GROUND VIBRATION ASSESSMENT AT Y-3 PANEL OF TUNÇBİLEK OPEN PIT LIGNITE MINE

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ABSTRACT

GROUND VIBRATION ASSESSMENT AT Y-3 PANEL OF TUNÇBİLEK OPEN PIT LIGNITE MINE

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Yörgüç village is within the close neighbourhood of the Western Lignite Corporation Y-3 panel. Although the nearest part of the mine is 1100 m and the farthest part is 2500 m from the village at present, some of the villagers complained about the ground vibration at the past. Therefore the assessment of damage risk and, if any, control and minimization of vibrations constitutes the aim and the scope of this research work.

The researh work consists of monitoring of vibration, characterising of the seismic waves by full wave form analysis, and determination of magnitude and frequency of the waves from round blasting practice. Also dominant frequencies are determined, using single-hole blasting records by special software. The analyses are continued by a critical discussion and evaluation, and, proposals for new firing methods are made. The proposed firing methods are validated by further monitoring. As a result the best blasting practice was selected and offered to control and minimize the ground vibration.

Keywords: Ground vibration, seismic wave, frequency, particle velocity, round blast.

ÖZ

TUNÇBİLEK AÇIK OCAK LİNYİT MADENİ Y-3 PANOSUNDA YER SARSINTILARININ DEĞERLENDİRİLMESİ

Büyükyıldırım, Kürşad
Y. Lisans, Maden Mühendisliği Bölümü
Tez Danışmanı: Doç. Dr. H. Aydın BİLGİN

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Yörgüç köyü, Garp Linyitleri İşletmesi Y-3 panosu ile yakın komşuluk içerisinde bulunmaktadır. Şu an için maden ocağının köye en yakın mesafesi 1100 m en uzak mesafesi 2500 m olmakla birlikte, geçmişte bazı köylüler yer sarsıntılarından şikayetçi olmuşlardır. Bu sebeple hasar olasılığı bulunup bulunmadığının değerlendirilmesi, ve varsa, sarsıntıların denetimi ve en aza indirgenmesi bu araştırma çalışmasının amacını teşkil etmektedir.

Bu araştırma gurup patlatmalarından kaynaklanan yer sarsıntılarının ölçülmesi ve kaydedilmesi, sismik dalgaların dalga formu incelenerek özelliklerinin belirlenmesi ve dalgaların büyüklük ve frekanslarının saptanmasını kapsamaktadır. Aynı zamanda tek delik patlatmalarında kaydedilen, dalgaların hakim frekansları özel bir yazılımla belirlenmiştir. Bu çalışmaları, ayrıntılı tartışma ve değerlendirmeler takip etmiş ve yeni gecikmeli ateşleme tasarımları yapılıp önerilmiştir. Önerilen ateşleme tasarımlarının geçerliliği yapılan yeni ölçümlerle değerlendirilmiştir. Sonuç olarak yersarsıntılarının denetimi ve en aza indirgenmesi için en iyi patlatma yöntemi seçilmiş ve önerilmiştir.

Anahtar Kelimeler: Yer sarsıntısı, sismik dalga, frekans, parçacık hızı, gurup patlatması.

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LIST OF ABBREVIATIONS

A	:	Amplitude of displacement
t	:	Period
f	:	Frequency
v	:	Velocity
R	:	Radial component of vibration
V	:	Vertical component of vibration
T	:	Transverse component of vibration
PV	:	Particle velocity
PPV	:	Peak particle velocity
a	:	Acceleration
s	:	Distance of any particle from its rest position
D	:	Absolute distance
Q	:	Co-operating charge (charge per delay)
SD	:	Scaled distance
Fd	:	Fundamental natural frequency
k	:	Ground transmission coefficient
m	:	Specific geological constant
VOD	:	Velocity of detonation
VS	:	Vector Sum of three vibration components
USBM	:	United States Bureau of Mines
OSMRE	:	Office of Surface Mining Reclamation and Enforcement
FFT	:	Fast Fourier Transform
R	:	Correlation Coefficient
$\mathbf{R^2}$	:	Coefficient of Determination

CHAPTER 1

INTRODUCTION

Mining minerals or quarrying rock which involve rock excavation played a great role in civilization. Rock excavation is done either by mechanical means or blasting. When blasting is concerned, some energy is to be spent to fragment the rock. This energy is provided by explosives but not all of the energy is transmitted to the rock. Transfer of energy is a function of both the characteristics of the explosive and that of the rock. Berta (1990) explains that only about 20% of total energy supplied by the explosive is consumed usefully in productive efforts such as rock fracturing, rock breakage and rock displacement.

Among the variety of effects produced by a blast, some of the effects can be regarded as useful work, where as the remaining consequential effects can be classified as non-productive, undesirable and inevitable.

Productive effects are:

1. fracture of rock in situ;
2. breakage of certain volume of rock into well defined regular sized elements;
3. displacement of broken rock to a certain distance from the original position.

Non-productive effects are:

1. excessive breakage of part of the blasted rock and dust formation;
2. over-breakage (permanent deformations in the rock behind the shot);
3. fly-rock (excessive throw of rock);
4. air-blast and noise;
5. ground vibrations.

As a result of the analysis for the total energy balance, Berta (1990), from his research deducted that the energy transmitted to the rock is roughly, distributed as follows:

- fracture in situ	< 1%
- breakage	15%
- displacement	4%
- excessive crushing in the viscinity of the hole	1.5-2%
- flyrock	< 1%
- deformation of the solid rock behind shot	<1%
- ground vibrations	40%
- airblast	38-39%

From this research it can be concluded that a greater percentage of the energy is spent in terms of the non-productive effects such as ground vibration and airblast. Therefore a great care should be spent on the planning and execution of blasting work. Otherwise great percentage of energy responsible for ground vibration and airblast may create damages in the structures and annoyance of the people.

Overburden stripping blasts for surface coal mining involve large quantity of explosives per delay. Since relatively small amount of energy is consumed in productive efforts, the remaining energy produces some undesirable and non-productive effects, which creates many disturbances to neighboring areas. The combination of large shots, thick soil and sedimentary rock overburdens, relatively good confinement and long range propagation make coal mine blast vibrations potentially more serious than other blast operations. However by contrast, coal mine high wall blasts are inefficient generators of air blast.

Many studies have been conducted to characterize ground vibration induced by blasting. The well-known ground vibration characteristics are the particle velocity magnitudes and frequency. Dowding, (1985); Konya and Walter, (1991); and before

That Siskind et. al., (1980), demonstrated that magnitude of ground vibration is directly proportional to amount of charge per delay and inversely proportional to traveling distance. As a result of that, the concept of scaled distance was put forward in order to calculate the attenuation of particle velocity in the ground. Therefore, using the attenuation equation, derived from the relationship between the scaled distance and vibration magnitude, it is possible to predict the peak particle velocity as well as to find out the maximum allowable charge weight per delay for the blasting site. Estimation of the peak particle velocity and other components of ground vibration with reliable approach provide important facilities to the miners. Although many studies were carried out to isolate site specific problems from prediction of the peak particle velocity and the other components of vibration a generally applicable theoretical formula has not been established yet. So a site specific study is still needed to minimize the ground vibration impacts.

1.1 Definition of the Problem

During the operations at the Turkish Coal Enterprise, Western Lignite Corporation, Y-3 Panel, claims of damage are made due to blasting induced ground vibrations by the villagers. Some of the villagers went to the court and compensations were decided. The compensations decided by the court from 1992 to 2002 can be seen in Table 1.1.

The decisions of the court are based on the reports which are lacking of monitoring and assessment of ground vibration. Therefore there is an ample need for the assessment of current situation by monitoring and damage risk and, if any, the control and minimization of the blast induced ground vibrations is required.

Table 1.1 Compensations decided by the court due to ground vibration.

Year	TL	$ Exchange Rate	US $
1992	11,181,247	6,909	1,618
1996	3,952,171,193	81,689	48,381
1997	2,588,150,993	148,400	17,440
1998	8,237,387,915	266,160	30,949
1999	16,526,318,253	419,045	39,438
2000	10,149,223,100	621,079	16,341
2001	10,042,081,784	1,311,862	7,655
2002	4,812,000,000	1,335,067	3,604
TOTAL			**165,426**

1.2 Research Objectives

The main objective of this study can be explained as the determination of the maximum allowable charge per delay with respect to the distances between Yörgüç village and the blasting sites in the mine based on the USBM criteria.

To reach this objective the following steps are followed;

i- Assessment of the current situation by monitoring the ground vibration induced by multi-deck round blasting performed at the mine site,

ii- Determination of dominant frequencies of waves for this site by conducting single hole blasts and assessment of these data,

iii- Establishment of a reliable empirical formula statistically by using the relationship between the scaled distance and the recorded peak particle velocities of components of vibration, and vector sum of the components, and the determination of the attenuation curve for the site, so that the PPV values for the site can be predicted, iv- Determination of the minimum distance that blasting operations can be done without causing any damage to the structures in Yörgüç village,

v- To make improvements in the blasting design and practice to eliminate the risks.

This research study summarizes the work done, in order to assess the damage risk, and if any, to minimize the ground vibration problem for Yörgüç village. Literature survey is presented in Chapter 2. Chapter 3 is devoted to the site description and the geology of the area. Blasting parameters and monitoring procedure are given and discussed in Chapter 4. The results of the measurements are given and discussed in Chapter 5. Lastly, the main conclusion drawn from this research and recommendations for future research are given in Chapter 6.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Kutter and Fairhurst (1971) indicated that there are three zones of varying destruction and deformation around the explosion. These zones are;

- hydrodynamic zone,
- the non-linear zone and
- the elastic zone.

In the first zone, the radial compressive stresses generated from the shockwave exceed the dynamic compressive strength of the surrounding rock, and develop complete crushing as rock fail in compression. In the second zone, fracturing is due to the tangential stress. Since the tensile stress of the rock is not very high, the tangential tensile stress create fractures. When the strain waves reach the free surface of the rock, they are reflected and cause spalling.

Since the velocity of the longitudinal waves is larger than the velocity of the shear waves and as the tensile strength of the rock is much less than that in compression, the reflected wave will break the rock in tension if it exceeds the tensile strength of rock.

After the passage of the wave, the expanding gases of explosion start to penetrate into the radial cracks and exert high quasi-static pressure. High pressure and high temperature borehole gases then flow into the system of the radial cracks generated and cause considerable additional extension of the number of these cracks (Olofsson, 1988). As the burden begins to move, high compressive stresses within the rock begin to unload and generate more tensile stresses which complete the fragmentation process. The sequence of the events in the rock mass is shown in Figure 2.1.

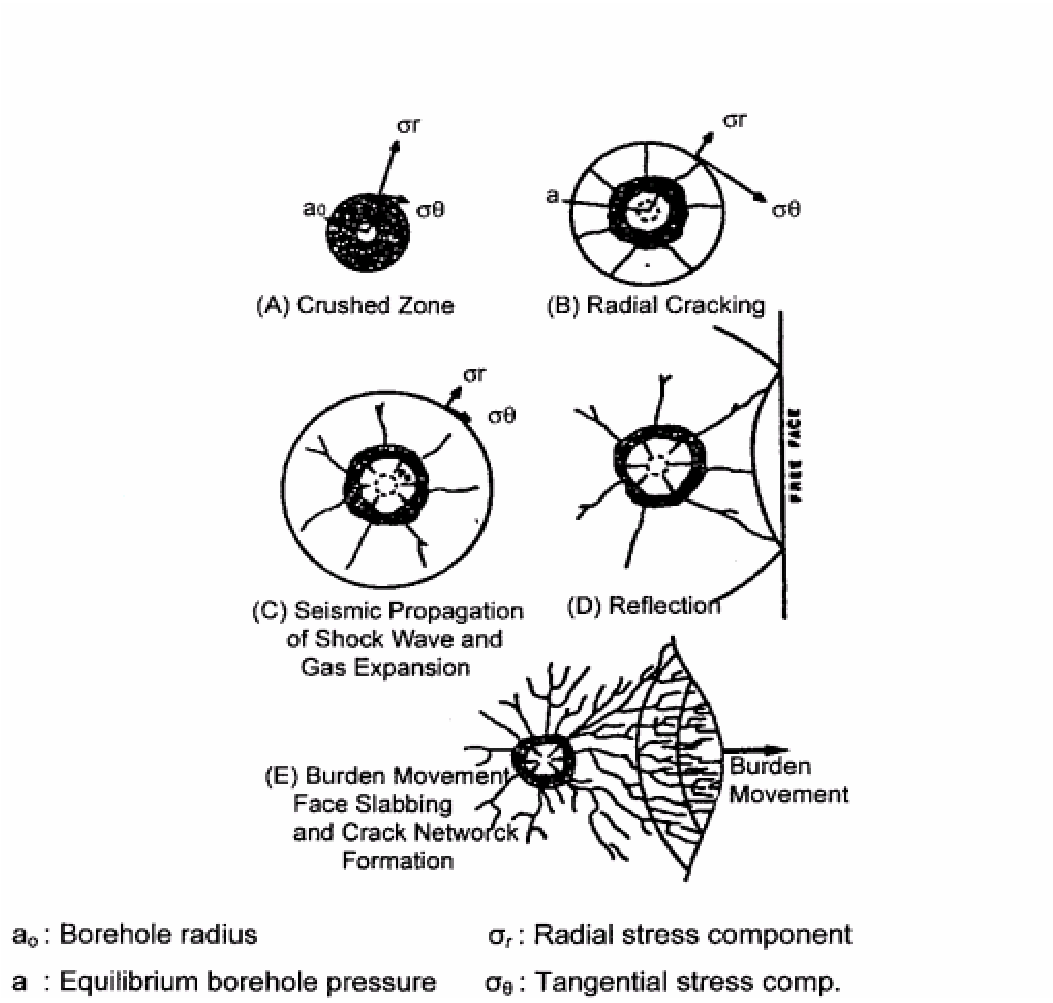

Figure-2.1 Sequence of events occuring in the rock mass after detonation (Dowding and Aimone, 1992)

In general, rock fracture during blasting is caused by the combined effects of shock and gas energies of an explosive and gas energy plays relatively higher role during the rock fragmentation.

2.2 Ground Vibration Characteristics

Ground vibration can be described as the transient movement of a particular point (particle) in the ground due to rock blasting. Ground vibrations which are a form of energy transport through the ground, may cause damage to the adjacent structures when they reach a certain level of magnitude. Some of the energy released from a blast, propagates in all directions from the borehole as seismic waves with different frequencies. The energy from these seismic waves is damped by distance and the waves with higher frequencies are damped faster. Therefore the dominant frequencies from the blast are high at short distances and lower at longer distances.

In Figure 2.2 a typical blast vibration time history is given. The most important parameters of the time history are; peak amplitude, principle period and the duration of the vibration. All these parameters are the function of the blast sequence and the transmission medium (Dowding,1985).

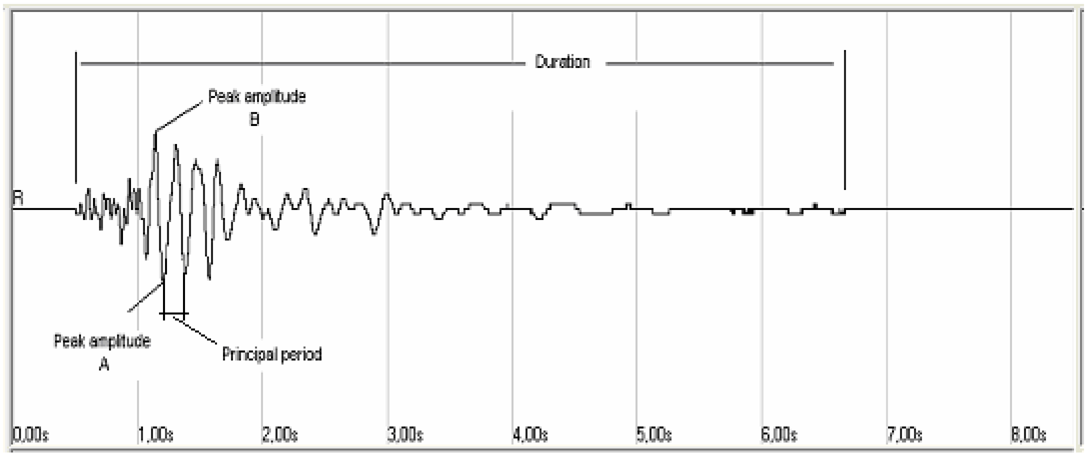

Figure 2.2 A typical coal mine blast history

2.2.1 Vibration Terminology

Amplitude (A): A time varying and kinematic vibration quantity of displacement.
Period (t): The time required to complete one oscillation.
Frequency (f): Number of cycles executed per unit time.
Cycle: one complete oscillation of repeated events.
Velocity (v): Displacement per unit time.
Particle Velocity (R,V,T): The displacement per unit time in reference to the speed or acceleration of the particles in the ground resulting from vibratory motion.
Peak Particle Velocity (PPV): The displacement per unit time in reference to a compressional disturbance propagating through any medium.
Acceleration (a): The velocity per unit time.
Displacement (s): Distance of any particle from its rest position.
Distance (D): Total lenght of travel path taken by an object starting at rest to its final position.
Co-operating Charge (Q): Total amount of explosive or blasting agent initiated per delay.
Scaled Distance (SD): Scaling factor that incorporates the charge weight influence on the source functions as a generator of vibration or noise.

The size of the ground vibration depends on:

- The amount of co-operating charge
- Distance from the blasting site
- Geology of the site
- Delay period
- Rock type

By selecting the right blast patern and correct drilling, ground vibrations can be controlled (Arseven, 2003).

2.2.2 Types of Vibration Waves

Interactions between vibrations and the propagating media give rise to several types of waves. The main wave types can be divided into two varieties (Dowding, 1985);

- body waves, and
- surface waves.

2.2.2.1 Body Waves

Body waves propagate through the body of the medium. They can be also subdivided into P-wave and S-wave.

P-wave

The P-wave is also called the primary compressional wave. It is the fastest wave through the ground. Particles in the path of wave move in the same direction as the propagation of the wave. The density of the material will change when the wave passes. Characteristics of the P-wave in solid medium is shown in the Figure 2.3. In the Figure C shows the compressional motion and D represents the dilational motion.

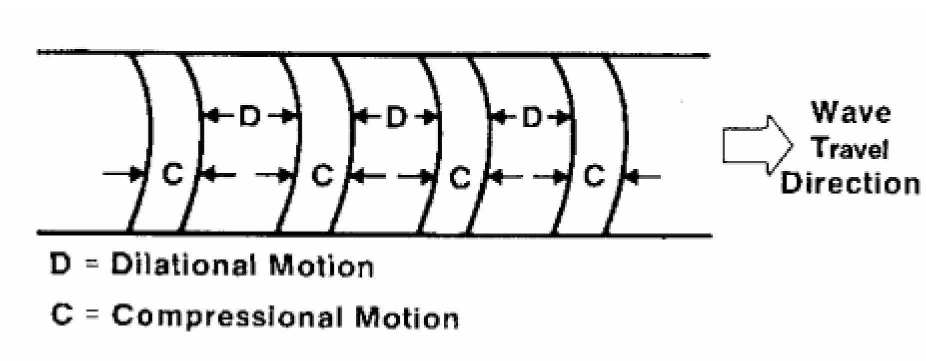

Figure 2.3 Characteristics of P-wave in a solid medium (Atlas, 1987)

S-wave

S-wave is also called the secondary or shear wave. It moves through the medium at the right angle to the wave propagation, but slower than the P-wave. Characteristics of the S-wave in solid medium is shown in the Figure 2.4.

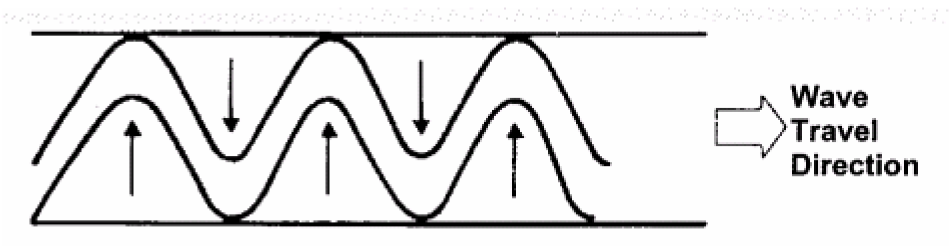

Figure 2.4 Characteristics of S-wave in a solid medium (Atlas, 1987)

2.2.2.2 Surface Waves

Surface waves are the waves that are transmitted along a surface. Surface waves generated in rock blasts are Rayleigh-R waves and Love waves.

R-wave

The R-wave propagates more slowly than the P and S- waves and particles move elliptically in the vertical plane and in the same direction as the propagation. Unlike the body wave’s unidirectional particle motions, R-wave particle motion is two dimensional. These waves are similar to those produced by dropping a stone into a pool of water. As the water wave passes a piece of rock, the motion of the cork in water is described by a forward circle. Whereas, in rock a particle will follow a retrograde elliptical path, with the ratio of horizontal to vertical displacements equal to 0.7. Characteristics of the R-wave in solid medium is shown in the Figure 2.5.

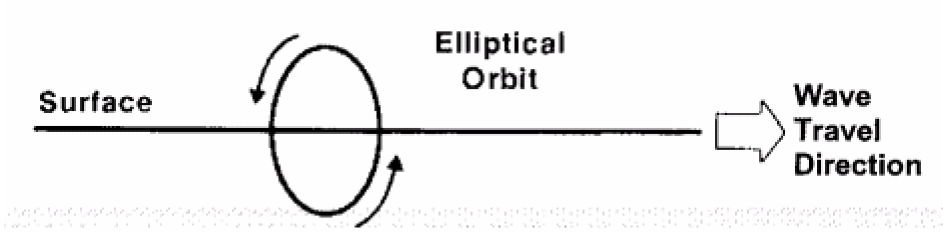

Figure 2.5 Characteristics of R-wave in a solid medium (Atlas, 1987)

Love wave

Love wave is a surface wave with horizontally polarized particle motion. It is a transverse wave propagated in a low-velocity surface layer overlying a medium in which elastic waves have higher velocities. It requires a material layer at the top and bottom boundaries having good reflecting properies. The Love waves are faster than the R waves and give particle motion that is transverse to that of propagation. Characteristics of the Love wave in solid medium is shown in the Figure 2.6.

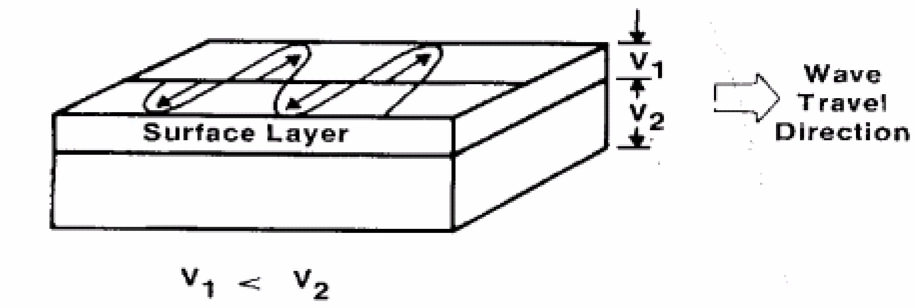

Figure 2.6 Characteristics of Love wave in a solid medium (Atlas, 1987)

Three perpendicular components of motion must be measured to describe the motions completely. The longitudinal component, L, is usually oriented along horizontal radius (radial direction) of explosion. Then two other components are vertical, V, and transverse, T. Directions of the L, V, T waves with respect to the explosion is shown at Figure 2.7.

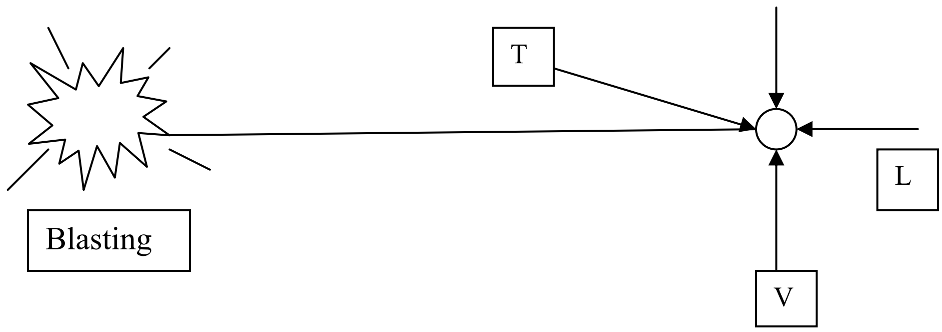

Figure 2.7 Three perpendicular components of ground vibration.

2.2.3 Propagation Velocity

Propagation velocity is the speed of the vibration waves travelling in the rock medium and it is measured in meters per second. Propagation velocity should not be confused with particle velocity, which is described as the velocity of a particle vibrating in the ground and measured in millimeters per second.

Jointing and weathering of rock masses greatly affect propagation velocities. Jointing changes the rock stiffness which in turn changes the propagation velocity. In general, with increasing depth, the intensity of jointing decreases and the propagation velocity increases.

2.3 Impact of Natural and Technological Factors on Seismic Effects of a Blast

2.3.1 Blasting Conditions:

In industrial blasts the wave picture is extremely complex. This is due to the prevailing geo-mining conditions on the travel path of blast induced seismic vibrations and also due to the special nature of the blast as a source of elastic waves.

In describing such a source we can only consider approximation of the models as applied to the properties of the medium in which blasting takes place. In actual conditions, various endogenous factors such as, type of explosives, weight, construction and shape of individual parts in a charge, the total charge in the block being blasted and initiation scheme as well as external factors such as properties of rocks, availability of free face, line of lest resistance and depth of charge directly or indirectly influence the blast (Arseven, 2003).

2.3.2 Construction of Explosive Charge

Properties of explosive used in the blasts primarily effects the intensity of the source of seismic vibrations. Explosives having low velocity of detonation (VOD) are prefered for conducting blasts to produce reduced seismic effects. Explosives with higher VOD generate significant vibrations. In their spectra, higher frequencies predominate, which absorb the major part of the energy. Therefore, while selecting explosives due consideration should be given to the requirements of fragmentation and absorbing properties of surrounding rocks at different phases in the frequency spectra of oscillation.

The most effective method of reducing blast induced seismic effects as well as enhancing the quality of fragmentation is to use inactive and air gaps and also inactive stemming. It has been established that the intensity of vibration is reduced by 1.2-2 times, depending on the properties of surrounding rocks, when charges with in-between air gaps are used. However, the use of such charges reduces the seismic effects only at specific ratios of volume of air gaps to the entire charge volume in a particular deposit. The ratio is about 0.3-0.4 (Arseven, 2003).

2.3.3 Conditions of Placing Charges

The conditions of charge placement influence the seismic effect of a blast. Maximum seismic effects are observed in blasts, conducted in a confined medium. The depth of charge placement plays a vital role, since with an increase in the depth the intensity of ground vibrations also increase. Therefore, as the number of free faces increases, vibration velocity in rock decreases. In such a case, seismic effects may be reduced by as much as 4-5 times compared to blasting in a confined medium. In a series of investigations the chance in seismic effects of a blast due to change in bench height or lenght of hole charge was considered. It was established that relativaly rapid growth of particle velocity is noticed when bench height is increased from 10 to 20 m. The enhanced intensity of seismic vibrations can be explained by the increased consumptions of explosive per unit time of blast and also by the lenghtening of charge (Arseven, 2003).

2.3.4 Properties of Rocks

An important property is the acoustic rigidity of rock. Placing a charge in a medium of lower acoustic rigidity reduces the seismic effects of a blast. A blast in rocks of relatively greater acoustic rigidity produces 3 times more seismic energy at the source boundary, compared to blasts in rocks with lower acoustic rigidity.

Blast in clays, marlstones and salts cause maximum ground movement due to the seismic wave. While blasting in hard rocks takes place, the expansion and development of existing fissuring affects the seismicity. At the same time, a vital role is played in not only by the number of fissures but also the expansion of their openning, filling by secondary products and spatial orientation.

The spatial disposition of fissures also influences the seismic effects of a blast. By properly orienting the drill grid, fragmentation and intensity of elastic vibrations can be regulated.

Change in the physicomechanical properties of rocks at the site of blasting also effects the frequency composition of blast induced ground vibrations. In rocks with a low value of acoustic rigidity, lower frequencies dominate compared to rocks with higher acoustic indexes (Arseven, 2003).

Ground vibration dissipation in rock is attributed to three mechanisms:

1- Viscous damping of ground vibrations, an effect more pronounced on higher frequencies and accompanied by a trend to lower ground vibration frequencies with increased distances from blast.

2- Solid friction absorbtion of energy in the ground motion wave, which is greater for rock for courser grain structures and extensive porosity.

3- Scattering of ground motion wave due to reflections at discontinuities and strata inhomogeneities in the rock, in which interactions between reflected pulses are often accompanied by a trend to selectively attenuate lower ground vibration frequencies.

Since rock masses are inhomogeneous, ground motion waves travel through strata of different acoustical impedance. Scattering the ground vibration waves, initiated at boundary of discontinuities by reflections, lowers the peak vibration levels. Interactions between the reflected pulses alter the frequency composition of the wave train. High frequencies are selectively attenuated while some lower frequencies are added to the ground vibrations.

The presence of joints, fractures, faults and shear zones in the path of a ground motion wave also act to scatter the peak vibrations. Some of the lateral components of ground motion are lost as the wave crosses a discontinuity. The degree of redirection and dissipation of a ground motion wave is relaxed to the nature and frequency of structural discontinuities in rock (Atlas, 1987).

2.4 Structure Response to Blast Excitation

Blasting can cause significant vibrations within the structures even in cases where the distance between a blast and the structure is large. High levels of vibration within structures are caused by a close match between the ground vibration frequency and the fundamental resonant frequency of the structure or some structural elements (Akeil, 2004).

2.4.1 Structure Components and Ground Vibration Parameters

Structures consist of many components, two of the most importants are walls and superstructural skeletons. Superstructure response, measured at a corner, is associated with the shearing and torsional distortion of the frame, while the all response, which measured in the middle of a wall, is associated with bending of that particular wall. The wall and the superstructure continue to vibration freely after the passage of the ground motion. The wall motion tends to be larger in amplitude than the superstructure motions and tends to occur at higher frequencies during free vibration than those of the superstructure (Dowding, 1985). The natural frequencies of walls range from 12 to 20 Hz and those of superstructures range from 5 to 10 Hz (Dowding et all.,1980).

Response of any structure to vibration can be calculated, if its natural frequency and damping are known. The fundamental natural frequency F_d of the superstructure of any tall building can be estimated from compilations of work in earthquake engineering (Newmark and Hall, 1982):

$$F_d = 1 / (0.1*N) \qquad (2.1)$$

Where, N is the number of stories.

Damping is function of a building construction and to some extent the intensity of vibration. Measurement reveals a wide range of damping for residential structure with an average of 5% (Dowding et al., 1981).

Excessive structural response has been seperated into three categories arranged below in the order of declining severity and increasing distance of occurance. Beginning with effects that occur closest to the blast, the categories are listed below:

1- Major (Permanent Distortion): Resulting in serious weakening of the structure.
2- Minor (Displaced Cracks): Surficial, not affecting the strength of the structure, hairline cracks in masonary.

3- Threshold (Cosmetic Cracking): Opening of old cracks and formation of new plaster cracks, dislodging of loose objects (Dowding, 1992).

2.4.2 Resonation and Amplification Factor

Probability of damage in structures depends on the relationship between dominant frequency of the ground vibration and natural frequency of the structure. Most significant for blasting is that the principal frequencies of the ground motion almost always equal or exceeds the gross structure natural frequencies of 4 to 10 Hz. In this case, structure resonates and it is shaked by amplified vibration a few seconds. People may still perceive and are concerned about this situation. While structure resonates, it may not be damaged but people may still complain even if particle velocity is much below the limiting vibration value. However, the damage within the structure is caused when structure resonates at a particle velocity exceeding vibration limit. Although amplitude of the exceeding wave travelling in the ground is not sufficient to cause damage to the structure, structure may be damaged due to amplification during resonation. Amplification is defined as the increase in the amplitude measured in the structure with respect to ground amplitude due to the transfer of the exciting wave on the ground to the structure. The ratio of amplitude of the structure to ground amplitude is called as amplification factor (Esen and Bilgin, 2001).

2.5 Human Response to the Disturbances Caused by Blasting

The tolerance and reactions of humans to vibrations are important when the standards are based on annoyance, work proficiency and health. Humans notice and react to blast induced vibrations at levels that are lower than the damage threshold. Persons inside buildings will hear and feel the predominantly 5 to 25 Hz structure mid wall and mid floor response vibrations. Ground vibrations are occasionally blamed for vibrations when long range air blasts propagating under favourable weather conditions are responsible. The very infrasonic air blast itself cannot be heard but the house responds as if subjected to a ground vibration.

Critical to levels of response are the vibration characteristics; duration, peak level, vibration frequency and the frequency of occurrence, and tolerance descriptions.
Several researchers recognized that the duration of the vibration was critical to its undesirability. It is evident that a higher level could be tolerated if the event was short.

Estimated ground vibration produced human reactions can be found at Figure 2.8. In the figure triangles, squares and circles correspond to 4 Hz, 9 Hz and 25 Hz frequencies respectively. The three lines of the figure show the distribution of the particle velocities.

Since reactions are most likely from stronger events, actual public reaction would occur somewhere between that corresponding to the mean vibration level and the maximum.

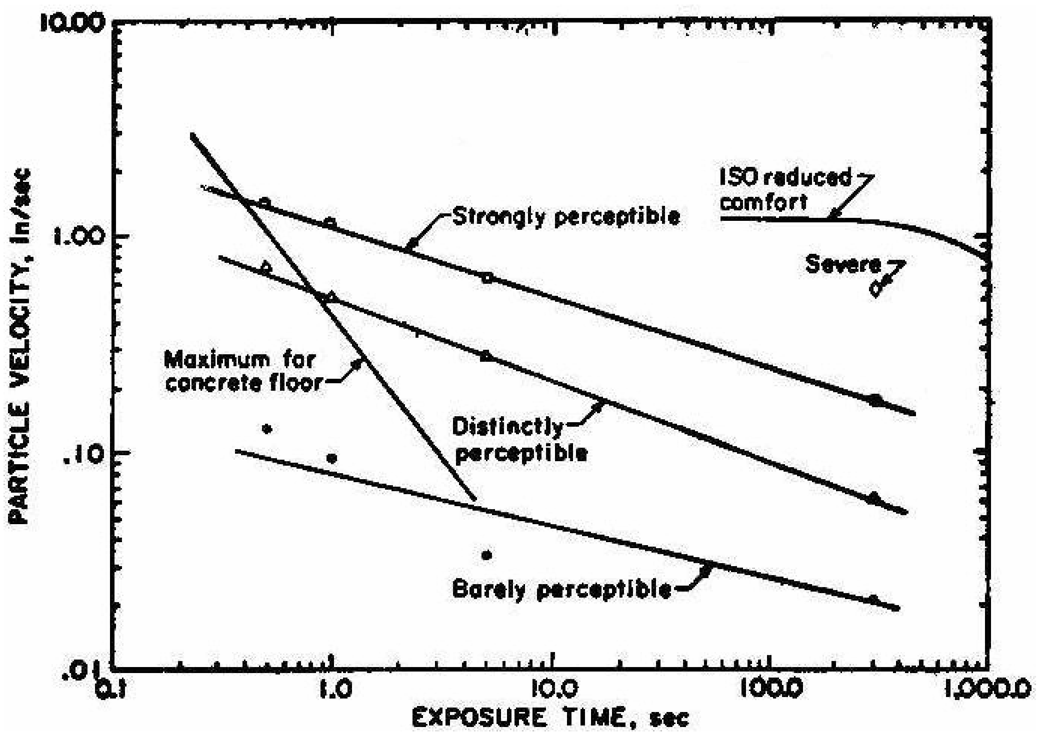

Figure 2.8 Human response to the blast induced ground vibration (Reiher and Meister, 1931)

2.6 Concept of Scaled Distance

Scaled distance is a concept put forward by using the amount of explosive energy in air shock and seismic waves, and this affects the basis of distance. Scaled distance is derived by combining the distance between source and measurement points, and the maximum charge per delay. Scaled distance is defined by the equation below:

$$\mathbf{SD = D / Q^{0.5}} \qquad (2.2)$$

Where,

SD is the scaled distance ($m/kg^{0.5}$),

D is the absoute distance between the shot and the measured station (m), and Q is the maximum explosive charge per delay (kg).

The ground motion wave front resulting from a column charge (lenght to diameter ratio greater than 6:1) takes the form of an expanding cylinder. The volume of this compression cylinder varies as the square of its radius. Thus, the peak level of ground motion at any given point is inversely proportional to the square of the distance from the shot point (Dowding,1985).

The peak particle velocity (PPV) is given by the following formula;

$$\mathbf{PPV\ (mm/sec) = k * (SD)^{-m}} \qquad (2.3)$$

Where,

k and m are site specific parameters.

2.7 Investigations on Damage Criteria

Although many studies have been conducted to avoid structural damage induced by blasting, a general theoretical approach has not been established yet. Complexity of ground motions, changing blasting and test site factors, and the variation of response of structure to the excitation restrict the establishment of a general damage criterion. Thus, experimental and site specific studies are still necessary for each site in order to minimize environmental problems.

2.7.1 Energy Approach as Damage Criteria

- United States Bureau of Mines (USBM) formula, 1942.

It was the first USBM criteria concerning the blast induced ground vibration and was based on amplitude, quantity and distance (Kahriman, 2001).

- Crandell's Energy Ratio Concept, 1949.

This damage criteria is based on pre and post blast investigations, and it has recommended that no damage can occur below 3.0 of energy ratio (Arseven, 2003).

Energy Ratio	Estimated Damage
Below 3.0	No damage
3.00 – 6.0	Some damage, use caution
Above 6.0	Damage

2.7.2 Peak Particle Velocity Approach as Damage Criteria

- Particle Velocity Criterion of Langefors, Kihlstrom and Westerberg, 1957.

It was adopted for the first time by State of Pennsylvania to assess the damage potential of the ground vibration, and 2.8 in/sec is used as an overall safe level for residential structures (Akeil, 2004).

Particle Velocity	Damage
2.8 in/sec	No noticable damage
4.3 in/sec	Fine cracks and fall of plaster
6.3 in/sec	Cracking of plaster and masonary walls
9.1 in/sec	Serious cracking.

- Edwards and Northwood's Particle Velocity Criteria, 1959.

This criteria is based on the amplitude of the velocity and type of damage, and indicated that no damage can occur below 2.0 in/sec (Arseven, 2003).

Particle Velocity	Damage
Below 2.0 in/sec	No damage
2.0 - 4.0 in/sec	Caution
Above 4.0 in/sec	Damage

- USBM Particle Velocity Criteria, 1971

USBM established the use of particle velocity in place of displacemet, and recommended to use 2.0 in/sec as an overall safe level for residential structure.

Particle Velocity	Damage
Below 2.0 in/sec	No damage
2.0 – 4.0 in/sec	Plaster cracking
4.0 – 7.0 in/sec	Minor damage
Above 7.0 in/sec	Major damage

Soon after the publication of these widely used recommendations of the 2.0 in/sec safe level criteria, it becomes apparent that it was not practical to blast at this high level of ground vibration. Although many mining operations which were in the close neighbourhood of residential structures designed to keep velocities as low as 0.4 in/sec, many homeowners were attributing all cracks to the blast vibration.

2.7.3 Peak Particle Velocity and Frequency Approach as Damage Criteria

- USBM Criterion, According to Siskind et al., 1980.

Safe blasting vibration criteria were developed by USBM for residential structures, involving frequency, velocity, and displacement. Safe levels of ground vibration from blasting range from 0.5 to 2.0 in/sec peak particle velocity depending on frequency. Criteria indicates that damage potentials for low-frequency blasts (<40 Hz) are considerably higher than those for high-frequency blasts (>40 Hz), with the latter often produced in the close distances from blast (Figure 2.9).

Practical safe levels of vibration for blasts that generate low frequency ground vibrations are 0.5 in/sec for plaster on lath interiors and 0.75 in/sec for modern houses for 3-12 Hz frequency range. For higher frequencies (>40 Hz), 2.0 in/sec maximum particle velocity is recommended for all structures.

