

Technical Note
**The Usage of Ground Penetrating Radar (GPR)
in Designing Blast Pattern***

By

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1. Introduction

The most powerful and determinant step affecting the efficiency and economy of a quarry is the rock fragmentation by blasting techniques. Economic investigations, considering sequential costs prove that blasting techniques affect the efficiency of drilling, loading, hauling, auxiliary equipment and finally the crushing units. Although it is necessary for the blast to break the rock mass effectively, it is essential that the rock should not be internally damaged as consumers require good-quality material of different grain sizes. For this reason, the controllable parameters of blasting operations, which are explosive type and amount, ignition system and geometrical pattern, should be studied carefully in order to prevent over-break, back-break and environmental impacts like ground vibration, fly-rock and air blast. The geological structure of a rock mass, however, is an uncontrollable parameter of blasting operation and imposes restrictions on the obtainment of desirable fragmentation. This brings an anisotropic character into the rock mass.

Conventional methods of blast design in a rock mass, consisting of joints, faults and fractures, may result in formation of large slabs which cannot be handled by the excavation and loading equipment without resorting to secondary blast (Rao, 1995).

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Outcherlony et al. (1990) reported from the Mrica project in Java that the average fragment size (k_{50}) after blasting was independent of specific charge and hence fully governed by geology. Gynemo (1992) shows how a decrease in a specific charge from 0.49 to 0.32 kg/m³ does not notably alter the post blast fragmentation size distribution. These findings illustrate the importance of geology in rock fragmentation process. Therefore, before starting the quarrying facilities at the mine, one should carry out detailed geological and geophysical analysis of discontinuities and decide on the orientation of the quarry benches. In fact, unsuitable orientation of quarry benches with respect to dominant discontinuities may lead to unsuitable fragmentation and increase in the cost of subsequent operations.

It is the purpose of this paper to present a study carried out in a quarry near Ankara, capital city of Turkey. The objective was to obtain the subsurface images of the discontinuities by using the ground penetrating radar (GPR) and design the blasting pattern in such a way that rock fragmentation by blasting could not be adversely affected by existing discontinuities. The benches at the quarry were formed by the owners of the quarry without considering the geological structures. Unfortunately, most of the benches cross the discontinuities. Moreover blasting, performed at these benches, causes coarser fragmentation. Therefore, the only manipulation that could be made in the quarry to improve the rock fragmentation was to study the blast design parameters suitable to the existing geological structures. In this paper, these manipulations on the blast design pattern to obtain finer fragmentation are discussed.

To achieve this aim, discontinuities, rough, broken and weathered zones of material were determined by using GPR at the selected bench. The principles of the GPR method have been explained extensively in the literature (Davis and Annan, 1989; Ulriksen, 1982; Morey, 1974) and especially for fault and fracture imaging (Benson, 1995; Grandjean and Gourry, 1996; Grasmueck, 1996; Grasmueck et al., 2005; Green et al., 2003).

2. Test Site Location and Rock Properties

The study site is a quarry situated in southeast of Ankara, Turkey. The rock consists mainly of dolomitic and stratified limestone which is white, massive and partly recrystallized. The dominant joint set is nearly vertical. About four hundred discontinuity measurements were conducted at all benches of the quarry and the dominant direction of the discontinuities was found to be N30° W by using commercial software. Laboratory experiments on representative samples taken from the test site were conducted according to ISRM (1981b) recommendations. Uniaxial compressive strength, tensile strength and density of limestone were found to be 100 MPa, 10 MPa, 0.0026 kg/m³, respectively.

3. Field Studies

Field studies were complemented in two groups. The first group study consists of GPR measurements. The second group study was carried out to design the optimum blast

patterns suitable to the geological structures identified by GPR. Moreover, the blasting results were compared with previous results obtained by quarry engineers.

3.1 First Group Studies

In order to image the subsurface geological structures, GPR measurements were carried out.

3.1.1 Data Measurement, Processing and 2D–3D Visualizations of GPR Data

The instrument used in the GPR measurements for data gathering was PULSE EKKO100A GPR with 25 MHz antennas. The study area was a horizontal platform with a size of 20×50 m in front of the working face. The surrounding working faces showed a dense fracture network marked by an E–W orientation and have an almost vertical dip. GPR profiles were arranged perpendicular to the main direction of the observed fault. Four measuring lines were established horizontally along the selected bench. The lines were spaced 2 m apart (Fig. 1). Data set were prepared with co-pole antenna system which is oriented perpendicular to the direction of profiles. Trace spacing was 0.5 m in each line. Sampling interval was 1.6 ns. 575 sampling were taken. Therefore, total data length was 920 ns ($1.6 \text{ ns} \times 575$ samples). To obtain a 3D representation of the fracture field, GPR profile are arranged along a series of parallel lines (Kadioglu and Daniels, 2002).

