CAUTIOUS BLAST DESIGN AND MONITORING NEARBY A BURIED HIGH PRESSURE GAS PIPELINE

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ABSTRACT

CAUTIOUS BLAST DESIGN AND MONITORING NEARBY A BURIED HIGH PRESSURE GAS PIPELINE

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Blasting nearby a buried high pressure gas pipeline needs high precision in blast design and careful practice. Although precision of the design is important, simultaneous monitoring plays a crucial role on both controlling the ground vibrations and optimization of the future blasts. Though, there are some other means of measurements, monitoring the blast effects by using blasting seismographs is the most practical method among all the others. In this research, cautious blast design and measurements using blast seismographs were done. The aim of the research is to investigate the applicability of excavation by blasting nearby a buried high-pressure natural gas transmission pipeline and neighboring buildings by utilizing small scale controlled test blast results, to design blast patterns for production blasting for the foundation excavation of a water tank construction and measurement and control of the ground vibrations and airblasts that is caused by production blasting. Within the scope of this study each blast was designed separately and simultaneous monitoring of vibration and air blast were carried out. The distance of the pipeline to the blast area varies from 112.5 m to 200m and the pipeline was the closest structure and relatively the most sensitive one. Other structures around the blast area were the buildings of various kinds. Their distances to the blast area ranged from 650m to 1200m.

By utilizing the information obtained from the test blasts, attenuation characteristics of the ground between the pipeline and the blast area were determined and charging & distance table was formed accordingly. By using this table each blast was designed separately and simultaneous monitoring of vibration and air blast were carried out. Vibration levels caused by test and production blasts stayed within the safe limits stated in German DIN4150, Austrian and American standards for blasting nearby pipelines and no damage to the pipeline was reported. As a result of the assessments made, BOTAŞ's regulation for blasting nearby pipelines was found to be conservative when compared to the standards of other countries and it was concluded that there exists a need for a more reasonable regulation for blasting nearby pipelines in Turkey.

Keywords: High Pressure Gas Pipeline, Blasting, Cautious Blast Design, Foundation Excavation.

ÖZ

YÜKSEK BASINÇLI DOĞALGAZ BORUSU YAKININDA SAKINMALI PATLATMA TASARIMI VE İZLENMESİ

Dağaşan, Yasin
Yüksek Lisans, Maden Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Hasan Aydın Bilgin

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Yer altına gömülü yüksek basınçlı boru hatları yakınında yapılacak patlatmalar hassas patlatma tasarımı ve dikkatli bir uygulama gerektirmektedir. Tasarımda gösterilecek hassasiyetin yanı sıra, patlatmaların eş zamanlı izlenmesi hem patlatma kaynaklı titreşimlerin kontrol edilmesinde hem de sonraki yapılacak patlatmaların iyileştirilmesinde (optimizasyonunda) önem taşımaktadır. Patlatmanın etkilerinin ölçümünde başka yöntemler de olmasına rağmen, patlatma sismograflarının (sarsıntı ölçer) kullanımı en kullanışlı ve pratik ölçüm yöntemidir. Bu araştırmada sakınmalı patlatma tasarımı ve sarsıntı ölçerler ile ölçümler yapılmıştır. Bu tezin amacı yapılacak küçük ölçekli kontrollü patlatmalardan elde edilen bilgilerle yer altına gömülü yüksek basınçlı doğal gaz boru hattı ve binalar yakınında patlatmalı kazı yapılabilirliğini saptamak, su deposu temel kazısı için yapılacak olan üretim patlatmalarının tasarımı ve bu patlatmalardan kaynaklanacak yer titreşimleri ve hava şoku ölçümlerini yapmak ve kontrolünü sağlamaktır. Bu çalışma kapsamında, her üretim patlatması ayrı ayrı tasarlanmış, titreşimlerin ve hava şoklarının eş zamanlı izlemesi yapılmıştır. Patlatma alanının boru hattına olan uzaklığı 112,5 m ile 200 m arasında değişmektedir ve patlatmaya en yakın ve en hassas yapı diğerlerine kıyasla boru hattıdır. Patlatma alanı yakınında bulunan diğer yapılar çeşitli binalardır. Bu binaların patlatma alanına olan

uzaklıkları 650 m ve 1200 m arasında değişmektedir. Test patlatmalarından elde edilen bilgileri kullanarak boru hattı ve patlatma alanı arasındaki zeminin sönümlenme özellikleri belirlendi ve bu özelliklere göre patlayıcı miktarı & mesafe tabloları oluşturuldu. Bu tabloları kullanarak her üretim patlatması ayrı ayrı tasarlanıp eş zamanlı olarak izlenmesi yapılmıştır. Üretim ve test patlatmaları sonucunda oluşan titreşim değerleri Alman DIN4150, Avusturya ve Amerikan standartlarında boru hatları için belirtilen güvenli titreşim seviyeleri dâhilinde kalmıştır ve boru hattına herhangi bir zarar gelmemiştir. Yapılan değerlendirmeler sonucunda BOTAŞ Teknik Emniyet ve Çevre yönetmeliğinde boru hatları yakınında yapılan patlatmalar ile ilgili standartların diğer ülkelerdeki standartlara kıyasla tutucu olduğu tespit edilmiş ve Türkiye'de boru hatları yakınında yapılan patlatmalarda daha makul bir yönetmeliğe ihtiyaç duyulduğu kanısına varılmıştır.

Anahtar Kelimeler: Yüksek Basınçlı Boru Hattı, Patlatma, Sakınmalı Patlatma Tasarımı, Temel Kazısı.

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To My Family

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LIST OF SYMBOLS-ABBREVIATIONS

Symbol	Description
PPV	Peak particle velocity
MIC	Maximum instantaneous charge
HEL	Hugoniot elastic limit
BOCA	Building officials and code administration
c	Propagation velocity
ISEE	International Society of Explosives Engineers
DS	Distance from the seismic source
USBM	Unite States Bureau of Mines
FFT	Fast Fourier Transform
SD, D_s	Scaled Distance
k	Ground transmission coefficient
β	Site specific geological constant
D	True distance
Q	Co-operating charge(per delay)
DIN	Deutsches Institut für Normung (German Institute for Standardization)
AGA	American Gas Association
ANFO	Ammonium nitrate fuel oil
TRO	Temporary restraining order
MTRO	Modified temporary restraining order
SMYS	Specified minimum yield strength
MOAP	Maximum allowable operating pressure
J	Flexibility ratio
TS	Turkish Standards
ISO	International Organization for Standardization

CHAPTER 1

INTRODUCTION

1.1 General Remarks

Because of increase in earthwork rate in engineering, rock breakage has become an important issue. There are mainly two types of widely used rock excavation methods which are namely rock excavation by mechanical tools and blasting. Rock blasting in today's world is a powerful engineering tool and it is used in many areas including mining and civil engineering works.

Blasting is generally preferred when the rock is hard and the excavation by mechanical tools takes time and is not economically viable. Another reason why blasting is preferred is the fact that it has some advantages over mechanical rock breakage in some conditions. These advantages can be stated as blasting's being more economical, its ability to break hard rocks and its being relatively less time consuming.

Blasting can be defined as the process of breakage of some certain amount of rock within a predefined area by using explosives. The aim of this process is to break the rock into smaller or larger pieces according to the purpose of the blast. In this branch of engineering, precision and control is of utmost importance because of the high amount of energy released after the detonation of an explosive which is around 4MJ/kg according to Persson et al (1993) and the amount depends on type and chemistry of the explosive.

However, when an explosive is detonated not all of its energy is used for the purpose of rock fragmentation. Only a small portion of its energy is responsible for rock breakage, while the rest is waste, cannot do any constructive work and creates some environmental problems like air blast, ground vibrations and fly rock (Morhard, 1987). Due to the increase in earth work rate in engineering, the need for blasting operations very close to residential areas due to construction or mining works has increased as well. These works include foundation excavations, driving tunnels under residential areas, highway cuts and mostly quarries in terms of mining. Unless carefully practiced, these blasting operations may result in severe environmental problems like human annoyance, damage to the structures etc. Without knowing explosives and understanding what happens during and after the detonation of an explosive it is very hard to control the blasting operation and achieve the desired precision.

1.2 Statement of the Problem

General Directorate of State Hydraulic Works (DSİ in Turkish acronym) is the primary state agency of Turkey for Nations overall water resources planning, managing and execution. DSİ constructs a Drinking Water Transmission Line and Water Treatment Plant in Yozgat-Musabeyli, and the construction of a 15000 m^3 water tank within the scope of this project is to be done by İNCEKAYA İnşaat Sanayi ve Ticaret Ltd. Şti. . The contractor initially started the excavation by mechanical rock breakage tools. After spending three weeks on the excavation by hydraulic hammers, they noticed that the work was going too slow and it was too hard and costly to work with hydraulic hammers in the existing hard rock conditions. They looked for another solution and came up with the idea of blasting. However, the existence of a buried high pressure natural gas pipeline in the close proximity created the need for an investigation on the applicability of the excavation by blasting.

The pipeline belongs to the Petroleum Pipeline Corporation (BOTAŞ in Turkish acronym) and its distance to the excavation area varies between 112.5m to 200m. In 11^{th} paragraph of 7^{th} article of Technical Safety and Environmental Regulations of BOTAŞ, it is stated that the practice of work which involves the use of explosives should at least be 200m away from the pipeline. However, in 21^{st} Paragraph of the same article it also states that this distance can be shortened depending on the topographical and geological conditions.

Although the excavation area is in blast-restricted region of BOTAŞ, In the light of 21st paragraph, the application of use of explosives is not impossible. However, considering a high pressure gas pipeline, a careful investigation is needed. Besides, if it is found possible, cautious blast design and its simultaneous monitoring are to be carried out as well.

1.3 Objectives and Methodology of the Research

The main objective of this research is to investigate the applicability of blasting practice for the foundation excavation of a 15000 m^3 water tank construction close to a buried high pressure gas pipeline which belongs to BOTAŞ Company. If it is found safe to carry out blasting, the other objectives are the followings;

1-To keep the ground vibrations and air blasts on both the pipeline and the other surrounding structures within the safe limits.

2-To do the excavation within a pre-determined area.

3-To meet the particle size demand of the contractor.

In order to reach these objectives the following steps were performed;

1-The area where the water tank will be placed was visited and the area to be blasted and the ground conditions were investigated.

2-The type of the structures around the blast area were determined, their conditions were investigated and their distances to the blast area were measured.

3-Small scale test blasts were designed by using previously experienced vibration formulations in the same rock structure in different parts of Turkey and in some other parts of the World.

4-Test blasts were carried out by using safe amount of explosives and ground vibrations were monitored.

5- Site attenuation characteristics of the ground vibrations were determined by using statistical regression analysis. Site specific constants were determined.

6-Vibration levels obtained from the test blasts were compared with permitted limits given in Turkish for residential buildings and U.S, Austrian and German Regulations for Pipelines. These vibration levels were also compared with the permitted limits in Technical Safety and Environmental Regulations of the pipeline company as well. By using these information, risk assessment was carried out.

7-Maximum Instantaneous Charge (MIC) values for different distances to the pipeline were determined. Similarly, safe distances for certain amount of explosives were determined. These distances and explosives amounts were determined by considering not to exceed some certain Peak Particle Values (PPV).

8-For each production blast drilling, loading and initiation plans were done. Besides, each blasting operation was supervised and its simultaneous monitoring was carried out.

CHAPTER 2

LITERATURE SURVEY

2.1 Principles of Rock Blasting

2.1.1 Introduction

When an explosive is detonated its energy is partitioned. While some of its energy is useful for rock breakage the rest is waste and cannot do any constructive work (Konya & Walter, 1990). Energy partitioning of detonation of an explosive is illustrated in Figure 2.1.

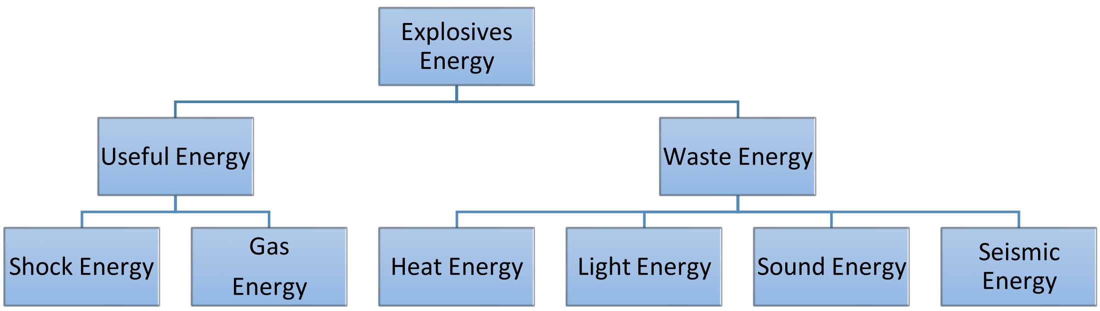


Figure 2.1 Energy partitioning of detonating explosives (Konya & Walter, 1990)

According to many researchers, the useful energies, namely gas and shock energy, are mainly considered to be responsible for rock breakage. Shock energy is estimated to approximately account for the 15% of the useful energy while gas pressure accounts for 85% of that (Konya & Walter, 1990). On the other hand, waste part of the energy resulting from the detonation does not do any constructive work and causes some environmental problems (Konya & Walter, 1990). The remaining energy is spent in terms of flyrock, deformation of the solid rock behind the shot, airblast and ground vibrations, etc.

According to Persson et al. (1993) the explosion energy of most explosives is order of 4MJ/kg. The resulting temperature of blasting is in the range of 2000-5000K and it produces a pressure ranging from 1 to 20 GPa. Considering the amount of energy released upon detonation and knowing that most of it is waste, it is very important to have a profound understanding of the breakage process in controlling the unwanted effects.

When an explosive is detonated to fragment the rock, the resulting energy is responsible for the followings (Hustrulid, 1999);

-Creating new fractures
-Extending old fractures
-Displacing parts of the rock mass relative to others (loosening)
-Moving the center of gravity of the blasted material forward (heave)
-Undesirable effects such as flyrock, ground vibration, air blast, noise and heat.

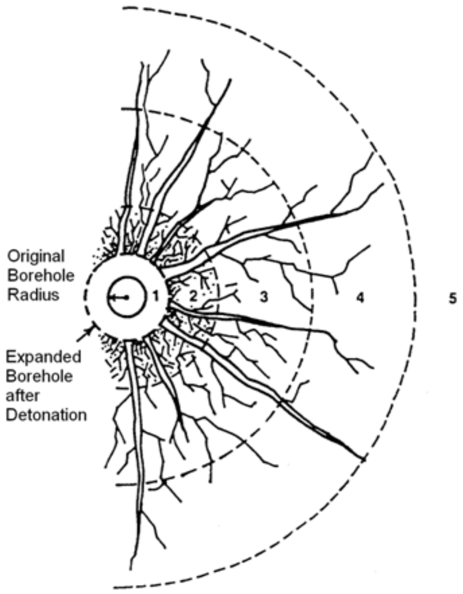
However, the distribution of the energy among these is related to some factors such as;

-The type of explosive
-The rock/rock mass
-The blast geometry

2.1.2 Blasting Mechanism and Damage Zones

When an explosive is initiated the ingredients of it, namely an oxidizer and a fuel-oil, turns into high pressure and temperature gases as a result of a rapid chemical reaction (Morhard, 1987). The sudden release of energy due to this very rapid chemical reaction causes compression waves in the explosives and surrounding rock material. These waves are called detonation or shock waves and they play an important role in fragmentation process (Persson et al., 1993). Due to the detonation pressure, a shock wave is produced and this causes compressive stress waves radiating outward from the borehole into the rock medium. As the stress waves propagate through the surrounding rock medium their amplitude decreases quickly with distance (Persson, Holmberg, & Lee, 1993). Soon their energy and amplitude reaches to a limit for plastic deformation called the Hugoniot Elastic Limit (HEL). From this limit the deformation is purely elastic and the stress waves propagate with the velocity of sound of the material (Persson et al., 1993).

The energy of the stress wave is at its maximum near borehole. Hence, the area next to the borehole is subjected to maximum damage and this zone is called as crushed zone (Morhard, 1987). In this zone explosive induced stresses exceed the dynamic strength of the rock by a factor of 40 to 400 and as a result an intense damage takes place in terms of crushing, shattering and pulverizing the borehole walls (Morhard, 1987). Next to the crushed zone there is a region called severely fractured zone. In this zone fracturing can range from severe crushing, through partial fracturing, to plastic deformation (Morhard, 1987). Zones 3 and 4 are called as elastic zones and tensile failure and crack extensions occur less due to the energy and amplitude decrease (Morhard, 1987). In zone 5, no more breakage occurs and the stress wave travels through the rock and vibrates the ground within its elastic limits causing ground vibrations. The distance of these zones from the borehole depends on the explosive type and the rock strength (Dowding & Aimone, 1992). According to experimental data, the crushed zone ranges from 2 to 4 borehole radii away from the center of the borehole while the fracture zone averages 20 borehole radii away and extends to 50 radii away (Dowding & Aimone, 1992). Damage zones around a blasthole is shown in Figure 2.2.



Legend

1. Crushed Zone
2. Severely Fractured Zone
3. Moderately Fractured Zone
4. Least Fractured Zone
5. Rock Undamaged (Seismic Zone)

Figure 2.2 Damage zones around a blasthole (Dowding & Aimone, 1992)

2.2 Blasting in Congested Areas and Cautious Blast Design

Blasting in populated areas creates big challenges to the blaster and blasting engineer in charge since this operation requires careful considerations both before and during the blasting operation. According to BOCA (Building Officials Code Administrators International) fire code of USA (BOCA, 1996), the definition of blasting in congested areas is as the following;

F-3009.10 Congested areas: "Where blasting is conducted in a congested area or in close proximity to a structure, railway or highway, or any other installation that will be affected, special precautions shall be taken to prevent damage and minimize ground vibrations, and air blast effects."

There are some controllable and uncontrollable variables affecting the success of the blast operations (Morhard, 1987). Controllable variables are the ones related to the design of the blast; like blasthole diameter, selected explosive types, geometry of the blast etc. Uncontrollable variables are mostly related to geology, like rock material strength, structural discontinuities etc.

Cautious blast design and monitoring close to a structure can be defined as carrying out the blasting operation within predefined area without causing any harm by modifying controllable variables according to uncontrollable ones. This blast design is needed where there exists a special structure or life of concern that may be damaged due to blasting operation. The structure of concern may include schools, hospitals, dams, pipelines, caves, etc.

2.3 Blast Induced Ground Vibrations

When an explosive is detonated in a blasthole, the rock immediately surrounding the hole is subjected to a high amount of deformation due to the intensity of the stress waves generated by the detonation. As the stress waves travel away from the blasthole their energy and amplitude decrease to a level which don't cause any plastic deformation and continue travelling through the rock causing elastic ground motions. The zone at which the stress waves only cause elastic deformations is called as seismic zone and as already mentioned before this zone starts 20-50 radii away from the borehole and may extend to a longer distances depending on the intensity of the blasting practice and the type of the rock structure at which the waves travel through. Ground vibration is one of the unwanted effects of blasting that doesn't serve for any constructive work and unless the blasting practices are carefully designed and implemented it may cause dramatic results and may cause damage to both property and life.

2.3.1 Characteristics of Ground Vibrations

2.3.1.1 Wave Parameters

The motion of the wave is described by its properties. Analyzing a simple harmonic wave motion is a good practice to show the wave parameters. A simple harmonic wave motion is as in equation 2.1 and the parameters of waves are given in Table 2.1

$$z = A\,Sin\,(\omega t) \qquad (2.1)$$

Where, z represents the displacement at any time t, measured from zero line and t stands for time in equation 2.1.

Table 2.1 Expression, definition and unit of some important parameters in dynamics (Bodare, 1996)

Parameter	**Expression**	**Unit**	**Definition**
A		m	Amplitude-displacement amplitude from the mean position
T	$2\pi/\omega$	s	Period-time for repetition, time for a full cycle
ω	$2\pi/T$	rad/s	Angular frequency
f	$1/T$, $\omega/2\pi$	s^{-1} or Hz	Frequency
c	$f\lambda$	m/s	Wave propagation velocity
v	$2\pi fA$	m/s	Particle Velocity
λ	c/f	m	Wavelength-distance between successive crests or troughs of a wave
ϕ		rad	Phase angle

2.3.1.2 Vibration Parameters

Vibration parameters refer to the characteristics of the motion of the ground by the passage of a seismic wave. When a seismic wave passes through a particle on the ground, the location of the particle is disturbed and undergoes a motion. The following parameters are used for vibration parameters (Figure 2.3):

Displacement: The distance of the particle from its original position when subjected to seismic wave.

Velocity: How fast the particle moves describes the *velocity* of the particle movement.

Acceleration: The rate of change of the velocity of the particle refers to *acceleration* of the particle motion.

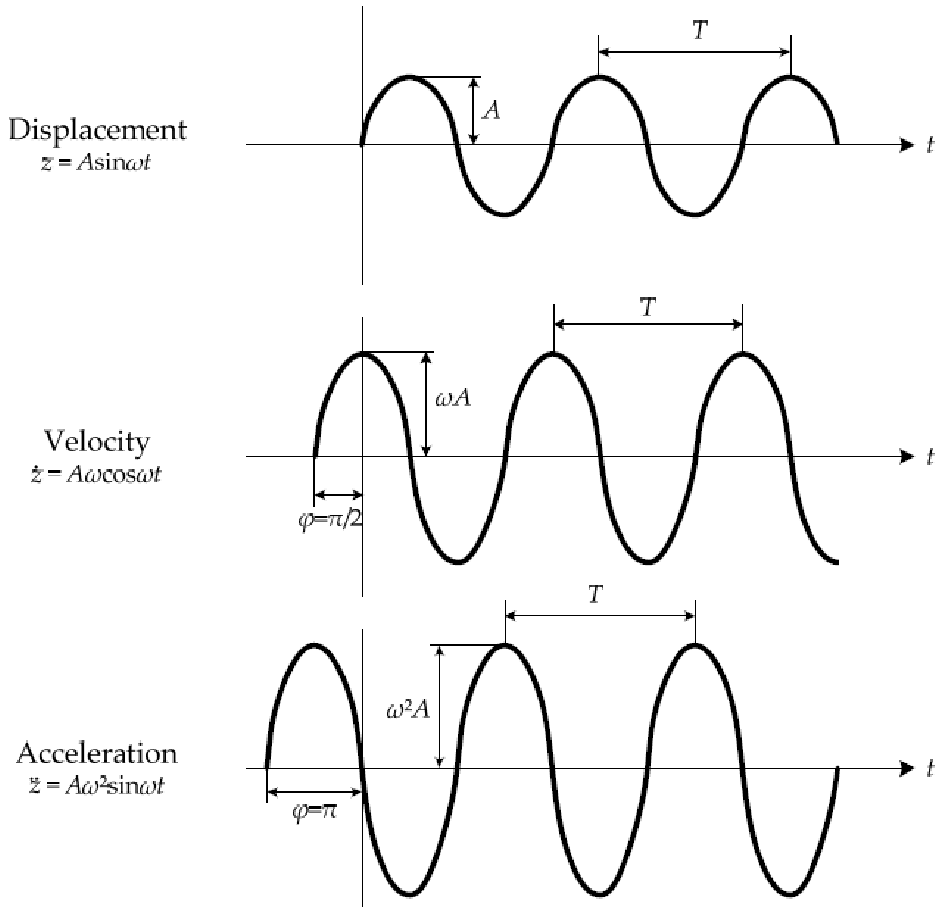


Figure 2.3 Commonly used vibration parameters used in dynamics, modified after Möller et al. (2000) and Holmberg et al. (1984).

2.3.1.3 Propagation Velocity

Wave propagation is called as the transportation of energy through a medium without causing any transportation of the particles (Decker, 2013). Waves propagating through a medium can be stated as to have two types of motions. One of these motions can be stated as the travelling speed of the waves which is called as *propagation velocity, c,* and the particles move with a *particle velocity, v* (Bodare, 1996)

Wave propagation velocity, c, means the speed of the seismic wave travelling through the ground medium. The particle velocity refers to the speed of the particle oscillating about an "at-rest" position. As an amplitude, the particle velocity is mostly used (Woods, 1997).

Propagation velocity is an important factor which gives an information about the properties of the ground and the other parameters which are depended on the ground properties indirectly. It is affected by jointing and weathering of rock masses and it gives an indirect information about the decay of the particle velocities and wavelengths (Dowding, 1985). Propagation velocity also helps us to calculate the strain and stresses on pipelines and buried structures. The formulas to calculate stresses and strains are introduced in Chapter 2.11.

Different type of wave motions have different propagation velocities. Type of wave motions are introduced in section 2.4.

2.4 Type of Wave Motions

Ground vibrations, contrary to harmonic waves, are complicated seismic events. The type of the waves can be categorized into two groups as body and surface waves. As their name imply body waves are transmitted through the body of the rock and soil, and surface waves are transmitted along a surface. Body waves propagate outward in a spherical manner until they are encountered with a boundary such as rock, soil or ground surface. When they encounter such intersection, shear and surface waves are produced.

2.4.1 Body Waves

There are two types of body waves which are Compressional (or P) and Shear (or S) waves.

2.4.1.1 P Waves

P-waves are also known as primary, compressional or longitudinal waves. They alternatingly cause compressions and dilations with particle movement in the direction of the movement and these are the fastest travelling waves through the ground. These waves change the volume but not shape of the materials (Jimeno et al., 1995). The motion of the particles within P wave can be considered to be as analogous to what happens when a long steel rod is struck on the end (Richards & Moore, 2005). The displacement characteristics of P waves are also shown in Figure 2.4.

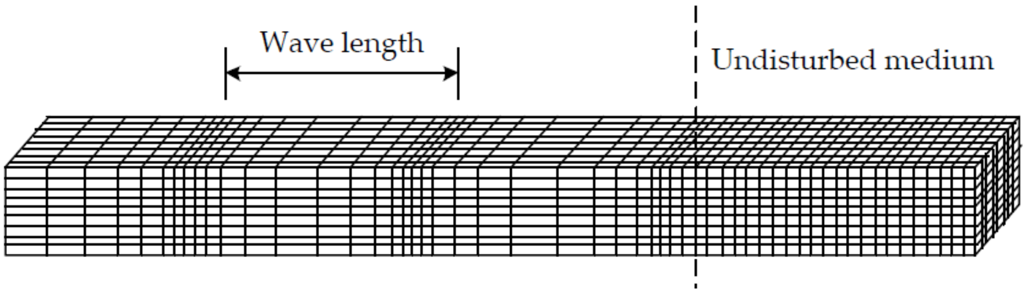


Figure 2.4 Displacement characteristics of P wave (Decker, 2013)

2.4.1.2 S Waves

S waves are called as shear, transverse or secondary waves. The particle movement takes place perpendicular to the direction of the wave propagation. These waves do not cause any volume change but rather cause shape change (Jimeno et al., 1995). The propagation velocity of S waves lies somewhere between that of P waves and Surface waves and is approximately 50-60% of the velocity of the P wave (Jimeno et al., 1995). The motion is illustrated in Figure 2.5.

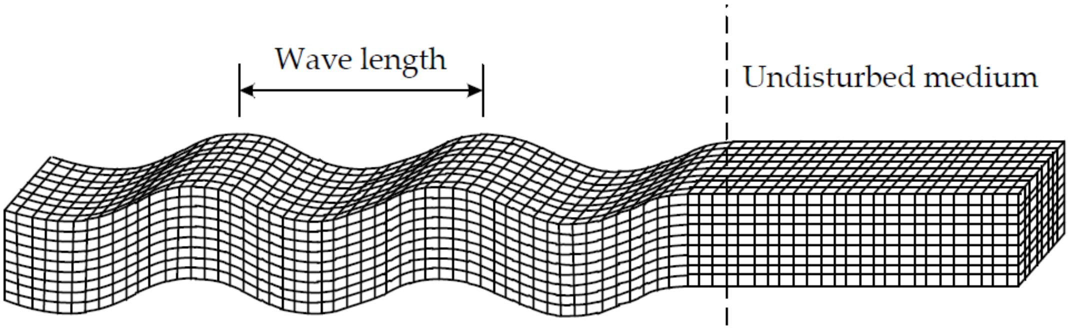


Figure 2.5 The motion of S waves (Decker, 2013)

2.4.2 Surface Waves

Surface waves are formed as a result of the body wave's interaction with the surface. They travel along the surface and their amplitude decreases rapidly with depth (Kramer, 1996). Although there are a number of surface waves only two are the most important. They are *Rayleigh* or R and *Love* waves.

2.4.2.1 Rayleigh Waves

Rayleigh or R wave is one of surface waves. Rayleigh waves can be seen as the combinations of P and vertical component of S waves (Decker, 2013). The motion takes place in the form of a retrograde ellipse. The motion of the wave is illustrated in Figure 2.6. Propagation speeds of Rayleigh waves are slower than that of body waves (Richards & Moore, 2005).

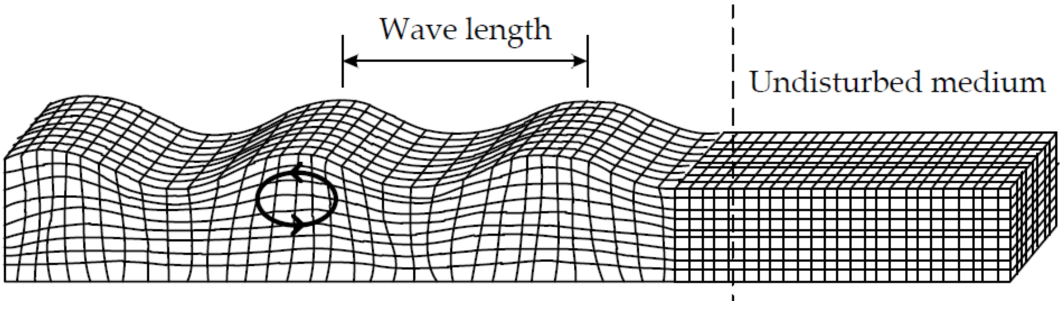


Figure 2.6 The motion of Rayleigh or R waves (Decker, 2013)

2.4.2.2 Love Waves.

Love waves are resulted from the interaction of horizontal component of the S waves and the P waves with the surface layer (Kramer, 1996). They are formed if only there exists a high velocity layer overlying a low velocity layer (Decker, 2013). Love waves have no vertical component, the movement takes place in horizontal direction (Whenham, 2011). The motion of Love Waves is illustrated in Figure 2.7.

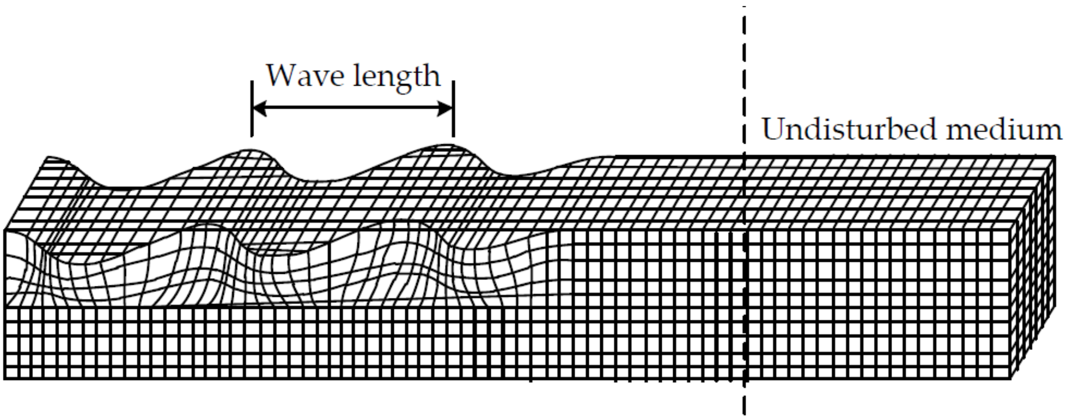


Figure 2.7 The motion of Love Waves (Decker, 2013)

2.5 Parameters Affecting Vibration Characteristics

Blast parameters can be classified into two as controllable and uncontrollable variables. Controllable variables are mostly related to design parameters and uncontrollable parameters mostly refer to the geology. The parameters which affect vibration characteristics are given in the following subsections.

2.5.1 Charge Weight per Delay

The intensity of the ground vibrations are affected by the amount of the explosive detonated per delay. When a delay interval is applied to a blasting group each hole is assigned with a time value at which it is supposed to blast. According to Jimeno et al. (1995) as long as the delay interval is sufficient not to cause any constructive interferences between the waves generated by different groups of blast holes, the largest charge per delay has the most direct influence on the intensity of the ground vibrations and these vibrations are not related to the total charge mass detonated in one shot. There exists such a relationship between the particle velocity and the amount of charge per delay. This relation is illustrated in Equation 2.2.

$$V \infty Q^{a} \tag{2.2}$$

Where;

V=Peak Particle Velocity

Q=Charge Amount

a=Coefficient

As the amount increases the expected vibration value increases as well.

2.5.2 Distance from Point of Blast

The distance from the point of blast also influences the intensity of the ground vibrations. As the distance increases the vibrations decrease according to the following law (Equation 2.3) (Jimeno et al., 1995):

$$V \infty \frac{1}{D^{b}} \tag{2.3}$$

Where;

V=Peak Particle Velocity

D=Distance

b=Coefficient

Apart from the intensity of the ground vibrations some changes take place in the characteristics of the ground waves. As the waves travel away from the point of blast, the higher frequencies are attenuated very fast and the earth can be considered as a low pass filter in this case. Thus, the vibrations have more energy in low frequency range (Jimeno et al., 1995).

2.5.3 Short Delay Blasting

Short delay blasting makes it possible to control and reduce the vibrations. This allows each hole to blast at different times. Hence, decreases the charge per delay initiated. Delay blasting can also help control the direction of throw which helps to shape the muckpile depending on the need (Richards & Moore, 2005).

2.5.4 Confinement

Confinement of the explosives also affect the intensity of the vibrations. When a charge is buried at a depth and there is no free face available, the energy is neither used for displacement nor the fragmentation of the rock. The energy is mostly used for crushing the borehole walls and most of the energy is spent in terms of seismic waves. (Hopler, 1998). On the other hand, lack of confinement has the opposite effect. If the charge is lightly confined at shallow depths or has small burden it has less work to do. Most of the energy is lost in terms of the venting of the gases into the atmosphere and less energy is transferred to the rock in terms of seismic waves (Hopler, 1998).

2.5.5 Physical Properties of Rock

Effect of the rock strength on the ground vibrations can also be analogous to the confinement effect. If the rock is stronger and difficult to break a great percentage of the energy is spent in terms of seismic waves (Hopler, 1998). Another effect is the homogeneity of the rock structure. The amount of jointing, discontinuity and fracturing affect the intensity of the ground vibrations. Wave travel efficiently at places where there is a rock structure which is a flat-lying, competent, horizontally layered sedimentary structure (Hopler, 1998).

2.5.6 Coupling

Coupling affects the energy transferred to the rock hence the amount of ground vibrations and fragmentation. The term coupling is described as the closeness between the outer wall of the explosive charge and the wall of the hole (Hustrulid, 1999). If a small-diameter explosive cartridge is placed in a large diameter hole and there exists a void between the explosive and the blasthole wall charges are said to be decoupled and less energy is transferred to the rock. The best coupling is seen in bulk explosives since they fill the entire hole and fully in contact with the hole walls (Hopler, 1998).

2.5.7 Spatial Distribution

Hopler (1998) makes reference to Oriard's (1970, 1992) works and states that spatial distribution refers to the geometric distribution of the explosives and the intensity and character of the vibrations are affected by this factor. This effect can be further explained by the following example: when a certain amount of explosive is distributed to a number of holes, the frequency and the intensity of the vibrations become different than that of obtained by blasting the same amount in one single hole. According to Hopler (1998) the frequencies will be higher when the charge is distributed.

2.5.8 Detonator Timing or Cap Scatter

Pyrotechnic detonators do not detonate precisely on their designed time and the actual firing times of detonators follow a normal distribution whose mean is near the rated time (Roy & Singh, 1999) (Konya & Walter, 1991). The time difference between a detonators' expected detonation time and its actual firing time is called as cap scatter (Lorsbach, 2000). The deviation from the nominal time may cause some problems in terms of both vibration and fragmentation. The problem for the ground vibration could be the overlap in timing which increases the intensity of the ground vibrations (Konya & Walter, 1991).

2.5.9 Type of Explosive

There exists a relation between the intensity of the ground vibrations and the type of the explosive used. The amount of the pressure generated in the blasthole shows variations depending on the type of the explosive. Since the blast induced stresses and strains are originated from the pressure exerted to blasthole walls by the explosive, the type of the explosive has an influence on the intensity of the vibrations (Jimeno et al., 1995).

2.5.10 Geometric Parameters of the Blast

Many of the geometric parameters of the blast have considerable effect on the intensity of the vibration. According to Jimeno et al. (1995) these parameters are the followings:

2.5.10.1 Drilling Diameter

Since the volume per meter of blasthole is depended on the drill diameter, it has an effect on the amount of the explosive that can be placed per meter of hole. If the diameter of the blasthole increases, the volume, hence the amount of explosive, per meter blasthole increases as well.

2.5.10.2 Bench Height

The fragmentation is affected by Height/Burden ratio. If this ratio is smaller than 2 there exists a poor fragmentation along with toe problems which increase confinement so the intensity of the ground vibration (Jimeno et al., 1995).

2.5.10.3 Burden and Spacing

The role of the burden and spacing can be considered as confinement effect. If there exists an excessive burden and spacing there forms a resistance to the displacement and fragmentation hence the explosive gases cannot vent out to the atmosphere. Due to this most of the energy is transformed into seismic energy and results in increase in ground vibrations. In the opposite case where there exists a considerably small burden and spacing, the gases vent out to the atmosphere earlier hence less energy is transferred into the seismic energy (Jimeno et al., 1995).

2.5.10.4 Subdrilling

Subdrilling is necessary in terms of having a desired elevation at the toe of a bench. Unnecessarily longer subdrillings may result in increase in the intensity of the ground vibrations since as the hole gets deeper and deeper, the confinement increases.

2.5.10.5 Stemming

Length of the stemming can be linked to the confinement as well. As the length of the stemming increases the confinement so the intensity of the ground vibrations increases too (Jimeno et al., 1995).

2.5.10.6 Blasthole Inclination

Blasthole inclination affects the energy concentration at the toe and may reduce the ground vibrations (Jimeno et al., 1995).

2.5.10.7 Decked Charges

Decked charging can reduce the intensity of the ground vibrations since the charge amount that normally is to be placed inside the hole is divided and initiated at different times. This decreases the amount of explosives detonated per delay, so the intensity of the ground vibrations.

2.5.10.8 Geometric Attenuation

Blast induced ground vibrations are complex combinations of different waves. Each of which has different wave motions and characteristics. For each type there exists different geometric absorption and attenuation which are proportional to:

-1/DS for body waves in an (semi)infinite medium.

-1/DS$^{0.5}$ for Rayleigh waves

-1/DS^{2} for body waves that travel along a free surface

Where DS stands for the distance from the seismic source (Jimeno et al., 1995).

2.5.10.9 Non Elastic Absorption

Rock masses are not composed of isotropic, elastic and homogenous structures. They rather show non-elastic or non-dispersive characteristics which cause loss of energy during wave transmission (Jimeno et al., 1995).

2.5.10.10 Interaction of elastic waves

Interaction of waves affect the intensity of the ground vibrations. The interaction of waves may result in higher or lower attenuation coefficients. The topographical and geological structures may cause reflection or concentration of waves at a specific point (Jimeno et al., 1995).

2.6 Analysis of Ground Vibration Measurements

2.6.1 Seismograph Record

Most of the seismographs used for the ground vibration measurement have 4 data acquisition channels. Three of these are used to measure the ground vibrations and the last one is used for acoustic measurements. There might not be an acoustic trace in a vibration record if it is not activated previously or the microphone cable is not plugged in.

When a seismograph record is analysed one can see four lines or traces which belong to vibration and acoustic records. Three of these traces belong to component of ground vibrations and indicate motion in three different orthogonal directions. One of these three is the record of the motion in vertical direction and the other two are the records of motion in horizontal direction. The vertical component measures the motion up and down and is designated as V. Movement in horizontal direction are specified as Longitudinal or Radial and Transverse. Longitudinal (L) or Radial(R) component represents the motion along a line jointing the vibration source and the recording point (Konya & Walter, 1991). Transverse component is the motion which takes place in perpendicular direction to the Longitudinal or Radial component. Components of ground vibrations are illustrated in Figure 2.8 and a typical seismograph record is shown in Figure 2.9.