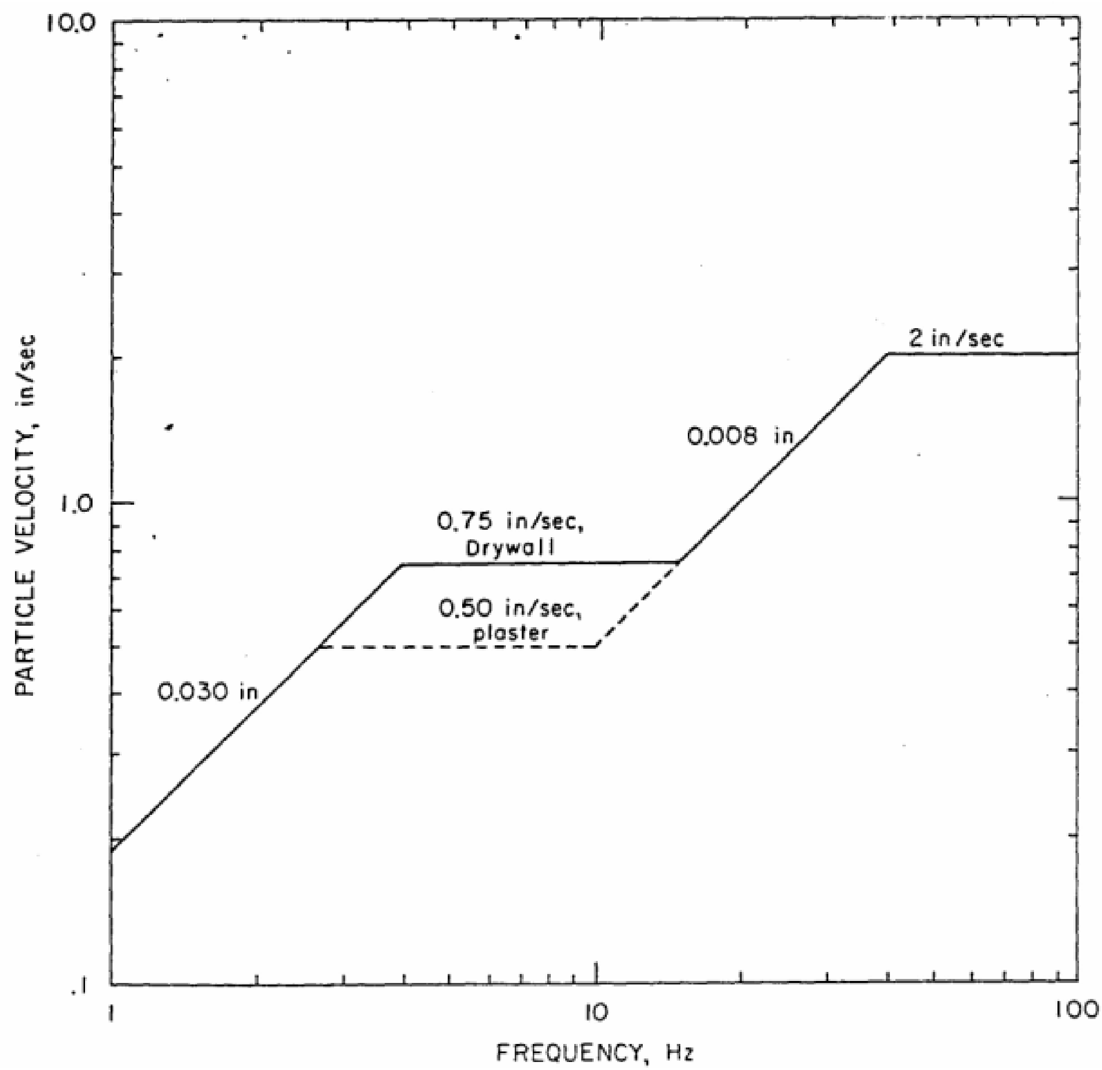

Figure 2.9 Safe Levels of Blasting Vibrations for Structures, USBM Standarts, 1980.

Then the USBM criteria were modified for regulations of blasting by U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE Regulations, 1983). These criteria are presented in Figure 2.10. The OSMRE criteria have the following displacement and velocity values for the ranges of the dominant frequency: 0.76 mm for 1 to 3.5 Hz, 19.05 mm/s for 3.5 to 12 Hz, 0.25 mm for 12 to 30 Hz and 51 mm/s for 30 to 100 Hz (Svinkin, 2003).

In this research the USBM criteria and the OSMRE criteria are considered together to achieve a reliable result.

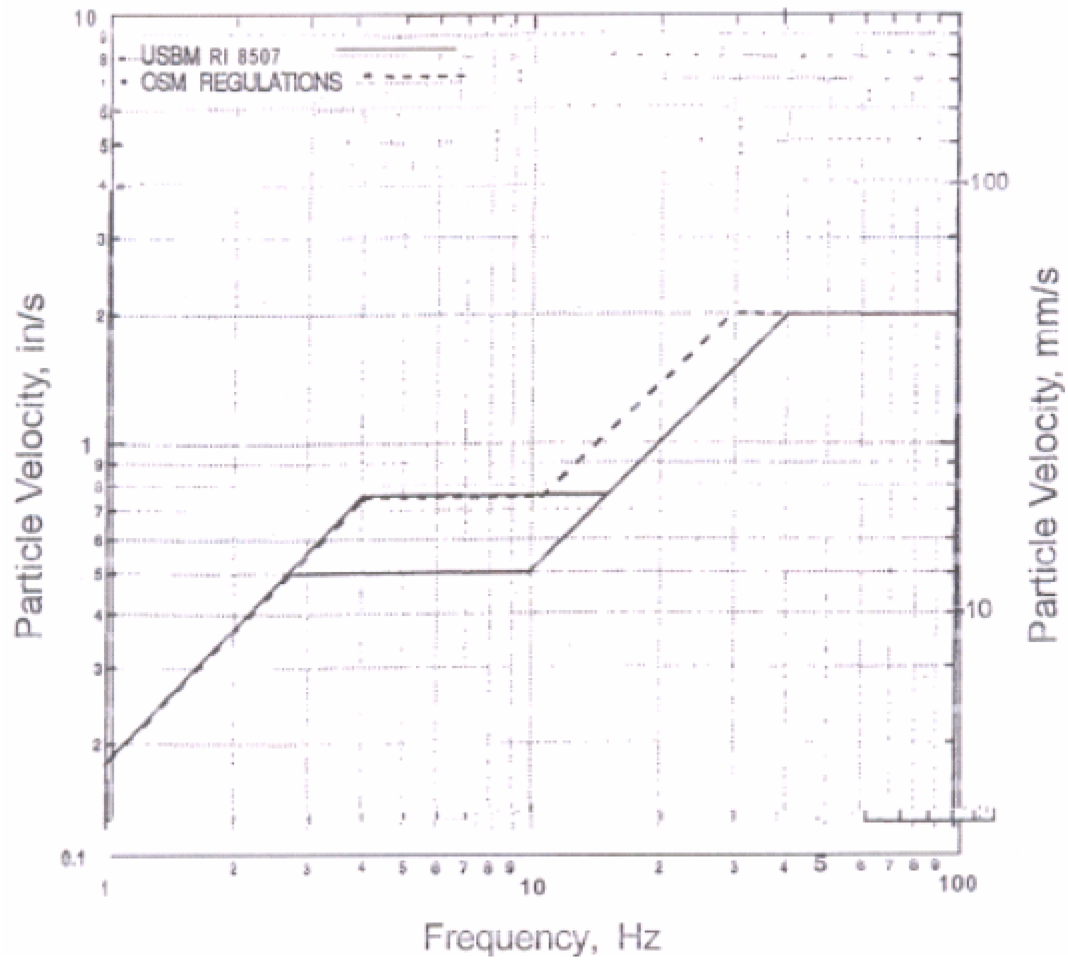

Figure 2.10 Safe level blasting criteria from USBM RI 8507 and OSMRE derivative version

CHAPTER 3

STUDY AREA AND GEOLOGY

3.1 Study Area

Study area is located in the region of Tunçbilek township (Tavşanlı county) of Kütahya province in the western region of Turkey (Figure 3.1). The measurements are taken at Y-3 panel which is operated by the state owned Garp Linyitleri İşletmesi (Western Lignite Co.) which is a subsidiary of Türkiye Kömür İşletmeleri (Turkish Coal Enterprise). Y-3 panel is about 2 km southeast of Yörgüç village. At present, the stripping and required blasting operations are done at distances varying between 1100 meters to 2500 meters from the village. However the mine will expand and come closer to the village in the future. After the expansion of the mine, the final border will be located a few hundred meters from the village. In Figure 3.2 general view of Yörgüç village from the mine site is presented.

The final stripping of overburden is done by a dragline (MARION 7820). Since the rock types in the field are not directly excavatable mechanically by dragline, the company uses explosives in order to loosen the overburden, so that the dragline can excavate the overburden easily.

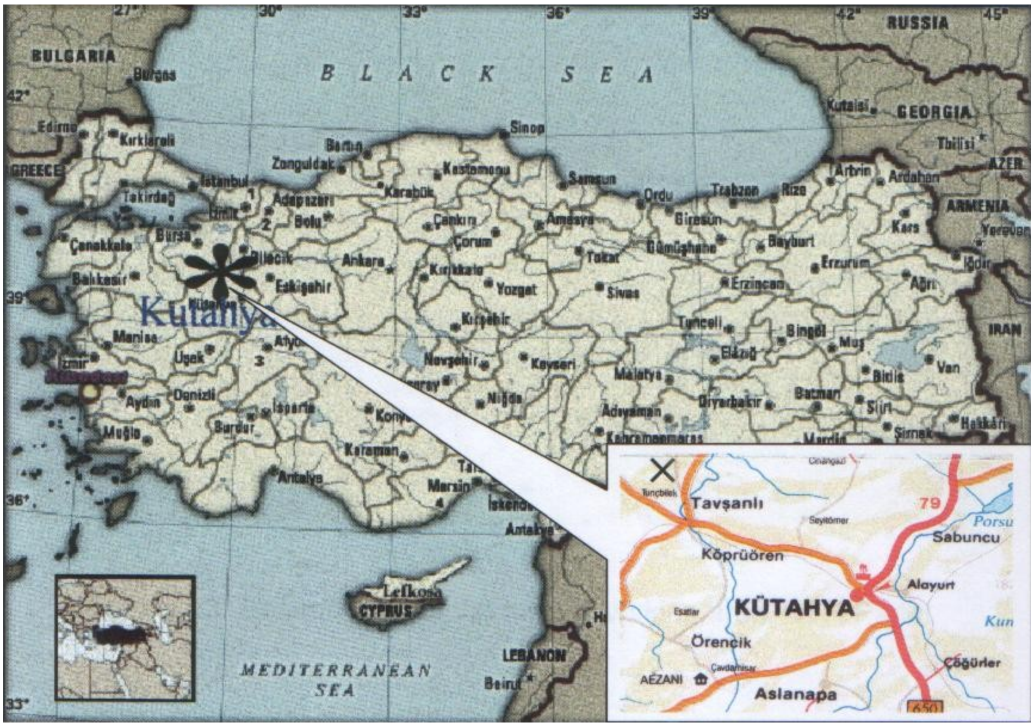

Figure 3.1 Location of the Mining site

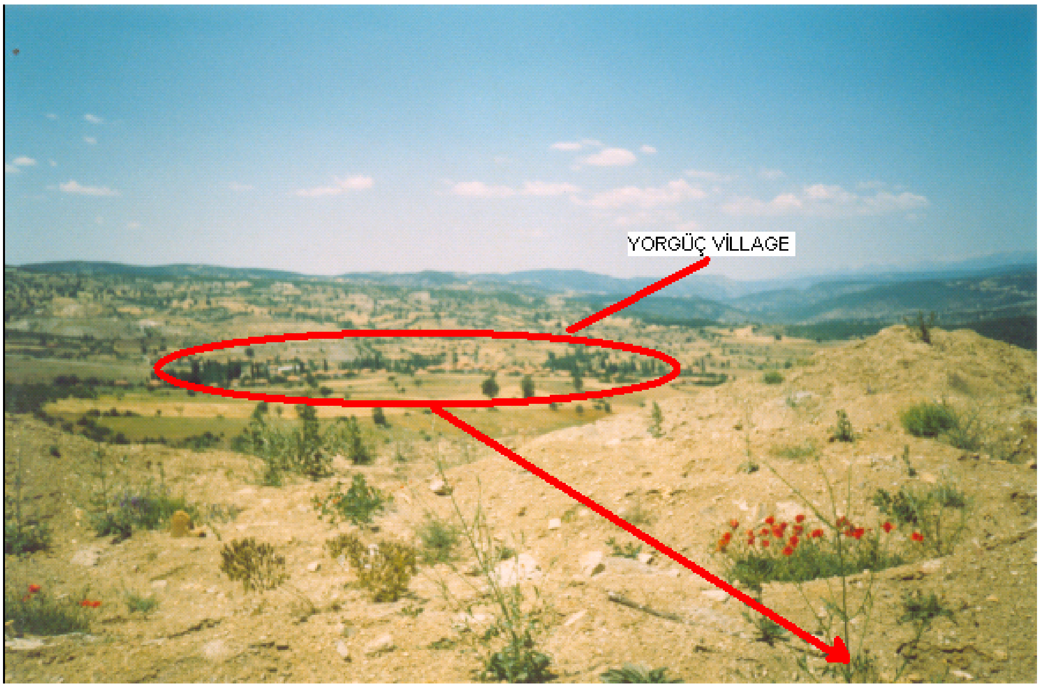

Figure 3.2 General view of Yörgüç village from the mining site. The red line with arrow indicates the line of the monitoring stations.

3.2 Geology

Geological map of the area is given in Figure 3.3. The map is provided from MTA originally mapped at 1/25.000 scale. Stratigraphic and structural features of the area will be explained based on this map.

3.2.1 Stratigraphy

The rock units exposed in the area can be divided into three main groups. These are, from bottom to top, basement rocks, Neogene rock sequences and Quaternary deposits.

3.2.1.1 Basement Rocks

Basement rocks refer to rocks older than Miocene in age. They are exposed in the western part of the area around Bozbelen village (Figure 3.3). They usually form high-relief regions of the area because of their resistance to the erosion.

The dominant lithology of the basement rocks is serpentinite. The age of the basement rocks are assigned as Pre-Cretaeous (Arseven, 2003).

3.2.1.2 Neogene Sequences

Neogene sequences are composed of four formations. These are from bottom to top; Beke formation, Tunçbilek formation, Saruhanlar formation and Karaköy volcanics (Arseven, 2003).

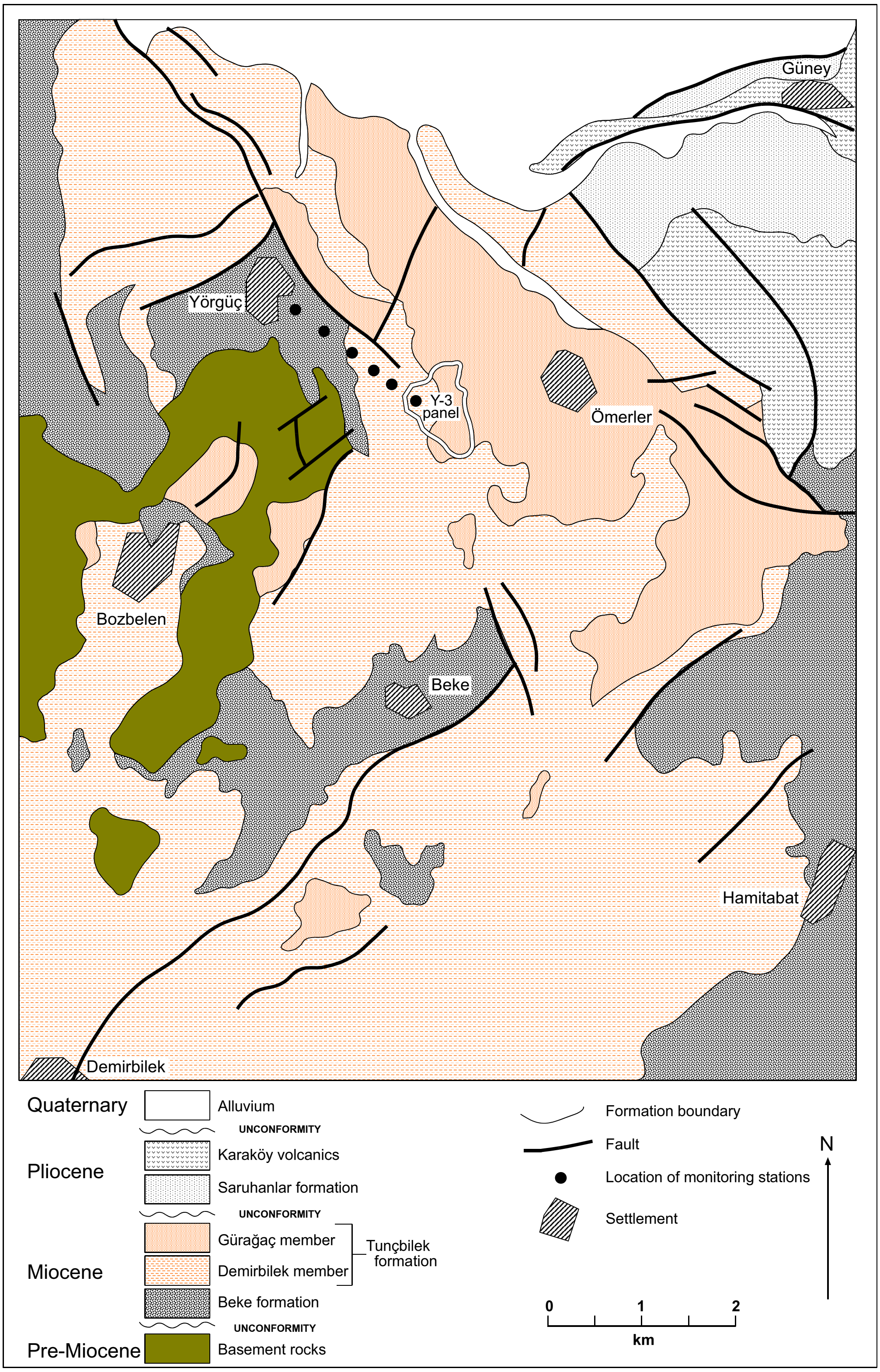

Figure 3.3 Geological map of the area.

Beke Formation:

Beke formation is exposed as several outcrops in the southeastern, central and northwestern parts of the area (Figure 3.3). The formation overlies the basement rocks non-conformably around Beke and Yörgüç villages and is overlain by Demirbilek member of the Tunçbilek formation conformably.

The basal part of the formation is composed of coarse-grained continental clastics of different size. General color of the formation is pinkish to red. Pebbles are sub-rounded to rounded. Grain size gradually decreases towards the middle parts of the sequence where the formation is represented by alternation of bedded conglomerates and sandstones. Cut and fill structures are common features observed in the middle part. Towards the top of the formation, it is represented by dark green marls with intercalations of black, thin coal measures of no economic value.

The age of the Beke formation is assigned as Middle Miocene based on the determinations of the pollen analysis from coal layers.

Tunçbilek Formation:

Tunçbilek formation is the most widespread rock unit exposed in the area. This formation is divided into two units as Demirbilek and Gürağaç members.

Demirbilek member: Demirbilek member is the lower member of the Tunçbilek formation. It is exposed extensively in the area as a belt extending in N-S direction. It conformably overlies and underlies the Beke formation and the Gürağaç member of the Tunçbilek formation, respectively. The ground vibration measurements taken in this study are mostly confined to this unit.

Typical stratigraphical column is observed 200 meters east of Demirbilek village. The member consists of marl, clay and coal with some siltstone, conglomerate and limestone inter-beddings. It starts with clay and marl alterations at the bottom. Marls dominate the units towards the top. General color of the formation is dark gray, bluish and greenish. The coal seam, reaching to 14 m thickness, is exposed either as single bed or exist as intercalations within clay-marl layers.

The marl layers lying above the coal seam contain considerable amount of Ostracpoda. The age of the formation based on ostracpoda and other pollens assigned as Late Miocene.

Gürağaç member: Gürağaç member is the upper member of the Tunçbilek formation. The main outcrop of this member is exposed around Ömerler village as a belt oriented in NW-SE direction. It overlies Demirbilek member conformably and is overlain by Saruhanlar formation unconformably.

The member consists of conglomerates, sandstone and clay. Dominant color of the unit is dark pink to red. Pebbles are well rounded. Cross bedding is a common feature in sandstone. Maximum observed thickness of the member is 75 meters.

An age of Late Miocene is assigned to the Gürağaç member considering the relative position of the member in the sequence.

Saruhanlar Formation

The typical section of the formation is exposed to the west of Saruhanlar village out of the study area. The formation is exposed in the close vicinity of Güney village (Figure 3.3). The formation unconformably overlies Gürağaç member of Tunçilek formation and conformably underlies Karaköy volcanics.

Common color of the formation is white, gray and light gray. It consists basically of conglomerates, sandstones, marls and tuffs. Thin limestone intercalations are also common.

Total thickness of the formation is about 300 m. The dominant lithology is conglomerate. The pebbles are well-rounded. Petrified wood is a common feature of the Saruhanlar formation.

No fossil is identified within the formation. An early Pliocene age is assigned considering the age of underlying Upper Miocene sequences.

Karaköy Volcanics

Karaköy volcanics extensively exposed between Ömerler and Güney villages as two large outcrops. These volcanics are observed in the form of lava flows. According to the field description, these volcanics are basaltic and andesitic in composition. Microscopic analysis of thin sections prepared from these volcanics revealed the presence of orthopyroxene, clinopyroxene and plagioclase. Olivine exist in minor amount.

3.2.1.3 Quarternary Units

The youngest units exposed in the area are Quarternary alluvial deposits. They are formed along the creeks and over the plain west of Güney village, in the northern parts of the area (Arseven, 2003).

3.2.2 Structural Geology

Two common geological structures exposed in the area are tilted (folded) layers and the faults.

The bedding planes in the area are usually horizontal with minor variations (5^{o}-11^{o}) in the dip amount. Some steep layers are observed in the close vicinity of the faults. These layers, however, are interpreted as “drag” folds formed by the vertical movement of the faults.

Faults are common in the area (Figure 3.3). Two common directions are NE-SW and NW-SE. Most of the faults are normal type as indicated by the maps prepared by the company.

3.2.3 Rock Characterization at Y-3 Panel

During the study the only rock type encountered at the Y-3 Panel is marl of Tunçbilek formation. In addition, monitoring stations are constructed on this rock, covered by 0.7-1 m thick soil. A sample columnar section showing rock unit and coal seam at or around Y-3 Panel is presented in Figure 3.4.

In-situ measurements for P-wave propagation velocity also were carried out by the same university (METU) and the results are shown in Table 3.1.

Geo-mechanical studies were conducted by the Mining Engineering Department of Middle East Technical University (METU) in Ankara, Turkey (Paşamehmetoğlu et. al., 1988). In the above mentioned study, many of the mechanical and physical properties of marl, existing at Y-3 Panel were determined (Table 3.2 and Table 3.3).

The rock properties were taken into account by Paşamehmetoğlu et.al. (1988), together with observations on actual blasting activities, to determine the excavability class of encountered rock units at Tunçbilek mines including the Y-3 panel. The values determined confirm that drilling and blasting is an unavoidable operation for the rock units.

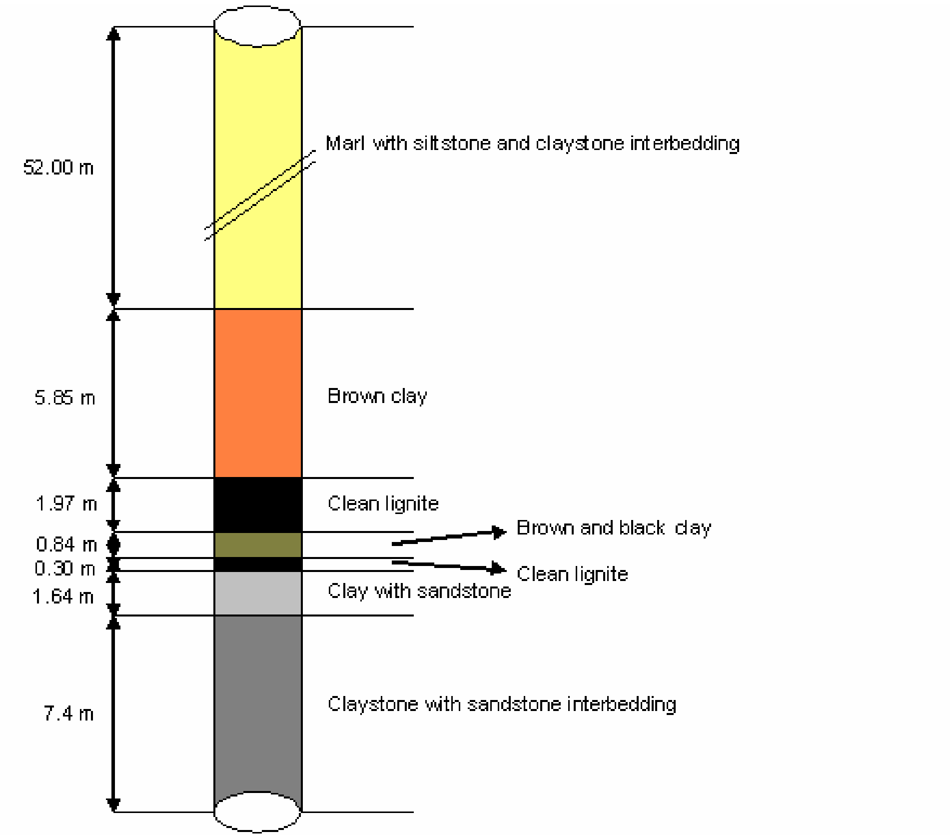

Figure 3.4 Columnar section of rock units existing in the Y-3 Panel

Table 3.1 In-situ measurements of P-wave velocity, Tunçbilek Y-3 Panel (Paşamehmetoğlu, et. al., 1988)

Rock Type	**Formation Description**	**P-wave Velocity (m/sec)**	**Thickness (m)**
Marl	- Fresh, occasionaly slightly weathered. - Bedding thickness 30-150 cm (Average 70 cm) - 1st Joint Set Spacing 40-80 cm, continuity 30 cm to few meters. - 2nd Joint Set Spacing 100 cm, continuity 0.3-100 cm	$V_1 = 703$	3.0
		$V_2 = 1900 – 2027$	>3.0

Table 3.2 Physical and mechanical properties of intact marl samples from Y-3 Panel, (Paşamehmetoğlu, et. al., 1988)

Rock Type	Uniaxial Compressive Strength (MPa)	Young's Modulus (10^3 MPa)	Poison's Ratio	Cohesion (MPa)	Internal Friction Angle (degree)	Natural Density (g/cm^3)	Moisture %	Hardness	Core Indenter Index	Indirect Tensile Strength (MPa)	Slake Durability Index %	Toughness ($N\text{-}cm/cm^3$)
Marl	(16.18-24.32) 18.92	4.835	0.28	5.88	37	2.043	7.970	38	2.38	5.23	0.994 0.991	1.13

Table 3.3 Rock mass properties of Tunçbilek Y-3 Panel (Paşamehmetoğlu, et. al., 1988)

Discontinuity Type	Position	Continuity (average) (m)	Spacing (m)	Roughness	Filling Material	Rebound Hardness	Notes
Bedding	Horizontal	-	0.7	-	-	-	-
First Joint Set	Perpendicular to Bedding	Horizontal 0.6 Vertival 0.7	0.6	Smooth Planar	No	Average 44.88 St. Deviation 3.44	1st Joint Set is dominant compared to 2nd Joint Set
Second Joint Set	Perpendicular to Bedding	Horizontal 0.6 Vertival 0.7	0.5	Smooth Planar	No	Average 44.88 St. Deviation 3.44	

Geotechnical description: Gray coloured, fresh marl, occasionally slightly to moderately weathered zone are present. Bedding plane thickness varies between 0.3 to 0.6m. after blasting, the average size boulders in the muck pile is 0.3mx0.4mx0.55m (0.07m^3), and the maximum size of boulders is 1.2mx1.2mx1m (1.44m^3).

CHAPTER 4

BLASTING METHOD AND MONITORING PROCEDURE

4.1 Blasting Method

The stripping operation is conducted in two stages at Y-3 panel of Western Lignite Co.'s open cast lignite mine. The upper horizons of the overburden rock were stripped by the shovel and truck operations in the first stage, until a thirty meter thick overburden is left just above the coal seam. In the second stage, the stripping operation of the rock just above the coal seam was carried out by dragline at Y-3 panel. The blasting method for dragline operations is explained below.

4.1.1 Drilling Pattern

Each blasting round consists of totally 18 blast holes in three rows (Figure 4.1). The drilling pattern for dragline stripping operation includes 6 holes per row, located at 9 meters intervals (Figure 4.1 and 4.2). The spacing between the rows is 7 meters.

The drill hole diameter used was 9 inches. The coal seam was divided into blocks as a result of normal faulting explained in the previous chapter. Thus the depth of the blast holes varied between 9 meters to 28 meters during the research study. Therefore the blast holes were charged rarely in single deck, but mostly in multi-deck.

Since the drilling pattern explained above was practical enough and developed as the result of the experience gained at this field, a new drill pattern was not proposed.

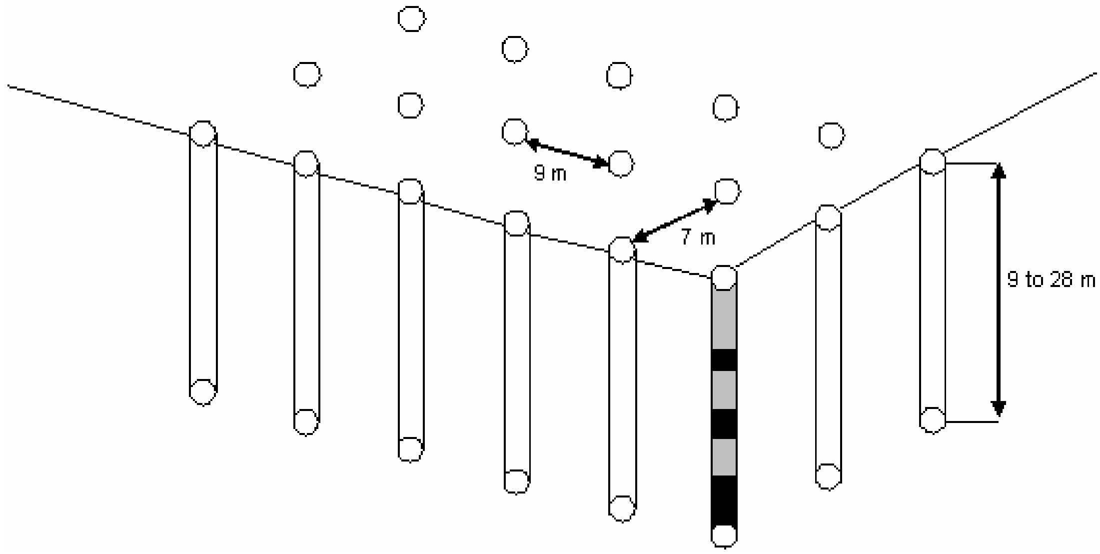

Figure 4.1 Drilling pattern used at the Y-3 panel

Figure 4.2 View of the blast holes.

4.1.2 Charging Method

Since the depths of the holes are varying from 9 meters to 28 meters, the number of decks and the amount of charge were changed for each hole according to the depth of the holes. For the holes which are deeper than 20 meters 3 deck charging was applied, where as for shallower holes 2 deck charging was practical. Single charging was applied when the hole depth was shallower than 10 meters. Sample charging plans for three holes having different depths are presented in Figure 4.3.

In a typical 3 deck charging, the bottom deck, the middle deck and the top deck contains 125 kg, 100 kg and 50 kg of ANFO respectively. For each deck, 1 kg of cap sensitive emulsion explosive was used as a primer.

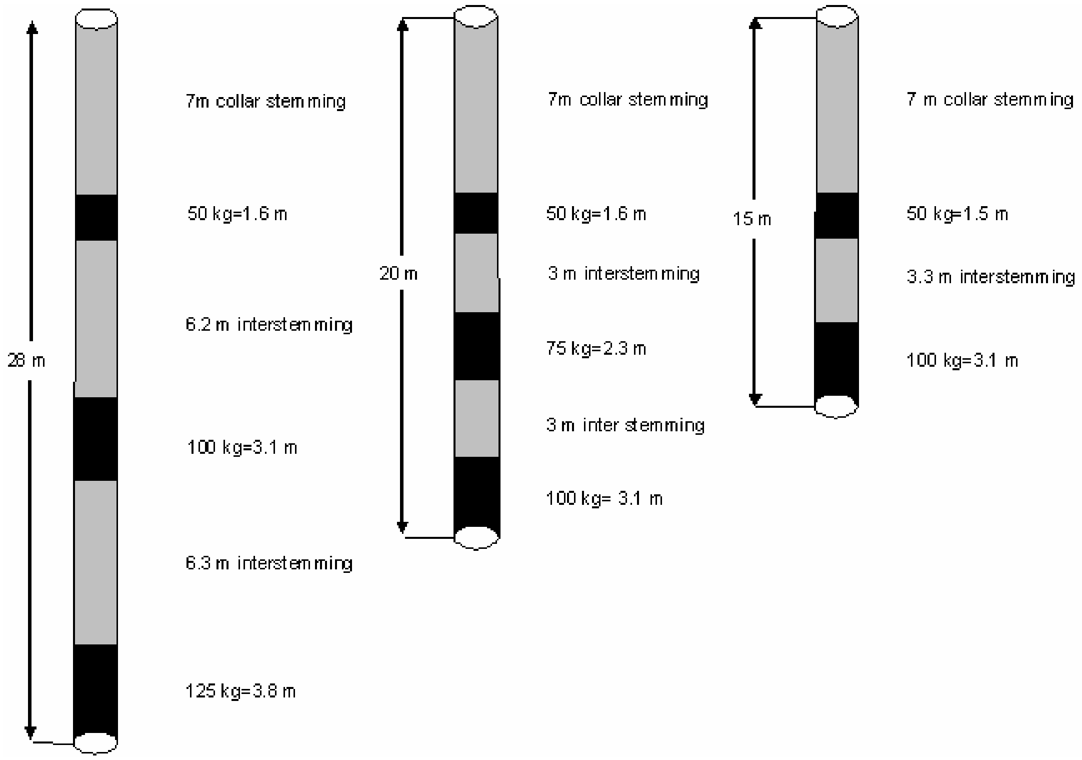

Figure 4.3 Sample charging plans, for three blast holes having different depths used at Y-3 panel

4.1.3 Firing Sequence

For the initiation of the blast holes and the decks in each blast hole, non-electric (NONEL) detonators are used. Multi-deck blasting differs from the single deck blasting in that the delay time between the decks is fixed as 25 milliseconds (Figure 4.4). The firing sequence used for the blasting rounds at Y-3 panel, before this study, is shown in Figure 4.5.

As it can be observed from Figure 4.5, the delay period between the holes in the same row was 25 milliseconds; same as the delay period between each deck which was 25 milliseconds. Therefore when this delay pattern was used, the bottom deck of the first hole, the middle deck of the second hole and the top deck of the third hole were detonating simultaneously and the charge per delay was increased to 275 kg's.

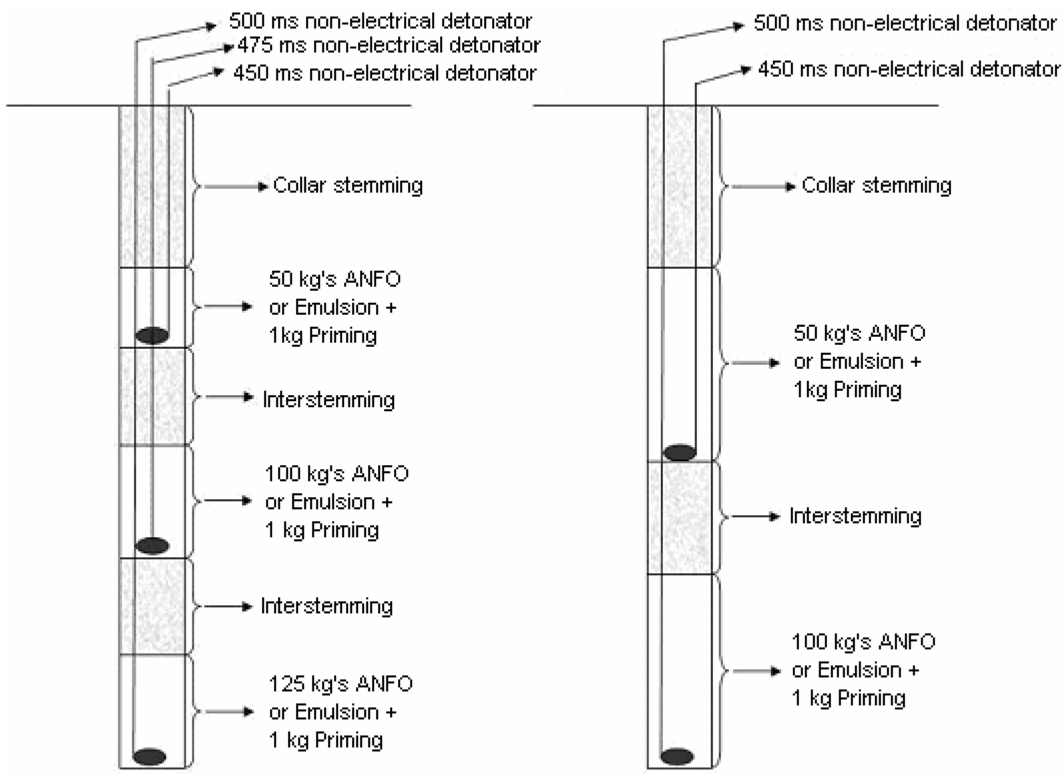

Figure 4.4 Delay period between the decks in a blast hole

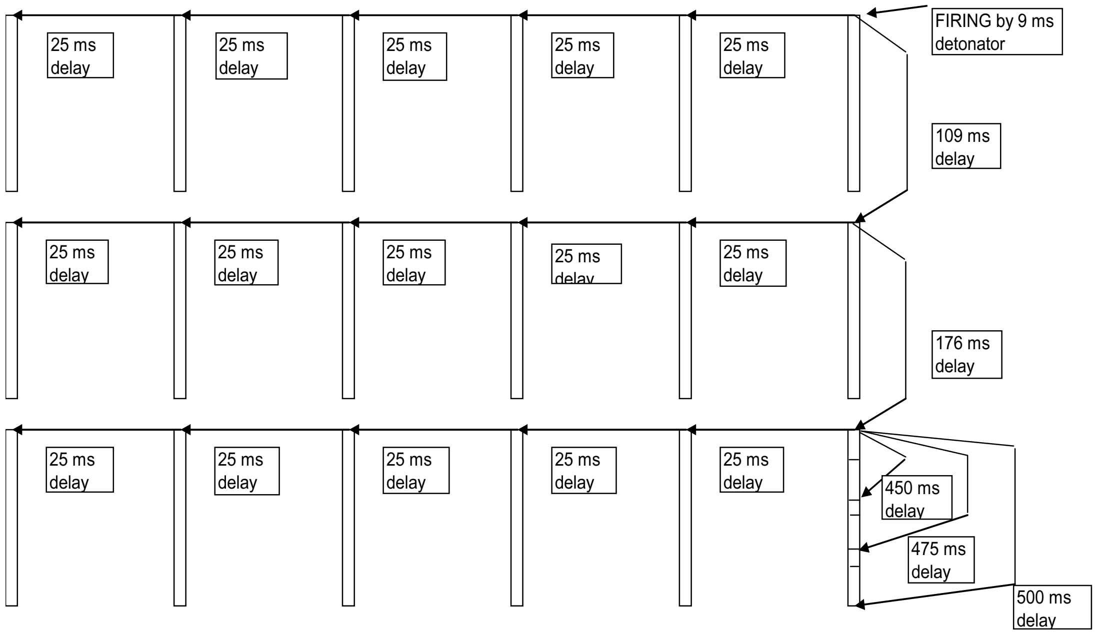

Figure 4.5 Firing sequence previously used at Y-3 panel

During this research work, in order to decrease the charge per delay and thus the ground vibration amplitude also, a new firing sequence was proposed (Figure 4.6). In the new firing sequence 17ms – 17ms – 65ms – 17ms – 17ms (milliseconds) delay periods are used between the holes for each row of the round. In addition, the delay period between the rows is increased to 200 milliseconds to prevent the simultaneous detonation of the charges at different rows. The proposed delay pattern provides a minimum of 8 milliseconds delay time between any two detonations, and only one deck detonates at a time. Thus charge per delay was decreased from 275 kg's, to the amount of charge per deck, such as 125 kg's. The proposed delay pattern was used throughout the research study.