The determination of the discontinuities cannot be directly obtained from the raw radar profiles. It requires a more detailed analysis of the radar signals. Then these discontinuities can be determined by the 2D and 3D visualizations of GPR data which were performed in a program called GPHYZ in IDL 5.5 developed by Daniels (2002). The following processing routine was applied to the collected data.

The second order Butterworth filter with 15 MHz cutoff frequency and 25 MHz bandwidth were applied to the whole data to eliminate low frequency ‘wow’ effect and high frequency noise. Amplitude attenuations were balanced by using linear gain. The propagation velocity was obtained by Wide Angle Reflection and Refraction (WARR)

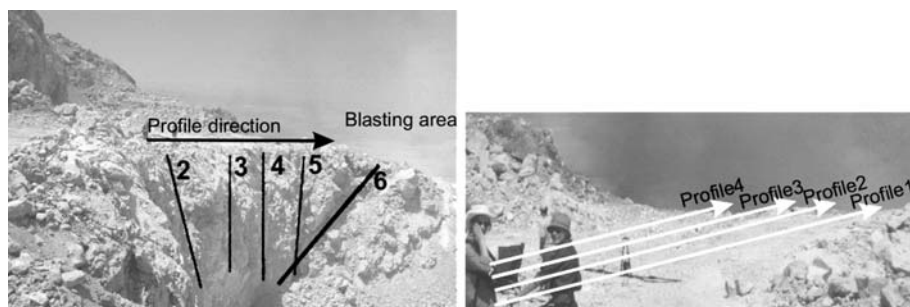


Fig. 1. Direct observations at the wall surface

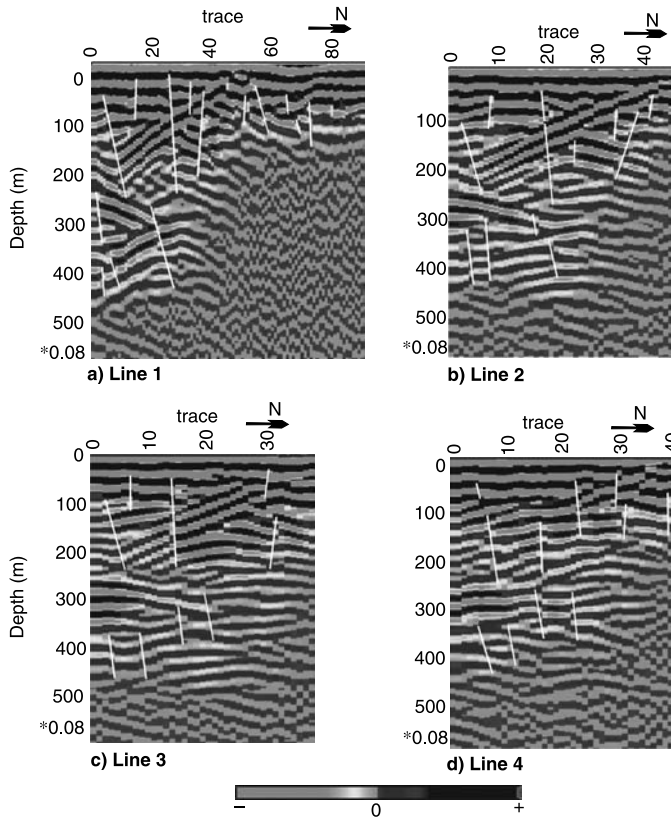


Fig. 2. Processed sections of georadar data

measurements. The average velocity was determined by velocity analysis as 0.1 m/ns. A block data by combining the profile lines was formed in 3D view. Amplitude color range and opacity functions of block data were assigned for 3D visualization.

2D radar sections (radagrams) in Fig. 2a–d show the processed GPR data profiles obtained with 25 MHz antenna. The horizontal axis on each radagram indicates the horizontal distance along the measuring line and the vertical axis indicates the two-way reflection travel time from the wall surface for reflections within the rock. Three radar sections are almost 20 m in length. In order to acquire data from the blasting area, at which drill holes were prepared when we were conducting GPR measurements, the length of line 1 was extended up to 40 m. The two-way travel time range for all GPR lines in Fig. 2 is 920 ns (575×1.6). The two-way travel time (T) can be converted to approximate depth (D) by using the propagation velocity of EM waves ($V = 0.1$ m/ns) in this base rock with the equation $D = VT/2 = 0.1 \times 575 \times 1.6/2 = 0.08 \times 575$. With this knowledge, the approximate depth was determined as 46 m at this site. By using all radar sections obtained from these parallel lines and making all the line lengths equal (line 1 to line 4), 3D visualization with a) linear amplitude opacity function and b) only positive amplitude opacity function, were prepared to see

