Effect of a pre-split plane on the frequencies of blast induced ground vibrations

Önder Uysal[1] *and* ***Mustafa Cavus***[2]

The effect of pre-split type artificial discontinuities on frequencies and peak particle velocities (PPV) of blast-induced ground vibrations was investigated. An artificial discontinuity (pre-split plane) was formed in between the blasting area and a recording station. The pre-split plane was generated by blasting a relatively small amount of explosives charged to holes at 1 meter intervals. Blast-induced ground vibrations were recorded in front of and behind the pre-split plane. In total, 126 ground vibrations were recorded. The experiments were carried out in Seyitomer Lignite Enterprise, Turkey. As a result of the assessment of the data, It was found that pre-split plane led to a sharp decrease in both PPV and frequency values. While the decrease in PPV has a positive influence on damage criteria, the decrease in frequency has a negative influence. This study focuses on an evaluation of frequency values which have been rather disregarded.

Keywords*: Ground vibration, Blasting, Pre-split, Frequency, PPV*

Introduction

Blasting is one of the most indispensible components of rock fragmentation in the constructions, mines, dams, and highways. However, it leads to various problems such as ground vibration, air shock or fly rocks particularly in areas that are close to public settlements. The first solution may be to decrease explosive charge per delay. However, this may also affect particle size or production rate. On the issue of minimizing blasting-related complaints, a large number of studies have been carried out apart from the ones that particularly focus on the reduction of explosive. Some of these studies investigated changing the blast-hole geometry (burden, spacing, drill hole length, drill hole diameter) (Bergmann et al., 1973; Blair and Birney, 1994; Lui and Ludwig, 1996; Heilig et al., 1997; Bilgin et al., 1998; Arpaz, 2000; Brent et al., 2002; Uysal et al., 2007), pre-split application (Devine et al., 1965; Berzal, 1976), barrier application (Uysal et al., 2008; Cebi, 2007) and trench application (Prakash et al., 2004; Fourney et al., 1997; Erarslan et al., 2008). In these studies, vibrations that are caused by blasting have been reported to have diminished at varying ratios. It is well known that peak particle velocity (PPV) is not the only parameter to take into account when investigating the impact of ground vibration on buildings. There are also other criteria that must be investigated. One of them is frequency. It is also a must to consider the frequency because it is frequency that makes habitants feel even the low-magnitude vibrations which do not generally lead to damage. This is solely due to the characteristics of low frequency waves (Bilgin et al., 1998). Low frequency waves are easily felt by habitants. Moreover, since frequencies below 10 Hz lead to vast displacements and large-scale unit deformations on the surface, low frequency waves are prone to increase the risk of damage (Siskind et al., 1980).

Many researchers have carried out studies that focus on decreasing PPV values. However, in these studies, details about the frequency values were relatively restricted. Prakash et al (2004) measured ground vibrations behind trenches of different depths. In addition to PPV values, the authors also surveyed the changes in frequency values. They concluded that frequency values increase at varying ratios depending on the depth of the trenches.

In the present study, the effect of a pre-split plane on frequency and PPV of ground vibration between the blasting area and the recording station was investigated. Measurements of blast induced vibration were taken behind and in front of a pre-split plane. A 58 % decrease was found in PPV values behind the pre-split. This reduction is of utmost importance in eliminating blast-based complaints. However, in order to provide an accurate assessment of the decrease in blast-induced ground vibrations, frequency must also be investigated.

[1] *Önder Uysal, M.Sc., PhD*., Dumlupinar University, Mininf Engineering Department, Kutahya, 43260, Turkey, uysal@dpu.edu.tr
[2] *Mustafa Cavus, M.Sc.,* Seyitomer Lignite Enterprise, 43100 Kütahya, Turkey, Mustaf43@mynet.com

Importance of Frequency

Damage risk in buildings is related to the between the frequency of the blast-induced wave and natural frequency of the building. Natural frequency of one or two storey buildings generally ranges between 5-10 Hz (Dowding, 1992). When the frequency of the ground vibration is equal to or close to the natural frequency of the building, the building begins to resonate. In such cases, buildings continue vibrating even after the ground vibration wave away. What makes habitants uneasy is that resonance. When the building is in resonance, no damage occurs to the building if the particle velocity is far below the limits, but habitants may feel uneasy. However, if the particle velocity is high during resonance, the building suffers damage. In the view of this fact, the most critical frequency value is between 5-10 Hz in regard to the damage risk.

