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Timing Simulation for the Selection of Optimum Delay Time

G.G.U.Aldaş
Barutsan A.Ş., Elmadağ, Ankara, Turkey
H.A.Bilgin
Department of Mining Engineering, Middle East Technical University, Ankara, Turkey
S.Esen
Julius Krüllschnitt Mineral Research Centre. The University of Queensland, Brisbane, Qld, Australia

ABSTRACT: This paper presents the use of the blast monitoring system to determine the optunum delay time for blasts in stripping work at Demir Export Kangal/Sivas Surface Coal Mine in Turkey. The blasting procedures and blast monitoring program followed are explained. Eight signature blasts were conducted at (he mine. A high-speed video camera system was used to determine the delay time interval resulting in an adequate relief. A timing simulation of the ground vibration record of one of these shots is carried out. The effect of the delay time on the amplitude of peak particle velocity and frequency İs shown. It was determined that the delay time for this mine was 120 ms, considering both timing simulation and high-speed video camera system output.

1 INTRODUCTION

With the recent advances in blasting technology, it is now possible to avoid many assumptions in blasting. Thus, optimum blast results are achieved considerably faster than with the trial and error approach of relying on the experience factor alone.

This study illustrates an experimental methodology to determine delay time using a blast monitoring system. Ground vibrations from the signature blast, which is defined as the detonation of a single hole at one time, were monitored by seismographs and evaluated by the software of die seismograph. The timing simulation approach to an event in the signature blast may help to determine the optimum delay time that results in lower peak particle velocity (PPV) amplitudes and higher frequencies. Combining the results with a high-speed video camera system, the optimum delay time may be determined. Adequate relief, low PPV amplitudes and high frequency are essential aims of these analyses. Thus, it is necessary to consider the outputs of both the blast vibration monitoring and high-speed video camera system.

One of the most important and constantly growing uses of seismographs is in recording and analysing single hole signature shot waveforms. This is the basis of investigating how delay times and detonator (conventional) scatter can affect ground vibration amplitudes and frequencies from time shifts and the resulting constructive or destructive interference patterns. Without proper simulations, a blaster could unknowingly create intense vibration levels by selecting improper delays (Chıappetta, 1998).

This paper is part of a project carried out jointly by the Middle East Technical University and the BARUTSAN Co. (Bilgin et al., 2000). Fieldwork was conducted in November 1999 at Demir Export Kangal/Sivas Surface Coal Mine in Turkey (Esen et al., unpubl.).

2 OVERBURDEN LITHOLOGY

Discontinuity surveys and seismic refraction technique are employed to characterize the rock mass at Kangal Surface Coal Mine. The rock type and properties of rock (intact and mass) are given in Table 1. The upper part of the current bench, consisting of weak and clayey limestone damaged by the previous blast, has a thickness of 1.0-1.5 m. The insitu p-wave velocity of this layer is 650 m/s. The clayey marl formation which is below this layer has an insitu p-wave velocity of 1500 m/s. A thin and unexploitable coal layer İs occasionally present in this layer.

3 BLASTING OPERATIONS AND BLAST MONITORING

Blasting operations for stripping work at Kangal/Sivas Open Cast Coal Mine in Turkey are carried out to loosen the rock formations for efficient

Table 1. Rock type and properties of rock (intact and mass).

Bench No	310
Rock Type	Clayey-Marl
Weathering	Low-medium
Discontinuity Spacing	1 m
Number of Joints	3
Joint Spacing	0.9 m
Joint Aperture	-
Joint Persistence	Continuous
Insitu p-wave Velocity	1500 m/s
Lab. p-wave Velocity	2902 m/s
Fracture Index	0.64
ROD (calculated)	35.1%
Uniaxial Compressive	8.5 MPa
Tensile Strength	1.23 MPa
Density	1.96 g/cm^3

loading and hauling operations. A shovel / truck combination is utilised for the removal of the upper horizons of overburden, whereas dragline removes the lower parts above the coal seam. This study was conducted at one of the upper benches where the shovel/truck system is used. The bit diameter of the drilling machine was 241 mm. The principal blasting agent was ANFO. Table 2 and Table 3 list the surface blast design parameters of the signature and production blasts, respectively.

The authors did not interfere with the surface blast design parameters of the production blasts. The complete sets of delay detonators were not available in the mine. Therefore, during vibration monitoring, instantaneous (0 ms), 30 ms *and* 330 ms delay caps were used in blasting operations. The authors simply monitored the blasts and obtained the records.