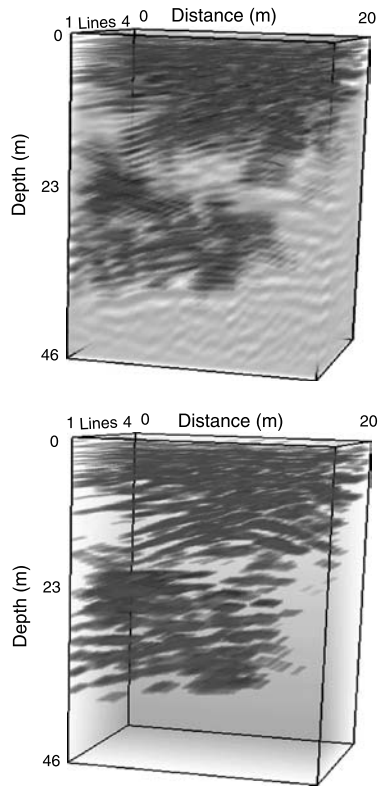


Fig. 3. 3D visualizations of GPR lines in Fig. 1

the fractures and their directions in 3D (Fig. 3). The orientation of the discontinuities and the depth of the compact zone (reflection-free area at the bottom of the 3D block) at the bench can be seen in Fig. 3.

3.1.2 Interpretation of GPR data

It is worth noting that a zone of high GPR signal attenuation can be seen at right hand side of all the radar sections in Fig. 2. This zone is interpreted as a zone of unconsolidated material and is called weak zone. The velocity analysis indicates that the velocity of this zone is less than 0.1 m/ns. Explosive type plays an important role in the blasting operations at these types of weak zones. Moreover, using explosive having high shock energy causes more than necessary fine fragmentation and let the rock mass internally damaged at this type of weak zone. Blasting process carried out by quarry engineers at this zone is discussed in the next section.

Approximately the same fractures (drawn by thin yellow lines) and the fault (drawn by thick yellow lines) are observed at all radagrams. Therefore, the markers of interpretation were made considering only line 1. Figure 4 shows the interpreted radagrams at line 1.

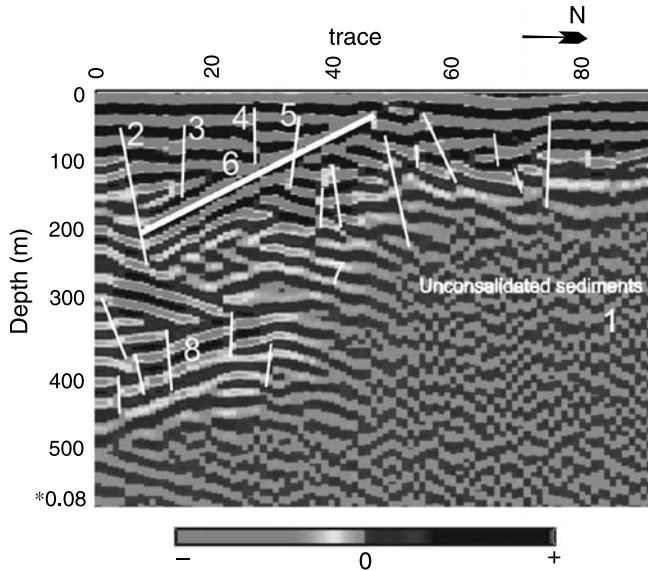


Fig. 4. Interpreted radagram at line 1

The direct observations of the discontinuities can be seen at the wall surface in Fig. 1. The fractures and the fault detected on the rock surface by visual observation are denoted by markers 2–5 (for fractures) and 6 (for the fault). Some of the reflections (marker 6) and discontinuities on the reflections (markers 2–5) at the radagram (Fig. 4) correspond in position to the fractures and the fault identified by surface observation (Fig. 1). Therefore they are indicated by the same numbers. Locations of discontinuities on the radagrams and the observed discontinuities are in generally good agreement, giving reasonably accurate positions when comparing the radagram with the observations of the rock surface. It is reasonable, therefore, to assume that the discontinuities on the reflections shown on the radagram are directly associated with the discontinuities confirmed by direct surface observation, and thus the same should be true for cracks within the body of the rock wall.