Frequency also appears to be important in forming blast-based damage criteria. According to the first damage criteria established by USBM (Siskind et al., 1980), PPV limit for 3-100 Hz frequency levels was determined as 51 mm/s (Nichols et al., 1971). The USBM's 51 mm/s vibration criterion for ground vibrations (which does not include frequency) was used to regulate blasting but could not properly reflect the effect of a variety of dynamic soil-structure interactions. Therefore, this criterion did not turn out to be effective in preventing numerous complaints from habitants. It became necessary to take into account the dominant vibration frequency to assess the vibration effect on structures. Intensive studies of residential structural damage in connection with measured displacement and velocity were conducted at the frequency range of 1-100 Hz by the USBM. As a result, the frequency-based safe limits for cosmetic cracking threshold shown in Figure 1 were developed, RI 8507 (Siskind et al., 1980). As safe-level guidelines, these limits reduced the existing 51 mm/s safe-level criterion by a factor of 2.5 to 3 in the frequency range of 4-12 Hz. RI 8507 has been recognized as a great achievement that provided the safety of low-rise residential structures from vibrations generated by mining blasting.

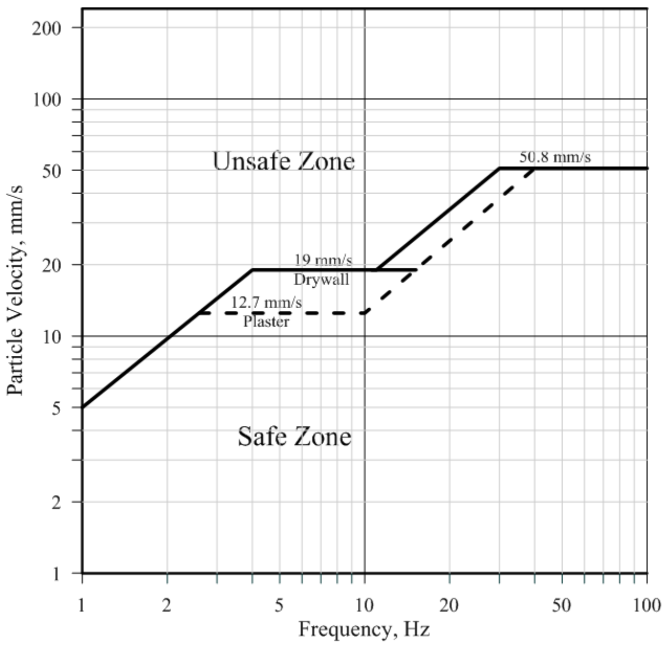

Fig. 1. The safe level blasting criteria from the USBM RI 8507 (Siskind et al., 1980).

Experiment field

Experiments were implemented in Seyitomer Coal Enterprise (SLE) of the Turkish National Coal Board, 30 km from Kutahya, Turkey (Fig. 2) (Erarslan et al., 2008).

