SUPPORT CAPACITY OF WEDGES AND RMR CLASSIFICATION ALONG THE ASPROVALTA TUNNEL OF EGNATIA HIGHWAY, IN N. GREECE

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ABSTRACT: In the present paper the support measures obtained with the RMR system, were used for estimating the support capacity of the created wedges, in relatively shallow tunnels. The orientation and spacing of the discontinuities were taken into account given that they affect the rock mass strength and quality influencing its response to construction. Where intersecting and daylighting joint surfaces are encountered at a cut face, closely spaced joint surfaces tend to cause numerous rock falls while widely spaced joints may tend massif catastrophic block failures. The estimated safety factors of the wedges, after their support, were compared with their geometric characteristics and significant relationships were determined. These relationships were used in order to explain the stability changes of the wedges, before and after their support. Furthermore the differences observed between the estimated RMR support measures and the minimum needed, for supporting the wedges, were also discussed.

RĖSUMĖ: Dans cet article le système de support obtenu suivant la methode RMR a été utilisé pour éstimer la capacité de support des blocs rocheux instables, le long de tunnels relativement peu profonds. L' orientation et l' espacement des discontinuités affectent la resistance de la roche masse et permetent le mouvement de volumes de toutes tailles. A la limite, lorsque la fracturation est extremement dense, le massif rocheux peut se comporter comme un millieu granulaire. La variation des coefficients de scurité estimés, après le support des blocs, a été comparé avec les caracteristics geometriques des blocs et de correlations dynamiques très significatives ont été determinées. Cettes correlations ont été utilisé pour expliquer le niveau de stabilité de blocs après de leur support. Les differences observées entre les systèmes de support RMR estimés et les minimum systèmes necessaires pour supporter les blocs, ont été discutés de plus.

INTRODUCTION

The tunnel is located at the north coast of Greece, in Asprovalta area, 80 Km to the east of Thessaloniki City. It is part of the, under construction, Egnatia highway that links the western borders of Greece with the eastern one, in N. Greece (Fig. 1).

The tunnel consists of two parallel branches; the right branch is 216m long while the left one is 222m long.

The support system along the tunnel was estimated according to the RMR classification (Bieniawski, 1989). These systems were 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.

Figure 1. Location of the area under study

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GEOLOGICAL SETTINGS

The area is geologically located in Serbomacedonian mass, which consists of metamorphic rocks (Dixon & Dimitriadis, 1984). The tunnel crosses gneiss (with pygmatitic veins) and marbles (Fig. 1). The gneiss is folded and jointed. The rockmass is relatively widely jointed at the entrance of the tunnel, becoming closely jointed in the inner parts of the excavation. Along the left branch, white marble is tectonically contacted with gneiss. Marble is medium bedded and jointed. Faults with important slip surfaces are also present (Papadopoulos & Kilias, 1985).