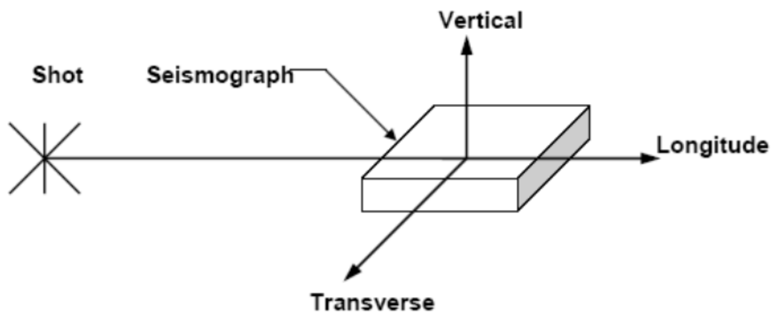


Figure 2.8 Components of ground vibrations (Dowding, 1985)

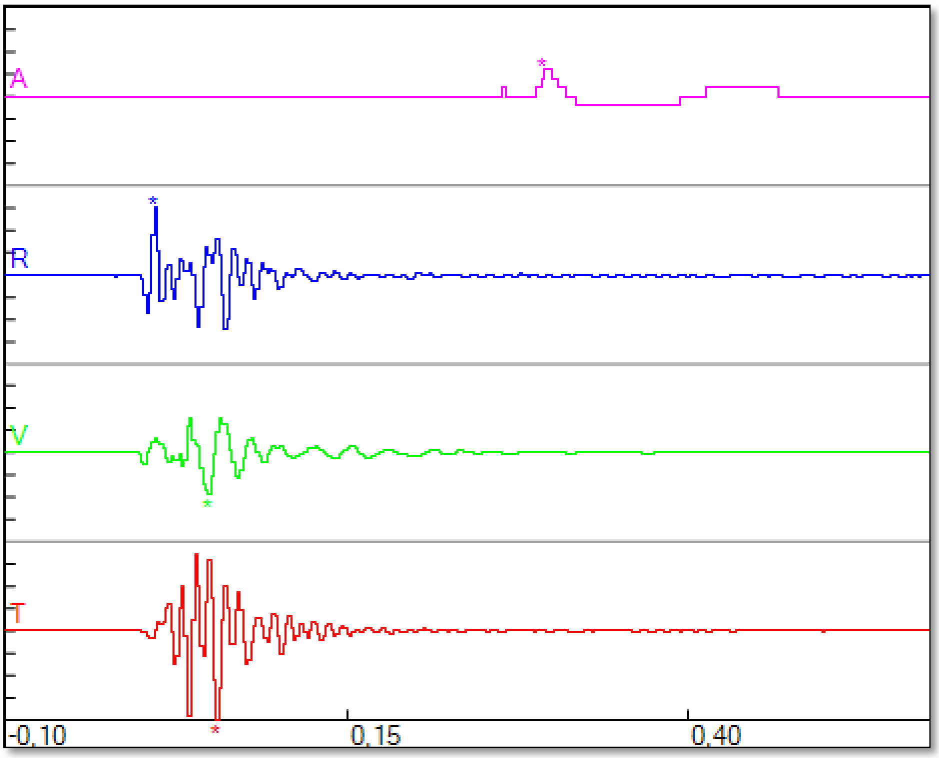


Figure 2.9 Typical seismograph record

2.6.2 Record Reading and Analysis

2.6.2.1 Peak Particle Velocity (PPV)

The maximum vibration value is found and determined by measuring the highest amplitude (Konya & Walter, 1991). As already mentioned before the ground motions occur in three dimensions and the motion in each dimension is recorded by the seismograph. Although the particle motion can be reported in terms of acceleration and displacement as well, the most commonly used parameter is the particle velocity and the maximum amplitude of it is called as *peak particle velocity* (PPV). The resultant of three vibration components defines a vector which is called as *vector sum* and the maximum value of this is called as *peak vector sum*. In reporting the ground vibrations only the maximum value of any three components should be taken into account instead of vector sum (Dowding, 1985).

2.6.2.2 Waveform Traces

A vibration history is a good diagnostic tool if it is comprehend well and may be useful in investigating the source of high vibration levels. A seismograph vibration record can tell so much more than the peak particle velocity or the intensity of the ground vibrations. It can also be helpful for the operator to control the vibration values as well as optimizing the blasting by the efficient use of the explosive to break the rock (Konya & Walter, 1991). A peak value existing in a vibration record might mean an energy release or confinement. By looking at the waveform traces one can easily understand where in the blast vibration peaks and can investigate the problem in order to optimize future blasts.

2.6.3 Frequency-Spectral Analysis

Since most of the damage criteria are frequency depended, the frequency values are as important as the intensity of vibrations. Frequency can be defined as the complete number of cycles per second and the unit is Hertz (Hz). The frequency of the ground waves generally do not show any harmonic motion and change as the wave propagate. This is mainly because of the interaction of different geologic media and structural interfaces and spreading out of the wave-train through dispersion, and/or absorption which is greater for higher velocities (Siskind et al., 1980). The frequency of ground waves are depended on the type and structure of the ground medium. For instance, hard rock blast vibrations tend to be shorter in duration and contain higher frequency motions compared to those of either quarry or coal mine blasts (Stagg & Engler, 1980).

The damage and frequency relation is mentioned in the report of USBM (Siskind, 1980) as the damage potentials for low-frequency blasts (<40 Hz) are significantly higher than those for high frequency (>40 Hz). So the lower the frequencies are, the higher the risk of damage.

2.6.3.1 Resonation and Amplification Factor

The damage criteria for the structures are related to the dominant frequencies as well as the intensity of the vibrations. According to the USBM report (Siskind, 1980), the natural frequency of the structures range from 4 to 12 Hz and when the frequency of the blast vibrations match that of structures', resonation is seen and the shaking and motions are amplified. Amplification effect on the vibrations is crucial since a vibration value which normally is not expected to cause any damage may cause damage due to this amplification during resonation.

Amplification can be 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 the amplitude of the structure to ground amplitude is called as amplification factor (Esen & Bilgin, 2001).

2.6.4 Methods Used to Measure Frequencies

There are basically two methods which are used to measure ground wave frequencies and they are *dominant frequency* and *principal frequency* methods (Yang, 2012).

2.6.4.1 Principal Frequency

This frequency is obtained from zero crossing time interval (Δt) at the peak vibration amplitude (Dowding, 2000). This time interval is illustrated in Figure 2.10 and the principal frequency is calculated as in the following equation (2.4):

$$f_{pr} = \frac{1}{2.\Delta t} \qquad (2.4)$$

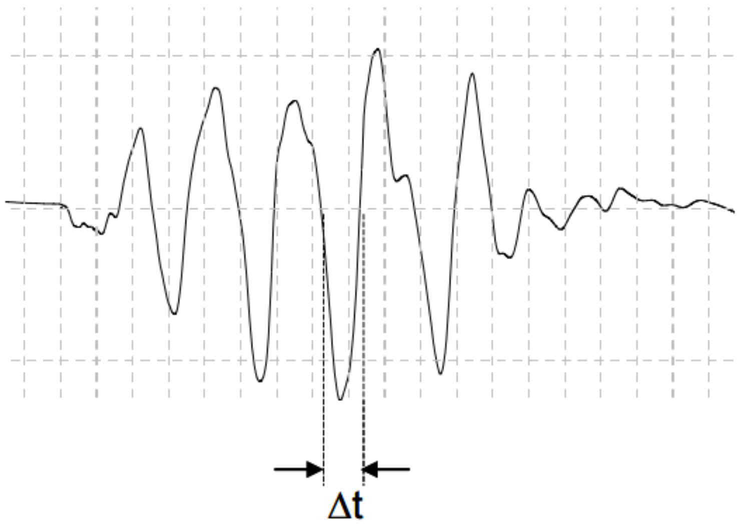


Figure 2.10 Zero-crossing time interval for principal frequency (Yang, 2012)

This method only gives a single frequency value at the peak velocity in three directions. Since it only considers the part where the vibration value peaks, problems arise when there exists a complex vibration time history and there exists strong low frequency values whose amplitude as not as high as the peak but their frequencies are close to the structures' natural frequencies and hence have more damage potential (Aimone-Martin et al., 2003).

2.6.4.2 Dominant Frequency

Dominant frequency analysis, in contrast to principal frequency analysis, not only gives a single value but shows full frequency spectrum for the vibration history. By using this method one can see the frequency values which are dominant throughout the vibration history. To decompose the waveforms into individual frequency components and calculate the complete frequency content of a ground vibration *Fast Fourier Transform* (FFT) technique can be used (Rholl, 1996). This technique transforms the vibration record which is in time domain into frequency domain as seen in Figure 2.11.

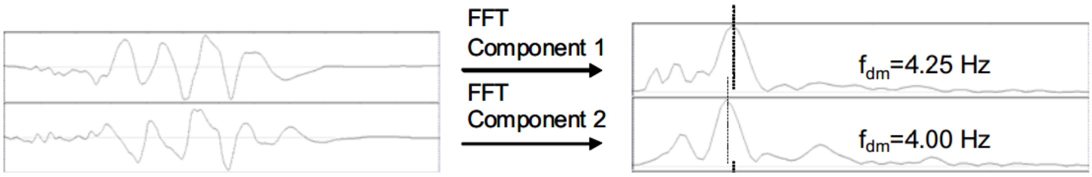


Figure 2.11 Dominant frequency of vibration components (Yang, 2012)

2.7 Assessment and Prediction of Ground Vibration Levels

2.7.1 Decay of Vibration Intensity and Variability of Vibration

Vibration is a measured quantity and affected by the parameters mentioned in previous chapters. The amplitude or the intensity of the waves decay in a regular manner with the distance and this makes them predictable with acceptable accuracy by changing the controllable variables. The decay is expressed with the term ***attenuation*** (Hopler, 1998). Even though carrying out blasting under the existence of exactly identical controllable and uncontrollable parameters, the vibration results show some scattering. This scatter approximates the normal distribution as a number of blast carried out and understanding the scatter is crucial in terms of the prediction and control of the vibrations (Konya & Walter, 1990).

2.7.2 Scaled Distance

Prediction of vibrations are carried out by plotting the recorded peak vibration values along with the distance from the source and the maximum amount of explosive blasted per delay. Consider a plot where X direction represents the distance and Y represents the particle velocity. In order to predict the result of a particle velocity for a certain amount of explosive in this type of plot, one has to draw a line for different charge weight. This may yield many lines and complicate the things. To avoid this complication the number of variables are combined. The distance and the explosive energy is combined to give a single variable called ***Scaled Distance.*** The most common way is to divide true distance by the square root of the maximum charge weight per delay (Dowding, 1985)

$$\mathrm{SD} = \mathrm{R}/\sqrt{Q} \tag{2.5}$$

Where,

SD is the scaled distance (m/$\sqrt{kg}$),

R is the absolute distance between the shot and the seismograph location and Q is the maximum charge per delay (kg).

2.7.3 Prediction of Ground Vibrations

A number of researchers have proposed different formulations for the prediction of the ground vibrations. The formula invented by United States Bureau of Mines, USBM, (Siskind, 1980) is widely used and the formula is:

$$V = k(\frac{D}{\sqrt{Q}})^{-\beta} \tag{2.6}$$

Where:

V =peak vibration (mm/s)

D=Absolute distance between the shot and the seismograph (m)

Q = instantaneous charge mass (kg)

K = site constant

β = site exponent

$\frac{D}{\sqrt{Q}}$ = scaled distance (square root)

By using this formula one can predict the vibration amplitude provided that the k and β constants are known. The determination of these site specific constants are mentioned in the following section.

2.7.4 Ground Calibration and Determination of Site Specific Properties

When entering a new area in which the vibration conditions and seismic transmission characteristics are unknown, the ground calibration should be made in order to understand the seismic characteristics of the rock. This can be done by firing a number of test shots and analysing the vibration records (Konya & Walter, 1990).

Charge weight and the distance are the parameters that affect vibration and they constitute controllable parameters. Other parameters which affect the intensity of vibration are mostly related to the geological conditions and interaction of these conditions has effect on the vibration transmission. Effect of the uncontrollable parameters can be calculated by doing a couple of test blasts and measuring the ground vibration. This method is called as ground or area calibration and all the factors affecting the ground vibration transmission are integrated in this formulation. (Konya & Walter, 1990).

This method is done by plotting the scaled distance values used in the test blasts and the corresponding measured PPV values on a log-log plot. The intercept and the slope of the best fit line constitute k and β values, respectively. A minimum number of 5 shots serve as a starting point with more data to be added as the number of any additional blasts are carried out (Konya & Walter, 1990).

The scaled distance formula embodies charge amount and the distance. In order to get more precise results in estimating the ground vibrations, the scaled distance should be changed so as to get a scattered scaled distance values and hence good correlation. This can either be done by changing the amount of explosives or the distance between the shot and the monitoring location. This is done in the design stage of the test blasts.

When the peak vibration values corresponding to different scaled distances are plotted, the k and β values are determined by drawing the best line which represents 50% confidence interval by least squares fit method. When the scatter of vibrations is considered, instead of using median line, using higher degree of confidence would be safer. In this study 95% (upper limit) confidence level and the corresponding k and β values are used to calculate the safe explosive amounts and distances.

2.7.5 Establishment of Estimation and Vibration Limit Tables

After determining the site specific constants, the prediction of the vibrations for different amount of explosives and distances is very straightforward by using Equation 2.6. It is a good practice to establish estimation tables for both distance and amount of explosives corresponding to specific vibration limit values. By the help of these tables the blaster can determine the amount of explosive to be blasted per delay not to exceed a certain vibration limit at a certain distance or determine the minimum distance for a certain amount of explosive to be detonated per delay.

2.8 Methods and Techniques to Reduce Ground Vibrations

Blast vibration control should be carefully practiced from the blast design step to load and tie operations. For this reason, all the people involving in the blasting operation should be qualified and experienced and be aware of the consequences of their actions.

Methods to reduce or control the ground vibrations are related to the controllable parameters of a blast and according to Jimeno et al., (1995) they are the followings:

-minimizing the explosive charge per delay,

-using smaller diameter to limit the explosive amount,

-shortening the length of the hole to limit the explosive amount,

-using deck charging to initiate less amount in different timing,

-reducing the number of blastholes having instantaneous detonators,

-choosing effective delay time between holes and rows which avoid wave interaction,

-setting the initiation direction so that the vibration propagates away from the structure to be protected,

-using adequate powder factor since as it is lowered the confinement may increase and may lead to increase in the intensity of the vibrations,

-designing the pattern so that bench height to burden ratio, H/B, is greater than 2.

-not using subdrills more than necessary not to cause increase in the confinement,

-controlling the explosive charge in the ground with solution cavities to eliminate pocket concentrations.

2.9 Damage Criteria for Rocks, Concrete and Buildings

2.9.1 Damage Criteria for Onset of Cracking in Concrete and Rocks

Dowding and Rozen (1978) investigated the conditions of a tunnel after earthquakes and stated that there is no risk of damage on the tunnels located in the rock provided that the peak particle velocity value (PPV) is below 200 mm/s. Another research was carried out by Kaslik et al. (2001) about investigating the effect of quarry blasts close to an old tunnel. In their research they state that they didn’t see any observable structural damage on the tunnel (concrete) even if the vibration values reached 263 mm/s. Siskind (2000) in his book, mentions about an investigation carried out by Sakurai and Kitamura (1977) about the structural response of 4 tunnels, 2 of which don’t have any support and the other two have concrete lining by measuring vibrations. Tunnels were located at a depth of 32 m and 61 m from the surface and the elevation difference between these tunnels was 24.4 m. The vibration value at which the onset of cracking of concrete was observed to be as 338 mm/s.

The reason why vibration values at which the concrete starts to crack is included in the literature survey is because of the possibility of the usage of any concrete within the construction process of both the pipeline and the pumping station and assessing the possibility of damage to the concrete in these structures.

Jimeno et al. (1995) states that the pouring concrete and excavation by blasting in some construction works are done simultaneously and careless blasting practices can cause damage to the concrete. Jimeno et al. (1995) making a reference to Oriard's (1984) work, have given the maximum limit particle velocity values in mm/s to not pose any damage to structural concrete and mass concrete by considering the hardening time.

According to Jimeno et al. (1995) the maximum allowable ground vibration levels depending on the hardening time are stated as follows: 1-3 days of hardening after pouring the concrete is 25mm/s, for 3-7 days of hardening 50 mm/s, for 7-10 days of hardening 125 mm/s, 10-28 days of hardening after pouring is 250 mm/s. Hence, it would be appropriate to stay below 250 mm/s vibration level for structural concrete.

Richard (1962) who investigates the effect of vibrations on structures built on rock structures, states that the vibrations do not cause any damage to structures above the ground, such as residential buildings, provided that the vibrations stay within 80 mm/s limit.

Hoek and Bray (1981) present a table which was formed by a reference work done by Langefors et al. In this table (Table 2.2) the vibration value corresponding to onset of cracking in rocks is stated to be as 635 mm/s and the rock is broken when the vibration values reach up to 2540 mm/s.

Table 2.2 Blast induced vibration level and type of damage (Hoek & Bray, 1981)

Particle Velocity (mm/s)	Damage Type
51	Limit below which risk of damage to structures, even old buildings, is very slight (less than 5%)
127	Minor damage, cracking of plaster, serious complaints
305	Rockfalls in unlined tunnels
635	Onset of cracking of rock
2540	Breakage of rock

Siskind (2000) states that the amplitude and the frequency of the vibrations are also depended on how deep the underground structure of concerns are from the surface. According to Siskind's vibration measurements in basement of the buildings at a shallow depths like 3m, it was proven that as the depth of the underground structure increases the intensity of the vibrations rapidly decreases.

Siskind (2000) mentions about vibration measurement and analysis carried out in Sweden by Langefors and Kihlström (1963). In his summary, Siskind (2000) states the vibration value that cause rockfalls in tunnels as 305 mm/s and onset of cracking as 600 mm/s.

2.9.2 Damage Criteria for Residential Buildings

The maximum allowable ground vibration levels that a building can be exposed have been set many years ago in other countries. In Turkey a new regulation was introduced in official gazette (no: 25862) in July 01, 2005 which was prepared by referencing a directive published by European Union (numbered: 2002/49/EC) in 25/6/2002 which is called as Evaluation and Management of Environmental Noise. This regulation was modified and published in official gazette dated 04.06.2010 and numbered 27601 which is entitled as Regulation on Assessment and Management of Environmental

Noise by keeping the existing vibration criterions safe and improving noise criteria. “Principles and Criteria for Environmental Vibrations” is indicated in 25th article of the regulation and the content of it is given below:

“**Environmental vibration criteria for structures**

ARTICLE 25- (1) principals to control the environmental vibrations which may be induced by various vibration sources are given below:

a) The vibration values measured on the ground of sensitive structures cannot exceed the ground vibration levels given in Table-6 in Appendix-VII.”

That **Table-6** located in Appendix-VII of Turkish Regulation is given below in Table 2.3:

Table 2.3 Maximum allowable ground vibration levels outside of the nearest very sensitive areas due to blasts done at mines or quarries in Turkish Regulation

Vibration Frequency (Hz)	**Maximum Allowable Vibration Value (Peak Value-mm/s)**
1	5
4-10	19
30-100	50

(Velocity limit lines rise from 5 mm/s to 19 mm/s in the frequency range of 1 Hz to 4 Hz, and from 19 mm/s to 50 mm/s in the frequency range 10 Hz to 30 Hz in log-log graph)”

When plotted logarithmically, the vibration values rise from 5 mm/s to 19 mm/s linearly when the frequency increases from 1 Hz to 4 Hz, between 10 Hz-30 Hz the vibration values rise from 19 mm/s to 50 mm/s again linearly. This situation is presented in Turkish regulation verbally. The maximum allowable vibration value corresponding to the dominant frequency values at which a rise seen were calculated and presented in Table 2.3 for different frequency values. A graphic logarithmically plotted is shown in Figure 2.12.

Values presented in Table 2.3 (Table-6) represent the maximum allowable vibration values depending on the dominant frequencies to avoid cosmetic damages that the plaster of the structures may be subjected to. In another saying, these values don't cause any damage on the walls, beams and columns of the houses. Turkish regulation doesn't mention about any allowable maximum vibration limit about human disturbance or annoyance. For this reason, the vibration standards for human disturbance of USA (ANSI, 1983) were referenced and the limit vibration value at which human starts to disturb is stated as 6.35 mm/s.

Table 2.4 Maximum allowable ground vibration limits for different seismic wave frequencies in Turkish Regulation.

Seismic Wave Frequency (Hz)	**Maximum Allowable Ground Vibration Limit (mm/s)**
1	5
1.50	6.95
2	9.35
2.50	11.60
3	13.86
3.50	16.40
4 – 10	19
12	24.10
14	26.00
16	29.85
18	32.35
20	35.05
25	42.90
30 – 100	50

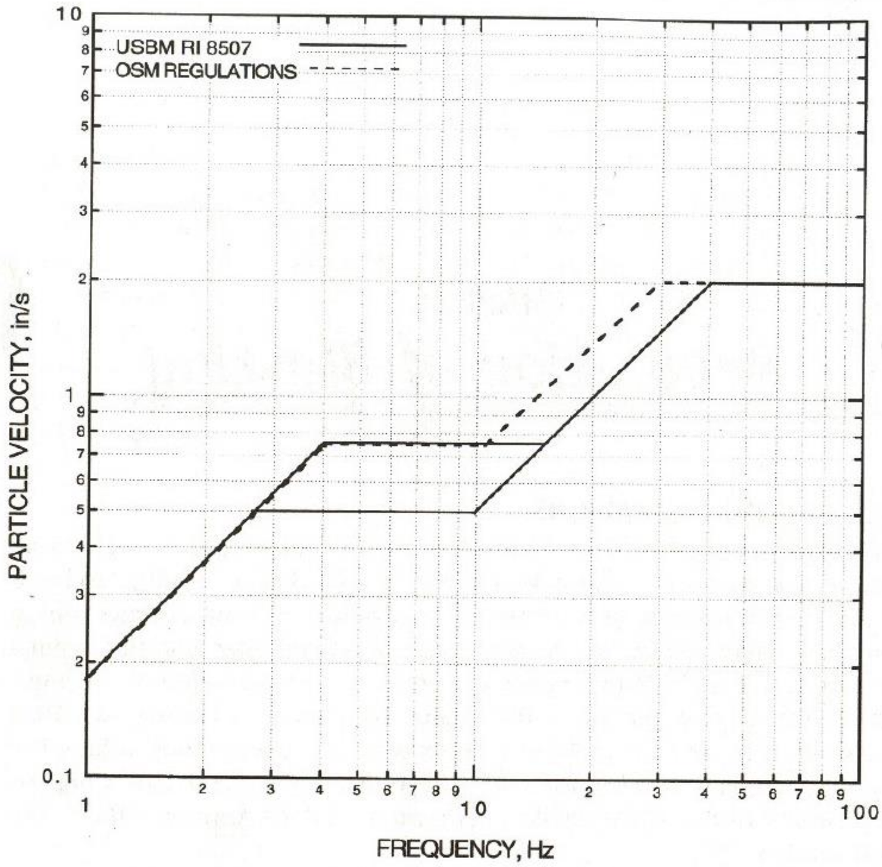


Figure 2.12 Safe level blasting vibration criteria for houses from USBM RI 8507 and the derivative version, the chart option from OSM Regulation (Siskind, 2000).

2.10 Damage Criteria for Pipelines

Pipelines are used for the transmission of fluids like petroleum, natural gas or water. Pipes used for the transmission of fluids are of steel welded, concrete, plastics (PVC) and metal flanged. Since the response of different types of pipes to seismic events from blasts or earthquakes is different irrespective of the type of the transmitted fluid, Institute of German Standards allows different level of ground vibrations to different types of pipes (Table 2.5, DIN 4150-3).

Table 2.5 Limit vibration levels stated in DIN 4150-3 for pipes.

Line	**Material of Pipe, connection**	**PPV on the pipe-mm/s**
1	Steel welded	100
2	Concrete, reinforced concrete, metal flanged	80
3	Plastics	50

In Turkey, although there is a regulation about residential type of structures, there exists no such regulations regarding transmission pipelines. For this reason, German DIN 4150-3 standard was used. In DIN 4150-3 standard, the maximum allowable ground vibration for steel welded pipes is 100 mm/s. Although the existing pipe has the thickness of 7.1 mm and is assessed to be capable of resisting 100 mm/s vibration according to DIN 4150-3 standard, a factor of safety value of 5 was applied to the limit value stated by German standard and the maximum allowable vibration value not to be exceeded on BOTAŞ pipeline was set to be as 20 mm/s.

Other than German Standards, some other standards from some other countries were considered as well. According to Austrian Gas Pipeline Company if there exists a blasting operation within 250 m distance to a pipeline, the pipeline company doesn't allow any blasting without conducting some test blasts and vibration monitoring by a competent person or company. If the distance is more than 250 m then there exists no blasting prohibition and blasting is allowed without even doing vibration prediction and monitoring. The type of the operation close to a pipeline in Austria and the corresponding distances which National Grid advice shall be sought are presented in Table 2.6.

Table 2.6 Prescribed distances within which the advice of Austrian National Grid shall be sought.

Activity	**Distance within which National Grid advice shall be sought**
Piling	15 m
Surface Mineral Extraction	100 m
Landfilling	100 m
Demolition	150 m
Blasting	250 m
Deep Mining	1000 m

Austrian standard states that the vibrations caused by blasting are limited to a maximum level of 75 mm/s and it is considered that this vibration level does not cause any damage to the pipelines. If the vibration values on the pipeline are predicted to exceed 50 mm/s, the ground vibrations should be monitored by the individual company undertaking the work and the results should be available to the responsible person at their request.

Dowding (1985) gives an example on a steel welded natural gas transmission pipeline. The diameter of the pipeline is 750 mm, the thickness is 7.5 mm, elastic modulus is $30x10^6$ psi and Poisson ratio of the pipe is 0.25. When this pipe is buried in a soil ground which has the modulus of elasticity of $10x10^3$ psi and Poisson ratio of 0.25 the flexibility ratio of the pipe to the ground is calculated to be as 42. He states that when the flexibility ratio is greater than 10, the deformations which take place on the pipe is equal to the deformations which take place in the ground.

According to the results of worst case experiments carried out by Dowding (1985), Westine and their friends for American Gas Association (AGA), it is possible to determine unit-deformations caused by blasting by using the particle velocity and the propagation velocity of the waves. In these experiments, they mention about the blasts carried out as close as 4 m to the existing steel welded pipe which has the diameter of

600 mm and 8 mm thickness. To understand the effect of blasting on pipelines strain gages were mounted onto the pipeline. In one of the experimental blasts they fired 6.8 kg ANFO at a distance of 4 m to the pipeline and the measured peak particle (PPV) value is reported to be as **1.14 m/s** which is equal to **1140 mm/s,** hoop deformations as 537 micron (0.537 mm) and longitudinal deformations as 786 micron (0.786 mm). No leakage was detected with these values.

Dowding (1985), evaluates the results of blasts carried out as safe and conservative for the following reasons:

-Blasts carried out very close to the pipeline and contrary to ordinary bench blasts in quarries or mines test blasts didn't have free face and this increases confinement.
-Although waves in soil have comparatively less propagation velocity, they have high deformation potential.

When these cases are compared with rock conditions instead of soil, less damage is expected by Dowding (1985) since in rock conditions most of the energy is spent in terms of breakage of the rock, fragmentation, heaving and due to presence of free face and the seismic waves lose their energy at rock-soil contact, the deformations stated are expected to be less in rock.

Another widely known blasting expert, Siskind (2000), in his book named as "Vibrations from Blasting" mentions about a research conducted by USBM in cooperation with AMAX Mining Company, who covered most of the expenses to investigate the effect of ground vibrations on pipelines. They state that the maximum amount of explosive per delay in their production blasts was 907 kg and blasts started at a distance of 520 m to the pipeline and got closer as close as 50 m. They stated that there were 5 pipes the diameter of whose were in between 152.4 mm and 508 mm and these pipes were subjected to the vibration values between 12.7 mm/s and 635 mm/s.

Siskind concluded that there has been no damage to the pipelines, 4 of which are steel and the other one is PVC, by continuously monitoring the pressures in the pipe and not detecting any pressure drop. Based on his experiences he proposed a conservative safe vibration level of 127 mm/s for natural gas pipelines.

Another researcher Oriard (1994) summarizes his experiences on blasting close to pipelines. Many of the works Oriard was involved in was excavating trenches, in which pipelines were to be placed, parallel and next to an existing pipeline. Oriard mentions about three situations that didn't documented with pipeline damage:

1) Excavation close to 4.27 m to the existing buried pipeline which created a vibration value of **1600 mm/s.**
2) Firing a 2133.6 m long trench blast instantaneously, without using any delay, resulted in vibration values ranging from **2540 mm/s** to **3810 mm/s**.
3) Blasting as close as 0.61 m and 0.91 m to existing buried pipelines resulted in vibration values ranging from **1270 mm/s** to **3810 mm/s.**

Oriard, based on his experiences, recommends three options for blasting close to buried pipelines which are buried in a trench overlying a sand:

a-) Not to exceed the maximum vibration limit of 304.8 mm/s

b-) In case of blasting within 6 m to the existing pipeline, blasting more than one hole at a time should be avoided

c-) Not to exceed the blasthole diameter of 2 $^{1}/_{2}$ inches in blasting operations very close to the pipeline.

The maximum allowable vibration values of different countries in order not to cause any kind of damage to the pipelines are summarized below in Table 2.7.

Table 2.7 Maximum allowable vibration values of different countries not to cause any damage to pipelines

Name of the Country	**Name of the Expert or Type of the Pipe**	**Maximum Allowable Vibration Value on the pipeline (mm/s)**
United States of America	Oriard	305
	Siskind	127
German Federal Republic	Steel Welded	100
	Concrete or Reinforced Concrete Pipe	80
	Plastic	50
Austria	Not given a Specific Type	75

2.10.1 Other Blasting Examples Nearby Natural Gas Pipelines

There are three case studies presented in this section. The last study is about the response of a high pressure gas pipeline to coal mine blasts.

Example Investigation 1: (Gangster, 2011)

The first one is about OMV Company which is the biggest supplier of oil and gas in Austria and the company transports gas through the West Austria Gasline for domestic consumption. After signing a new contract with Russian Gazexport to guarantee the gas supply until 2027 they needed a capacity increase from 7 billion m^3 to 11 billion m^3 per year through pipelines. For this reason, the company planned to build a new gas pipeline parallel to and 9 m from the existing one since the capacity of the existing pipe was fully utilized.

The geology is shaped by hard rocks like granites and gneiss and there needed blasting operations for the excavation. Since blasts are planned to be done very close to the pipeline all the blast should be done by controlled blasting techniques.

Austrian National Grid states that no blasting is allowed within 250 m of the pipeline without assessment of the vibration levels at the pipeline. The vibration values should strictly be below 75 mm/s and if the vibrations are predicted to be above 50 mm/s the vibrations should be monitored and reported to the responsible person at the pipeline company upon their request.

The authorities and the engineers had two questions. The first one was the fact that there was no evidence on the quality of the welding seams of the existing pipe. Welding was more than 35 years old and there was no accurate documentation about their quality. The second question they had was the uncertainty about the bedding layer that normally has to be 30 cm sand.

OMV Company got technical support and consultancy from experts. The maximum amount of explosive per delay was chosen to be as 1.1 kg for test blasts. Two different equations were used and compared in order to predict the vibration levels at 9 meters distance when 1.1 kg was detonated. Calculated vibration value by using the first equation was 36.58 mm/s, by using the second equation it was 38.00 mm/s. To be on the safe side, instead of using 1.1 kg, 0.833 kg was chosen to be as the starting point. It was decided that if the vibration values were found to be lower than the expected by using the indicated amount of explosive, the amount was going to be increased. The results of test blasts are presented in Table 2.8.

Table 2.8 Overview of the test blast results done in Austria (Ganster, 2011)

Test blast No.	**Charge weight per delay kg (lb)**	**Distance to the pipeline m (ft)**	**PPV on Pipe mm/s (in./s)**	**PPV on Surface mm/s (in./s)**
1	0.833 (1.84)	9 (29.52)	14.99 (0.59)	23.11 (0.91)
2	1.40 (3.08)	9 (29.52)	29.21 (1.15)	36.45 (1.44)
3	2.1 (4.63)	9 (29.52)	34.26 (1.35)	39.18 (1.54)

Since the vibration results of the first blast was lower than the expected values, the charge amount was increased in second and third blasts. Although only one hole was blasted in the first trial, the number of holes in one shot was increased up to 12 for the second and 21 for the third blast. PPV measured on the surface shows that the values are significantly higher when compared to the measured PPV values on the pipeline.

The results from the test blasts have been used by plotting the vibration values corresponding to each scaled distance value on a logarithmic plot to do regression analysis to determine site specific constants by using the equation of the 95% confidence line. The prediction equation to be used in the production blasts was found as $PPV=1356 \times (D/\sqrt{Q})^{-1.82}$. By using this formula and selecting the distance value as 9 m, maximum amount of explosive to be blasted so as not to exceed 50 mm/s level is calculated as 2.15 kg and not to exceed 75 mm/s the amount is calculated as 3.36 kg. For the excavation to be economical 300 m of trenching per day was necessary. The depth of the trench was 3.20, width was 1.60 m and the drill diameter was 41 mm. The combination of 1/3 gelatinous explosives (Dynamite) and 2/3 emulsion explosives with a diameter of 35 mm each was used.

The initial design had a pattern of 0.8 m x 0.8 m, 10 cm of subdrill and a powder factor of 1.30 kg/m^3. Having analyzed the performance of the initial blasts and concluded that the particle size was smaller than the necessary, they changed their pattern to 1.1 m by 1.2 m. This increase in the burden and spacing resulted in decrease in powder factor to 0.79 kg/m^3 value.

In trench blasting operations, dual detonators having 500 ms in-hole and 25 ms surface delay were used. Production blasts were fired at a distance of 9 m to the pipeline and the charge amount was 2.6 kg/delay. The biggest shot was consisted of 491 holes and 985 kg of explosive was used in total. 47 blasts were carried out in 63 days and only 4 reached to the alarm level which was 50 mm/s. The maximum ground vibration was reported to be as 54.61 mm/s. No damage to the pipeline was reported. The excavated trench at a distance of 9 m from the existing one is shown in Figure 2.13.

Figure 4. Construction site.

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Figure 2.13 Trench which was excavated by blasting at a distance of 9 m from the existing one in Austria (Ganster, 2011).

<u>Example Investigation 2:</u> (Wheeler, 2012)

The topic of the other example is about an issue between Whitaker Companies, Inc. (WCI) and Mid-America Pipeline Company, LLC (MAPL) about pertaining to blasting near one of underground high pressure gas pipe of the pipeline company. The pipeline company sought and received an ex parte Temporary Restraining Order (TRO) against Whitaker. With the help of the encouragement of the judge, the parties entered into discussions and as a result they came to an agreement and a modified TRO (MTRO) was issued in May 2008 with the following stipulations:

1-No blasting within 457 m without notifying MAPL in advance.

2-No blasting within 305 meters without advance notification and seismograph monitoring.

3-No blasting within 152 meters without 5 days notification and seismograph monitoring.

MAPL demands the vibration value that shouldn't be exceeded on the pipeline to be as 51 mm/s and demands that no blasting take place within 26 meters of the pipeline. Whitaker finds 51 mm/s as strictly conservative and hires experts and consultants to investigate the situation. MAPL also hires experts and consultants too.

Consultants of Whitaker Company prepared test blast designs and vibration measurement plans. As a first approach, the experts used a formula stated in page 601 of "Blasters Handbook" published by ISEE which is $PPV=242x\ (D_s)^{-1.6}$ for metric and $PPV=160\ (D_s)^{-1.6}$ for imperial to calculate the safe amount of explosive per delay.

Consultancy experts reviewed the results of the research conducted by American Gas Association (AGA). AGA conducted the research by blasting charge weights from 14 grams to 6.8 kg at standoff distances of 0.23 to 6.9 meters in point source experiments. The line source experiments involved 14 grams to 180 grams at standoff distances of 0.46 meters and 4.6 meters respectively. The grid source experiments had charge weights ranging from 23 grams to 140 grams. Since the charge weights were considered to be relatively low and not to be representative to typical quarry blasting or even most construction blasting, the results were not used by the experts.

WCI consultant experts, as a second approach, determined the maximum allowable vibration limit that is caused by blasting on the pipeline as 127 mm/s as indicated in the report of United States of Bureau of Mines (USBM) RI 9523. Besides, by considering the topographical conditions, they concluded that it was possible to do blasting by complying with the limit value of 127 mm/s at a distance within 30.5 meters. After the discussions, the pipeline company which previously prohibited the vibration values to be above 51 mm/s allowed the vibration values up to 102 mm/s and unless the opposite was proven by the measurements the company stated that the vibration values were not allowed to exceed 102 mm/s.

According to the second modified TRO:

a-) the vibration limit was set to be as 102 mm/s and if this limit is exceeded adjustments are made to bring the PPV within the limit,
b-) the parties agree to meet again 60 days later and to decide whether to continue, increase or decrease the 102 mm/s
c-) Whitaker Company should provide all blast seismographs report to MAPL
d-) Whitaker should notify the pipeline company at least 5 days before each blast planned
e-) Whitaker and MAPL shall work together in good faith to communicate concerning the development of the quarry pit.

Before the next meeting there were many blasts including the one which was detonated at 11.9 m with a charge per delay of 9.9 kg. The vibration value resulted from this blast was 138 mm/s on the pipeline and *no damage on the pipeline was reported* from this. After collecting a number of data, Mid-American Pipe Line (MAPL) accepted 127 mm/s as a maximum safe vibration level and the quarry planned its blast designs by considering this vibration value.

76 blasting and vibration measurements done in total. Scaled distance in these blasts varied from 3.8 $m/kg^{1/2}$ to 91 $m/kg^{1/2}$ Lowest vibration recorded from these blasts was 3.05 mm/s and the highest vibration value was 138 mm/s. The shortest physical distance from the pipeline and the blast was 11.9. It is stated that the scaled distance should be greater than 9.1 $m/kg^{1/2}$ not to exceed the vibration value of 127 mm/s.

The final order between the WCI and MAPL companies contains the following:

1-It has been accepted that for blasting operations 61 meters away from the pipeline, there is no need submit any pre-blast design or notification.

2-Consultant Experts of MAPL and WCI companies agreed on development and evaluation of pre-blast designs that take place within 61 meters to the pipeline. The accepted scaled distance was 5.7 m/kg$^{1/2}$ any adjustment in this value might be done with agreement of MAPL and Whitaker.

3-Consultant experts from both company agreed on the date of the Pre-Blast Design review and notice of blast date as 5 days before each blast.

4- If a blast must be postponed due to some reasons, the pipeline company should be notified about this and the new blast date should be provided as soon as possible.

5-Whiteaker Company should take seismic measurements for each blast that takes within 61 meters and Post-Blast reports including seismic measurements should be provided to MAPL as soon as possible.

6-If the vibration values exceed 127 mm/s within 61 m all the blast shall be ceased until MAPL completes the inspection of the pipeline.

Example Investigation 3: (Aimone-Martin et al., 2003)

The response of 11 coal mine blast vibrations to a high-pressure natural gas pipeline was investigated by The Pittsburg & Midway Coal Mining Company (P&M), El Paso Natural Gas Company (EPNG), and New Mexico Tech (NMIMT). The X-52 grade steel pipeline had an outside diameter of 0.762 m and the pressure inside the pipeline was 5.83 MPa and it was buried 2.13 m below the surface. They did velocity measurements on the pipeline, ground adjacent to pipeline and at the ground surface directly above the pipeline. The properties of the pipeline are given in Table 2.9.

Table 2.9 Properties of the X-52 Pipeline (Aimone-Martin et al., 2003)

Wall Thickness:	8.61 mm
Specified Minimum Yield Strength(SMYS):	358.6 MPa
Tensile Strength:	448 MPa
Elastic Modulus:	203 GPa
Poisson Ratio:	0.292
Maximum Allowable Operating Pressure (MOAP):	5.83 MPa

Aimone-Martin et al. (2003) state that the pipeline company had a policy to restrict the ground motions to 101.6 mm/s or less at frequencies above 25 Hz. These values were considered to be applied for the measurements done in the ground surface above the pipeline. Furthermore, the limit of 25.4 mm/s was imposed by the pipeline company in cases where the standoff distance is less than 38.1 m.