All blasts were monitored by continuous velocity of detonation recorder for assessment of explosive performance and detection of incomplete detonation, if any. A high-speed video camera system was used for determining dynamic response time, delay time and face velocity, and seismographs were used for measuring ground vibration and airblast. The evaluation of the records is discussed in the next section.

4 EVALUATION OF THE RECORDS OF THE BLAST MONITORING SYSTEM

Field velocity of detonation (VOD) measurements were performed with a continuous VOD recorder (VODR-1) developed by EG&G and BAL They were carried out to assess the performance of the blasting agent (ANFO) and primer. It was found that the average VOD of ANFO was 3955 m/s. The tetonation performance of ANFO and the primer has been shown to be sufficient, yielding good blast results (Esen et al., unpubl.).

In order to determine the delay time for this bench which will provide an adequate relief, a KineView 1256p high-speed video camera system was used (Figure 1). Images were obtained at 250 frames per second. MOTION TRACKER - 2D software was used to carry out motion analysis. Markers on the bench were tracked to compute the face velocity and delay time.

Table 2. Blast design parameters for signature blasts.

Bench height	13m
Hole length	12 m
Burden (B)	7m
Stemming length	7m
Weight of Explosive	150 kg
Blasthole inclination	Vertical
Charging configuration	Bottom priming, continu-
Initiation system used	Electric detonator

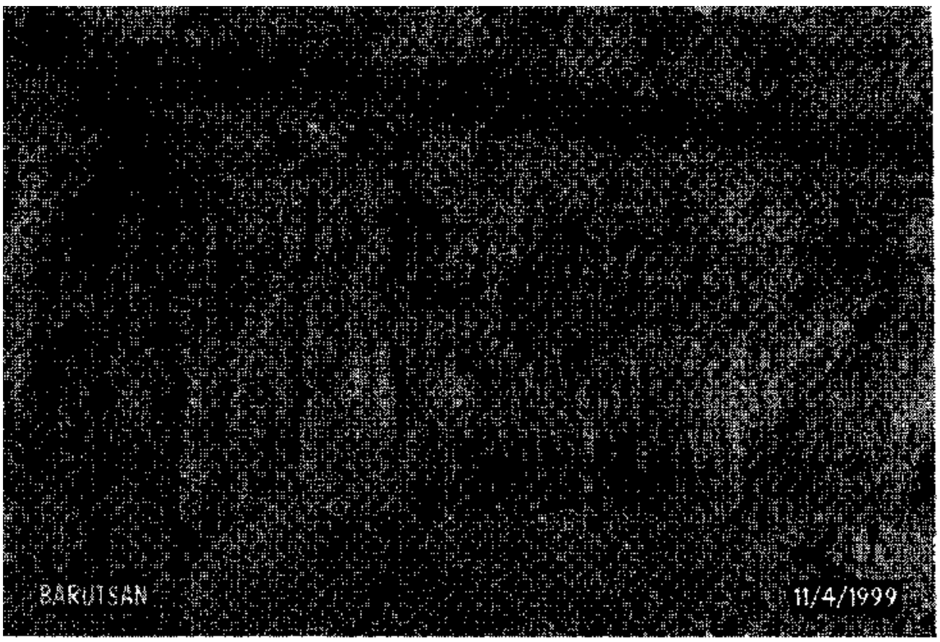
Table 3. Blast design parameters for production blasts.

Bench height	13 m
Hole length	8.2-11.7 m
Burden (B)	9.8-12.3 m
Spacing (S)	8.0-12.3 m
Stemming length	4.9-6.6 m
Weight of Explosive	150-250 kg
Average Specific Charge	0.181 kg/m^3
Blasthole inclination	Vertical
Charging configuration	Bottom priming, continu-
Blasthole partem	Rectangular
Initiation system used	Electric detonator
Delay between rows	0, 30, 330 ms