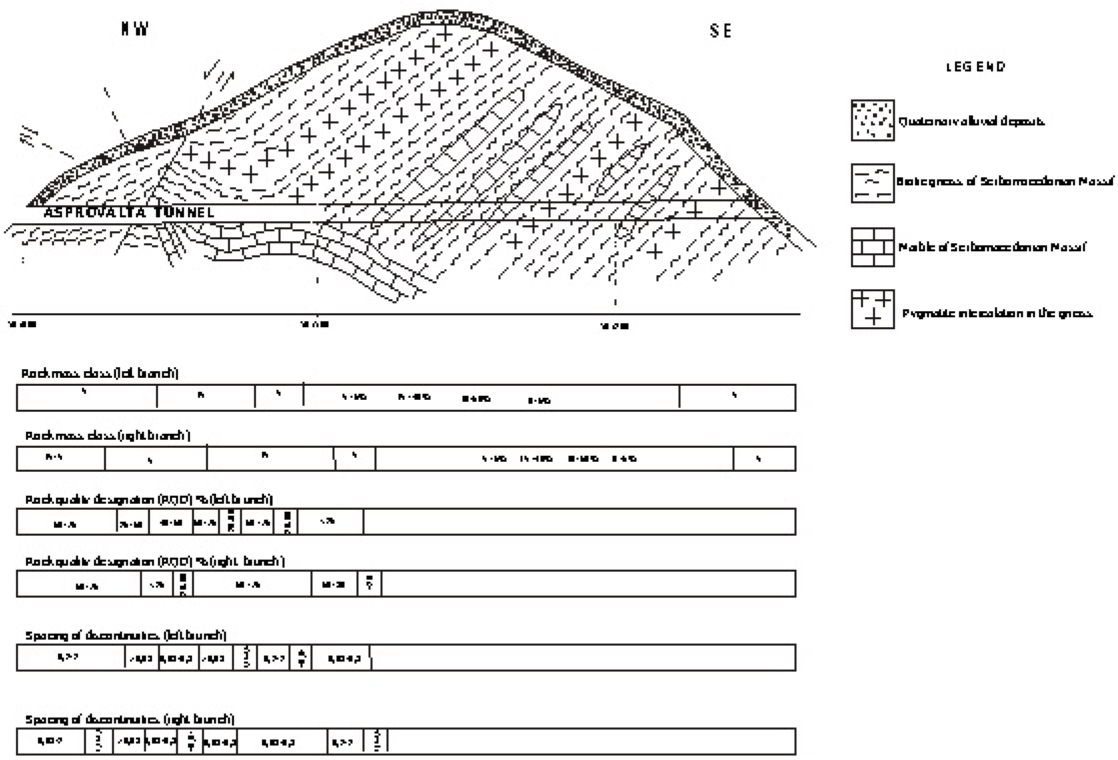

Figure 2. Geotechnical section along the tunnel under study

SUPPORT MEASURES

The excavation was performed in two stages. Bolts and thin flexible shotcrete lining are rapidly installed to take only a part of the load; deformation, of 10-100mm, is permitted as rock takes up the remaining stress, before the secondary lining is installed (Waltham, 1999). The quality of the rock mass was characterized as poor to very poor (categories IV and V), using RMR classification (Bieniawski, 1989). Referring to the RMR classification steel ribs, grouted rockbolts and shotcrete were mainly used for the permanent support of the tunnel. Rockbolts were placed at the upper part of the face of the excavation in order to avert the fall of heavy blocks as well as around the excavation in order to strengthen the rock mass. However, rock bolts were also used for supporting better the steel ribs and create more safe conditions. Steel ribs were placed where the rock mass was very poor (category V).

The failure of a rock mass around an underground opening depends upon the in situ stress level and upon 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 & Brown, 1980). Failure, involving slip along intersecting discontinuities in a heavily jointed rock mass, is assumed to occur with zero plastic volume change (Duncan Fama, 1993). As the tunnel, under study, is not deep the geometry of the discontinuities is considered to be the main instability cause, 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 et al., 1995).

Eleven unstable wedges, which could not be supported only with shotcrete, were determined along the right bore of the tunnel. The quality of the rock mass, the characteristics of the wedges, the support measures used, and the related safety factors, are given in Table 1. The weight of the wedges usually varies from 100 to 900 tons. Only few wedges were out of this range. Shotcrete 10cm thick, with shear strength of 200t/m^2, was used together with rockbolts for supporting the wedges. Rockbolt spacing varied from 1x1, to 4x4 depending on the joint spacing, joint orientation and overall ground conditions, according to Bieniawski, 1989. The length of the used rockbolts was 6m, in very poor rock mass and 4m, in poor rock mass. The safety factor of the wedges, before their support, was 0,0-0,6. In the very poor parts of surrounding the tunnel rock mass (category V) the closely spaced joints create unstable small wedges. The safety factor of these wedges increased to 6-9, after their support. However, the safety factor increased only to 1 in the cases where the wedges have a relatively important height. In cases where the rock mass is cut into very small pieces (closely spaced joints of length shorter than 10 cm), shotcrete could be the main appropriate support system, considering that bolting could not increase significantly the safety factors.