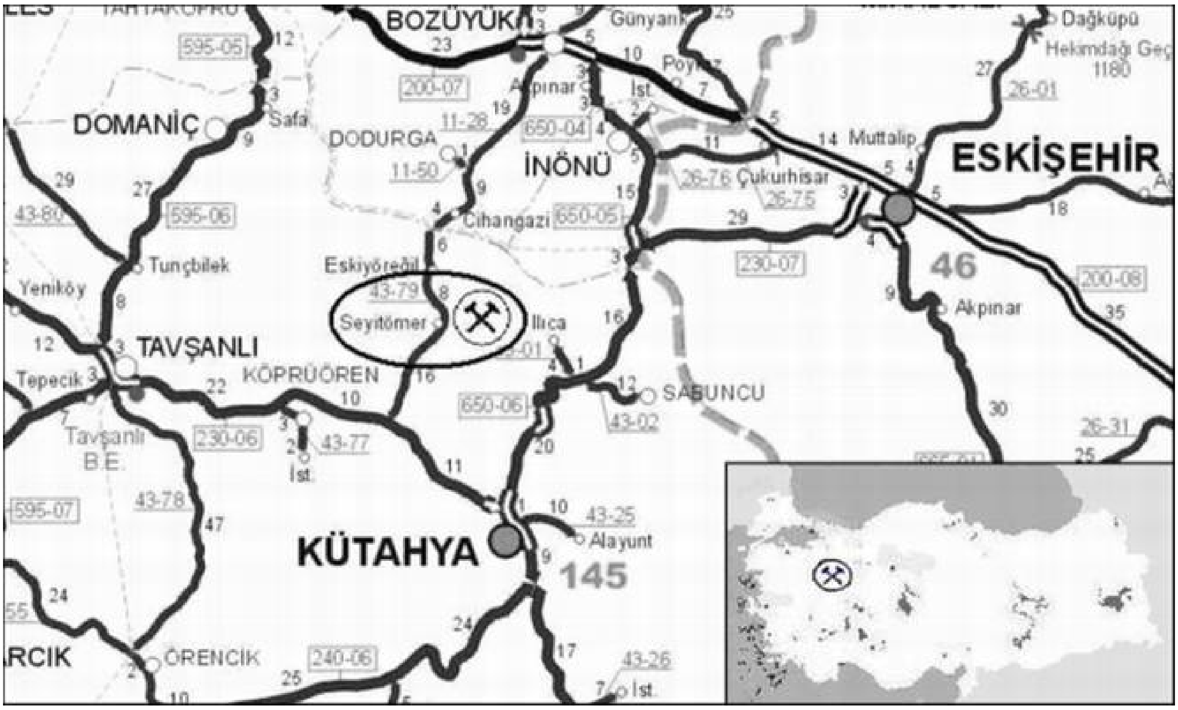

Fig. 2. Location map of Seyitomer Lignite Enterprise in Turkey (Erarslan et al., 2008).

Geology

The Seyitomer basin is a sedimentary type lake of Neogene period. According to paleontological indications, sediments in the lake base belong to late-miocene or early pliocene periods (Ozcan, 1986). Basic rocks before Neogene are of Cretaceous age (Akkus, 1962; Okay, 1981). Neogene sediments can be classified into two groups as Seyitomer and Kocayatak formations (Sariyildiz, 1987). Base rocks are ophiolitic serpentines.

The Seyitomer formation includes five members, namely sandstone-conglomerate, mudstone-claystone, laminated shale, silicified limestone and clayey limestone (Sariyildiz, 1987). Laminated shale (marl) where blasting operations were carried out is greenish gray, partially light gray and greenish white colored. Yellowish gray colored siltstone and light brown silicified limestone are seen as inter-layers.

Mining

Open pit mining method is applied and drilling-blasting is carried out for loosening. A 45 m^3 (60 yd^3) dragline is used to move blasted material. There are several villages around the mine. Residents of the villages complain and suffer from blast induced vibrations. Sometimes the enterprise is faced to reimburse the damages. Engineers of the enterprise try several blasting patterns to overcome the problem.

This experimental research has been realized in the dragline panel. It was 400 m long and 100 m wide. The overburden material was the marl whose mechanical properties are given in Table 1. One section of the formation is given in Figure 3. Blast holes were 24 m deep and 228.6 mm (9 inch) in diameter (Fig. 4) (Uysal et al., 2008). Burden and spacing of the blast holes were 10 m. Explosive is ANFO. The delay between each hole was 42 m and in-hole delay, 25 m.

Tab. 1. Mechanical properties of the marl formation.

Density [g/cm^3]	2.17
Unaxial compressive strength [MPa]	6.63
Indirect tensile strength [MPa]	1.6
Schmidt hardness	29.37 (Slight strong)
Point load test [MPa]	1.74
Friction angle [°]	9
Cohesion [MPa]	3.4

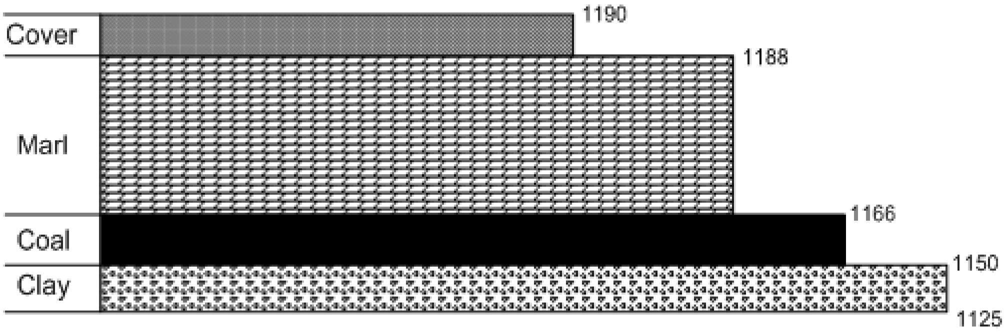

Fig. 3. Section view of the formation carried out experiments.

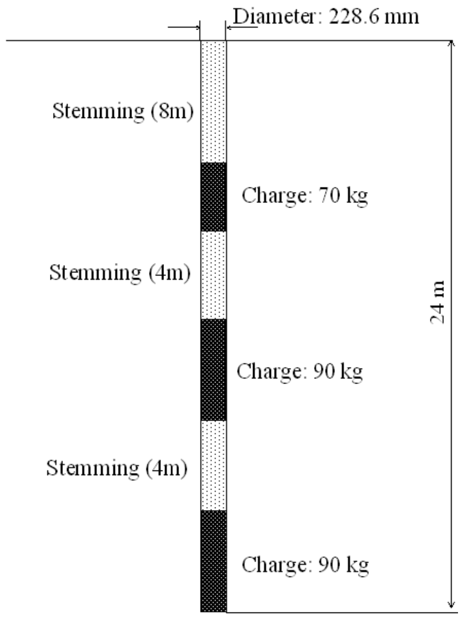

Fig. 4. Charge method of the blast holes (Uysal et al. 2008).

