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FRAGMENTATION, COST AND ENVIRONMENTAL EFFECTS OF PLASTER STEMMING METHOD FOR BLASTING AT A BASALT QUARRY

STOPIEŃ ROZDROBNIENIA, KOSZT I SKUTKI DLA ŚRODOWISKA SPOWODOWANE PRZEZ STOSOWANIE PRZYBITKI GIPSOWEJ PRZY PRACACH STRZAŁOWYCH W KAMIENIOŁOMACH GDZIE POZYSKUJE SIĘ BAZALT

In this study, the plaster stemming application for blasting at a basalt quarry is studied. Drill cuttings are generally used in open pits and quarries as the most common stemming material since these are most readily available at blast sites. However, dry drill cuttings eject very easily from blastholes without offering much resistance to blast energy. The plaster stemming method has been found to be better than the drill cuttings stemming method due to increased confinement inside the hole and better utilization of blast explosive energy in the rock. The main advantage of the new stemming method is the reduction in the cost of blasting. At a basalt quarry, blasting costs per unit volume of rock were reduced to 15% by increasing burden and spacing distances. In addition, better fragmentation was obtained by using the plaster stemming method. Blast trials showed that plaster stemming produced finer material. In the same blast tests, +30 cm size fragments were reduced to 47.3% of the total, compared to 32.6% in the conventional method of drill cuttings stemming. With this method of stemming, vibration and air shock values increased slightly due to more blast energy being available for rock breakage but generally these increased values were small and stayed under the permitted limit for blast damage criteria unless measuring distance is too close.

Keywords: Plaster stemming, stemming, fragmentation, cost, vibration, basalt

W pracy zbadano zastosowanie przybitki gipsowej przy pracach strzałowych w kamieniołomach gdzie pozyskuje się bazalt. W kopalniach odkrywkowych i w kamieniołomach najczęściej stosowanym materiałem na przybitkę są zwierciny, gdyż są one materiałem łatwo dostępnym w miejscach prowadzenia prac strzałowych. Jednakże suchy urobek wiertniczy jest bardzo łatwo wyrzucany z otworów strzałowych, w niewielkim stopniu tylko hamując energię strzału. Stwierdzono, że metoda z wykorzystaniem przybitki gipsowej jest korzystniejsza niż z wykorzystaniem zwiercin, ponieważ gips ściślej upchany jest w otworze, co zapewnia lepsze wykorzystanie energii wybuchu w skale. Główną zaletą nowej przybitki jest obniżenie kosztów prac strzałowych. W kamieniołomach gdzie pozyskuje się bazalt, koszty prac strzałowych w przeliczeniu na jednostkę objętości skały obniżono o 15% poprzez zwiększenie odległości pomiędzy otworami i zwiększenie grubości nadkładu. Ponadto, przy zastosowaniu przybitki gipsowej

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uzyskano korzystniejszy stopień rozdrobnienia. Próbne prace strzałowe pokazały, że przy zastosowaniu przybitki gipsowej uzyskuje się drobniejszy materiał. W trakcie prowadzonych strzałów próbnych proporcja fragmentów skał o wymiarach +30 cm została zredukowana do 47.3% całego materiału, co porównać można do poziomu 32.6% uzyskiwanych przy strzałach z zastosowaniem konwencjonalnej przybitki. Przy nowej przybitce zanotowano nieznaczny wzrost poziomu wibracji i fali uderzeniowej powietrza jako że większa energia zostaje wykorzystana do kruszenia skał, jednakże wzrosty te były nieznaczne i mieściły się w dopuszczalnych limitach mających odniesienie do skutków prac strzałowych, pod warunkiem że pomiary nie dokonywane były w zbyt bliskiej odległości.

Słowa kluczowe: przybitka gipsowa, przybitka, rozdrobnienie skał, koszt, wibracje, bazalt

1. Introduction

Fragmented basalt is used in aggregate sector in great quantities, especially for high-speed rail construction. The cheapest way to fragment basalt rock mass is by blasting. Blasted basalt is send to crushers to reduce its size. Therefore, producing fragments as fine as possible reduces the work of crushers thus the cost of breaking is reduced as well as the cost of loading

The stemming of blasthole collars in surface mines with an inert material redirects blasting energy to the rock more efficiently, thus the energy is utilized more effectively in breaking rock. In this procedure, high efficiency of blockage is important since the blast gases should not be allowed to escape due to loose stemming material. More efficient stemming with better confinement therefore increases the generation of fines. In addition, better rock breakage can be obtained. On the other hand, scatter distance is increased, giving rise to a looser muck pile that can be more easily loaded and transported (Ozkahraman, 2006).