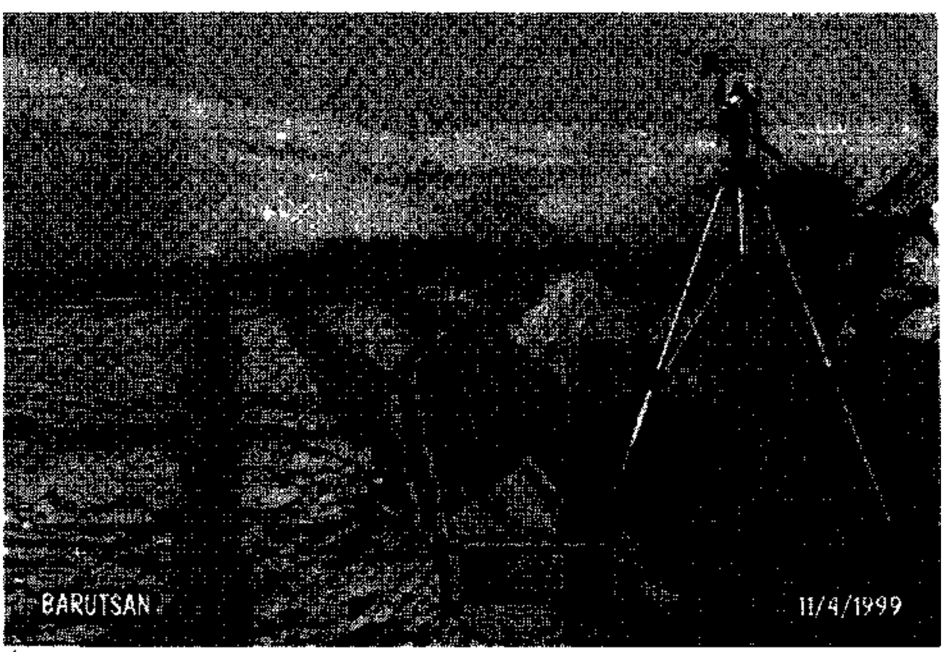
The delay time between rows was found to be in the range of 120-140 ms by the high-speed video camera system. However, the best delay time between rows should be determined by considering the outputs of both a high-speed video camera system and ground vibration analysis.

Eight signature blasts were conducted at bench no. 310. The ground vibration monitoring line was parallel to the bench face (N84E). Blast vibration measurements were carried out using two 4-channel seismographs and one 8-channel seismograph. The PPV in transverse (T), vertical (V) and longitudinal (L) components, the distance from the measurement point to the blast site (R) and the maximum weight of explosives per delay (Q) are shown in Table 4.

When the records from all eight signature blasts are analysed, it can be seen that body waves dominate due to the short scaled and absolute distances. It was also observed that in six of the eight records from single shots, the longitudinal (L) component of vibration dominates. Therefore, in the evaluation of the timing simulation, this component İn particular was taken into account.



(a)



(b)

Figure I {a) Bench face ı!tuvtı<ıltng maiker* (.b) High - speed video camera system

Table 4. Ground vibration levels for signature blasts

Shot No	*Date*	***R, m***	*Q.kg*	*\m/kg^ni*	*T, mm/s*	*V, mm/s*	*L, mm/s*
İ	03.11.1999	20.3	150	1,66	128.0	247.0	178.0
2	03.11.1999	30.3	150	2.47	104 0	208.0	136.0
3	03.11.1999	62 1	150	5.07	125.0	53-7	140.0
4	03.11.1999	50.3	150	4.11	84.5	116.0	123.0
S	03.11.1999	36.0	150	2.94	83.6	85.7	119.0
6	03.11.1999	46.0	150	3.76	87.9	63.8	113.0
7	03.11.1999	77.8	150	6.35	47.4	35-3	58.5
8	03.11.1999	66.0	150	5.39	34.8	35.8	71.1

*SD: Scaled distance

It is well known that pyrotechnic detonators have a certain scatter İn their nominal detonation time. In other words, blastholes in a production blast may detonate at a time different than their nominal detonation time. Furthermore, blast design parameters certainly affect vibration levels. Therefore, it is not possible to use a ground vibration record obtained from a production blast in timing analysis. Ground vibration records from signature blasts should be used in these analyses. Different delay times may be simulated to determine the optimum delay time by using the timing analysis. The optimum delay time is selected considering the PPV amplitudes and frequency spectrum.

The timing simulation of the 7th shot shown in Table 4 was performed. The delay times used in time simulation were 30, 60 90, 120, 150 and 330 ms. the effect of the delay time on the amplitudes of PPV and frequency is shown in Table 5.

