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ROCK BOLTS AND SHOTCRETE EFFECTIVENESS AGAINST GEOLOGICAL FAILURES. APPLICATION ON EGNATIA HIGHWAY IN N. GREECE

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ABSTRACT

This paper investigates the support techniques and measures as far as geological failures are concerned, and also the applicability of the most common used support measures, rock bolts and shotcrete, against the above geological failures. The investigation was based on in-situ observation of the support techniques and measures effectiveness during the construction of Thessaloniki – Kavala section of the Egnatia highway in N. Greece.

Comparing different support measures, shotcrete up to 8cm thick could support with efficacy the unstable wedges better than rock bolts, as rock bolts could not support the cracked wedges using them alone. Rock bolts from 1m to 3m and one hundred per cent grouted were also effective. When rock bolts were longer than 3m, they could not increase the safety. Also, the safety of a semi-grouted bolt was equal to the safety of non-grouted one. Examining the effectiveness of different types of anchors, on suddenly changed rock mass quality, we concluded that the mechanical anchors could support more wedges than the swellex could do.

The support ability of shotcrete was related mainly to the grain size of aggregates than to the pumping characteristics. The most effective grout mix contained only sand without gravel, diameter of grains smaller than 10mm and proportion of cement to sand about 50 kg cements to 0.1m^3. The most uniform the grain size distribution of the mixing was, the better applicable could be. Also, mineral composition affected shotcrete application. The presence of calcite and dolomite facilitated the application ability of shotcrete, while the presence of quartz made the use of shotcrete more difficult.

KEYWORDS: Tunnels, Support Measures, Shotcrete, Rock Bolts, Grouting

INTRODUCTION

The present paper refers to the support methods used in tunnels, including rock bolts and shotcrete, as it tries to divide the different support functions for determining their application properties. The theoretical investigation is applied on tunnels support at the 100km part of Egnatia Highway, which connects Thessaloniki and Kavala cities, in Northern Greece (Figure 1): Vrasna tunnel, Asprovalta tunnels and Symvolo tunnel. During the excavation works, tectonic data were collected and rock mass quality classification systems, RMR (Bieniawski, 1989), and GSI (Hoek, 1994) were used in order to study the quality and estimate the stability along the tunnels. In stability analysis, test Markland (Markland, 1972) was used.

The main support measures on tunneling construction are steel ribs, rock bolts, wire mesh and shotcrete. The choice of the appropriate support measure is due to rock mass quality. Although steel ribs are usually used on poor quality rock masses and rock bolts are efficient on good quality rock masses, shotcrete is highly used on poor and also on good quality rock masses. It supports the soil, creating a stable shell around the excavation, it penetrates among the joints of a cracked rockmass, increasing the cohesion strength and creates a protection shell which prevent rock pieces to fall down (Oraee-Mirzamni et al, 2011).

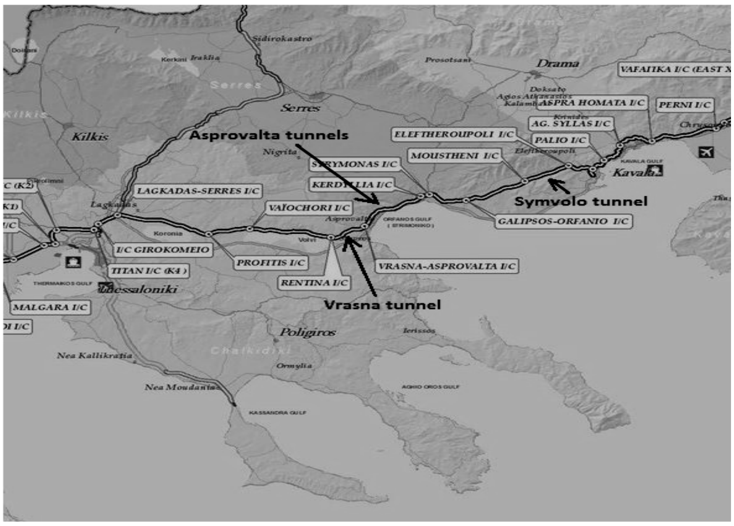

Figure 1: Egnatia Highway of Thessaloniki – Kavala Section in N. Greece

SUPPORT INVESTIGATION AT VRASNA TUNNEL

Vrasna tunnel, which is located at the western part of the highway, is about 12 m high. It 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 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). The presence of karst phenomena, which are observed in marbles, during the excavation, is also taken into account on the estimations.

As it is well known, 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, taking also into account that no groundwater is present higher than the construction floor.