According to the data of Table 1, the use of RMR support system increases the safety factors of the wedges to a wide range of values (1.15-9.66). Where the wedges are high the safety factors do not increase so considerably, after the support application, as it happens in cases where the height of the wedges is not so important.

Table 1. Data of important wedges created alont the twin bore tunnel under study

ROCK TYPE	RMR	J1	J2	J3	SL.DIR.	F(m^2)	W(tons)	Bolt: L(m) / spacing(m)	SF_{bs}	SF_{as}	SF_{as}/SF_{bs}	W/F (Tn/m^2)
LEFT BORE (shotcrete 10 cm thick with shear strength of 2 Mpa)												
Gneiss	20/V	161/65F	124/57J	198/55J	J3/J1	21,80	69,00	6/1,5x1	0,38	6,69	17,61	3,17
Gneiss	18/V	296/19S	142/57F	124/52J	J2	149,50	557,00	6/3x3	0,33	6,02	18,24	3,73
Granite	20/V	330/12S	100/50J	147/57 F	J2/J3	156,50	476,00	6/3x3	0,36	6,73	18,69	3,04
Gneiss	21/V	60/45J	107/55J	331/52F	J1	52,90	466,00	6/2x2	0,29	1,29	4,45	8,81
Gneiss	20/V	238/58J	149/60J	306/45F	J1	71,20	290,00	6/2x2	0,18	2,64	14,67	4,07
Gneiss	20/V	183/52F	17/2S	163/15S	J1/J3	194,30	5992,00	6/3x3	0,94	1,99	2,12	30,84
Gneiss	14/V	25/31S	344/44F	141/62 J	J1/J2	111,30	965,00	6/3x3	0,13	1,01	7,77	8,67
Gneiss	14/V	25/31S	50/80J	344/44F	J3	45,50	422,00	6/2x2	0,29	3,17	10,93	9,27
Gneiss	21/V	143/54J	153/85J	67/30J	J3	135,50	2227,00	6/3x3	0,50	1,35	2,70	16,44
Gneiss	21/V	67/30J	153/85J	356/25S	J2/J1	34,10	75,00	6/2x2	0,66	9,53	14,44	2,20
Gneiss-marble	18/V	182/12S	173/65F	322/77J	J2/J3	62,10	261,00	6/2x2	0,44	3,41	7,75	4,20
marble	38/IV	340/47J	66/27F	146/71F	J2	231,30	1786,00	4/3x3	0,99	0,99	1,00	7,72
marble	31/IV	88/63F	205/88J	112/51S	J1/J2	52,50	920,00	4/2x2	0,36	1,13	3,14	17,52
marble	31/IV	120/55F	192/72J	144/35S	J1/J2	154,80	2495,00	4/2x2	0,32	1,14	3,56	16,12
RIGHT BORE (shotcrete 10 cm thick with shear strength of 2 Mpa)												
Gneiss	19/V	157/81J	100/32J	206/37J	J1	33,80	96,00	6/1,5x1	0,12	8,91	74,25	2,84
Gneiss	19/V	157/81J	174/4S	206/37J	J3/J1	61,50	153,00	6/2x1	0,36	7,09	19,69	2,49
Gneiss	20/V	165/63J	326/14S	308/80J	J3/J1	113,10	239,00	6/2x2	0,09	6,36	70,67	2,11
Gneiss	19/V	123/80J	145/80J	113/41J	J1	49,10	165,00	6/2x2	0,16	6,95	43,44	3,36
Gneiss	8/V	336/33S	64/67F	295/74J	J2/J3	30,50	306,00	6/1,5x1	0,25	1,82	7,28	10,03
Gneiss	15/V	276/83J	181/30S	153/64F	J1/J3	29,50	116,00	6/2x2	0,18	6,95	38,61	3,93
Gneiss	10/V	135/58J	87/55J	165/29S	J1	127,40	1513,00	6/2x2	0,18	1,15	6,39	11,88
Gneiss	14/V	140/64F	70/41S	340/74J	J2/J3	127,30	2053,00	6/2x2	0,33	1,15	3,48	16,13
Gneiss	30/IV	175/12F	120/41S	332/46J	J3	161,16	450,00	4/4x4	0,47	9,66	20,55	2,79
Gneiss	30/IV	332/46J	156/60F	261/39S	J3	403,00	1454,00	4/3x3	0,66	1,66	2,52	3,61
Gneiss	30/IV	37/27F	69/29S	350/43J	J1/J3	42,80	869,00	4/3x3	0,96	0,96	1,00	20,30