Test Procedure

In this study, the effect of a pre-split plane on frequency of ground vibration was investigated. A pre-split plane was formed between the blasting area and a recording station (Fig. 5). To form the pre-split holes were drilled at 1 meter intervals. Those holes were 228.6 mm (9 inches) in diameter and 24 m deep. 25 kg explosive was placed into each of these holes. Pre-split holes were blasted in one go with delays. The blasts formed a loose zone of approximately 2 meters long with cracks. For recordings two correlated instruments (Instantel minimate plus, Instantel minimate blaster) were used. Instruments were located 2 m in front and 2m behind the pre-split plane (Fig. 6). The PPV and frequency values of the blasts were recorded.

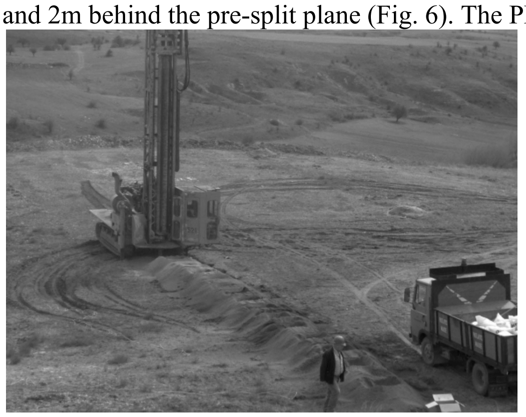

Fig. 5. Pre-split plane employed in the experiments.

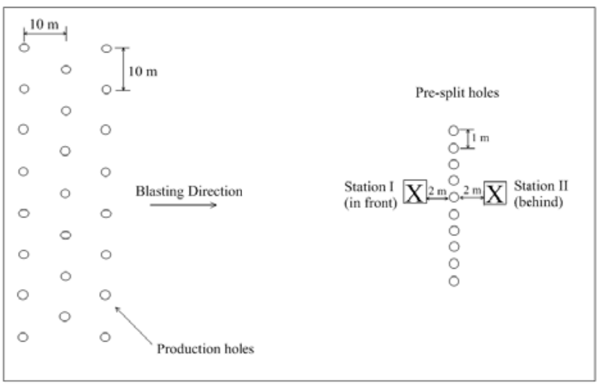

Fig. 6. Pre-split plane and record stations used in the experiments.

Measurement results

126 ground vibrations were recorded from 63 blasts. 63 were recorded in front of the pre-split, and 63 behind it. The distance between blasts and recording stations was increased up to 400 from 75 m. Data about the blasts and the results are shown in Table 2 (Cavus, 2010).

Table 2. Result of the vibration measurements (Cavus 2010).

