (Table 1). Gneiss is closely jointed and weathered. Marble is widely jointed and less weathered than gneiss. Karst phenomena, like small cavern, were observed in marbles, during the excavation. Pegmatite veins are also observed, crossing the geological formations.

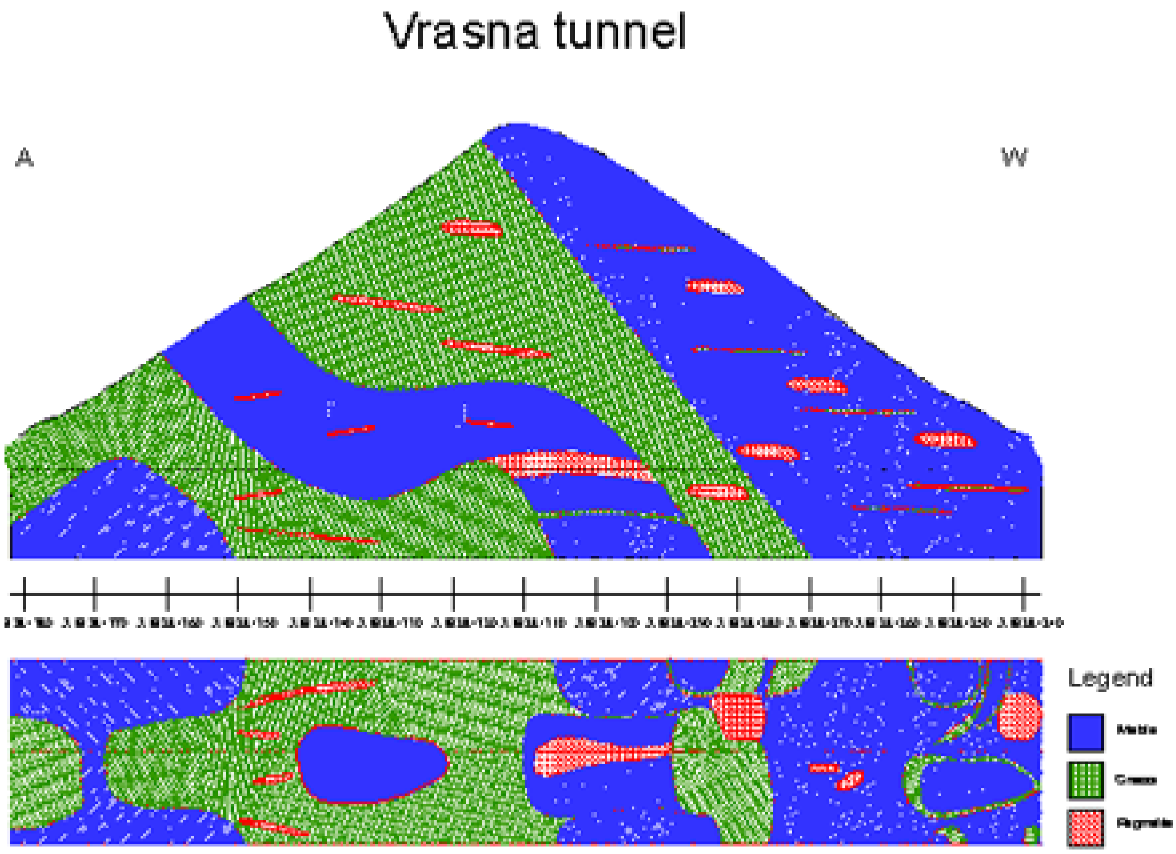

Fig. 2. Geological section along Vrasna tunnel

3. Support measures

The excavation was performed in two stages. Referring to the RMR classification, steel ribs, grouted rockbolts and shotcrete were mainly used for the permanent support of the tunnel. Steel ribs were placed where the rock mass was very poor (category V).

Rockbolts were also placed, where the rock mass was very poor, around the excavation, in order to strengthen the rock mass. However, rockbolts were also used for supporting better the steel ribs and creating more safe conditions. Rockbolts, which were placed in rock mass of good quality, avert the fall of heavy blocks. Thin flexible shotcrete lining is installed to take only a part of the load (Chatziangelou & Christaras, 2003).