Zhu et al. (2008) found that strong confinement can efficiently block explosion products (gases) escaping from the borehole, thus it can intensify the extent of rock damage, which enhances the blasting efficiency. Boshoff and Webber-Youngman (2011) developed a stemming performance testing rig for small-diameter boreholes, and showed that different stemming products have differences in terms of their functionality, which can have a major impact on the efficiency of rock breaking. Blasting results showed that coarse angular crushed rock is better than fine drill cuttings for stemming (Tamrock, 1984). Dobrilovi'c et al. (2005) studied stemming material consisting of broken limestone and found that the +16–32 mm fraction was the best-suited material.

In this study, a new stemming material is investigated with the aim of increasing the blast energy directed to the rock. For this purpose, quick-setting moulding plaster was used as a stemming material. Apart from the work of Cevizci (2012), there is no previous work found in the literature citing the usage of this material. Blasting tests were carried out in quarries using both the suggested new stemming method and classical stemming material, and performance measurements carried out by image analysis of fragmented rock piles.

Drill cuttings are the most common stemming material used in open pits and quarries, since they are most readily available at blast sites and are cheap. However, dry drill cuttings eject very easily from blastholes without offering much resistance to the explosion. Thus, a great percentage of blast energy is wasted and lost to the atmosphere. Cevizci (2012) carried out blasting tests by changing the blasting parameters of open pit blasts and obtained better results with the plaster stemming method in two different limestone quarries and one clay quarry. These blasting trials were carried out on same benches and under same rock conditions. The new method employs a plaster prepared as a thick paste, which hardens in less than 25-30 minutes after application. The hardened plaster creates a very strong plug, therefore the stemming column length can be reduced and the explosive column length increased. This increased explosive column results in better rock breakage than similar holes stemmed with dry drill cuttings. Also, this increased utilization of hole length reduces specific drilling costs due to increased burden and spacing distances. Blasthole drilling constitutes a major cost in blasting operations. Another advantage of the new method is better fragmentation, with more induced cracking in the rock mass.

In one series of blast tests, blasting costs per unit volume of rock were reduced to 16% by increasing burden and spacing distances (Cevizci, 2012). In addition, better fragmentation was obtained by using the plaster stemming method. Blast trials showed that plaster stemming produced finer material. In the same blast tests, +30 cm size fragments reduced to 5.4% of the total, compared to 37.7% in the conventional method of drill cuttings stemming. With this method of stemming, vibration and air shock values increased slightly due to more blast energy being available for rock breakage, but these increased values were small and under the permitted limit for blast damage criteria.

Peak particle velocity (PPV) known to be a function of site conditions (i.e. geological conditions) and scaled distance is calculated from following equation,

$$SD = D/W^{(1/2)} \tag{1}$$

where D is the distance from the blast face to the vibration monitoring point and W is weight of explosive per delay for surface blasting (Devine et al., 1966; Karakus et al., 2010).

In the plaster stemming method, 61.3 kg explosive per delay was used compared to 58.7 kg in the drill cuttings stemming (Cevizci, 2012). This increase in explosive charge caused an increase in PPV value from 12.0 mm/s to 17.8 mm/s, whereas it should cause only a 0.4 mm/s increase in PPV value according to calculation from the theoretical formula. In addition, air shock increased from 132.0 dB to 132.9 dB. The vibration and air shock values measured at the Bozanonu limestone quarry test trials with both the drill cuttings stemming and the plaster stemming were under the safety limits specified in the limit criterion. At the top level bench, small quantities of fly rock were generated, but this did not constitute a major problem. In addition, the plaster stemming round resulted in a slightly more scattered muck pile owing to more blast energy directed to the rock, but this did not create a big problem either. Loading of the muck pile was easier due to the looser particles.

At Bastas limestone quarry, a 25 cm of drill cuttings were placed between the explosive and the plaster paste. Length of plaster column was 45 cm. The top 55 cm of the drill hole was filled with drill cuttings. With plaster stemming round, total length of stemming was 1.25 m and no fly rock was generated at the top level bench, similar to the drill cuttings stemming round test trial. Also, the scattering of the muck pile with the plaster stemming round was similar to scattering of the drill cuttings stemming round.