	in front of the pre-split plane					**behind the pre-split plane**					**Variation**	
Shot No	**Distance** [m] **R**	**Charge per delay** [kg] **W**	**Scaled Distance** [R/W$^{0.5}$]	**PPV** [mm/s]	**Frequency** [Hz]	**Distance** [m] **R**	**Charge per delay** [kg] **W**	**Scaled Distance** [R/W$^{0.5}$]	**PPV** [mm/s]	**Frequency** [Hz]	**PPV** [%]	**Frequency** [%]
1	350	90	36.89	8.76	16	354	90	37.31	7.87	14	**-10.16**	**-12.50**
2	350	90	36.89	9.78	16	354	90	37.31	7.24	12	**-25.97**	**-25.00**
3	350	90	36.89	8.89	4	354	90	37.31	7.37	3.8	**-17.10**	**-26.92**
4	342	90	36.05	8.51	4.3	346	90	36.47	7.25	3.8	**-14.81**	**-30.91**
5	343	450	16.17	16.40	13.0	347	450	16.36	14.7	8.1	**-10.37**	**-37.69**
6	385	450	18.15	11.4	14.0	389	450	18.34	10.2	17.0	**-10.53**	**21.43**
7	350	450	16.50	17.5	14.0	354	450	16.69	11.8	19.0	**-32.57**	**35.71**
8	360	120	32.86	9.8	6.9	364	120	33.23	7.6	6.2	**-22.09**	**-10.14**
9	343	120	31.31	12.80	11.0	347	120	31.68	7.62	3.8	**-40.47**	**-65.45**
10	400	120	36.51	14.2	6.8	404	120	36.88	5.97	6.5	**-57.96**	**-4.41**
11	338	600	13.80	17.00	13.0	342	600	13.96	14.60	12.8	**-14.12**	**-1.54**
12	338	600	13.80	14.60	12.0	342	600	13.96	12.70	18.0	**-13.01**	**50.00**
13	328	90	34.57	17.00	8.3	332	90	35.00	12.30	13	**-27.65**	**56.63**
14	343	90	36.16	20.80	9	347	90	36.58	14.90	7.8	**-28.37**	**-13.33**
15	328	90	34.57	17.90	16	332	90	35.00	13.70	14	**-23.46**	**-12.50**
16	360	600	14.70	11.7	3.2	364	600	14.86	10.2	3	**-12.82**	**-6.25**
17	350	600	14.29	11.3	5.7	354	600	14.45	8.6	4.8	**-23.54**	**-15.79**
18	330	600	13.47	13.8	5.0	334	600	13.64	8.5	4.0	**-38.33**	**-20.00**
19	350	90	36.89	9.4	15	354	90	37.31	6.1	3.2	**-35.11**	**-78.23**
20	340	90	35.84	12.4	5.1	344	90	36.26	8.8	4.2	**-29.35**	**-17.65**
21	330	90	34.79	15.4	14	334	90	35.21	10.7	4.8	**-30.52**	**-65.71**
22	255	90	26.88	12.7	9	259	90	27.30	11.6	5.3	**-8.66**	**-41.11**
23	292	90	30.78	8.8	4.2	296	90	31.20	7.3	5.4	**-16.67**	**5.88**
24	282	90	29.73	14.2	7.1	286	90	30.15	9.1	4.9	**-35.63**	**-30.99**
25	262	90	27.62	12.4	3.7	266	90	28.04	10.8	4.7	**-12.90**	**27.03**
26	242	90	25.51	14.20	8.7	246	90	25.93	12.3	4.5	**-13.38**	**-48.28**
27	232	90	24.45	15.20	14	236	90	24.88	13.3	12.1	**-12.50**	**-13.57**
28	270	90	28.46	10.50	6.6	274	90	28.88	8.38	4.3	**-20.19**	**-34.85**
29	270	90	28.46	14.70	4.5	274	90	28.88	12.40	2.6	**-15.65**	**-42.22**
30	260	90	27.41	16.10	6.0	264	90	27.83	13.90	4.1	**-13.66**	**-31.67**
31	250	90	26.35	19.00	4.1	254	90	26.77	15.80	3.1	**-16.84**	**-24.39**
32	260	90	27.41	14.70	3.3	264	90	27.83	13.00	3.2	**-11.56**	**-3.03**
33	269	90	28.36	20.4	4.9	273	90	28.78	17.30	4.1	**-15.20**	**-24.07**
34	289	90	30.46	13.8	3.9	293	90	30.88	12.10	3.2	**-12.32**	**-17.95**
35	279	90	29.41	13.1	3.2	283	90	29.83	11.20	4.5	**-14.50**	**40.63**
36	251	90	26.46	21.1	6	255	90	26.88	15.20	4.5	**-27.96**	**-25.00**
37	269	90	28.36	18.5	5.5	273	90	28.78	16.70	4.1	**-9.73**	**-25.45**

38	230	90	24.24	12.8	17	234	90	24.67	11.2	3.7	**-12.50**	**-78.24**
39	250	100	25.00	13.5	4.3	254	100	25.40	11.8	3.3	**-12.59**	**-23.26**
40	260	90	27.41	11.9	9.5	264	90	27.83	9.8	4.5	**-17.65**	**-52.63**
41	250	90	26.35	13.00	5	254	90	26.77	10.9	4.1	**-16.15**	**-18.00**
42	240	90	25.30	13.8	4	244	90	25.72	11.7	3.7	**-15.22**	**-7.50**
43	230	90	24.24	10.5	4.3	234	90	24.67	9.5	3.9	**-9.52**	**-9.30**
44	230	90	24.24	14.5	7.1	234	90	24.67	12.8	4.7	**-11.72**	**-33.80**
45	185	90	19.50	40	4.2	189	90	19.92	25	17	**-37.50**	**304.76**
46	175	90	18.45	68.8	10	179	90	18.87	28.4	4.8	**-58.72**	**-52.00**
47	185	90	19.50	26.8	6.1	189	90	19.92	23	5.4	**-14.18**	**-11.48**
48	175	90	18.45	36.2	7.9	179	90	18.87	23.6	18	**-34.81**	**127.85**
49	185	90	19.50	57.4	22	189	90	19.92	49	16	**-14.63**	**-27.27**
50	175	90	18.45	18.5	6.8	179	90	18.87	15.6	5	**-15.68**	**-26.47**
51	175	90	18.45	48.1	20	179	90	18.87	36.6	19	**-23.91**	**-5.00**
52	125	100	12.50	42.4	15	129	100	12.90	25	7.1	**-41.04**	**-53.29**
53	75	100	7.50	36.2	16	79	100	7.90	30.4	9	**-16.02**	**-43.75**
54	75	100	7.50	38.7	18	79	100	7.90	28.8	6.8	**-25.58**	**-62.22**
55	125	100	12.50	40.5	18	129	100	12.90	28.8	10	**-28.89**	**-44.44**
56	135	100	13.50	28.1	6.4	139	100	13.90	15.7	5.8	**-44.13**	**-9.38**
57	115	100	11.50	40.3	5.7	119	100	11.90	33	5.4	**-18.11**	**-5.26**
58	130	100	13	25.1	7.5	134	100	13.40	21.4	5.9	**-14.74**	**-21.33**
59	95	100	9.50	39.5	6.1	99	100	9.90	34	17	**-13.92**	**178.69**
60	85	100	8.50	41	14	89	100	8.90	35.2	5.7	**-14.15**	**-59.29**
61	75	100	7.50	46.5	15	79	100	7.90	35.4	7.6	**-23.87**	**-48.99**
62	75	100	7.50	47.2	10	79	100	7.90	36.7	8.1	**-22.25**	**-19.00**
63	75	100	7.50	46.5	8.3	79	100	7.90	41.7	8	**-10.32**	**-3.61**

