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# SHOTCRETE APPLICATION EFFECTIVENESS AS SUPPORT MEASURE AT POOR QUALITY ROCK MASSES

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ABSTRACT: Shotcrete is applied pneumatically and compacted dynamically under high velocity creating a shell around the excavation, increasing the cohesion of the rock mass. It supports the face of excavation preventing the fall of small rock pieces and the sliding of the face. In the case of a shattered zone, the shotcrete forms a layer spanning between reinforcing elements /rockbolts which can prevent the loose material from degradation. In the case of more massive blocks, the shotcrete covers joints which could leach out if calcite filled or wash out if filled with clay. Because of these factors, shotcrete provides a safe environment to construction works and long-term protection thereafter. The advantages of shotcrete lie primarily in its good applicability in sealing exposed cavities as fast as possible and thereby avoiding detrimental loosening around the rim of the cavity. In this paper the applicability of different types of grout mix is studied at shotcreting on cracked, weathered and soiled surface. For this purpose different grain size and mineral composition used in order to estimate the most applicable grout mix.
The effectiveness of shotcrete application is due to its composition. Cement and sand is usually used. The sand employed shall be clean, sharp and free from clay, loam and silt. It shall be graded 10mm down by screening and shall not have a moisture content over 8%. The promotion of cement to sand in shotcrete shall be about 50kg cement to 0.1 cubic meter sand measured by volume.

## INTRODUCTION

The main support measures on tunneling construction are steel ribs, rock bolds, 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 bolds are efficient on good quality rock masses, shotcrete is highly used on poor and also on good quality rock masses.

The function of shotcrete is due to rock mass quality. So, shotcrete may support the soil creating a stable shell around the excavation, it may penetrate between the joints of a cracked rockmass increasing the cohesion strength and it may be a protection shell which prevent rock pieces to fall down.

## SHOTCRETE PRODUCTION

There are two ways producing shotcrete; dry mix process and wet mix process. In dry mix process, the mixture of cement and moist sand is conveyed through the delivery hose to a nozzle where most of the mixing water is added under pressure. In wet mix process all the ingredients including water are mixed before they enter the delivery hose, and then are pumped through the delivery hose to a nozzle where additional compressed air under pressure is added to increase impact velocity (Shroff & Shah, 1993).

Shotcrete, which used for supporting Asprovalta tunnels, was produced by wet mix process. All the ingredients, including mixing water were mixed. Then, the mortar was introduced into the chamber of the delivery equipment. The mixture was forced into the delivery hose and conveyed by compressed air to a nozzle. Finally, the mortar was jetted from the nozzle at high velocity onto the surface to be shotcreted.

SHOTCRETE COMPOSITION AND PROCESS OF SHOTCRETING

Shotcrete is composed by sand and cement. Sand shall be clean, sharp and free from clay, loam and silt (Shroff & Pandya, 1989). The grain size needs to be 10mm (3/8'') down by screening and shall not have a moisture content over 8%. The proportion of cement to sand in shotcrete shall be about 50 kg cements to 0,1 m$^3$ sand measured by volume. All materials over 10mm in size shall be removed by screening before placing the mixture in the hopper of the cement gun. The pressure in the lower chamber of the cement gun shall produce a nozzle velocity of 115-155m/sec when a tip with 20mm opening is used and 130-155m/sec when a tip with 32mm opening is used. The velocities must be steadily maintained.