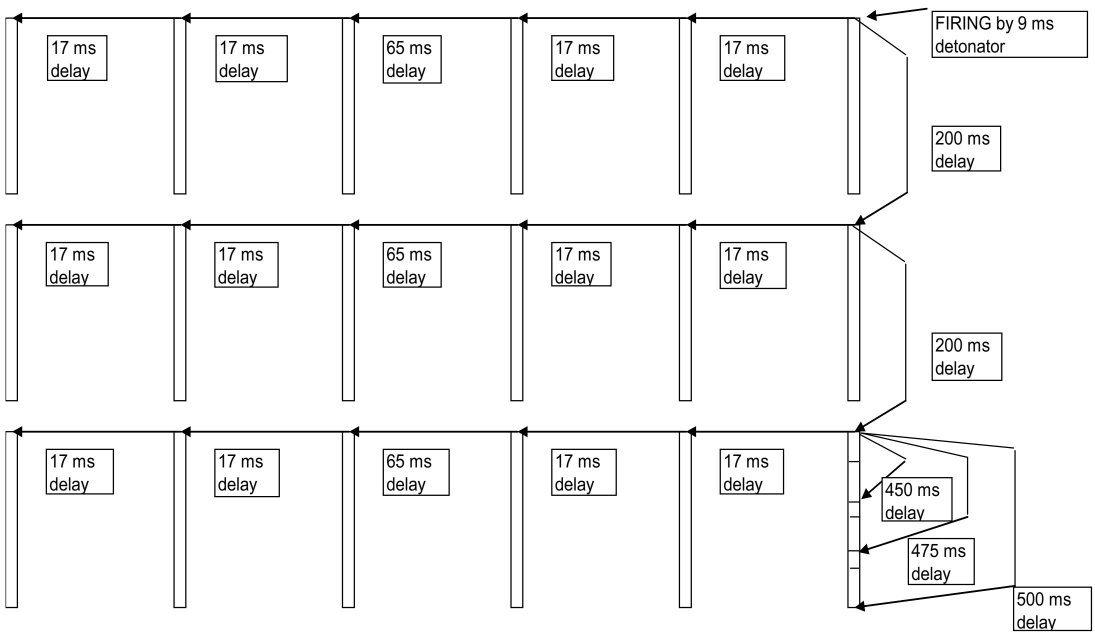

Figure 4.6 The proposed and the applied delay sequence throughout the research study

4.1.4 Firing Direction

Before the research study, the firing was started at the first blast hole at the either end of the first row, irrespective of the village direction. However this may cause scatter in the data. The difference in the amplitude of seismic waves may be expected due to the anisotropy likely to be observed in ground conditions prevailing before or after the detonation of the first hole, in which the waves were propogating and the possibility of superpositioning of seismic wave trains. To eliminate this drawback, the firing direction is fixed as follows:

i- In the first group of tests, the direction of initiation was taken towards the Yörgüç village only (Figure 4.7-A).

ii- In the second group of tests, the direction of initiation was taken away from the Yörgüç village only (Figure 4.7-B).

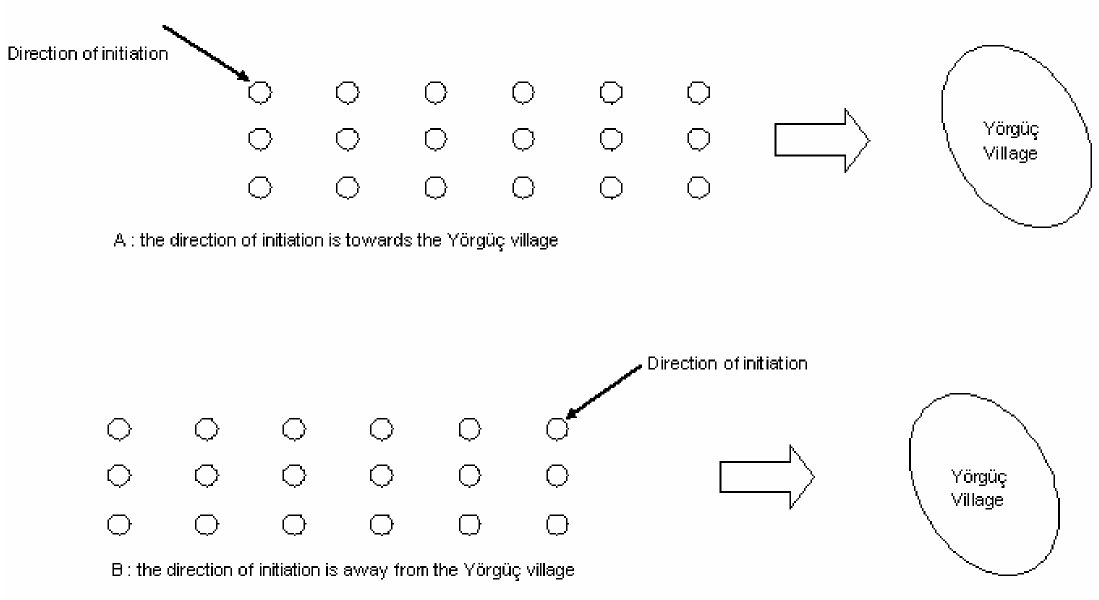

Figure 4.7 Direction of initiation according to the Yörgüç village.

4.2 Monitoring Procedure

In order to be able to predict the peak particle velocity, a site specific propogation and attenuation equation is to be produced which will allow also the estimation of the maximum allowable charge per delay for the site. Ground vibration monitoring and recording is carried out at the field to obtain the data for the determination of the site specific propogation equation. Field work and data collection was conducted in accordance with the dragline operation, covering at about 10 month's period of time. Field work consists of collecting ground vibration data from 8 different monitoring stations along a prefered line between the mine and the Yörgüç village.

At Y-3 panel, the stripping operation is done by the Western Lignite Cooperation itself. Blasting operation is conducted as multi-deck round blasts. During the study totally 20 round blast records are taken. For the comparison of the effects of the direction of initiation on the ground vibration induced from the same blasting pattern, for the 10 records the initiation is started towards the Yörgüç village direction and for the other 10 of the records the initiation is started from the Yörgüç village direction. In Figure 4.8 locations of the blastholes which are initiated towards Yörgüç village direction and the monitoring stations are shown.

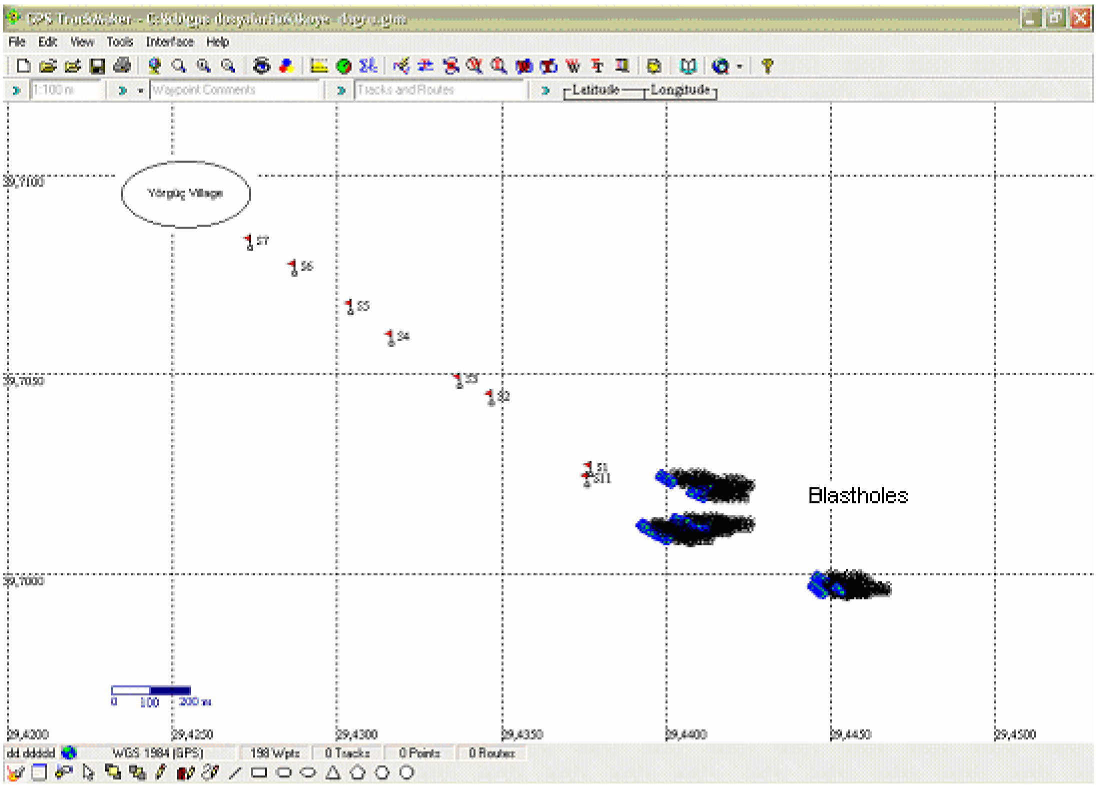

Figure 4.8 Blast holes which are initiated towards Yörgüç village direction and the monitoring stations.

In Figure 4.9 locations of the blastholes initiated from Yörgüç village direction and the monitoring stations can be seen.

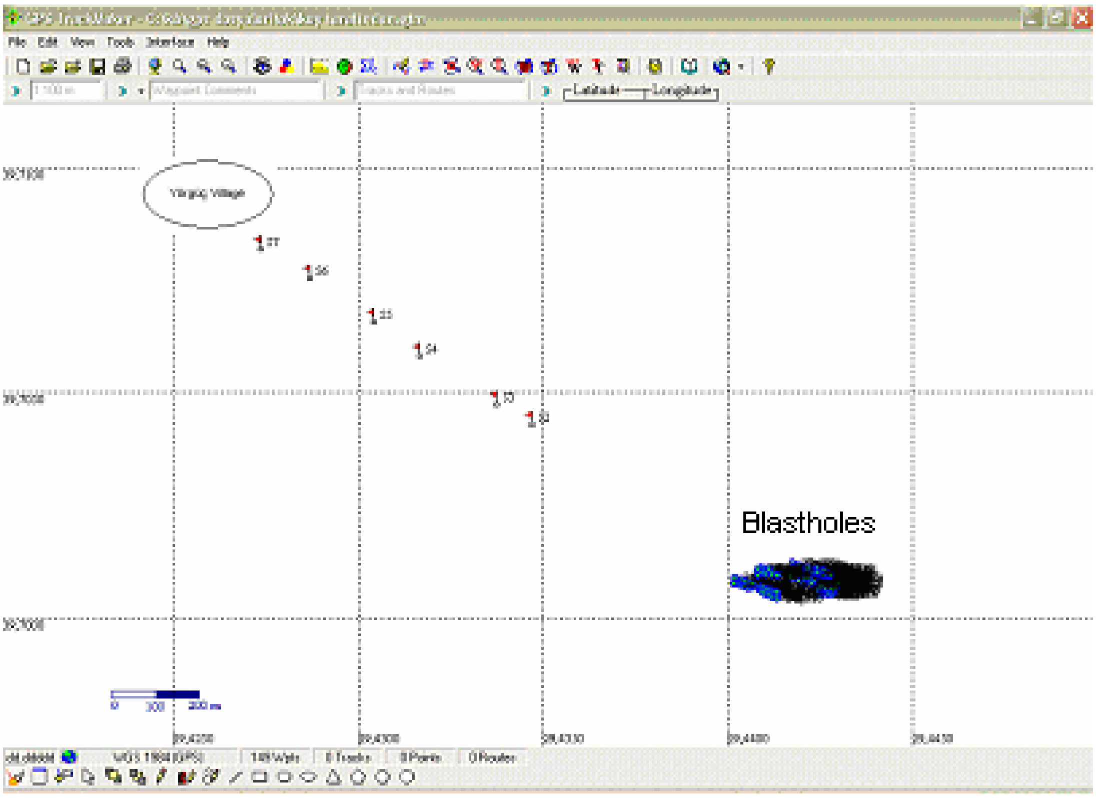

Figure 4.9 Blast holes which are initiated from Yörgüç village direction and the monitoring stations.

In addition, during the study, 20 single hole blast records are taken for the determination of the frequency properties of the site more accurately and to control the maximum co-operating charge per delay, by eliminating the superposition of the vibration wave trains caused by round blasting practices. These data are also used for the production of the site specific propogation equation and estimation of the maximum allowable charge for the single hole blast in case of the future use of the single hole blasts.

For determination of the coordinates of the holes and the monitoring stations a hand-held GPS (Global Positioning System) instrument is used. The absolute distances between the boreholes and the monitoring stations are also calculated by GPS instrument.

For the monitoring of the ground vibration components White Mini-Seis II model digital seismograph is used. Instruments used in the study are shown in Figure 4.10.

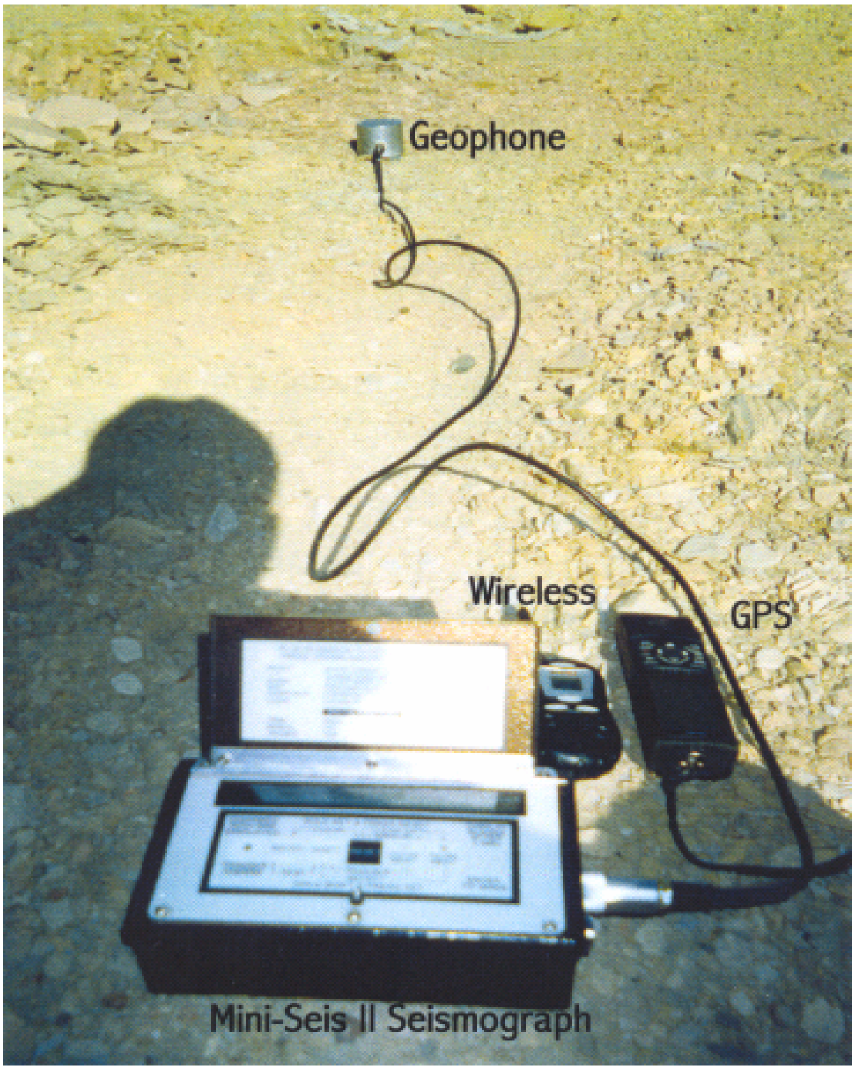

Figure 4.10 Instruments used in the study.

The specifications of the seismograph are summarized below:

- The model is portable seismograph for monitoring and recording seismic and sound signals produced from blasting.

- It can be used for a single shot or a continuous mode.
- It basically consists of three geophones (radial, vertical and transverse) positioned perpendicular to each other.
- A microphone rated to at least 160 dB can be connected to the seismograph.
- Mini-Seis II can record frequencies from 1 to 250 Hz.
- The full wave form signature is stored in solid state memory for up to 341 events.
- Seismic recording range can be selected from 0.125 to 64 mm/sec.
- Maximum recording duration is 9 seconds.

Mini-Seis II digital seismograph records the peak particle velocities of three components of the vibration, namely radial (longitudinal), vertical and transverse as well as the time histories of seismic vibrations. Seismograph has its own data analysis software called “White Seismograph Data Analysis 2003” which provides easy access and analyzes recorded data. An example wave form time-history of a blasting event is given in Figure 4.11.

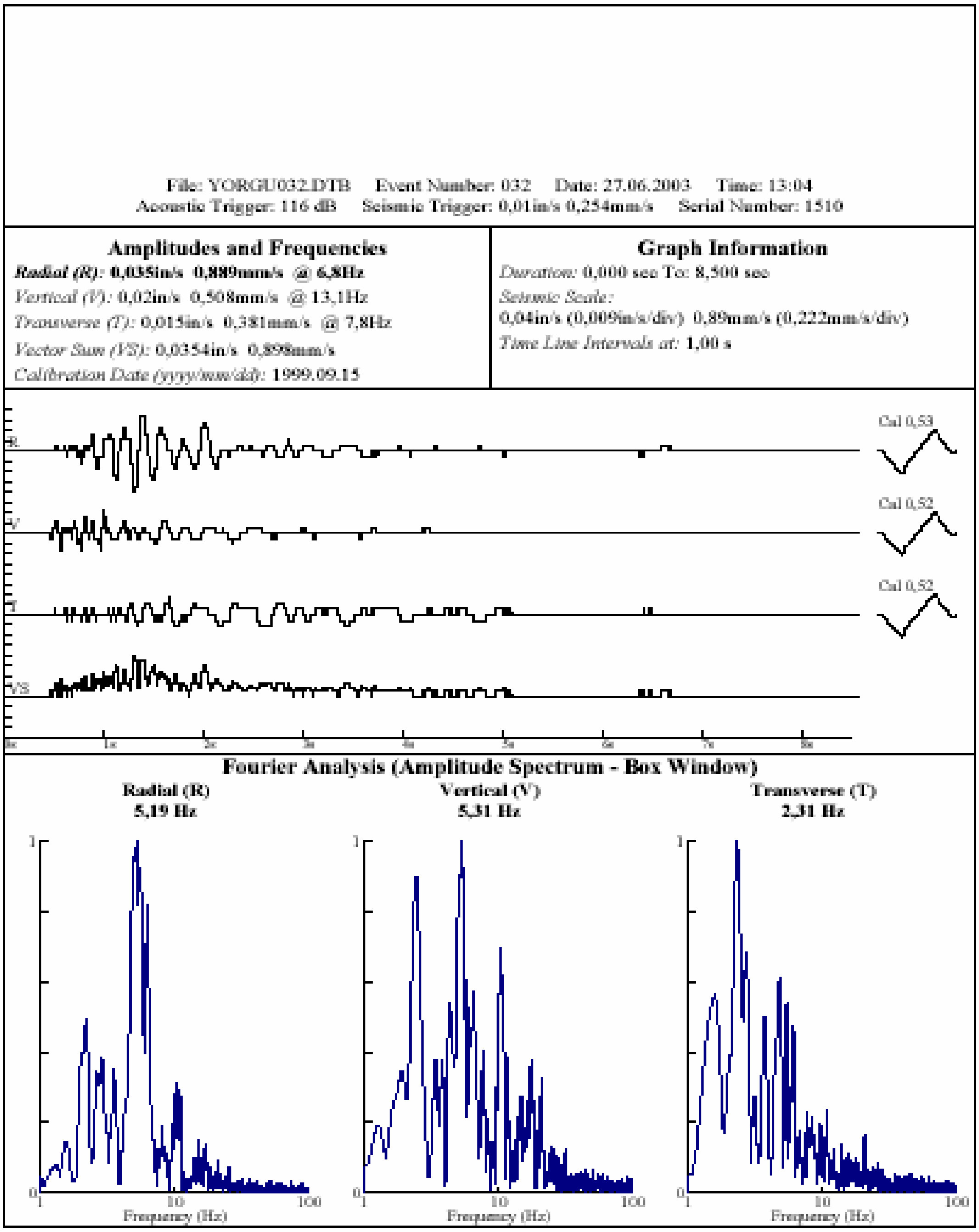

Figure 4.11 An example wave form time-history of a blasting event

CHAPTER 5

RESULTS AND DISCUSSIONS

During the study totally 20 round blast records and 20 single-hole blast records are taken. For the first 10 of the round blasting records, the initiation is started towards Yörgüç village direction (Figure 4.7 A), by using the delay sequence presented in Figure 4.6. These records are given in Appendix A.

In the research 20 single-hole blast records are taken for the determination of the frequency properties of the site and to control the maximum co-operating charge per delay, by eliminating the superposition of the vibration wave trains caused by round blasting practices. These data are also used for the production of the site specific propagation equation and estimation of the maximum allowable charge for the single-hole blasts in case of the future use of the single hole blasts. These data are presented in Appendix B.

For the comparison of the effects of the direction of initiation on ground vibration provided that the same blasting pattern is used, for the other 10 of the round blasting records, the initiation is started from Yörgüç village direction (Figure 4.7 B), by using the delay sequence presented in Figure 4.6. These records are given in Appendix C.

5.1 Rounds for Which, Initiation Started towards Yörgüç Village Direction

During the study 10 rounds each having 18 blast holes is initiated towards the direction of Yörgüç Village. The data obtained from these blasting records are shown in the Table 5.1.

In the table; event no, codes for the rounds, monitoring date, monitoring time, monitoring station, amplitudes of the vibration components for radial (R, mm/s), vertical (V, mm/s) and transverse (T, mm/s), vectoral summation of the components of the vibration (VS, mm/s), peak particle velocity (PPV, mm/s), frequencies of the components of the vibration as radial (R, Hz), vertical (V, Hz) and transverse (T, Hz), co-operating charge (Q, kg) for each round, absolute distance (D, m) and scaled distance (SD, $m/kg^{1/2}$) are given respectively.

Frequency values are the dominant frequency values calculated by Fast Foourier Transform (FFT) analysis for radial, vertical and transverse components of the vibration. Absolute distances are calculated by GPS instrument.

The scaled distance range from 59.93 to 121.64. The lowest scaled distance, 59.93 was measured on 08.07.2003 at the monitoring station 2 (S2) which is located 670 m away from the blast hole which contain the maximum charge per delay. The peak particle velocity (PPV) ranged from 0.508 to 4.318 mm/sec. Co-operating charge (maximum charge per delay) used for blasting ranged from 120 kg to 175 kg and the absolute distance ranged from 670 m to 1380 m.

Table 5.1 Vibration data for initiation started towards Yörgüç village direction.

Event No	Round No	Date	Time	Station	R (mm/s)	V (mm/s)	T (mm/s)	VS (mm/s)	PPV (mm/s)	R (Hz)	V (Hz)	T (Hz)	Q (kg)	D (m)	SD
74	04G2	04.07.2003	12:37	S7	0.508	0.254	0.381	0.635	0.508	4.75	10.63	10.81	125	1360	121.642
75	04G3	04.07.2003	12:50	S3	2.413	4.318	1.270	4.826	4.318	4.75	10.63	10.81	130	700	61.394
92	08G1	08.07.2003	11:55	S2	2.159	1.778	1.905	2.413	2.159	7.63	3.69	4.00	125	670	59.927
97	09G1	09.07.2003	14:33	S5	1.524	0.762	1.016	1.651	1.524	5.00	4.81	4.13	125	1030	92.126
98	09G2	09.07.2003	14:43	S6	2.032	1.651	0.889	2.286	2.032	9.56	9.88	10.31	175	1170	88.444
193	20A1	20.04.2004	11:14	S7	0.635	1.016	0.508	1.016	1.016	4.63	4.00	3.81	150	1380	112.677
194	20A2	20.04.2004	11:22	S6	1.016	1.651	1.016	1.778	1.651	4.75	10.63	10.81	150	1250	102.062
168	18G1	18.02.2004	14:02	S11	2.540	1.397	1.270	2.921	2.540	2.56	2.94	2.38	120	690	62.988
170	19G1	19.02.2004	11:58	S1	2.540	2.413	1.651	2.794	2.540	2.69	3.19	2.88	120	740	67.552
171	20G1	20.02.2004	11:57	S11	2.667	1.397	1.270	3.048	2.667	2.56	2.94	2.44	120	700	63.901

By using data, given in the Table 5.1, scaled distance (SD) versus vibration amplitude graphs are drawn for the 50% probability and 95% probability of the occurrences, for each of three components of the vibration, vectoral summation of these three components and the peak particle velocity. These graphs are given in Figures 5.1, 5.2, 5.3, 5.4, 5.5 respectively.

In this research study, to be on the safer side, one of the three components of the vibration, which gives the higher particle velocity for the SD = 50 and SD = 65 will be selected and future calculations will be based on the peak particle velocity (PPV), vectoral summation of the three components of the vibration (VS) and one of the three components of the vibration, which gives the higher particle velocity for the SD = 50 and SD = 65.

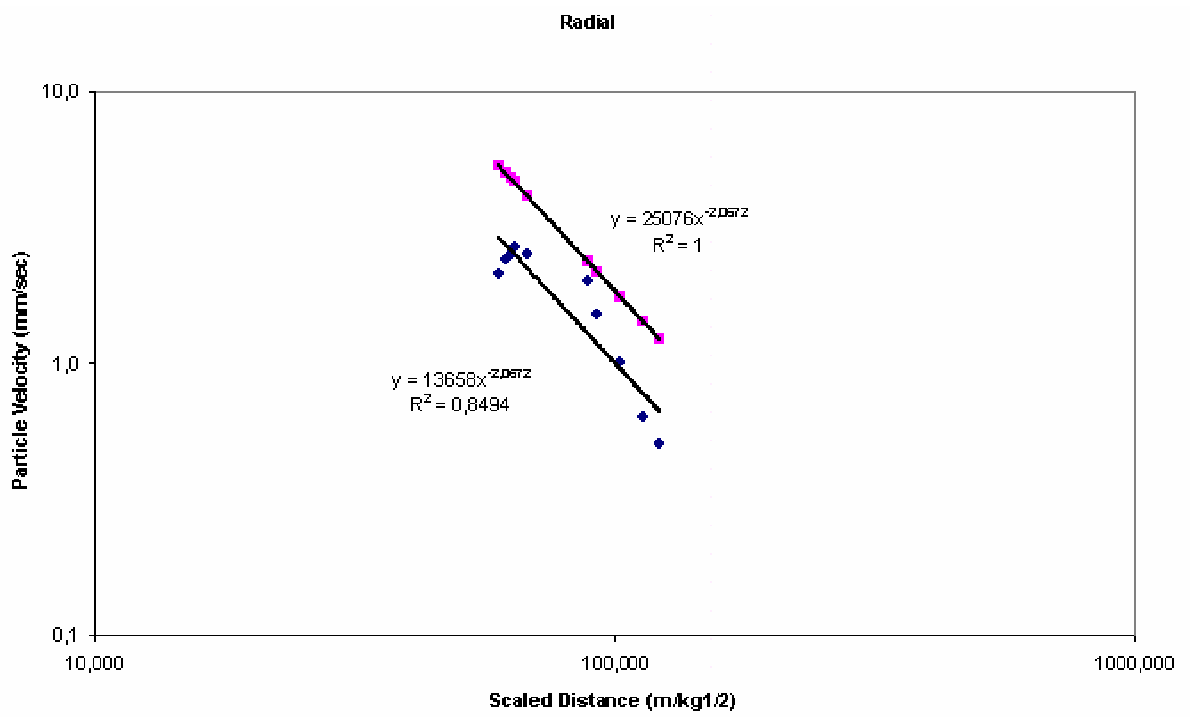

Figure 5.1 Scaled Distance (SD) vs Radial (R) Vibration Component Graph for the group that initiation started towards Yörgüç village direction.

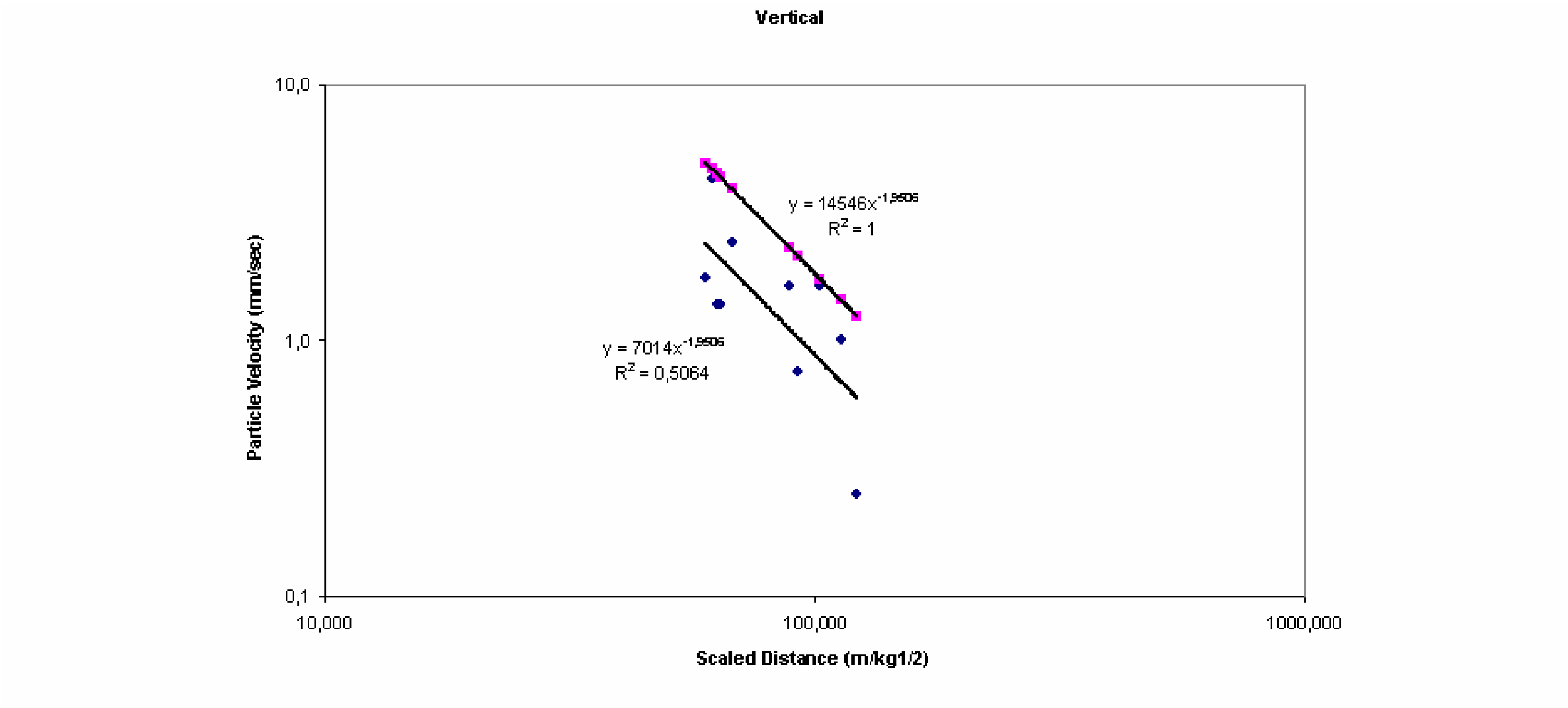

Figure 5.2 Scaled Distance (SD) vs Vertical (V) Vibration Component Graph for the group that initiation started towards Yörgüç village direction.

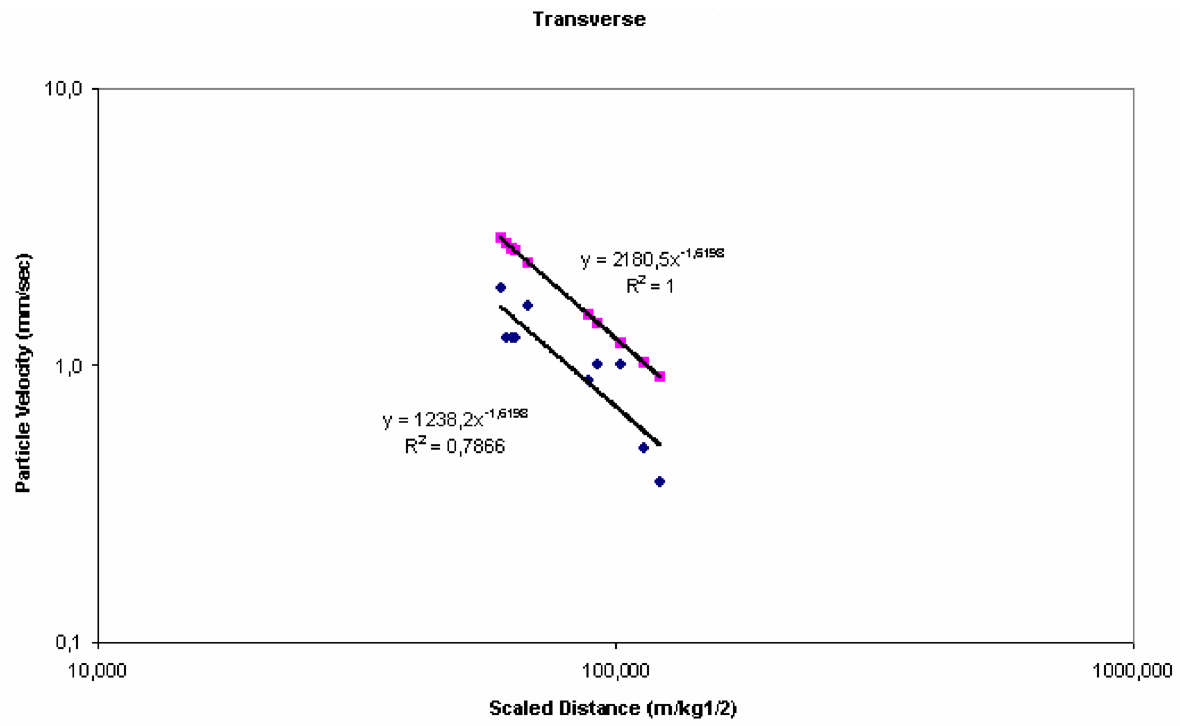

Figure 5.3 Scaled Distance (SD) vs Transverse (T) Vibration Component Graph for the group that initiation started towards Yörgüç village direction.

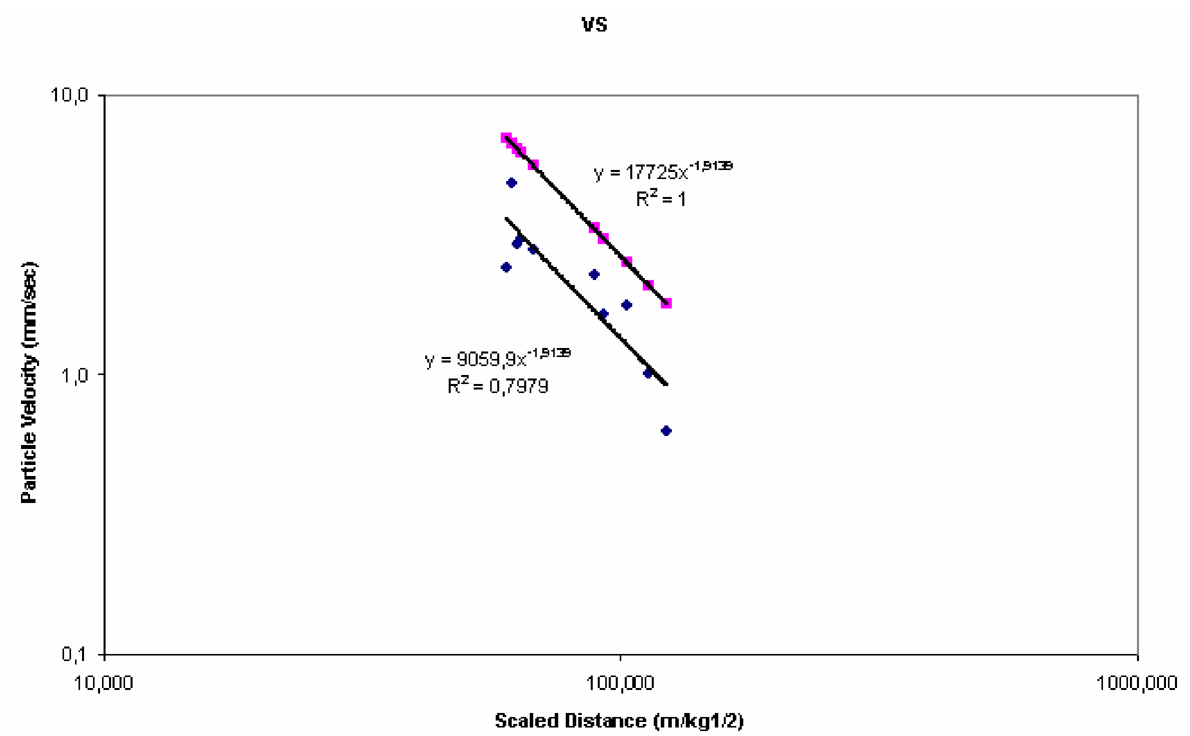

Figure 5.4 Scaled Distance (SD) vs Vector Summation (VS) of the Vibration Components Graph for the group that initiation started towards Yörgüç village direction.

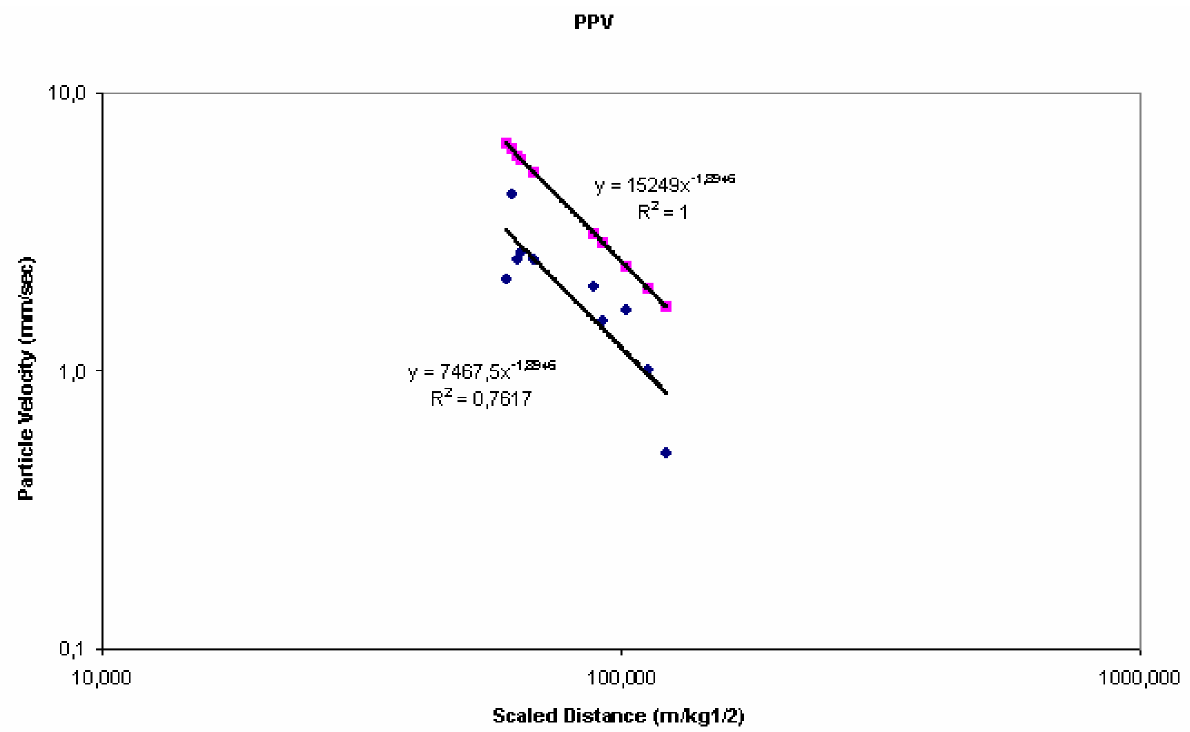

Figure 5.5 Scaled Distance (SD) vs Peak Particle Velocity (PPV) Graph for the group that initiation started towards Yörgüç village direction.

The relationship between the particle velocity and the scaled distance for all particle velocities are presented in the form of constants in Table 5.2.

Table 5.2 Coefficient of determinations (R^2) and the site specific parameters (k, m) for 50% and 95% probabilities for the initiation case started towards Yörgüç village direction.

Initiation towards village direction (50%)

	k	m	R^2
Radial	13658	-2.0672	0.8494
Vertical	7014	-1.9506	0.5064
Transverse	1238	-1.6198	0.7866
VS	9060	-1.9139	0.7979
PPV	7468	-1.8946	0.7617

Initiation towards village direction (95%)

	k	m	R^2
Radial	25076	-2.0672	1
Vertical	14546	-1.9506	1
Transverse	2181	-1.6198	1
VS	17725	-1.9139	1
PPV	15249	-1.8946	1

By using k and m values obtained from Figures 5.1, 5.2, 5.3, 5.4, 5.5, and for scaled distance 50 and 65, particle velocities are calculated for 50% and 95% probabilities (Table 5.3). Among the three vibration components, the highest amplitude for the particle velocity is obtained by the attenuation equation of the radial component of the vibration. Therefore, future calculations will be based on the radial component (R) of the vibration, peak particle velocity (PPV) and the vectoral summation (VS) of the components of the vibration.