Thirty-seven unstable wedges, heavier than 5tns, are estimated. In order to stabilize the wedges, the thickness of shotcrete is considered 10cm and the length of rock bolts is considered 6m. Taking into account the orientation, the spacing of discontinuities and the overall ground conditions, the rock bolt spacing is considered to be varied from 1.5mx1.5m to 1.5mx1m. In accordance to our estimations, shotcrete, from 1cm to 3cm thick, can support the majority of the wedges, increasing the safety factor to about 9,88. The maximum thickness of shotcrete, which can support successfully the wedges, without using other support measures, was 8cm, although in the most cases, shotcrete 1cm thick is enough in order to prevent small rock pieces from falling down. Rockbolts, from 1m to 3m long, can also support the most wedges, increasing the safety factor to about 9,43.

Five wedges are not be effectively supported by rock bolts, although they were effectively supported by shotcrete. Consequently, shotcrete can support with efficacy the unstable wedges better than rock bolts. As it is observed, according to the linear relation between the safety factor of the wedges being supported by shotcrete of 10cm thick and the safety factor of the wedges being supported by shotcrete with the minimum required thickness, the safety, which provided by the installation of the proposed by RMR system shotcrete thick, is about ten times the safety which provided by the shotcrete with the minimum required thickness installation;

$SF_{shot.=10cm} = 9.6604 * SF_{shotcrete} - 4.1394$ (1)

$R^2 = 0,97$.

$SF_{shot.=10cm}$= safety factor of the wedges being supported by shotcrete of 10cm thick

$SF_{shotcrete}$ = safety factor of the wedges being supported by shotcrete with the minimum required thickness

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 of the minimum required length, an increase of bolts length more than 3m, are not increase the safety;

$SF_{bolts=6m} = 0.988 * SF_{bolts} - 0.5776$ (2)

$R^2 = 0,91$

$SF_{bolts=6m}$= safety factor of the wedges being supported by bolts of 6m long

SF_{bolts} = safety factor of the wedges being supported by bolts of the minimum required length

SUPPORT INVESTIGATION AT ASPROVALTA TUNNELS

Asprovalta tunnels, which are located at the central part of the highway, are about 250m long, each. The geological formations which are crossed by the tunnels are; i) jointed gneiss, from slightly weathered to abrasive rock mass, ii) slightly to medium weathered jointed marbles, iii) good qualified amphibolite, iv) pegmatitic and aplitic veins (Christaras et al, 2002). The deformations, which were measured during the excavation, were less than 8,71cm along the X-axis and less than 4,4cm along the Y-axis. That is because the crack of rock mass helps the detonation of tensions around the excavation. Although extensive failures are not possible to take place, big pieces of rock mass fall down from the roof or slide from the walls. The above observation shows that the deformations are not connected with the failures. The failures are related to cracked wedges. The cracked wedges may fall down or slide along a sliding surface, as the connection of the rock mass, between the discontinuities, is not enough to balance the power of sliding, which was due to weight of wedges and the weight of the overlying formations. Actually, the failure of wedges is completed in stages. At the beginning, the sliding and falling of the small pieces of wedges, which are uncovered during the excavation, took place. Those small pieces cause the failure of the wedges behind themselves.

Comparing different support measures, shotcrete creates the most effective support. Shotcrete, some centimetres thick, can effectively support the potential cracked wedges. We conclude to a relationship between the thickness of shotcrete and the face area of the wedges;

$F_{(m2)} = 0,3489 * (h_{(cm)})^2 + 16,654 * h_{(cm)} + 14,049$ (3)

h = the thickness of shotcrete

F = the face area of the wedge

The correlation coefficient of the above relationship is 0,882.

The presence of rock bolts increases the safety factor 8%, but the rock bolts cannot support the rock mass using them alone; the rock bolts support a point of the rock mass, so the pieces which are not in the influence radius of that point are sliding.

As the rock mass is cracked and weathered, shotcrete supports the poor quality rock mass creating a stable shell around the excavation. So, it penetrates between the joints of the cracked rockmass increasing the cohesion strength and it also becomes a protection shell, which prevents rock pieces from falling down. Shotcrete is produced by wet mix process (Shroff & Shah, 1993). All the ingredients, including mixing water are mixed.

Then, the mortar is introduced into the chamber of the delivery equipment. The mixture is forced into the delivery hose and convey by compressed air to a nozzle (Hans & Dietz, 1982). Finally, the mortar is jetted from the nozzle at high velocity onto the surface to be shotcreted.

The rockmass of Asprovalta tunnels is very cracked and weathered. At the beginning, we tried to use a mixture of 20% gravel (Figure 2) and 80% sand (Table 1, Figure 3), 450kg/m^3 of cement and 22% of water. The diameter of the grains was less than 12,5mm and the ratio of cement to sand was 45 kg cement to 0,1m^3 sand measured by volume. The fluidity time of afflux of grout without water was 18.5sec and the fluidity time of afflux of grout with 22% water was 14.5sec (Klein and Polivka, 1958).