A section of the pipeline was exposed to install instruments on the pipeline and adjacent to the pipeline (Figure 2.14) to measure vibrations.

Figure 2.14 The pipeline is exposed to place instruments (Aimone-Martin et al., 2003)

To measure the effect of blast vibrations, they placed two geophones and four single component transducers to measure strains and ground vibrations. A triaxial geophone was buried next to the pipeline centerline at a distance of 15.24 cm from the pipeline and oriented toward blasting. A second geophone was buried at a depth of 15.24 cm from the ground surface above the pipeline. Four, single component velocity transducers were placed by gluing to the pipeline to record velocities in R (Radial), T (Transverse) and V (vertical) directions. The V and T transducers were placed on top of the pipeline and the two radial components were placed at the pipeline sides in a way that one of them is oriented toward the blast (R1) and the other is oriented away from the blast (R2). Location of the single component transducers are shown in Figure 2.15.

Blasting operations took place at distances varying from 80.47 m to 1133.86 m. ANFO or Blends (70%-30% or 60%-40% ANFO-Emulsion) was used in the blasts and the diameter of the blastholes were 250.8 mm and the length of the holes ranged from 6.71 m to 16.7 m. Two different blast schemes were used to measure the vibration effects of confinement. One series was timed to provide a high degree of confinement while the second series provided a high degree of relief.

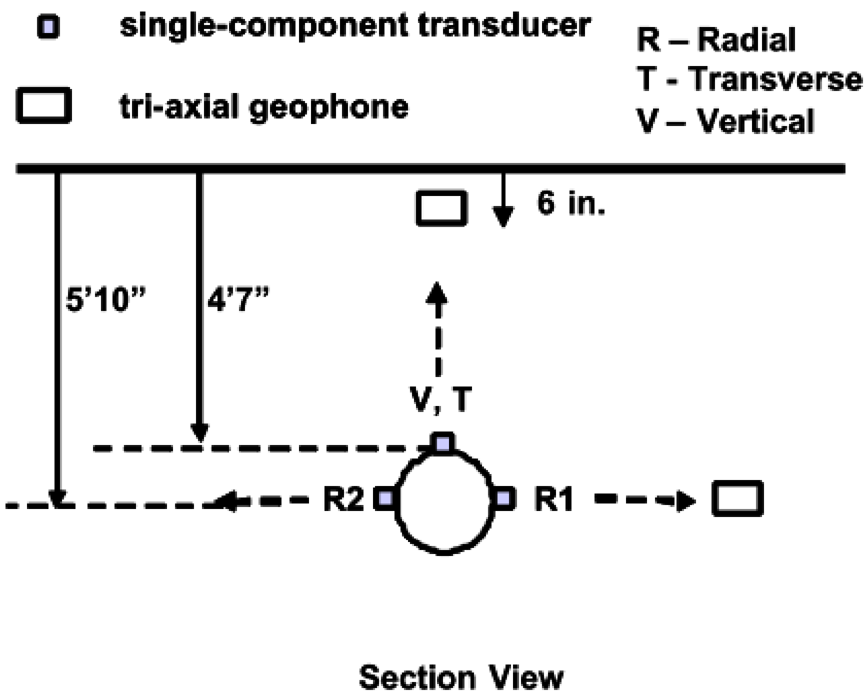


Figure 2.15 Location of single component transducers (Aimone-Martin et al., 2003)

The vibration levels measured and average FFT frequencies recorded in different locations and different components were as follows (Table 2.10).

Table 2.10 Vibration levels measured in different locations and in different components (Aimone-Martin et al., 2003)

Location	**Velocity**	**Component**	**FFT Frequency(Hz)**
Ground Surface	151.6 mm/s	V	16.9
Buried Next to Pipeline	106.7 mm/s	R1	16.7
On Pipeline	111.8 mm/s	R1,toward the blast	14.5

Average ratio of velocities measured at various locations were computed by comparing the ground surface velocity with the velocities measured at depth(adjacent to the pipeline), ground surface velocity with pipeline motions, and the pipeline motions with the velocities in the soil adjacent to the pipeline. The results are shown in Table 2.11.

Table 2.11 Average ratios of velocities measured at various locations (Aimone-Martin et al., 2003)

Component	Ground Surface to Buried	Buried to Pipeline	Ground Surface to Pipeline	
			High Confinement	High Relief
Radial	1.43	0.90	1.3	1.1
Vertical	2.17	0.86	2.0	1.3
Transverse	1.80	1.51	3.0	1.7

As it can be seen from the vibration levels and the average rations of velocities, the amplitude of ground surface velocity was higher than the amplitude in the ground at depth. However, the pipeline velocities were slightly higher than the velocities in the soil adjacent to the pipeline in the R and V directions. It is obvious that the pipeline moved with the soil in these directions. However in T direction (along the pipeline axis), the motions were constrained by the geometry.

The vibration levels data of confined blast was scattered which shows a correlation coefficient (R^2) value ranging from 0.44 to 0.54 whereas the vibration measurement data obtained from high relief show less scatter and results in average R^2 value of 0.985.

As expected, the ground vibrations are relatively higher in the ground surface compared to the same point at depth. This means that if exposure of the pipe is not possible, stress computations based on the velocity measurements taken on the ground surface are rather safe since the values are higher than that of next to the buried pipeline and on the pipeline as well.

When calculating the strains on the pipeline Aimone-Martin et al. (2003) takes in to consideration of the ratios of 1.1 and 1.7 which are given in the Table 2.11 for the calculations of bending and longitudinal strains respectively. This is done by using the formulas which are used for the estimation of strains (2.8, 2.9 and 2.10) and dividing them by the ratios obtained.

They conclude that based on the measurements taken during production blasting, the maximum circumferential stresses that the pipeline was subjected to was 10.9% of the maximum hoop stress resulting from MOAP for the X-52 pipeline. And the stress is 42.5 % of the recommended maximum pressure generated from transient loads.

2.11 Pipeline Response

2.11.1 Allowable Stresses in Pipelines

Criteria for stresses imposed in transmission pipelines are generally specified in terms of a maximum allowable stress and this stress is based on circumferential or hoop stress. Aimone-Martin et al. (2003) present the Equation (2.7) to calculate the hoop stress produced by internal pressurization based on thin-walled cylinder equation.

$$\sigma_c = \frac{PD}{2t} \tag{2.7}$$

Where:
P=Maximum allowable operation pressure (MOAP)
D=Pipe inside diameter
t=Wall thickness

For transient loads imposed on pipelines, taking the 18% of the SMYS as a limit is a general industry practice (Siskind, 1994). This transient loads include environmental and transient loads such as traffic over a pipeline beneath a highway.

Other criteria which are used by the transmission industry is presented by Enron (1988) ,who specifies two different allowable stresses for different types of welding, and are judged to be highly restrictive (Aimone-Martin et al., 2003). The Enron standard states that the maximum allowable blast induced hoop stress for electrically welded pipes is

6.9 MPa and 3.45 MPa for gas-welded or mechanically jointed steel pipes.

2.11.2 Procedures to Estimate Strains and Stresses in Pipeline from Velocity Measurements

It is stated that it is possible to record strains on the pipeline if gages are mounted on it and if the elastic properties of the pipeline are known the stresses induced can be computed as well (Aimone-Martin et al., 2003). However, it might not always be possible to expose the pipeline hence measure the strains directly. In these kind of situations the strains can be estimated indirectly from velocity measurements.

Strains can be estimated by using the following equations:

$$\varepsilon_b = \frac{Vr2\pi f}{{C_s}^2} \qquad (2.8)$$

$$\varepsilon_l = \frac{V}{C_l} \qquad (2.9)$$

$$\gamma = \frac{V}{C_s} \sim \varepsilon_c \qquad (2.10)$$

Where:

ε_b=bending strain

ε_l=longitudinal strain

V=maximum velocity measured on the pipeline.

f=frequency of the velocity time history at the peak V.

C_s=shear wave velocity

C_l=compressional wave velocity

r=radius of the pipeline

V in equations 2.8 and 2.9 represents R and T respectively when the seismograph is directed towards the blast and the incoming ground vibrations are perpendicular to the pipeline.

The hoop strains in pipeline resulting from blasting close to surface coal mine blasts can be calculated by the equation presented by Siskind, et al. (1994). The equation is as the following (2.11).

$$\varepsilon_c = 24.1 \text{ R} \qquad (2.11)$$

Where R(mm/s) is the radial component of the surface ground motions in the ground. This 24.1 factor represents the worst case estimate for ε_c.

The above analysis becomes valid when the pipeline is considered to be sufficiently flexible and deforms with the ground surrounding the pipe. The flexibility ratio, J, given by Dowding (1985) is as follows (Equation 2.12).

$$\text{J}=\frac{E/_{1+v}}{\left[{}^{6E_pI_p}/_{1-v_p{}^2}\right]\left({}^1/_{r^3}\right)} \qquad (2.12)$$

Where:

E=Young's modulus of the surrounding (backfill) media

E_p=Young's modulus of the pipeline material

ν= poisson ratio of the surrounding (backfill) media

ν_p= poisson ratio of the pipe

I_p=moment of inertia of the pipe, ½(t^3b)

t=pipe wall thickness

r=pipe radius

b=a unit length along the pipe axis

Subscript p refers to the pipeline and the constants without subscript refers to the properties of the surrounding soil media. If J>10, the buried pipeline is stated to be as having low stiffness compared to the surrounding media and responds the same as soil and the elastic formulations given above may apply (Dowding, 1985).

By knowing the elastic properties of the steel pipeline, the stresses induced in the pipeline can be computed. The biaxial stress-strain relationship is given in equations 2.13 and 2.14 and shown schematically in Figure 2.16.

$$\sigma_c = \frac{E}{(1 - v^2)} (\varepsilon_c + v\varepsilon_l) \qquad (2.13)$$

$$\sigma_l = \frac{E}{(1 - v^2)} (\varepsilon_l + v\varepsilon_c) \qquad (2.14)$$

σ_c is the circumferential or hoop stress; σ_l is the longitudinal stress, ε_c is the circumferential strain, ε_l is the longitudinal strain, E is the Young's modulus of elasticity, and ν is the Poisson's ratio. Bending stress is given by:

$$\sigma_b = E\varepsilon_b \qquad (2.15)$$

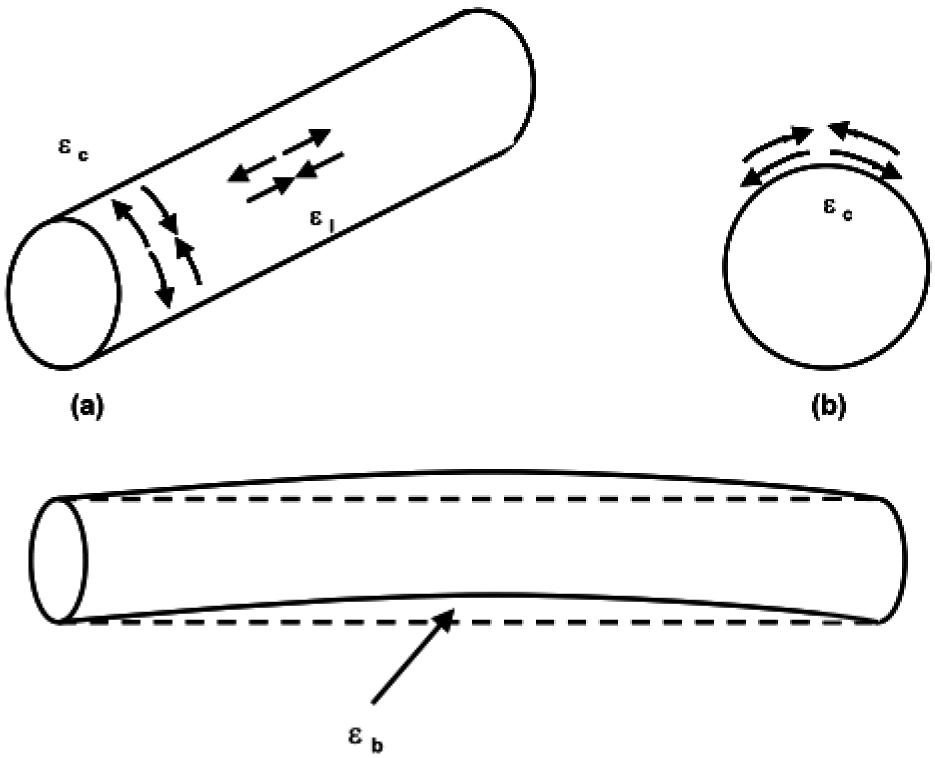


Figure 2.16 (a) Longitudinal, ε_l and (b) circumferential, ε_c, and (c) bending, ε_b, strain components of pipeline deformations (Aimone-Martin & Clah, 2003)

2.12 Air Blast-Noise and Human Discomfort Criteria

Air-Blast and noise are the common description of air overpressure waves generated by explosive detonation. To limit the air overpressure, upper part of the blasthole is filled with stemming material instead of explosive. This functions as a plug and prevents air blast and fly rock.

Blasting, in addition to ground vibrations, generates energy transmitted through the air called as air blast. Air blast overpressures have low frequency and medium-high frequency components. Most of the energy of the air blast is below 2 Hz hence it is not audible by human (Siskind, 2000). When the stemming length is designed as insufficient or shorter than it should be, the explosive energy is released to the atmosphere suddenly and may create high frequency air over pressure which causes annoying noise. When the conditions are appropriate for a sound wave to travel at long distances, the ground vibrations are held to be responsible for the vibrations on buildings (Siskind, 2000). Since the frequencies of the infrasound is less than 20 Hz it cannot be heard, but when the buildings are subjected to it the response becomes like as if they are subjected to ground vibrations and secondary noises, such as rattling, generated by mid-wall vibrations are formed (Siskind et al., 1980).

Air blast is important for three reasons. First, the audible portion of the air blast directly creates noise. Second, inaudible part generates vibration on the structures and creates noise on the structures. Third, depending on the intensity of the air blast it may break the windows.

There are three different scales which are used to measure the noise generated. These scales are stated to be as “A” scale, “C” scale and “L” scale. Human cannot hear low frequency vibrations which are also known as infrasound. Since buildings are mostly sensitive to low frequency range waves and the highest level of air blasts are mostly seen in the low frequency range, using “A” scale for monitoring air overpressure induced by blasting is not suitable (Dowding, 1992). Since C scale is the least sensitive to frequencies its usage in air blast is not appropriate too. For this reason, L scale is used in air blast monitoring and the unit is dB “decibel”.

Having published in Official Gazette No: 27601 dated 04.06.2010, Turkish regulation entitled “Evaluation and Management of Environmental Noise” (EMEN) entered into force by replacing the former one. A scale, which is not appropriate for blast noise measurements, is given in the Noise Management Regulation for the operations other than mining and quarrying and continuous noise source. In appendix-I, chapter 1.2 of the new regulation it is stated that it might be beneficial to use special noise indicator under some circumstances.

Indicators are defined and explained in EMEN Appendix 1, Chapter 1.2 Noise Indicators. As defined in TS 9798 (ISO 1996-2), “A” scale is a weighted long-term sound average and daytime is determined by considering total daytime duration in a year. However, blast noises are not long term noise rather they are transient noises. Regarding the statement “it might be beneficial to use special noise indicator under some circumstances” some example indicators are given and presented below:

a) If the noise source of interest operate at a short period of time , i.e., 20 % less than total daytime or nighttime in a year,
b) The average number of noise events at a time or duration of a time is so low, (i.e., noise event occurring less than once per an hour: this can be defined as an event duration of which is less than 5 minutes. Passage of a train or plane can be example to this.). Blast noise is also like this kind, very short durations are seen.
c) Strong low frequency content of airblast waves completely covers and defines the blasting event. Considering the duration of time which is shorter than 5 minutes and also less than 20% of 12 hours day time duration, “L” scale and limit values given in USA regulations are taken as basis in assessment of the blast noises by researchers.

In Definitions section of Artice-4 of EMEN it is stated that “dBA: Defines a sound level criterion, expressed as A-weighted sound level ,in which more attention is paid in the mid-high frequencies which the human auditory system is more vulnerable to and this is widely used for the assessment and control of noise exposure”. In the regulation it is stated that the human auditory system is more sensitive to mid-high frequencies and this subject has been verified by (Dowding, 1992).

Dowding (1992) stated that it was determined that the windows are broken in the sound pressure range of 136 and 140 dB when measured with L scale (linear) type sensors. The following table (Table 2.12) is given in the USA Federal Regulation (30 CFR, Parts 618.67(b)).

Table 2.12 Maximum allowable noise levels given in USA Federal Regulation in accordance with the frequency band.

Lowest frequency limit of the measurement system(Hz)	**Maximum level of noise (dB)**
2 Hz or less	133
6 Hz or less	129

Hoek and Bray (1981), presented a scale prepared by Ladegaard-Pedersen and Dally (1975) in their book “Rock Slope Engineering” and this scale is given in Figure 2.17. According to Figure 2.17 When the sound level is reached to 95 dB it starts to attract the attention of people. Personnel complaints start at the level of 117 dB and at this level dishes and windows start rattle. 120 dB is the threshold value for pain. Damage threshold level value to buildings is stated as 140 dB. Threshold value corresponding to damage to buildings in Figure 2.17 is higher than those stated in the US regulations (129 or 133 dB). According to the scale 150 dB windows start to break and when the value is reached up to 170 dB most of the windows break. At 180 dB structures are damaged by plaster cracks.

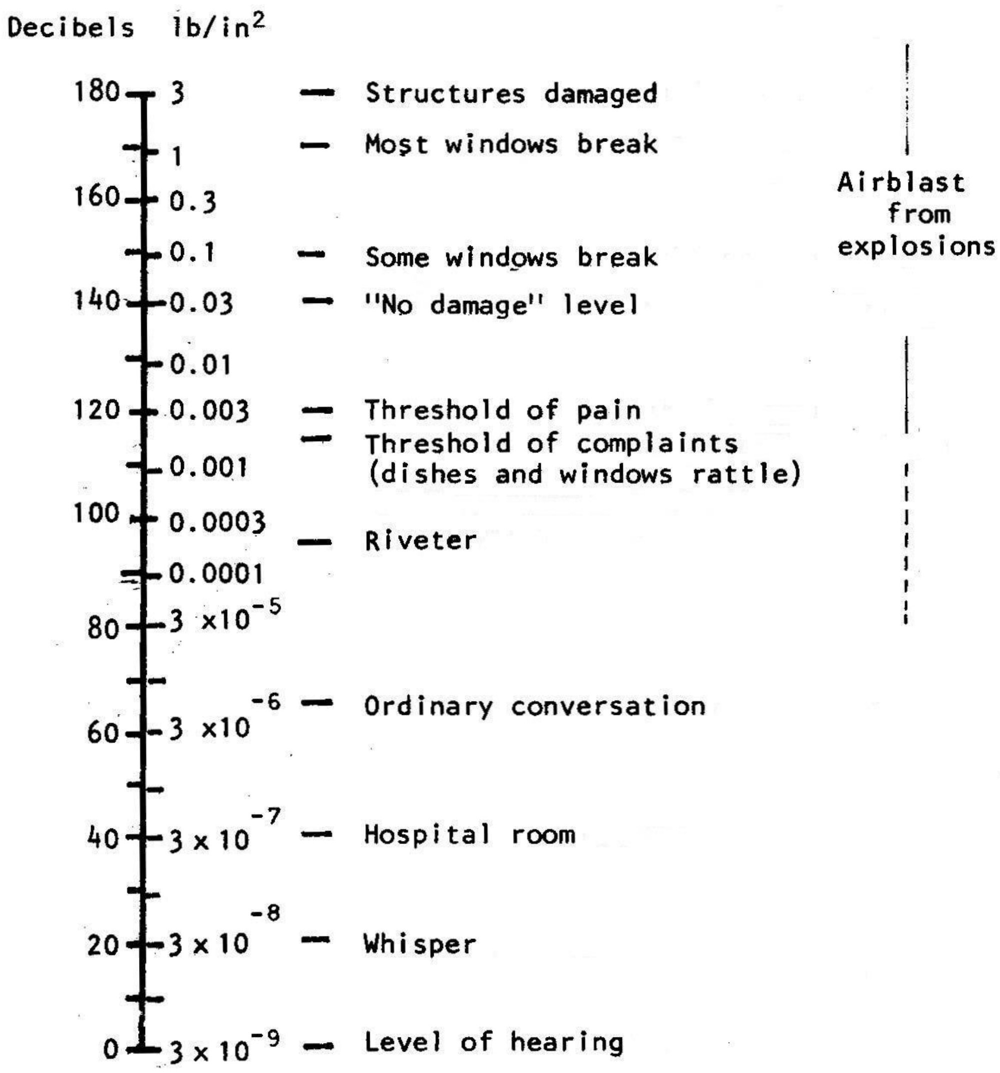


Figure 2.17 Responses of structures and human to different level of air blast (Ladegaard-Pedersen & Dally, 1975)

CHAPTER 3

STUDY AREA AND GEOLOGY

3.1 Study Area and the Properties of the Water Tank

The construction area was located in Yozgat city which is in Central Anatolia region of Turkey. The town is located at an elevation of 1335 m and situated at 170 km east of Ankara. The location is shown in Figure 3.1. The construction of a water tank was planned to be carried out at higher elevations of a hill by starting with foundation excavation. The location of water tank on the hill is shown in Figure 3.2. As it can be seen from Figure 3.2 the most distant point of the construction area is 200 m and the nearest point is 112.5 m away from the pipeline.

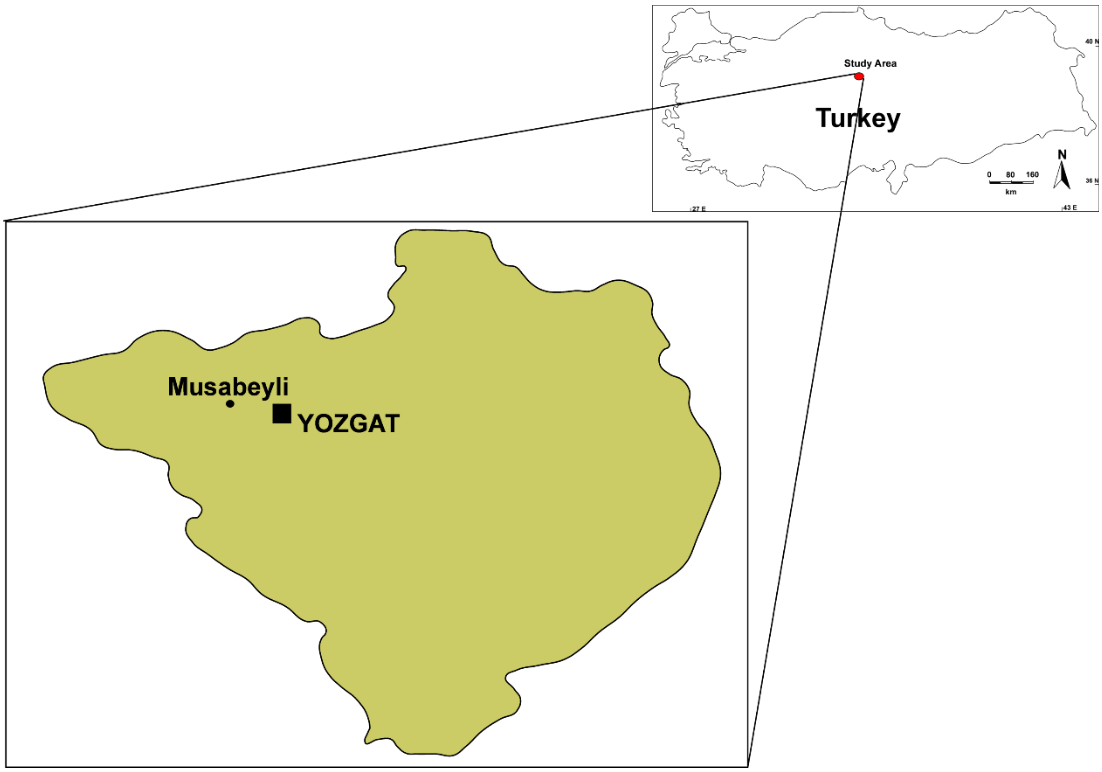


Figure 3.1 Location of the construction area

The capacity of the water tank was planned to be as 15,000 m^3. The dimensions of the tank are like the following; width of the tank: 65.50 m, length of the tank: 49.10 m, water height: 5.25 m and the depth of the foundation: 4.50 m. The area to be levelled for the foundation excavation and the location of the pipeline which is in the north of this area are presented in Figure 3.3. B-B and C-C cross-sections are shown in Figure 3.4 and the maximum depth of excavation by blasting is shown. According to this, the excavation starts by valve chamber excavation at the hillside at an elevation of 1468.90 m and 200 m distance to the pipeline.

The base elevation of the water tank, as shown in B-B cross-section in Figure 3.4 is 1470.75 m and the topographical elevation is 1485 m. The depth of the excavation at a distance of 112.5 m from the pipeline is 14.25 m (Figure 3.4). Similarly, the topographical elevation in C-C cross-section (Figure 3.4) is 1486 m at the distance of 112.5 m from the pipeline and the depth of the excavation at this point is 15.25 m (Figure 3.4). Hence, assuming the maximum depth of the excavation as 15 m at the distance of 112.5 m from the pipeline would be a correct assumption.

As it is seen in Figure 3.4, three benches having 5m bench heights were planned to be constructed at the north end of the construction. Planned excavation scheme with three benches as shown in Figure 3.4 can be done by two ways. One of them is to carry out the excavation in two 7.5 m high benches and the other one is by conducting it in three 5 m high benches. The depth of the excavation changes the depth of the blastholes to be drilled hence the amount of the explosive. By considering a vibration controlled blasting, the height of the benches will be determined according to the results of the test blasts.

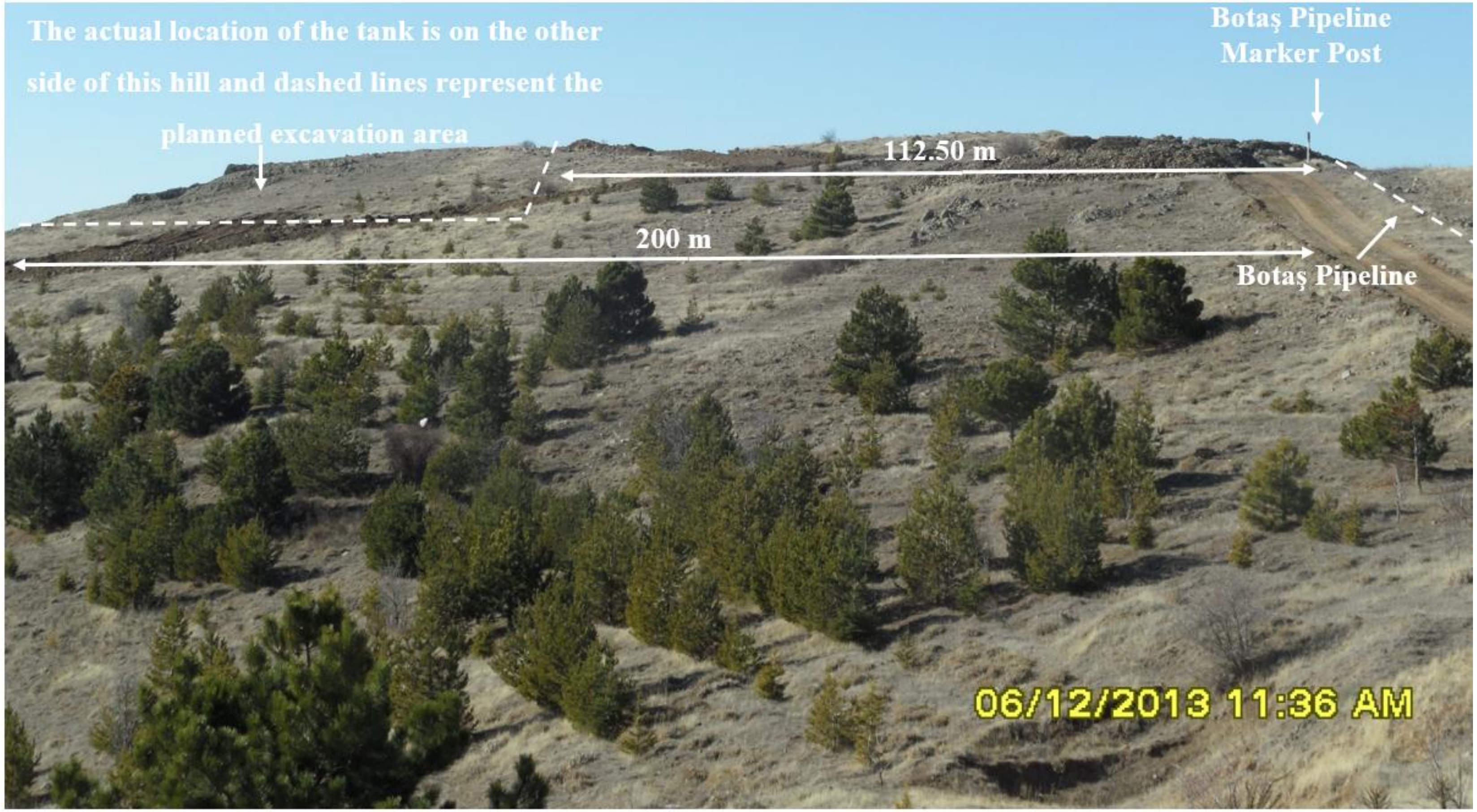


Figure 3.2 The hill where the construction area is planned to be located and the pipeline

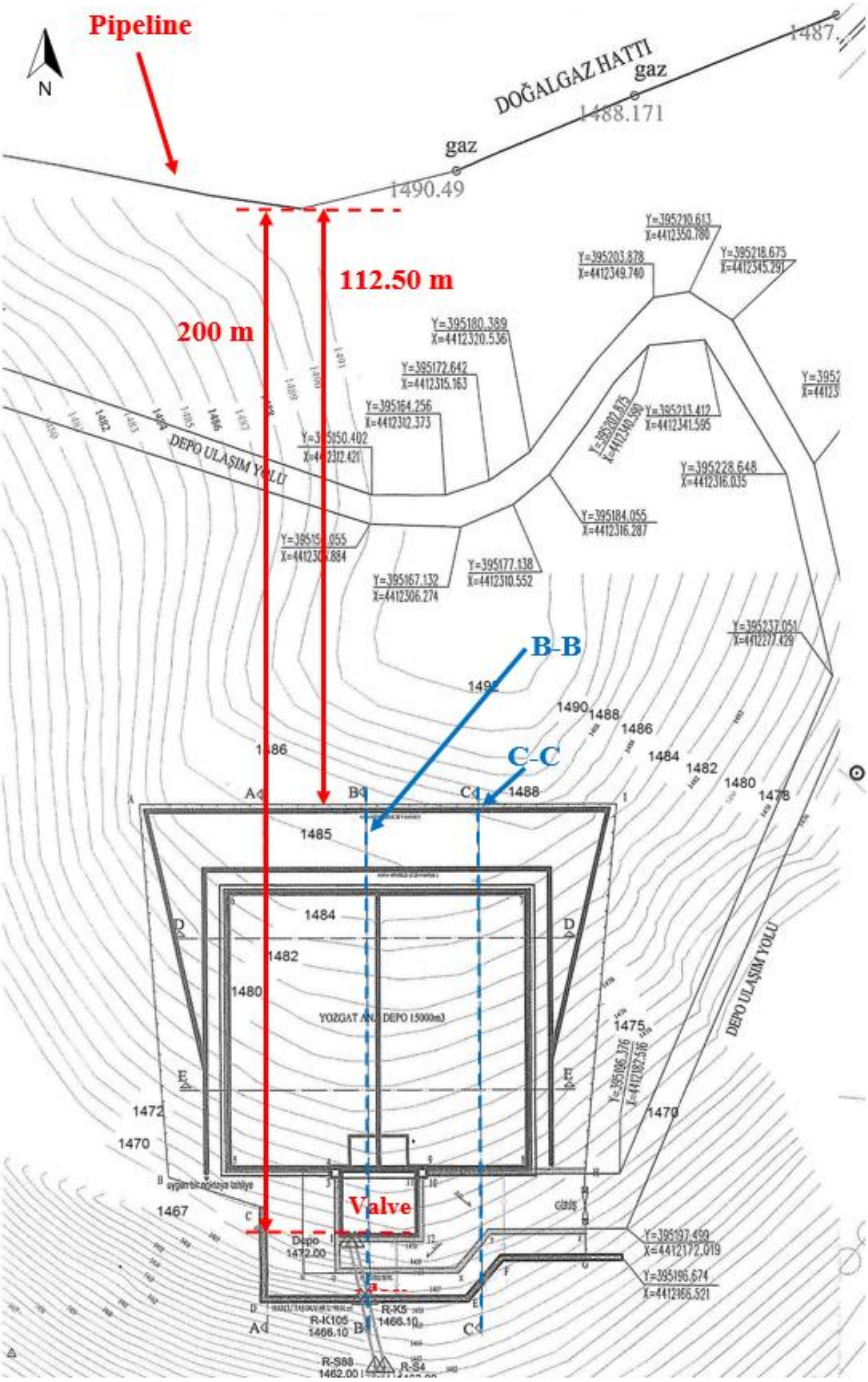
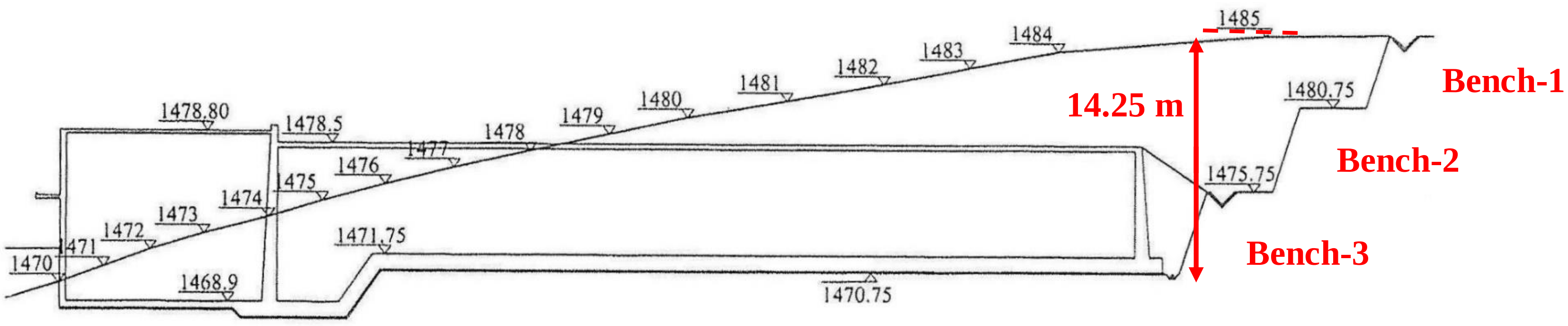
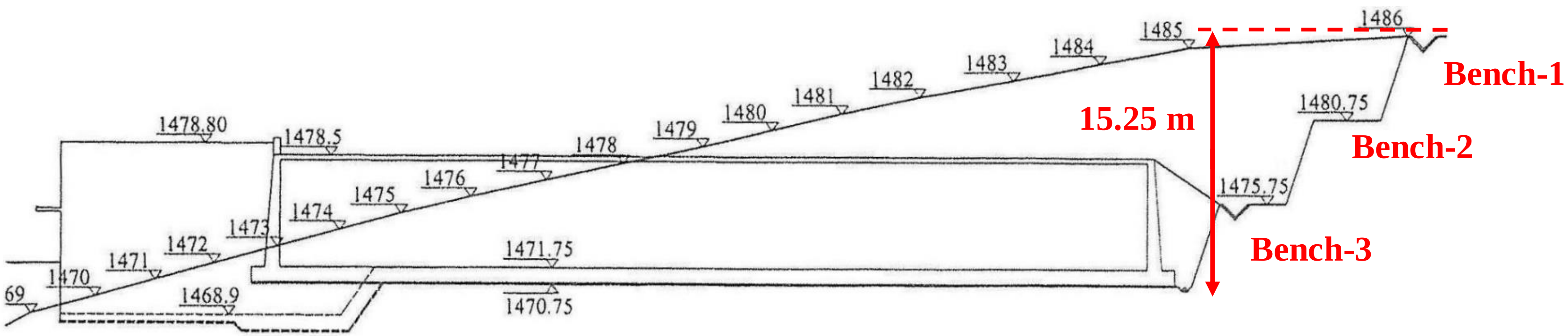


Figure 3.3 Yozgat main water tank construction plan and the gas pipeline



B-B CROSS-SECTION



C-C CROSS-SECTION

Figure 3.4 The maximum excavation depth ranges from 14.25 to 15.25 m depending on the topography.

3.2 Geological Information and Geotechnical Properties

Project area takes place in Yozgat Plateu. Volcanic rocks formed during Cenozoic geologic era are exposed within the water tank construction area. These volcanic rocks, which are called as “Başıbüyüklü Volcanics” are said to be formed as a part of Eocene volcanic Facies. Calc-alkaline volcanic rocks are said to be the product of abyssal volcanism (Ketin, 1983 & Ternek, 1987).

Three different volcanic rock types are identified by their colors upon macroscopic analysis made at the site. Samples are taken from these three types of rocks and mineralogical and petrographical analysis were carried out at Geological Engineering Department of METU. These are basaltic andesite, and andesite-1 and andesite-2 (Goncuoglu, 2014). The common features of these rocks are being fine grained and massive volcanic rocks.

Basaltic andesite is beige-gray colored and under the microscope the sample is microphanetic and shows perfect flow texture. Plagioclase, rare quartz and chloritised biotite are major minerals. The dominating phase is 0.3-1 mm long plagioclase laths which are aligned with their long axis parallel to the flow direction (Goncuoglu, 2014). The matrix is made of the same minerals as the phenocrysts. No glass is observed. Chlorite and calcite occur as alteration products and are of limited extend. The dominating mineral phase, the plagioclases are commonly fresh.

Andesite-1 is a fine grained and massive volcanic rock with distinguishing greenish color. The dominating microphaneritic phase is prismatic plagioclase. The crystals are 0.5-1.2 mm long, zoned and oriented parallel to each other and the main flow direction. The matrix is microcrystalline and mainly of lath-shaped plagioclase.

Andesite-2 is also a fine grained and massive volcanic rock which is distinguished from Andesite-1 by its dark-grey to black color. Under the microscope the sample is microphaneritic and shows perfect flow (trachytic) texture. The microphenocrysts are mainly 0.2-0.6 mm long laths of plagioclase. The matrix is made of microliths of prismatic plagioclase. No glass is observed. The sample doesn't include water-soluble minerals nor open voids or cracks and the constituent minerals mainly the plagioclases are very fresh.

3.3 Rock Mass Description

Discontinuity survey and dip direction/dip measurements were done on the field to identify the joint sets (Figure 3.6). Measured values were used to determine the direction and dip of the joint sets. As a result, two major joint sets and a minor fault plane were identified by Rockscience Dips 5 software and the plot is shown in Figure 3.5. Average dip direction and dip angles of discontinuities are determined as follows:

<u>Joint Set 1</u>: 035/79

<u>Joint Set 2</u>: 317/83

<u>Minor Fault</u>: 303/77

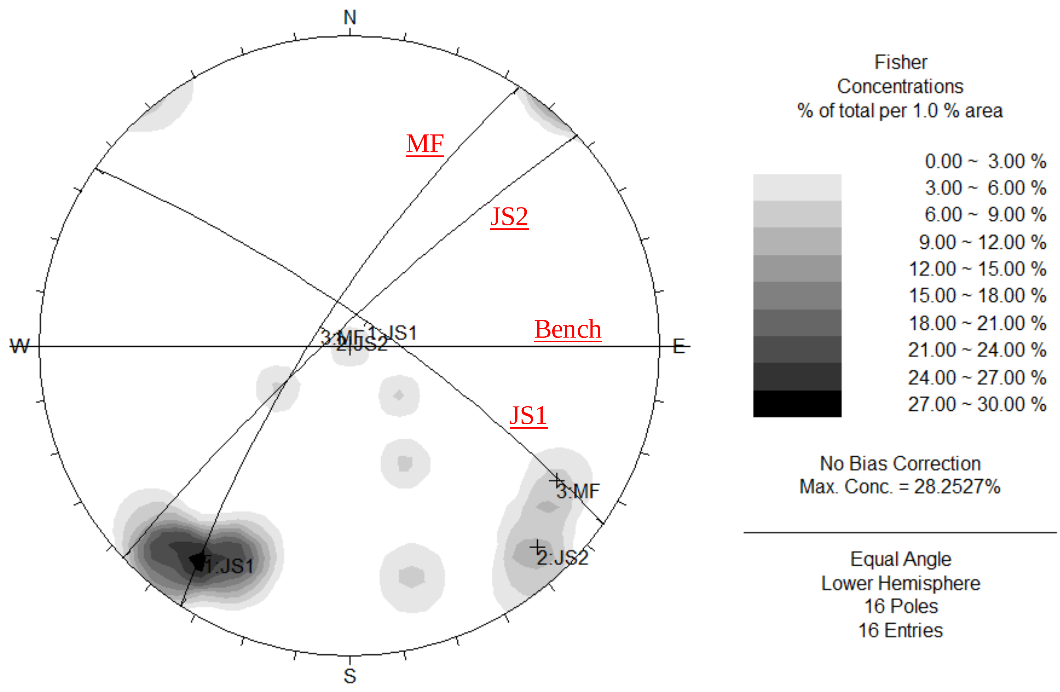


Figure 3.5 Stereonet plot of joints, minor fault and bench

Figure 3.6 Strike & dip measurement along minor fault

The rock mass in the west side of the excavation area is composed of highly weathered to intensely weathered andesite and the block size cannot be defined (Figure 3.7). GSI value in the rock mass is found to be between 35 and 45 by using the modified GSI system (Sonmez & Ulusay, 2002).