If the dominant frequencies of the vibrations for which the initiation started towards Yörgüç village direction are considered, it can be seen that they are mainly below 8 Hz (Table 5.4) So it can be accepted that, 12.7 mm/sec peak particle velocity is the maximum allowable limit for vibration.

Table 5.3 Particle velocities for SD=50 and SD=65 for the group that initiation started towards Yörgüç village direction.

50%	Particle Velocity for SD=50 (mm/s)	Particle Velocity for SD=65 (mm/s)
Radial	4.20	2.44
Vertical	3.40	2.04
Transverse	2.19	1.43
VS	5.08	3.07
PPV	4.51	2.74

95%	Particle Velocity for SD=50 (mm/s)	Particle Velocity for SD=65 (mm/s)
Radial	7.71	4.48
Vertical	7.06	4.23
Transverse	3.86	2.52
VS	9.93	6.01
PPV	9.21	5.60

Table 5.4 Frequency distribution of blast vibration for the group that initiation started towards Yörgüç village direction.

	F < 8,00 Hz	8,00 Hz < F < 12,00 Hz	12,00 Hz < F < 18,00 Hz	18,00 Hz < F
Radial	9	1	-	-
Vertical	6	4	-	-
Transverse	6	4	-	-

During this study, although the charge per delay is varied between 100 kg's and 175 kg's, normally the maximum co-operating charge used for blasting was 125 kg. Therefore, accepting this amount of blasting agent as the maximum charge for future blasts, the minimum distance that the blasting can be done without causing damage to the structures nearby is calculated for both 50% and 95% probabilities and shown in Table 5.5.

It can be observed from Table 5.5 that the minimum distance calculated for which 125 kg blasting agent can be detonated per delay without causing damage to the surrounding structures for radial component of the vibration is 327.32 m, for vectoral summation (VS) of the vibration is 346.17 m and for peak particle velocity (PPV) is 323.72 m; for 50% of probability. In addition, the corresponding distance values are 439.16 m, 491.57 m, 471.88 m for the radial component of the vibration, VS and PPV respectively; for 95% of probability. Therefore the safest results can be obtained by using the vectoral summation (VS) equation for vibration determination calculations at 95% confidence. In summary, 125 kg explosive per delay can be detonated safely at a minimum distance of 491.57 m or greater.

Table 5.5 Minimum safe distance (D_{min}) for 125 kg charge per delay for the initiation case started towards Yörgüç village direction.

Q=125kg

50%	D_{min} (m)
Radial	327.32
VS	346.17
PPV	323.72

Q=125kg

95%	D_{min} (m)
Radial	439.16
VS	491.57
PPV	471.88

By accepting the 12.7 mm/sec as the limiting value for the particle velocity and using the attenuation curves of the radial component (R) of the vibration, peak particle velocity (PPV) and the vectoral summation (VS) of the components of the vibration, maximum allowable amounts of charges per delay are calculated for the 50% and 95% probabilities and shown in Table 5.6.

When Table 5.6 is considered, at 95% confidence and VS attenuation equation for safest results, the following results can be recommended.

- When the blast site is 700 m away from the Yörgüç village, the maximum amount of explosive per delay is 253.48 kg's.
- When the absolute distance between the blast site and the village reduces to 600 m, the maximum amount of explosive per delay decreases to 186.23 kg's.
- When the blast site is 400 m away from Yörgüç village, the maximum amount of explosive per delay must be reduced to 82.77 kg's.

- When the absolute distance between the blast site and the village decreases to 350 m, the maximum amount of explosive per delay must further be reduced to 63.37 kg's.

Table 5.6 Maximum allowable charges for different distances for the group that initiation started towards Yörgüç village direction.

PV=12.7 mm/s

50%	Maximum Allowable Charge, Qmax (kg)		
D (m)	Considering Radial Component of Vibration	Considering VS	Considering PPV
350	142.92	127.78	146.12
400	186.68	166.89	190.85
450	236.26	211.22	241.54
500	291.68	260.77	298.20
600	420.02	375.51	429.40
700	571.69	511.11	584.47
800	746.70	667.57	763.38
900	945.04	844.90	966.16
1000	1166.72	1043.08	1192.79
1250	1823.00	1629.82	1863.73
1500	2625.12	2346.94	2683.77
1750	3573.08	3194.44	3652.91
2000	4666.88	4172.33	4771.15

PV=12.7 mm/s

95%	Maximum Allowable Charge, Qmax (kg)		
D (m)	Considering Radial Component of Vibration	Considering VS	Considering PPV
350	79.40	63.37	68.77
400	103.70	82.77	89.82
450	131.25	104.75	113.68
500	162.04	129.33	140.34
600	233.33	186.23	202.09
700	317.59	253.48	275.07
800	414.81	331.07	359.28
900	525.00	419.01	454.71
1000	648.15	517.30	561.37
1250	1012.73	808.28	877.14
1500	1458.33	1163.93	1263.08
1750	1984.95	1584.24	1719.19
2000	2592.59	2069.21	2245.47

5.2 Single-Hole Blasts

During the study, 20 single-hole blast records are taken for;

- determining the dominant frequencies of the site more sensitively,
- controling the maximum co-operating charge per delay, by eliminating the superposition of the vibration wave trains caused by round blasting practices,
- obtaining the site specific propagation equation and the estimation of the maximum allowable charge for the single hole blast in case of the future use of

the single hole blasts.

These data are shown in the Table 5.7.

In the table; event no, codes for the blasts, monitoring date, monitoring time, monitoring station, amplitudes of the vibration components for radial (R, mm/s), vertical (V, mm/s) and transverse (T, mm/s), vectoral summation of the components of the vibration (VS, mm/s), peak particle velocity (PPV, mm/s), frequencies of the components of the vibration as radial (R, Hz), vertical (V, Hz) and transverse (T, Hz), co-operating charge (Q, kg) for each record, absolute distance (D, m) and scaled distance (SD, m/kg$^{1/2}$) are given respectively.

Frequency values are the dominant frequency values calculated by Fast Fourier Transform (FFT) analysis for radial, vertical and transverse components of the vibration. Absolute distances are calculated by GPS instrument.

The scaled distance range from 4.51 to 131.18. The lowest scaled distance, 4.51 was measured on 01.07.2003 at the monitoring station 11 (S11) which is located 50 m away from the blast hole which contain the co-operating charge. The peak particle velocity (PPV) ranged from 0.508 to 53.340 mm/sec. Co-operating charge used for blasting ranged from 41 kg to 123 kg and the absolute distance ranged from 50 m to 1163 m.

Table 5.7 Vibration data for single hole blasts.

Event No	Date	Time	Station	R (mm/sec)	V (mm/sec)	T (mm/sec)	VS (mm/sec)	PPV (mm/sec)	R (Hz)	V (Hz)	T (Hz)	Q (kg)	D (m)	SD
12	25.06.2003	12:32	S1	5.461	4.445	3.937	6.731	5.461	6.00	5.25	8.38	41	140	21.864
13	25.06.2003	12:36	S1	5.334	5.334	0.445	7.239	5.334	6.06	5.25	5.88	41	140	21.864
14	25.06.2003	12:41	S1	40.640	53.340	17.272	53.721	53.340	4.06	6.19	7.69	41	50	7.809
15	25.06.2003	12:46	S1	44.704	53.340	14.732	54.102	53.340	4.63	6.06	6.50	82	50	5.522
16	25.06.2003	13:04	S1	24.892	22.352	10.287	25.527	24.892	4.56	5.00	8.50	41	60	9.370
17	25.06.2003	13:10	S1	50.292	53.340	22.352	54.356	53.340	4.63	4.94	8.38	123	60	5.410
18	25.06.2003	13:38	S2	1.143	1.270	0.635	1.270	1.270	6.75	3.94	4.56	41	390	60.908
19	25.06.2003	13:44	S3	1.524	2.032	0.762	2.159	2.032	24.69	23.94	4.50	41	490	76.525
20	25.06.2003	13:55	S5	0.381	0.508	0.381	0.508	0.508	3.63	10.75	10.06	41	840	131.186
21	25.06.2003	14:48	S6	0.762	0.762	0.254	0.889	0.762	11.00	9.75	2.94	82	1030	113.744
22	25.06.2003	14:55	S7	0.381	0.762	0.381	0.762	0.762	3.50	10.00	4.06	123	1163	104.864
55	01.07.2003	14:39	S11	13.716	17.272	5.334	18.669	17.272	7.19	5.75	8.44	41	60	9.370
56	01.07.2003	14:42	S11	20.828	32.512	7.493	33.274	32.512	4.63	6.31	7.56	82	60	6.626
57	01.07.2003	14:47	S11	37.084	44.196	13.716	45.974	44.196	4.63	5.75	4.50	123	57	5.140
58	01.07.2003	15:02	S11	9.271	15.113	12.192	17.018	15.113	4.56	5.88	4.25	41	60	9.370
59	01.07.2003	15:05	S11	21.844	27.432	12.954	29.718	27.432	4.63	6.75	5.00	82	60	6.626
60	01.07.2003	15:09	S11	46.228	44.704	17.780	48.768	46.228	5.44	5.88	4.69	123	50	4.508
61	01.07.2003	15:17	S2	1.143	1.270	0.889	1.270	1.270	5.50	5.56	3.81	41	380	59.346
62	01.07.2003	15:21	S3	1.397	1.778	0.635	2.032	1.778	25.50	3.56	3.19	41	470	73.402
63	01.07.2003	15:29	S5	0.508	0.889	0.381	0.889	0.889	4.00	18.63	3.75	82	815	90.002

By using data, given in the Table 5.7, scaled distance (SD) versus vibration amplitude graphs are drawn for the 50% probability and 95% probability of the occurrences, for each of three components of the vibration, vectoral summation of these three and the peak particle velocity. These graphs are given in Figures 5.6, 5.7, 5.8, 5.9, 5.10 respectively.

In this research study, to be on the safer side, one of the three components of the vibration, which gives the higher particle velocity for the SD = 50 and SD = 65 will be selected and future calculations will be based on the peak particle velocity (PPV), vectoral summation of the three components of the vibration (VS) and one of the three components of the vibration, which gives the higher particle velocity for the SD = 50 and SD = 65.

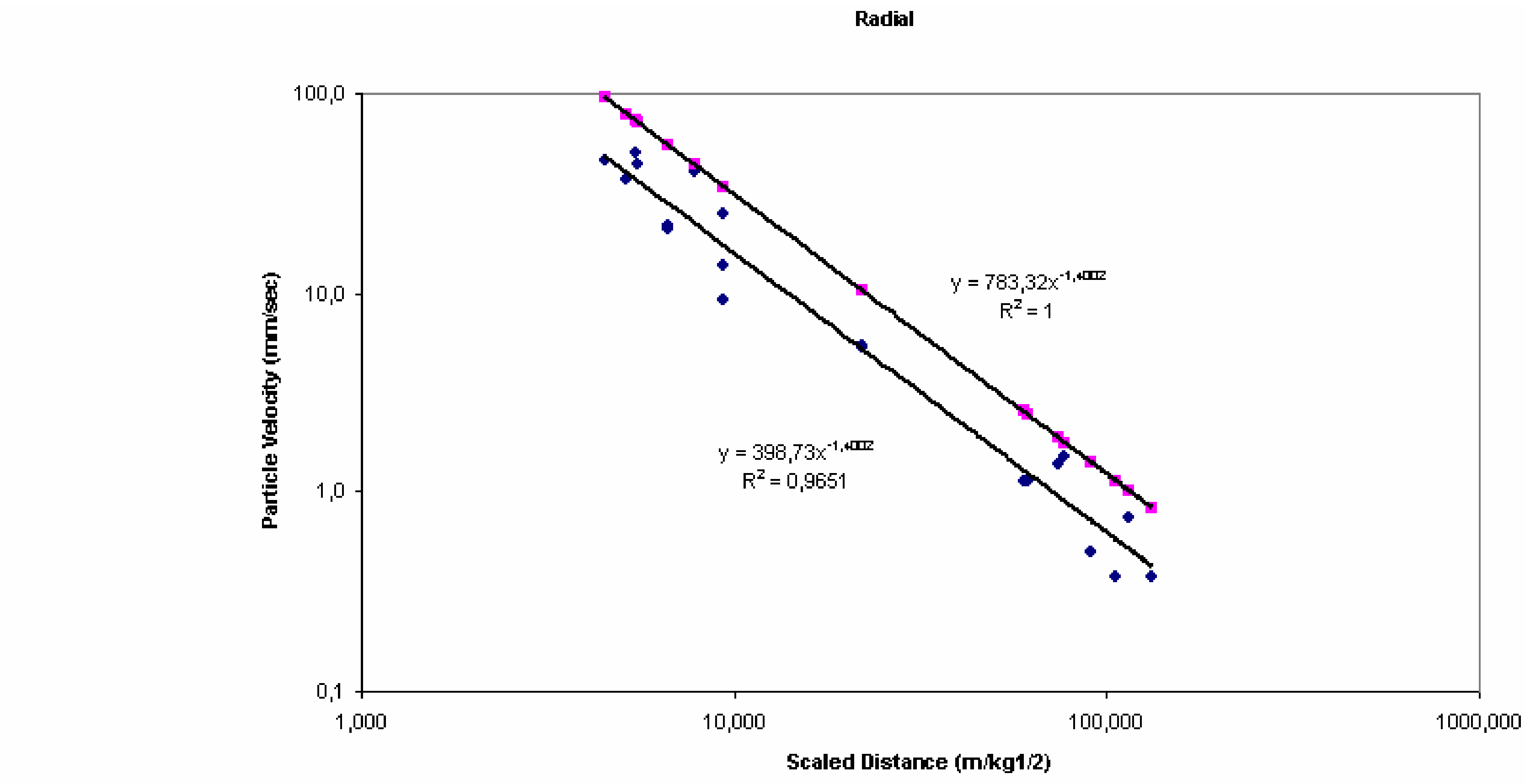

Figure 5.6 Scaled Distance (SD) vs Radial (R) Vibration Component Graph for single hole blasts.

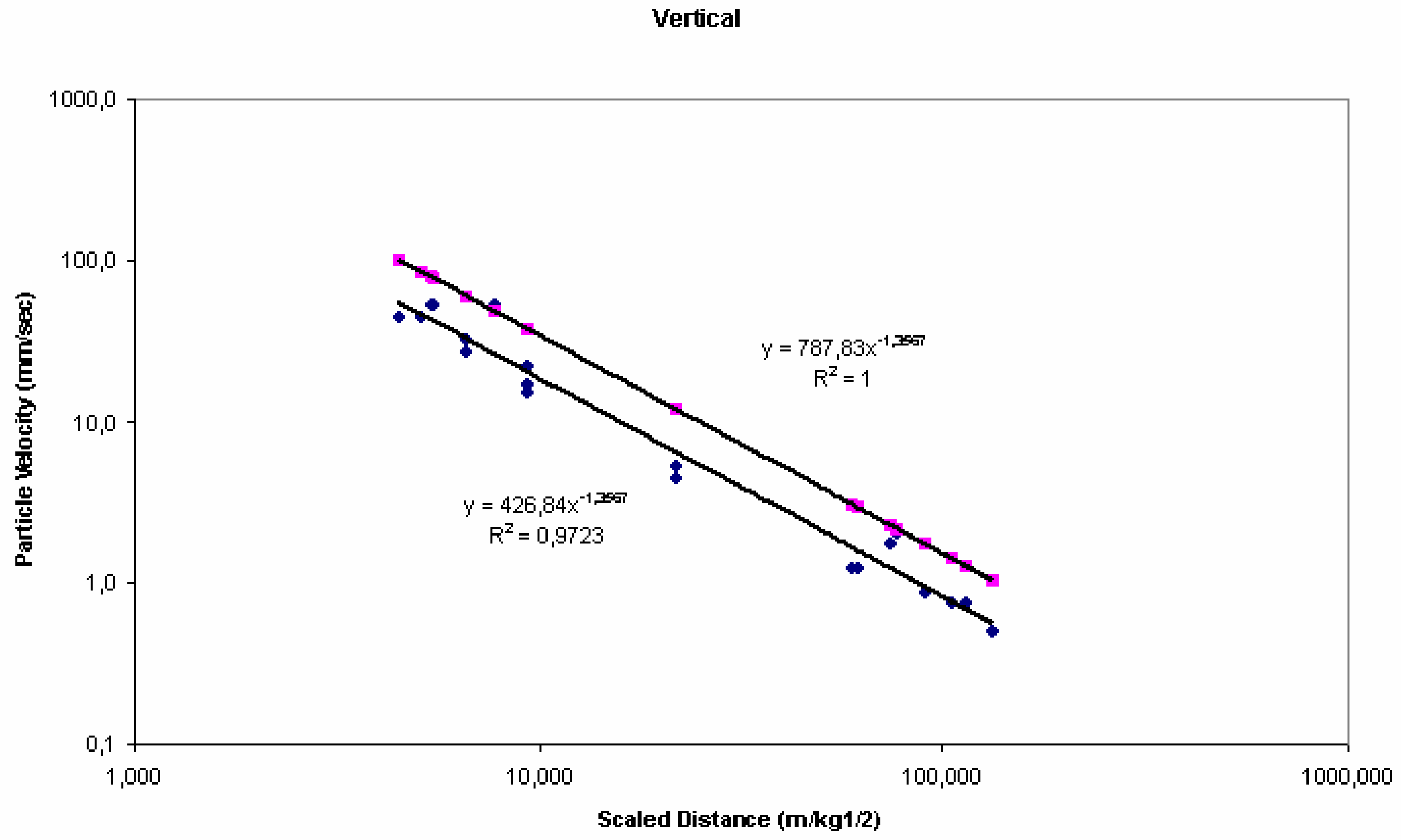

Figure 5.7 Scaled Distance (SD) vs Vertical (V) Vibration Component Graph for single hole blasts.

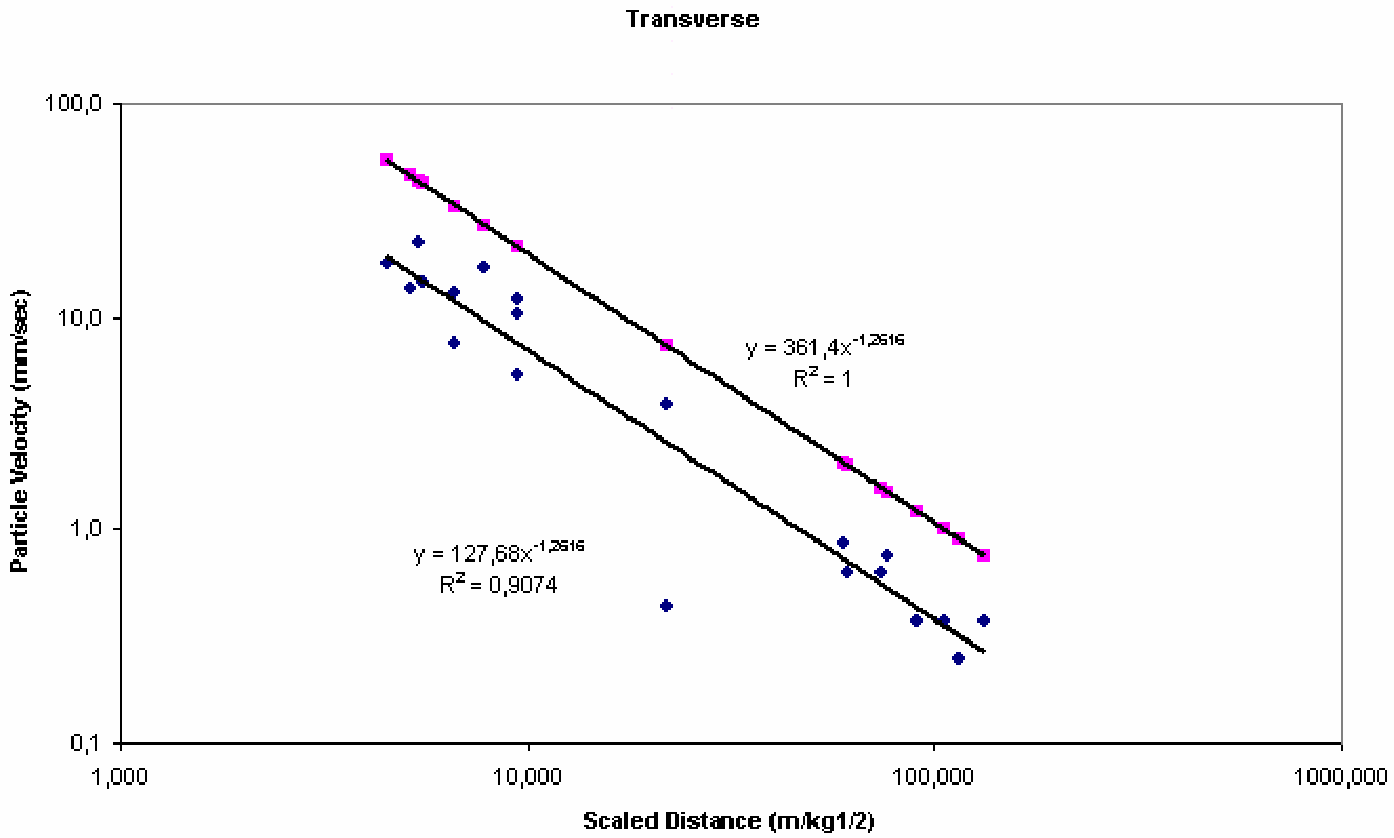

Figure 5.8 Scaled Distance (SD) vs Transverse (T) Vibration Component Graph for single hole blasts.

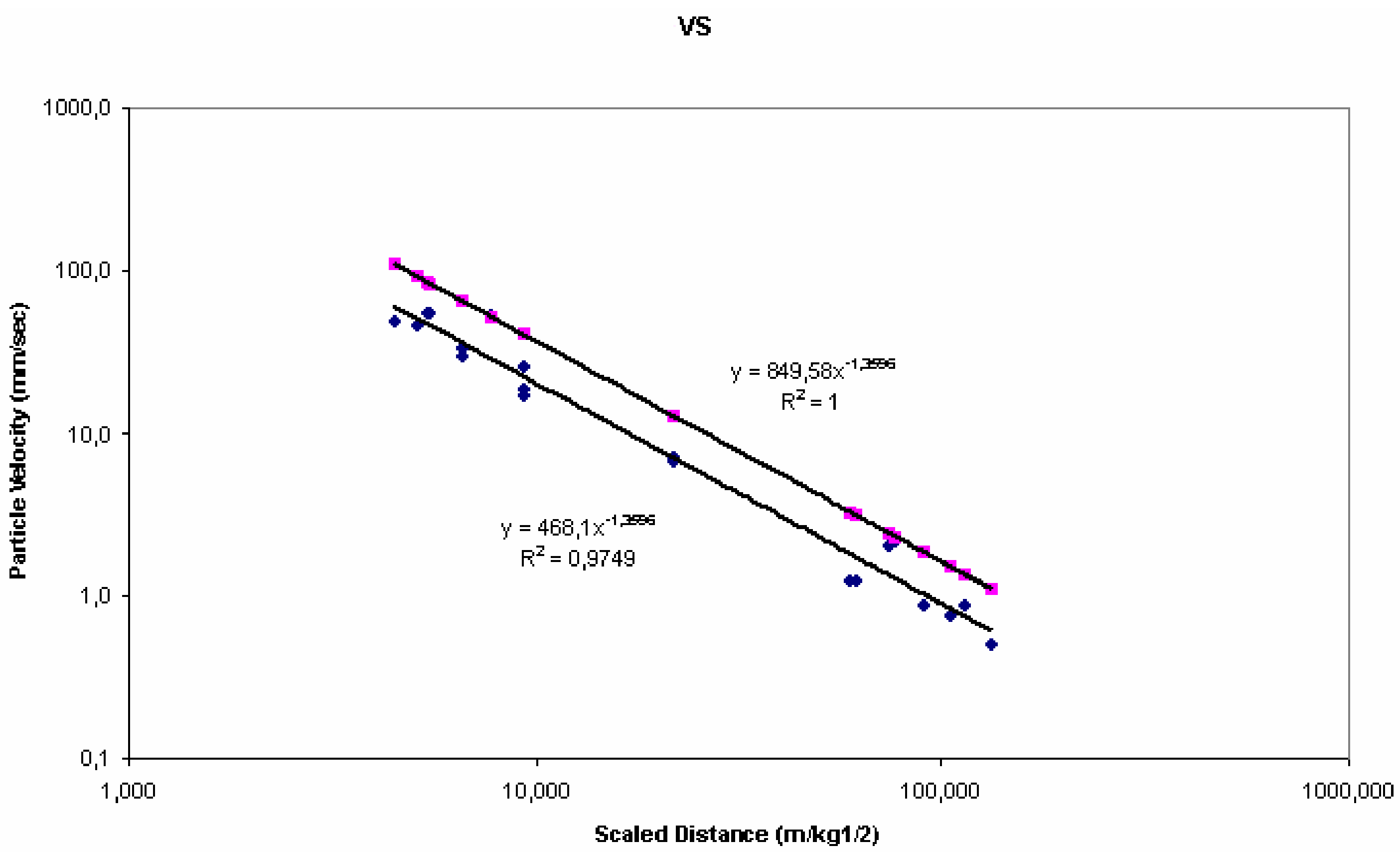

Figure 5.9 Scaled Distance (SD) vs Vector Summation (VS) of the Vibration Components Graph for single hole blasts.

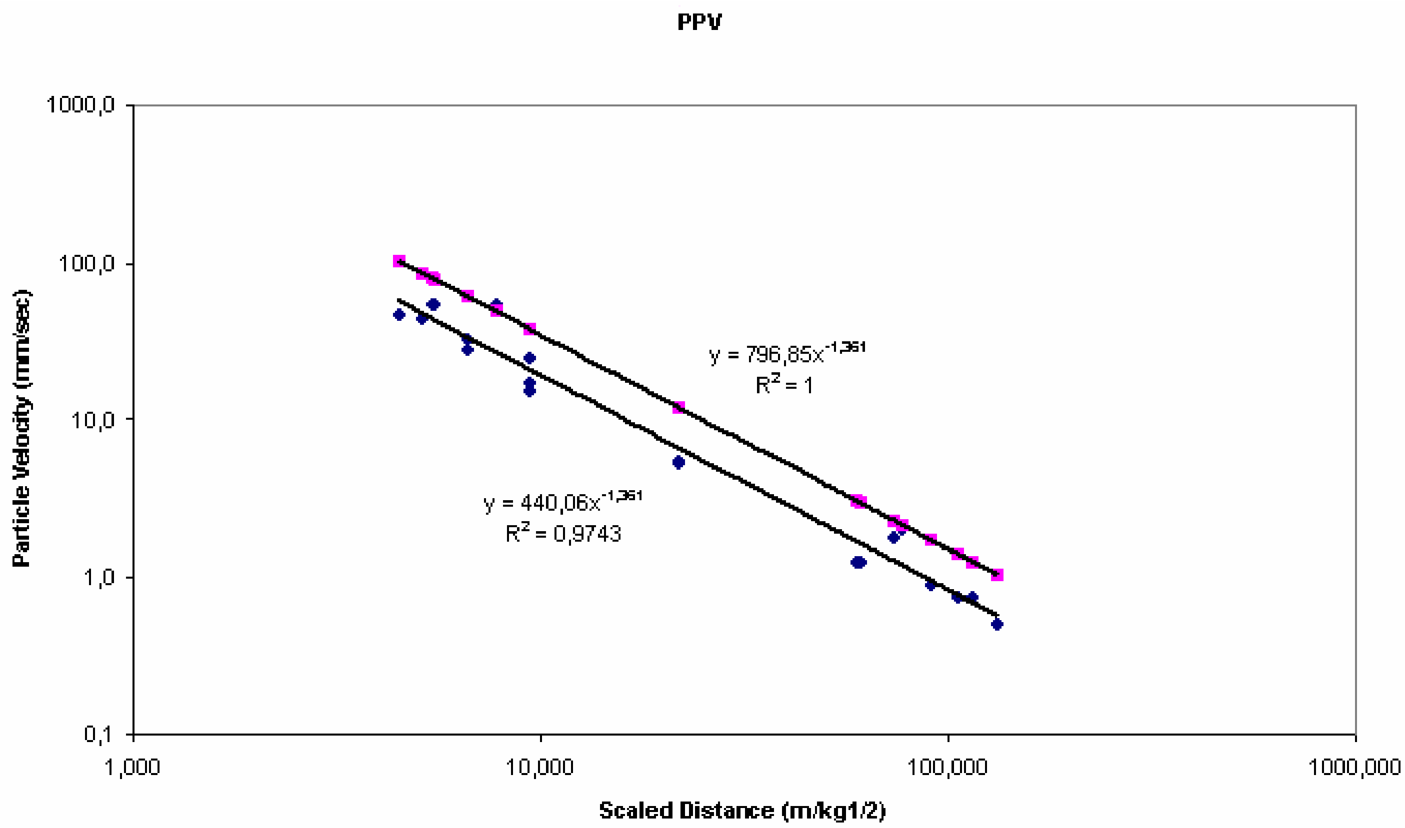

Figure 5.10 Scaled Distance (SD) vs Peak Particle Velocity (PPV) Graph for single hole blasts.

The relationship between the particle velocity and the scaled distance for all particle velocities are presented in the form of constants in Table 5.8.

Table 5.8 Coefficient of determination (R^2) and the site specific parameters (k, m) for 50% and 95% probabilities for single hole blasts.

Single Hole (50%)

	k	m	R²
Radial	398.73	-1.4002	0.9651
Vertical	426.84	-1.3567	0.9723
Transverse	127.68	-1.2616	0.9074
VS	468.10	-1.3596	0.9749
PPV	440.06	-1.3610	0.9743

Single Hole (95%)

	k	m	R²
Radial	783.32	-1.4002	1
Vertical	787.83	-1.3567	1
Transverse	361.40	-1.2616	1
VS	849.58	-1.3596	1
PPV	796.85	-1.3610	1

By using k and m values obtained from Figures 5.6, 5.7, 5.8, 5.9, 5.10, and for scaled distances of 50 and 65, particle velocities are calculated for 50% and 95% probabilities (Table 5.9). Among the three components of vibration the highest amplitude for the particle velocity is obtained by the attenuation equation of the vertical component of the vibration. Therefore, future calculations will be based on the vertical component (V) of the vibration, peak particle velocity (PPV) and the vectoral summation (VS) of the components of the vibration.

If the dominant frequencies of the vibrations for single hole blasts are considered, it can be seen that they are mainly below 8 Hz (Table 5.10) So it can be accepted that, 12.7 mm/sec peak particle velocity is the maximum allowable limit for vibration.

Table 5.9 Particle velocities for SD=50 and SD=65 for single hole blasts.

50%	Particle Velocity for SD=50 (mm/s)	Particle Velocity for SD=65 (mm/s)
Radial	1.67	1.15
Vertical	2.11	1.48
Transverse	0.92	0.66
VS	2.29	1.61
PPV	2.14	1.50

95%	Particle Velocity for SD=50 (mm/s)	Particle Velocity for SD=65 (mm/s)
Radial	3.27	2.27
Vertical	3.90	2.73
Transverse	2.60	1.87
VS	4.16	2.91
PPV	3.88	2.72

Table 5.10 Frequency distribution of blast vibration for single hole blasts.

	F < 8,00 Hz	8,00 Hz < F < 12,00 Hz	12,00 Hz < F < 18,00 Hz	18,00 Hz < F
Radial	17	1	-	2
Vertical	15	3	-	2
Transverse	15	5	-	-

During this study, although the charge per delay is varied between 100 kg's and 175 kg's, normally the maximum co-operating charge used for blasting was 125 kg. Therefore, accepting this amount of blasting accepted as the maximum charge, the minimum distance that the blasting can be done without causing damage to the structures nearby is calculated for both 50% and 95% probabilities and shown in Table 5.11.

Table 5.11 Minimum distances (D_{min}) that the blasting can be done without causing damage to the structures with 125 kg blasting agent for single hole blasts.

Q=125kg

50%	D_{min} (m)
Vertical	149.14
VS	158.73
PPV	151.27

Q=125kg

95%	D_{min} (m)
Vertical	234.30
VS	246.07
PPV	234.01

It can be observed from Table 5.11 that the minimum distance calculated for which 125 kg blasting agent can be detonated per delay without causing damage to the surrounding structures for vertical component of the vibration is 149.17 m, for vectoral summation (VS) of the vibration is 158.73 m and for peak particle velocity (PPV) is 151.27 m; for 50% of probability. In addition the corresponding distance values are 234.30 m, 246.07 m, 234.01 m for the vertical component of the vibration, VS and PPV respectively; for 95% of probability. Therefore the safest results can be obtained by using the vectoral summation (VS) equation for vibration determination calculations at 98% confidence. In summary, 125 kg of explosive per delay can be detonated safely at a minimum distance of 246.07 m or beyond for single hole blasts.

By accepting the 12.7 mm/sec as the limiting value for the particle velocity and using the attenuation curves of the vertical component (V) of the vibration, peak particle velocity (PPV) and the vectoral summation (VS) of the components of the vibration, maximum allowable amounts of charges per delay are calculated for the 50% and 95% probabilities and shown in Table 5.12.

When Table 5.12 is considered, at 95% confidence and VS attenuation equation for safest results, the following results can be recommended.

- When the blast site is 700 m away from the Yörgüç village, the maximum amount of explosive per delay is 1011.56 kg’s.
- When the absolute distance between the blast site and the village reduces to 500 m, the maximum amount of explosive per delay decreases to 516.10 kg’s.
- When the blast site is 300 m away from Yörgüç village, the maximum amount of explosive per delay must be reduced to 185.80 kg’s.
- When the absolute distance between the blast site and the village decreases to 150 m, the maximum amount of explosive per delay must further be reduced to 46.45 kg’s.

Table 5.12 Maximum allowable charges for different distances for single hole blasts.

PV=12.7 mm/s

50%	Maximum Allowable Charge, Qmax (kg)		
D (m)	Considering Vertical Component of Vibration	Considering VS	Considering PPV
150	126.45	111.63	122.90
200	224.80	198.45	218.50
250	351.26	310.08	341.40
300	505.81	446.52	491.62
350	688.46	607.76	669.15
400	899.22	793.81	873.99
450	1138.07	1004.66	1106.14
500	1405.02	1240.32	1365.61
600	2023.23	1786.06	1966.48
700	2753.85	2431.03	2676.60
800	3596.86	3175.22	3495.96
900	4552.28	4018.64	4424.58
1000	5620.10	4961.29	5462.44
1250	8781.40	7752.01	8535.07
1500	12645.21	11162.90	12290.50
1750	17211.54	15193.94	16728.73
2000	22480.38	19845.15	21849.77

PV=12.7 mm/s

95%	Maximum Allowable Charge, Qmax (kg)		
D (m)	Considering Vertical Component of Vibration	Considering VS	Considering PPV
150	51.23	46.45	51.36
200	91.08	82.58	91.31
250	142.31	129.03	142.67
300	204.93	185.80	205.44
350	278.94	252.89	279.63
400	364.32	330.31	365.24
450	461.10	418.04	462.25
500	569.26	516.10	570.68
600	819.73	743.19	821.78
700	1115.75	1011.56	1118.53
800	1457.30	1321.23	1460.94
900	1844.40	1672.18	1849.00
1000	2277.03	2064.42	2282.72
1250	3557.86	3225.65	3566.75
1500	5123.32	4644.94	5136.12
1750	6973.41	6322.28	6990.83
2000	9108.12	8257.67	9130.88

5.3 Rounds for Which, Initiation Started from Yörgüç Village Direction

For the comparison of the effects of the direction of initiation on ground vibration provided that the same blasting pattern is used, for the 10 of the round blasting records, the initiation is started from Yörgüç village direction. These data are shown in the Table 5.13.

In the table; event no, codes for the rounds, monitoring date, monitoring time, monitoring station, amplitudes of the vibration components for radial (R, mm/s), vertical (V, mm/s) and transverse (T, mm/s), vectoral summation of the components of the vibration (VS, mm/s), peak particle velocity (PPV, mm/s), frequencies of the components of the vibration as radial (R, Hz), vertical (V, Hz) and transverse (T, Hz), co-operating charge (Q, kg) for each round, absolute distance (D, m) and scaled distance (SD, m/kg$^{1/2}$) are given respectively.

Frequency values are the dominant frequency values calculated by Fast Fourier Transform (FFT) analysis for radial, vertical and transverse components of the vibration. Absolute distances are calculated by GPS instrument.

The scaled distance range is from 70.66 to 148.00. The lowest scaled distance, 70.66 was measured on 23.06.2003 at the monitoring station 2 (S2) which is located 790 m away from the blast hole which contain the co-operating charge. The peak particle velocity (PPV) ranged from 0.381 to 1.905 mm/sec. Co-operating charge used for blasting ranged from 100 kg to 175 kg and the absolute distance ranged from 790 m to 1480 m.

Table 5.13 Vibration data for initiation started from Yörgüç village direction.

Event No	Round No	Date	Time	Station	R (mm/s)	V (mm/s)	T (mm/s)	VS (mm/s)	PPV (mm/s)	R (Hz)	V (Hz)	T (Hz)	Q (kg)	D (m)	SD
4	23G1	23.06.2003	16:39	S2	1.905	1.524	1.905	2.159	1.905	5.94	5.56	5.50	125	790	70.660
5	23G2	23.06.2003	16:53	S3	1.143	1.270	0.508	1.651	1.270	5.31	5.19	1.56	125	910	81.393
8	24G1	24.06.2003	13:02	S5	0.508	0.381	0.381	0.635	0.508	5.44	5.00	9.94	110	1130	107.741
9	24G2	24.06.2003	13:16	S6	0.508	0.635	0.381	0.762	0.635	6.00	10.50	10.31	110	1280	122.043
10	24G3	24.06.2003	13:29	S7	0.381	0.254	0.254	0.508	0.381	4.38	5.69	5.38	100	1480	148.000
31	27G1	27.06.2003	12:57	S6	0.635	0.508	0.508	0.762	0.635	5.25	4.94	5.25	125	1210	108.226
32	27G2	27.06.2003	13:04	S7	0.889	0.508	0.381	0.889	0.889	5.19	5.31	2.31	125	1350	120.748
44	30G1	30.06.2003	14:40	S6	0.889	0.508	0.508	0.889	0.889	6.06	5.31	2.25	150	1300	106.145
67	02G1	02.07.2003	11:08	S7	0.381	0.381	0.381	0.381	0.381	6.31	6.00	5.38	110	1420	135.392
73	04G1	04.07.2003	12:33	S7	0.381	0.508	0.254	0.508	0.508	6.31	6.00	5.38	175	1430	108.098

By using data, given in the Table 5.13, scaled distance (SD) versus vibration amplitude graphs are drawn for the 50% probability and 95% probability of the occurrences, for each of three components of the vibration, vectoral summation of these three and the peak particle velocity. These graphs are given in Figures 5.11, 5.12, 5.13, 5.14, 5.15 respectively.

It is well known that the simplest form of blast vibration analysis is peak level determination. However in this research study, to be on the safer side, one of the three components of the vibration, which gives the higher particle velocity (PPV) for the SD = 50 and SD = 65 will be selected and future calculations will be based on the peak particle velocity (PPV), vectoral summation of the three components of the vibration (VS) and one of the three components of the vibration, which gives the higher particle velocity for the SD = 50 and SD = 65.