RMR: Rock mass rating (Bieniawski, 1989), $J_{1,2,3}$: Discontinuity sets (J: joint, S: surface, F: fault), SL.DIR.: Sliding direction, F: Face area of wedges, W: Weight of wedges, L: Bolt Length, SF_{bs}, SF_{as}: Safety factors of wedges, before and after support

Along the left bore of the tunnel, fourteen unstable wedges were also determined. The characteristics of these wedges are also given in Table 1. The weight of the wedges varies from 100-1000 tons. Shotcrete, 10cm thick, with shear strength of 200t/m^2 was used together with rockbolts for supporting the wedges. The spacing of the rockbolts varies form 1,5x1 to 3x3. The length of the rockbolts used was 6m in very poor rock mass and 4m in poor rock mass. The safety factor of the wedges, before the support, was 0,0-0,9.

The safety factors of the wedges increased two to three times, after their support, where the ratio of the weight to the surface of the intersection of the wedge with the inner surface of the tunnel (face area) was >15. Furthermore, the safety factor increased 4-10 times when the ratio of the wedge weight to the face area was 7-10. Where the ratio of the weight to the face area of the wedges was 2-5, the safety factors increased 14-19 times, after the support. In some wedges, the safety factors, before and after their support, are still near to 1. In that cases the joint length is smaller than 10cm and the rock mass is cut into small pieces, the wedges donnot need any further support than shotcrete.

The collected data and the after elaboration obtained results were correlated statistically and power regressions with significant negative correlation (at the level of 99%, for n-2=23) were determined between the following parameters:

(a) The ratio of the weight to the face area of the wedges and the ratio of the safety factors before and after their support ($\{SF_{as}/SF_{bs}\} = 73.165\{W/F\}^{-1.1584}$, $R^2 = -0.60$, Fig. 3).

(b) The weight of the wedges and the ratio of the safety factors before and after their support ($\{SF_{as}/SF_{bs}\} = 1084.6W^{-0.7744}$, $R^2 = -0.59$, Fig. 4).

(c) The ratio of the weight to the face area of the wedges and the safety factors of the wedges after their support ($SF_{as} = 14.669\{W/F\}^{-0.8931}$, $R^2 = -0.70$, Fig. 5).

The weight of the wedges and the safety factors of the wedges after their support ($SF_{as} = 90.925W^{-0.55625}$, $R^2 = -0.60$, Fig. 6).

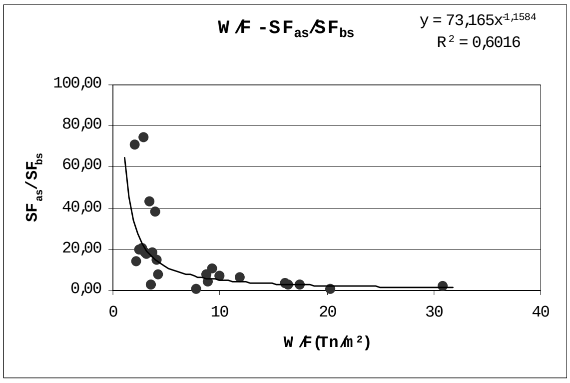

Figure 3. Regresion diagram between the ratio of the wedge weight to its face (W/F) and the ratio of the safety factors of the wedges, before and after their support (SF_{as}/SF_{bs})