Evaluation of the results

The results given in Table 2 include PPV and frequency. PPV values fell by up to 58 %. This signifies an important decrease. When investigating blast-induced ground vibrations, frequency must also be taken into consideration. Frequency values were generally below 10 Hz. This finding further accentuates the importance of frequency in the area since these values are close to the natural frequencies of buildings.

When Table 2 is examined, it is obvious that the frequency values obtained from behind the pre-split are lower than the ones obtained from the front. From 53 of the 63 blasts, lower frequency values were obtained behind the pre-split; only in 10 higher frequency values were obtained. The variations among the frequencies were far different. The range between 1.54 % and 78.24 % in the 53 blasts where the frequency decreased. In the 10 blasts, where the frequency increased, the differences range between 5.88 % and 304.76 %. The frequency values obtained in front of and behind the pre-split are given in Figure 7.

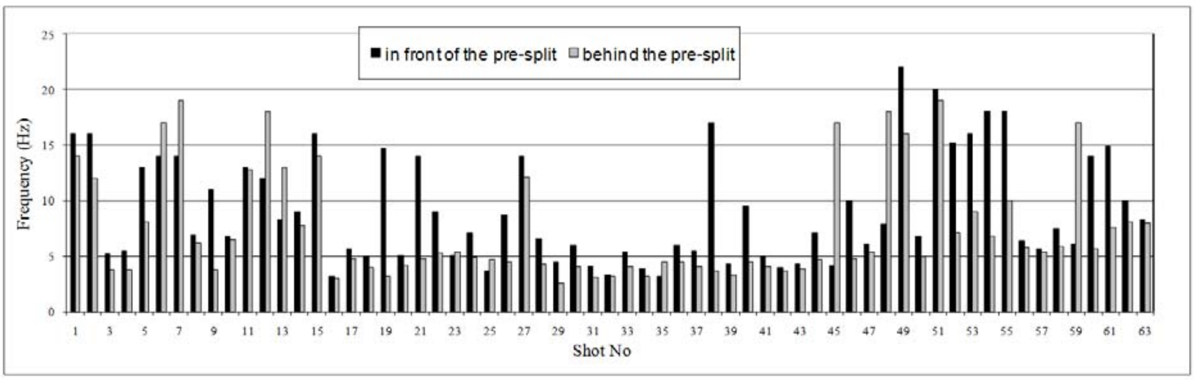

Fig. 7. The frequency values measured in front of and behind the pre-split.

The graphics clearly demonstrate that the frequency values at behind the pre-split are generally lower. In front and behind the pre-split, a difference is also observed in the separation of frequency values. Distribution of the frequencies is given in Figure 8. In front of the pre-split, frequency values concentrated ranging between 5 and 7 Hz. Behind the pre-split, the majority of the frequency values range from 3 to 5 Hz.