The minimum strength of shotcrete was 285kg/cm^2, the ratio of water to cement was ½, the ratio soil to cement was 3.5/1, the density of mixture was 2280kg/m^3, the consolidation at 5’ after the application result of shotcrete was 18cm and after 30’ the application result of shotcrete was 11cm. As in Figure 4 shown, the total composition of grout was ununiform (U=8). Using shotcrete of this composition, a rebound of an amount of 50% was observed and shotcrete could not be well applied on the rock mass surface.

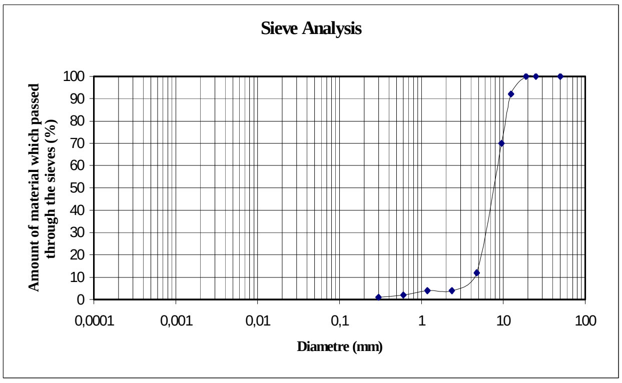

Figure 2: Grain Size of Gravel Used in the Shotcrete of Asprovalta Tunnel

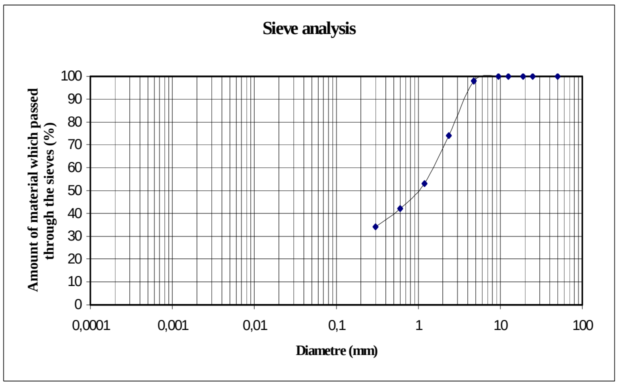

Figure 3: Grain Size of Sand Used in the Shotcrete of Asprovalta Tunnel

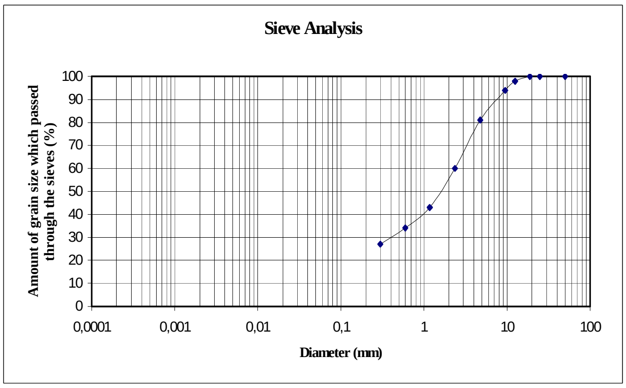

Figure 4: Aggregates Grain Size of the Used Grout at Asprovalta Tunnel

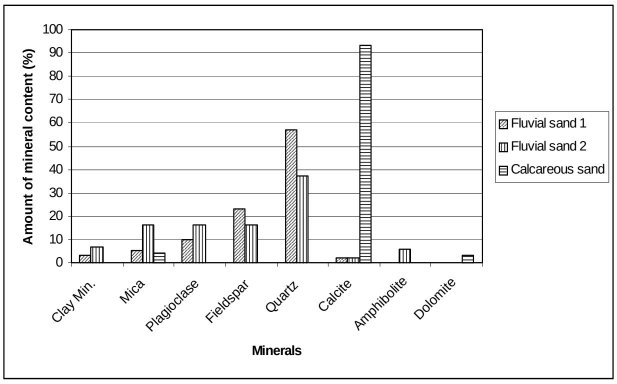

Figure 5: Diagram of Mineral Contents to Different Types of Sand

As in Figure 4 shown, the total composition of grout is ununiform (U=8). Using shotcrete of this composition, a 50% amount of rebound was observed and shotcrete couldn't be well applied at rock mass surface. Removing the grains of gravel from the composition of shotcrete, which is described above, a good application and small amount of rebound is succeeded. The diameter of grains that is used for the new composition of shotcrete is less than 10mm. With the same amount of water (22%), which was used at the beginning shotcrete composition, the fluidity time of afflux of the new composition of grout is the same. The Uniform Factor is calculated 5,3. The improved composition is more uniform than the composition, which was used at the beginning, as a 10% amount of rebound is observed and shotcrete is well applied at rock mass surface. Sand samples having different mineralogical composition are tested in order to find the most appropriate grout mix for gneiss rock mass (Bombay Port Trust, 1981).