The failure of a rock mass around an underground opening depends upon the in situ stress level and the characteristics of the rock mass. In highly stressed rock masses the failure, around the opening, progresses for 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. As the tunnel, under study, is not deep 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 created potential wedges was detected along the tunnel, using support measures obtained with the RMR classification method and the related safety factors were determined, using the UNWEDGE software (Hoek, 2000). For our calculations, marble strength was estimated by point load test as 2,67Mpa, moderately weathered gneiss strength was also estimated 4,34Mpa and very weathered gneiss strength was estimated 0,62MPa. Pegmatite veins strength was estimated using point load test 4,45Mpa. Friction angle was considered 21^{o} on schistosity planes and 35^{o} on joint planes. Furthermore, the no cohesion was taken into account, as the discontinuities were opened.

Thirty-two unstable wedges, heavier than 15tns, were estimated. The quality of the rock mass, the characteristics of the wedges, the support measures, which were used, and the related safety factors, are given in Table 2 and Table 3. Rockbolt spacing varied from 2x1.5, to 1.5x1 depending on the joint spacing, joint orientation and overall ground conditions, according to Bieniawski, 1989. The effectiveness of support measures, shotcrete with thickness between 1cm and 20cm and rockbolts with length 2m to 20m, was tested.

Shotcrete, less than 6cm thick, can support the majority of the wedges (twenty-nine wedges), increasing the safety factor up to 6,11. The rest three wedges are supported by shotcrete 8-15cm thick. So, the maxinum thickness of shotcrete, which can support successively the wedges, without using other support measures, is 15cm, although in the most cases, shotcrete 1cm thick is enough for the support. Rockbolts, up to 6m long, can also support a numerous of the wedges (twenty-two wedges), increasing the safety factor up to 7,11. Rock bolts up to 3m long, can support the most of these wedges. Nine wedges cannot be effectively supported by rockbolts. The use of RMR support system increases the safety factors of the wedges up to 23,45. After the permanent support having been used at the high wedges, the safety factors do not increase considerably, as in cases where the wedges are not so high. Generally, the proposed RMR measures increase the safety factor 60%. The calculated safety factor after the RMR support is 10 to 26 in nine cases. There is a wedge (Table 2, a/a.21) that cannot be supported, using the proposed RMR measures, the wedge needs 15cm thick shotcrete in order to be supported as according to RMR support in this case where the rockmass quality is good, the maximun shotcrete thickness is 3cm. On the other hand, there is a case of a wedge (Table 2, a/a.17) that the safety factor using RMR measures

create an excessive support (SF=99,5). In this case, 1cm thick shotcrete is enough to support the wedge and the application of rock bolts increase, highly, the safety factor.

There are also three wedges at the left bore (Table 2, a/a.19-21) which are only supported by shotcrete and the safety factor is calculated from 1,05 to 1,25. When the rock bolts are used, that wedges become unstable (S.F.0, 46 – 1,11).

The collected data and the after elaboration obtained results were correlated statistically and power regressions with significant correlation factors (R) were determined between the following parameters (Fig.3-10):

Wedge weights (W) and the safety factors (SF) after the minimum required support with shotcrete ($SF = 11{,}937\ W^{-0,3867}$, $R^2 = 0{,}8$).

Wedge weights (W) and the safety factors after the minimum required support with bolts ($SF = 23{,}5\ W^{-0,5584}$, $R^2 = 0{,}9$).

Wedge weights and the safety factors (SF) after the application of RMR support system ($SF = 114{,}46\ W^{-0,5793}$, $R^2 = 0{,}8$).

Wedge volumes (V) and the minimum required shotcrete thickness (T) in order the wedges to be supported ($T = 5*10^{-5}\ V^2 + 0{,}0028W + 1{,}0731$, $R^2 = 0{,}8$).

Wedge volumes (V) and the minimum required bolts length (L) in order the wedges to be supported ($L = 0{,}0615\ V + 1{,}1591$, $R^2 = 0{,}8$)

Wedge volumes (V) and the safety factor (SF) after the minimum required support with shotcrete ($SF = 13{,}394\ V^{-0,5533}$, $R^2 = 0{,}9$).

Wedge volumes (V) and the safety factor (SF) after the suitable application of RMR support ($SF = 64{,}956\ V^{-0,5781}$, $R^2 = 0{,}8$).

Safety factor after the minimum required bolt lengths (SF_b) and the application of RMR support (SF_{RMR}) ($SF_{RMR} = 3{,}9151\ SF_b^{\ 1,112}$, $R^2 = 0{,}8$).

According to the above-mentioned relationships, a slight decrease of the wedge weight causes a significant increase of the safety factors of the wedges being weighted lower than 100tns. On the contrary, if the wedges are heavier than 500 tns the safety factors do not increase significantly by the decrease of weight.