It is shown that minimum PPV and suitable frequency values were attained when the delay time was 120 ms. Higher frequency is preferred as there is less risk of damage than with lower frequencies. Figure 2 and Figure 3 illustrate waveforms and frequencies, respectively, for the signature blast and simulated blast with a delay time of 120 ms. Tran, Vert and Long refer to the PPV components in transverse, vertical and longitudinal directions, respectively. SSM1, SSM2 and SSM3 are the PPV components in transverse, vertical and longitudinal directions, respectively, for the new waveform obtained with a delay time of 120 ms.

By considering both the timing simulation of the signature blast vibration and high-speed video camera system analysis, the best delay time between the rows was selected as 120 ms. While determining the optimum delay time for the blasting operations in stripping work, the following criteria are taken into account: good looseness for subsequent loading and hauling operations, minimum PPV values and greater frequencies (above resonant frequencies) that are as high as possible so as not to cause environmental damage.

The site factors determined for signature and production blasts are given in Table 6. Twenty-two ground vibration records were obtained for production blasts. When all of the 22 vibration records from production blasts were analysed in terras of PPVs for the L-component, it was observed that the blasts with instantaneous and 30-ms detonators produced higher vibrations than those blasts with a 330-ms delay penod (Bilgin et al., 2000). This experimental result is also supported by the evidence derived from the timing simulation given in Table 5. Another finding from vibration monitoring of the production blasts was that surface waves (especially Rayleigh waves) dominate in most of the waveforms (Bilgin et al., 2000).

The scaled distance (SD) and monitoring distance (R) ranges of signature and production blasts were 1.66-6.35 m/kg^{0}*, 20.3-77.8 m; 10.25-29 70 nVkg^{05}, 290-630 m, respectively. Unfortunately, due to physical limitations arising from the bench dimensions, the monitoring distances for the signature blasts could not be kept the same as those of the production blasts.

Due to the differences in waveforms, scaled distances and absolute distances, any comparison (and prediction) between signature and production blasts would not be meaningful and reliable. Therefore, in the future, new signature blasts should be conducted at similar distances so that the predicted ground vibrations using timing simulation of the new signature blasts can be meaningfully compared with the ground vibrations resulting from production blasts.

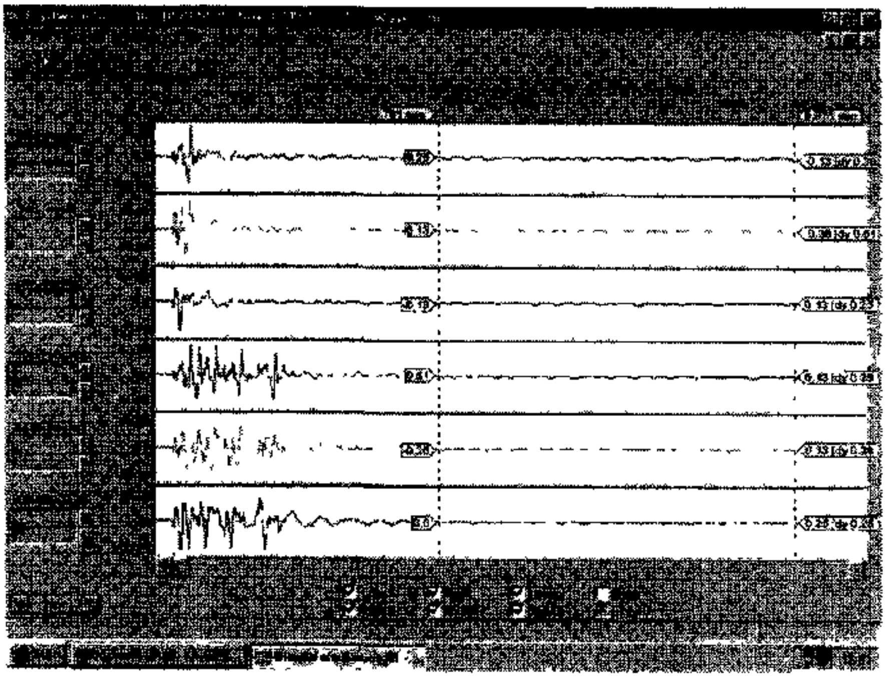


Figure 2 Waveform» *of signature* blast and *simukicd blast* with detay (ime of f 20 *ms.*