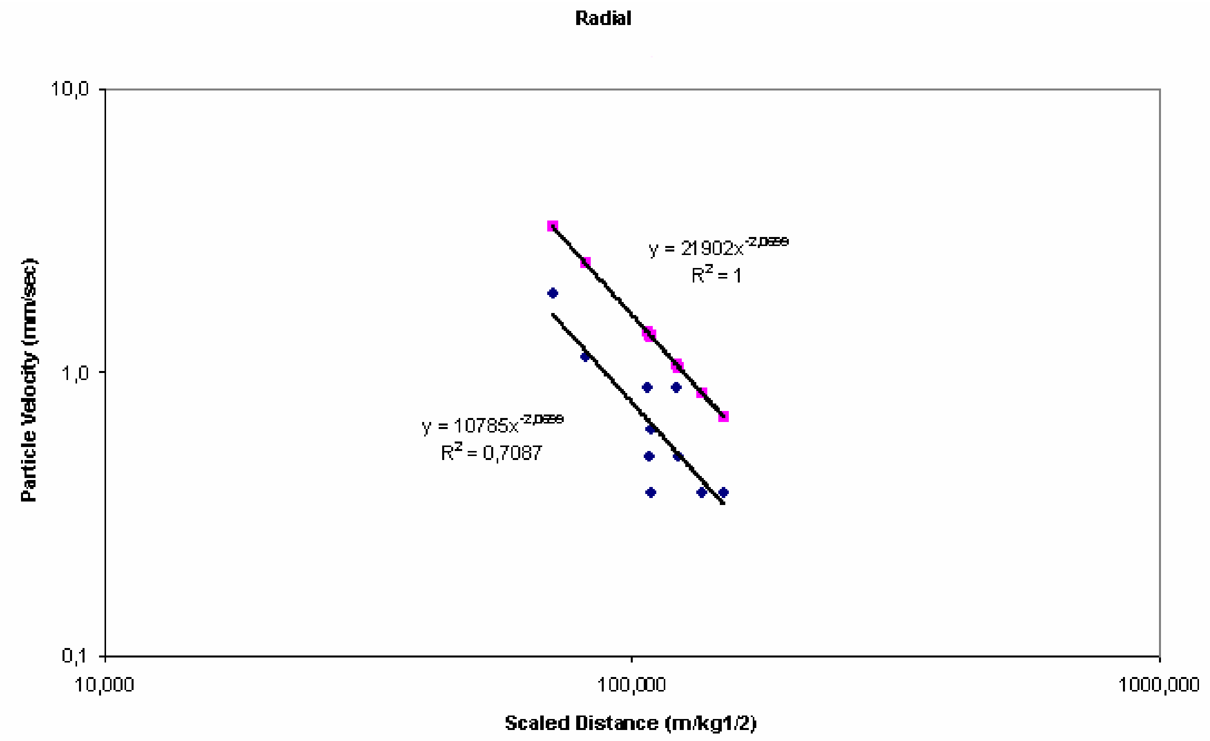

Figure 5.11 Scaled Distance (SD) vs Radial (R) Vibration Component Graph for the group that initiation started from Yörgüç village direction.

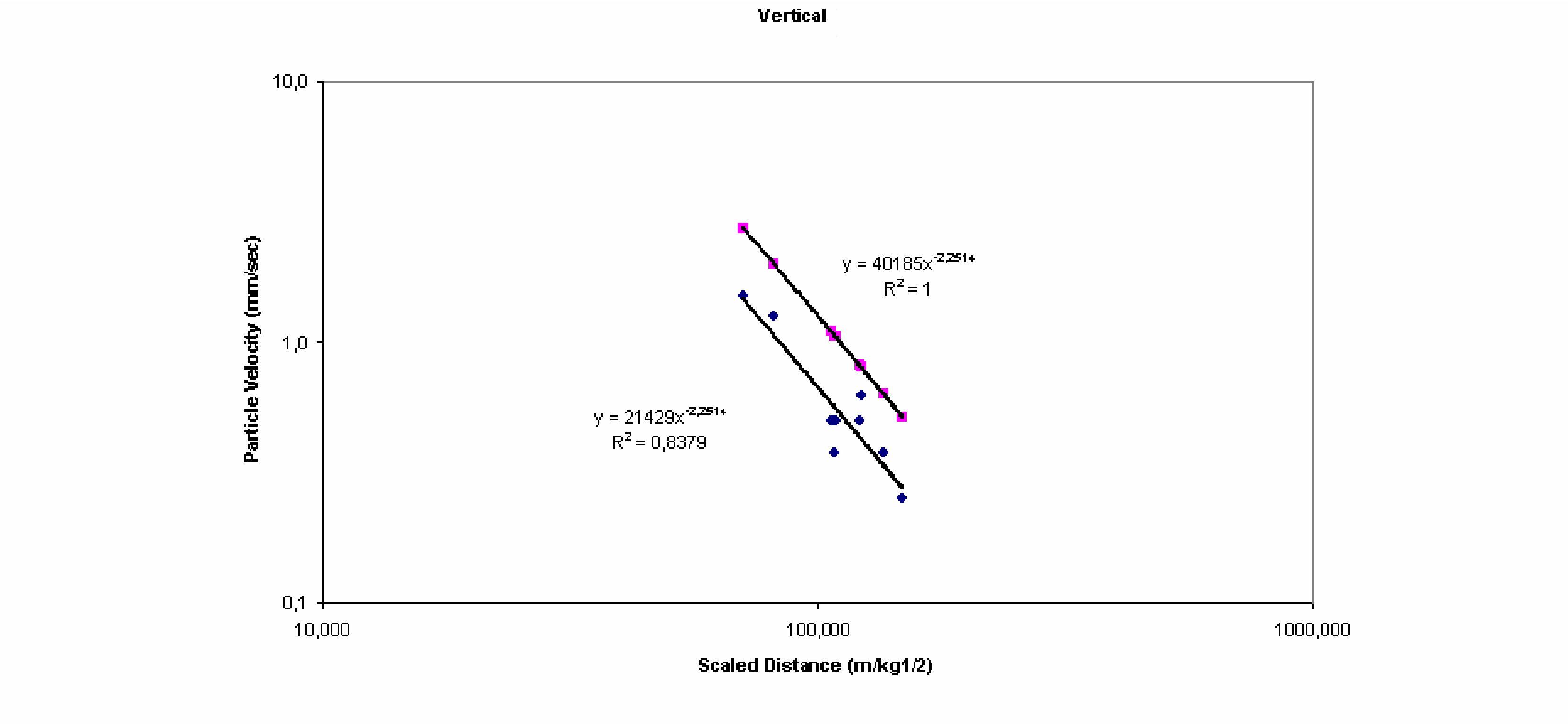

Figure 5.12 Scaled Distance (SD) vs Vertical (V) Vibration Component Graph for the group that initiation started from Yörgüç village direction.

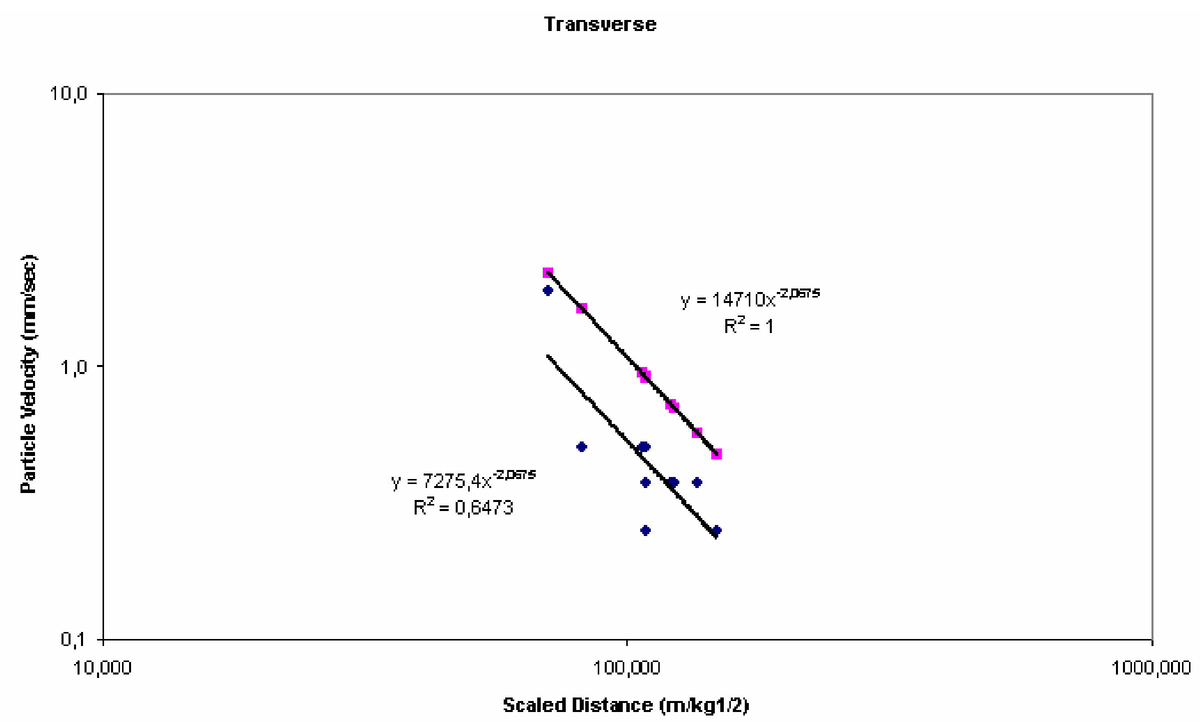

Figure 5.13 Scaled Distance (SD) vs Transverse (T) Vibration Component Graph for the group that initiation started from Yörgüç village direction.

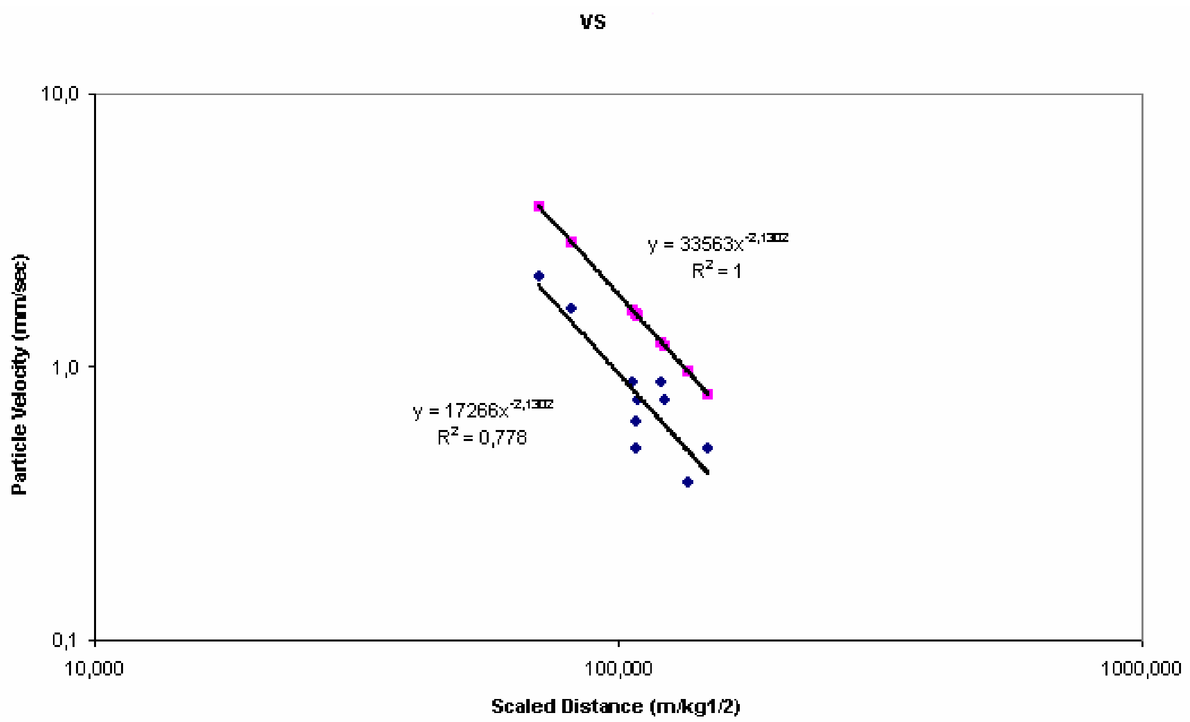

Figure 5.14 Scaled Distance (SD) vs Vector Summation (VS) of the Vibration Components Graph for the group that initiation started from Yörgüç village direction.

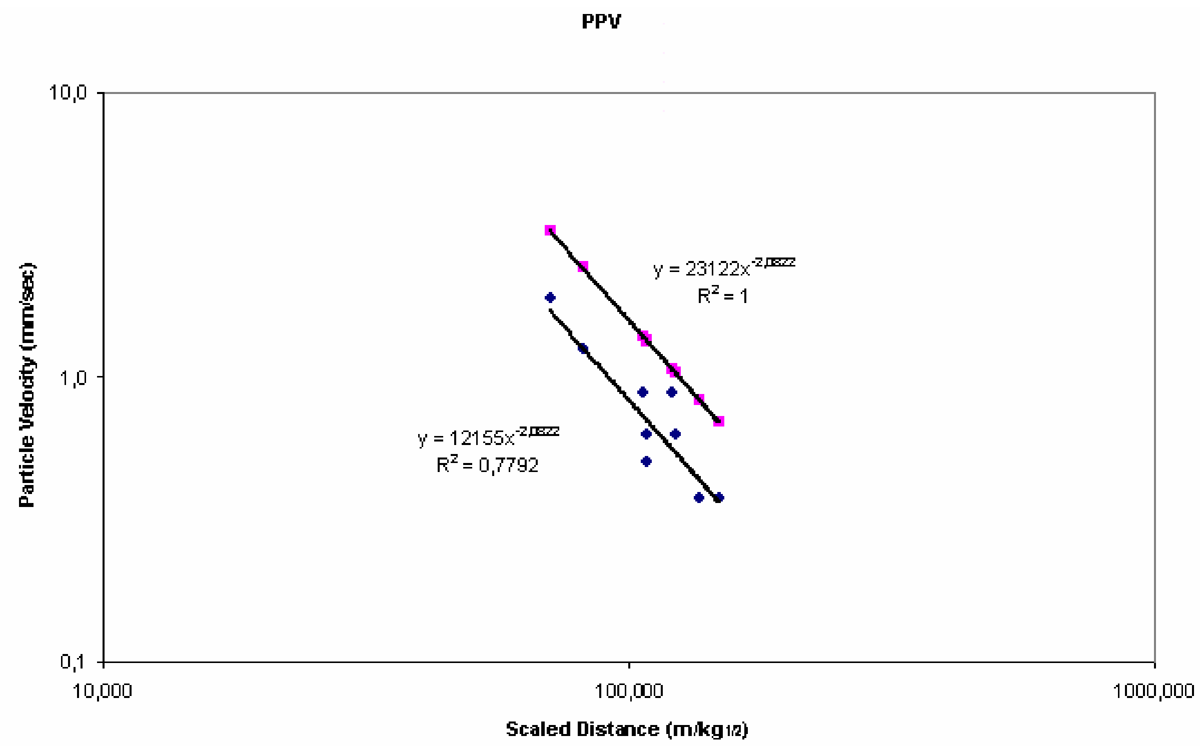

Figure 5.15 Scaled Distance (SD) vs Peak Particle Velocity (PPV) Graph for the group that initiation started from Yörgüç village direction.

The relationship between the particle velocity and the scaled distance for all particle velocities are presented in the form of constants in Table 5.14.

Table 5.14 Coefficient of determination (R^2) and the site specific parameters (k, m) for 50% and 95% probabilities, for the initiation case started from Yörgüç village direction.

Initiation from village direction (50%)

	k	m	R^2
Radial	10785	-2.0699	0.7087
Vertical	21429	-2.2514	0.8379
Transverse	7275	-2.0675	0.6473
VS	17266	-2.1302	0.7780
PPV	12155	-2.0822	0.7792

Initiation from village direction (95%)

	k	m	R^2
Radial	21902	-2.0699	1
Vertical	40185	-2.2514	1
Transverse	14710	-2.0675	1
VS	33563	-2.1302	1
PPV	23122	-2.0822	1

By using k and m values obtained from Figures 5.11, 5.12, 5.13, 5.14, 5.15, and for scaled distances of 50 and 65, particle velocities are calculated for 50% and 95% probabilities (Table 5.15). Among the three components of vibration the highest amplitude for the particle velocity is obtained by the attenuation equation of the radial component of the vibration. Therefore, future calculations will be based on the radial component (R) of the vibration, peak particle velocity (PPV) and the vectoral summation (VS) of the components of the vibration.

If the dominant frequencies of the vibrations for which the initiation started from Yörgüç village direction are considered, it can be seen that they are mainly below 8 Hz (Table 5.16) So it can be accepted that, 12.7 mm/sec peak particle velocity is the maximum allowable limit for vibration.

Table 5.15 Particle velocities for SD=50 and SD=65 for the group that initiation started from Yörgüç village direction.

50%	Particle Velocity for SD=50 (mm/s)	Particle Velocity for SD=65 (mm/s)
Radial	3.28	1.91
Vertical	3.21	1.78
Transverse	2.23	1.30
VS	4.15	2.37
PPV	3.53	2.04

95%	Particle Velocity for SD=50 (mm/s)	Particle Velocity for SD=65 (mm/s)
Radial	6.66	3.87
Vertical	6.01	3.33
Transverse	4.52	2.63
VS	8.07	4.61
PPV	6.71	3.88

Table 5.16 Frequency distribution of blast vibration for the group that initiation started from Yörgüç village direction.

	F < 8,00 Hz	8,00 Hz < F < 12,00 Hz	12,00 Hz < F < 18,00 Hz	18,00 Hz < F
Radial	10	-	-	-
Vertical	9	1	-	-
Transverse	8	2	-	-

During this study, although the charge per delay is varied between 100 kg's and 175 kg's, normally the maximum co-operating charge used for blasting was 125 kg. Therefore, accepting this amount of blasting agent as the maximum charge, the minimum distance that the blasting can be done without causing damage to the structures nearby is calculated for both 50% and 95% probabilities and shown in Table 5.17.

It can be observed from Table 5.17 that the minimum distance calculated for which 125 kg blasting agent can be detonated per delay without causing damage to the surrounding structures for radial component of the vibration is 290,74 m, for vectoral summation (VS) of the vibration is 330.67 m and for peak particle velocity (PPV) is 302.06 m; for 50% of probability. In addition the corresponding distance values are 409.40 m, 451.76 m, 411.35 m for the radial component of the vibration, VS and PPV respectively; for 95% of probability. Therefore the safest results can be obtained by using the vectoral summation (VS) equation for vibration determination calculations at 95% confidence. In summary, 125 kg of explosive per delay can be detonated safely at a minimum distance of 451.76 m or beyond.

Table 5.17 Minimum safe distance (D_{min}) for 125 kg charge per delay for the initiation case started from Yörgüç village direction.

Q=125kg

50%	Dmin (m)
Radial	290.74
VS	330.67
PPV	302.06

Q=125kg

95%	Dmin (m)
Radial	409.40
VS	451.76
PPV	411.35

By accepting 12.7 mm/sec as the limiting value for the particle velocity and using the attenuation curves of the radial component (R) of the vibration, peak particle velocity (PPV) and the vectoral summation (VS) of the components of the vibration, maximum allowable amounts of charges (Q_{max}) per delay are calculated for the 50% and 95% probabilities and shown in Table 5.18.

When Table 5.18 is considered, at 95% confidence and VS attenuation equation for safest results, the following results can be recommended.

- When the blast site is 700 m away from the Yörgüç village, the maximum amount of explosive per delay is 300.12 kg's.
- When the absolute distance between the blast site and the village reduces to 600 m, the maximum amount of explosive per delay decreases to 220.50 kg's.
- When the blast site is 400 m away from Yörgüç village, the maximum amount of explosive per delay must be reduced to 98 kg's.

- When the absolute distance between the blast site and the village decreases to 300 m, the maximum amount of explosive per delay must further be reduced to 55.12 kg's.

Table 5.18 Maximum allowable charges for different distances for the group that initiation started from Yörgüç village direction.

PV=12.7 mm/s

50%	Maximum Allowable Charge, Qmax (kg)		
D (m)	Considering Radial Component of Vibration	Considering VS	Considering PPV
300	133.09	102.89	123.30
350	181.15	140.04	167.83
400	236.60	182.91	219.20
450	299.45	231.50	277.43
500	369.69	285.80	342.51
600	532.35	411.56	493.21
700	724.59	560.18	671.31
800	946.40	731.66	876.82
900	1197.79	926.00	1109.72
1000	1478.75	1143.21	1370.03
1250	2310.55	1786.27	2140.67
1500	3327.19	2572.23	3082.56
1750	4528.68	3501.10	4195.71
2000	5915.01	4572.86	5480.11

PV=12.7 mm/s

95%	Maximum Allowable Charge, Qmax (kg)		
D (m)	Considering Radial Component of Vibration	Considering VS	Considering PPV
300	67.12	55.12	66.49
350	91.36	75.03	90.49
400	119.33	98.00	118.20
450	151.02	124.03	149.59
500	186.45	153.12	184.68
600	268.49	220.50	265.94
700	365.44	300.12	361.98
800	477.31	392.00	472.78
900	604.10	496.12	598.37
1000	745.80	612.50	738.73
1250	1165.31	957.02	1154.26
1500	1678.05	1378.11	1662.13
1750	2284.01	1875.77	2262.35
2000	2983.20	2449.98	2954.91

5.4 Comparison and Discussion of the Ground Vibration

Table 5.19 is prepared by using the maximum co-operating charges calculated for vector sum (VS) ground vibration for 95% confidence.

Table 5.19 Comparison of co-operating charges for VS values for 95% confidence, considering 12.7 mm/sec as limiting vibration value.

D (m)	Initiation Started from Yörgüç Village Direction (kg)	Initiation Started towards Yörgüç Village Direction (kg)	Single Hole Blasts (kg)
150	-	-	46.45
200	-	-	82.58
250	-	-	129.03
300	55.12	46.56	185.80
350	75.03	63.37	252.89
400	98.00	82.77	330.31
450	124.03	104.75	418.04
500	153.12	129.33	516.10
600	220.50	186.23	743.19
700	300.12	253.48	1011.56
800	392.00	331.07	1321.23
900	496.12	419.01	1672.18
1000	612.50	517.30	2064.42
1250	957.02	808.28	3225.65
1500	1378.11	1163.93	4644.94
1750	1875.77	1584.24	6322.28
2000	2449.98	2069.21	8257.67

Considering Table 5.19, following results can be achieved;

- Previously applied delay sequence (Figure 4.5) used at the Y-3 panel has resulted in the simultaneous detonation of the 3 decks in different holes at a time and this in turn resulted in the detonation of 275 kg's of ANFO. Therefore by using previous delay sequence (275 kg/delay), the minimum distances, that the blasting can be done without causing damage, are determined as follows:
    i. For the rounds that the initiation is started towards Yörgüç village direction, minimum is about 730 meters.
    ii. For single-hole blasts the minimum distance is about 360 meters.
    iii. For the rounds that the initiation is started from Yörgüç village direction, minimum distance is about 680 meters.

  By using the delay pattern proposed in this research study (Figure 4.6), the maximum co-operating charge is decreased to 125 kg's and the minimum distances, that the blasting can be done without causing damage, are determined as follows:
    i. For the rounds that the initiation is started towards Yörgüç village direction, minimum distance is about 491 meters.
    ii. For single-hole blasts the minimum distance is about 246 meters.
    iii. For the rounds that the initiation is started from Yörgüç village direction, minimum distance is about 452 meters.

  In the future, when the mine expands and comes closer to the Yörgüç village, the proposed delay sequence must be applied.

- For round blasting practices, the direction of initiation has great importance, as proven by the initiation started from Yörgüç village direction which causes lower ground vibration amplitudes with respect to the case where initiation started towards Yörgüç village direction. Vibration wave trains superposed and the amplitude of vibration increased when the initiation started towards the village. Therefore it is safer to initiate rounds from Yörgüç village direction.

- The minimum absolute distance that, the blasting can be done without causing damage to the nearby structures is 150 m and this can be achieved by using single hole blasts with the co-operating charge of 46.45 kg's.

- For the absolute distances smaller than 300 m, only single-hole blasting is applicable without causing damage to the nearby structures.

- For different absolute distances Table 5.19 can be used as a guideline for determining the co-operating charges for round blasting practices and for the single hole blasting practices.

- The mine will expand towards the village in the future; therefore for absolute distances closer than 451.76 m to the village; 4 deck charging must be used instead of 3 deck charging for safe and effective blasting. In this case, the co-operating charge will be decreased in accordance with the absolute distance.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions drawn from this research study are summarized as follows:

- The great majority of dominant frequencies of the seismic waves are mostly below 8 Hz. Therefore the maximum acceptable limit for the particle velocity is accepted as 12.7 mm/sec in accordance with USBM criteria to be at the safe side.

- The safest results are obtained by using vectoral summation (VS) of the components of the vibration.

- For round blasting practices, direction of initiation has importance, such that it will be safer to start initiation from the Yörgüç village direction as it creates lower ground vibration amplitude with respect to initiation started towards village direction.

- For round blasting practices, 125 kg of explosive per delay can be detonated safely at a minimum distance of 451.76 m or greater by using the proposed delay sequence (Figure 4.6) and the initiation case which is started from Yörgüç village direction.

- For single-hole blasts, 125 kg of explosive per delay can be detonated safely at a minimum distance of 246.07 m or greater.

- For the distances closer than 451.76 m, 125 kg co-operating charge can be used only in single-hole blasting case, considering the vectoral summation (VS) of the vibration components and 95% confidence limit.

- For the distances closer than 246.07 m to the village, co-operating charge must be decreased even for the single hole blasting.

- For the different distances, Table 5.18 can be used as a guideline to determine the co-operating charge for safe round blasting practices.

- For the different distances, Table 5.12 can be used to determine the co-operating charge for safe single-hole blasting practices.

- For the absolute distances smaller than 451.76 meters; 4 decks charging must be used instead of 3 decks charging for safe and effective round blasting, as co-operating charge decreases with respect to the absolute distance.

- Continous monitoring of ground vibrations are recommended not to cause any damage in structures in the village surprisingly, which may arise from unexpected geological features. If an anomaly is observed in the records during continous monitoring, necessary measures can be taken accordingly.

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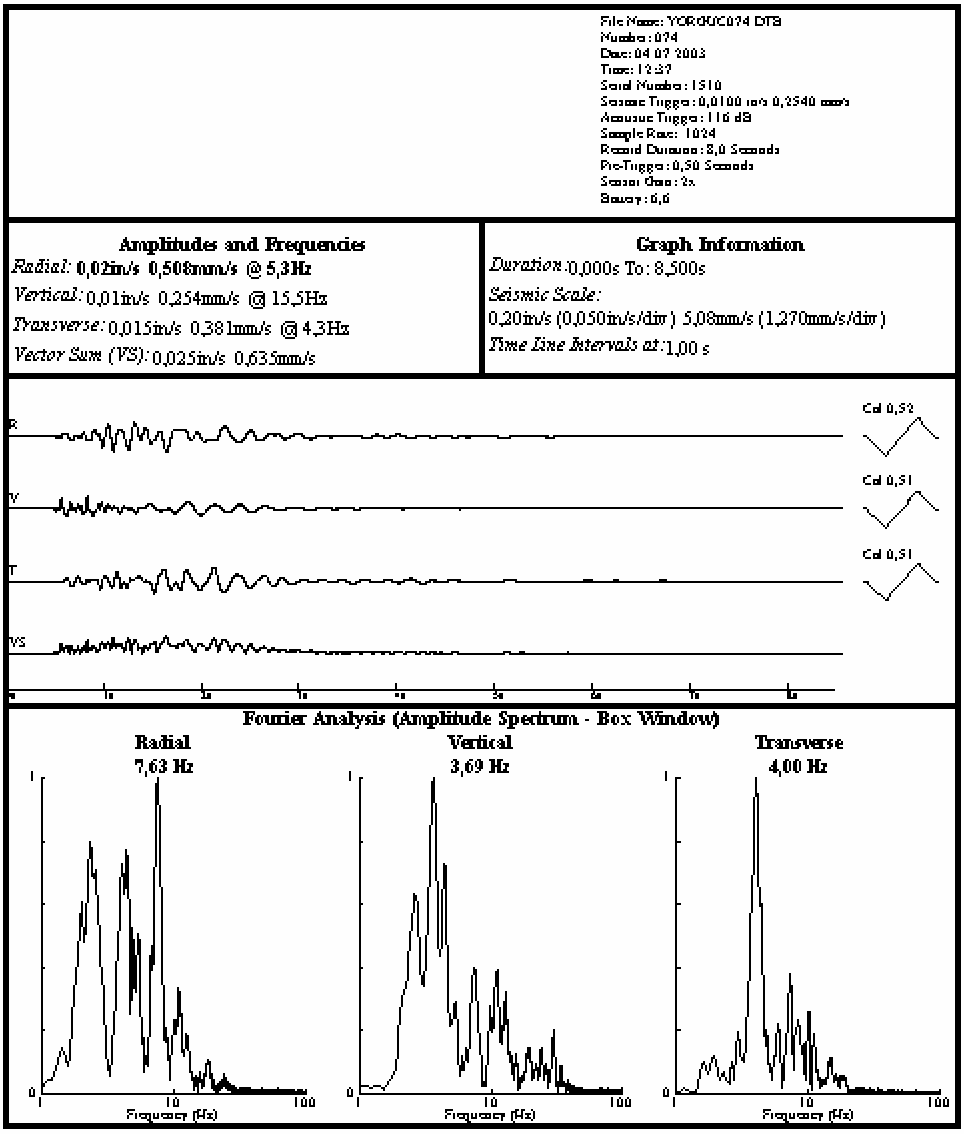
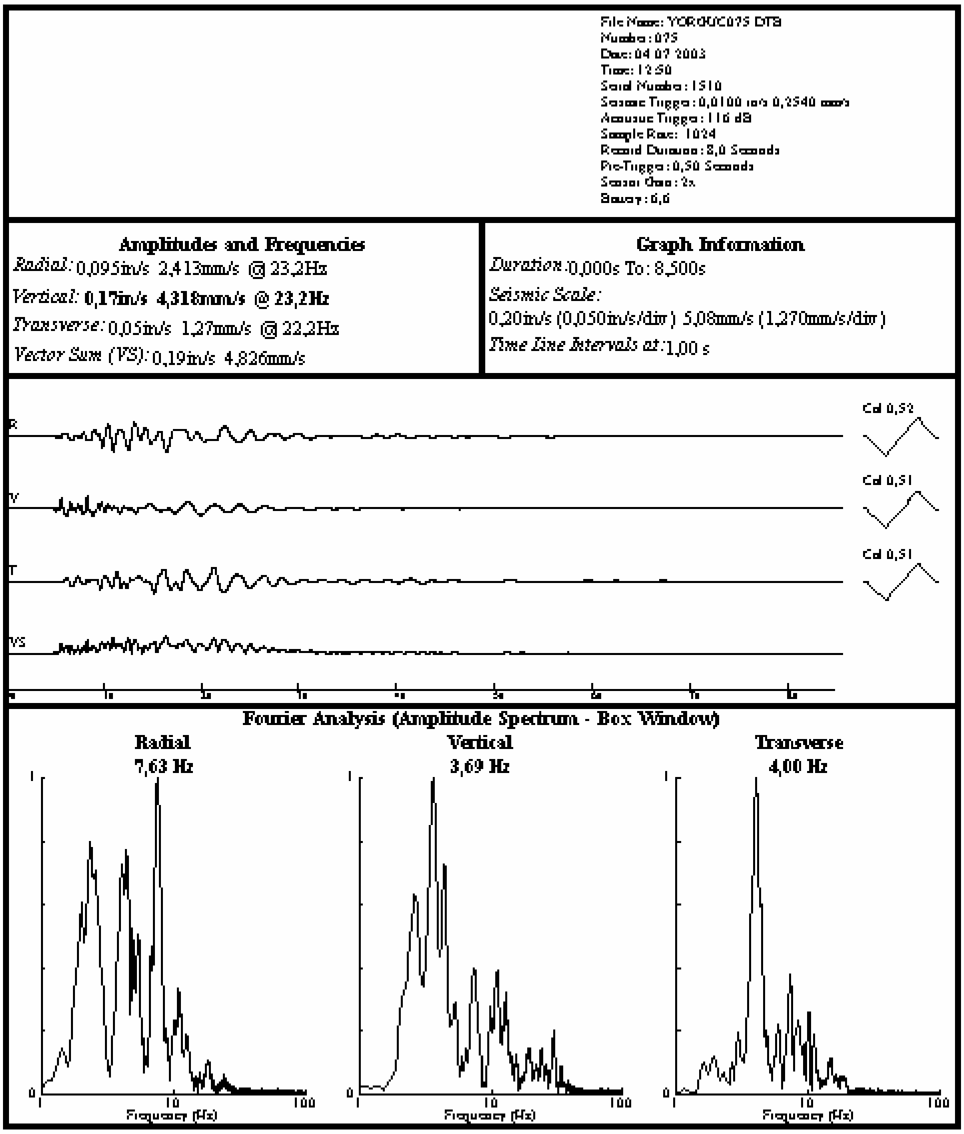


Appendix A.1 1st vibration record for initiation towards Yörgüç village.



Appendix A.2 2nd vibration record for initiation towards Yörgüç village.

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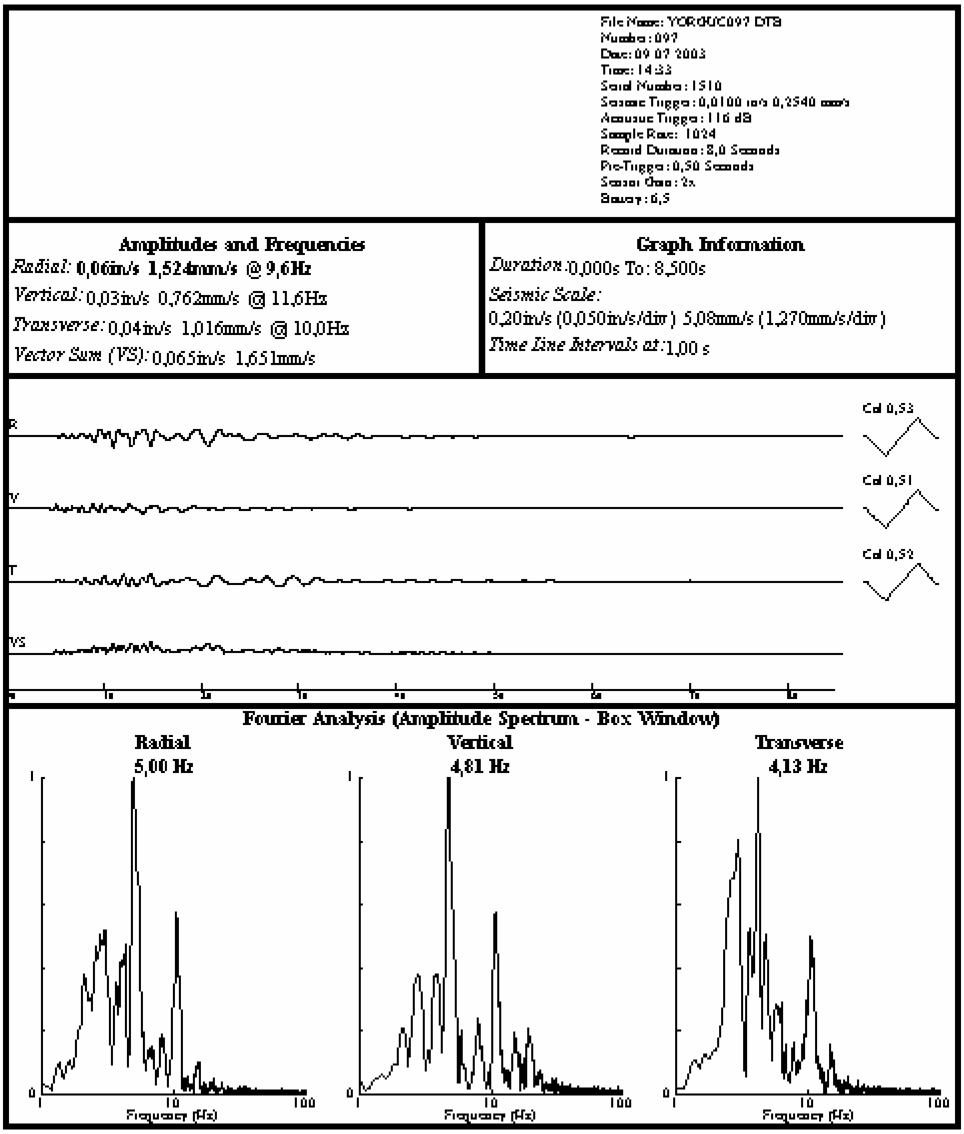

Appendix A.3 3rd vibration record for initiation towards Yörgüç village.

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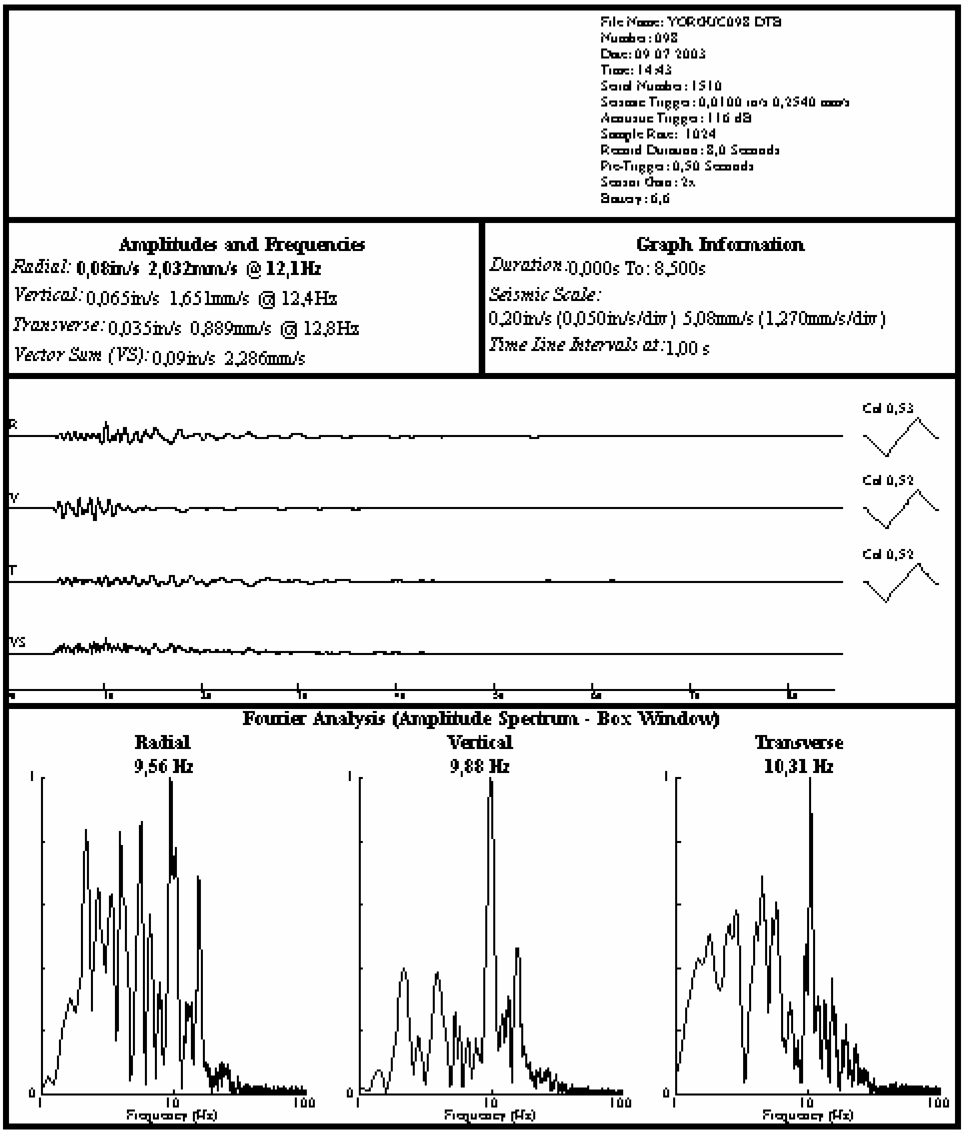

Appendix A.4 4th vibration record for initiation towards Yörgüç village.