Figure 3.7 West face of the excavation area having moderately weathered rocks

The photo shown in Figure 3.8 was taken by looking at northern part of the project area which is close to the pipeline. In the face of upper bench there is columnar basalt and in the lower bench there is weathered basaltic andesite. Limonite stains were observed on all joint surfaces examined. GSI value of the upper bench is between 70 and 80 and GSI value of lower bench is between 55 and 65.

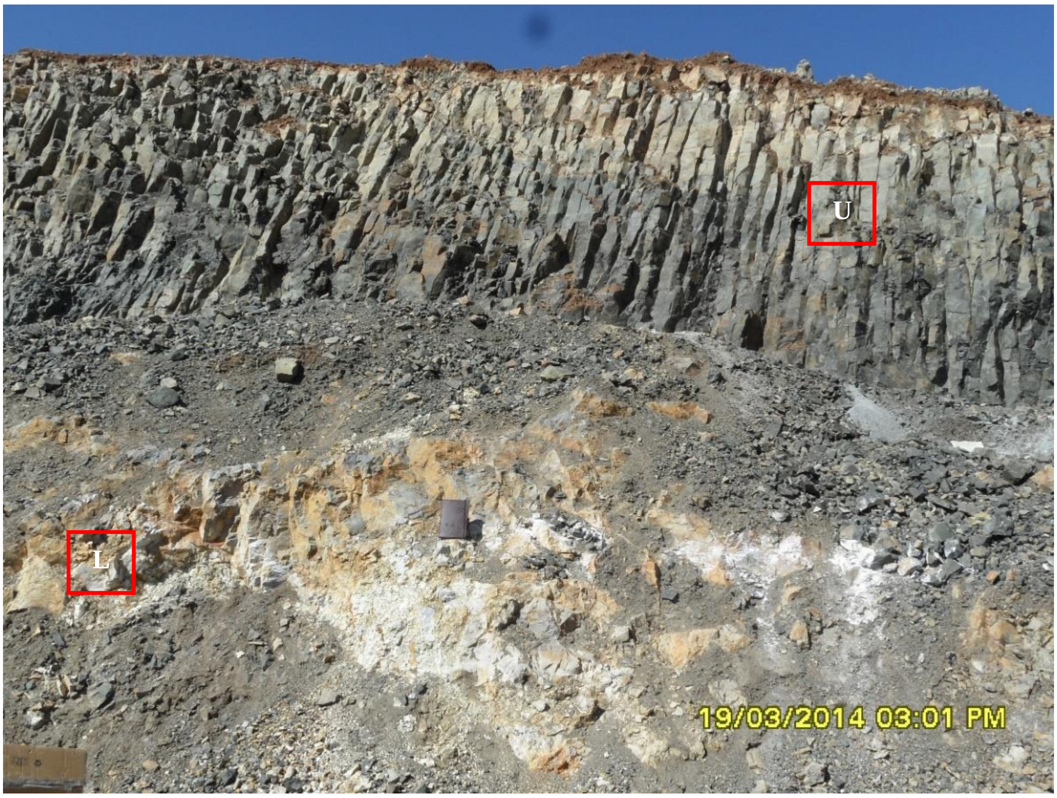


Figure 3.8 Face at the north of excavation area and the columnar structure behind (Face direction is east-west).

The photo shown in Figure 3.9 was taken by looking at northern part of the project area which is close to the pipeline. The brown notebook seen as a scale has the dimensions of 17 cm by 24 cm. The bench shown in Figure 3.9 consists of three different rock formations which are layered from top to bottom as blocky basaltic andesite, moderately to highly weathered basaltic andesite and jointed to massive andesite respectively. GSI value of the upper part of the bench is between 60 and 70, GSI value of the middle part of the bench is between 35 and 45 and GSI value of lower bench is between 70 and 80.

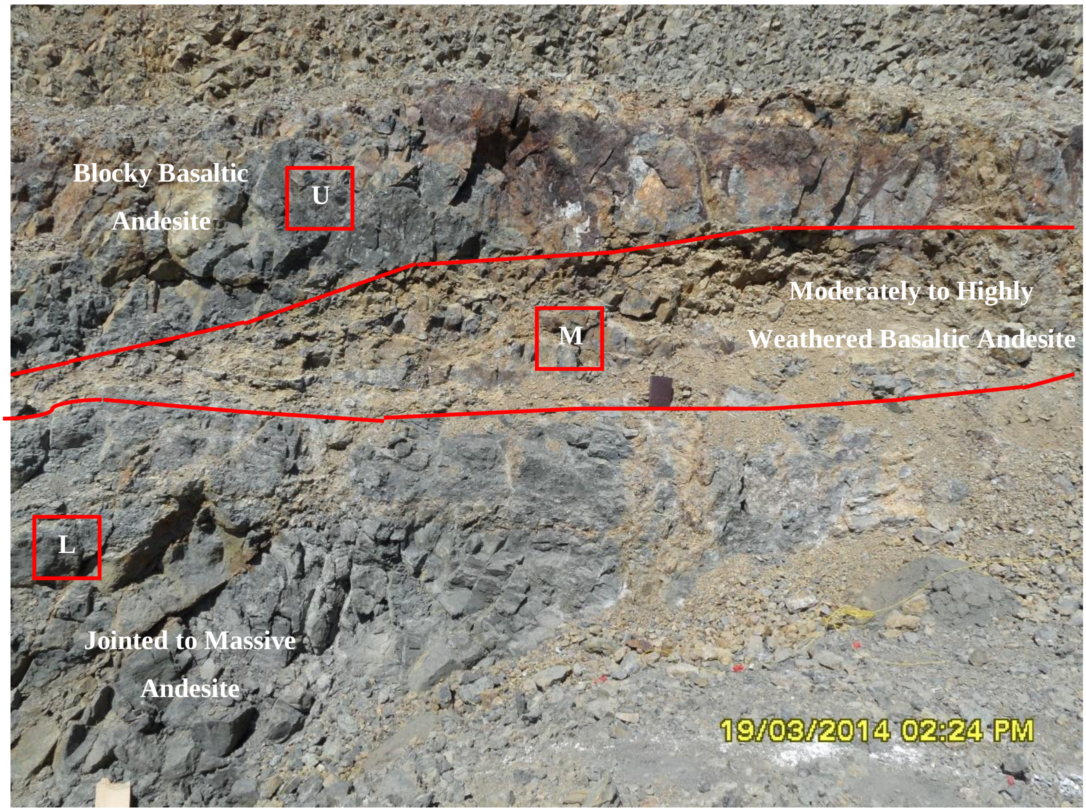


Figure 3.9 Bench geology

The photo shown in Figure 3.10 was taken at east side of the bench by looking at northern part of the project area which is close to the pipeline. Rock formations seen are layered from top to bottom as columnar jointed basalt, blocky basaltic andesite and massive andesite. GSI value of upper part of the bench is 55 and 65 and GSI value of the lower part of the bench is between 75 and 85.

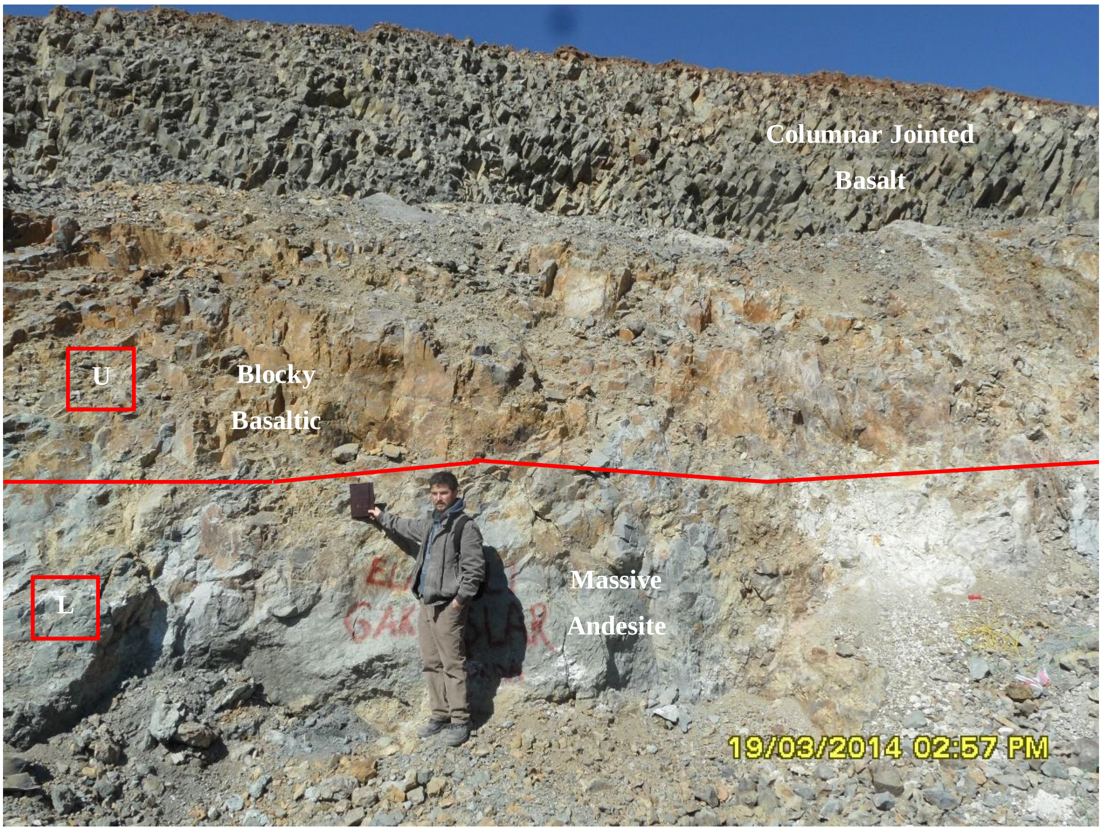


Figure 3.10 Geology of east side of the bench (taken by looking north)

To sum up, the rock mass at the site which shows different degrees of weathering, jointing and thickness can be considered to offer moderate resistance against blasting based on the performance obtained from production blasts. Specific charges applied (around 0.300 kg/m^3) were relatively low considering the fragmentation obtained in this type of rock like andesite and basaltic andesite. GSI values measured are shown on a map along with the excavation area in Figure 3.11.

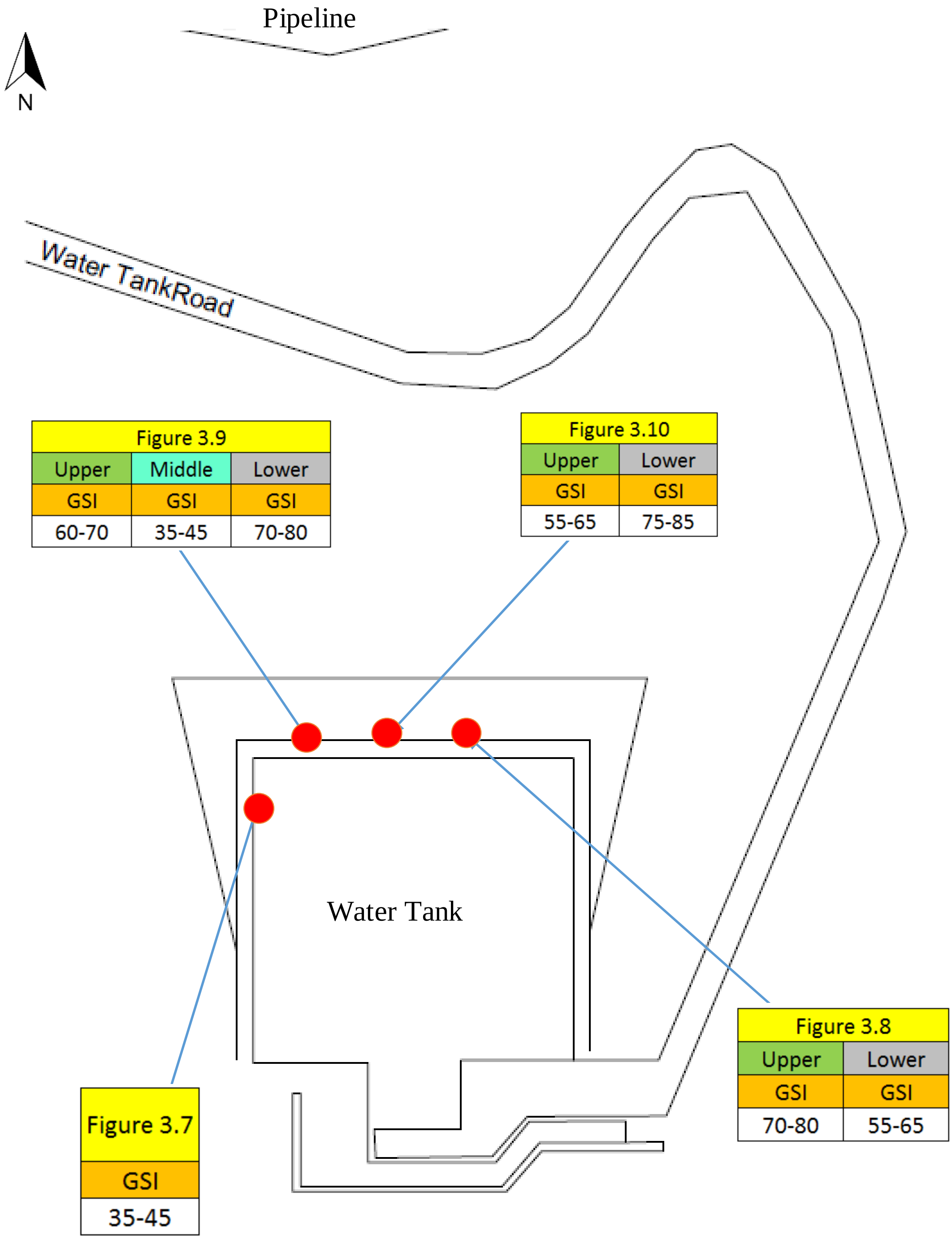


Figure 3.11 Locations of the pictures taken and GSI values

3.4 Geophysical Properties

Block samples belonging to three different rock types distinguished by their colors were collected from the site to be analyzed in the laboratory to determine the P and S wave velocity properties along with dynamic properties. Cores were prepared from these rock samples in the Rock Mechanics Laboratory of METU Mining Engineering Department (Figure 3.12). Then P and S wave velocities of these cores were measured. In total, 3 samples of Basaltic Andesite, 6 samples of Andesite and another 6 samples of Andesite having different color were tested. It is possible to determine dynamic properties of rock samples by using some formulas given by Altıntaş (1996). Dynamic properties of the samples were calculated utilizing P and S wave velocity measurements. Formulas used in the calculation of dynamic properties are presented in Equations 3.1, 3.2, 3.3, 3.4, 3.5. P and S wave measurements with other calculated properties are presented in Table 3.1.

$$\rho=0.2\ V_p+1.6 \qquad (3.1)$$

$$\nu=\frac{(\frac{Vp}{Vs})^2}{2(\frac{Vp}{Vs})^2-2} \qquad (3.2)$$

$$E_d= V_p\ \rho\ \frac{(1-2\nu)(1+\nu)}{(1-\nu)} \qquad (3.3)$$

$$G_d= V_s^2\ \rho \qquad (3.4)$$

$$K_d= G_d\frac{2(1+\nu)}{3(1-\nu)} \qquad (3.5)$$

Where;

ρ=density (gr/cm^3)

ν=Poisson ratio

V_p=P wave velocity (km/s)

V_s=S wave velocity (km/s)

G_d=Dynamic Shear Modulus (kg/cm^2)

E_d=Dynamic Young’s Modulus (kg/cm^2)

K_d=Dynamic Bulk Modulus

Table 3.1 P and S wave measurements of the rock samples collected on-site

Sample Group	V_p (m/s)	V_s (m/s)	Poison Ratio(ν)	G_d (Gpa)	E_d (Gpa)	K_d (Gpa)	Density (gr/cm3)
Basaltic Andesite	2872±120	1795±107	0.18	7.16	16.86	8.76	2.17
Andesite	5411±131	2554±72	0.36	17.85	48.38	56.34	2.68
Andesite	5534±310	2594±53	0.36	18.58	48.82	60.11	2.70

Figure 3.12 Core cutting from a block sample collected from the site

CHAPTER 4

TEST BLASTS AND GROUND VIBRATION ASSESSMENT

4.1 Application and Parameters of the Test Blasts

The location for the test blasts was chosen as the most remote place of the excavation area from the pipeline, which ranged between 185 m and 200 m, based on the topographical conditions and on-site inspections.

When calculating the safe amounts of explosives to be used in test blasts to keep the effects of test blasts within the safe limits and to gain a better insight into the attenuation characteristics of the ground vibrations towards the pipeline, some references were used. These references were, Technical Safety and Environmental (TEC) Regulations of the pipeline company (BOTAŞ), German, American, Austrian standards and Dr. Bilgin’s past experiences in the similar rock conditions. In the light of these information, amounts per delay starting from 4.5 kg up to 18.5 kg were shot in the test blasts. Explosive charges were either ANFO or water resistant explosives (65% ANFO/35% AN emulsion) and the charge diameter was 89 mm. The depth of the holes ranged from 1.5 m to 8 m depending on the topographical conditions. To understand the attenuation characteristics and analyze the ground vibrations, three available seismographs were located between the test blast area and the pipeline. One of the seismographs was located at the ground surface on top of the pipeline, second one was located 73.5 m ahead of the first seismograph, and the last one was located 97.9 m ahead of the first seismograph and towards the blast area. Locations of the seismographs and the pipeline, the recorded ground vibration values at each location and the test blast area are shown in Figure 4.1.

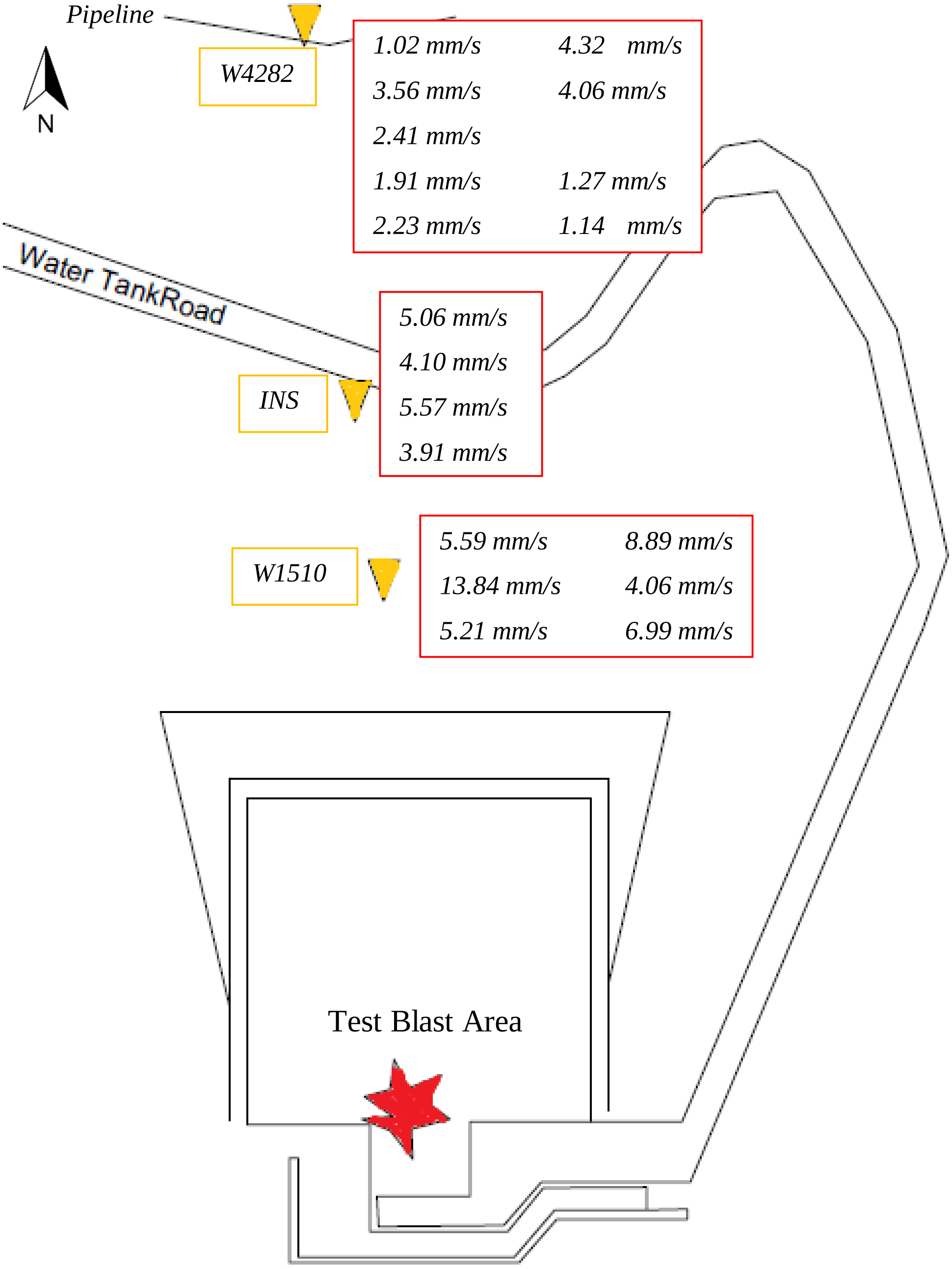


Figure 4.1 Test blast area and seismographs with measured vibration values

To be on the safe side in the test blasts, a safety factor of 5 has been applied. The reason behind applying this is the existence of uncertainties about the condition of the pipe, which is uncertainty in quality of welding and the thickness of the sand bed. It's always the weakest link in the chain that breaks. The weakest link of a steel welded pipeline is its weld. Considering that the pipeline was built a few decades ago, the available welding technology at that time and the time it has passed since its production, a precaution was found to be necessary. Although the vibration values given for the damage criteria for the pipelines are rather safe compared to the results of the worst case studies given in the literature review part, a safety factor was applied and this resulted in rather safer values. Determination of the factor of safety was based on Dr. Bilgin's experiences and it could also be some other value as well.

According to DIN 4150-3 standard the maximum allowable ground vibration value for welded steel pipes is 100 mm/s (Table 2.5). By applying the safety factor, the maximum allowable vibration value given in DIN-4150-3 standard was modified. Hence, the amounts of explosives for test blasts in this research were calculated so as not to exceed 20 mm/s on top of the pipeline. Calculation of the amount of explosives to be detonated in test blasts was based on the vibration data measured in different parts of Turkey in similar rock conditions and also on the vibration measurement results obtained from blasting operations done nearby a buried high pressure pipeline in Austria and the United States of America. In these calculations some attenuation formulas obtained from the vibration measurements in Basalt in Samsun Bafra (Bilgin, Çakmak, 2008a), Syenite in Ordu in Turkey (Bilgin, Çakmak, 2008b) were referenced. Besides, 2 formulas which were used for blasting operations nearby a buried pipeline in similar hard rock conditions in Austria and the U.S, Texas were referenced as well. The results of the calculations done in order not to exceed 20 mm/s are like the followings;

$PPV=138.63xSD^{-0.8567}$ 435 kg/delay-Bafra Equation (Bilgin, Çakmak, 2008a) (4.1)

$PPV=529.75xSD^{-1.3517}$ 313 kg/delay-Ordu Equation (Bilgin, Çakmak, 2008b) (4.2)

$PPV=1140xSD^{-1.6}$ 255 kg/delay-Austria Equation1 (Ganster, 2011) (4.3)

$PPV=969xQ^{-0.6} xD^{-1.5}$ 878 kg/delay-Austria Equation2 (Ganster, 2011) (4.4)

$PPV=160xSD^{-1.6}$ 560 kg/delay-USA, Texas Equation (Wheeler, 2012) (4.5)

$m<k\sqrt{q}$ 16 kg/delay- Pipeline Company Regulation Equation (4.6)

Where PPV stands for Peak Particle Velocity (mm/s),
SD for Scaled Distance $m/kg^{1/2}$ for first four equations and $ft/lb^{1/2}$ in Texas Equation
D is the distance from the blast to the structure of interest (m) in first 4 equations and ft for Texas Equation.

Q is the amount of explosives blasted per delay (kg for first 4 equations and lb for Texas equation)

According to Equation 4.6, which is stated in BOTAŞ regulation, for a distance of 200 m and k value of 50, the allowable amount is found as 16 kg. However, even taking the expected maximum particle velocity that may result from the test blasts as low as 20 mm/s compared to its original value given in DIN 4150-3 standard, which is 100 mm/s, the calculated amounts according to previous formulations are 255 kg, 313 kg, 435 kg, 560 kg, 878 kg. Considering the diameters of the blasthole used for this kind of construction excavations, this much of explosive in one hole is too much. This much of explosive can be detonated only when more than one hole is shot simultaneously without using any delay time between successive holes and rows. These amounts paved the way for carrying out test blasts to prove that blasting was possible.

The calculated charge by using BOTAŞ formula, which is 16 kg, is relatively low when compared to the charge amounts calculated by other formulations. It should be noted that 16 kg is for the distance of 200 m. When the distance from the nearest end of the construction area is considered, this amount drops down to 5 kg per delay. This much low amount results in very high blasting costs.

The charge amount used in the test blasts ranged from 4.5 kg to 18.5 kg. 4.5 kg was shot in the beginning of the test blasts and the vibration level was read on top of the pipeline. Since it was understood that the vibration level was safe, test blasts were kept carrying out by increasing the amount gradually and the charge amounts used in the test blasts were 4.5 kg, 6.5 kg, 8.5 kg, 13.0 kg, 14.5 kg, 16.5 kg, and 18.5 kg. The maximum level of vibration was measured at the surface on top of the pipeline when 18.5 kg was detonated at 185 m away from the pipeline and the value was 4.06 mm/s. This level of vibration is 1/24.6 of the maximum allowable level of vibration in Germany, 1/18.45 of that of Austria and 1/31.15 of that of USA. It is obvious that the vibration value was low and it was concluded that this value could have no adverse effect on the pipeline.

Test blasts were carried at the most distant end of the excavation area at an elevation of 1470 m. The number of blasts shot during the test blasts were sufficient and the amplitude of the seismic waves were clear enough to interpret the propagation and attenuation characteristics of the vibrations.

In order to calculate the safe amount of explosives to be detonated per delay, vibration values from test blasts were used. By using the vibration values, ground calibration was carried out by determining the attenuation formula for the site. Then, estimation and vibration limit tables were formed to be used for the production blasts.

Powder factor used in the test blasts was 0.308 kg/m^3 and this resulted in good fragmentation since the rock was jointed, slightly, moderately or highly weathered at test blast area.

Holes having different amount of explosives were used to form group of holes to be blasted in a shot by using 25 ms delay between each holes. The location of each hole was measured by using GPS device and the amount of explosive in each hole was recorded to determine the maximum amount of explosive blasted per delay. Location of the seismographs were measured by using GPS devices as well. By using the physical distances between the locations and charge amounts per delay, scaled distances for each blast was calculated.

4.2 Monitoring

Monitoring of the ground vibrations was performed by using three available digital seismographs. Two of these seismographs were White Mini-Seis II model and one seismograph was Instantel Minimate Blaster model. The location of each seismograph was measured by using GPS device. The distance between the blastholes and the monitoring stations were calculated manually by using the coordinates.

The specifications of the instruments used to measure ground vibrations and air blasts are shown in Appendix B and their pictures are shown in Figure 4.2 and Figure 4.3.

Figure 4.2 White Mini-Seis II seismograph located on top of the pipeline

Figure 4.3 Instantel Minimate Blaster Seismograph located 73.5 m ahead of the pipeline

4.3 Assessment of Ground Vibrations Induced by Test Blasts

As previously mentioned, three seismographs were placed between the blast area and the pipeline. In the vibration terminology, R stands for “Radial component” of the particle velocity, V stands for “Vertical” and T stands for “Transverse” and these are represented in mm/s. Since R, V and T values do not reach their peak values at the same time, the highest among these is considered as Peak Particle Velocity.

The peak vibration value obtained from the seismograph located 97.9 m in front of the pipeline is 13.84 mm/s. This vibration value was measured when 8.50 kg of explosive was detonated at a distance of 98.13 m to the monitoring point. When this value is compared to that of at which rock starts to crack, which is 635 mm/s, it can be seen that the measured vibration value is 1/45 of 635 mm/s. We can conclude that even 97.9 m away from the pipeline there was no plastic deformation that took place, instead the ground vibrated in its elastic limits. The minimum dominant frequency calculated by using FFT method was 33 Hz. Since there is no frequency related vibration standard for blasting nearby pipelines, using the frequency values for sensitive residential housing may give an idea. If the frequency values given for sensitive residential housing are considered, the allowable ground vibration level corresponding to 33 Hz is stated as 50 mm/s in Turkish Regulation (Table 2.4). Hence, the ground vibration levels 97.9 m in front of the pipeline were below the values stated in the regulation and there was no risk of damage to the structures if there were residential housing 97.9 m in front of the pipeline and 98.13 m away from test blast location.

The peak vibration value obtained from the seismograph located 73.5 m in front of the pipeline is 5.57 mm/s. This vibration value was measured when 14.5 kg of explosive was detonated at a distance of 117.83 m to the monitoring place. When this value is compared to that of at which rock starts to crack which is 635 mm/s it can be seen that the measured vibration value is 1/114 of 635 mm/s. We can conclude that even 73.5 m away from the pipeline there was no plastic deformation that took place, instead the ground vibrated in its elastic limits. The minimum dominant frequency calculated by using FFT method was 23.3 Hz. Since there is no frequency related vibration standard for blasting nearby pipelines, using the frequency values for sensitive residential housing may give an idea. If the frequency values given for sensitive residential housing are considered, the allowable ground vibration level corresponding to 23.3 Hz is stated as 39.20 mm/s in Turkish Regulation (Table 2.4). Hence, the ground vibration levels 73.5 m in front of the pipeline were below the values stated in the regulation and there was no risk of damage to the structures if there were residential housing 73.5 m in front of the pipeline and 117.83 m away from test blast location.

The peak vibration value obtained from the seismograph located on top of the pipeline is 4.32 mm/s. This vibration value was measured when 18.50 kg of explosive was detonated at a distance of 179.54 m to the monitoring place on top of pipeline. When this value is compared to that of at which rock starts to crack which is 635 mm/s it can be seen that the measured vibration value is 1/147 of 635 mm/s. We can conclude that even at the pipeline which is 179.54 m away from the test blast location there was no plastic deformation that took place, instead the ground vibrated in its elastic limits. Moreover, this vibration value is well below the value which was set by applying a factor of safety value of 5 which is 20 mm/s and 1/24.6 of German standards. In two test blast cases, the dominant frequencies were 1.0 Hz in Transverse direction and in Turkish Regulation corresponding allowable maximum ground vibration level is stated to be as 5.0 mm/s. Measured PPV corresponding to this frequency was 1.14 mm/s and it is ¼ of the allowable level. So even if there were a sensitive residential housing on top of the pipeline, there wouldn't be any damage. Contrary to a building which freely moves when excited, the pipeline is a buried structure and around it there is a sand fill material. Hence, it is less likely to freely vibrate and be damaged.

The vibration values measured at top of the pipeline when 18.5 kg of explosive is detonated at a distance of 179.54 are compared to the maximum allowable vibration levels at other countries and presented below;

1-Measured value is ((4.32/75)*100)=5.76% of maximum allowable PPV stated in Austrian Standards.

2-Measured value is ((4.32/100)*100)=4.32% of maximum allowable PPV stated in German DIN 4150-3 Standards.

3-Measured value is ((4.32/127)*100)=3.40% of maximum allowable PPV stated in American USBM Standards.

By looking at the comparison above, one can conclude that the test blasts didn’t cause any damage to pipeline and the values are far below their allowable values. After the test blasts, BOTAŞ reported that there was no drop in gas pressure and no leakage in the pipeline. All the vibration measurement results are presented in Table 4.1. Seismograph records of test blasts are given in Appendix A.1 part.

Table 4.1 Vibration measurement data of the test blasts

No	Device	Measurement Station	Peak Particle Velocity (mm/s)					Amount Q (kg)	Dist. D (m)	Scaled Dist. SD (m/kg$^{0.5}$)	Dominant Frequency of Ground Vibration Waves (Hz)			Time Meas.	Date Measured	Noise Level and Frequency of Sound Waves dB/Hz	Appendix Figure
			R	V	T	VS	PPV				R	V	T				
1	W1510	97.9 m Ahead	4.191	2.667	5.588	6.223	5.588	6.50	96.25	37.752	48.50	44.50	91.50	16:31	06.12.2013	116.0 / 6.00	A.1
2	W4282	Pipeline	0.762	0.889	1.016	1.397	1.016	6.50	194.18	76.164	37.00	28.00	1.00	16:30	06.12.2013	106.0 / 7.50	A.2
3	W1510	97.9 m Ahead	8.255	2.540	8.890	9.144	8.890	13.00	101.96	28.279	103.00	44.50	91.50	16:32	06.12.2013	116.0 / 5.00	A.3
4	W4282	Pipeline	0.889	1.143	1.905	2.032	1.905	13.00	200.26	55.542	37.00	43.00	48.00	16:31	06.12.2013	106.0 / 1.00	A.4
5	W1510	97.9 m Ahead	11.557	8.128	13.843	17.970	13.843	8.50	98.13	33.658	85.00	43.00	85.50	16:33	06.12.2013	137.0 / 42.50	A.5
6	INS.	73.5 m Ahead	5.060	4.520	4.460	6.320	5.060	8.50	122.49	42.014	26.40	43.90	43.40	16:33	06.12.2013	130.5 / 43.1	A.16-17
7	W4282	Pipeline	2.286	2.032	2.032	2.794	2.286	8.50	195.87	67.183	34.50	43.50	104.00	16:33	06.12.2013	126.0 / 43.50	A.6
8	W1510	97.9 m Ahead	3.429	2.159	4.064	5.207	4.064	4.50	94.37	44.486	61.00	43.50	43.00	17:05	06.12.2013	138.0 / 50.00	A.7
9	INS.	73.5 m Ahead	3.910	1.870	3.020	4.110	3.910	4.50	119.11	56.149	28.10	43.50	33.50	17:05	06.12.2013	132.4 / 27.4	A.18-19
10	W4282	Pipeline	0.889	0.889	1.270	1.524	1.270	4.50	192.82	90.896	40.50	44.00	104.00	17:05	06.12.2013	127.0 / 22.00	A.8
11	W1510	97.9 m Ahead	5.207	1.905	3.556	5.588	5.207	8.50	95.34	32.701	71.50	39.50	106.00	17:17	06.12.2013	120.0 / 6.50	A.9
12	INS.	73.5 m Ahead	4.100	2.290	2.670	4.740	4.100	8.50	119.82	41.098	24.10	23.30	35.90	17:17	06.12.2013	115.0 / 5.25	A.20-21
13	W4282	Pipeline	0.889	0.889	1.143	1.397	1.143	8.50	193.34	66.315	36.00	28.00	1.00	17:16	06.12.2013	106.0 / 1.00	A.10
14	W1510	97.9 m Ahead	6.477	4.191	6.985	7.874	6.985	14.50	93.34	24.512	52.50	42.50	42.50	17:42	06.12.2013	123.0 / 4.00	A.11
15	INS.	73.5 m Ahead	5.180	3.330	5.570	5.890	5.570	14.50	117.83	30.944	35.40	43.90	38.50	17:42	06.12.2013	117.2 / 3.50	A.22-23
16	W4282	Pipeline	2.413	1.778	2.032	2.921	2.413	14.50	191.37	50.256	37.00	43.00	103.00	17:42	06.12.2013	112.0 / 4.00	A.12
17	W4282	Pipeline	1.905	2.159	3.556	3.683	3.556	16.50	184.48	45.416	38.10	41.50	109.00	14:50	07.12.2013	125.0 / 1.50	A.13
18	W4282	Pipeline	3.429	4.318	3.937	4.572	4.318	18.50	179.54	41.742	40.50	85.50	41.50	15:27	07.12.2013	118.0 / 2.50	A.14
19	W4282	Pipeline	3.175	3.302	4.064	5.207	4.064	18.50	185.06	43.026	30.00	55.50	26.00	15:49	07.12.2013	124.0 / 7.00	A.15

CHAPTER 5

PREDICTION OF GROUND VIBRATIONS AND VIBRATION CONTROLLED BLAST DESIGN

5.1 Prediction of Ground Vibrations

Best fit regression analysis was used to determine the level of ground vibration along a path between the blast area and the pipeline. The seismographs were located on this path to determine the attenuation characteristics of the ground along the path. Vibration data that was presented in Table 4.1 was analyzed and the mathematical relation between PPV and Scaled Distance was determined by plotting the vibration data on a logarithmic plot. The attenuation relation is shown in Figure 5.1. The upper line in the figure represents 95% confidence line and the equation of it is $PPV=5326.5 \times SD^{-1.773}$. By using the attenuation formula obtained, the maximum amount of explosive that can be detonated per delay so as not to exceed a certain vibration level at some specific distance was calculated and is presented in Table 5.1.

The frequency of the ground waves are higher close to the blasthole and decrease as they travel away. The blast area is close to the pipeline and the existence of volcanic hard rock formation makes seismic waves travel at frequencies 20 Hz or higher. This actually is a favorable condition in terms of reduction of risk of damage to the pipeline.

Regarding the predetermined maximum vibration limit, which was 20 mm/s, when a safety factor of 5 was applied, the maximum amount of explosives at different distances to the blast area are presented in Table 5.1.

For the foundation excavation blasting practice in full scale, it would also be very useful to calculate the safe distances at which the PPV will reduce to a given safe vibration level, when the charge amount per delay is known. For this purpose, Table 5.2 is prepared.

It should be noted that the attenuation relation given in Figure 5.1 was created using the vibration measurements taken in this site and it is site specific. Hence, it might not valid for other sites or ground conditions.