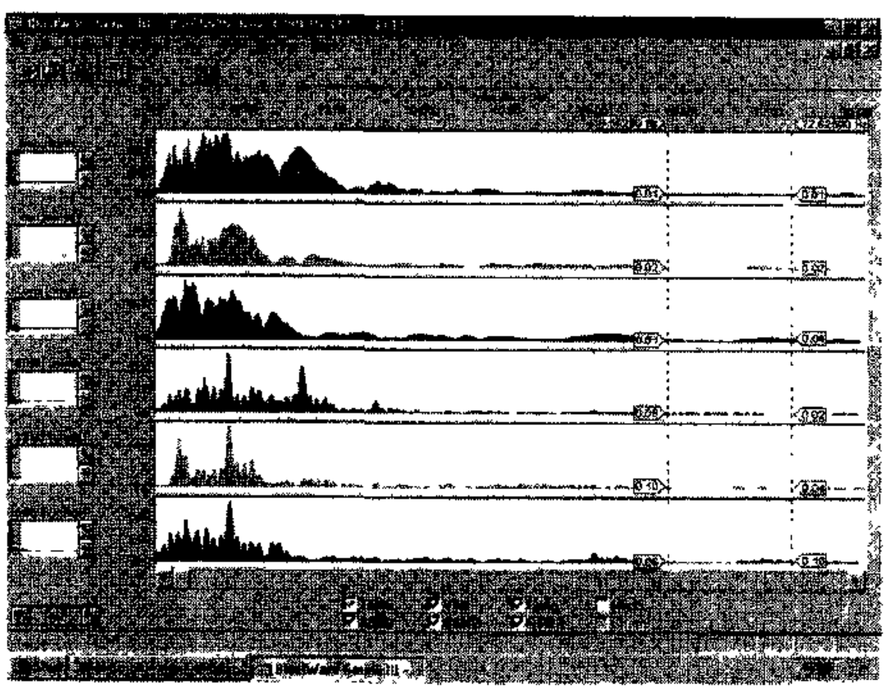


Figure 3. Frequencies of signature bla« and Minulaied blast with delay time of İ20 *m%.*

Table 5. Delay timing simulation results with 30, 60,90,120, 150 and 330 ms delays in ternis of predicted ground vibration amplitudes and frequencies.

	Peak Simulated Amplitudes			*Dominant Frequencies*		
	T,	*V.*	*L.*	*T Hz*	*KHz*	*L.Hz*
Signature	47.4	35.3	58.5	8.0	3.0	4.0
30 ms delay	62.2	74.8	79.6	6.9	3.1	1.5
60 ms delay	68.1	60.8	60.2	16.5	3.1	3.5
90 ms delay	59.9	48.1	65.5	11.1	11.0	3.5
120 ms delay	63.0	58.5	58.4	8.3	8.4	8.4
150 ms delay	59.7	43.1	67.2	6.6	2.9	6.9
330 ms delay	53.3	41.8	65.5	6.1	3.0	9.1

Table 6. Site factors determined at 50% confidence interval for signature blast and production blasts.

	Signature Blast			*Production Blast*		
	k	**ß**	R^2	**k**	**ß**	R^2
T	191.96	-0.6754	0.4400	843.87	-1.5846	0.4057
V	608.89	-1.5561	0.8476	3797.5	-2.048	0.5144
L	253.18	-0.6152	0.5765	1370.9	-1.6878	0.3784

5 CONCLUSIONS

The main conclusions derived from this study are given below:

1. Blast monitoring is a very valuable, indispensable and quaJ'tative tool which eliminates the trial and error approach and most of the guess work.
2. Blast monitoring which enables the quantitative evaluation of blasting results helps to optimize blasting and minimize the environmental effects.
3. The primer and ANFO perform very well, as indicated by the VOD measurements.
4. Motion analysis of high-speed camera records indicated that the best delay period varied in the range 120-140 ms.
5. The best delay time obtained by timing simulation was 120 ms. Thus, the optimum delay time for this mine was found tu be 120 ms considering both timing simulation and high-speed video camera system output.
6. Timing simulation of the ground vibration record from signature blasts enables manipulation of the PPVs and frequencies and helps to determine the best delay period so as to minimize the risk of structural damage.
7. In order to be able to carry out meaningful and reliable one-to-one comparison of predicted values from timing simulation of signature blast records and values from production blasts, new signature blasts should be conducted at similar scaled and absolute distances as the production blasts.

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