Furthermore, a slight decrease of the wedge volume causes a significant increase of the safety factors of the wedges when they are supported by bolts or RMR support system for volume lower than 50 m^3. On the contrary, when wedges are heavier than 200 m^3, the safety factors don’t increase significantly decreasing the weight.

4. Conclusions

The tunnel crosses weathered, brown colored gneiss with schistosity surfaces, karstified marble and pegmatite veins. The quality of gneiss is poor and near tectonic contacts is very poor, although marble quality is good and near tectonic contacts is poor.

Thirty-two unstable wedges, heavier than 15tns, were identified along the excavation. The effectiveness of shotcrete, rockbolts and RMR proposed measures were estimated so that the wedges become supported. The majority of the wedges are supported by shotcrete less than 6cm thick, increasing the safety factor up to 6,11. Many wedges can also be supported by rockbolts up to 6m long increasing the safety factor up to 7,11, although there are some other wedges that cannot be supported by rock bolts. In some cases, the presence of rockbolts minimizes the safety factor when they are placed in combination to shotcrete. The application of the RMR system supports the created wedges along the tunnel safely. The differences between the calculated safety factors, after the use of the RMR system and the minimum support measures needed, varies considerably depending on the geometry of the wedges, the joint spacing and the ground quality. The use of RMR proposed measures sometimes creates excessive support as it increases the safety factor of the wedges on 60%. On the other hand, there is a case of wedge that cannot be supported by RMR proposed measures. The elaboration of our results gave power regressions with significant correlation between the geometrical characteristics of the potential wedges and the safety factors, obtained with the shotcrete, bolts and the RMR system. According to the above-mentioned relationships, a slight decrease of the wedge weight causes a significant increase of the safety factors of the wedges being weighted lower than 100tns. On the contrary, if the wedges are heavier than 500 tns, the safety factors do not increase significantly by the decrease of the weight. Furthermore, a slight decrease of the wedge volumes cause a significant increase of the safety factors of the wedges when they are supported with bolts or RMR support for wedge volumes lower than 50 m^3. On the contrary, when wedges are bigger than 200 m^3, the safety factors don't increase significantly by decreasing the weight.

References

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Table 1. Classification along the excavation of the tunnel

Right bore									
Ch. - Ch.	**RMR**	**Class**	**RQD**	**Spacing of discontinuities (m)**	**Discontinuity length (m)**	**Separation (aperture) (mm)**	**Roughness**	**Infilling (gouge)**	**Weathering**
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 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 and support of possible wedges along the left bore of the tunnel