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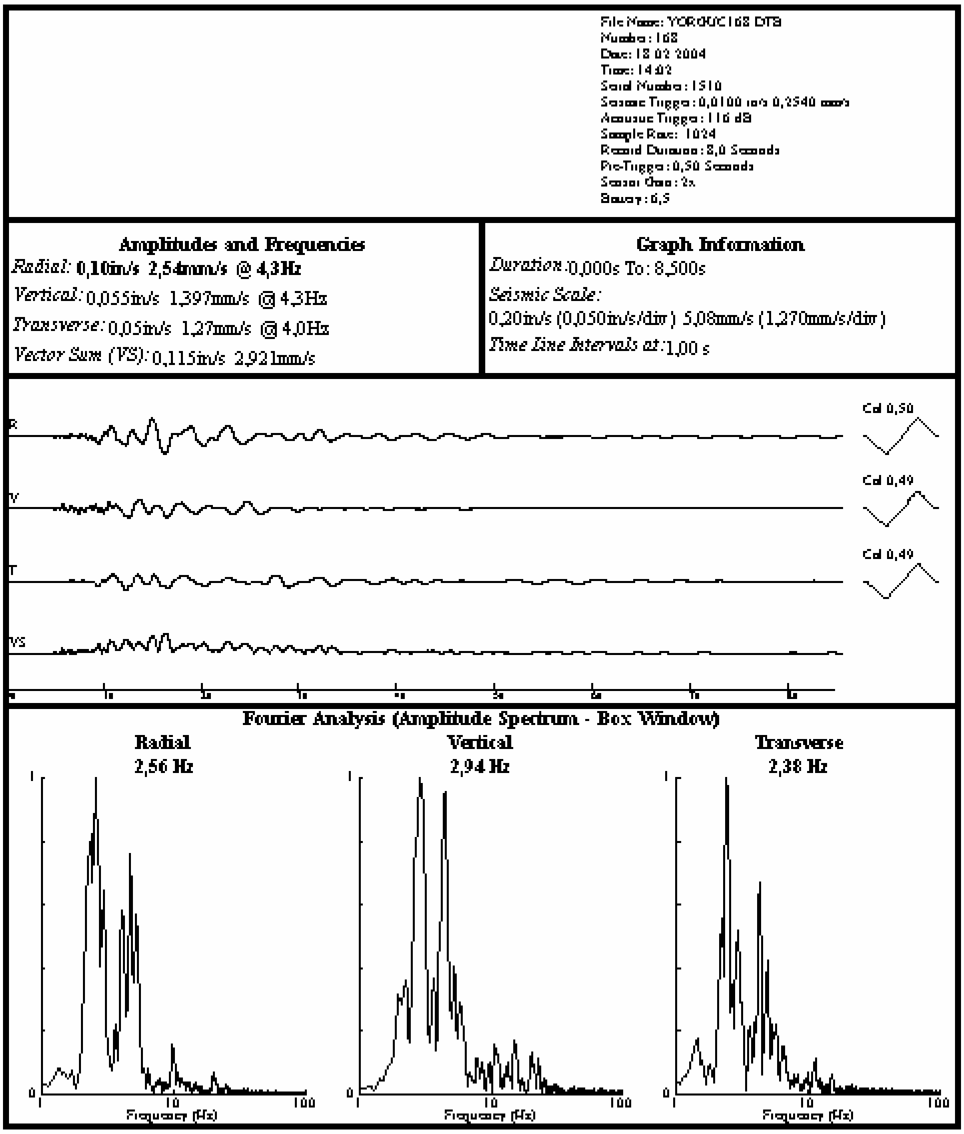

Appendix A.5 5th vibration record for initiation towards Yörgüç village.

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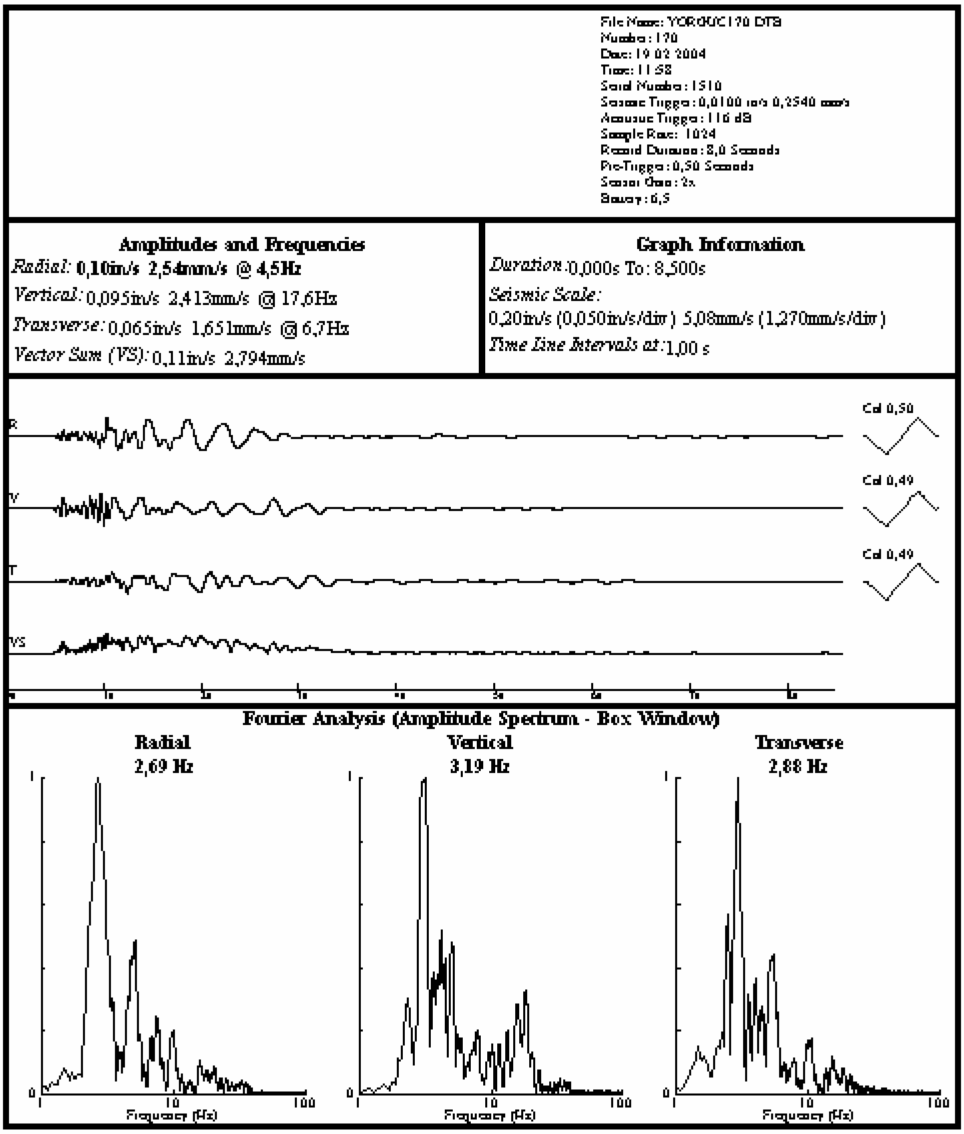

Appendix A.6 6th vibration record for initiation towards Yörgüç village.

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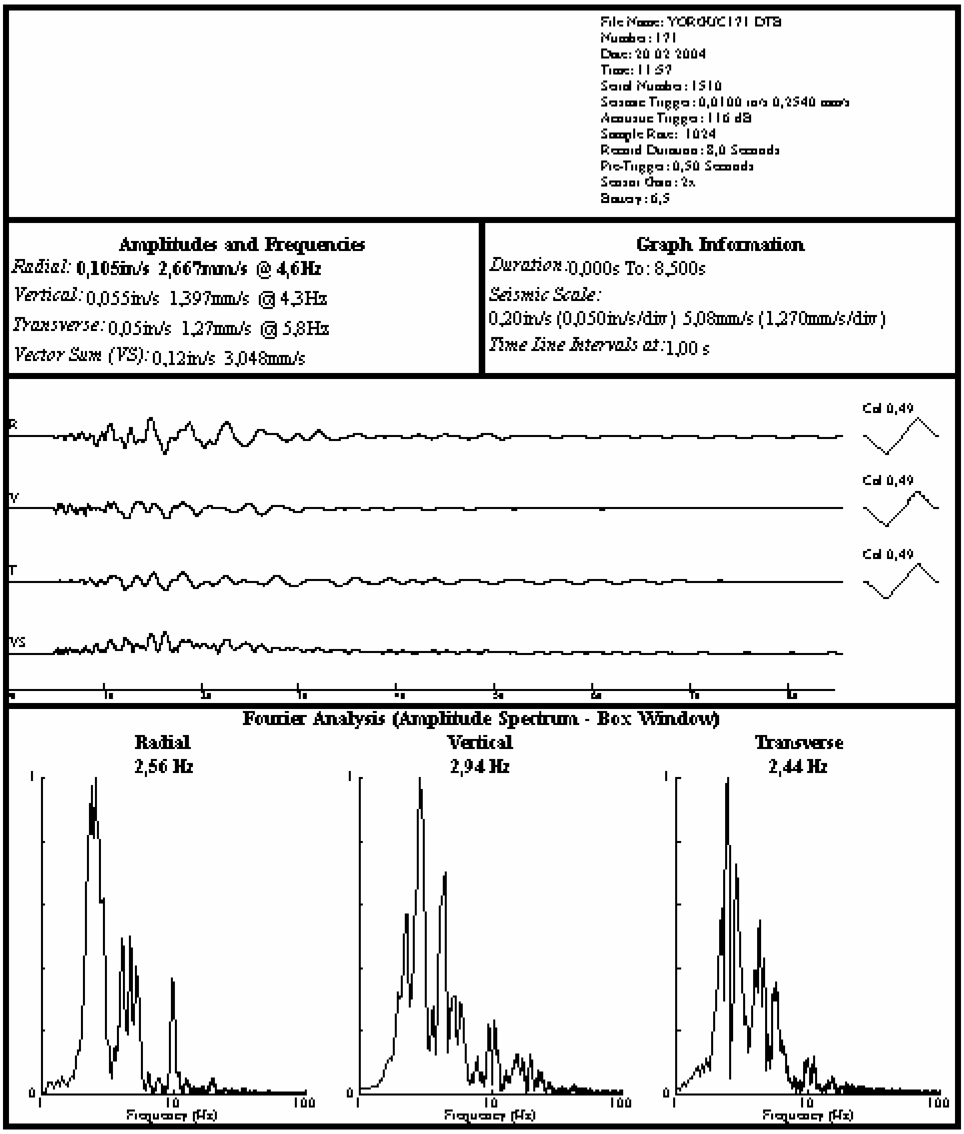

Appendix A.7 7th vibration record for initiation towards Yörgüç village.

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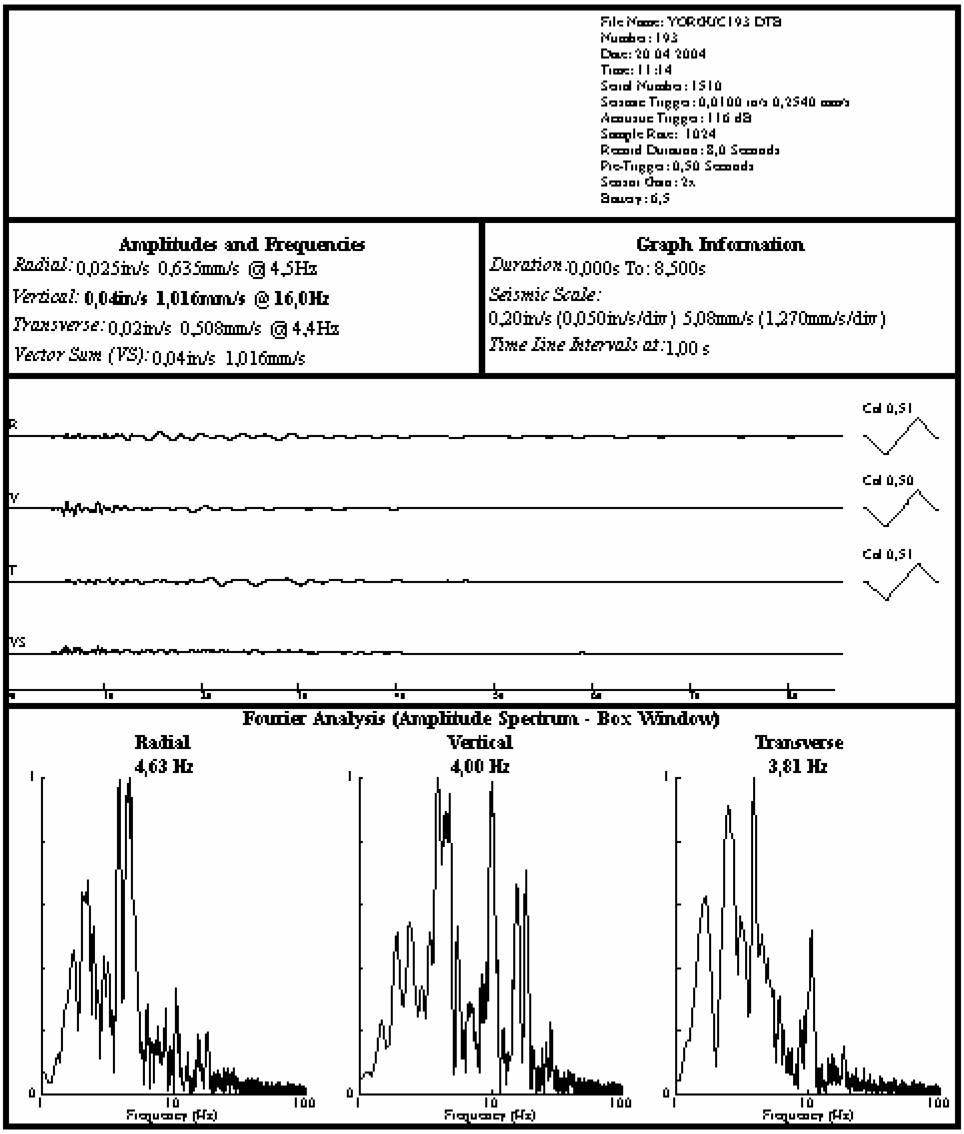

Appendix A.8 8th vibration record for initiation towards Yörgüç village.

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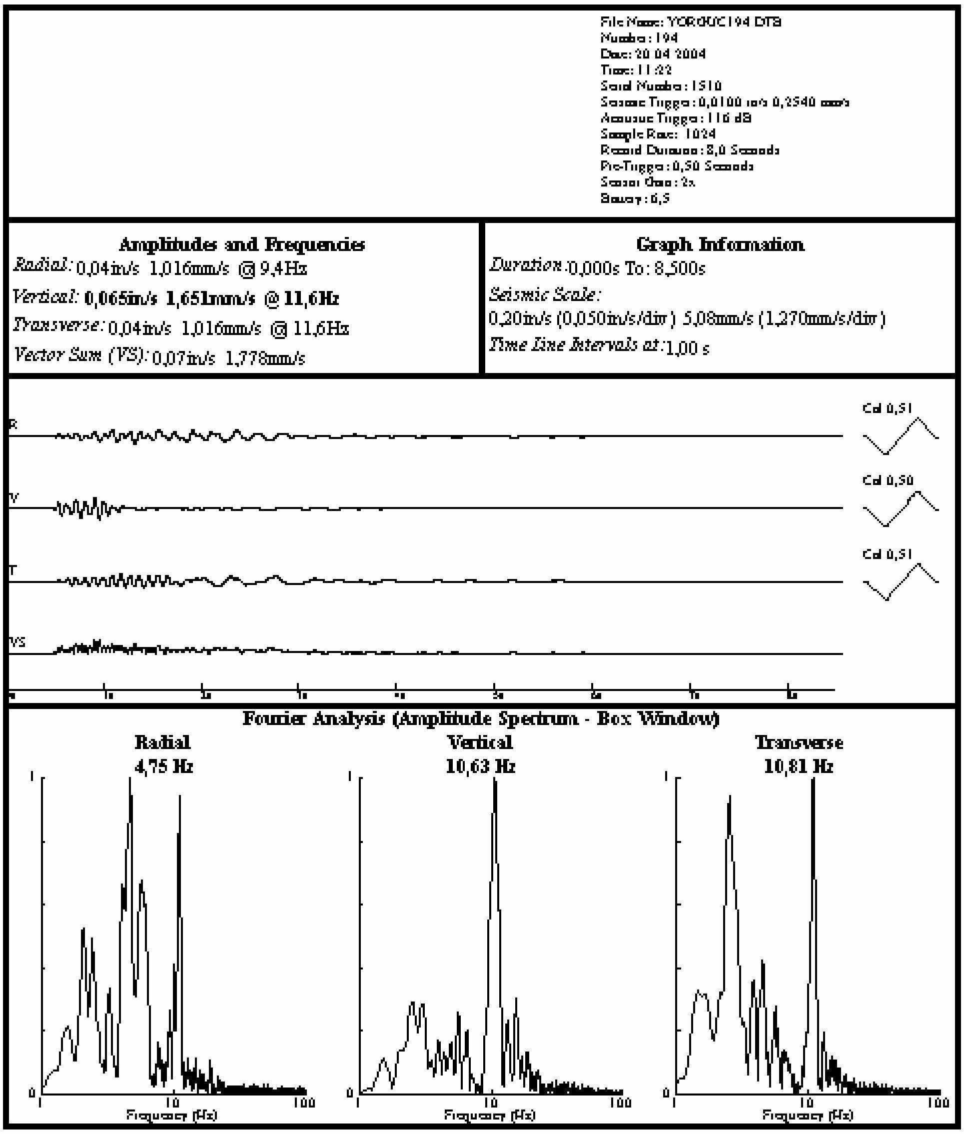

Appendix A.9 9th vibration record for initiation towards Yörgüç village.

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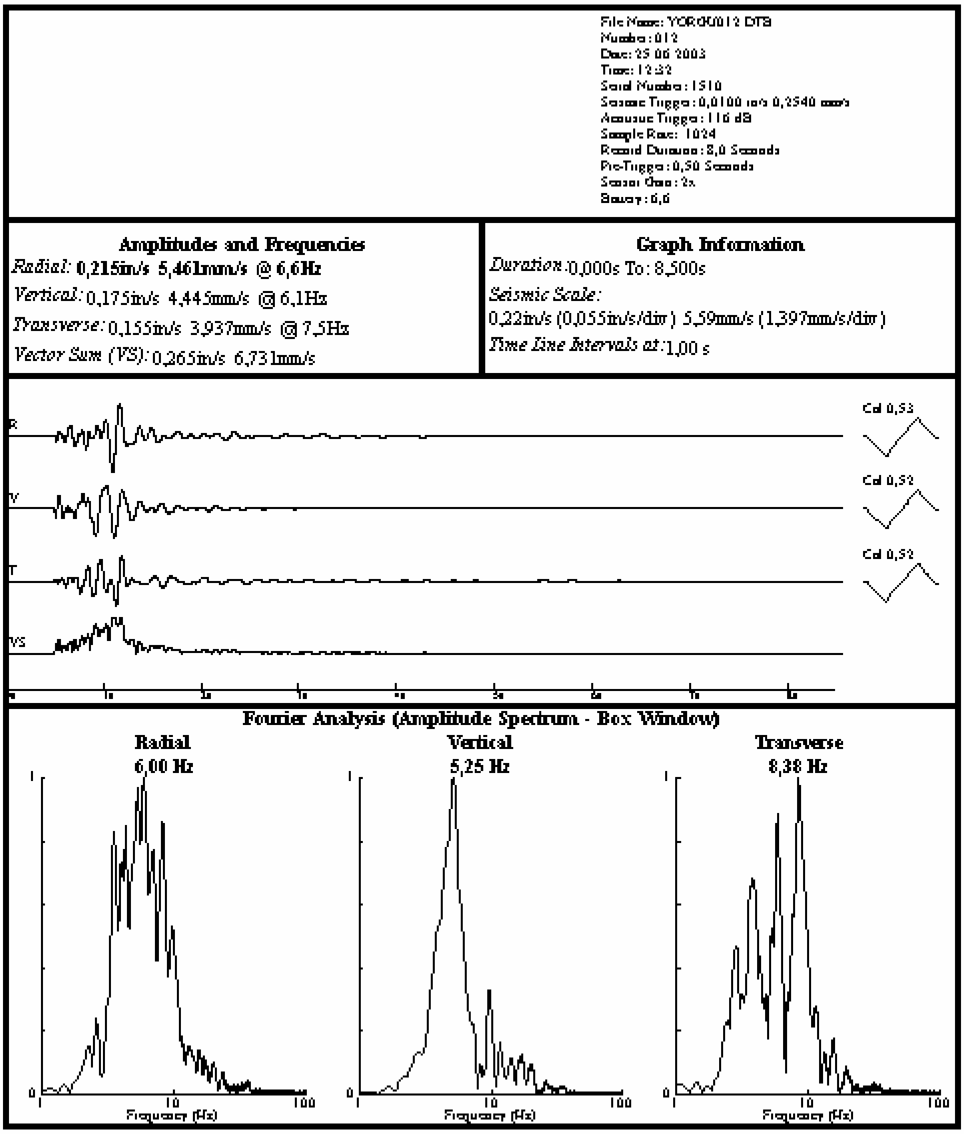

Appendix B.1 1st vibration record for single hole blasting.

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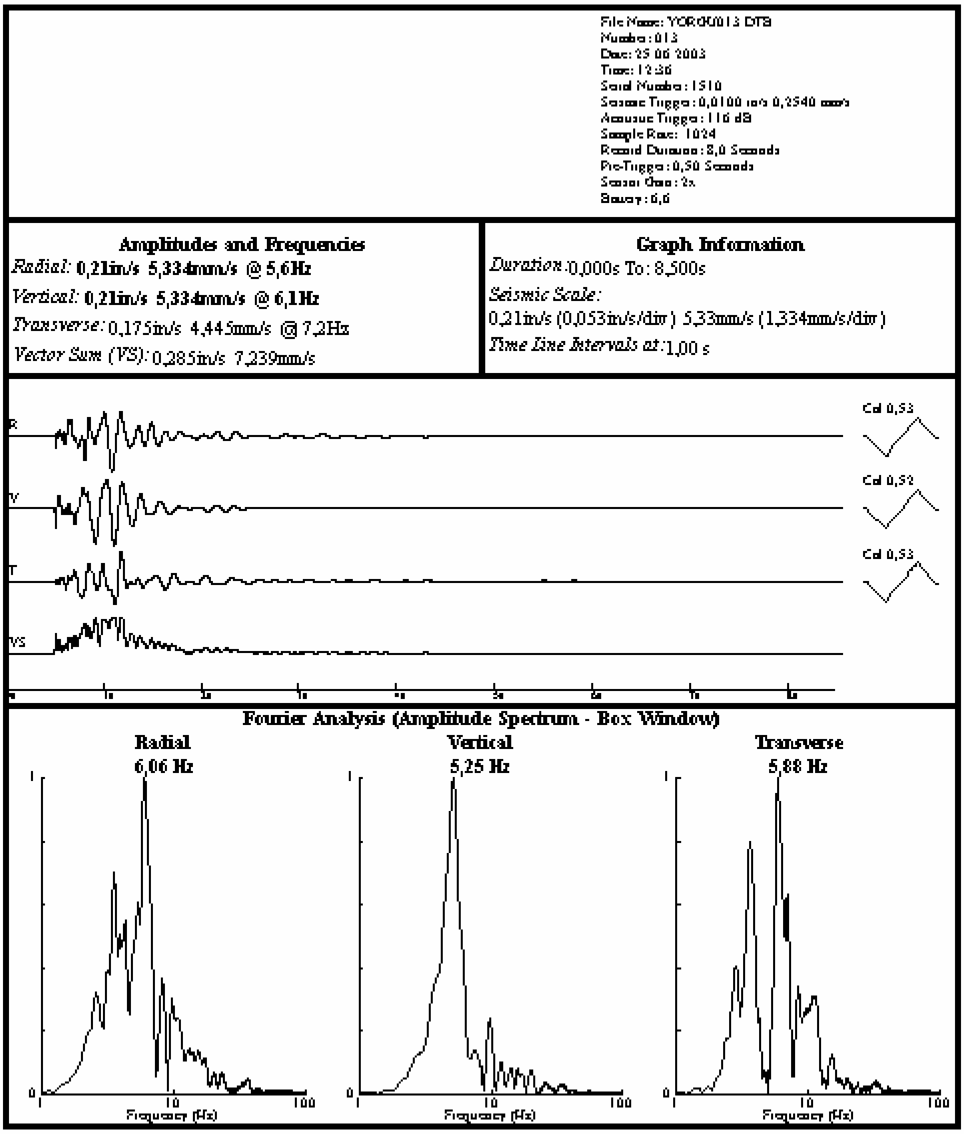

Appendix B.2 2nd vibration record for single hole blasting.

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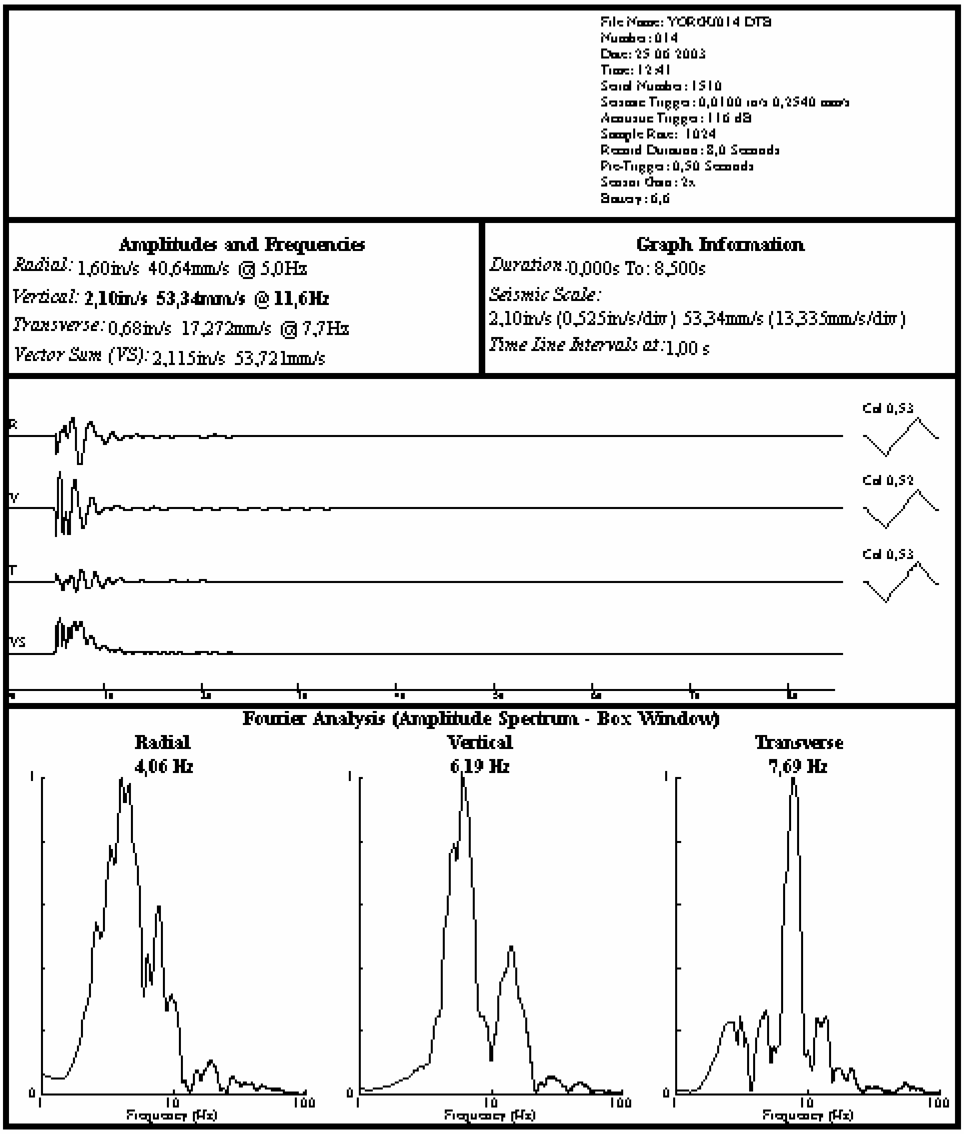
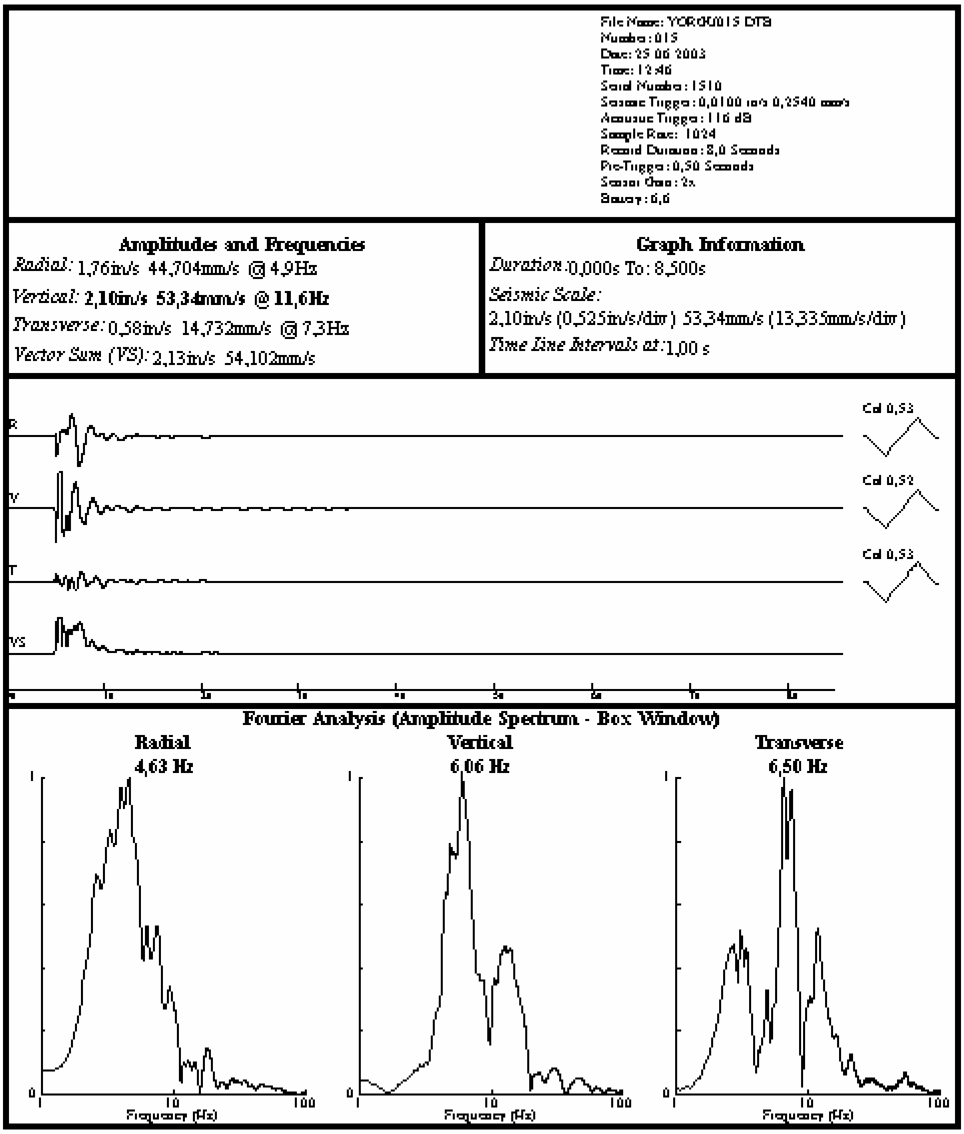
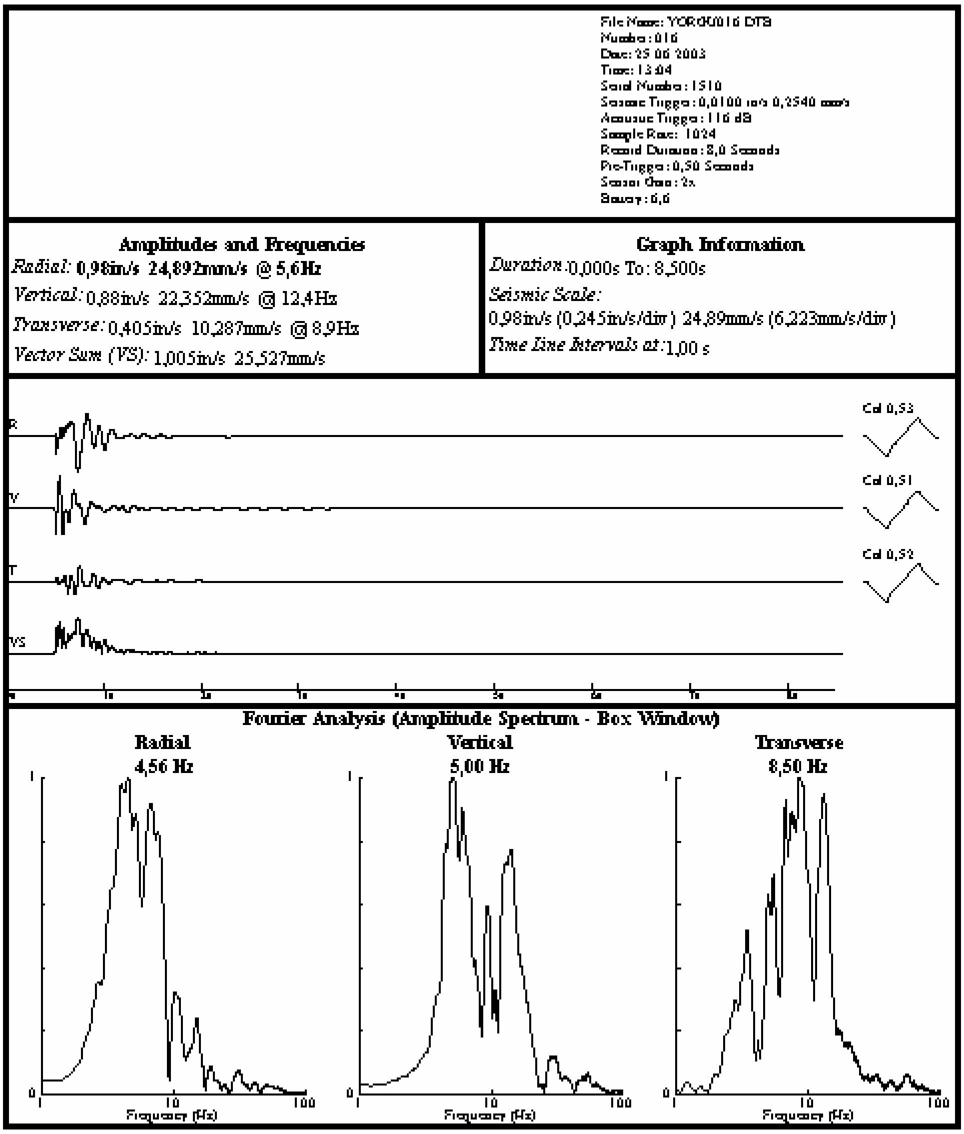


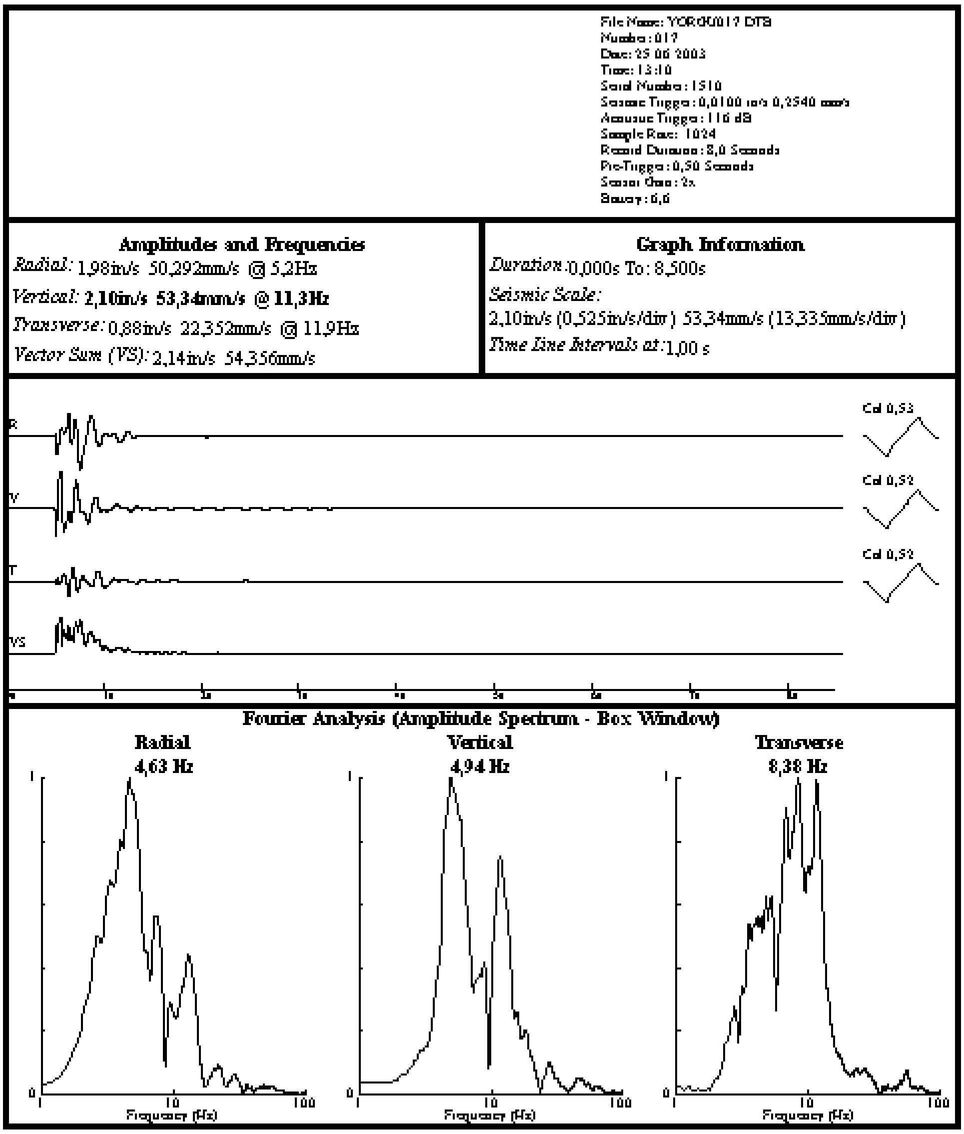
Appendix B.3 3rd vibration record for single hole blasting.



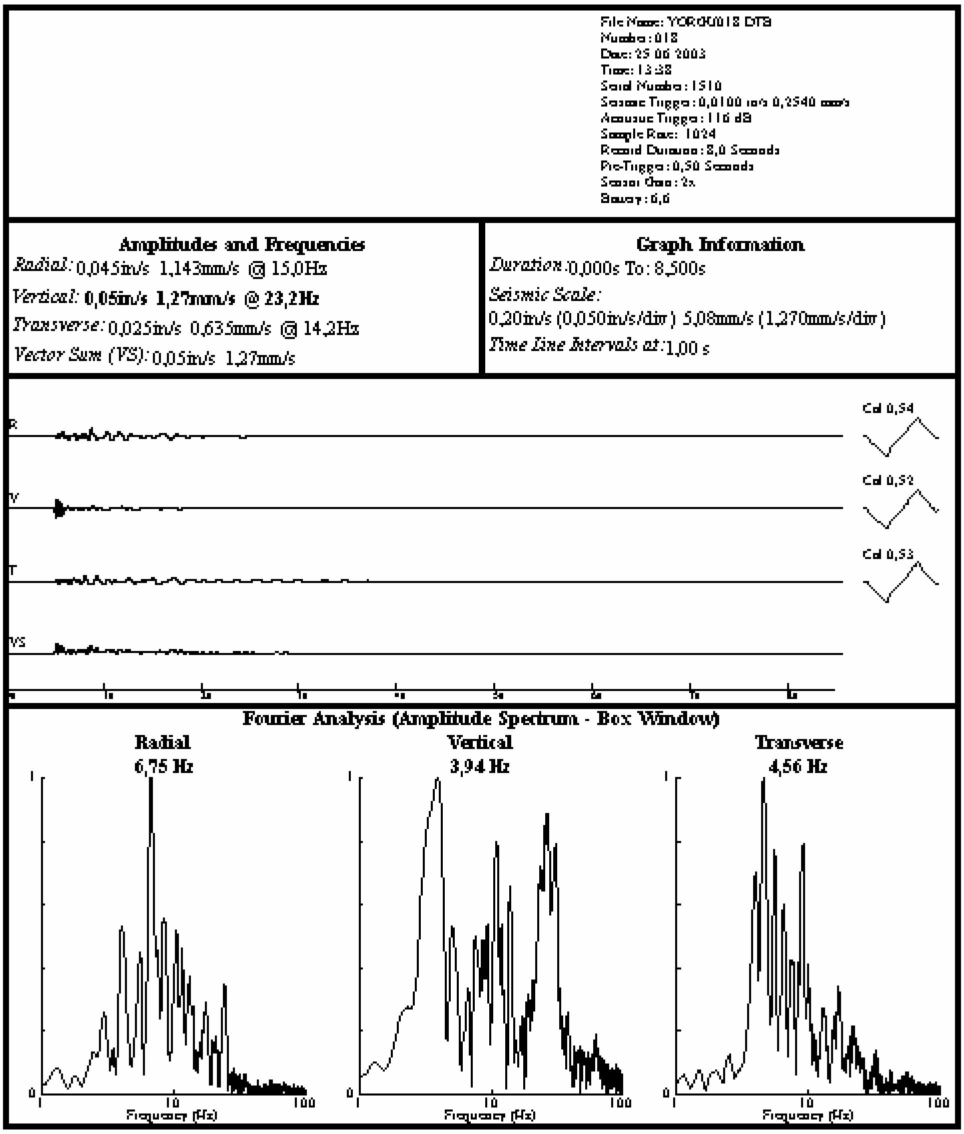
Appendix B.4 4th vibration record for single hole blasting.