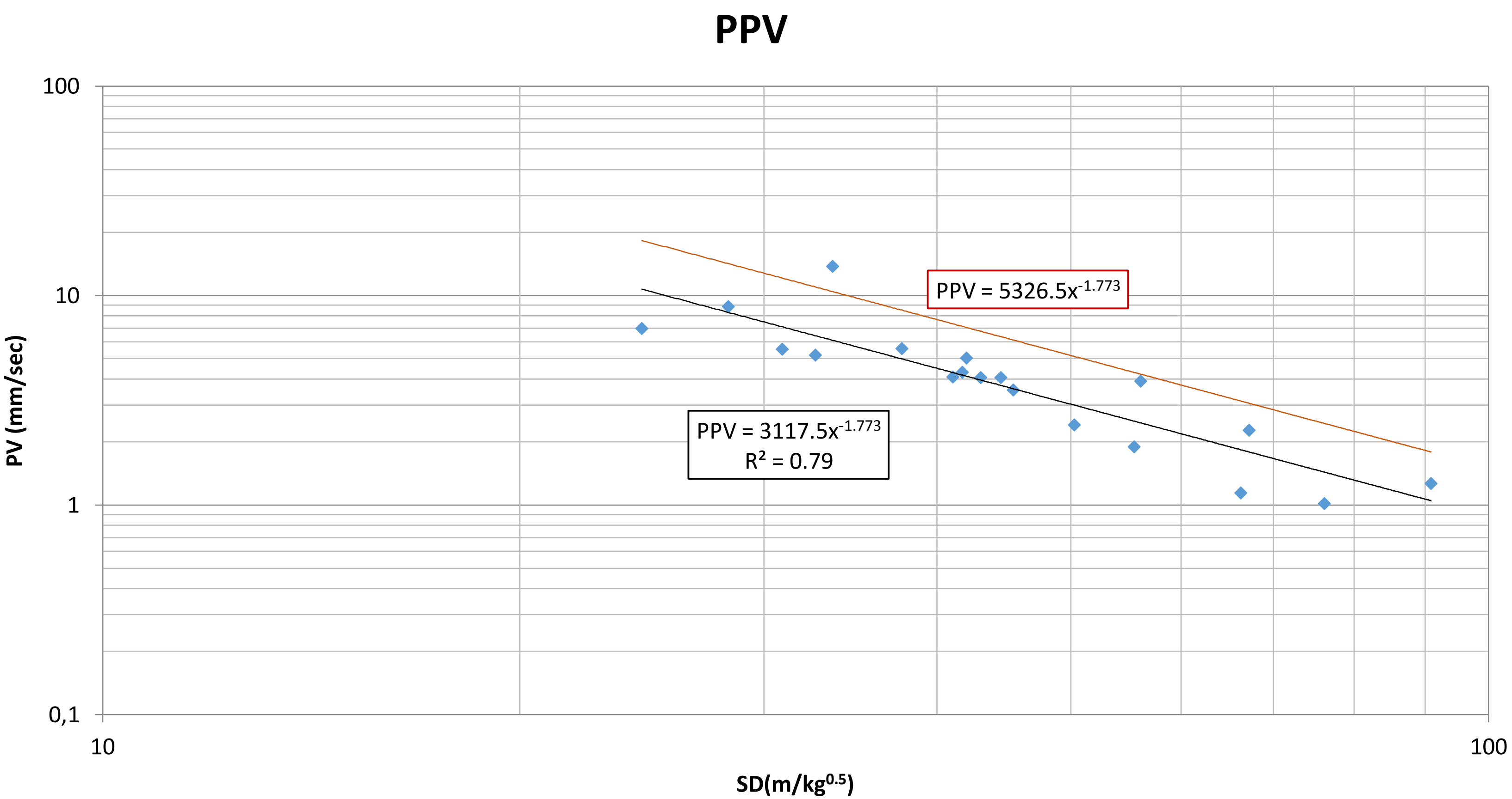


Figure 5.1 Attenuation plot in pipeline direction

Table 5.1 Maximum amount of explosive that can be blasted per delay depending on the distance to the pipeline

Distance to the Pipeline (m)	Maximum amount of explosives to be detonated per delay (kg) to not exceed a given PPV value (mm/s) for different distances (m) to the pipeline							
	20.00 mm/s		25.00 mm/s		33.00 mm/s		50.00 mm/s	
	VS	PPV	VS	PPV	VS	PPV	VS	PPV
110	19.40	22.24	25.35	28.61	35.35	39.13	58.15	62.52
120	23.09	26.47	30.17	34.05	42.07	46.57	69.20	74.40
130	27.10	31.07	35.41	39.96	49.37	54.65	81.21	87.32
140	31.43	36.03	41.06	46.34	57.26	63.38	94.19	101.27
150	36.08	41.36	47.14	53.20	65.73	72.76	108.13	116.26
160	41.05	47.06	53.63	60.53	74.79	82.78	123.02	132.27
170	46.35	53.13	60.55	68.33	84.43	93.45	138.88	149.33
180	51.96	59.56	67.88	76.60	94.66	104.77	155.70	167.41
190	57.89	66.36	75.63	85.35	105.47	116.74	173.48	186.53
200	64.15	73.53	83.80	94.57	116.86	129.35	192.22	206.68

Table 5.2 Safe distances at which the PPV will reduce to the vibration level not to be exceeded when the charge amount per delay is known.

Charge Amount Per Delay (kg)	Safe distance (m) to the pipeline not to exceed a given PPV value (mm/s) for different charge amounts							
	20.00		25.00		33.00		50.00	
	VS	PPV	VS	PPV	VS	PPV	VS	PPV
4.5	52.97	49.48	46.35	43.63	39.25	37.30	30.60	29.51
6.5	63.67	59.46	55.70	52.43	47.17	44.83	36.78	35.47
8.5	72.80	68.00	63.70	59.96	53.94	51.27	42.06	40.56
10.5	80.92	75.58	70.79	66.64	59.95	56.98	46.74	45.08
12.5	88.29	82.46	77.24	72.71	65.41	62.17	51.00	49.19
16.5	101.43	94.74	88.75	83.54	75.15	71.43	58.60	56.51
18.5	107.41	100.32	93.97	88.46	79.58	75.64	62.05	59.84
20.5	113.06	105.60	98.92	93.12	83.77	79.62	65.31	62.99
25.5	126.10	117.78	110.33	103.85	93.43	88.80	72.84	70.25

5.2 Vibration Controlled Blast Design

The foundation excavation were planned to be at distances between 120 m and 200 m from the pipeline. In Table 5.1, it is shown that the amount of explosive corresponding to 20 mm/s and 120 m is 26.47 kg. Considering ANFO bags which are 25 kg and a primer of 0.5 kg, 25.5 kg in each hole (also per delay) is practical and satisfies vibration requirements. Expected PPV from this much of explosive is expected to be at most, considering the closest distance which is 120 m, can be calculated as;
PPV = 5326.5 $(120\ \text{m}/\sqrt{25.50}\ \text{kg})^{-1.773}$ = 19.36 mm/s, which is below 20 mm/s.

Blasting parameters used for the blast design are the followings:

A-Blasthole diameter was kept the same as 89mm as used in test blasts. The reason for this was to limit the amount of explosive physically.

B-Burden was chosen to be 2.9 m and spacing as 3.5 m.

C-Bench height was chosen to be 7.5 m and longer than this height is not allowed in order to limit the use of explosive.

D- Considering the sub drill amount, maximum hole depth was chosen as 8.4 m. .

E-It is not allowed to load more than 25.5 kg of explosive into a blast hole due to ground vibration limitations.

F-If the particle size is found to be small, charge amount should be decreased.

G-Detonators having delay time of 17/500(17 ms surface delay time, 500 ms in hole delay time) are to be used.

H-It is not allowed to blast more than 3 rows in order to eliminate the interaction of the stress waves and to eliminate the possibility of pipeline resonance by limiting the duration. Limiting the number of rows limits the duration of blasting.

I-The number of blasthole fired per delay should not be more than one at a time in 8ms time window.

J-25ms delay should be used between rows (SD or Exel HTD)

K-In each hole only 0.5 kg of high explosive should be used as a primer.

Blast design parameters are shown in Figure 5.2 and Figure 5.3.

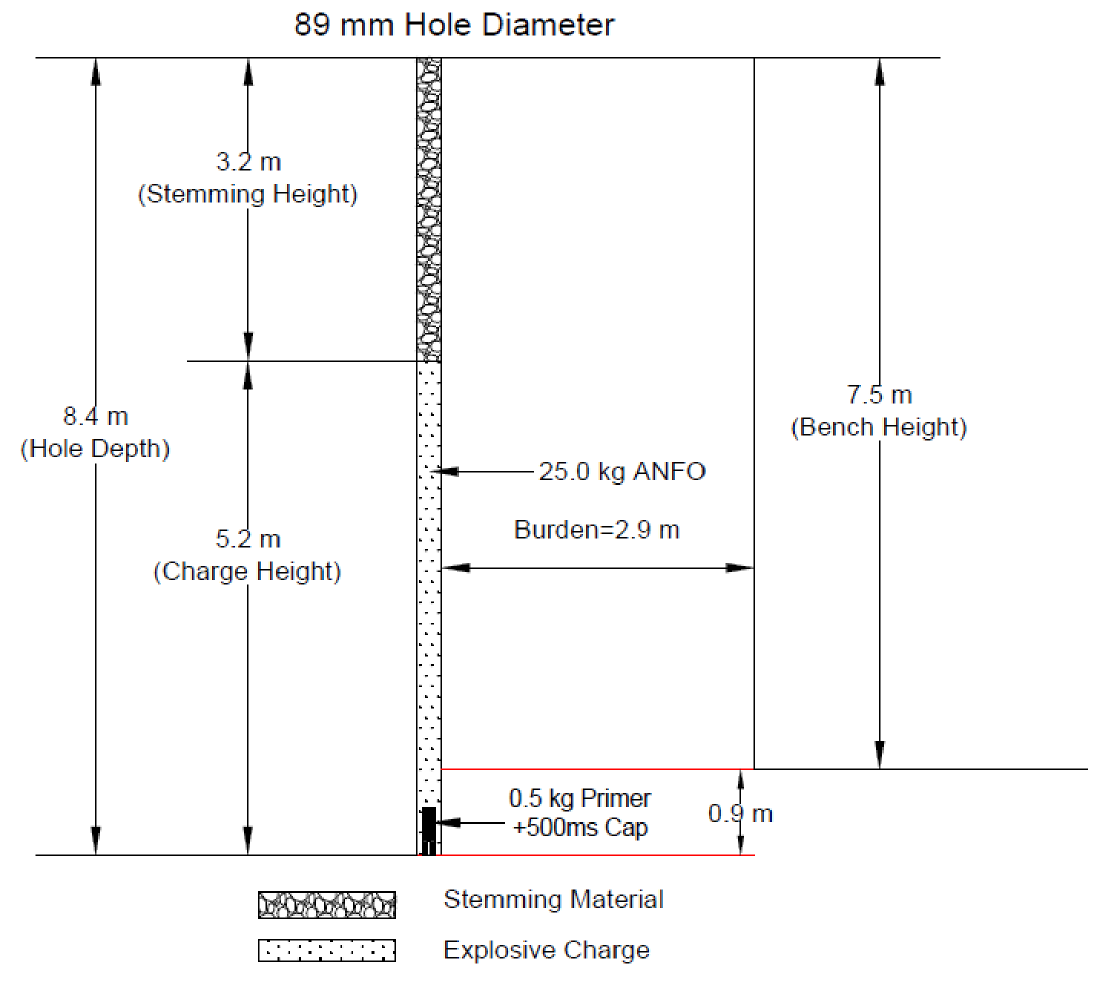


Figure 5.2 Bench blast design for production blasts for 7.5 m bench height

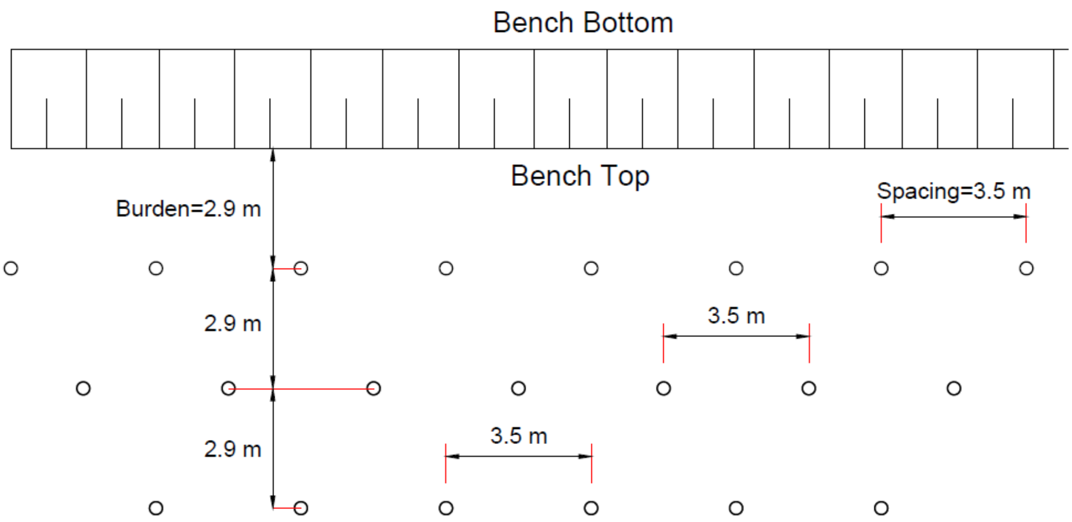


Figure 5.3 Blast pattern for production blasts for 7.5m bench height

Provided that the blasts are done as described above, it was concluded that there is no risk of damage to the pipeline based on the vibration measurements and the attenuation relation found.

This work is not a mining work hence the product of blasting will not be crushed or there is no need for further comminution so the particle size is not so important. However, the construction company demanded boulder size stones for wall construction. To meet the particle size demand of the contractor company, the specific charge had to be decreased either by changing the blasting pattern while keeping the amount of explosive per hole constant or by keeping the blasting pattern the same as described above and reducing the amount of charge that is loaded into a hole. When the results of the test blasts are analyzed, it can be concluded that the particle size after blasting was relatively small for this kind of work. The specific charge of the above described blasting pattern is 0.335 kg/m^3. Test blasts had lower specific charge (q=0.308 kg/m^3) than planned production blasts. There seems a contradiction here but the reason applying higher specific charge for production blasts even though coarser particle size is demanded is that test blasts were carried out close to the earth surface where the rock was fractured, fissured and weathered close to the surface. It was thought that applying the same specific charge as applied in test blasts might not yield desired results and the optimum specific charge was to be determined according to the results of the production blasts. If the particle size is found to be smaller than necessary, the amount is to be reduced down to 23 kg of ANFO while keeping the blasting pattern the same. If this is still not found enough, there might be additional decrease in ANFO down to 22 kg.

Considering the opposite situation, at which the size of the boulders are more than required, specific charge should be increased to increase the particle size. This can be achieved either by changing the blast pattern by decreasing the burden and spacing value or increasing the amount of explosives per hole (per delay). The latter is not practical since the maximum allowable charge amount was determined as to be 25.5 kg to keep the ground vibrations within the safe limits. So, for this kind of situation the specific charge should be decreased by modifying the blast geometry.

For example, if the particle size is found to be coarser than needed, the pattern may be narrowed to 2.8 m x 3.35 m (burden x spacing) and the volume of rock to be broken becomes (2.8 m x 3.35 m x 7.5 m = 70.35 m^3). The specific charge increases to 25.5kg/70.35 m^3 =0.362 kg/m^3. Similarly, if not satisfied with the results, the pattern may be further narrowed. Alternative patterns are presented in Table 5.3.

Table 5.3 Alternative blasting patterns to increase the specific charge by narrowing the pattern to decrease the particle size for 7.5 m bench height and 25.5 kg of explosive in one hole.

Burden (m)	**Spacing (m)**	**Bench Height (m)**	**Powder Factor(kg/m^3)**
2.90	3.50	7.5	0.335
2.80	3.35	7.5	0.362
2.70	3.25	7.5	0.387
2.60	3.10	7.5	0.420
2.50	3.00	7.5	0.453

As shown in Figure 3.4 three benches were planned to be constructed at final walls. To shape the final walls of the excavation in this way, different blasting patterns are needed. For this purpose benches with bench height of 5 m should be blasted and blast designs were carried for this length of bench height.

Blast pattern for 5 m bench height was determined to be as 2.5 x 3.0 m. There should be 1/3 inclination in the bench and the length of the blasthole was determined to be as 6.0 m. The length of the bench face becomes 5.25 m due to the inclination. The volume of the rock one hole breaks is 2.5 m x 3.0 m x 5.25 m =39.40 m^3. Considering the proposed powder factor which is 0.335 kg/m^3, the amount of explosive in one hole is calculated as 39.40 m^3 x 0.335 m^3 = 13.2 kg. 0.5 kg of this amount is the primer so the ANFO or Emulsion amount is calculated as 13.2-0.5=12.7 kg. This amount can be obtained by separating the amount of explosives in one ANFO bag (25 kg) equally into two holes. Hence the amount in one hole is calculated as 12.5 kg + 0.5 kg =13.0 kg. Blast design for 5m bench height is shown in Figure 5.4 and Figure 5.5

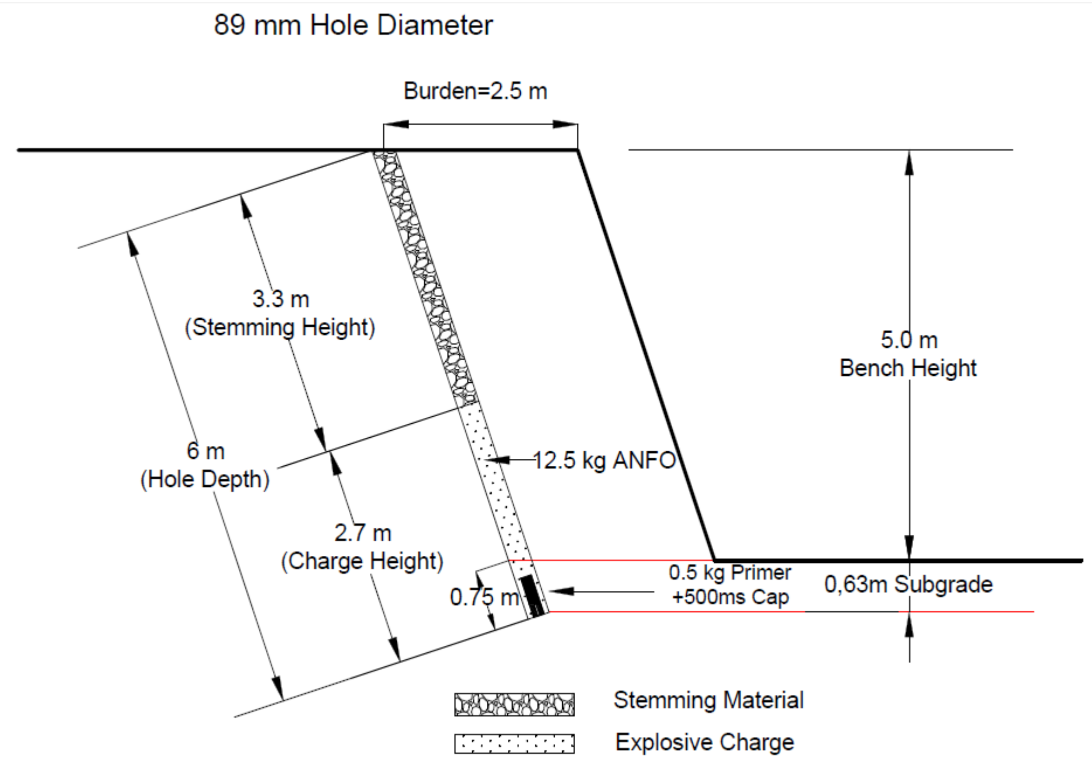


Figure 5.4 Bench blast design for 5 m bench height

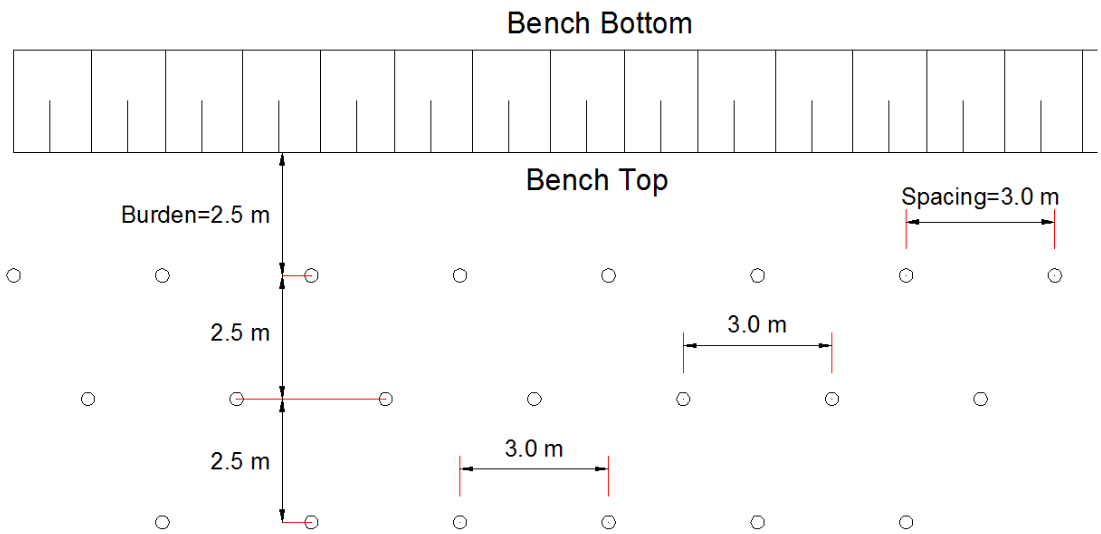


Figure 5.5 Blast pattern for 5 m bench height

Above given patterns should be tested and the results should be observed and evaluated for the optimization of the future blasts. If 0.329 kg/m^3 is found to be insufficient, the pattern may be narrowed to 2.4 m x 2.9 m. Corresponding specific charge for this pattern is calculated as 0.355 kg/m^3. If this is not found sufficient, the pattern may be further narrowed and the alternative patterns for particle sizing used in 5 m bench height is presented in Table 5.4.

Table 5.4 Alternative blasting patterns to increase the specific charge by narrowing the pattern to decrease the particle size for 5.0 m bench height and 13.0 kg of explosive in one hole.

Burden(m)	**Spacing(m)**	**Bench Height(m)**	**Powder Factor(kg/m^3)**
2.50	3.00	5.0	0.329
2.40	2.90	5.0	0.355
2.30	2.75	5.0	0.391
2.20	2.65	5.0	0.425

The charge amount calculated for 7.5 m bench height was given as 25.5 kg and the charge amount for 5 m bench height is 13.0 kg. 25.5 kg satisfies the vibration limits considering the minimum distance between the pipeline and the excavation or blasting area. Charge amount for 5 m bench height is less than 25.5 kg and it is calculated as 13.0 kg. Since the charge amount is less, expected vibration values don’t have any risk of damage to the pipeline for both 7.5 m and 5.0 m bench heights.

CHAPTER 6

PRODUCTION BLASTS AND GROUND VIBRATION ASSESSMENT

6.1 Production Blasts

Prior to each blast, surveyors were measuring and sending the boundary coordinates of the area to be blasted via e-mail. In Figure 6.1, one of the surveyors measuring the coordinates of the boundary of the area to be blasted is shown. Blasthole locations were determined based on the boundary of the area to be blasted. After creating the drill pattern and determining the locations of the blastholes on computer software, the coordinates of the blashole locations were sent back to the surveyors again. The surveyors were extracting all the coordinates of the holes from the drawing software and marking them on the field. Then, the driller was drilling all the holes at their exact location accordingly. After drilling, they were measuring the actual depth of the holes and the explosive amount was ordered accordingly. This was the production cycle for each blast. In total, more than 10 blasts were shot within the scope of Yozgat Main Water tank construction project.

Figure 6.1 One of the surveyors measuring the boundary of the area to be blasted.

Since actual depth of each hole was recorded by the surveyors, the amount of explosive to be loaded into each hole was calculated beforehand and predetermined for explosive ordering. On blasting day, depth and condition of each hole was checked again and compared with the reported one. If there become any change with the depth of hole, the charge amount to be loaded was recalculated on-site instantly by using a charging table which was prepared for each blast to satisfy the specific charge requirement for different burden, spacing and hole depth. Measured depth of blasthole, amount of explosive, and length of stemming was recorded and used for further evaluation of the blast. Besides, each blasting was monitored by seismographs and video recording of the blasts was done.

Because of the topography, not all the holes in one blast round had the same depth. So the length of the hole was depended on the surface elevation. After marking the blasthole locations, surveyors were measuring the surface elevation by GPS device.

By knowing the desired toe level after blasting, they were determining the depth of the hole to reach that level. For this reason, the blast geometry which was proposed in Section 5.2 only guided on the production blasts since not all the times the bench height was 7.5 m. Even in one blast round, there were blastholes depths ranging from 5.0 m to 7.5 m.

Blasthole locations of the first production blast in foundation excavation of the water tank construction project was determined by the drillers and it was noticed that the blastholes didn’t have any regular pattern. As it was mentioned before, the first specific charge value of 0.335 kg/m^3 was applied and the performance of the blast was evaluated. It was noticed that the particle was smaller than necessary, especially close to the surface, so the powder factor was determined to be decreased for the next blasts. The particle size distribution of the initial blasts are shown in Figure 6.2.

Figure 6.2 Particle size distribution after initial production blasts

The construction company needed boulder size fragments and to meet this requirement the powder factor used was decreased by changing the blast pattern. The initial actual blast design had around 0.335 kg/m^3 powder factor. This was lowered to around 0.300 kg/m^3 by increasing the burden and spacing or decreasing the charge amount. This resulted in big boulders for the construction company to do walling. The company selected the blasted rocks which were larger than 0.5 m. The fragment size after modifying the powder factor is shown in Figure 6.3 and Figure 6.4.

Figure 6.3 Fragment size distribution after blasting with decreased specific charge

To determine the length of the stemming to prevent flyrock problem different length of stemming were tried starting from 2.20 to 3.20. Since the rock structure close to the surface was fractured, longer stemming was needed and the best results were obtained from the application of stemming length of 3.20 m.

There become additional blasts in this foundation excavations which were unnecessary and could have been avoided if the driller and the surveyor were paid attention to the subdrill amount. Since the surveyors did some mistake in subdrill amounts, the desired level of the excavation area initially was not reached. Hence, additional blasts for leveling work were required. The required additional excavation length varied from 0.70 m to 3.5 m but most of the excavation requirement was in between 0.7 m and 2.0 m. For this work more than 900 holes were drilled to reach the desired level for the foundation. This was an extra work and resulted in higher cost for the contractor company. Leveling blast was done in the area shown in Figure 6.5.

Figure 6.4 Example boulder size after decreasing the specific charge

Figure 6.5 Area where additional drill and blast operations were done for leveling work

6.2 Assessment of Ground Vibration and Noise Induced by Production Blasts

6.2.1 Assessment of Ground Vibrations Caused by Production Blasts

Production blasts started in 11.01.2014 and ended in 04.04.2014. The maximum amount of explosives per delay blasted in production blasts ranged from 2.5 kg to 27.5 kg. Usage of 27.5 kg of explosives was due to loading an additional 2 kg of explosive cartridge mistakenly by workers. Production blasts were carried out at a minimum distance of 112.64 m and a maximum distance of 192.75 m to the pipeline. In total 31 seismograph data was recorded on top of the pipeline and the minimum PPV value was reported to be as 1.27 mm/s and the maximum PPV was reported to be as 29.10 mm/s. PPV values which exceeded 20 mm/s are 23.30 mm/s, 25.90 mm/s, 29.10 mm/s, 20.30 mm/s, 21.90 mm/s. The measured and the predicted values together with permitted ground vibration levels for buried pipes are given in Figure 6.6. All the vibration records taken on top of the pipeline are presented in Table 6.1 and Table 6.2. Seismograph records of production blasts are given in Appendix A.2.

Only five PPV values exceeded 20 mm/s maximum vibration limit aimed at this research. The reason for the vibration values to be higher than expected was because of the confinement due to choke blasting (blasting in the existence of previously blasted pile) and problems occurred with the detonators (misfires).

Upon initiation of some production blasts there existed a few cut-off incidents. This can be visualized by considering two rows that are tied together to be blasted. In the first row there existed a cut off and there didn't exist any cut-off in the second row. Since, the second row had a burden distance greater than normal after the cut-off in the first row, there existed a solid confinement hence this resulted in ground vibration values higher than aimed 20 mm/s vibration level. High vibration values were resulted from this fact. This could have been avoided if echelon type of tie-up were done instead of row by row delaying.

Although those 5 vibration measurements are higher than 20 mm/s, they are still well below the vibration limits set by different countries. The maximum PPV obtained was 29.10 mm/s. This value is 38.8% of the vibration limit set by Austrian Standard, 29.1% of the vibration limit set by German DIN Standard and 22.9% of the vibration limit set by USBM Standards for pipelines. Considering the fact that the vibration limits set by other countries in their vibration standards also accommodate factor of safety and the values are well below the maximum allowable limit set by other countries, the vibration levels caused by production blasts were within safe limits. Besides, the pipeline company didn't report any leakage or pressure drop during or after production blasts.

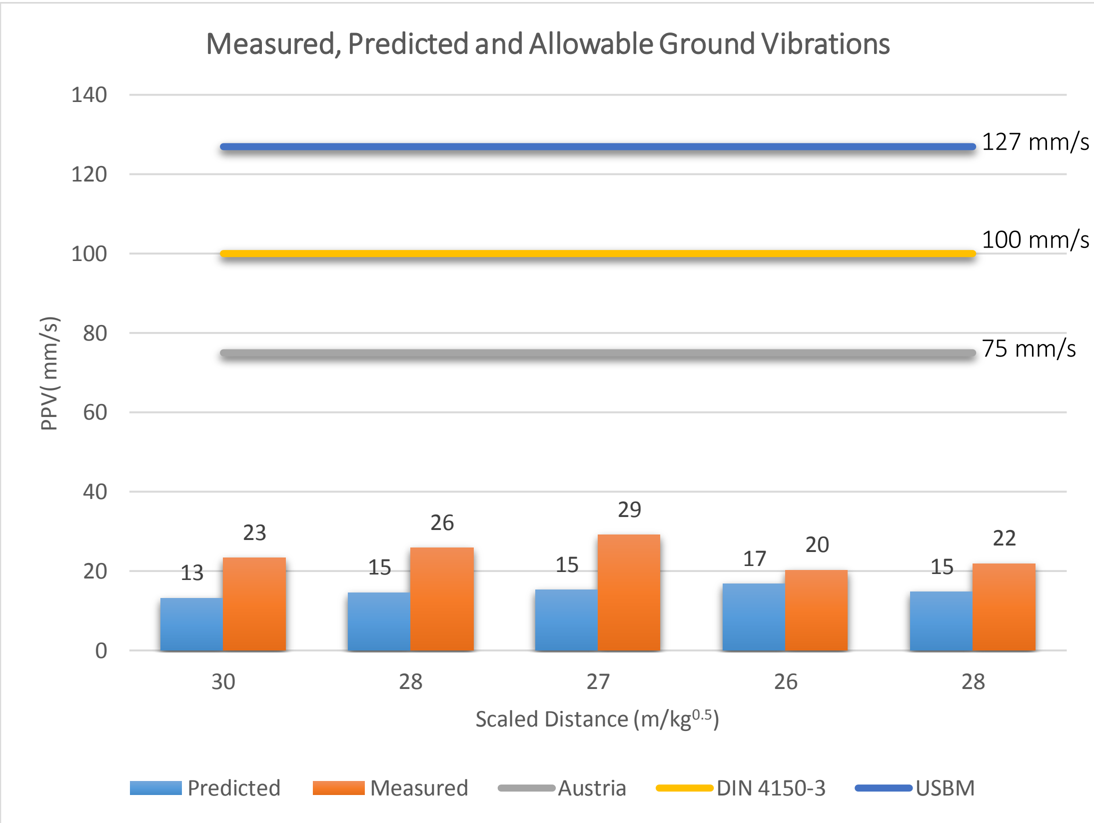


Figure 6.6 Measured, predicted and permitted ground vibration levels

Table 6.1 Vibration measurements taken at the ground surface on top of the pipeline

No	Device	Measurement Station	Peak Particle Velocity (mm/s)					Amount Q (kg)	Dist. D (m)	Scaled Dist. SD ($m/kg^{0.5}$)	Dominant Frequency of Ground Vibration Waves (Hz)			Time Meas.	Date Measured	Noise Level and Frequency of Sound Waves dB/Hz	Appendix No
			R	V	T	VS	PPV				R	V	T				
1	INS	Pipeline	3.170	1.250	1.950	3.280	3.170	6.50	192.75	75.60	128.00	52.10	62.50	12:57	11.01.2014	114.2 / 2.50	A.24-25
2	INS	Pipeline	5.780	2.290	3.140	5.870	5.780	10.50	182.40	56.29	37.30	29.50	135.00	13:21	11.01.2014	103.5 / 2.00	A.26-27
3	INS	Pipeline	8.570	4.050	5.600	9.100	8.570	16.50	179.87	44.28	56.40	83.40	84.30	13:40	11.01.2014	115.2 / 2.25	A.28-29
4	INS	Pipeline	10.100	5.130	6.430	10.700	10.10	18.50	166.08	38.61	52.90	47.50	51.00	15:20	11.01.2014	115.2 / 2.00	A.30-31
5	INS	Pipeline	9.810	5.810	5.750	9.910	9.810	24.50	182.93	36.96	36.00	78.50	42.80	15:47	11.01.2014	109.5 / 3.38	A.32-33
6	INS	Pipeline	5.560	7.780	7.870	10.000	7.870	18.50	180.25	41.91	80.60	80.90	68.10	13:59	17.01.2014	114.8 / 5.00	A.34-35
7	INS	Pipeline	8.700	8.860	12.000	13.000	12.00	22.50	173.23	36.52	57.60	65.80	64.30	14:18	17.01.2014	117.2 / 5.88	A.36-37
8	INS	Pipeline	10.800	11.800	10.500	14.900	11.80	26.50	162.55	31.58	50.40	77.10	41.40	14:38	17.01.2014	115.6 / 2.50	A.38-39
9	INS	Pipeline	12.100	12.000	15.700	18.700	15.70	26.50	158.23	30.74	56.30	74.50	60.30	14:57	17.01.2014	110.9 / 2.00	A.40-41
10	INS	Pipeline	12.300	8.190	17.700	18.400	17.70	19.50	155.36	35.18	117.00	117.00	63.00	14:31	24.01.2014	121.1 / 8.88	A.42-43
11	INS	Pipeline	11.500	10.100	23.300	23.400	23.40	25.50	149.00	29.51	119.00	29.80	71.40	14:44	24.01.2014	127.1 / 12.3	A.44-45
12	INS	Pipeline	15.300	17.400	25.900	28.100	25.90	27.50	145.90	27.82	47.90	110.00	102.00	15:01	24.01.2014	129.1 / 4.75	A.46-47
13	INS	Pipeline	17.600	14.700	29.100	31.000	29.10	25.50	137.00	27.13	47.60	33.90	65.80	15:15	24.01.2014	113.5 / 4.88	A.48-49
14	INS	Pipeline	8.970	8.350	11.800	12.300	11.80	20.00	157.73	35.27	54.30	76.50	92.60	16:20	11.02.2014	120.5 / 4.38	A.50-51
15	INS	Pipeline	9.100	8.060	10.100	11.700	10.10	18.00	145.49	34.29	55.90	47.10	46.50	16:45	11.02.2014	114.4 / 10.50	A.52-53
16	INS	Pipeline	18.400	16.700	20.300	23.100	20.30	25.50	129.84	25.71	57.10	42.60	46.00	17:09	11.02.2014	136.2 / 18.10	A.54-55
17	INS	Pipeline	6.510	6.640	11.000	12.000	11.00	22.50	125.39	26.43	51.30	43.00	52.40	17:34	11.02.2014	125.0 / 9.00	A.56-57
18	INS	Pipeline	7.430	5.430	8.920	9.630	8.920	22.50	125.51	26.46	38.60	28.30	39.00	11:44	12.02.2014	126.6 / 5.25	A.58-59
19	INS	Pipeline	11.500	11.700	9.460	15.300	11.70	20.50	116.85	25.81	29.60	43.00	40.10	12:11	12.02.2014	119.7 / 6.38	A.60-61

Table 6.2 Vibration measurements taken at the ground surface on top of the pipeline (continued)

No	Device	Measurement Station	Peak Particle Velocity (mm/s)					Amount Q (kg)	Dist. D (m)	Scaled Dist. SD (m/kg$^{0.5}$)	Dominant Frequency of Ground Vibration Waves (Hz)			Time Meas.	Date Measured	Noise Level and Frequency of Sound Waves dB/Hz	Appendix No
			R	V	T	VS	PPV				R	V	T				
20	W4282	Pipeline	1.397	0.889	1.524	1.581	1.524	6.50	183.18	71.85	39.00	45.75	39.00	13:25	14.03.2014	118.0 / 6.75	A.62
21	W4282	Pipeline	2.286	1.143	2.413	3.095	2.413	6.50	167.57	65.73	94.25	31.25	36.50	14:11	14.03.2014	114.0 / 21.75	A.63
22	W4282	Pipeline	2.286	1.016	1.143	2.290	2.286	2.50	156.69	99.10	138.50	76.00	86.00	15:36	15.03.2014	114.0 / 17.00	A.64
23	W4282	Pipeline	2.667	1.270	1.778	2.739	2.667	4.50	146.50	69.06	133.50	102.00	91.25	16:13	15.03.2014	114.0 / 16.00	A.65
24	W4282	Pipeline	1.270	0.635	0.635	1.276	1.270	2.50	148.75	94.08	119.00	115.50	95.50	16:46	15.03.2014	106.0 / 12.50	A.66
25	W4282	Pipeline	17.780	9.652	9.271	18.309	17.780	20.50	137.31	30.33	52.25	45.25	41.75	17:17	15.03.2014	114.0 / 3.00	A.67
26	W4282	Pipeline	17.272	10.668	12.065	17.546	17.272	20.50	136.41	30.13	125.50	42.00	59.00	17:54	15.03.2014	116.0 / 3.00	A.68
27	W4282	Pipeline	8.763	6.096	5.080	10.535	8.763	18.50	134.45	31.26	52.50	43.00	45.50	18:30	15.03.2014	118.0 / 6.50	A.69
28	INS	Pipeline	10.300	6.570	13.900	14.400	13.90	20.50	123.02	27.17	51.30	74.40	61.80	14:11	19.03.2014	108.0 / 8.75	A.70-71
29	INS	Pipeline	21.900	10.500	14.000	23.100	21.90	16.50	112.64	27.73	40.00	46.40	55.90	14:59	19.03.2014	113.3 / 3.00	A.72-73
30	INS	Pipeline	12.700	5.700	12.100	13.000	12.70	18.50	133.14	30.95	45.60	45.80	83.90	14:40	04.04.2014	108.8 / 3.00	A.74-75
31	INS	Pipeline	11.500	6.020	11.500	13.100	11.50	22.50	125.3	26.42	46.60	45.90	62.10	15:09	04.04.2014	114.2 / 5.00	A.76-77

The vibration measurements were taken on the ground surface on top of the pipeline and according to Aimone Martin & Clah (2003), the vibration values measured on ground surface are higher than that of measured at depth. In their paper they present the ratio of vibrations measured on the ground surface to that of measured at depth (1.78 m from the surface) for two types of blasts, namely high relief and high confinement. These ratios are presented in Table 2.11.

When those five measurements which are above 20 mm/s are analyzed further, it can be seen that four of them are in transverse direction and one in radial direction. By using Table 2.11 these values can be converted to the PPV values likely to be monitored on the buried pipeline if it was permitted by BOTAŞ to be directly monitored on the pipeline. Blasts giving these high values are confined blasts, hence dividing the vibration values in transverse direction by 3 and the values in radial direction by 1.3 would be a convenient approach. Corresponding indirect vibration values that the pipeline was assumed to be exposed to are calculated and presented in Table 6.3

Table 6.3 Indirect vibration values on the pipeline

PPV Component	PPV monitored at the surface on top of buried pipeline (mm/s)	Ratio	PPV likely to be monitored on the pipeline (mm/s)
Transverse	23.3	3.0	7.77
Transverse	25.9	3.0	8.63
Transverse	29.1	3.0	9.70
Transverse	20.3	3.0	6.77
Radial	21.9	1.3	16.85

Although the vibration values on the surface are above 20 mm/s, vibration values which are likely to be monitored on the pipeline are well below 20 mm/s.

Apart from the pipeline, other structures around the blast area, although they are relatively distant, were considered. For this purpose, vibration and noise measurements were done next to buildings of various kinds. These buildings and their distance to the blast are shown in Figure 6.7. Information about the vibration and noise measurements done next to these buildings are presented in Table 6.4.