Left bore																
Ch. - Ch.	**A/A**	**Position**	**J1**	**J2**	**J3**	**Sliding**	**Weight (tns)**	**Face area (m^2)**	**Volume (m^3)**	**Height (m)**	**SF_{before}**	**min.thickness of shotcrete (cm)**	**$SF_{shotcrete}$**	**min. length of bolts (m)**	**SF_{bolts}**	**SF_{rmr}**
28+262-28+272,95	1	roof	204/42	143/41	182/77	fall	168	45,43	62,39	4,71	0	8	1,15	10	0,85	3,64
28+262-28+272,95	1	roof	204/42	143/41	182/77	fall	168	45,43	62,39	4,71	0	8	1,15	12	0,91	3,64
28+262-28+272,95	2	roof	204/42	143/41	340/50	fall	31	25,25	11,34	1,53	0	1	2,99	2	2,8	16,34
28+262-28+272,95	3	l/h wall	204/42	143/41	340/50	J1/J2	15	14,8	5,73	1,37	0,29	1	6,11	3	5,16	23,45
28+262-28+272,95	4	r/h wall	204/42	143/41	340/50	J2	37	26,7	18,66	1,73	0,59	1	3,65	3	3,89	13,07
28+262-28+272,95	5	roof	143/41	182/77	340/50	fall	128	58,32	47,31	2,74	0	2	1,9	3	1,34	6,07
28+263,76-28+339,40	6	r/h wall, roof	179/63	190/39	359/46	J1/J2	515	21,92	190,94	30	0	3	1,14	6	0,88	4,51
28+263,76-28+339,40	7	r/h wall	179/63	190/39	225/8	J1/J2	277	15,53	104,12	30	0	2	1,03	6	1,03	5,66
28+263,76-28+339,40	8	l/h wall, roof	179/63	121/50	359/46	J2	55	14,6	20,5	4,74	0,32	1	1,15	3	1,95	10
28+263,76-28+339,40	9	l/h wall	179/63	121/50	225/8	J2	59	23,75	21,9	3,82	0,32	1	1,39	3	2,37	12,08
28+263,76-28+339,40	10	r/h wall, roof	121/50	190/39	225/8	J2	144	42	53,15	5,43	0	1	1,06	3	1,45	7,43
28+272,95-28+339,21	11	l/h wall, roof	166/48	228/61	338/45	J2	84	23,62	30,97	4,48	0,21	2	1,23	3	1,28	11
28+272,95-28+339,21	12	roof	166/48	228/61	65/44	fall	351	89,4	129,88	5,85	0	3	1,01	8	0,82	4,17
28+272,95-28+339,21	12	roof	166/48	228/61	65/44	fall	351	89,4	129,88	5,85	0	3	1,01	10	0,82	4,17
28+272,95-28+339,21	13	roof	228/61	338/45	65/44	fall	111	56,68	40,99	2,86	0	2	1,91	3	1,65	11,12
28+272,95-28+339,21	14	l/h wall	228/61	338/45	65/44	J3	48	29,23	17,75	2,13	0,73	1	2,84	3	4,88	24,93
28+272,95-28+339,21	15	r/h wall	228/61	338/45	65/44	J2/J1	59	38,57	21,72	2,38	0,26	1	2,17	3	7,11	25,9
28+272,95-28+339,21	16	l/h wall, roof	166/48	338/45	65/44	J3	344	58,48	127,45	7,97	0,73	1	1,07	10	5,87	2,23
28+272,95-28+339,21	17	l/h wall	166/48	338/45	65/44	J2/J1	97	32,47	35,9	5,45	0	1	7,39	3	97	99,56
28+339,21-28+356	18	r/h wall, roof	314/51	256/40	117/58	J2	44	13,15	16,34	4,17	0,46	1	1,67	3	2,67	5,55
28+339,21-28+356	19	r/h wall, roof	314/51	256/40	174/47	J2	566	48,1	209,59	15,45	0,46	5	1,15	15	0,71	1,11
28+339,21-28+356	20	r/h wall, roof	314/51	117/58	174/47	fall	69	17,75	25,73	4,84	0	5	1,25	20	0,34	1,04
28+339,21-28+356	21	r/h wall, roof	256/40	117/58	174/47	fall	637	52,28	235,82	15,49	0	15	1,05	20	0,18	0,46
28+356,6-28+399	22	r/h wall, roof	126/34	161/66	102/9	J1/J2	632	48,51	234,15	18,29	0,8	1	1,08	3	1,37	4,19

Table 3. Geometrical characteristics and support of possible wedges along the right bore of the tunnel

Right bore																
Ch. - Ch.	A/A	Position	J1	J2	J3	Sliding	Weight (tns)	Face area (m^2)	Volume (m^3)	Height (m)	SF_{before}	min.thickness of shotcrete (cm)	$SF_{shotcrete}$	min. length of bolts (m)	SF_{bolts}	SF_{rmr}
28+238,5-28+242,5	1	l/h wall, roof	186/70	155/64	223/49	J1	1687	101,58	624,95	21,14	0,25	11	1,02	20	0,42	1,06
28+238,5-28+242,6	2	l/h wall	155/64	155/33	223/49	J1/J2	215	33,68	79,76	8,09	0,66	1	1,19	3	1,34	3,96
28+238,5-28+242,7	3	l/h roof	186/70	155/33	223/49	J1	191	47,5	70,88	5,13	0,25	2	1,41	4	1,17	3,82
28+339,40-28+373,40	4	l/h wall, roof	153/39	63/31	160/72	J3/J2	596	39,44	280,92	19,58	0	6	1,15	20	0,65	3,5
28+242,5-28+248,5	5	l/h roof	178/75	246/26	134/42	J1	118	35,9	41,97	4,03	0,19	2	1,81	3	1,43	10,4
28+248,5-28+263,76	6	roof	192/64	139/32	356/43	fall	112	62,43	41,58	2,46	0	1	1,06	3	1,74	7,1
28+248,5-28+263,76	7	l/h wall	192/64	139/32	356/43	J1	60	41,49	22,26	2,06	0,34	1	2,43	3	2,92	9,34
28+248,5-28+263,76	8	r/h wall	192/64	139/32	356/43	J3	64	40,18	23,58	2,01	0,41	1	2,41	3	3,32	9,23