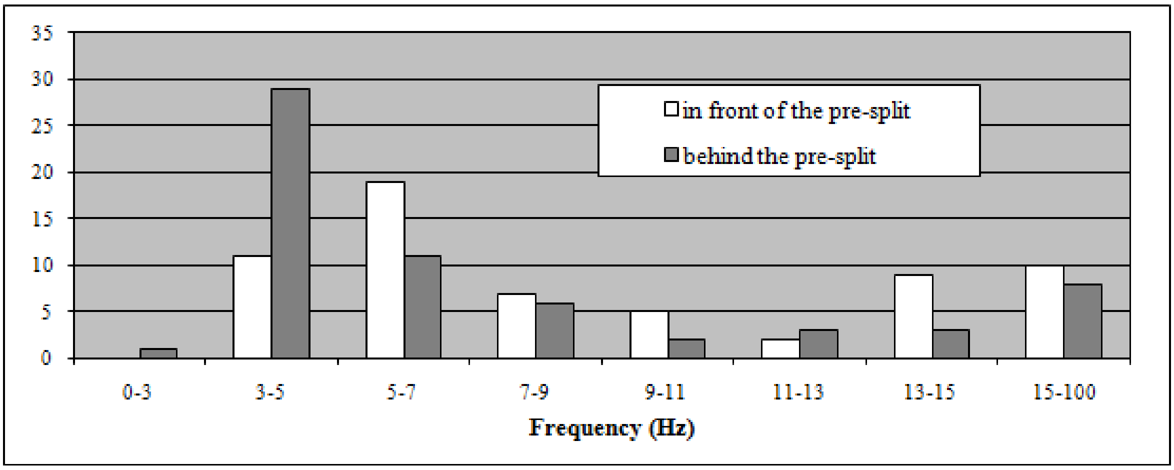

Fig. 8. Scatter diagram of the frequency measured in front of and behind the pre-split.

It is possible to draw two conclusions from this study. The first finding is that it is possible to decrease PPV values in the desired way. The other finding is that there was an undesired fall in the frequency values. To show the two sets of data together, PPV and frequency values were marked on the graph, developed by USBM, which indicates the damage criteria (Fig. 9). From this graph, the positive effect of reduction of PPV and the negative effect of reduction of frequency can be seen.

The fluctuations in frequency are thought to have been originated by the disturbance in wave pattern that is caused by pre-split plane during the spread of blast-induced vibrations. Frequency is closely related to the features of the ground. Frequency is high in hard and strong formations, and low in loose formations. The data shows that when the vibration waves rising from the ground reach the pre-split plane, the loose zone there decreases the vibration frequency. Low frequency rates are a disadvantage in terms of damage criteria due to the fact that low frequency takes down damage limits.

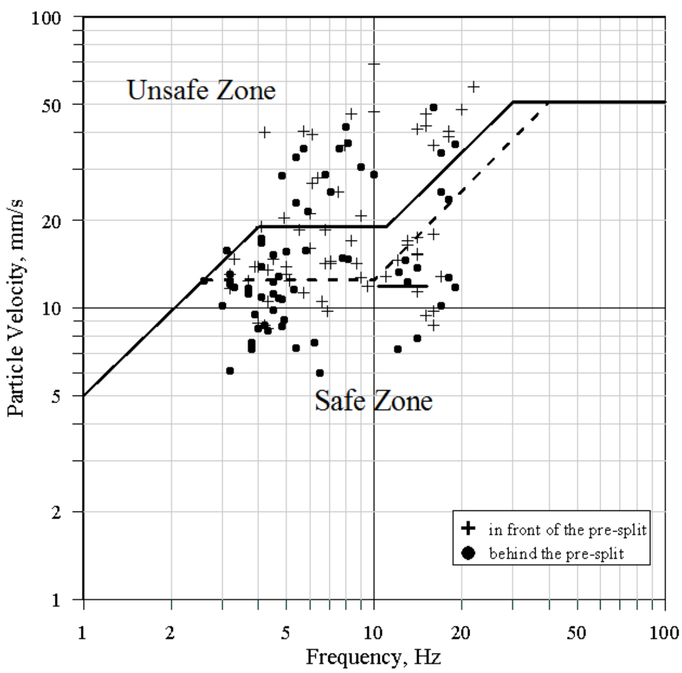

Fig. 9. Evaluation of the measured values according to the USBM damage criteria.

Conclusions

In this study, the effects of pre-split plane on blast-induced ground vibrations were investigated. Ground vibration values were measured behind and in front of a pre-split plane. The pre-split plane provided a decrease of up to 58 % in PPV values. This study has shown the need to take into account frequency values in ground vibrations. After evaluating the frequency values, contrary to what was expected, decreases in the frequency behind the pre-split plane were observed. However, these decreases were not too sharp. As is known, the decrease in the frequency increases the risk of blast-induced damage. This study clearly indicates that the impact of the intended measure on frequency must be taken into account in studies that are carried out to investigate the reduction in vibration. In future studies, when setting up the pre-split plane, it would be wise to form a hard corrugated ground instead of a loose one to increase frequency besides decreasing PPV values.