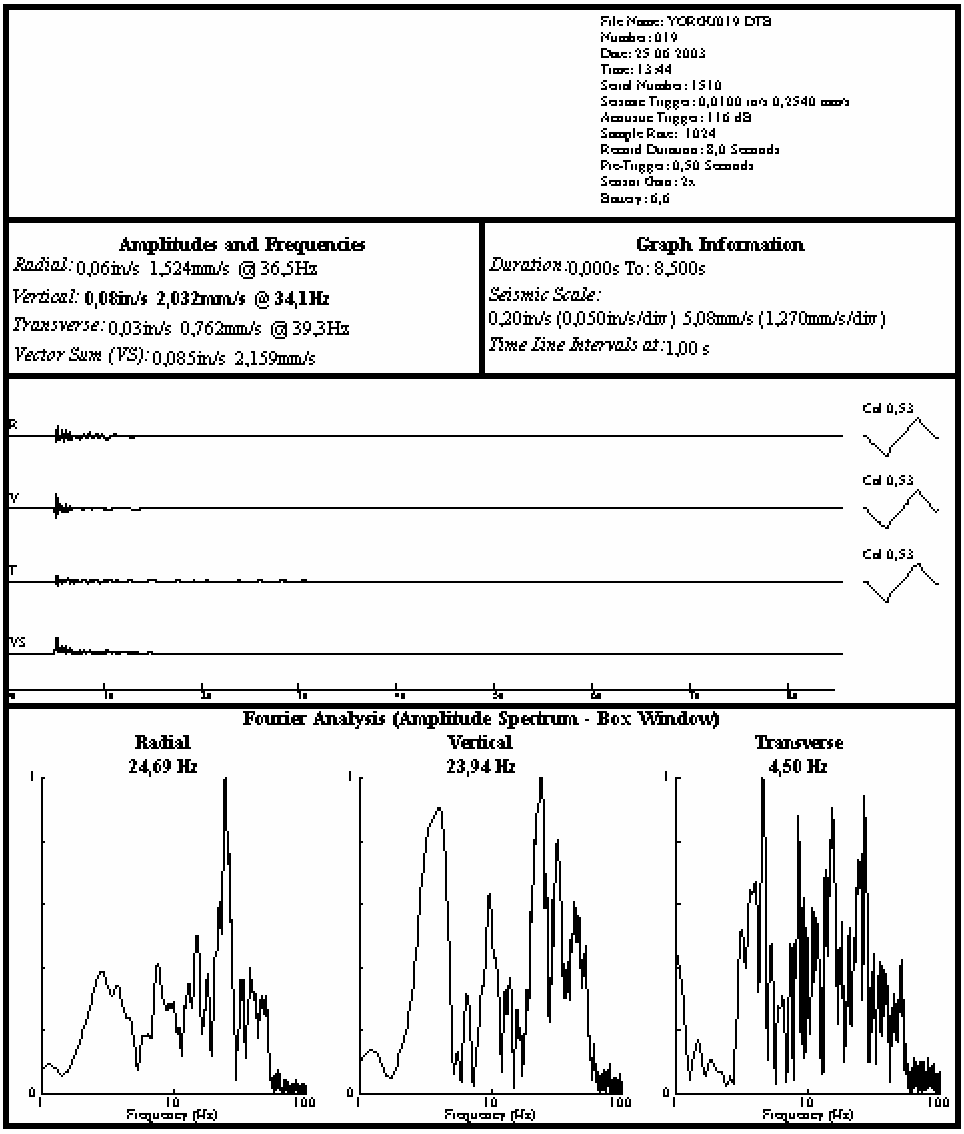
Appendix B.5 5th vibration record for single hole blasting.



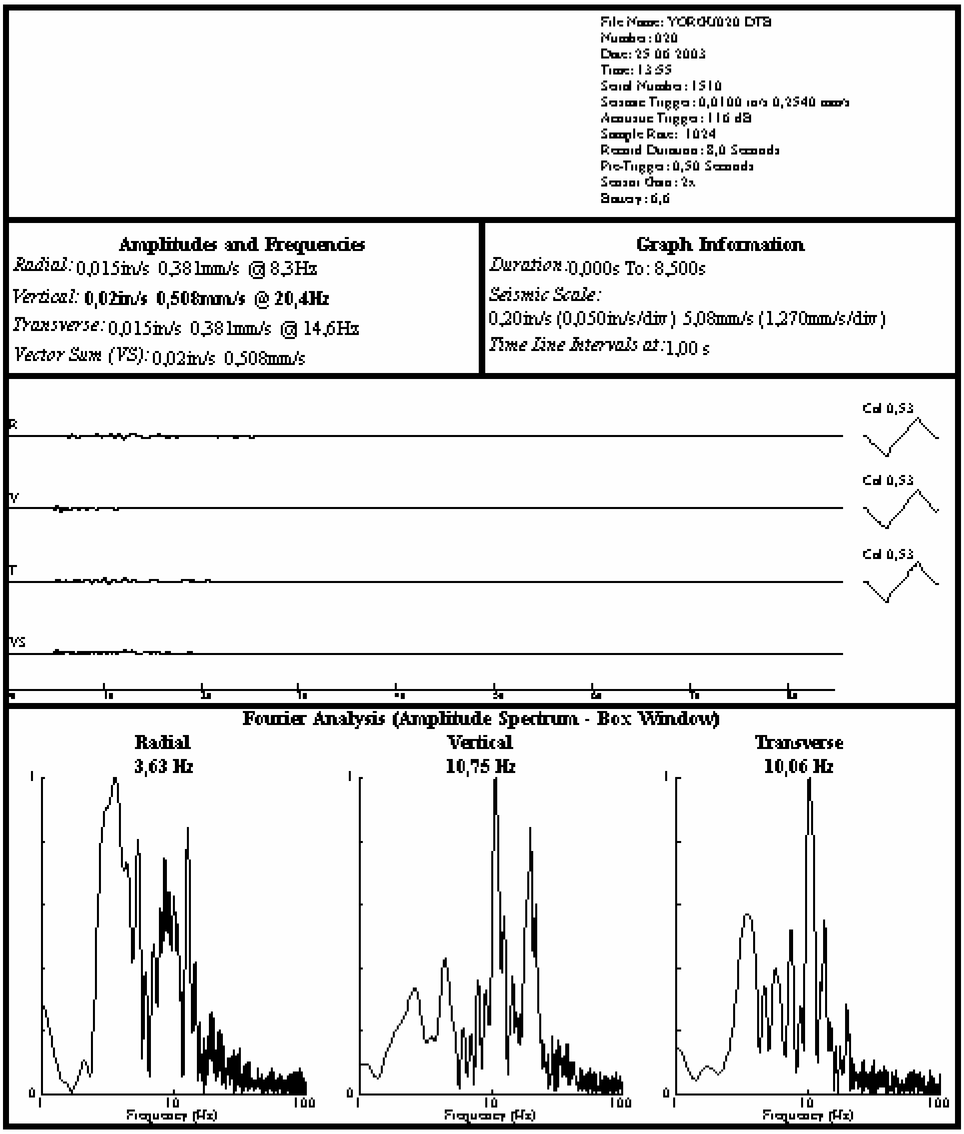
Appendix B.6 6th vibration record for single hole blasting.



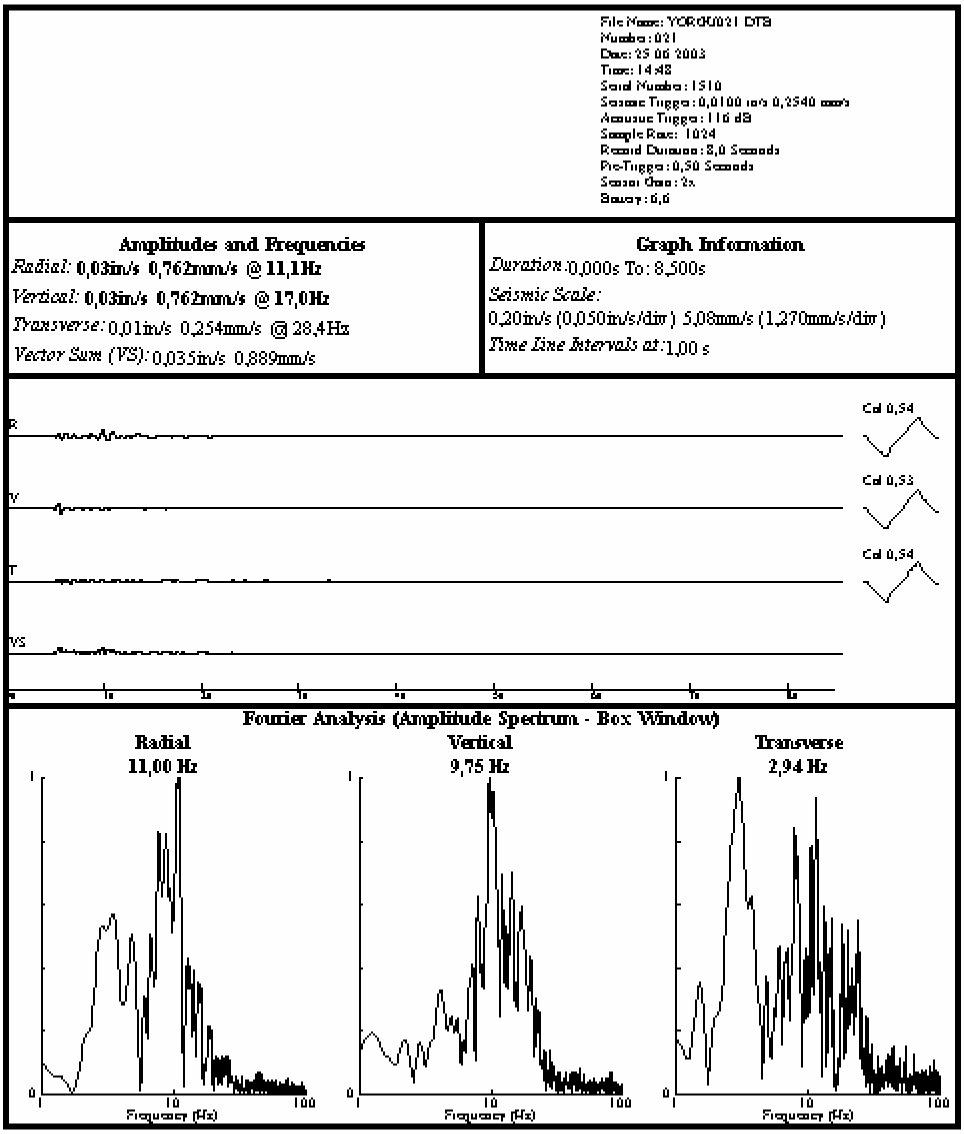
Appendix B.7 7th vibration record for single hole blasting.



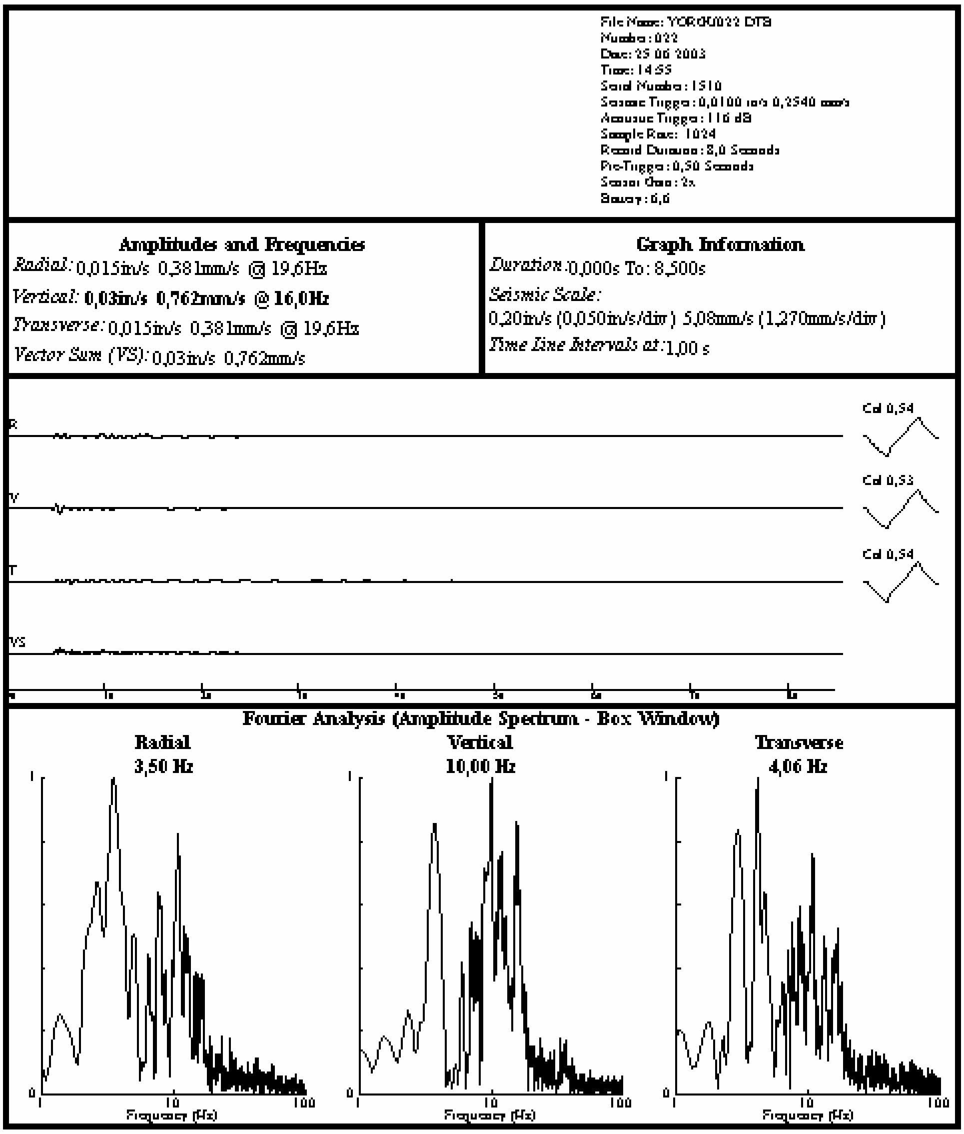
Appendix B.8 8th vibration record for single hole blasting.



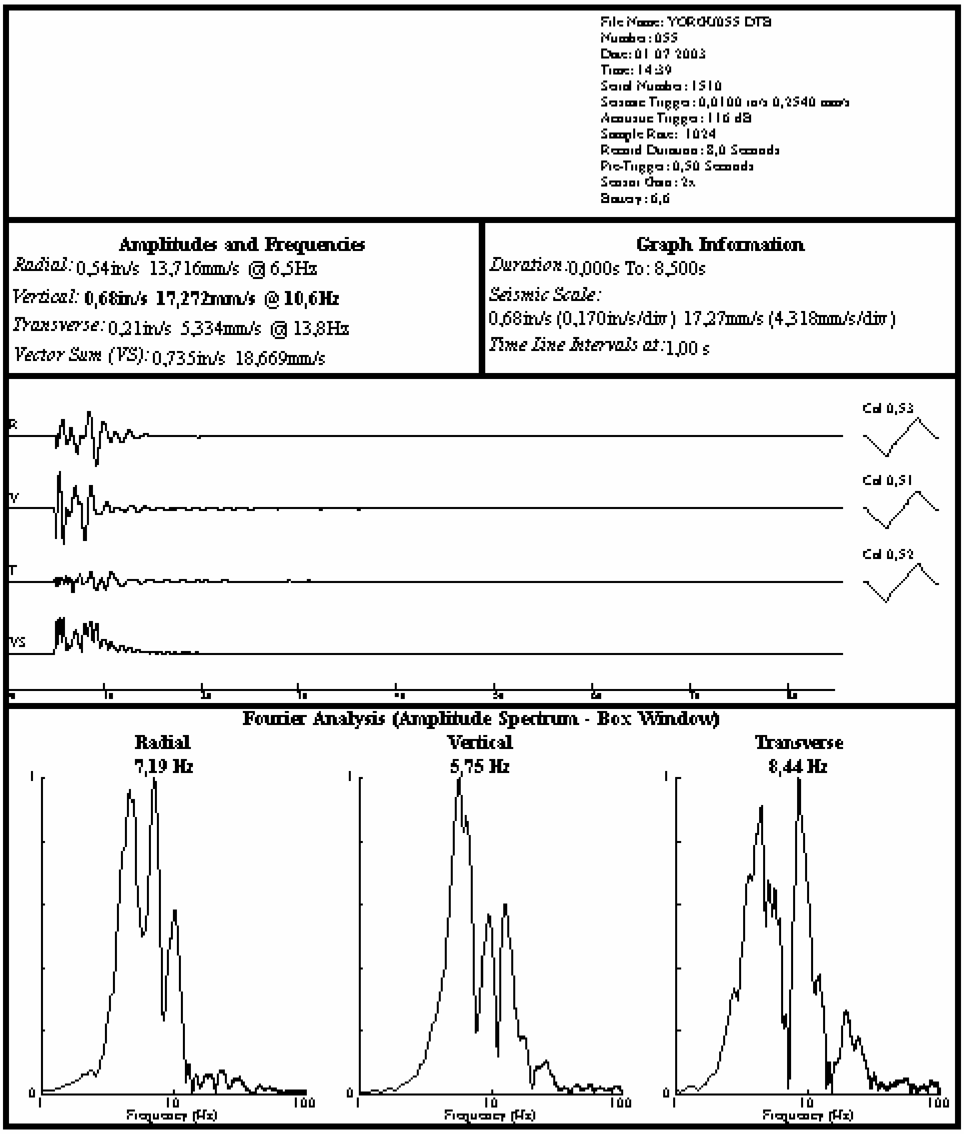
Appendix B.9 9th vibration record for single hole blasting.



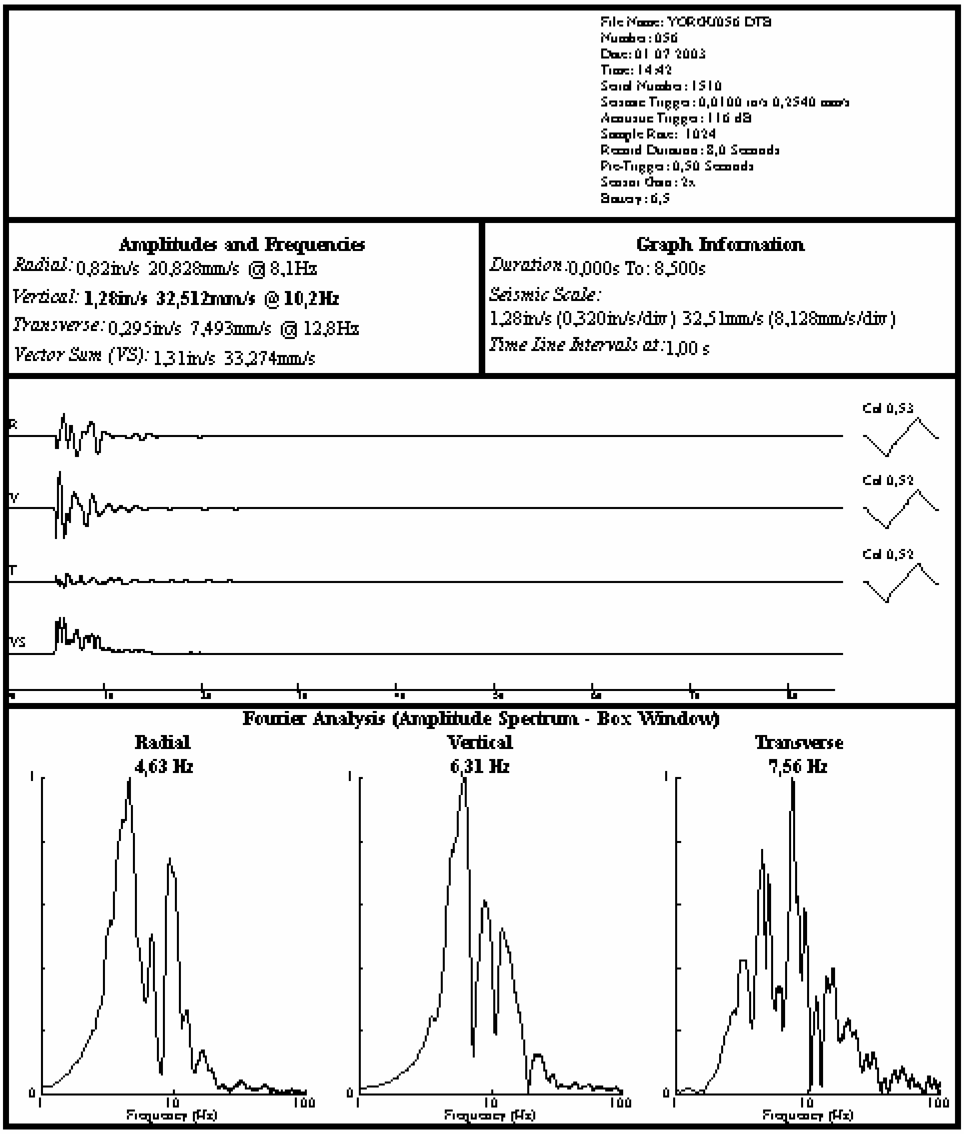
Appendix B.10 10th vibration record for single hole blasting.



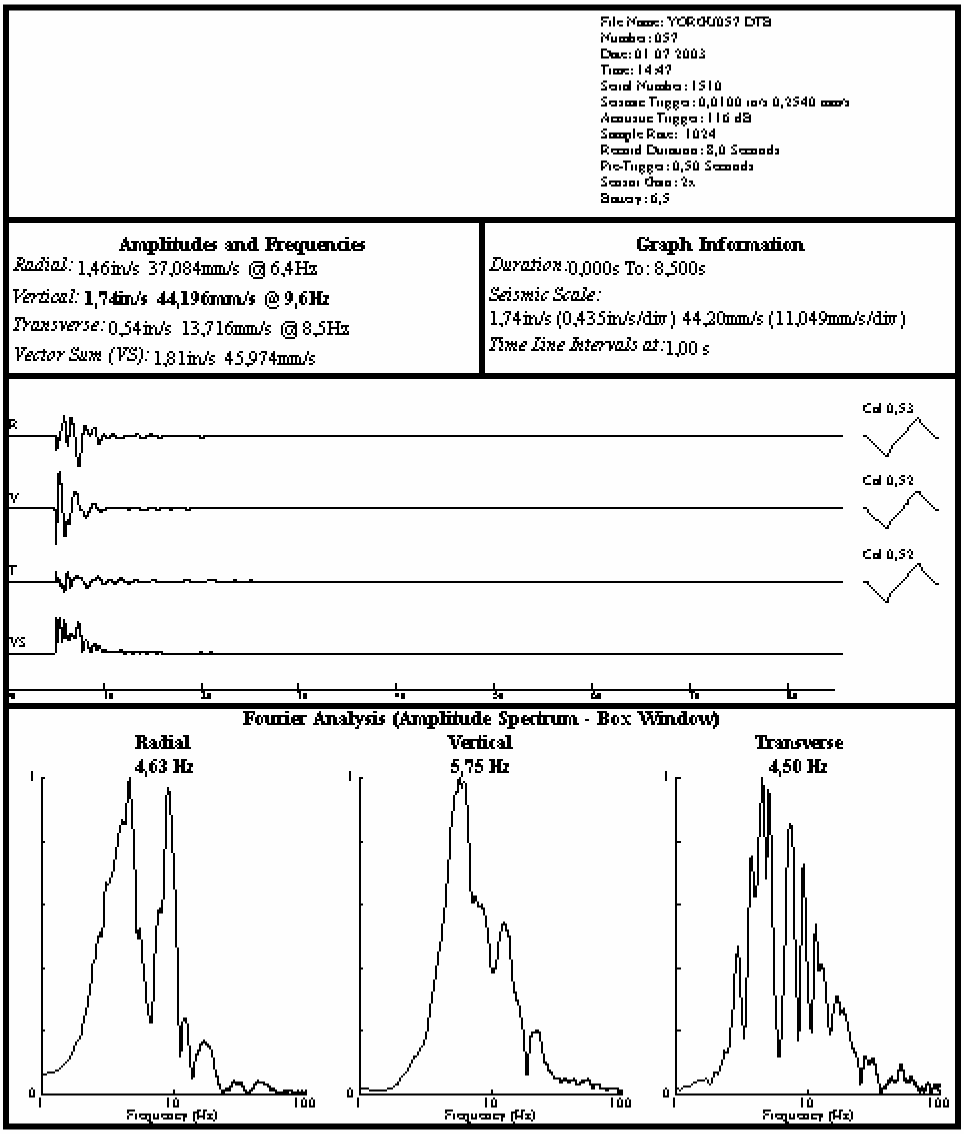
Appendix B.11 11th vibration record for single hole blasting.



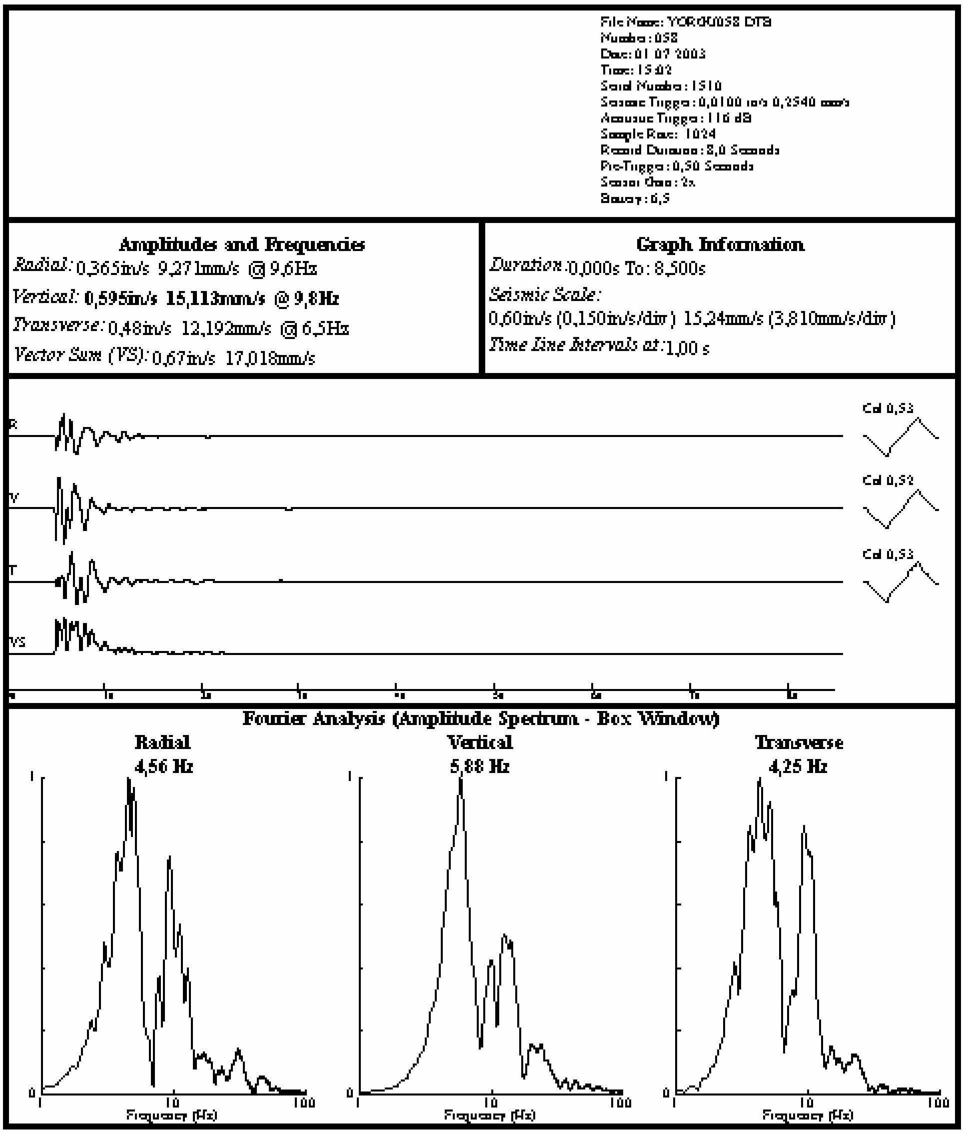
Appendix B.12 12th vibration record for single hole blasting.



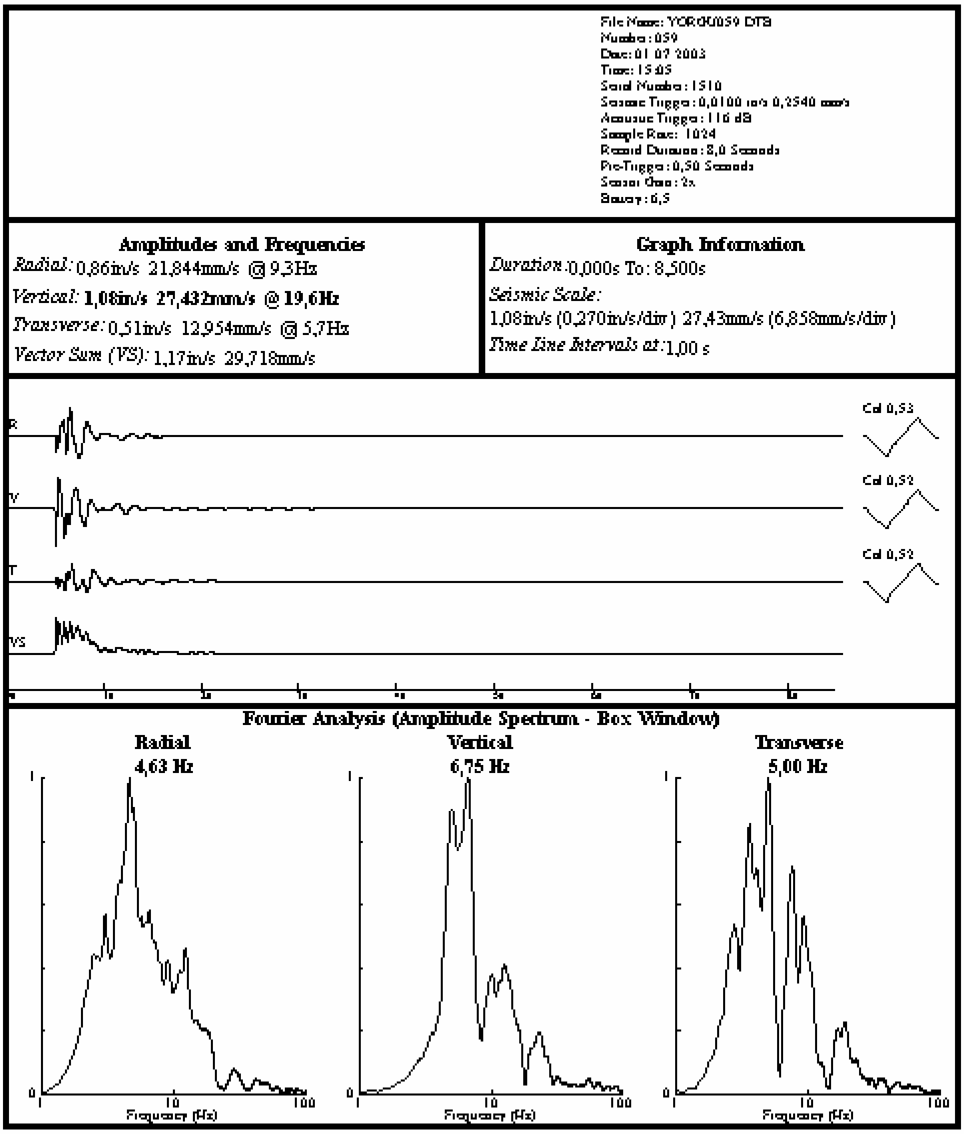
Appendix B.13 13th vibration record for single hole blasting.



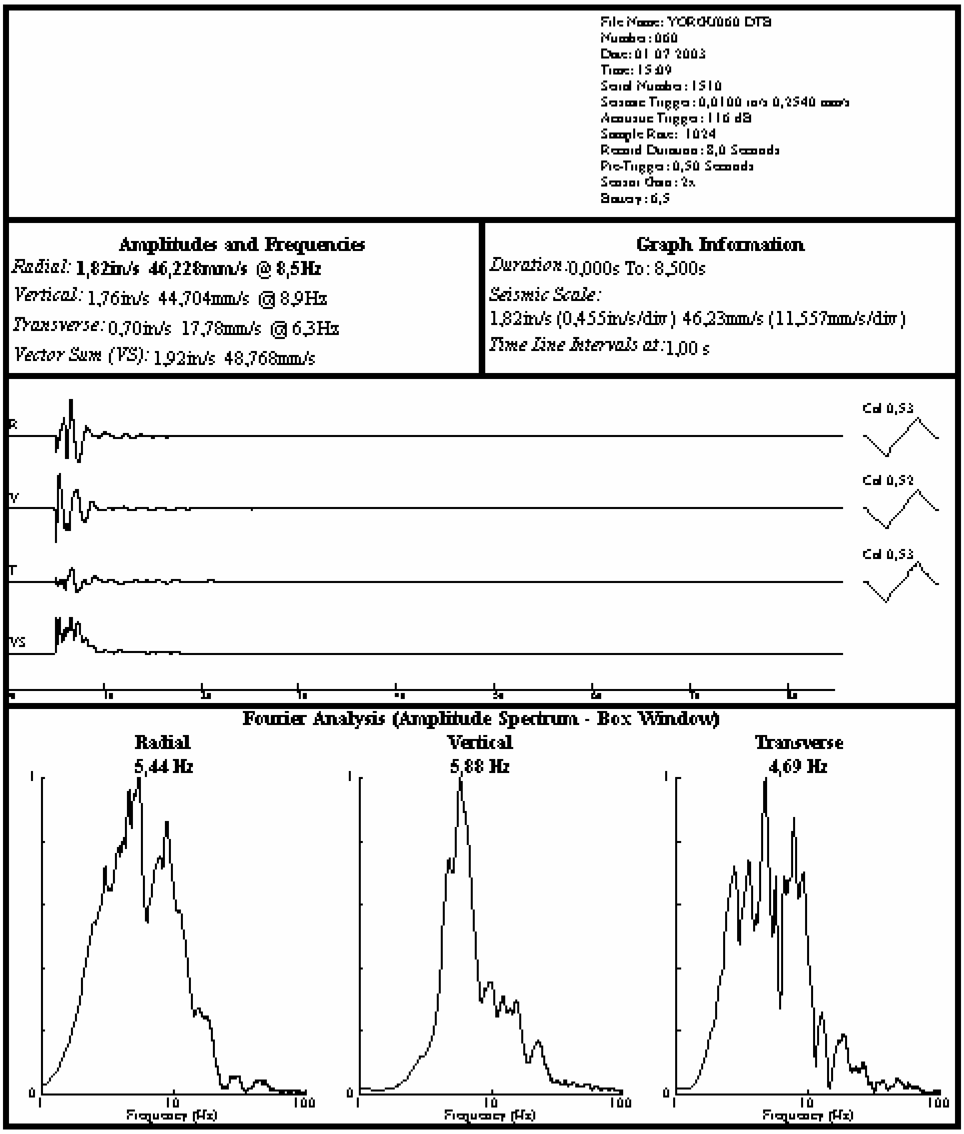
Appendix B.14 14th vibration record for single hole blasting.



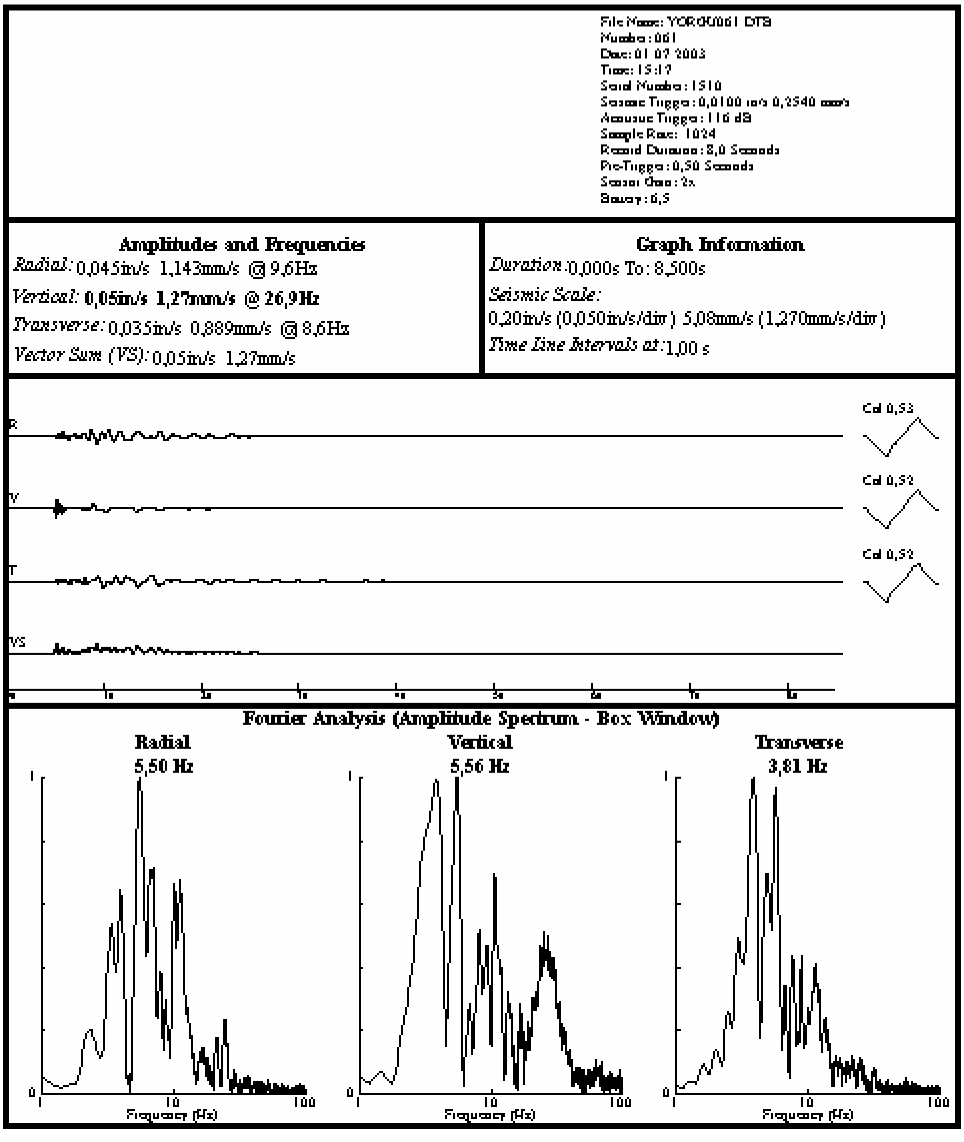
Appendix B.15 15th vibration record for single hole blasting.



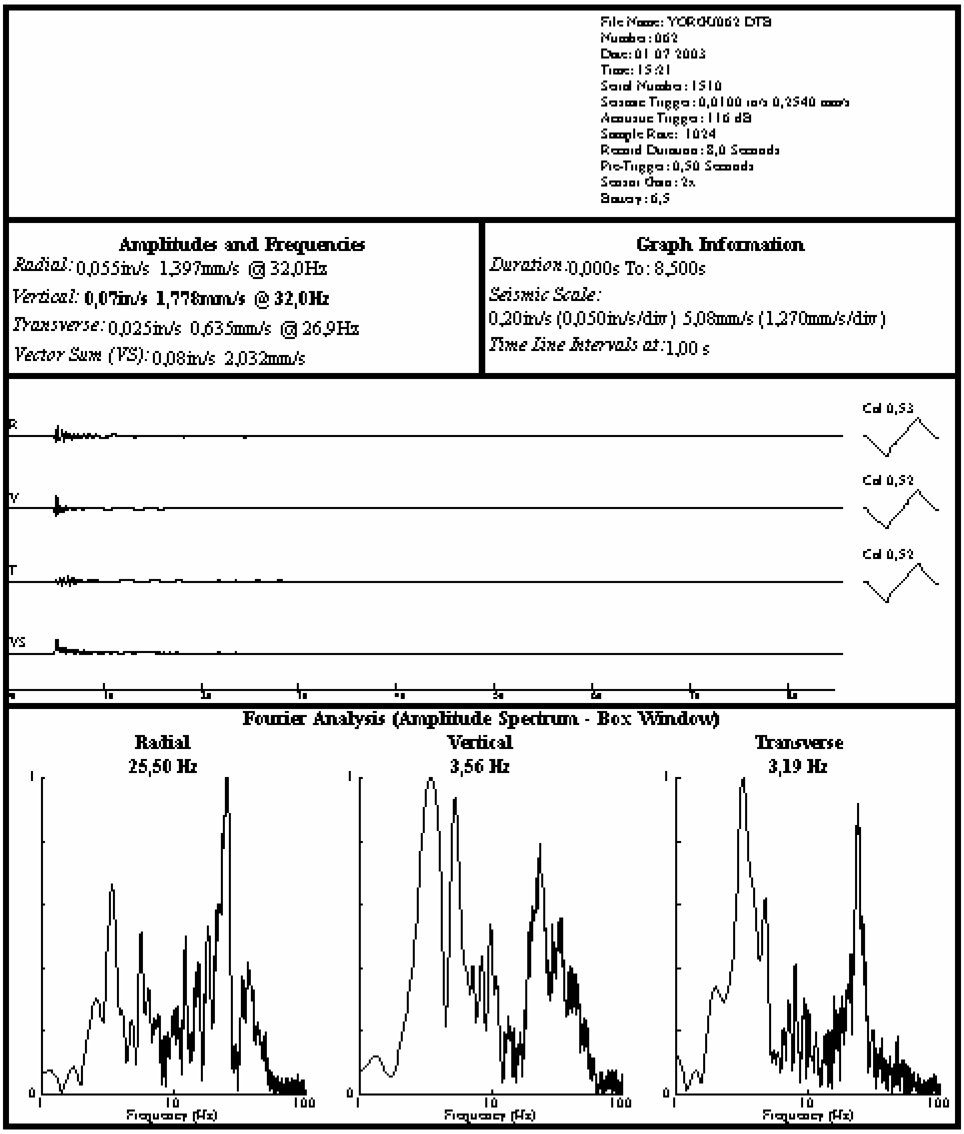
Appendix B.16 16th vibration record for single hole blasting.