2. Method

The study was carried out at Asagi Caglayan basalt quarry of Bazalt Company. The quarry is located at south-west of Eskisehir city. A summary of the properties of material at the blast site, blast patterns, measurements of blast tests, and features of the bench faces is shown in Table 1. Both fast-setting moulding plaster and drill cuttings were used as stemming material at different lengths in similar blastholes on the same quarry bench. A thick milky moulding plaster was

TABLE 1

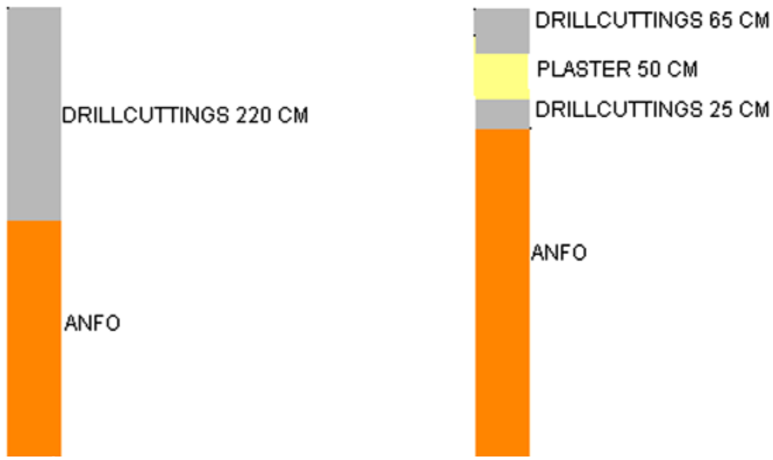
Summary of properties of material at Asagi Caglayan basalt quarry blast site, blast patterns and measurements of blast tests

Blast Tests	**Dip direction/ angle of dip /angle of blast direction relative to dip direction of discontinuity**	**Block size index, (cm)**	**RQD, (%)**	**Stemming length, (m)**	**Average burden, (m)**	**Average spacing, (m)**	**Bench height, (m)**	**+30 cm size fraction, (%)**	**–10 cm size fraction, (%)**	**Surface delay/bottom delay, (ms)**	**Specific charge, (kg/m^3)**	**Specific drilling, m/m^3**
Drillcuttings stemming round	30/65/0	44	60	2.2	2.4	2.65	9	47.3	14.1	25/500	0.78	0.21
Plaster stemming round	30/65/0	44	60	1.4	2.4	2.65	9	32.6	31.9	25/500	0.71	0.17

prepared by mixing ten units of plaster powder and seven units of water in a barrel, and charged into the blastholes as shown in Figure 1. This wet paste hardens in 25-30 minutes. The design of the stemming, using the tests at Asagi Caglayan basalt quarry is shown in Figure 2.

Wet plaster should not be placed in contact with ANFO, which is water-sensitive, thus 25 cm of drill cuttings were placed between the explosive and the plaster paste. The length of plaster column was 50 cm. The top 65 cm of the drill hole was filled with drill cuttings since this section of the collar was deformed and cracked during drilling (Fig. 3). No benefit is expected from filling this section with plaster, and it was therefore it filled with dry drill cuttings after the plaster had hardened instead of leaving it empty. This had the advantage of protecting the hole from loose stones dropping in.

Fig. 1. Application of plaster paste to hole collar



(a) Stemming with drill cuttings (b) Stemming with plaster

Fig. 2. Blast hole stemming at Asagi Caglayan basalt quarry

Fig. 3. Cracked hole collar and hardened plaster

3. Blast trials and results at Asagi Caglayan basalt quarry

Two blast rounds eleven metres apart were carried out with the plaster stemming and with the classic conventional drill cuttings stemming, each consisting of one row of ten holes. First round was carried out by using plaster stemming. Second round was carried out by drill cuttings stemming. Both two rounds all 89 mm diameter holes were drilled with Gemsa drillers. Compared to blasting with drill cuttings stemming, burden and spacing distances were approximately 10 % larger at plaster stemming method. Nobelex TG dynamites were used as primer at the bottom of holes. Only one primer initiated with Nonel cap in each hole which was considered enough for detonation. The firing was started with detonation cord. At the surface 25 ms and at hole bottom 500 ms Nonel millisecond caps were used. Nonel detonation guarantees any misfires.