The extent of the fault on the radagram at line 1 (Fig. 4) can be seen up to 16 m (200×0.08). The bottom of the fault zone is broken and crushed. We called this zone as collapsed zone (marker 7 at Fig. 4). At the bottom left side of the radagram, powerful reflections are observed (marker 8 at Fig. 4). These reflections are interpreted as the border of a compact zone corresponding to a depth of 30–32 m. Therefore it also represents the end of effective area of blasting for the upper part. In other words, maximum depth for obtaining good fragmented rock for this bench is 32 m. The blasters at the quarry said that uncrushed rock was obtained at the bottom of the blast holes when blasting of long holes (more than 30 m) at this bench. This information proves our statement that effective depth of blasting for the bench is 30 m. Formation of benches higher than 30 m is not meaningful. After this depth, there is a more compact zone which needs a different blasting pattern.

3.2 Comparative Measurements of Blasting

While GPR data measurements were being conducted at line 1, the blasters were preparing the drill holes for blasting. The blasting area was at the end of line 1 (Fig. 1). GPR data could also be obtained at the blasting area. As stated in the previous section, the interpretation of the GPR data sections illustrated that blasting area coincided with the unconsolidated, weak zone. As an aggregate producer's point of view, using explosives with high shock energy may internally damage this zone and causes formation of unnecessarily fines. In order to see the results, we did not interfere with the blast design parameters and just monitored the blast. A total of 49 blast holes were fired with electric detonators. The firing pattern is illustrated below:

First row: 19 blast holes were detonated with 30 ms delay.

Second row: 13 blast holes were detonated with 90 ms delay.

Third row: 12 blast holes were detonated with 150 ms delay.

Fourth row: 5 blast holes were detonated with 210 ms delay.

Moreover, 55 small drill holes were prepared at the boulders and blasted as another group. Surface blast design parameters of the quarry are given in Table 1.

As expected, blasting of this weak zone by using a great amount of powerful primers (having high shock energy) did not provide acceptable fragmentation. As far as the size distribution (determined by digital imaging technique) is concerned, the average fragmentation was 220 mm. Some part of the blasting area was left in place (Fig. 5) as the rock mass was internally damaged and could not be economic to drill the new blast holes.

Another reason of coarse fragmentation was due to the ratio between burden and spacing. In order to get the good fragmented rock, it is known that spacing should be 1.25 times burden. Moreover, depth of the hole should be 0.3 times the bench height (Olofsson, 1988). However, the depth was shorter than the bench height and this caused a formation of stumps (unfractured material) at the bottom of the bench.

By using the GPR data interpretation results, an attempt was made to design the blast (Table 2). The height of the bench, at which to perform a blast, was unfortunately greater than 30 m. It was also known from the interpreted radagrams that the more compact zone started after 30 m. Therefore, we used a high amount of jelinite dynamite to initiate the blast at the bottom of the hole in order to prevent unbreakage.

Table 1. Surface blast design parameters given by quarry blasters

Hole diameter	6"
Bench height, K	20 m
Depth of hole, H	17 m
Burden, B	4 m
Spacing, S	4 m
Stemming length, St	3 m
Ignition system	electrical
Delay between caps	30 ms
Explosive type	12 jelinite dynamite (JD) as bottom primer and 6 JD as middle primer and ANFO as column charge.
Loading density	18.5 kg/m



Fig. 5. Blasting area left in place

Table 2. Surface blast design parameters given by authors

Hole diameter	6''
Bench height, K	32 m
Depth of hole, H	33 m
Burden, B	3 m
Spacing, S	3.5 m
Stemming length, St	3 m
Ignition system	electrical
Delay between caps	30 ms
Explosive type	14 jelatinitite dynamite (JD) as bottom primer and 6 JD as middle primer and ANFO as column charge.
Loading density	18.5 kg/m

At the first blast, designed by quarry blasters, burden and spacing (i.e. distance between hole and bench face and distance between two holes) were both equal to 4 m. The view of muckpile illustrated that fragment size was coarser. Therefore, we changed the burden and spacing to 3 m and 3.5 m, respectively (spacing was 1.25 times burden). The average fragmentation was determined by digital imaging technique as 118 mm.

4. Conclusion

With the objective to study the applicability of the GPR method to detect the crack distribution and continuity within the base rock, fractured by blasting for aggregate

production in a quarry, we conducted GPR data measurements and made some interpretations, so as to design the blasting pattern suitable to the existing geological structure. As a result, the following conclusions were drawn:

- The maximum penetration depth with 25 MHz antenna frequency for this field (according to the velocity analysis of the GPR data) was found to be approximately 44–46 m.
- The maximum depth for efficient blasting was found to be 30 m for the selected bench. Therefore, formation of a bench higher than 25 m is not economic in terms of achieving a good fragmentation.
- The weak zones and closed or compact fracture zones that need special type of blast design can be identified by the GPR method.

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