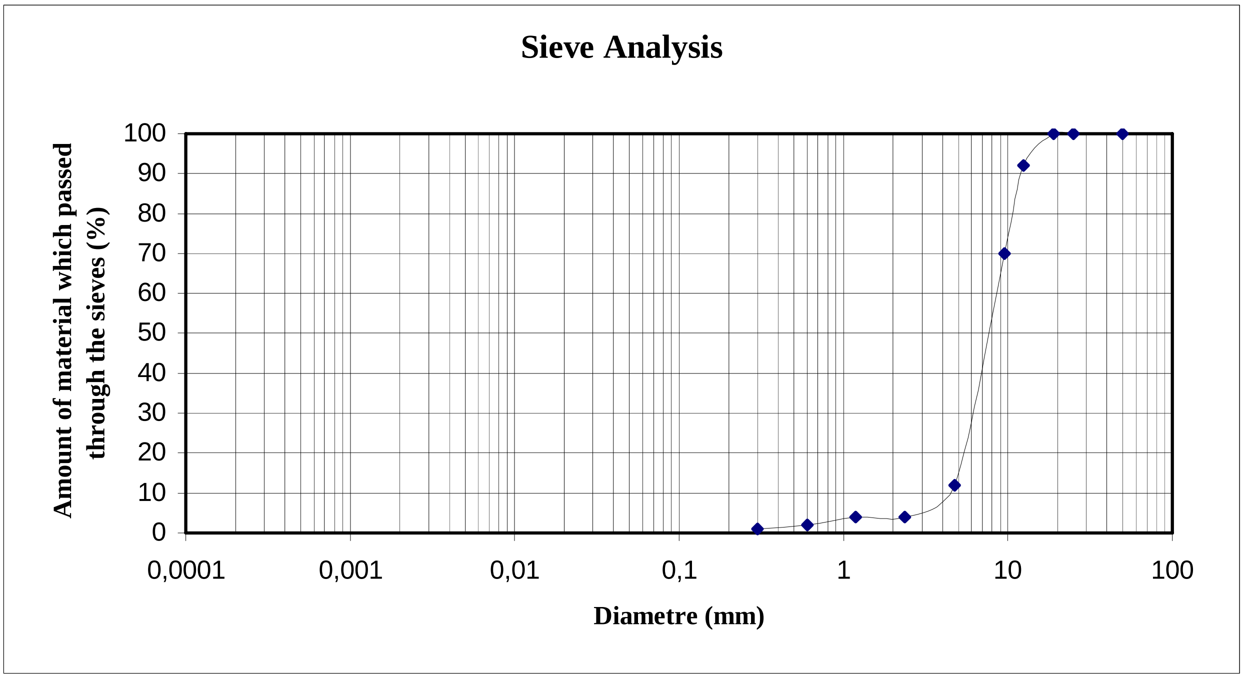


*Figure 1. Grain size of gravel used in the shotcrete of Asprovalta tunnel*

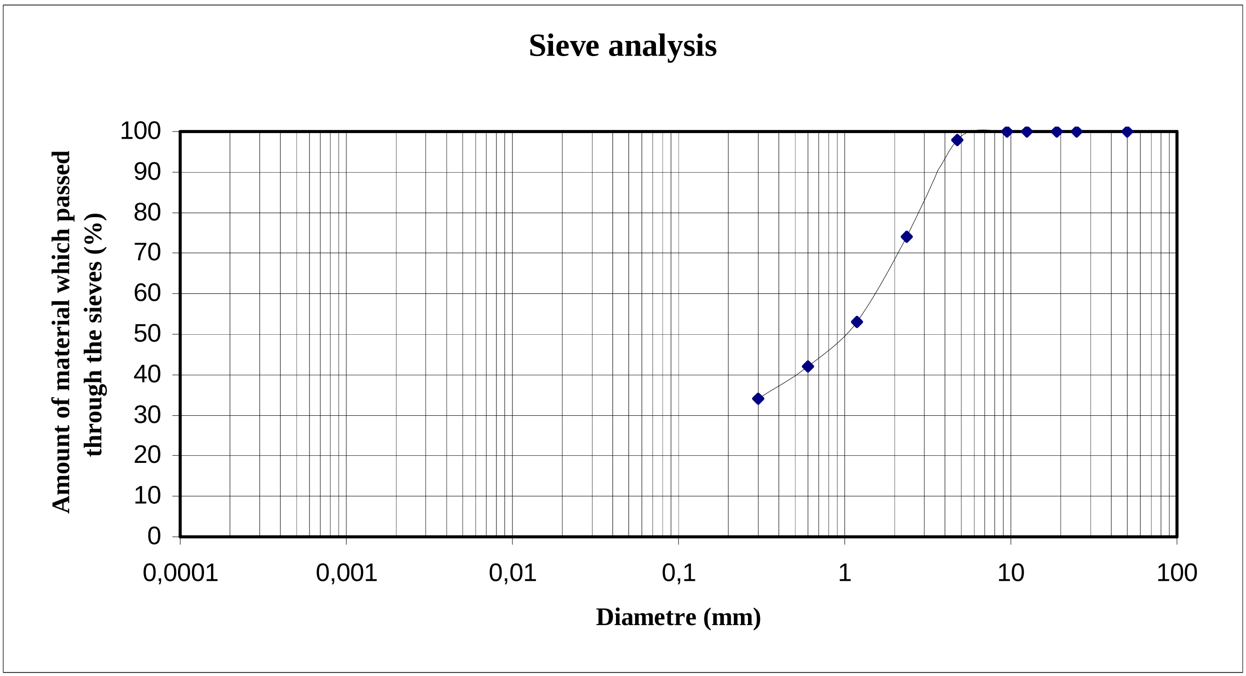


*Figure 2. Grain size of sand used in the shotcrete of Asprovalta tunnel*

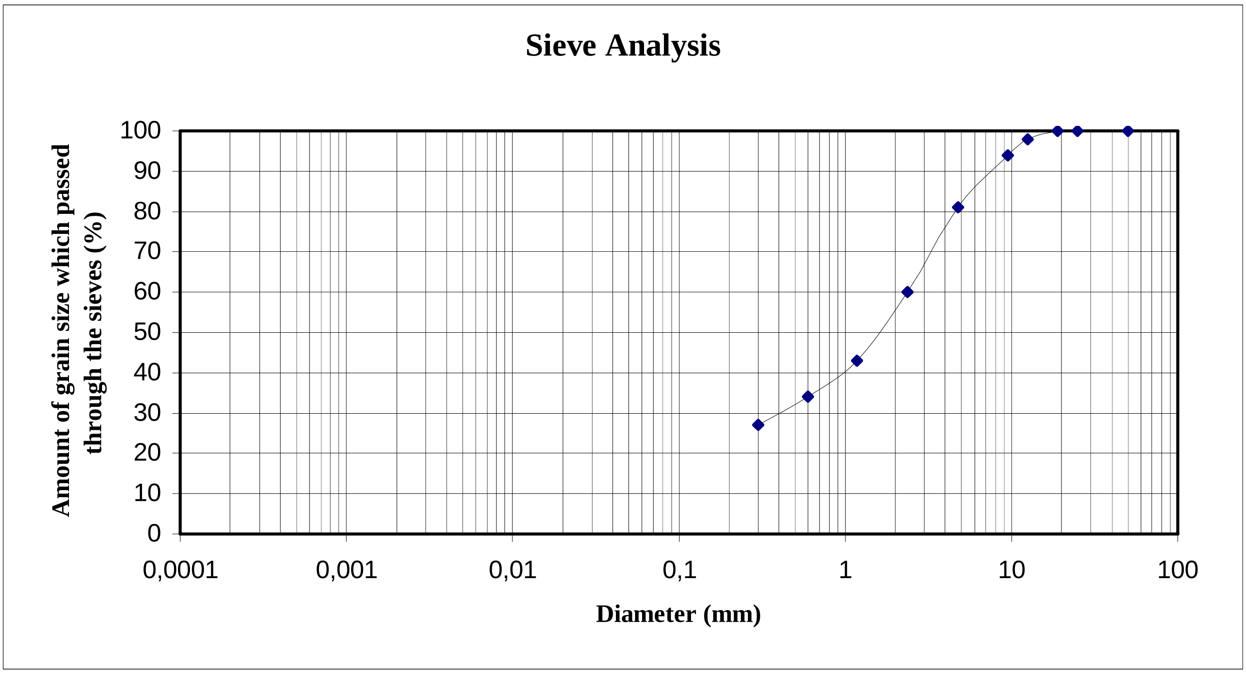


*Figure **Σφάλμα! Άγνωστη παράμετρος αλλαγής.**. Grain size of agregates of the used grout at Asprovalta tunnel*

The water used for hydrating the materials at the nozzle needs to be cleaned and freed from all substances that would tend to interfere with the setting qualities or strength of the cement. The water shall be maintained at uniform pressure of at least 1,05 kg/cm$^2$ greater than the air pressure at the cement gun (Bombay port trust, 1981).

## COMPOSITION OF SHOTCRETE USED FOR PREVENTING ROCK FALLS AT ASPROVALTA TUNNELS

The rockmass of Asprovalta tunnels is very cracked and weathered. We tried to use a mixture by 20% gravel (Fig.1), 80% sand (Table 1, Fig.2),450kg/m$^3$ of cement and 22% of water. The diameter of grains was less than 12,5mm and the promotion of cement to sand was 45 kg to 0,1m$^3$ sand measured by volume.
The fluidity time of afflux of grout without water is 18.5sec and the fluidity time of afflux of grout with 22% water is 14.5sec (Klein and Polivka, 1958). The minimum strength of shotcrete is 285kg/cm$^2$, the ratio water to cement is ½, the ratio soil to cement is 3.5/1, the density of mixture is 2280kg/m$^3$, the consolidation at 5' after the application of shotcrete is 18cm and 30' after the application of shotcrete is 11cm.

As in Fig.3 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.

## IMPROVED SHOTCRETE COMPOSITION

Removing the grains of gravel from the composition of shotcrete, which was described above, a good application and small amount of rebound was succeeded. The diameter of grains that had been used for the new composition of shotcrete was less than 10mm. Keeping the same ammount 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 factor of uniform is calculated 5,3. The improvement composition is more uniform than the composition used at the beginning, as a 10% amount of rebound was observed and shotcrete was well applied at rock mass surface.