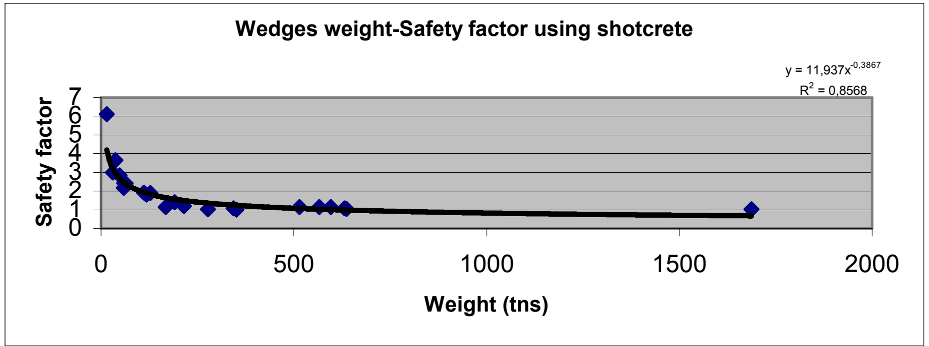

Fig. 3. Correlation between wedges weight and safety factor using shotcrete

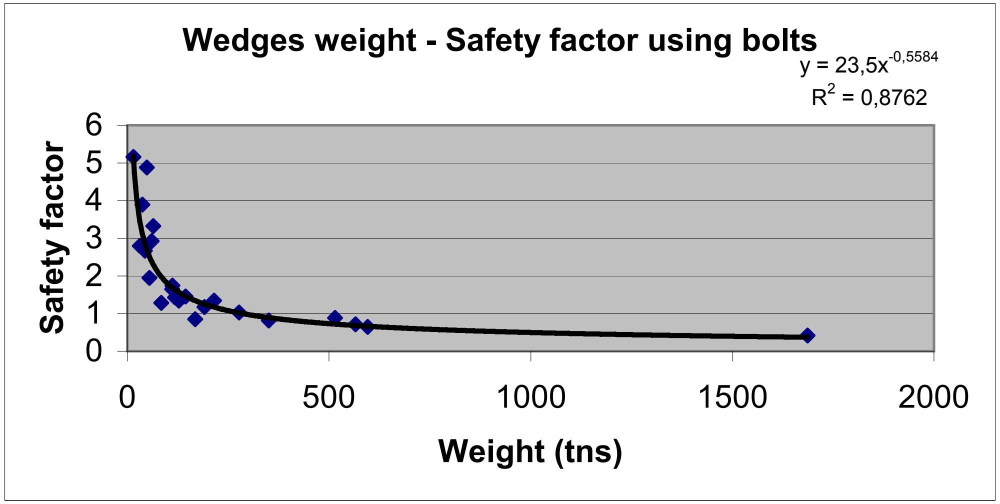

Fig. 4. Correlation between wedges weight and safety factor using bolting method

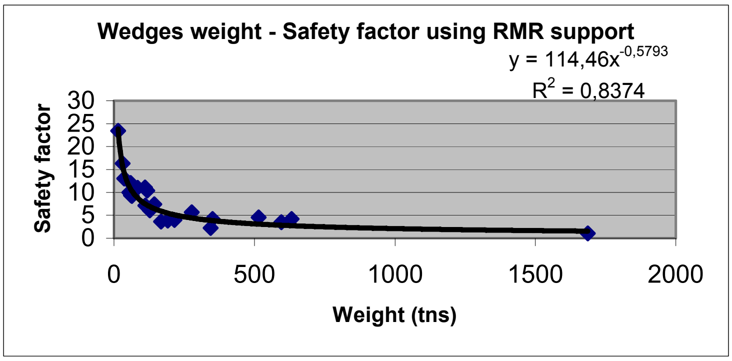

Fig. 5. Correlation between wedge weight and safety factor using the RMR support

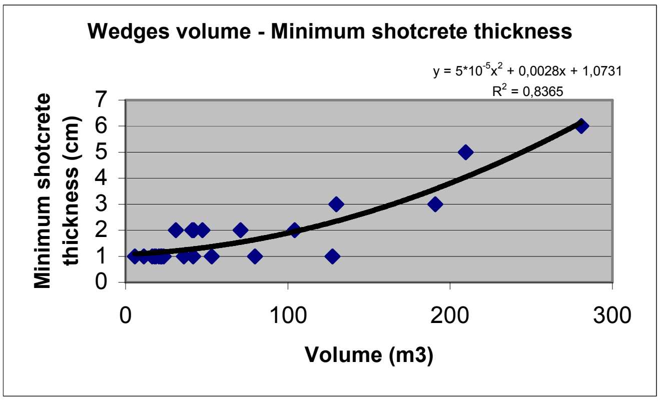

Fig. 6. Correlation between wedge volume and minimum shotcrete thickness