Table 6.4 Ground vibration and noise measurements taken next to the buildings

Location	PPV(mm/s)	Amount(kg)	Dist.(m)	SD(m/kg$^{0.5}$)	dB	Date
Prison Hou.	0.254	22.5	955.75	201.49	106	17.01.2014
Prison Hou.	0.381	26.5	959.75	186.44	100	17.01.2014
Prison Hou.	0.381	26.5	957.06	185.92	100	17.01.2014
TOKI Hou.	0.127	19.5	1209.32	273.86	106	24.01.2014
TOKI Hou.	0.127	25.5	1227.61	243.10	106	24.01.2014
TOKI Hou.	0.127	27.5	1224.56	233.51	112	24.01.2014
TOKI Hou.	0.127	25.5	1225.25	242.64	106	24.01.2014
Milk-Meat	0.254	18.5	639.64	148.71	116	17.01.2014
Milk-Meat	0.381	22.5	645.82	136.15	118	17.01.2014
Milk-Meat	0.381	26.5	655.34	127.30	118	17.01.2014
Milk-Meat	0.635	26.5	656.01	127.43	112	24.01.2014
Milk-Meat	0.381	19.5	650.14	147.23	119	24.01.2014
Milk-Meat	0.508	25.5	667.28	132.14	122	24.01.2014
Milk-Meat	0.381	27.5	665.23	126.85	124	24.01.2014
Milk-Meat	0.508	25.5	667.75	132.23	110	24.01.2014

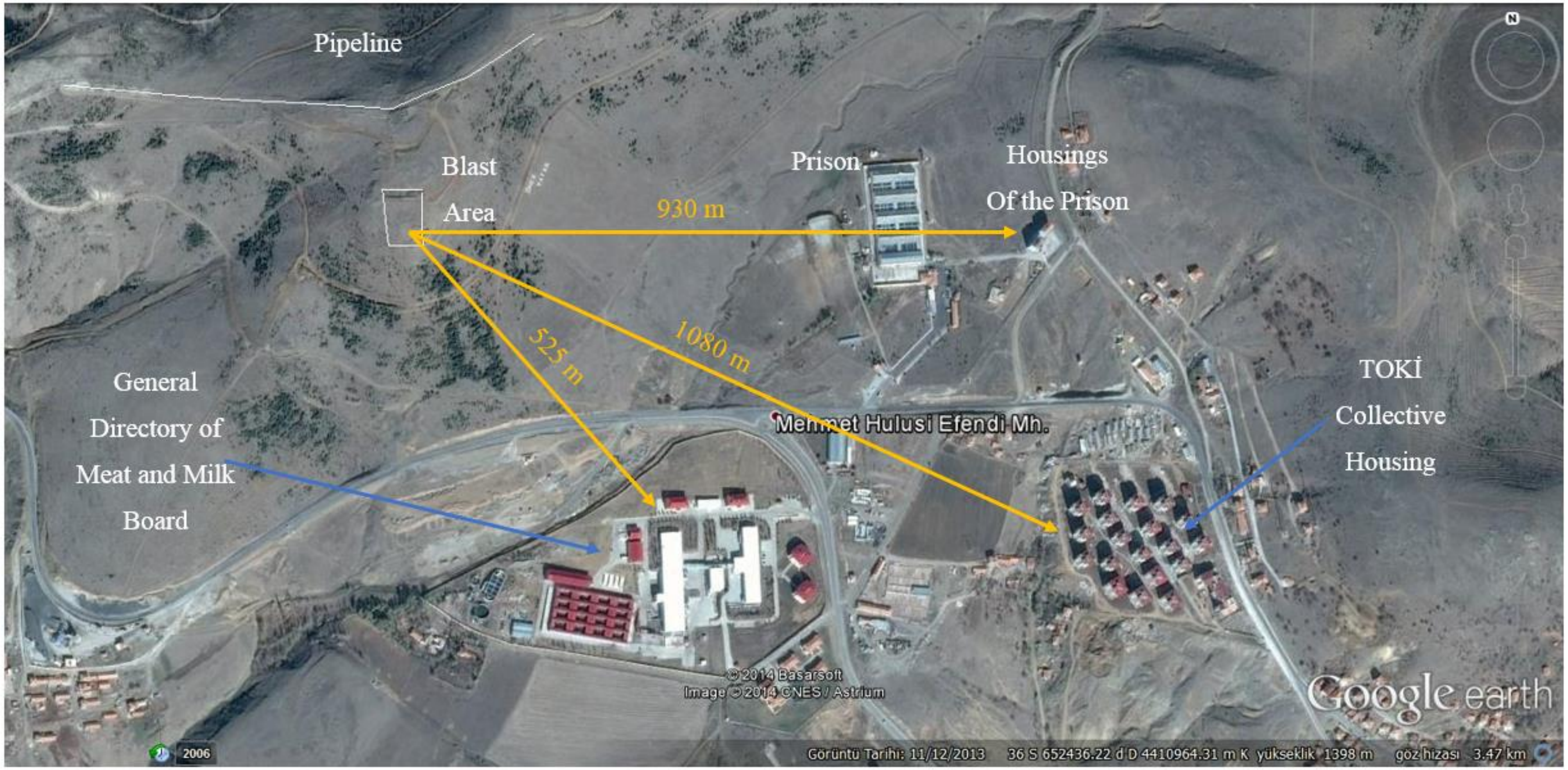


Figure 6.7 Buildings and their distances to the blast area

When vibration values obtained from the measurements done next to Housings of the Prison are analyzed, it can be seen that the maximum PPV was 0.381 mm/s and this value was recorded when 26.5 kg of explosive was detonated at a distance of 957.06 m to the Housings of the Prison. The minimum dominant frequency calculated by using FFT method was 34.13 Hz and the allowable ground vibration level corresponding this is stated as 50 mm/s in the regulation. Hence, the ground vibration levels on the Housings of the Prison were below the values stated in the regulation and there was no risk of damage to the structures.

When vibration values obtained from the measurements done next to TOKI Collective Housing are analyzed, it can be seen that the maximum PPV was 0.127 mm/s and this value was recorded when 27.5 kg of explosive was detonated at a distance of 1224.56 m to Housings. The minimum dominant frequency calculated by using FFT method was 1.0 Hz and the allowable ground vibration level permitted for this frequency is stated as 5 mm/s in Turkish regulation. The reasons why this much of low frequency value was measured were due to a great distance of 1224 m and due to the existence of a thick landfill around the housings. Since 0.127 mm/s ground vibration level measured at the ground of housings is well below 5.0 mm/s as stated in the regulation, there was no risk of damage to the structures.

When vibration values obtained from the measurements done next to the buildings of the General Directorate of Meat and Milk Board are analyzed, it can be seen that the maximum PPV was 0.635 mm/s and this value was recorded when 26.5 kg of explosive was detonated at a distance of 656.01 m to the buildings. The minimum dominant frequency calculated by using FFT method was 10.31 Hz and the allowable ground vibration level for the frequencies between 4-10 Hz in the regulation is stated to be as 19 mm/s. Since 0.635 mm/s is well below 19 mm/s, the ground vibration levels monitored on the ground of buildings of the Milk and Meat Board were below the values stated in the regulation and there was no risk of damage to the structures.

6.2.2 Assessment of Noise Caused by Production Blasts

No limiting value for the noise induced by blasting operation is given in Turkish regulation. Therefore, the limiting values given in US Federal Regulation are taken into account for the evaluation of the noise levels monitored.

The maximum and minimum level of noise measured next to the Housings of the prison was recorded to be as 106 dB and 100 dB, respectively. When these values are compared to the permitted 133 dB value stated in US Federal Regulations, it is understood that the air vibration levels caused by production blasts next to the housings of the prison were below the permitted limit and complying with the regulation. These values are even lower than the level of air vibration at which people start to complain which is 117 dB.

The maximum and minimum level of noise measured next to the TOKI Collective Housings was recorded to be as 112 dB and 106 dB, respectively. When these values are compared to the permitted 133 dB value stated in US Federal Regulations it is understood that the air vibration levels caused by production blasts next to the housings were below the permitted limit and complying with the regulation. These values are even lower than the level of air vibration at which people start to complain which is 117 dB.

The maximum and minimum level of noise measured next to the buildings of Milk and Meat Board was recorded to be as 124 dB and 110 dB, respectively. When these values are compared to the permitted 133 dB value stated in US Federal Regulations it is understood that the air vibration levels caused by production blasts next to the buildings were below the permitted limit and complying with the regulation. However, the air vibration levels of 5 out of 8 recorded blasts were above the complaining level of 117 dB but based on the conversations with the people working at Milk and Meat Board there was no complaint for the blast events.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The foundation excavation for 15,000 m^3 capacity Yozgat City water tank was tried by mechanical excavation means for two months. The existing rock conditions were found to be hard for mechanical excavation. Therefore, this research study was planned and carried out in two steps; first, a test blast and monitoring program, and second, a cautious blast design and implementation and monitoring program based on the first step.

The main conclusions and the recommendations drawn from this research, on controlled blasting design and implementation nearby a buried gas pipeline and vibration monitoring are:

1. It was decided that the existing rock conditions were hard to work with mechanical excavation and blasting was the only way out in terms of time and money.
2. If the whole excavation was carried out by mechanical rock excavation, the estimated cost would be about 2.5 to 3 times of that of blasting.
3. Unless blasting was carried out, the foundation excavation for water tank would take 6 months to 1 year longer.
4. Test blasts were carried out by using explosive amounts ranging from 4.5 to 18.5 kg. The maximum PPV was measured when 18.5 kg of explosive was detonated at a distance of 179.5 m and it was 4.32 mm/s. This result proved that the full scale cautious blast was feasible.
5. The resulted vibration values from test blasts were low, so they didn't cause any damage to both the pipeline and the other structures around the blast area, as it was expected.

6. DIN 4150-3 standard for steel welded pipes was referenced to design and implement both test and full scale blasts. The maximum allowable PPV value aimed at in this study was selected as 20 mm/s.
7. By using the site attenuation relation, it was found that there was no damage risk of blasting to the pipeline even at the closest end of the excavation unless safe amounts of explosive were not exceeded.
8. Maximum allowable amount of explosive to be detonated was calculated as 25.50 kg/delay. To limit the charge amount, the bench height was selected as 7.5 m at maximum for a blasthole diameter of 89 mm.
9. All the vibration values were nearly as they were expected. However, 5 of them were above 20 mm/s and this was thought to be caused by the confinement effect generated by cut-off related issues like blasting to an excessive burden and also choke blasting applications.
10. Row by row delaying played major role in the occurrence of cutoffs and the formation of high confinement due to excessive burden distance generated by cut offs. This could have been avoided if echelon type of tie-up were done instead of row by row delaying.
11. The vibration monitoring was done at the ground surface directly on top of the buried pipeline during both test and full scale blasts. Aimone Martin & Clah (2003) reported that the vibration measured at or nearby a buried pipe is always less than that of measured at the ground surface by some factors. Accordingly, the PPV values measured in this study which are exceeding 20 mm/s, were divided by the factors reported by Aimone Martin & Clah (2003) to find the vibration amplitudes likely to be monitored on the pipeline. The calculated vibration values on buried pipeline were found to be below 20 mm/s.
12. Ground and air vibration levels were measured next to the buildings of various kinds. Measured values were within the permitted limits stated in Turkish Regulation and US Federal Regulation.
13. Vibration levels on the pipeline were also below the vibration value at which onset of cracking on concrete was expected (338 mm/s). Hence, if any concrete structured material is used in the pipeline construction, no risk of damage is predicted.

14. No leakage and pressure drop was detected and reported by BOTAŞ following both production and test blasts.
15. All blasts were carried out successfully within the distance prohibited by BOTAŞ which was 200m. Hence, regulation of BOTAŞ was found to be very conservative and it was revealed that there exists a need for a blast regulation for the pipelines in Turkey.
16. In future research work on controlled blasting near the pipelines, the vibration monitoring should be done not only at ground surface on top of the pipeline, but also in a trench dug for the purpose and at the ground next to pipeline and directly on the pipeline. This will lead to better understanding of the response of pipeline and the variation of wave propagation characteristics with depth.

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APPENDIX A

A.1. GROUND VIBRATION AND AIRBLAST MEASUREMENTS OF TEST BLASTS

Ground vibration and airblast measurements of test blasts are presented in the following pages.