Drill cutting stemming method is generally used globally in open pits and quarries. Therefore the stemming blast holes with drill cutting procedure was a standard procedure and details of this procedure is not given in the paper instead the new and more efficient plaster stemming method is more emphasized. For comparison of two steming procedure, test blasts were carried out in the same location**.** Therefore, the rock structure and strength were similar. In both rounds ANFO, with one primer containing of 500 g dynamite was used. A quick hardening moulding plaster was used for plaster stemming.

3.1. The evaluation of blast trials

The blasting results of two stemming method were compared. Rock pile fragmentation was evaluated using Split Desktop image-analysis software and verified standard "compare photo" method (Ozkahraman, 2006). The rock piles from the blasting tests at Asagi Caglayan basalt quarry are shown in Figure 4 and Figure 5. The cumulative percentage of retained size at the Asagi Caglayan basalt quarry blasting tests is given in Table 2.

TABLE 2

Comparison of cumulative percentage of retained size (oversize) from blast trials with plaster stemming and drill cuttings stemming

Fragment size, (cm)	Drill cuttings stemming round, (%)	Plaster stemming round, (%)
100	0.0	0.0
70	2.3	2.1
50	13.8	8.6
40	27.7	18.0
30	47.3	32.6
20	67.6	50.2
15	77.1	58.3
10	85.9	68.1
5	93.9	79.8

The first round was carried out using plaster stemming with ten holes. The length of the stemming was 1.4 m (Fig. 2). The second round was carried out by drill cuttings stemming with ten holes. The length of the stemming was 2.2 m. Each blasthole was filled with 36 kg ANFO initiated with one primer with 0.5 kg in weight in the case of the drill cuttings stemming method. For the plaster stemming method, the quantity of ANFO was 40 kg per blasthole. The total length of ANFO column in the plaster stemming method was 80 cm greater than for the conventional method of drill cuttings stemming.

The blasted area was 52.03 m^2 for the drill cuttings stemming trial, and blasted volume was 468.3 m^3 in situ. The specific charge was found to be 0.78 kg/m^3 and the specific drilling was 0.21 m/m^3. The blasted area was 63.43 m^2 for the plaster stemming blast trial and yielding the blasted volume was 570.9 m^3 in situ. The specific charge was 0.71 kg/m^3 and the specific drilling was 0.17 m/m^3.

Fig. 4. Rock pile of blast round with drill cuttings stemming at Asagi Caglayan basalt quarry

Fig. 5. Rock pile of blast round with plaster stemming at Asagi Caglayan basalt quarry

The total length of holes for the plaster stemming trial at Asagi Caglayan basalt quarry was 20.8 m less than for the drill cuttings stemming round (if obtained same volume of rock at drill cuttings stemming round). This resulted in 22% less drilling per unit volume rock. The cost saving for drilling calculated was $ 224.8 (20.8 m X10.8 $/m). At this site, specific drilling and specific charge decreased because a larger burden and spacing were applied with the plaster stemming method. In order to fragment the same volume of rock as for the plaster stemming round, an additional hole length of 20.8 m should be drilled for the drill cuttings stemming round. The profit per unit volume was $ 0.48 and total profit by using plaster stemming was $ 273.7 (Table 3). Therefore, the plaster stemming trial was found to be more economic as well as giving better fragmentation. For instance, the +30 cm size fraction dropped from 47.3% to 32.6%. Therefore, better fragmentation is obtained with $ 273.7 profit. Also, the amount of –10 cm size material was increased from 14.1% to 31.9%. This has benefits in crushing and grinding.

TABLE 3

Comparison of blasting cost of plaster stemming versus drill cuttings stemming

Cost item	Drill cuttings stemming ($)	Plaster stemming ($)
Cost of ANFO	360	400
Nonel caps (surface + bottom)	71.9	71.9
Detonation cord	0.5	0.5
Dynamite	19.1	19.1
Moulding plaster and labor cost	-	10
Drilling cost	1026	1026
Total Cost	1477.5	1527.5
Fragmented rock (m^3)	468.3	570.1
Unit cost ($/$m^3$)	3.16	2.68
Specific charge (kg/m^3)	0.78	0.71
Specific drilling (m/m^3)	0.21	0.17

3.2. Environmental effects of plaster stemming method

Vibration and air noise levels for both stemming methods were measured with an Instantel Minimate Blaster placed 32 m away from the blastholes.