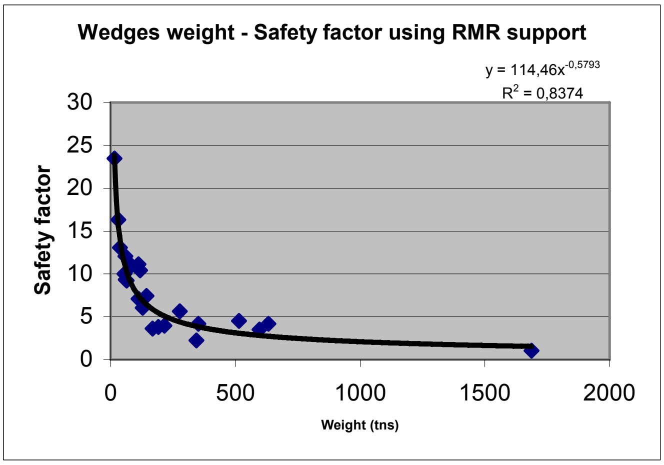

Fig. 7. Correlation between wedges volume and minimum bolt length

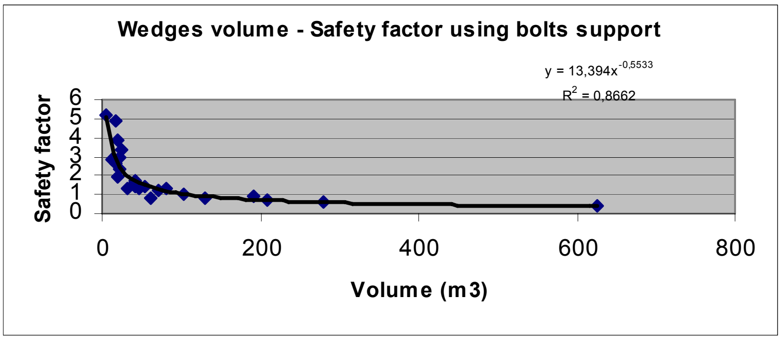

Fig. 8. Correlation between wedges volume and safety factor using bolt supporting system

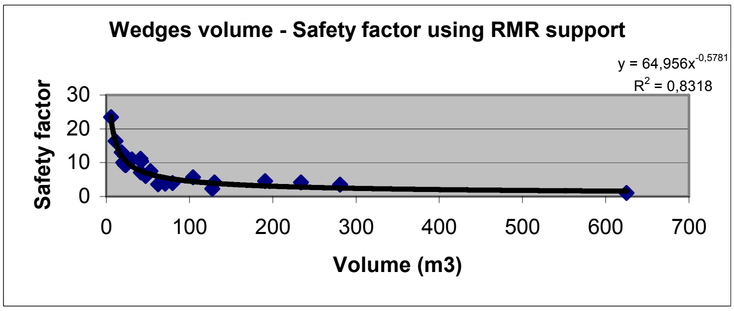

Fig. 9. Correlation between wedges volume and safety factor using the RMR support system

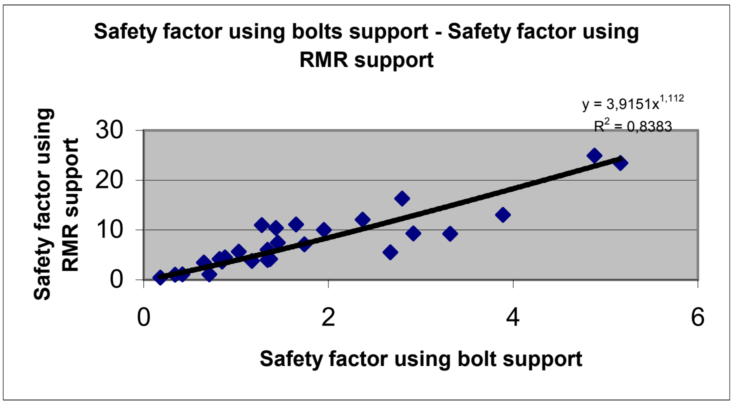

Fig. 10. Correlation between safety factor using bolts support and safety factor using the RMR support system