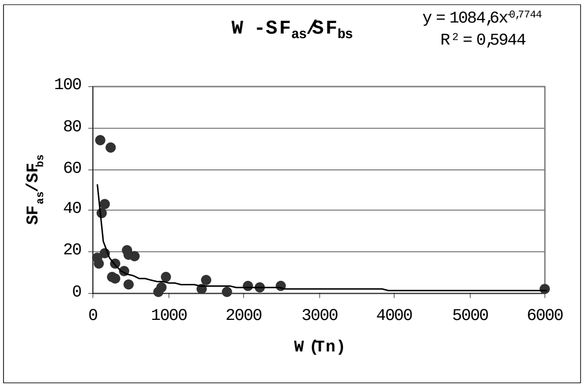

Figure 4. Regresion diagram between the wedge weight (W) and the ratio of the safety factors of the wedges, before and after their support (SF_{as}/SF_{bs})

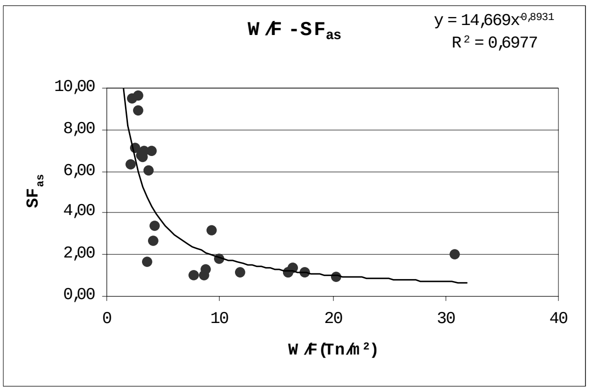

Figure 5. Regresion diagram between the ratio of the wedge weight to its face (W/F) and the safety factors of the wedges, after their support (SF_{as})

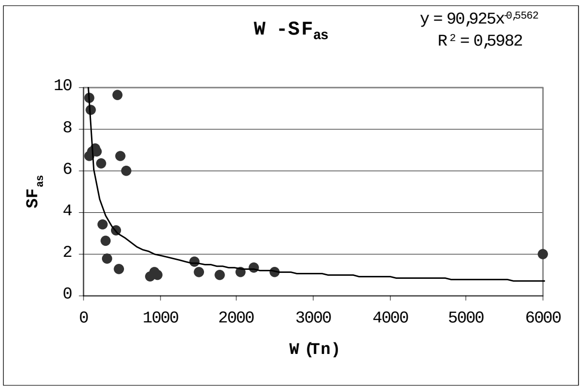

Figure 6. Regresion diagram between the wedge weight (W) and the ratio of the safety factors of the wedges, after their support (SF_{as})

According to the above-mentioned relationships, a slight decrease of the ratio “wedge weight to its face area – W/F” causes a significant increase of the safety factors of the wedges for W/F values lower than 5. On the contrary, when W/F values are greater than 5 (or the wedges are heavier than 500 Tn), the safety factors donnot increase significantly decreasing the weight.

CONCLUSIONS

The quality of the rock mass of the site of the tunnel was characterized as poor to very poor (categories IV and V). The support measures calculated according to the RMR classification data were used for estimating the support capacity of the wedges, created at the roof and the sidewalls of the tunnel, by the joint sets.

The application of the RMR system covers the demand for supporting the created wedges along the tunnel, with safety. The differences between the calculated safety factors, after the use of the RMR system and the minimum safely need, varies considerably depending on the geometry of the wedges, the joint spacing and the ground quality. This is because in closely jointed rockmasses, where the material is broken into small pieces the use of reinforced shotcrete could be more efficient than bolting, even in wedges of dimensions.

For this reason, some big wedges present only small increase of their safety factors, in after the installation of the RMR support system, contrast with others, where a considerable change occur.

The elaboration of our results gave power regressions with significant negative correlation between the change of the dimensions of the potential wedges and the safety factors, obtained with the RMR system. According to these relationships, a slight decrease of the ratio "wedge weight to its face area – W/F" causes a significant increase of the safety factors of the wedges for W/F values lower than 5. On the contrary, when W/F values are greater than 5 (or the wedges are heavier than 500 Tn), the safety factors donnot increase significantly decreasing the weight.

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