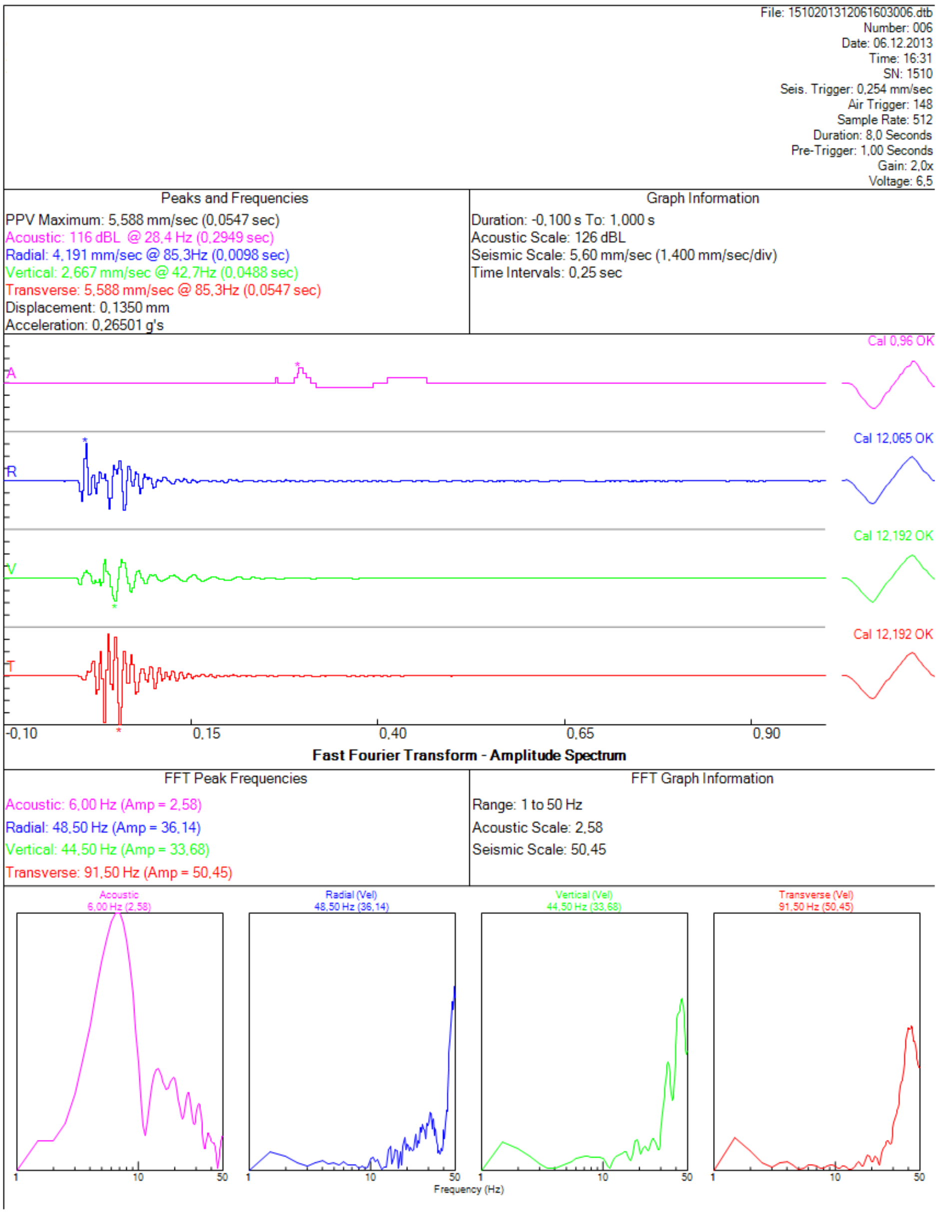


Figure A. 1 No:1 Seismograph record of test blasts

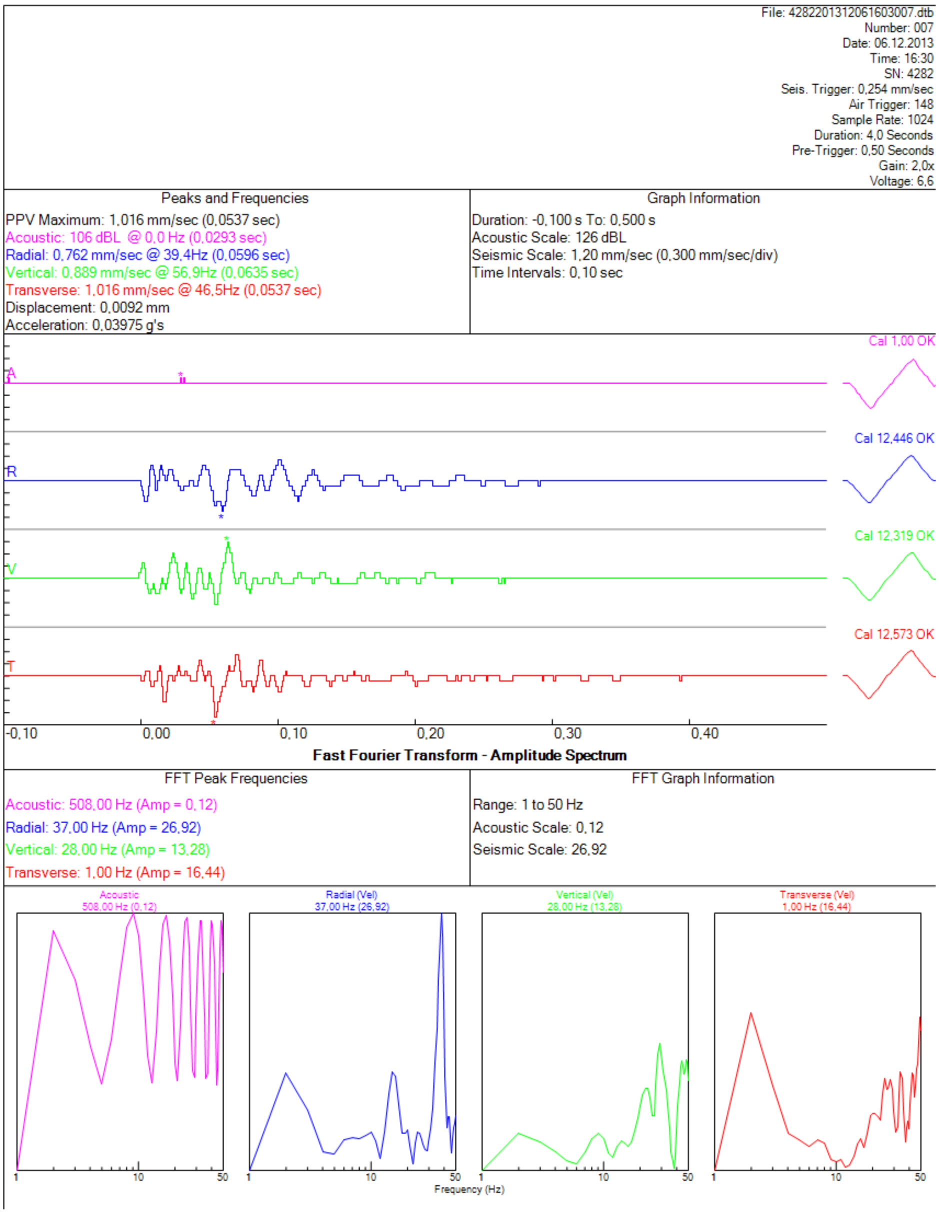


Figure A. 2 No:2 Seismograph record of test blasts

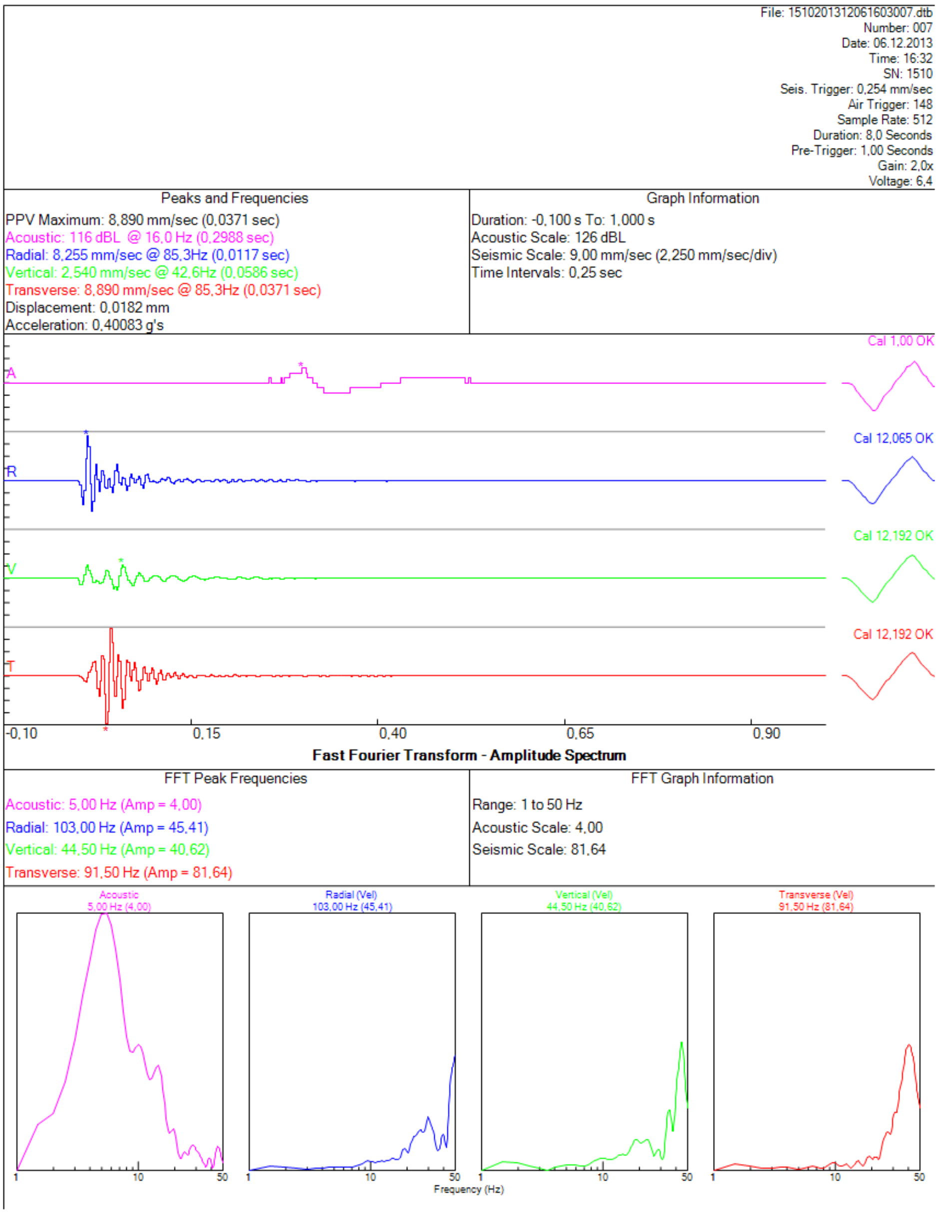


Figure A. 3 No:3 Seismograph record of test blasts

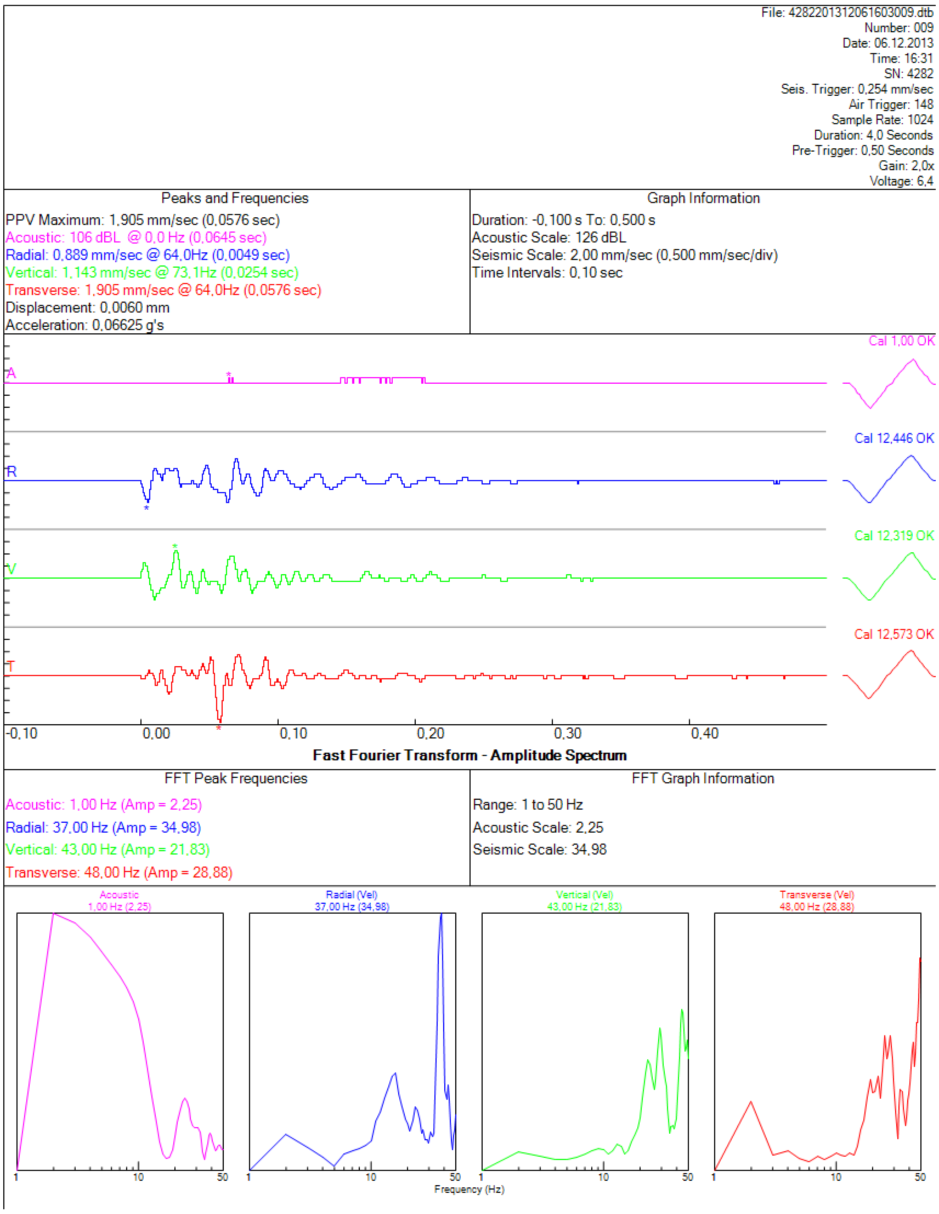


Figure A. 4 No:4 Seismograph record of test blasts

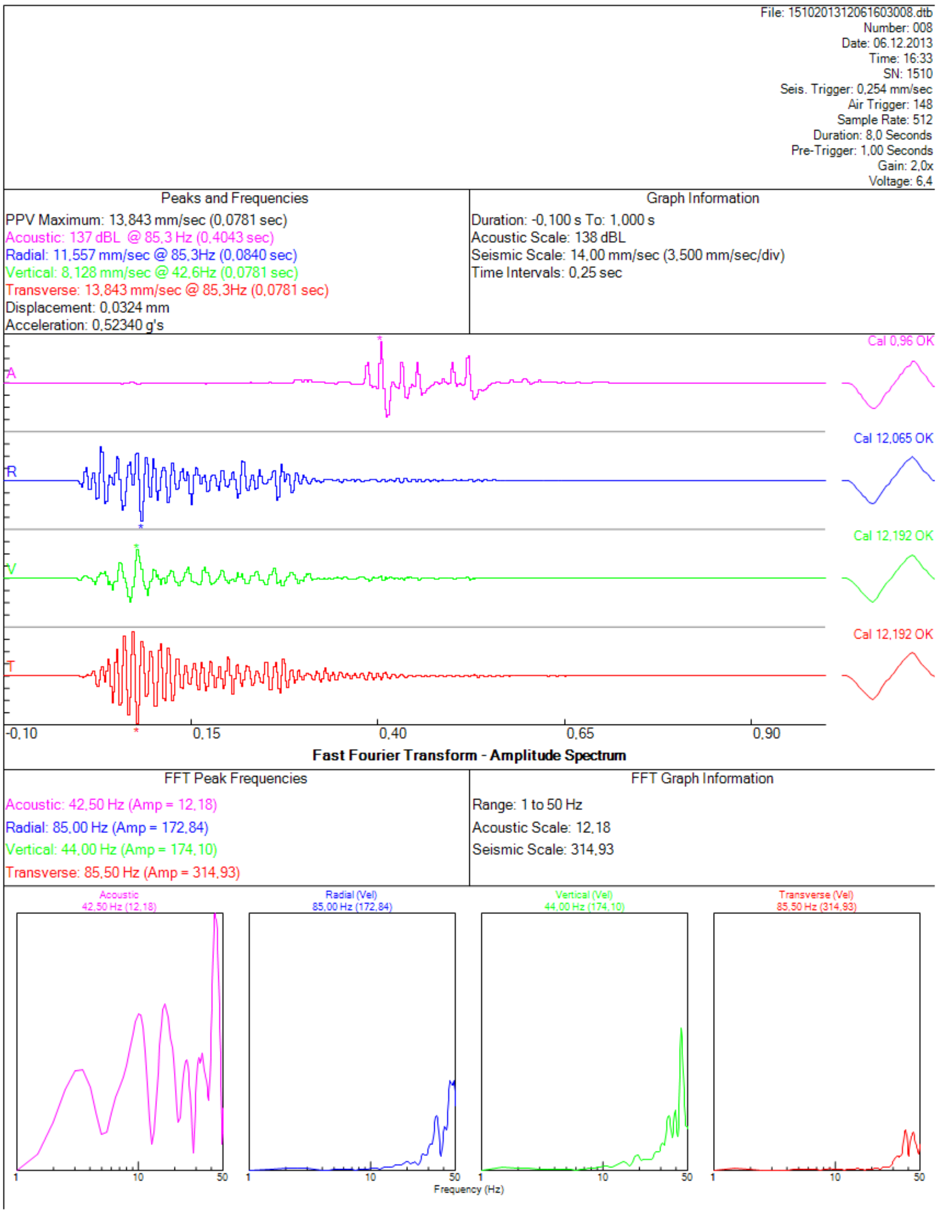


Figure A. 5 No:5 Seismograph record of test blasts

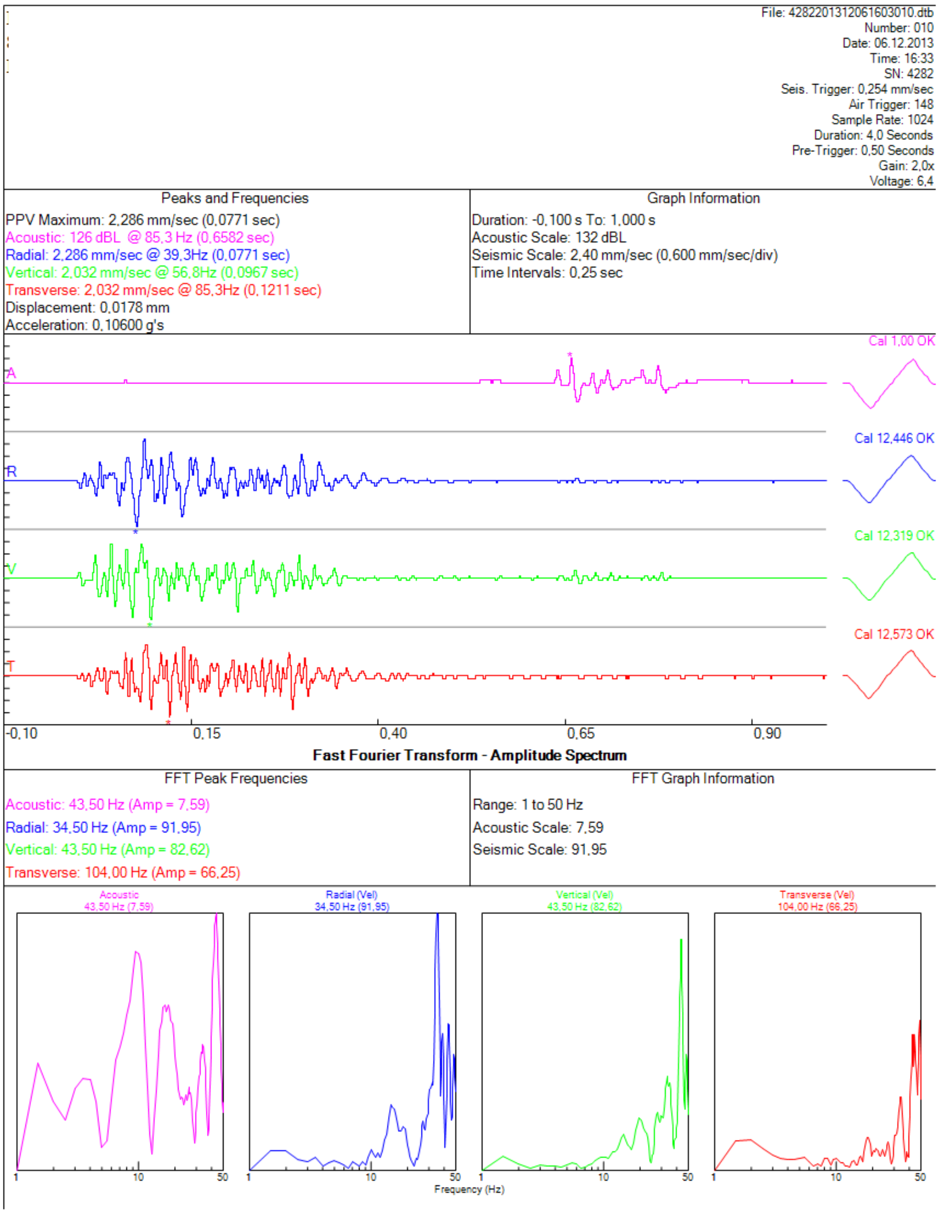


Figure A. 6 No:7 Seismograph record of test blasts

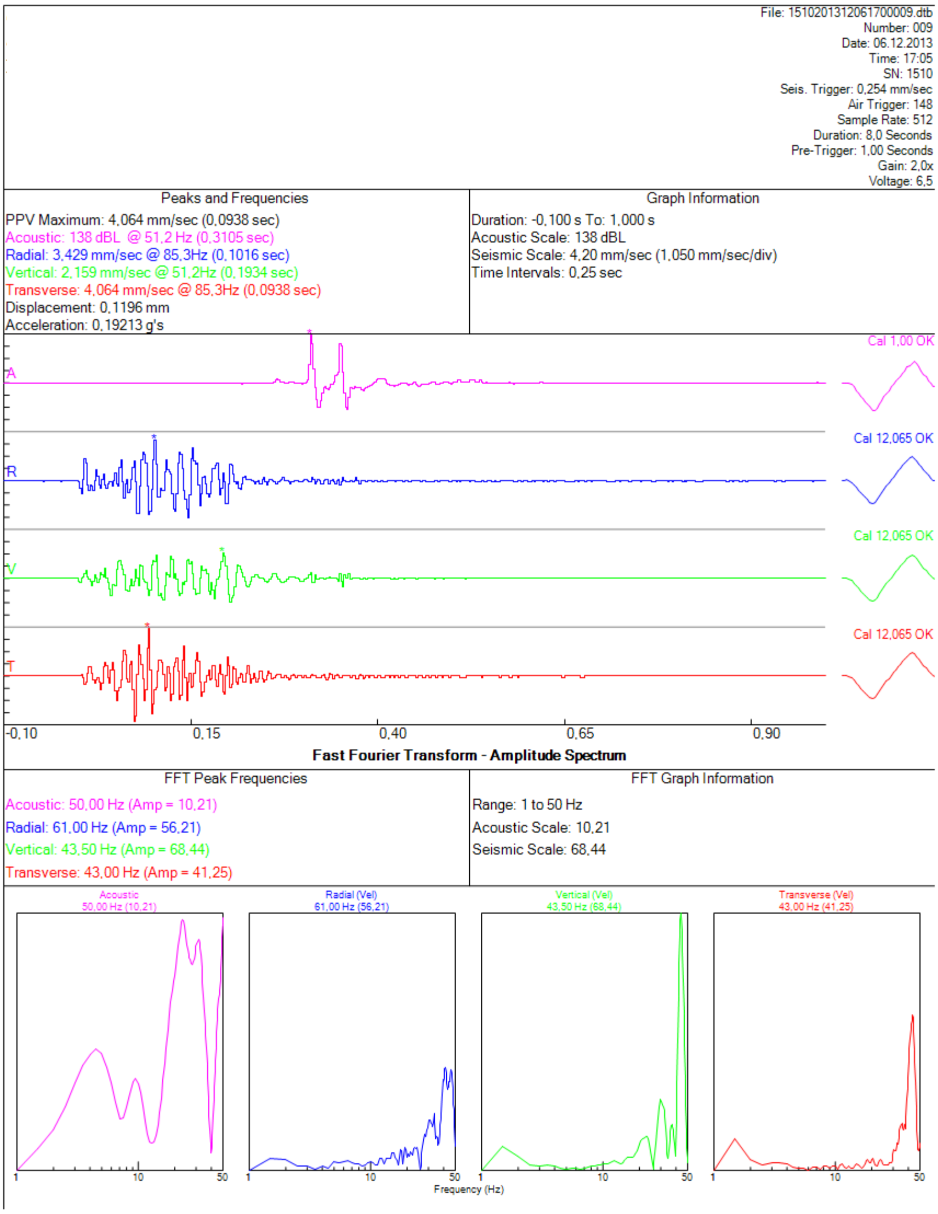


Figure A. 7 No:8 Seismograph record of test blasts

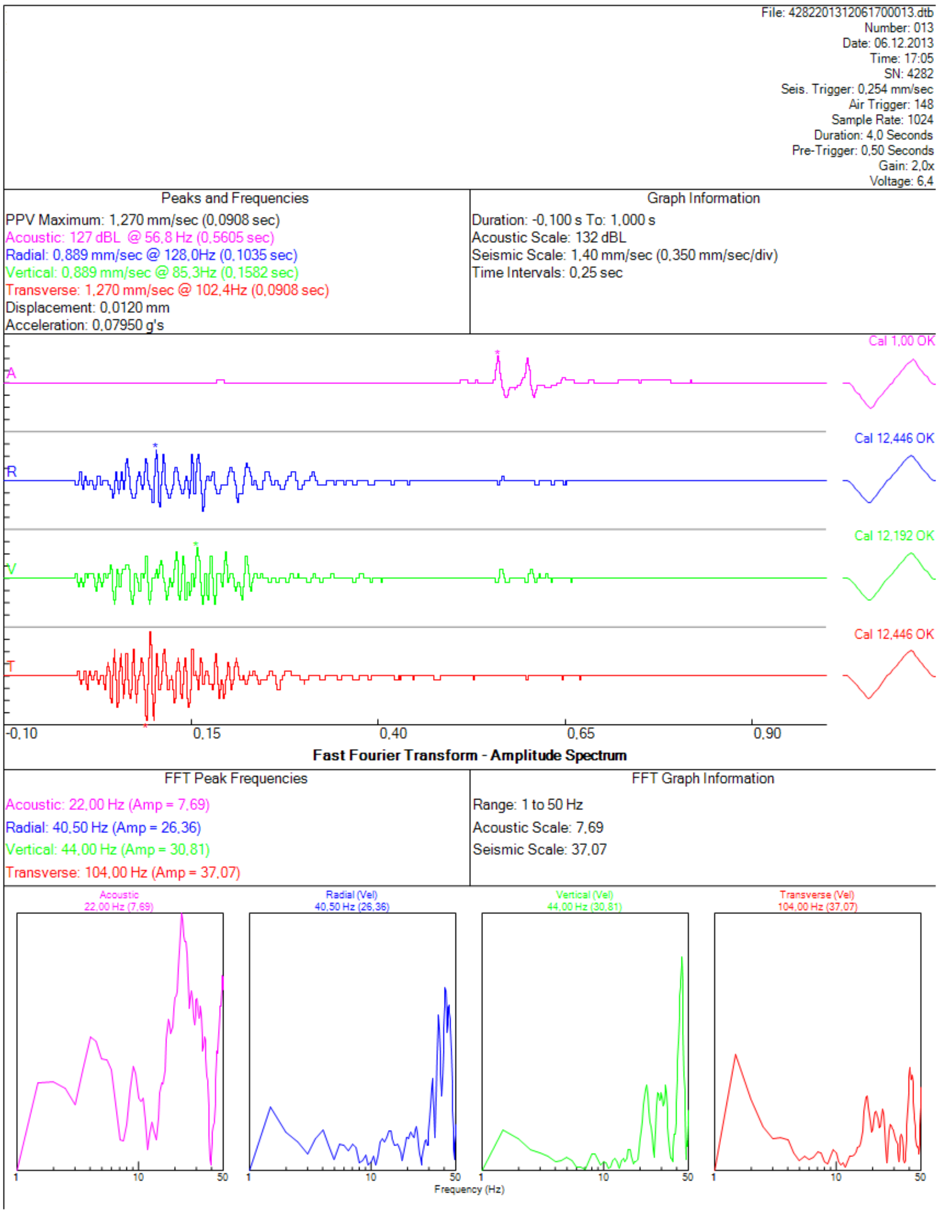


Figure A. 8 No:10 Seismograph record of test blasts

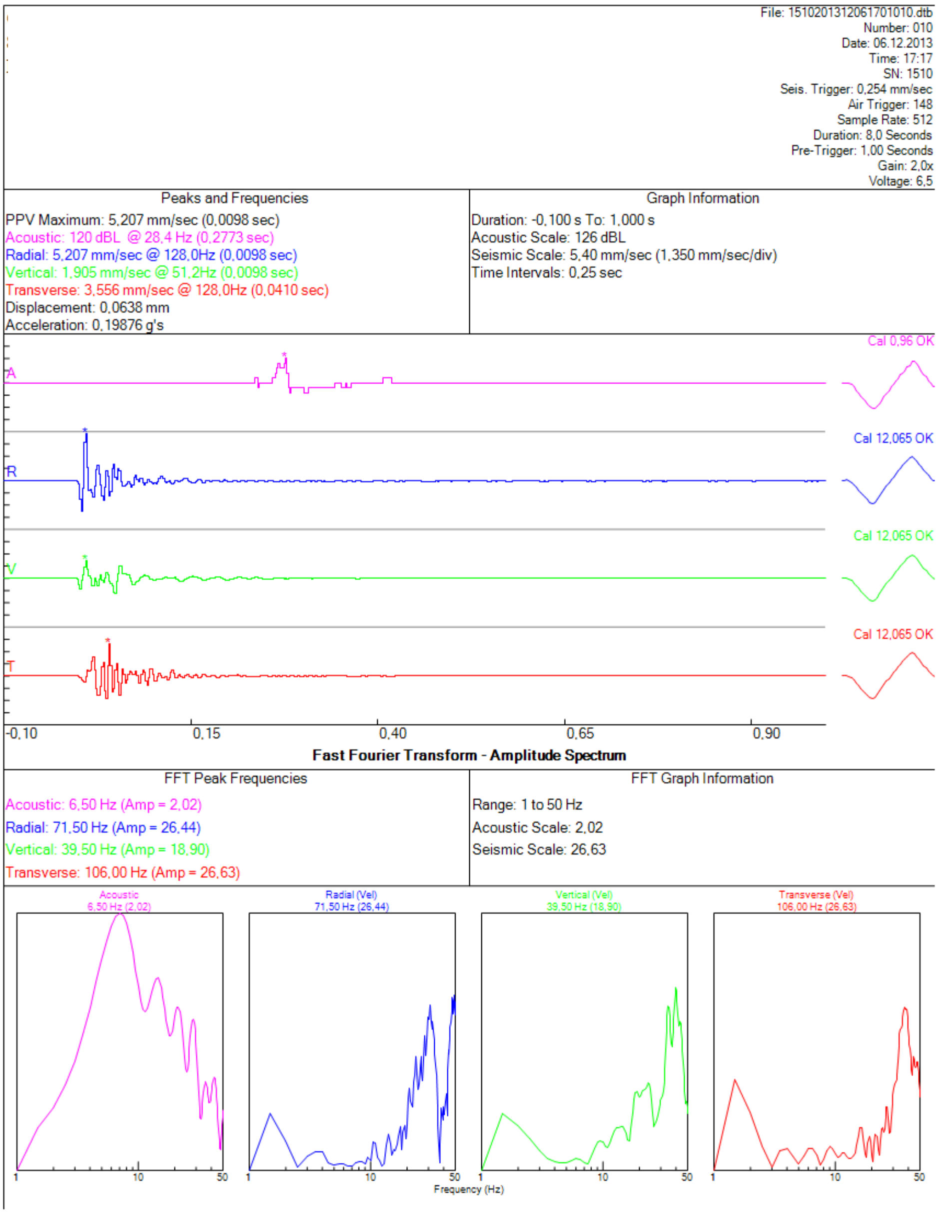


Figure A. 9 No:11 Seismograph record of test blasts

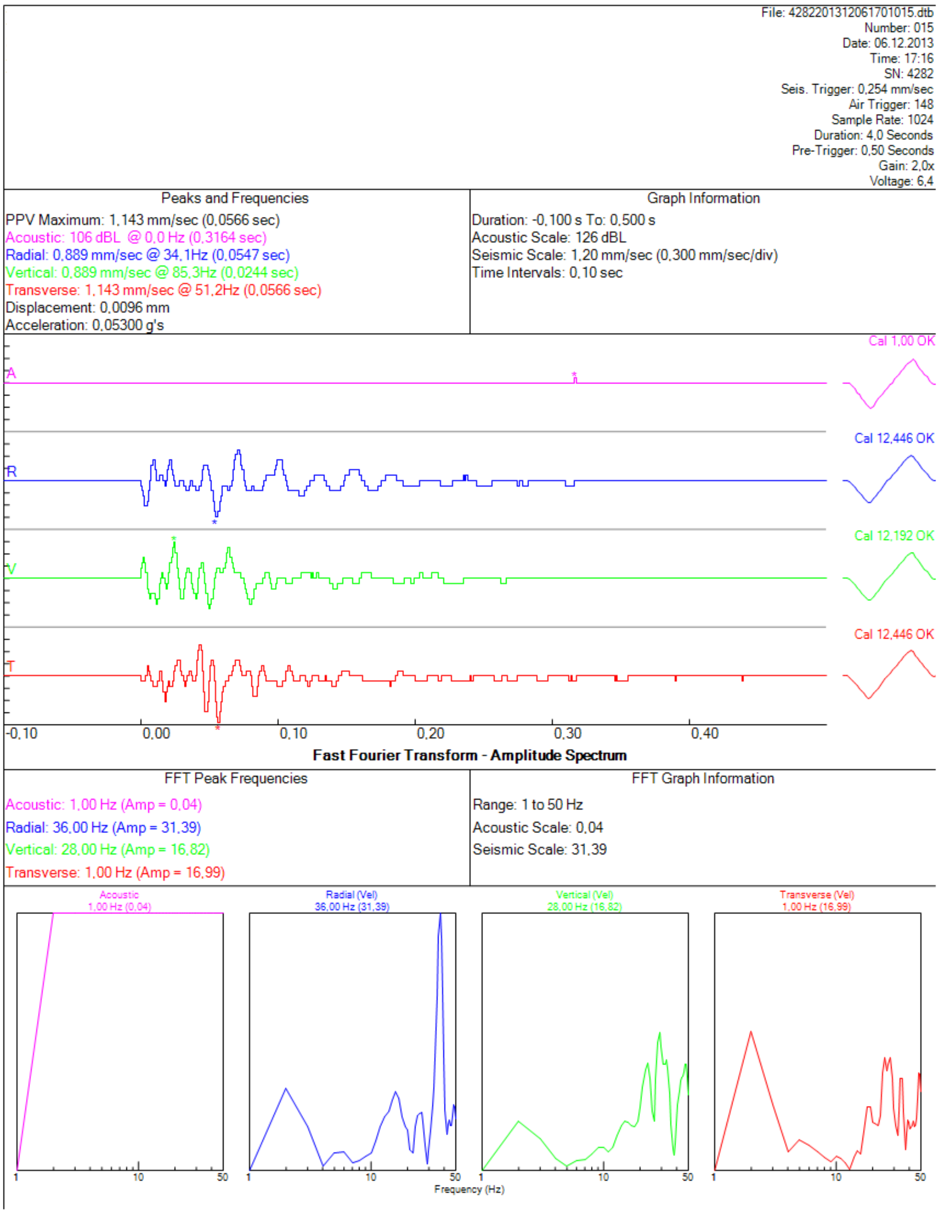


Figure A. 10 No:13 Seismograph record of test blasts

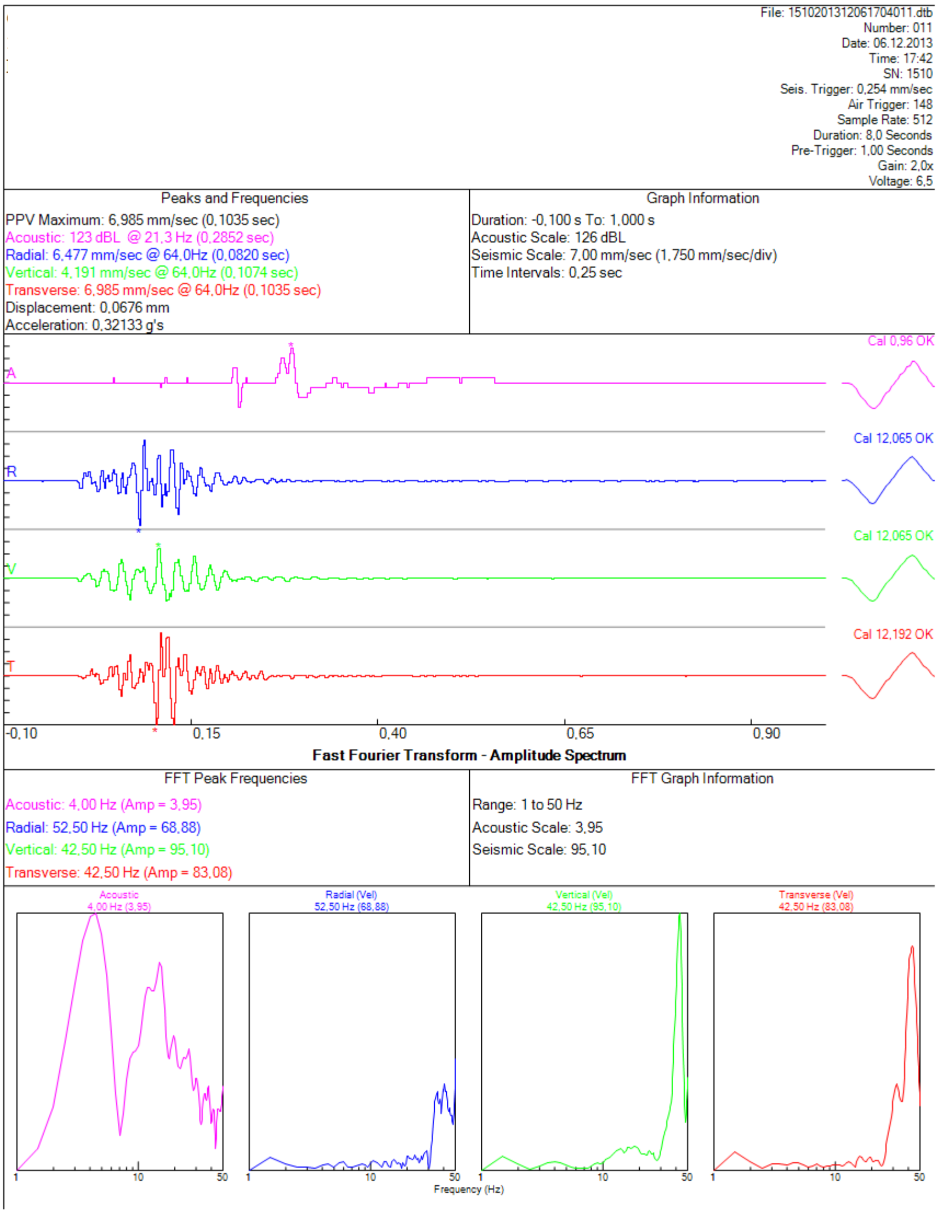


Figure A. 11 No:14 Seismograph record of test blasts

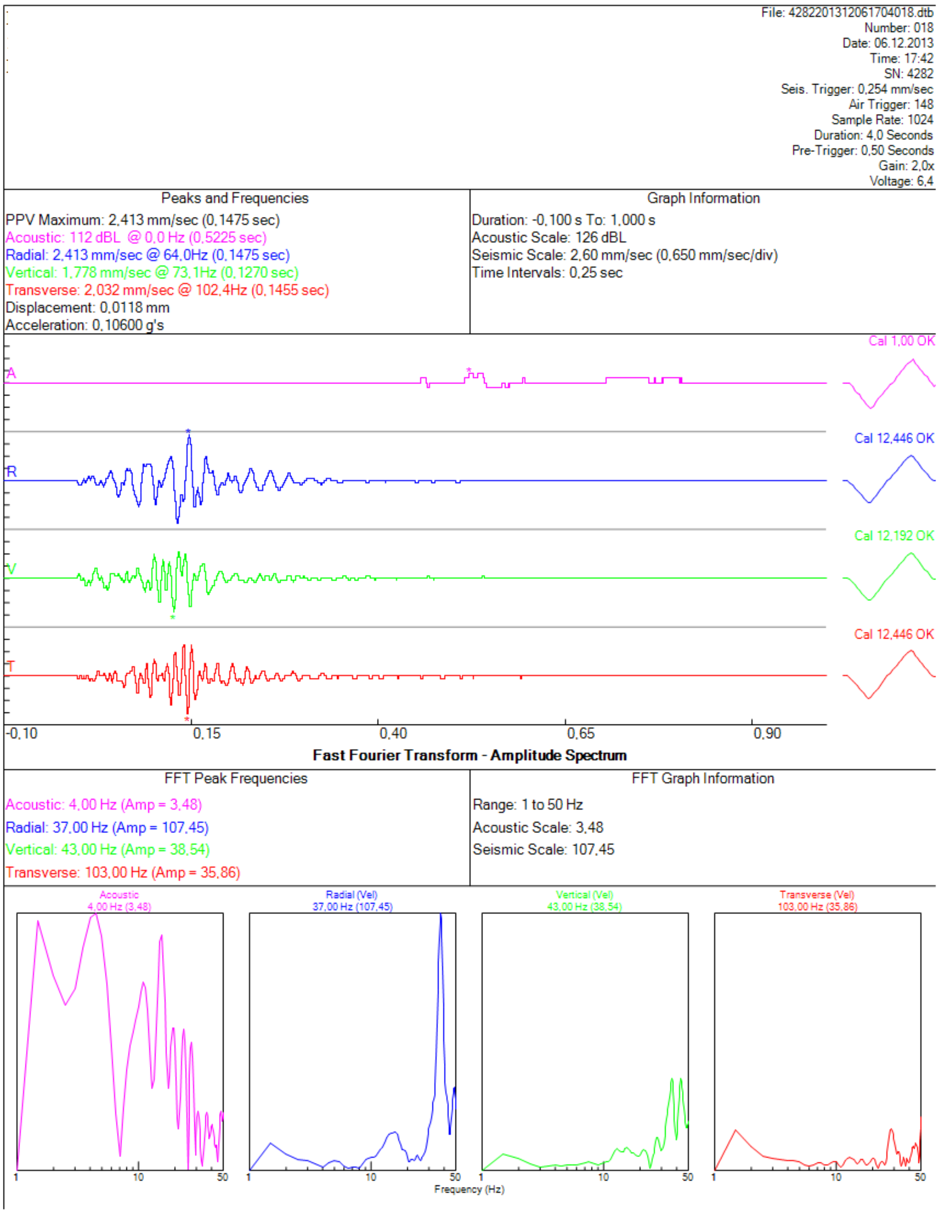


Figure A. 12 No:16 Seismograph record of test blasts

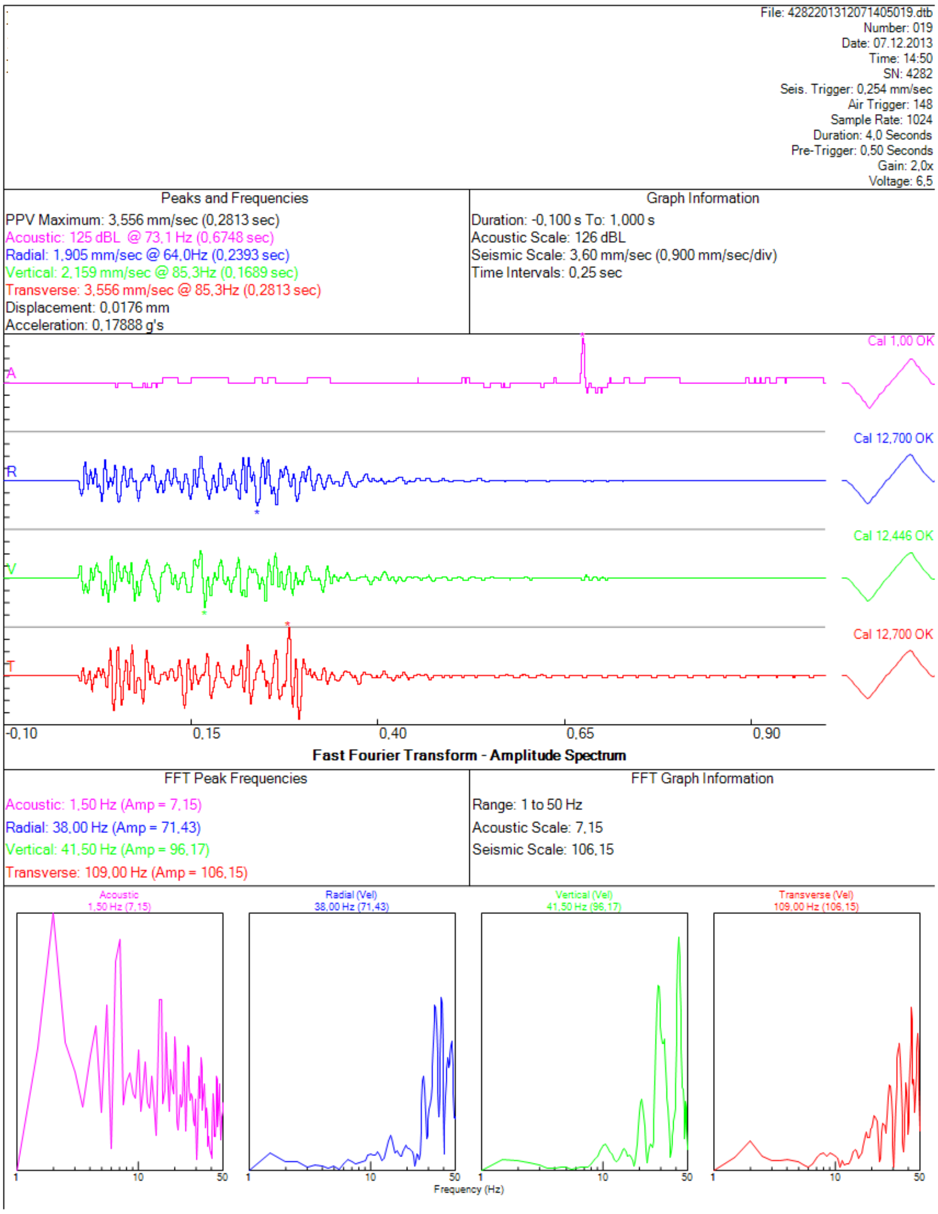


Figure A. 13 No:17 Seismograph record of test blasts

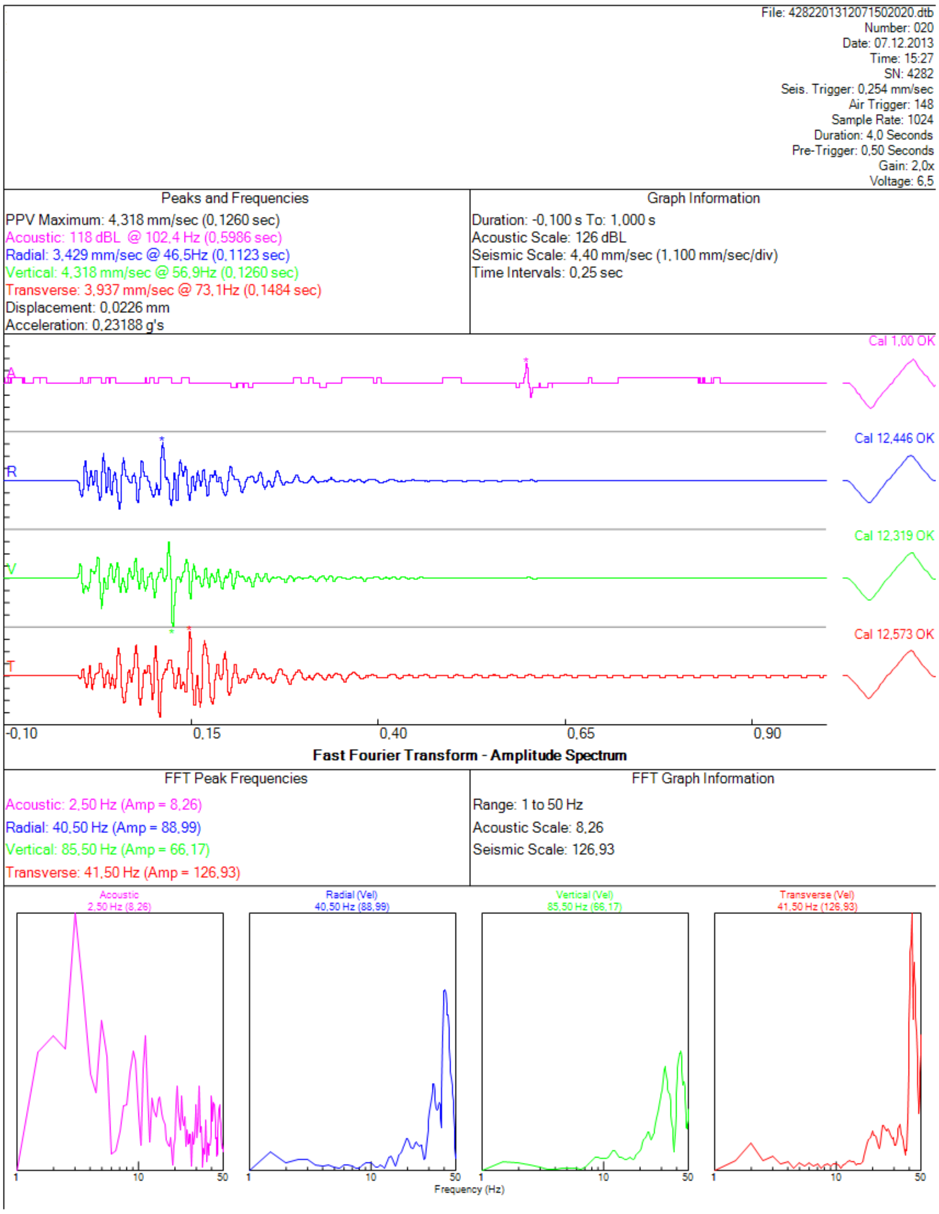


Figure A. 14 No:18 Seismograph record of test blasts

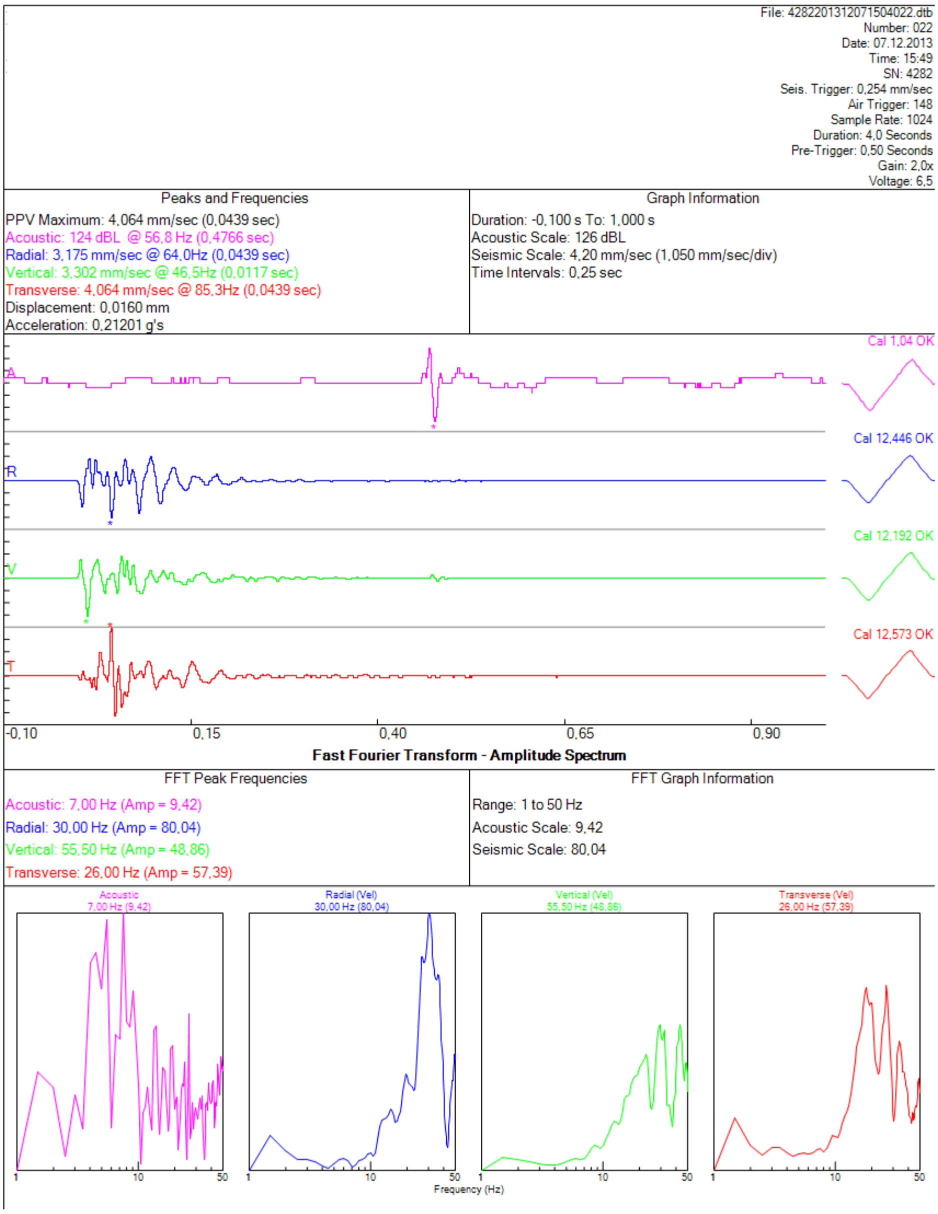


Figure A. 15 No:19 Seismograph record of test blasts

Instantel

Event Report

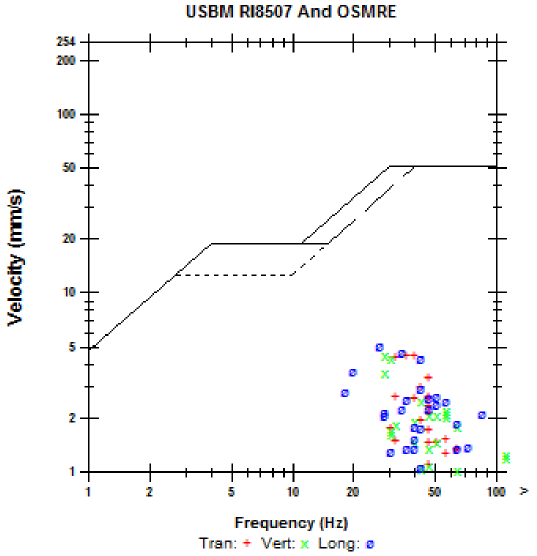
Date/Time	Vert at 16:33:57 December 6, 2013	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F3JY.0L0
Job Number:	1		
Notes		**Post Event Notes**	

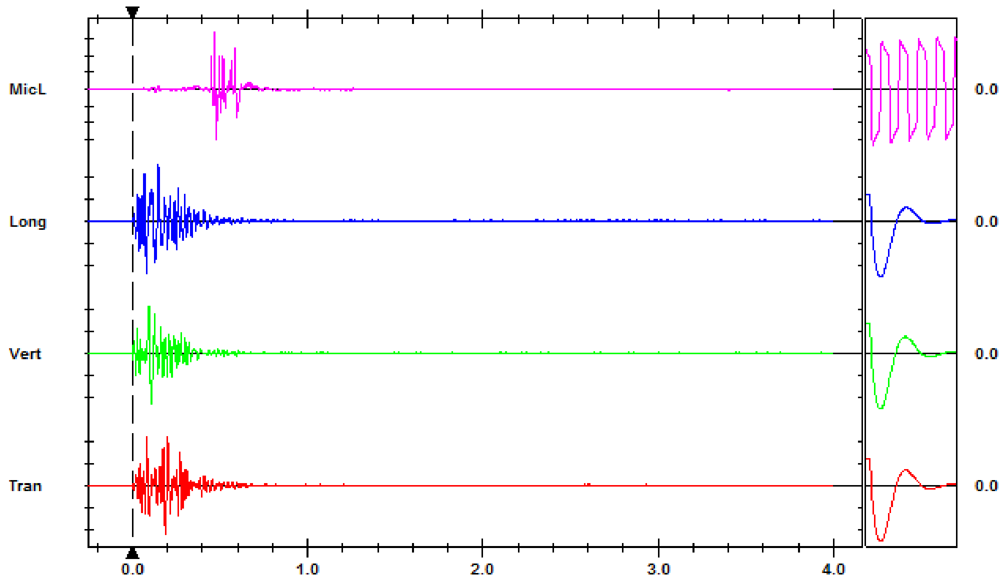
Location:
Client:
User Name:
General:

Microphone	Linear Weighting
PSPL	130.5 dB(L) at 0.470 sec
ZC Freq	73 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 680 mv)

	Tran	Vert	Long	
PPV	4.46	4.52	5.06	mm/s
ZC Freq	39	28	27	Hz
Time (Rel. to Trig)	0.084	0.108	0.149	sec
Peak Acceleration	0.129	0.131	0.143	g
Peak Displacement	0.0194	0.0225	0.0252	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.2	Hz
Overswing Ratio	3.9	3.6	4.4	

Peak Vector Sum 6.32 mm/s at 0.084 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 20.0 pa.(L)/div Sensor Check

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Figure A. 16 No:6a Seismograph record of test blasts

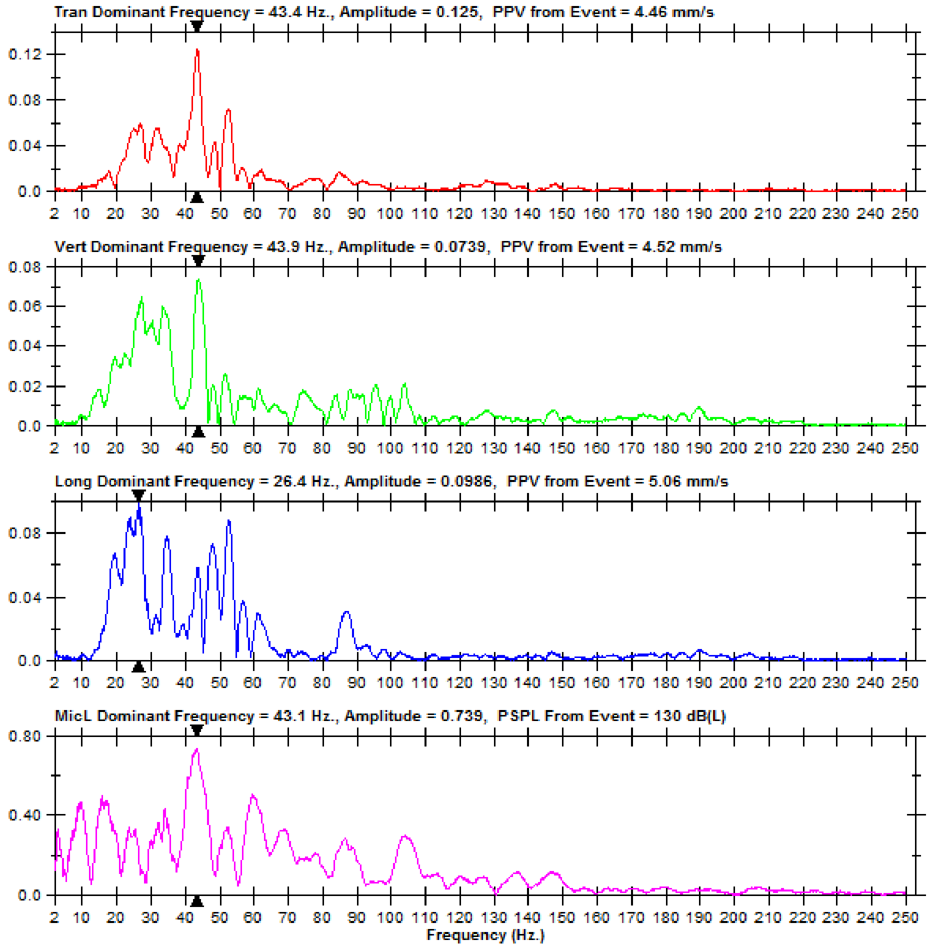
Instantel

FFT Report

Date/Time	Vert at 16:33:57 December 6, 2013	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F3JY.0L0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: December 11, 2013 (V 10.60 - 10.60)

Figure A. 17 No:6b Seismograph record of test blasts

Instantel

Event Report

Date/Time	Vert at 17:05:53 December 6, 2013
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F3JZ.HT0

Notes
Location:
Client:
User Name:
General:

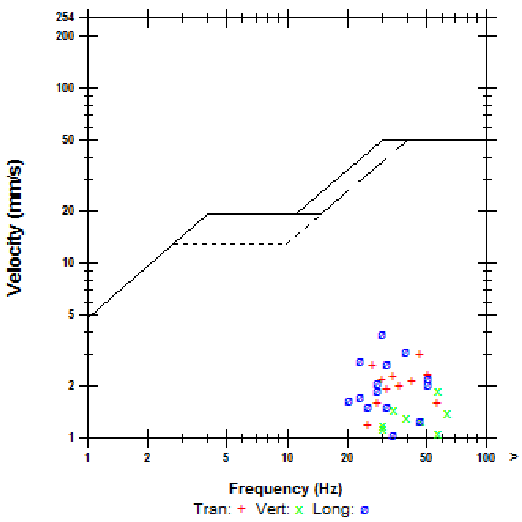
Post Event Notes

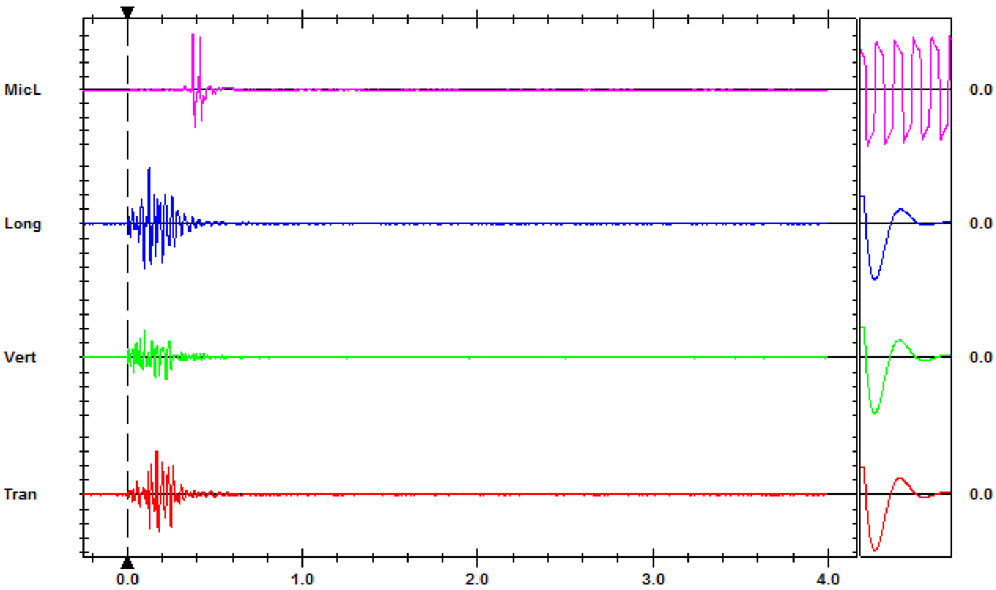
Microphone	Linear Weighting
PSPL	132.4 dB(L) at 0.374 sec
ZC Freq	43 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 704 mv)

	Tran	Vert	Long	
PPV	3.02	1.87	3.91	mm/s
ZC Freq	47	57	30	Hz
Time (Rel. to Trig)	0.168	0.099	0.123	sec
Peak Acceleration	0.0829	0.0895	0.0961	g
Peak Displacement	0.0110	0.00710	0.0153	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.4	7.6	7.2	Hz
Overswing Ratio	3.9	3.6	4.5	

Peak Vector Sum 4.11 mm/s at 0.123 sec

USBM RI8507 And OSMRE





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 1.000 mm/s/div Mic: 20.0 pa.(L)/div

Sensor Check

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Figure A. 18 No:9a Seismograph record of test blasts

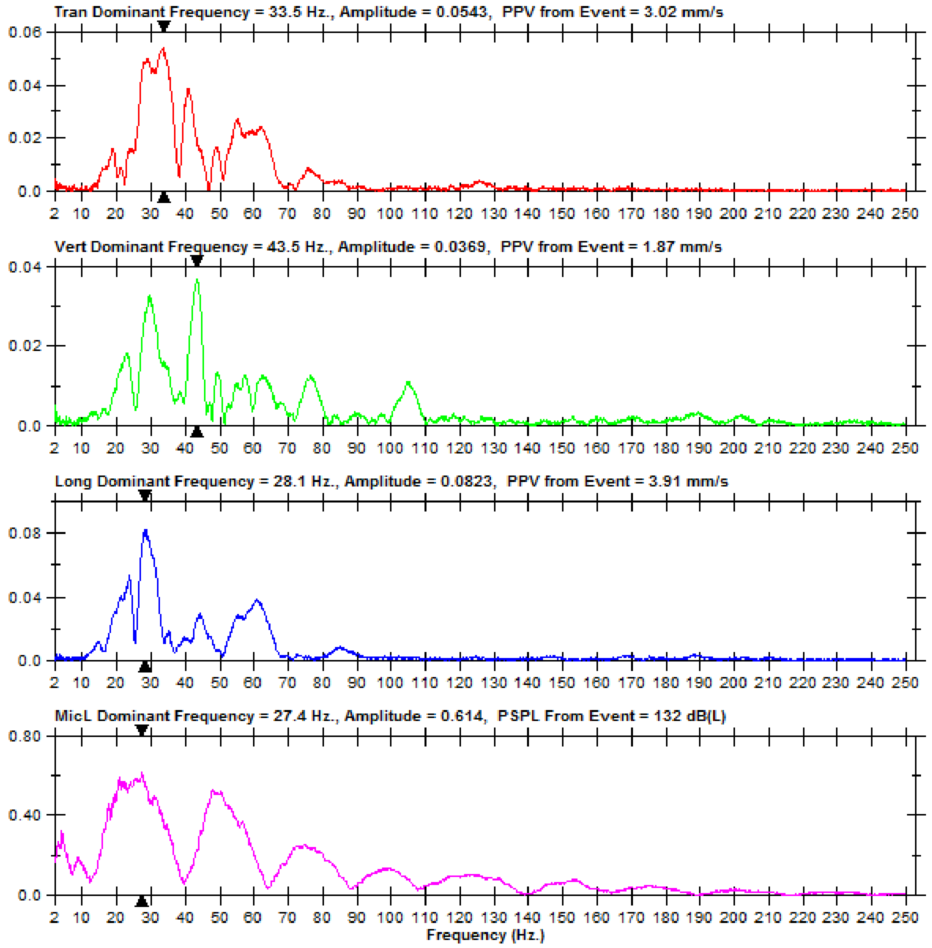
Instantel

FFT Report

Date/Time	Vert at 17:05:53 December 6, 2013	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F3JZ.HT0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: December 11, 2013 (V 10.60 - 10.60)

Figure A. 19 No:9b Seismograph record of test blasts

Instantel **Event Report**

Date/Time	Vert at 17:17:31 December 6, 2013
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

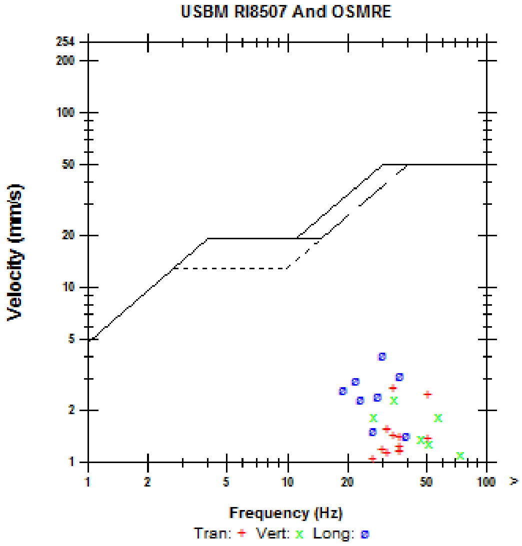
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F3K0.170