In the plaster stemming method, 40 kg explosive per delay was used compared to 36 kg in the drill cuttings stemming. This increase in explosive charge caused an increase in PPV value from 92.8 mm/s to 119.0 mm/s (Figs 6 and 7), whereas it should cause only a 6.8 mm/s increase in PPV value according to calculation from the theoretical formula (1).

Airblast-overpressure is related to the distance and explosive charge weight of per delay. The scaled distance factor (SD) is calculated as follow:

$$SD = D/W^{0.33} \tag{2}$$

where D denotes the distance (m or feet) to the explosive charge and W the explosive charge weight (kg or lb).

In this study, increase in explosive charge caused an increase in airblast-overpressure value from 122.9 dB to 129.0 dB (Figs 6 and 7), whereas it should cause only a 0.4 dB increase in airblast-overpressure value according to calculation from the theoretical formula (2). This also explains that plaster stemming provides better confinement compared to drill cuttings.

The vibration and air shock values measured for both the drill cuttings stemming and the plaster stemming at the Asagi Caglayan basalt quarry test trials were above the safety limits specified in the limit criterion due to short measuring distance, which was 32 m. At the top level bench, small quantities of fly rock were generated, but this did not constitute a major problem.

In addition, the plaster stemming round resulted in a slightly more scattered muck pile owing to more blast energy directed to the rock, but this did not create a big problem either. Loading of the muck pile was easier due to the looser particles.