The average mineral contents are shown on Table 1. "Fluvial sand 1" is quartz sand containing 57% quartz. "Fluvial sand 2" is ultramafic sand containing 6% amphibolite. "Calcareous sand" contains 93% calcite while fluvial sands contain 2% calcite. Calcareous sand does not contain quartz and feldspars (Figure 5). Using the same grain size composition for the improvement shotcrete composition which is described above, we test the application of fluvial and calcareous sand. We observe that fluvial sand application is not effective although calcareous sand is well applied at rock mass surface. That means that the mineral composition is an important factor for selecting sand. Although, the big amount of calcite facilitates the application of shotcrete, the presence of quartz makes the application difficult.

Table 1: Mineral Contents at Different Types of Sand

Minerals	Fluvial Sand 1	Fluvial Sand 2	Calcareous Sand
Clay Minerals	3%	7%	
Mica	5%	16%	4%

Table 1: Contd.,

Plagioclase	10%	16%	
K-feldspar	23%	16%	
Quartz	57%	37%	
Calcite	2%	2%	93%
Amphibolite		6%	
Dolomite			3%

SUPPORT INVESTIGATION AT TUNNEL OF SYMVOLO MOUNTAIN

The tunnel of Symvolo mountain is located at the eastern part of the highway, near Kavala city. The tunnel, which is oriented from West to East, is about13 m high and consists of two parallel bores, about 1150 m long each. The area is geologically located in mass of Rila - Rodope, generally consisting of gneiss, schist, amphibolites, marbles and plutonic rocks.

The tunnel was excavated dangerously because of the difficult geological status with unexpected failure conditions (Usuda et al, 2010). The sliding along a plane, the décollement from the roof and the fall of wedges are 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. The explosive measures were the most effective on poor and medium quality of hard rock mass. Also, light explosion was used in order to crack the hard rock mass helping the excavation. Chloritic schist formation and the locations, where the loose weathered material flowed from the walls and the face, were excavated by the SCL method. The sudden change of rock mass quality created the necessity of fore polling (Anagnostou et al, 2010).

One hundred and eleven wedges are measured along the right bore of the tunnel. All the wedges are to be collapsed, so the calculated safety factor, before the application of support is zero. Twenty five wedges are observed to be supported with mechanical anchors with length of 6m. Five wedges are supported using swellex. So, the mechanical anchors can support more wedges than the swellex can do. 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 higher safety factors than the grouted anchors with 50% bond length. The percentage 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. 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 to the demanded shotcrete thickness (thinner than 40cm), in order the unstable wedges to be supported, a relationship is resulted;

$$F\ (m^2) = 0{,}0061 * [h\ (cm)]^2 + 0{,}7484 * h(cm) + 1{,}4068 \quad (4)$$

where h = shotcrete thickness (cm)

F = apparent face of the wedge (m2)

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

CONCLUSIONS

Comparing different support measures, shotcrete can support with efficacy the investigated unstable wedges, better than rock bolts. Shotcrete up to 8cm thick can effectively support the potential cracked wedges. Actually, the safety, which provided by the installation of the proposed by RMR system shotcrete thick, is about ten times the safety which provided by the shotcrete with the minimum required thickness installation. Rockbolts, from 1m to 3m long, can also support the most wedges, increasing the safety factor to about 9,43. But the application of rock bolts longer than 3m, is not increase the safety. Concerning the cracked rock masses, the presence of rock bolts increases the safety factor 8%, but the rock bolts ccan not support the rock mass using them alone; The rock bolts support a point of the rock mass, so the pieces that are not in the influence radius of that point are sliding. Furthermore, the safety is increased twice when the bolts are totally grouted. The safety of a semi-grouted bolt is equal to the safety of no-grouted one. Examining the effectiveness of different types of anchors, on suddenly changed rock mass quality, we conclude that the mechanical anchors can support more wedges than the swellex can do.

Finally, for supporting unstable wedges, a relationship between the apparent face of the wedges and the required thickness of the shotcrete, was given:

$$y = a * x^2 + b * x + c$$

The support ability of shotcrete was related mainly to the grain size of aggregates than to the pumping characteristics. The most effective grout mix contained only sand without gravel the diameter of grains needed to be less than 10mm and the proportion of cement to sand should be about 50 kg cements to $0.1m^3$. The most uniform the grain size distribution of the mixing was the better applicable could be. Also, mineral compositions affected shotcrete application. The presence of calcite and dolomite facilitated the application ability of shotcrete while the presence of quartz made the use of shotcrete more difficult. Shotcrete was used also for increasing the cohesion of rock mass.

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