## INFLUENCE OF MINERALOGICAL COMPOSITION OF THE SAND OF GROUT MIXING

Sand samples having different mineralogical composition were tested in order to find the most appropriate grout mix for gneiss rock mass. The average mineral contents are shown on Table 1.

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

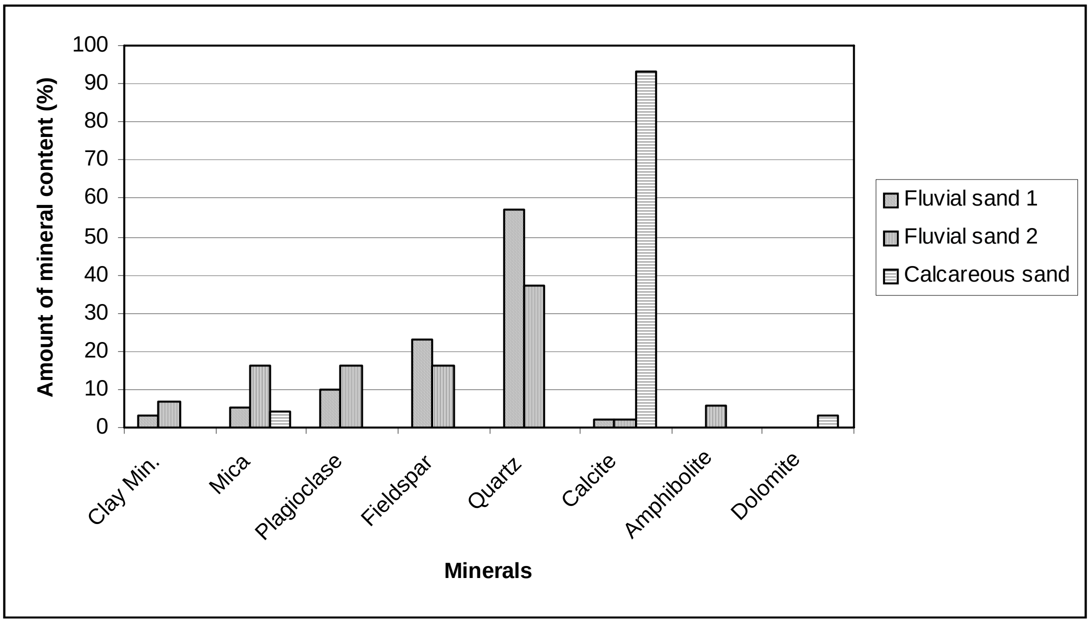


*Figure 4. Diagram of mineral contents to different types of sand*

"Fluvial sand 1" is a 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 (Fig.4). Using the same grain size composition the improvement shotcrete composition which was described above, fluvial sand application was not effective although calcareous sand was 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.

## USE OF SHOTCRETE FOR STRENGTHEN AN ERODED ROCK MASS (GROUTING TECHNIQUE).

Grouting technique was also applied in order to strengthen the eroded gneiss. At first, grout of ratio "cement to water" <1:0,7 was pressed at 5-6 atm in order to increase the cohesion of rock mass. Grout entered in the joints and the voids of the rock mass increasing the cohesion. Then, the content of cement and the pressure of grouting were decreased in order to succeed longer grouting penetration. The ratio of cement to water was 1:<0,8 and the grouting pressure used was 4-5 atm. So, a steady shell was created around the excavation which made the rock mass cohesive and stable (Hans, 1982).

## CONCLUSIONS

The support ability of shotcrete, is related mainly to the grainsize of aggregates, than to the pumping characteristics. During the construction of Asprovalta's tunnels, the effectiveness of shotcrete was tested. Different material compositions had been tested in order to choose the more appropriate one for making a protection shell which can prevent successfully rock falls down. The most effective grout mix contains only sand without gravel, the diameter of grains is good to be less than 10mm and the proportion of cement to sand shall be about 50 kg cements to $0{,}1m^3$. The most uniform the grain size distribution of the mixing is, the better applicable can be. Also, mineral compositions affect shotcrete application. The presence of calcite and dolomite, facilitates the application ability of shotcrete while the presence of quartz makes the use of shotcrete more difficult.

Shotcrete used also for increasing the cohesion of rock mass. In this case the quantity of water at the grout mixing is higher than twice of the quantity used for protection shells. The increase of the quantity of water assist grout mixing to penetrate between joints and voids in the rock mass.

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