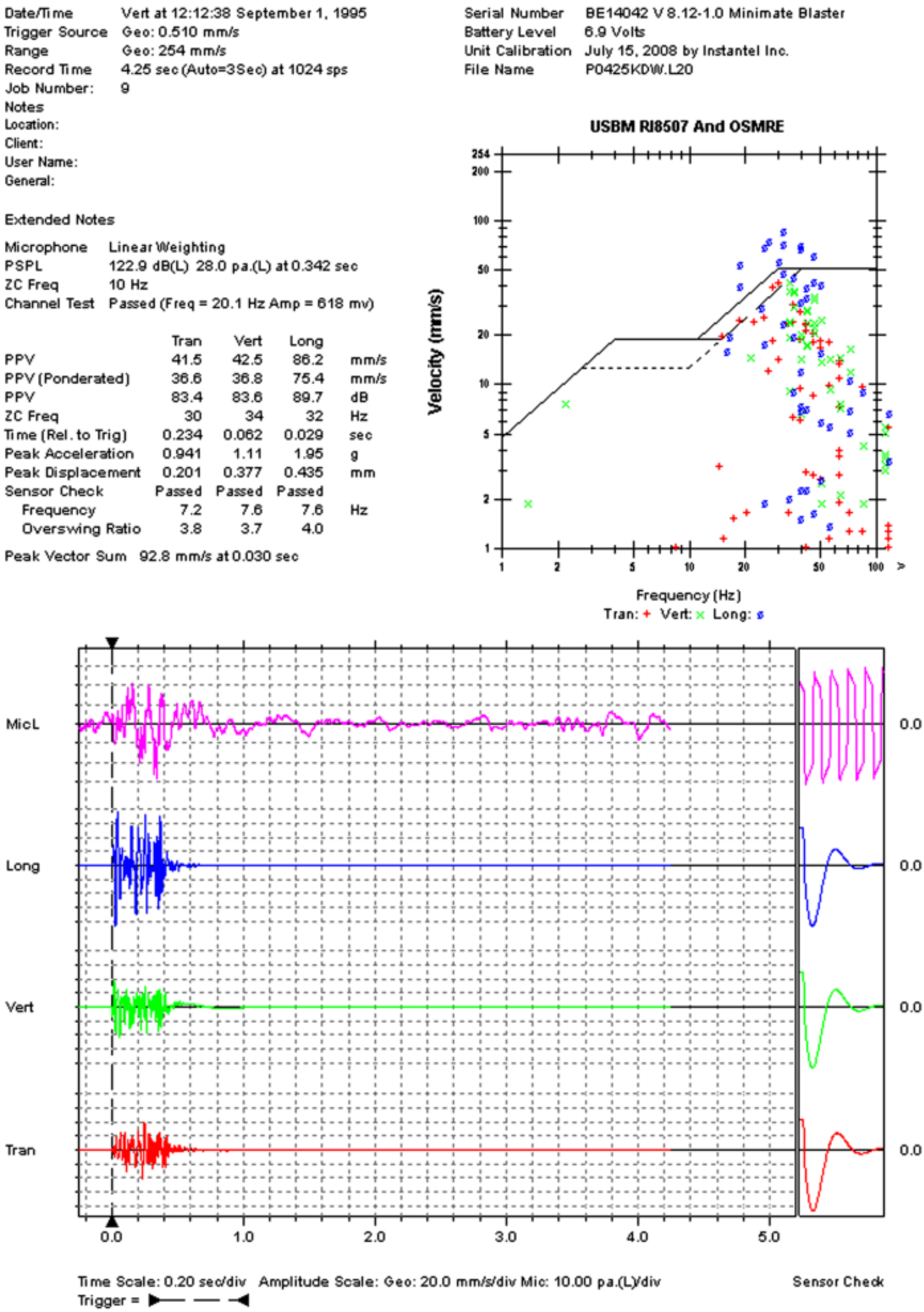


Fig. 6. Measured vibration and noise levels in the drill cuttings stemming test at Asagi Caglayan basalt quarry