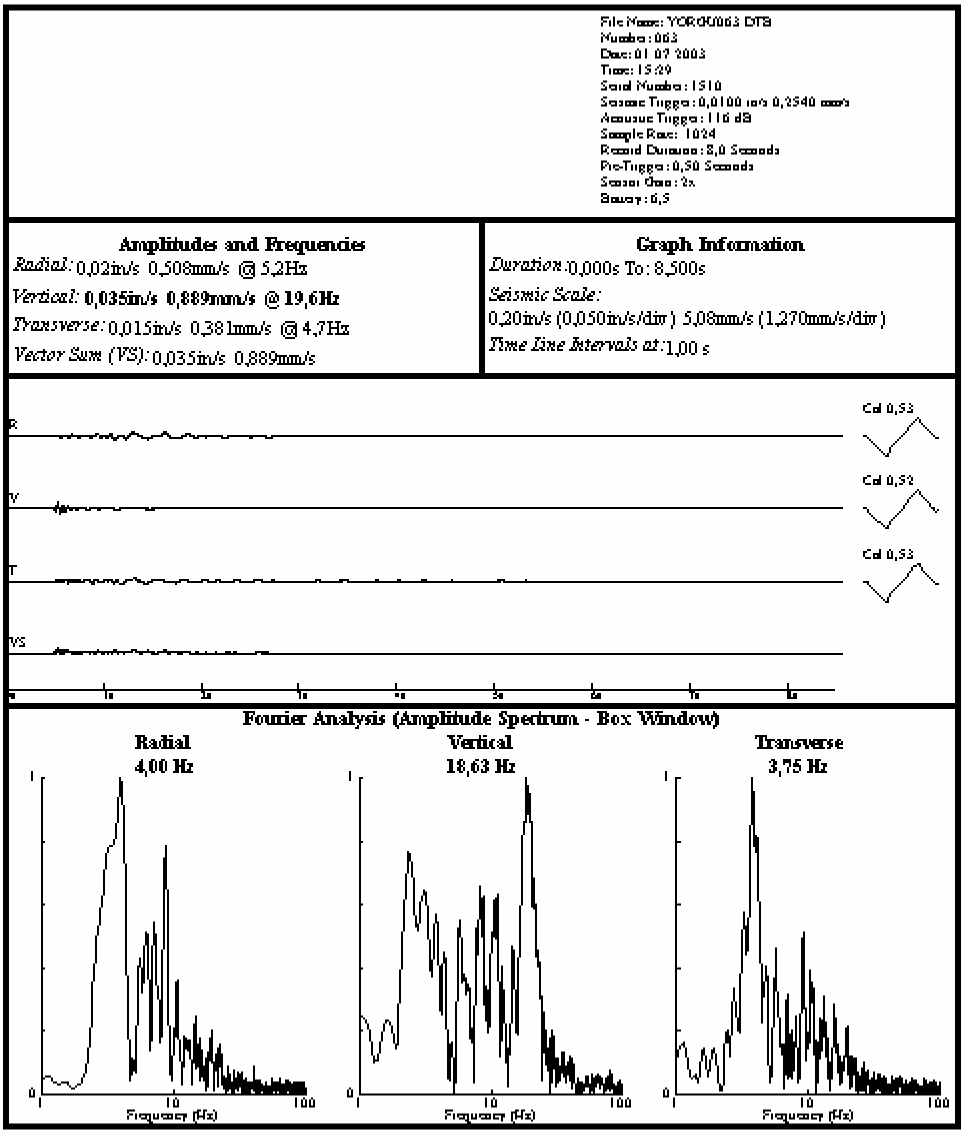
Appendix B.17 17th vibration record for single hole blasting.



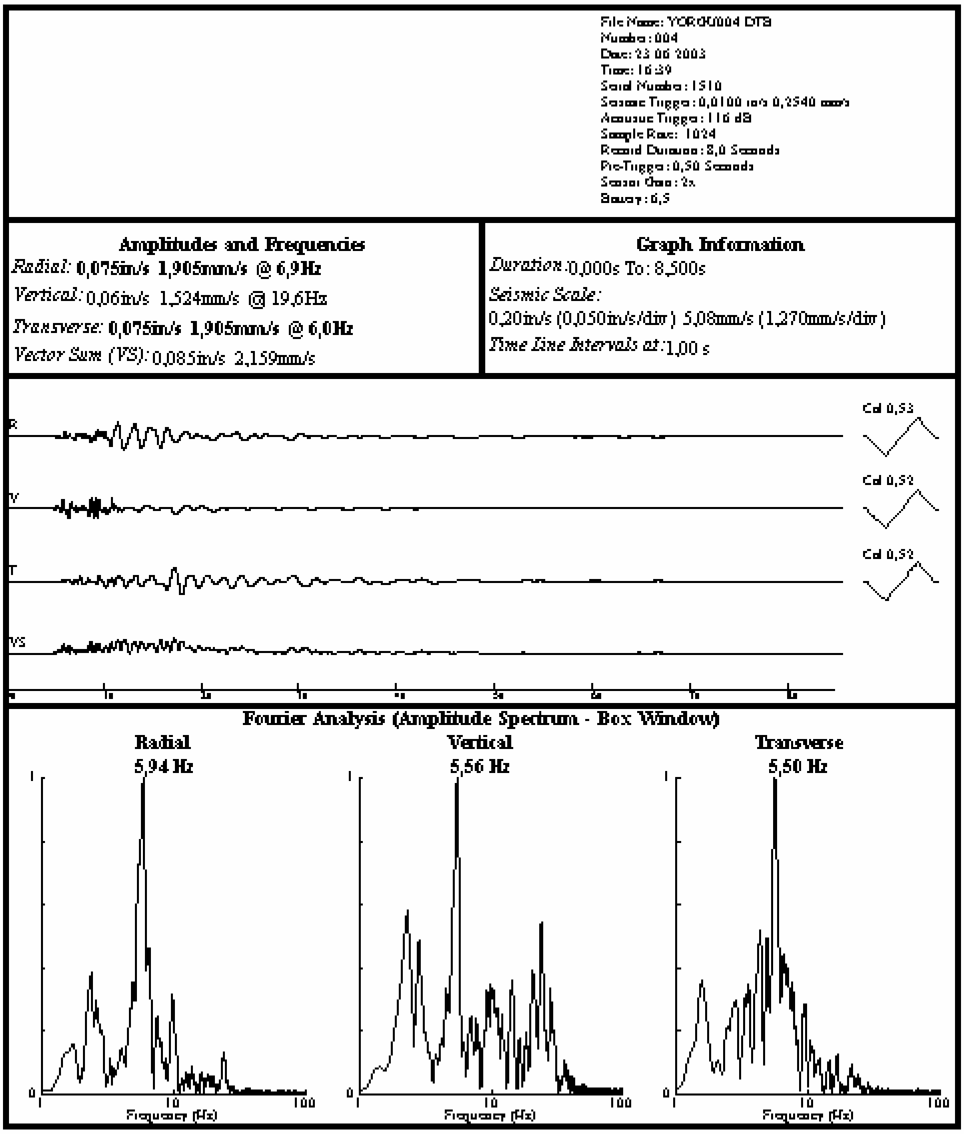
Appendix B.18 18th vibration record for single hole blasting.



Appendix B.19 19th vibration record for single hole blasting.



Appendix B.20 20th vibration record for single hole blasting.



Appendix C.1 1st vibration record for initiation from Yörgüç village.

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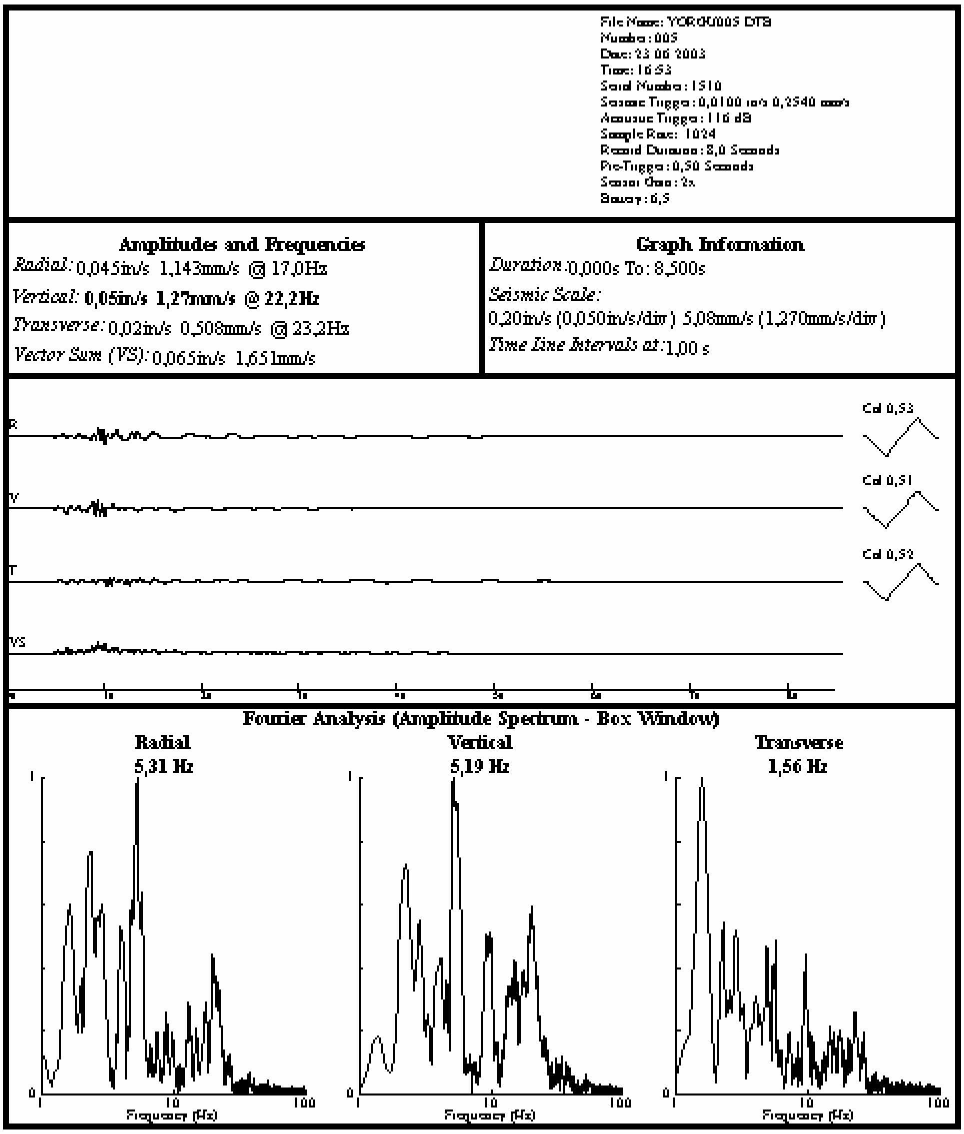
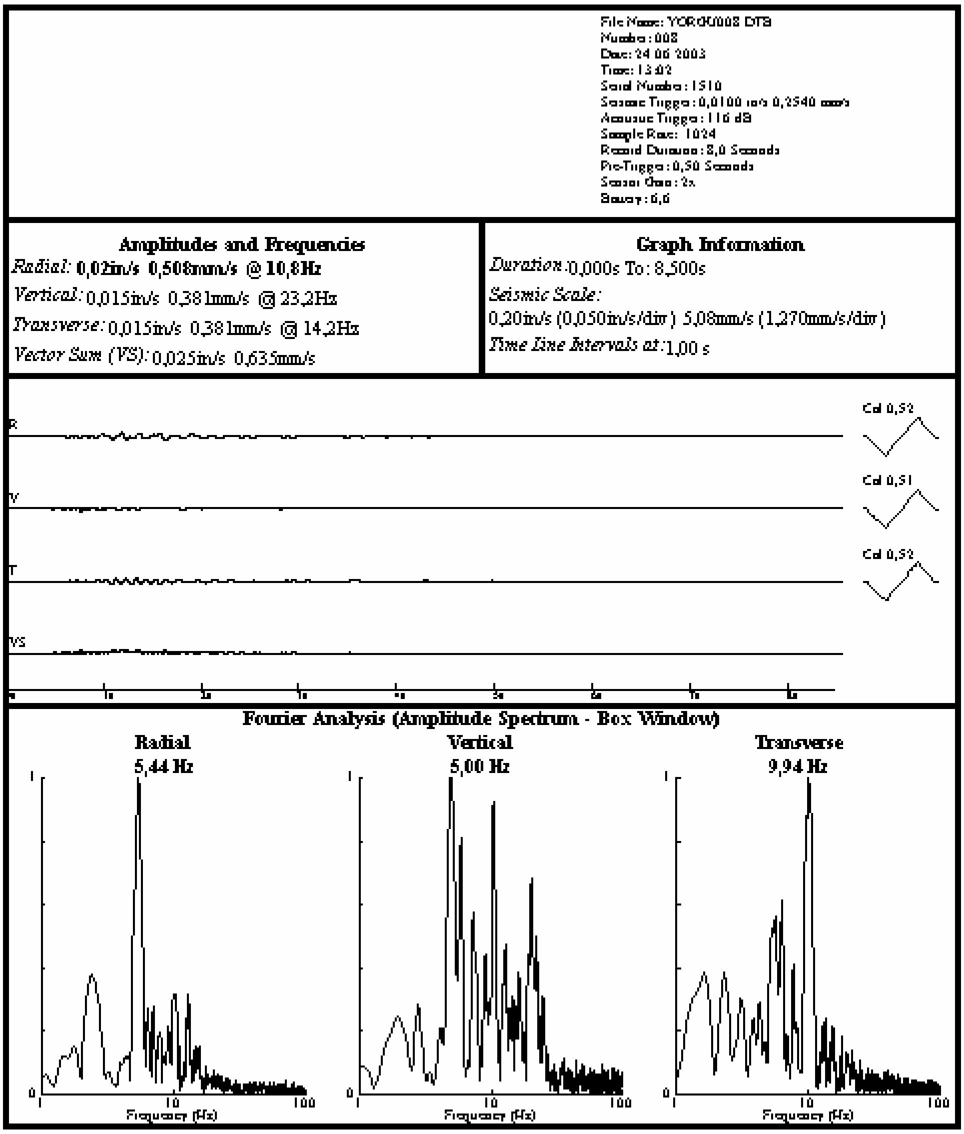
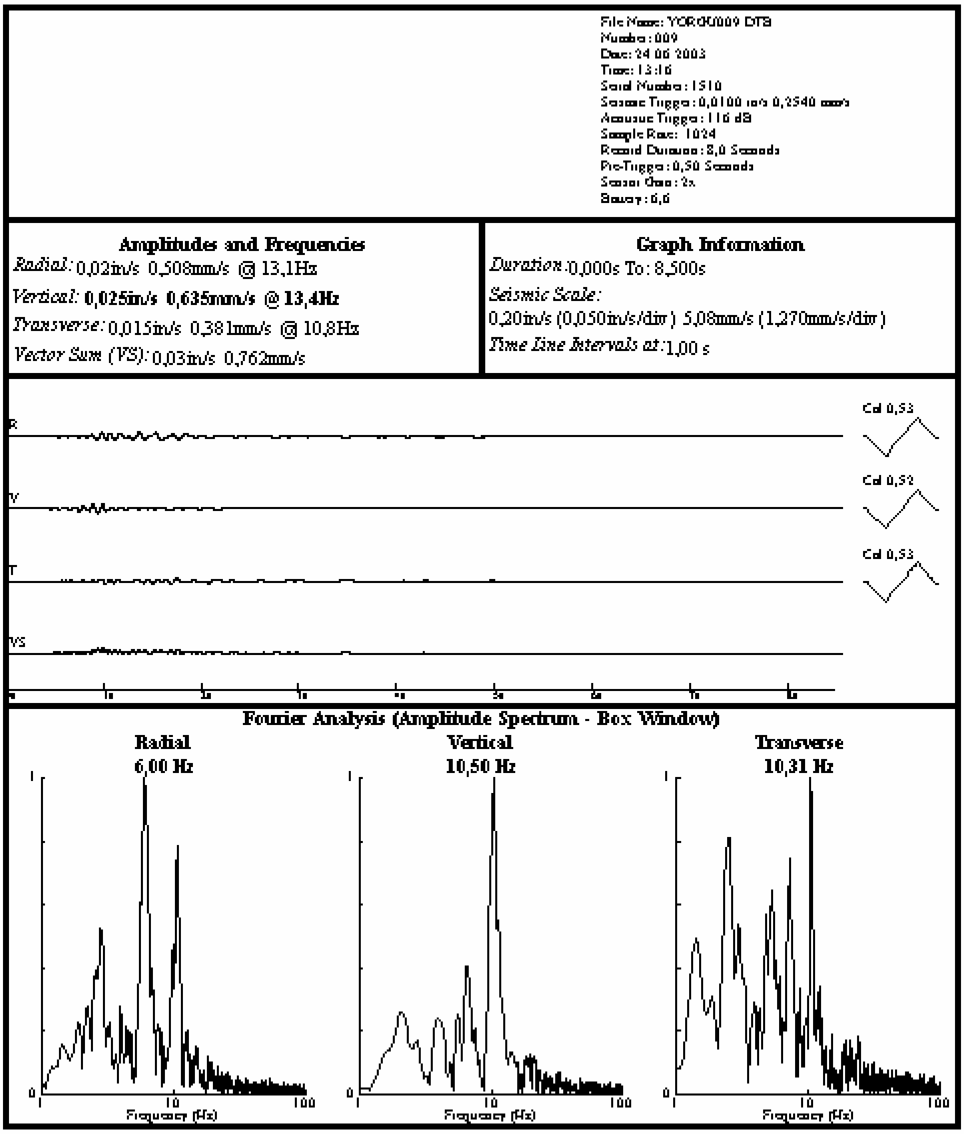


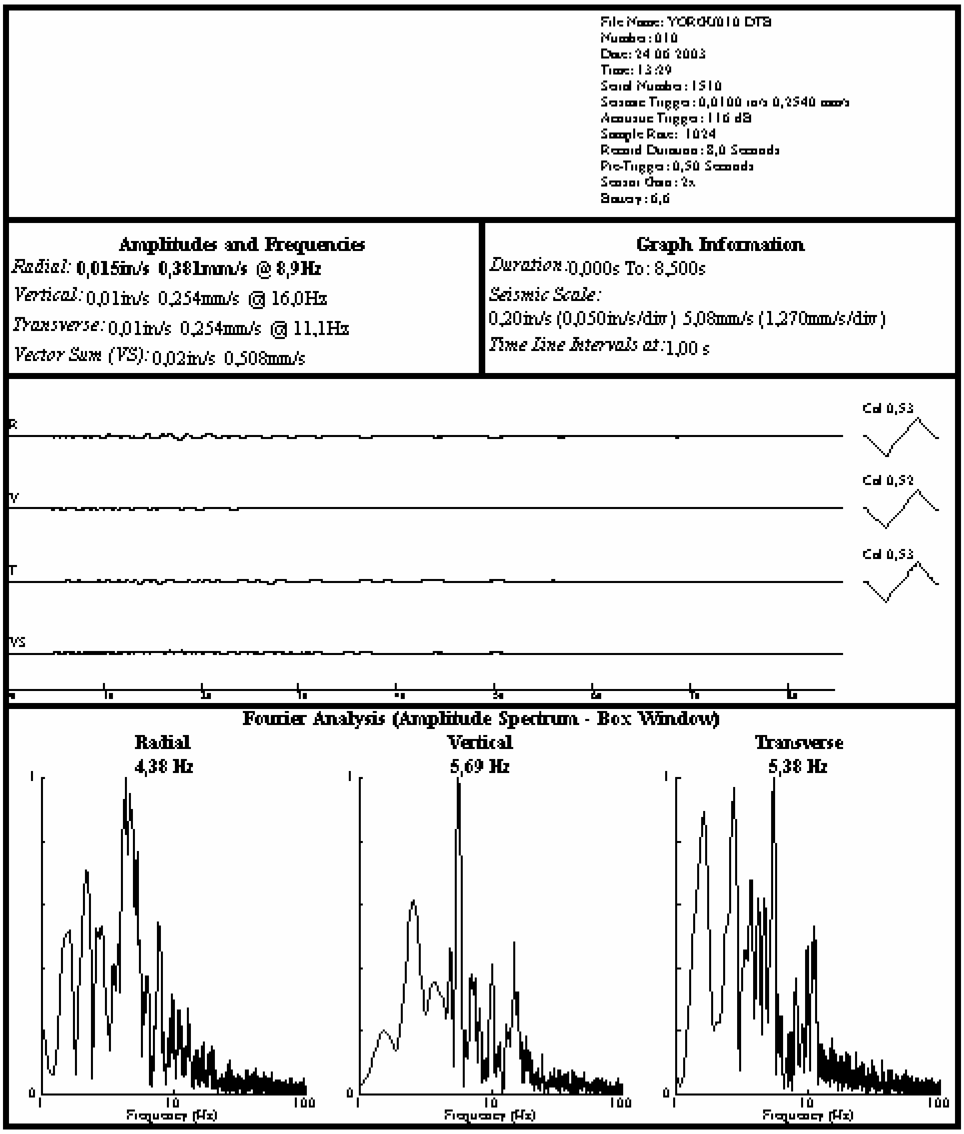
Appendix C.2 2^{nd} vibration record for initiation from Yörgüç village.



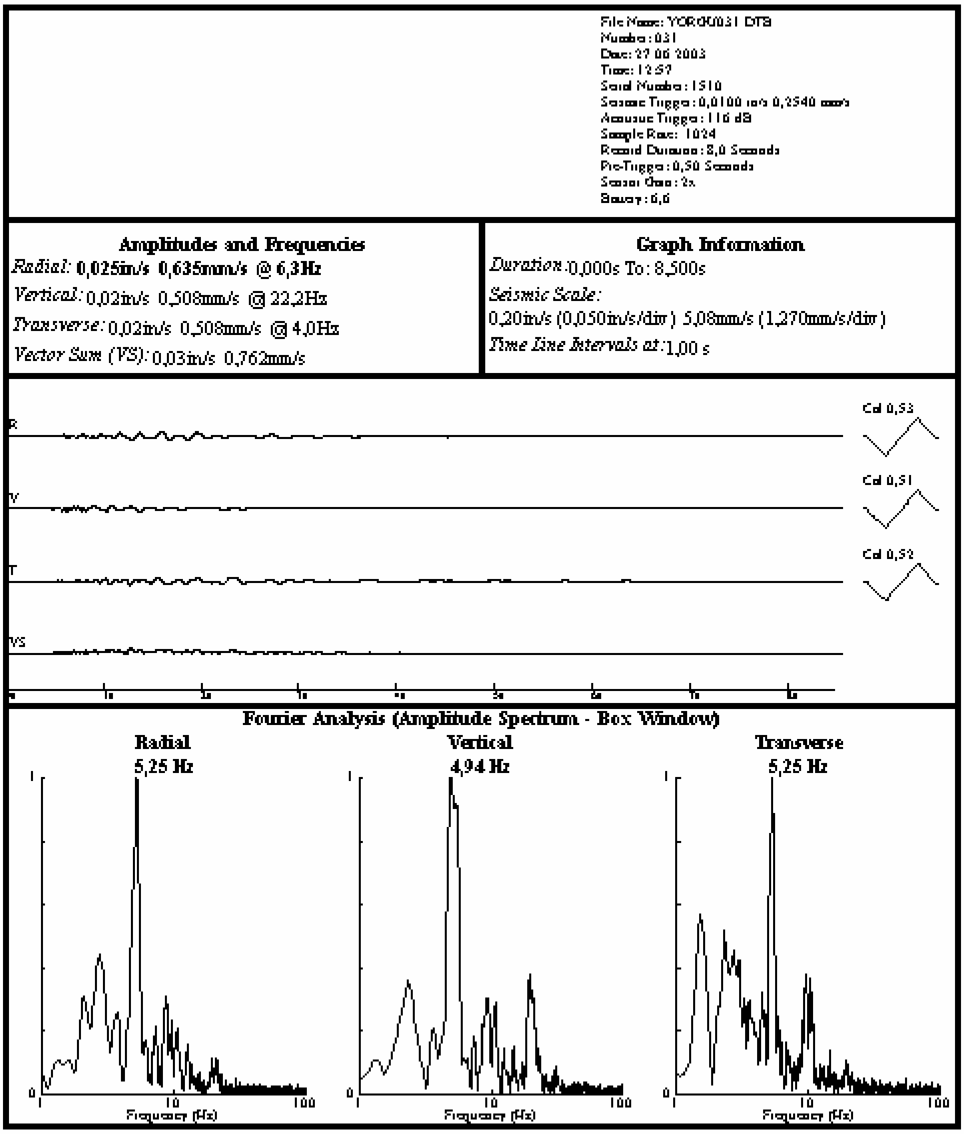
Appendix C.3 3rd vibration record for initiation from Yörgüç village.



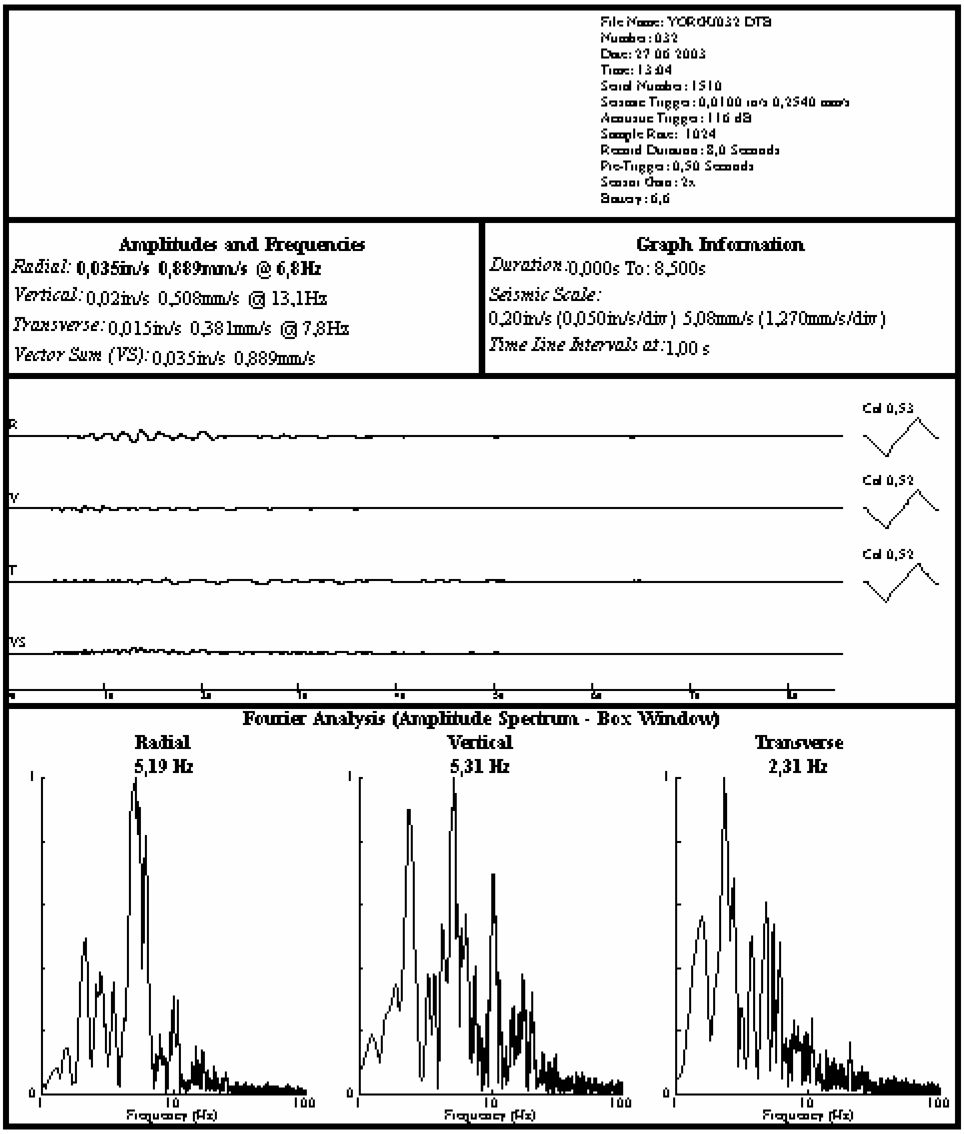
Appendix C.4 4th vibration record for initiation from Yörgüç village.



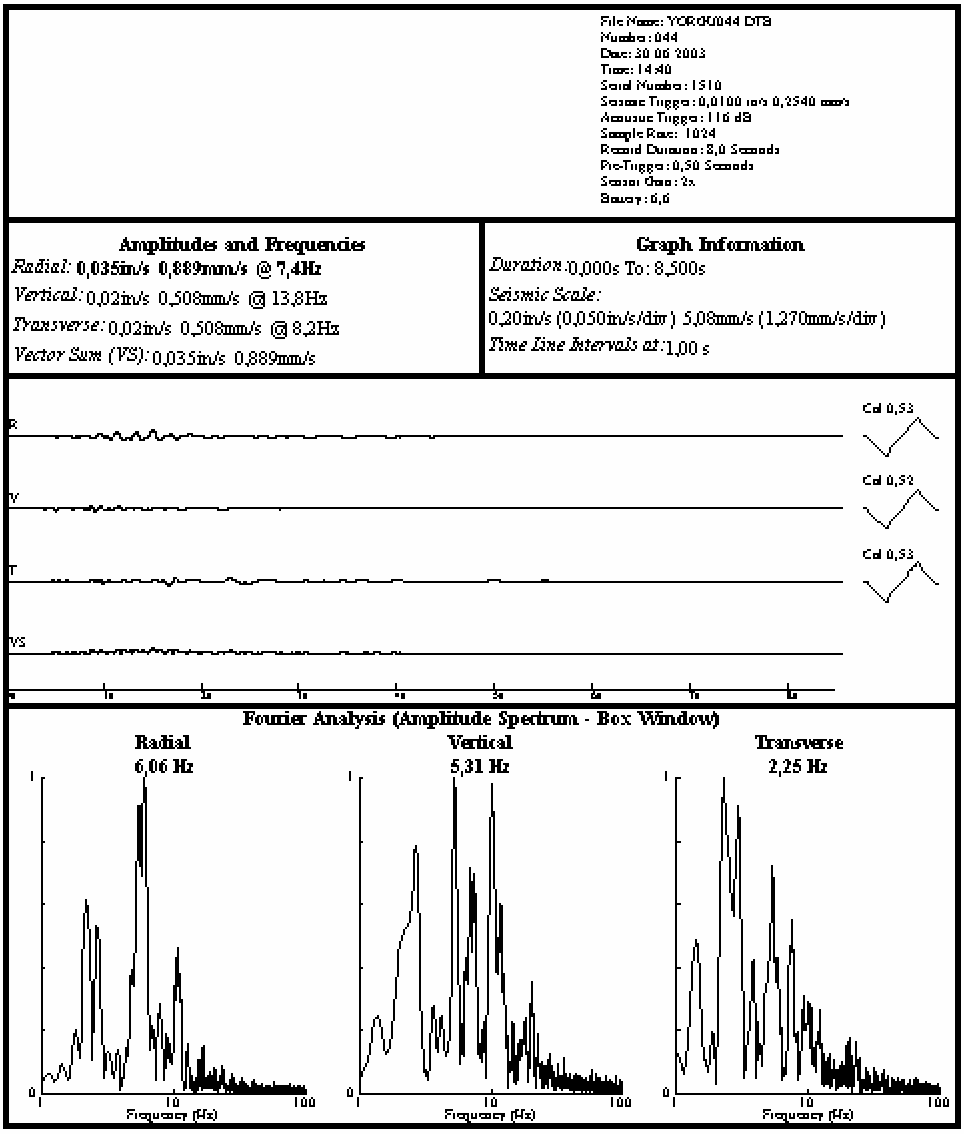
Appendix C.5 5th vibration record for initiation from Yörgüç village.



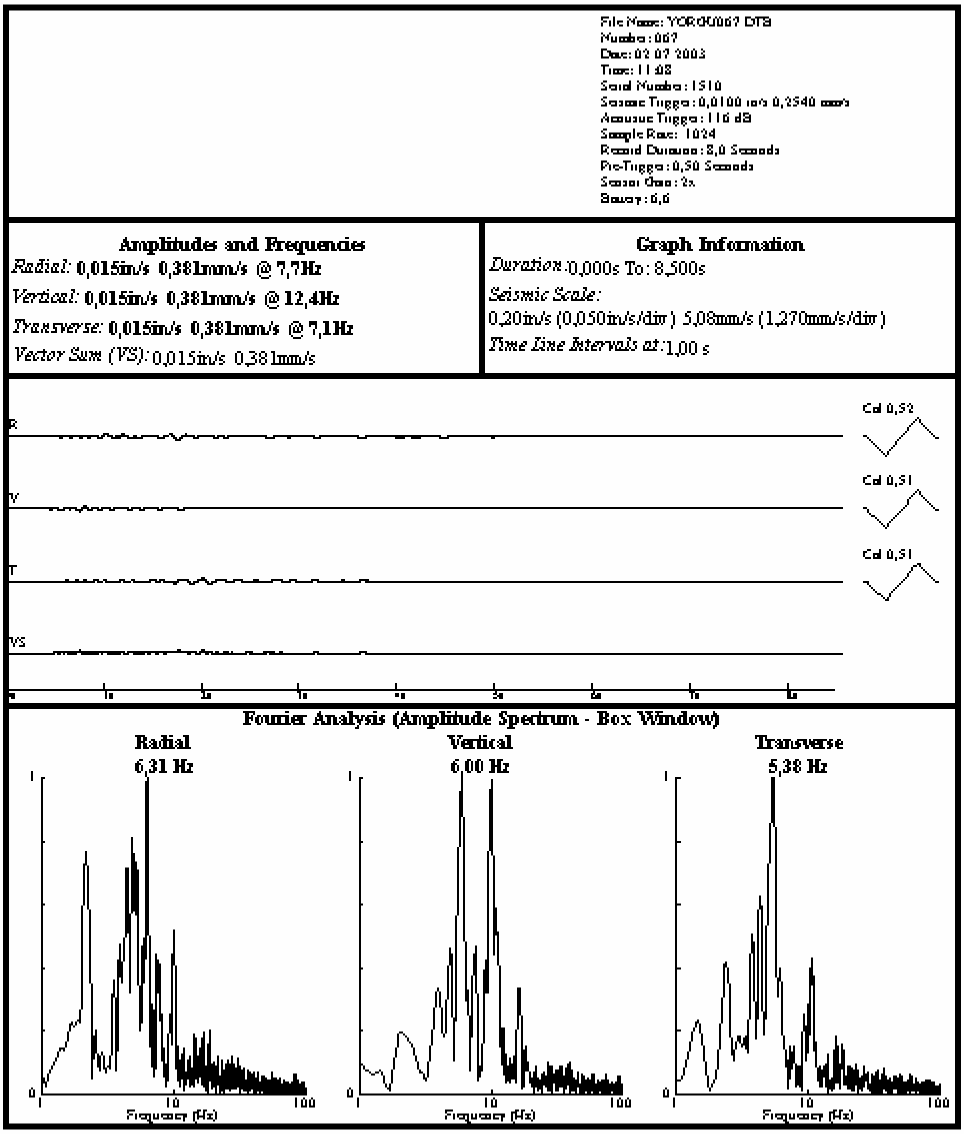
Appendix C.6 6th vibration record for initiation from Yörgüç village.



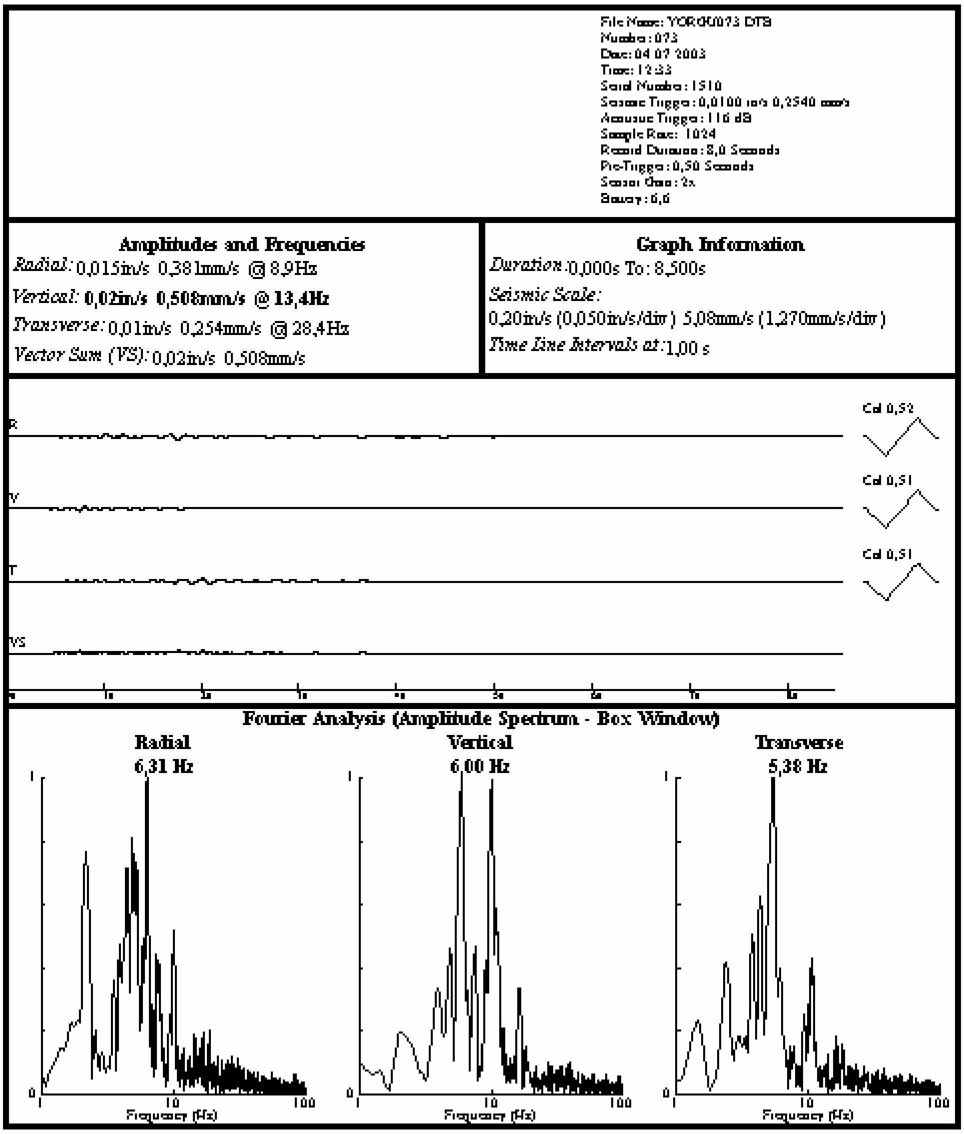
Appendix C.7 7th vibration record for initiation from Yörgüç village.



Appendix C.8 8th vibration record for initiation from Yörgüç village.



Appendix C.9 9th vibration record for initiation from Yörgüç village.



Appendix C.10 10th vibration record for initiation from Yörgüç village.