***Acknowledgments**: The authors are grateful to the staff of the Seyitomer Coal Enterprise for their hospitality and kind support during the field investigations.*

References

Akkus M.F.: Kütahya Gediz arasındaki sahanın jeolojisi, *M.T.A. 58:20-30, 1962*.

Arpaz E.: Türkiye'deki Bazı Açık İşletmelerde Patlatmadan Kaynaklanan Titreşimlerin İzlenmesi ve Değerlendirilmesi, *Cumhuriyet University, PhD Thesis Sivas, Turkey (in Turkish), 2000*.

Bergmann O.R., Riggle J.W., Wu F.C.: Model rock blasting effect of explosives properties and other variables on blasting results. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 10:558-612, 1973*.

Berzal R.L.: Blasting vibration levels transmitted across fracture planes. *Mining Magazine October: 135(4):361-363, 1976*.

Bilgin A., Esen S., Kılıç M.: TKİ Çan Linyit İşletmesi'nde Patlatmaların Yol Açtığı Çevre Sorunlarının Giderilmesi İçin Araştırma. *Final Report, Turkish Coal Enterprise, Ankara, 1998*.

Blair D.P., Birney B.: Vibration Signatures Due to Single Blastholes Fired in the Charlotte Deeps. *ICI Confidential Internal Report, 1994*.

Brent G.F., Smith G.E., Lye G.N.: Studies on the effect of burden on blast damage and the implementation of new blasting practices to improve productivity at KCGMs Fimiston Mine. *Fragblast 6:189-206, 2002*.

Cavus M.: Açık işletmelerde yapay süreksizliklerin patlatma kaynaklı yer sarsıntıları üzerindeki etkisi. *MSc Thesis, Dumlupinar University, Turkey (in Turkish), 2010*.

Cebi M.A.: SLI'de yapay süreksizliklerin patlatma kaynaklı yer sarsıntılarına etkisinin incelenmesi. *MSc Thesis, Dumlupinar University, Turkey (in Turkish), 2007*.

Devine J.F., Beck R.H., Meyer A.V.C.: Vibration levels transmitted across a presplit fracture plane. RI 6695, *US Bureau of Mines p 29, 1965*.

Dowding C.H..: Monitoring and control of blast effects. *SME Mining Engineering Handbook, H.L. Hartmon, Ed. Society of Mining Engineers, pp. 746-760, 1992*.

Erarslan K., Uysal O., Arpaz E., Cebi M.A.: Barrier holes and trench application to reduce blast induced vibration in Seyitomer coal mine. *Environmental Geology, 54:1325-1331, 2008*.

Fourney W.L., Dick R.D., Fordyce D.F., Weaver T.A.: Effects of open gaps on particle velocity measurements. *Rock Mech Rock Engng 30: 95-111, 1997*.

Heilig J., Zoitsas A., Cox N.: Free face blasting: Is it the best for quarry? *41st Annual Conf. Institute of Quarrying, Australia, 1997*.

Lui Q., Ludwig G.: A blast damage study in blasthole open stope mining. *15th Int. Symp. on Rock Fragmentation by Blasting. Balkema, Vienna, 451-459, 1996*.

Nicholls H.R., Johnson C.F., Duvall W.I.: Blasting Vibrations and Their Effects on Structures. *United States Department of Interior, USBM, Bulletin 656, 1971*.

Okay A.: Kuzeybatı Anadoludaki Ofiyolitlerin Jeolojisi ve Mavişist Metamorfizması (Tavsanlı-Kütahya), *TJK Bulletin 24:85-95, 1981*.

Ozcan N.: Seyitomer (Kutahya) Linyitlerinin Polinolojik ozellikleri. *MSc Thesis, Dokuz Eylul University, Turkey (in Turkish), 1986*.

Prakash A.J., Palroy P., Misra D.D.: Analysis of blast vibration characteristics across a trench and a pre-split plane. *Fragblast 8 (1):51-60, 2004*.

Sariyildiz M.: Seyitomer(Kutahya) KB'sındaki Kömürlü Neojen Kayaların Jeolojisi. *MSc Thesis, Dokuz Eylul University, Turkey (in Turkish), 1987*.

Siskind D.E., Stagg M.S., Kopp J.W., Dowding C.H.: Structure response and damage produced by ground vibrations from surface blasting. RI 8507, *U.S. Bureau of Mines, Washington, D.C., 1980*.

Uysal O., Arpaz E., Berber M.: Studies on the effect of burden width on blast induced vibration in open pit mines. *Environmental Geology 53:643-650, 2007*.

Uysal O., Erarslan K., Cebi M.A., Akcakoca H.: Effect of barrier holes on blast induced vibration. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 45:712-719, 2008*.