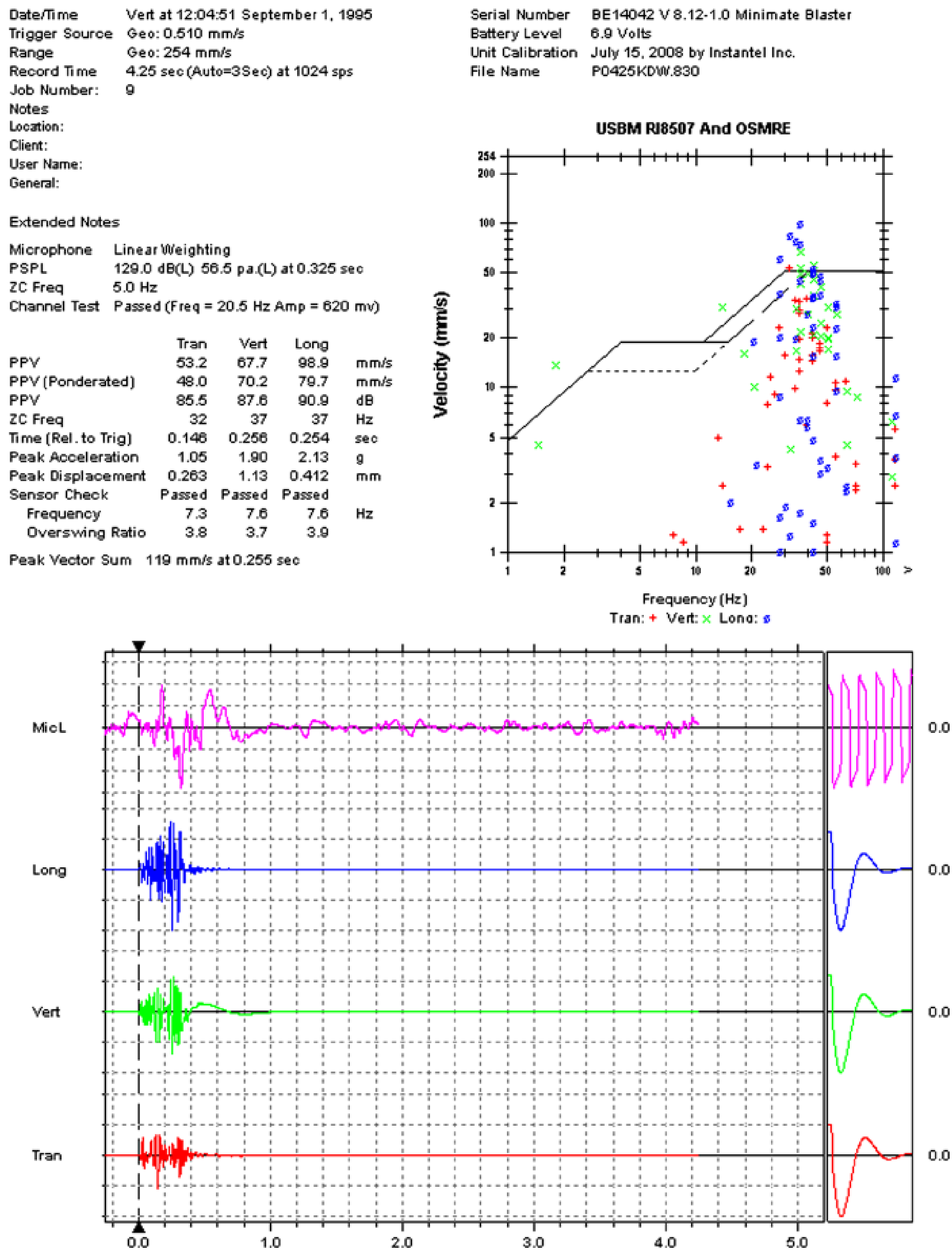


Fig. 7. Measured vibration and noise levels in the plaster stemming test at Asagi Caglayan

4. Conclusion

Blasting experiments carried out in basalt quarry proved that the plaster stemming results in better confinement in blastholes, especially in short holes, where the explosive column length is short giving a lower explosive charge. In such cases, the plaster stemming method offers great benefits in breaking rock more effectively. Also, this method of stemming provided better fragmentation at the upper collar region and prevented production of oversized boulders since stemming length were lesser than drill cuttings stemming.

Additionally, the new method offers a more profitable solution. The cost of drilling for one metre of hole length is almost $10.8. With plaster stemming, more of the hole length is better utilized by increasing the loaded length of hole, resulting in better breakage at the hole collar. The increased length of loading in the hard cap rock region improves the cap rock breakage, thus reducing the creation of oversized boulders and increasing both efficiency and profit (Cevizci & Ozkahraman, 2012). It was observed that a plaster stemming column 0.5 m in length provided a more robust sealing than 2.2 m of drill cuttings used in the classical method.

The energy utilization rate increased with the plaster stemming method by creating effective confinement with better clogging. Also, better fragmentation, increased vibration levels, fly rock and air shock levels are all indicators of the increase in energy usage. But these increased values were small and under the permitted limit for blast damage criteria, in spite of short measuring distance, 88 m (Cevizci, 2012).

In plaster stemming, if the total length of stemming including the top and bottom drill cuttings is more than 100 cm, the muck pile scatter distance is the same as for the drill cuttings stemming. It is found that total length of the plaster stemming method should be 125 cm-150 cm; if it exceeds 150 cm muck pile fragmentation becomes worse.

Recently, this stemming method was found acceptence by some quarries. It was reported from these quarries that new method meet their needs for aggregate production with minimum cost.

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References

Boshoff D., Webber-Youngman R.C.W., 2011. *Testing stemming performance, possible or not?* The J. of the South African Inst. of Min. and Metall., December, p. 871-874.

Cevizci H., 2012. *A newly developed plaster stemming method for blasting*. The J. of the South African Inst. of Min. and Metall., December, p. 1071-1078.

Cevizci H., Özkahraman H.T., 2012. *The effect of blast hole stemming length to rockpile fragmentation at limestone quarries*. International Journal of Rock Mechanics and Mining Sciences, vol. 53, p. 32-35.

Devine J., Beck R., Meyer A., Duvall W., 1966. *Effect of charge weight on vibration levels from quarry blasting Bureau of Mines*. Washington.

Dobrilović M., Ester Z., Janković B., 2005. *Measurement in blast hole stem and influence of stemming material on blasting quality*. [In:] Rudarsko-geološko-naftni zbornik, Vol. 17, Zagreb, p. 47-53.

Karakus D., Pamukcu C., Onur A.H., Konak G., Safak S., 2010. *Investigation of the effect of ground vibration on buildings due to blasting*. Arch. Min. Sci., Vol. 55, No 1, p. 123-140.

Ozkahraman H.T., 2006. *Fragmentation assessment and design of blast pattern at Goltas limestone quarry, Turkey*. International Journal of Rock Mechanics& Mining Sciences, 43. p. 628-633.

Tamrock, 1984. *Handbook on Surface Drilling and Blasting*. Painofaktorit, Finland, 310 pp.

Zhu Z., Xiea H., Mohanty B., 2008. *Numerical Investigation of Blasting-induced Cracking in Cylindrical Rocks*. Int. J. of Rock Mechanics and Mining Science, Vol. 45, No. 2, p. 111-121.

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