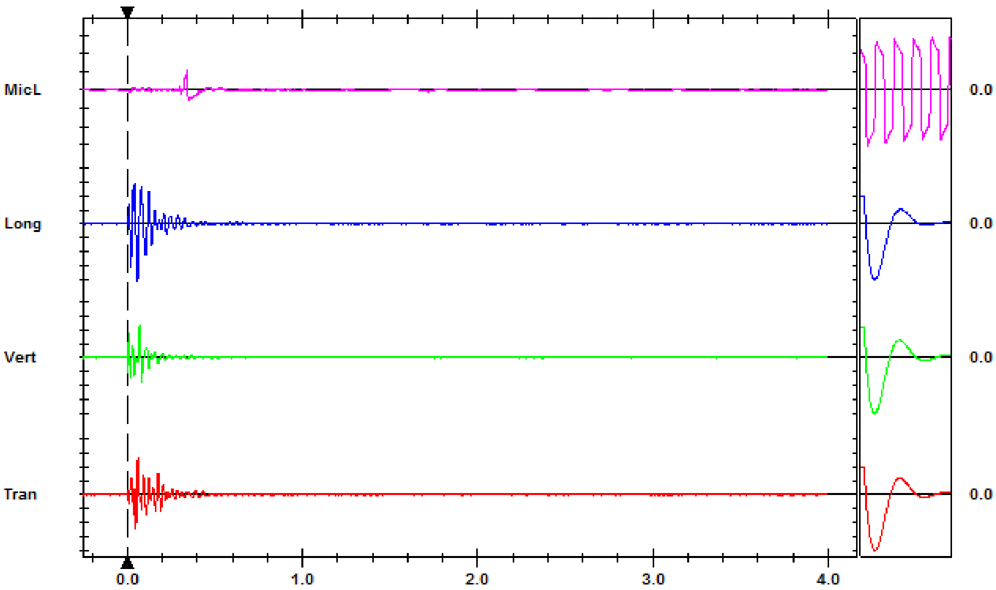
Post Event Notes

Microphone	Linear Weighting
PSPL	115.0 dB(L) at 0.341 sec
ZC Freq	18 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 735 mv)

	Tran	Vert	Long	
PPV	2.67	2.29	4.10	mm/s
ZC Freq	34	34	30	Hz
Time (Rel. to Trig)	0.062	0.069	0.060	sec
Peak Acceleration	0.0696	0.0696	0.0911	g
Peak Displacement	0.0111	0.00961	0.0210	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.4	7.6	7.2	Hz
Overswing Ratio	3.9	3.6	4.5	

Peak Vector Sum 4.74 mm/s at 0.060 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 1.000 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

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Figure A. 20 No:12a Seismograph record of test blasts

Instantel

FFT Report

Date/Time	Vert at 17:17:31 December 6, 2013	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F3K0.170
Job Number:	1		

Notes

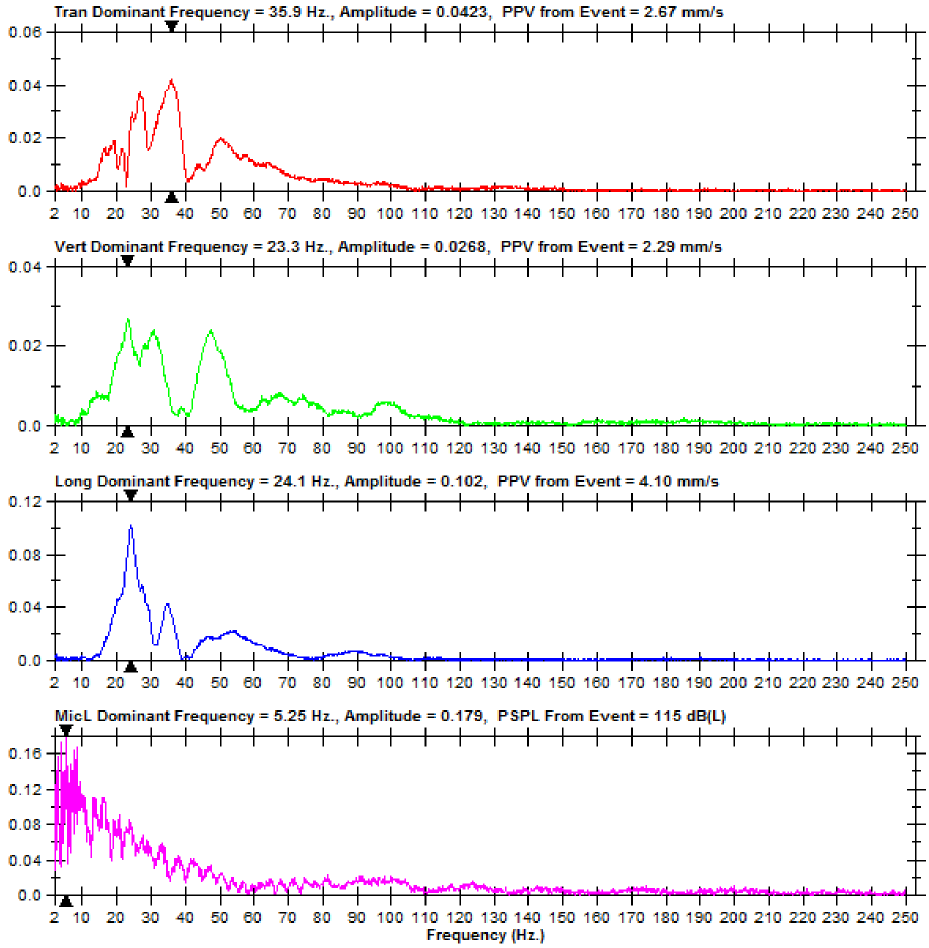
Location:

Client:

User Name:

General:

Post Event Notes



Printed: December 11, 2013 (V 10.60 - 10.60)

Figure A. 21 No:12b Seismograph record of test blasts

Instantel **Event Report**

Date/Time	Vert at 17:42:58 December 6, 2013
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F3K1.7M0

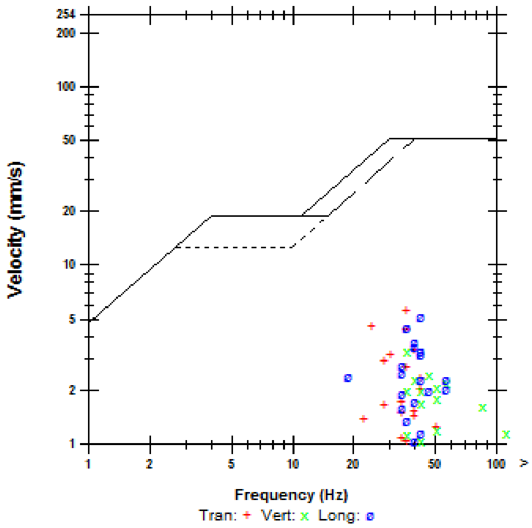
Post Event Notes

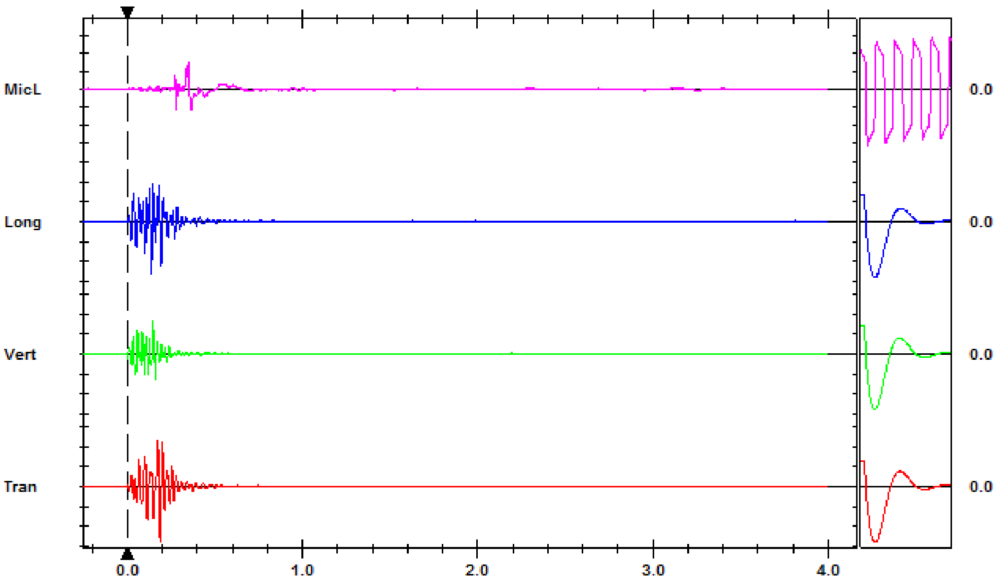
Microphone	Linear Weighting
PSPL	117.2 dB(L) at 0.349 sec
ZC Freq	17 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 742 mv)

	Tran	Vert	Long	
PPV	5.57	3.33	5.18	mm/s
ZC Freq	37	37	43	Hz
Time (Rel. to Trig)	0.188	0.147	0.139	sec
Peak Acceleration	0.131	0.109	0.162	g
Peak Displacement	0.0249	0.0120	0.0187	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.4	7.6	7.2	Hz
Overswing Ratio	3.9	3.6	4.5	

Peak Vector Sum 5.89 mm/s at 0.189 sec

USBM RI8507 And OSMRE





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

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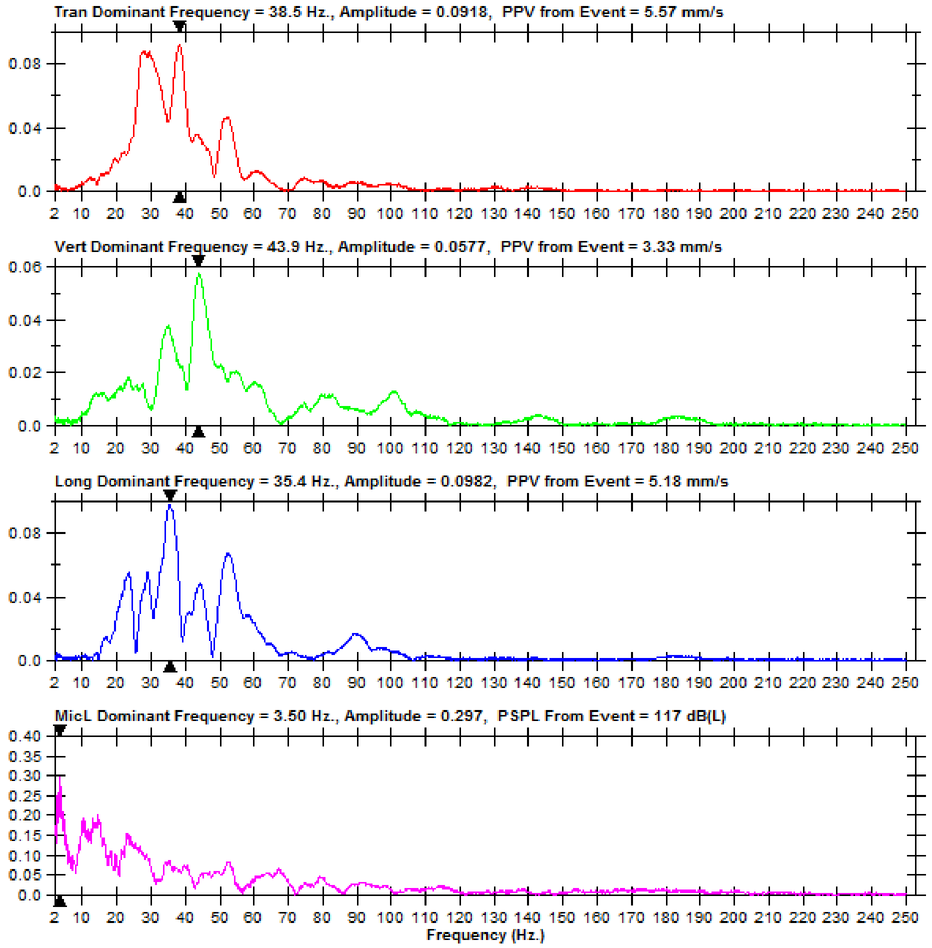
Figure A. 22 No:15a Seismograph record of test blasts

FFT Report

Date/Time	Vert at 17:42:58 December 6, 2013	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F3K1.7M0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: December 11, 2013 (V 10.60 - 10.60) Format © 1995-2013 Xmark Corporation

Figure A. 23 No:15b Seismograph record of test blasts

A.2. GROUND VIBRATION AND AIRBLAST MEASUREMENTS OF PRODUCTION BLASTS

Ground vibration and airblast measurements of production blasts are presented in the following pages.

Instantel

Event Report

Date/Time	Long at 12:57:36 January 11, 2014
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.0 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F5EC.000

Notes
Location:
Client:
User Name:
General:

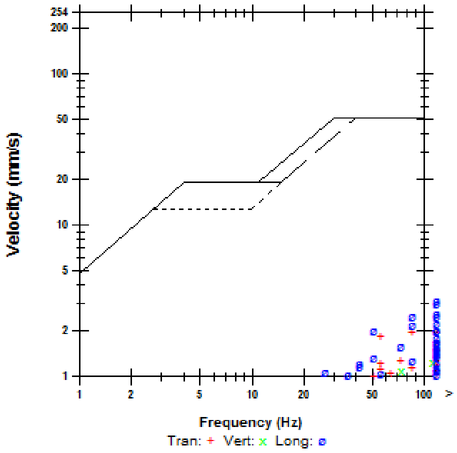
Post Event Notes
Cihaza 192,75 m Uzaklikta,
6,5 Kg Patlatildiginda,
Boru Hatti Uzerinde Alinan Kayit.

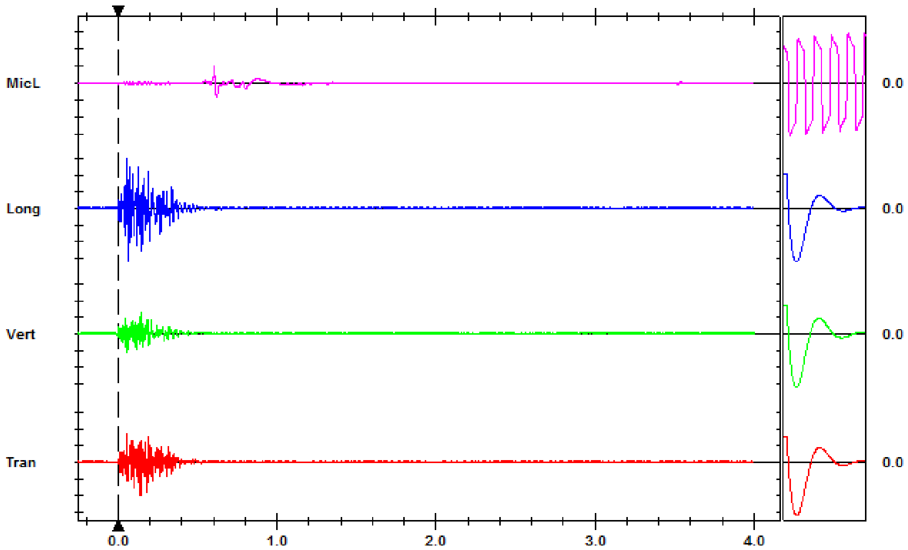
Microphone	Linear Weighting
PSPL	114.2 dB(L) at 0.604 sec
ZC Freq	20 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 631 mv)

	Tran	Vert	Long	
PPV	1.95	1.25	3.17	mm/s
ZC Freq	85	>100	>100	Hz
Time (Rel. to Trig)	0.137	0.142	0.063	sec
Peak Acceleration	0.118	0.0696	0.212	g
Peak Displacement	0.00368	0.00359	0.00439	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.3	Hz
Overswing Ratio	3.9	3.6	4.4	

Peak Vector Sum 3.28 mm/s at 0.059 sec

USBM RI8507 And OSMRE





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 1.000 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 1.000 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 24 No:1a Seismograph record of production blasts

Instantel

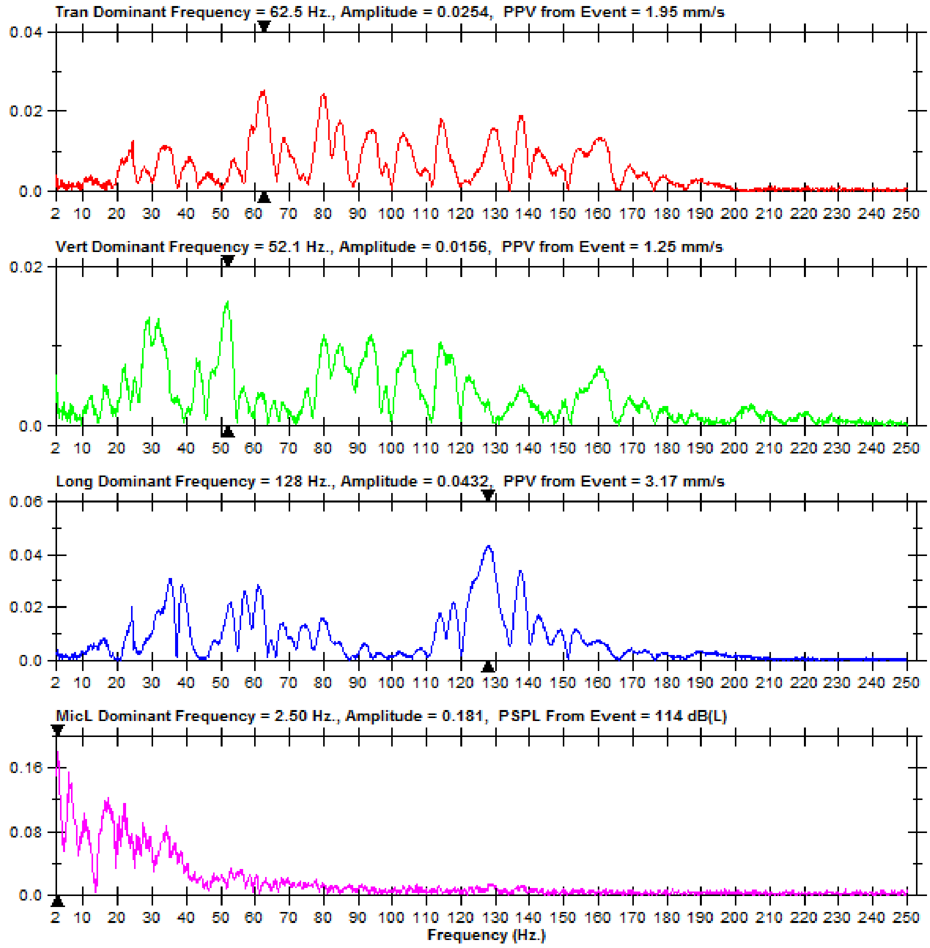
FFT Report

Date/Time Long at 12:57:36 January 11, 2014
Trigger Source Geo: 0.254 mm/s, Mic: 100 dB(L)
Range Geo: 31.7 mm/s
Record Time 4.0 sec at 1024 sps
Job Number: 1

Serial Number BE15218 V 10.40-1.1 Minimate Blaster
Battery Level 6.0 Volts
Unit Calibration October 23, 2012 by Instantel
File Name Q218F5EC.000

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 25 No:1b Seismograph record of production blasts

Instantel **Event Report**

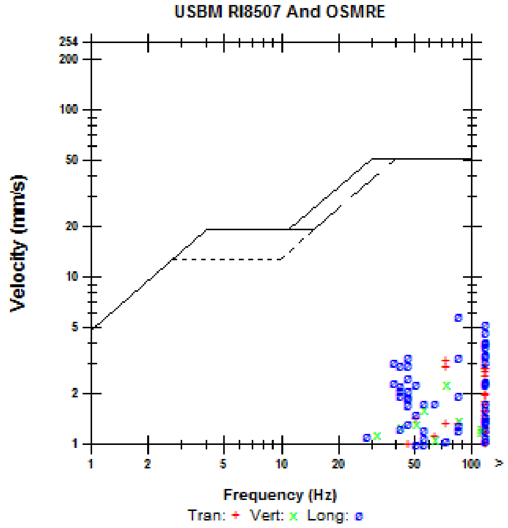
Date/Time	Long at 13:21:27 January 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5ED.3R0
Job Number:	1		
Notes		**Post Event Notes**	

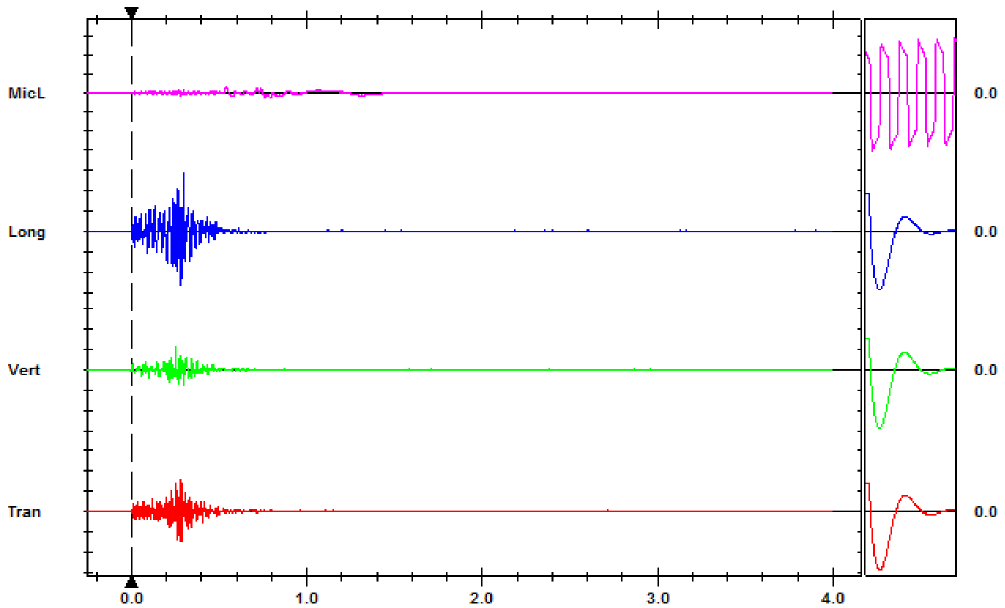
Location:
Client:
User Name:
General:

Microphone	Linear Weighting
PSPL	103.5 dB(L) at 0.538 sec
ZC Freq	18 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 708 mv)

	Tran	Vert	Long	
PPV	3.14	2.29	5.78	mm/s
ZC Freq	73	73	85	Hz
Time (Rel. to Trig)	0.278	0.254	0.297	sec
Peak Acceleration	0.250	0.129	0.345	g
Peak Displacement	0.00574	0.00382	0.00928	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.3	Hz
Overswing Ratio	3.9	3.6	4.4	

Peak Vector Sum 5.87 mm/s at 0.297 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 26 No:2a Seismograph record of production blasts

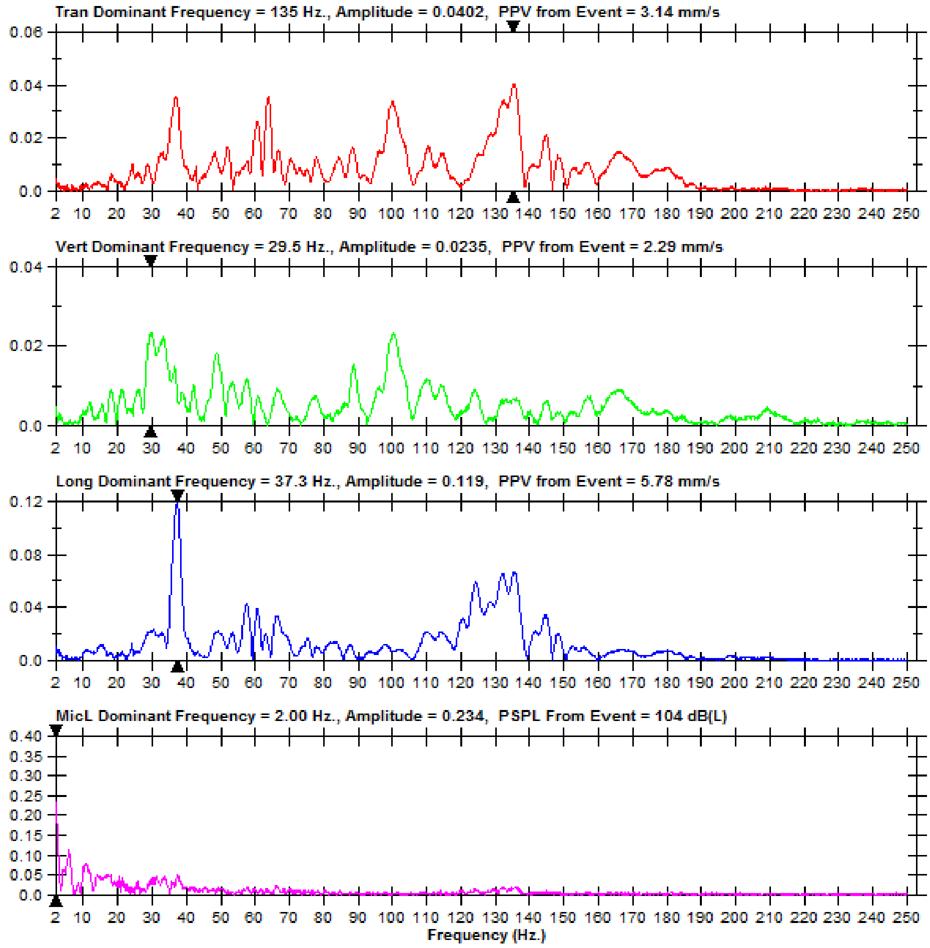
Instantel

FFT Report

Date/Time	Long at 13:21:27 January 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5ED.3R0
Job Number:	1		

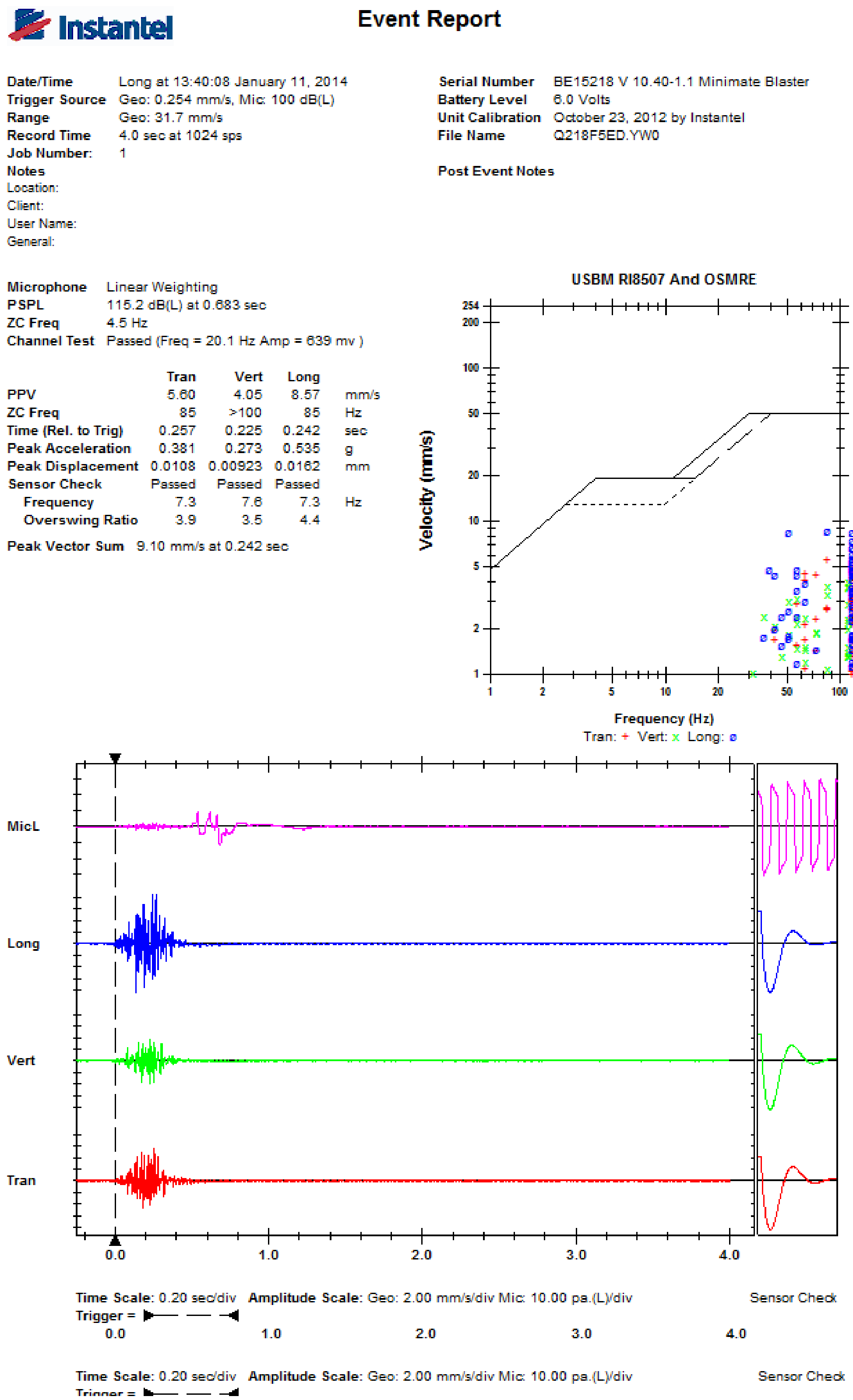
Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 27 No:2b Seismograph record of production blasts



Instantel

Event Report

Date/Time	Long at 13:40:08 January 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5ED.YW0
Job Number:	1		
Notes		**Post Event Notes**	

Location:
Client:
User Name:
General:

Microphone	Linear Weighting
PSPL	115.2 dB(L) at 0.683 sec
ZC Freq	4.5 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 639 mv)

	Tran	Vert	Long	
PPV	5.60	4.05	8.57	mm/s
ZC Freq	85	>100	85	Hz
Time (Rel. to Trig)	0.257	0.225	0.242	sec
Peak Acceleration	0.381	0.273	0.535	g
Peak Displacement	0.0108	0.00923	0.0162	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.3	Hz
Overswing Ratio	3.9	3.5	4.4	

Peak Vector Sum 9.10 mm/s at 0.242 sec

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 28 No:3a Seismograph record of production blasts

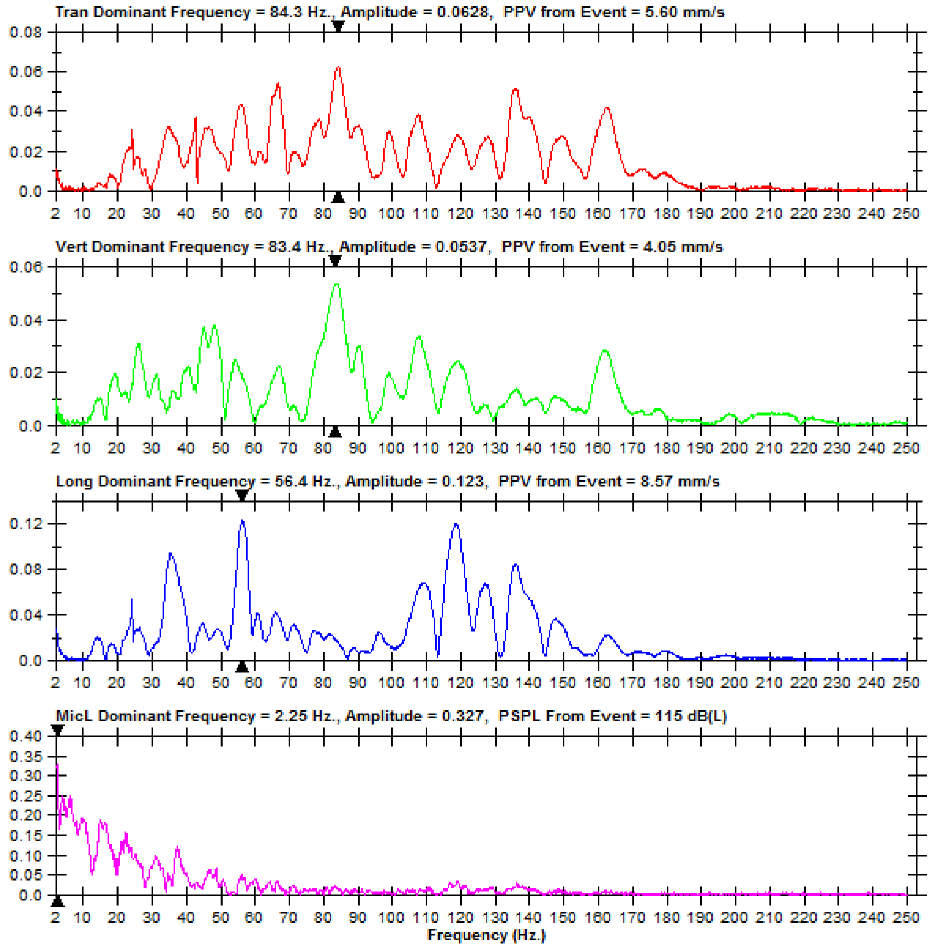
Instantel

FFT Report

Date/Time	Long at 13:40:08 January 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5ED.YW0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 29 No:3b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 15:20:00 January 11, 2014
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

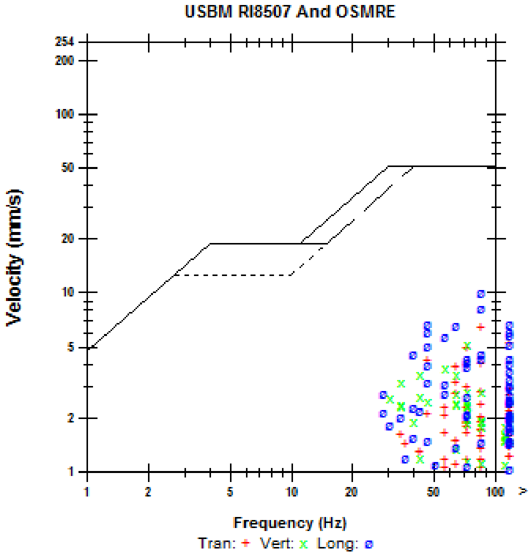
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.0 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F5EI.LC0

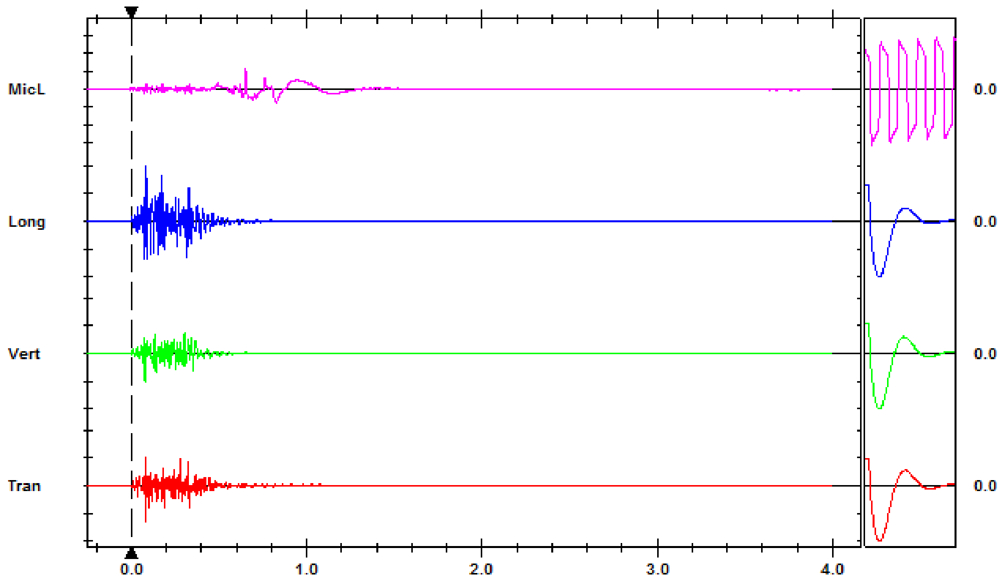
Post Event Notes

Microphone	Linear Weighting
PSPL	115.2 dB(L) at 0.651 sec
ZC Freq	43 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 723 mv)

	Tran	Vert	Long	
PPV	6.43	5.13	10.1	mm/s
ZC Freq	85	73	85	Hz
Time (Rel. to Trig)	0.080	0.078	0.086	sec
Peak Acceleration	0.414	0.278	0.548	g
Peak Displacement	0.0107	0.0123	0.0183	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.4	Hz
Overswing Ratio	4.0	3.6	4.5	

Peak Vector Sum 10.7 mm/s at 0.086 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger = ▶— —◀
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger = ▶— —◀

Figure A. 30 No:4a Seismograph record of production blasts

Instantel

FFT Report

Date/Time	Vert at 15:20:00 January 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5EI.LC0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes

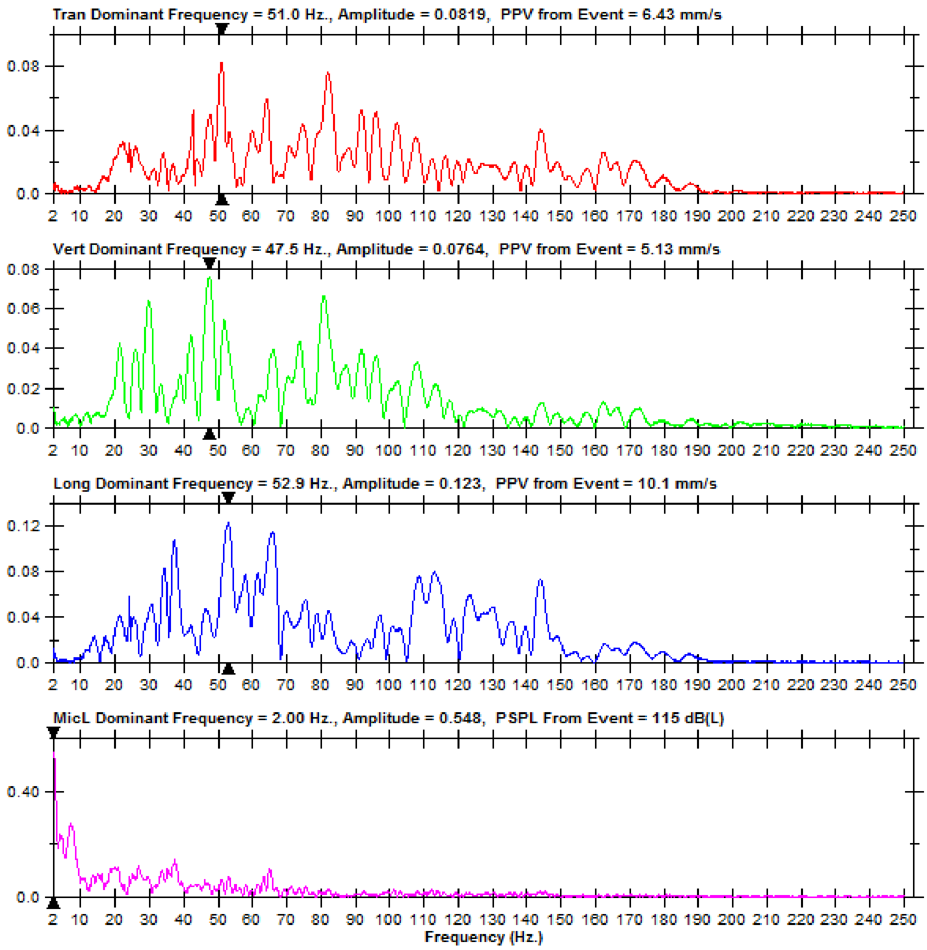


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Figure A. 31 No:4b Seismograph record of production blasts

Event Report

Date/Time	Vert at 15:47:01 January 11, 2014
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1
Notes	
Location:	
Client:	
User Name:	
General:	

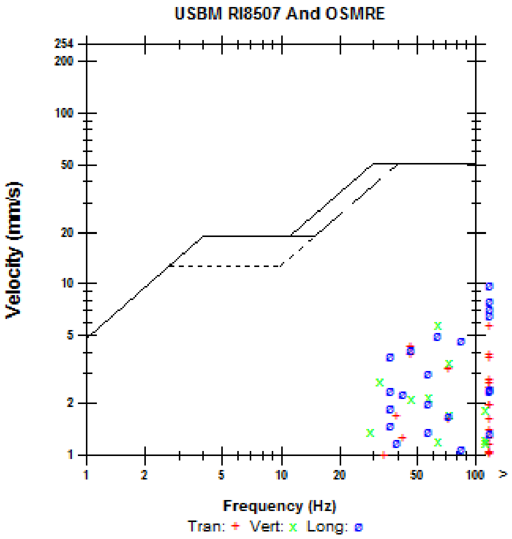
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	5.9 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F5EJ.UD0

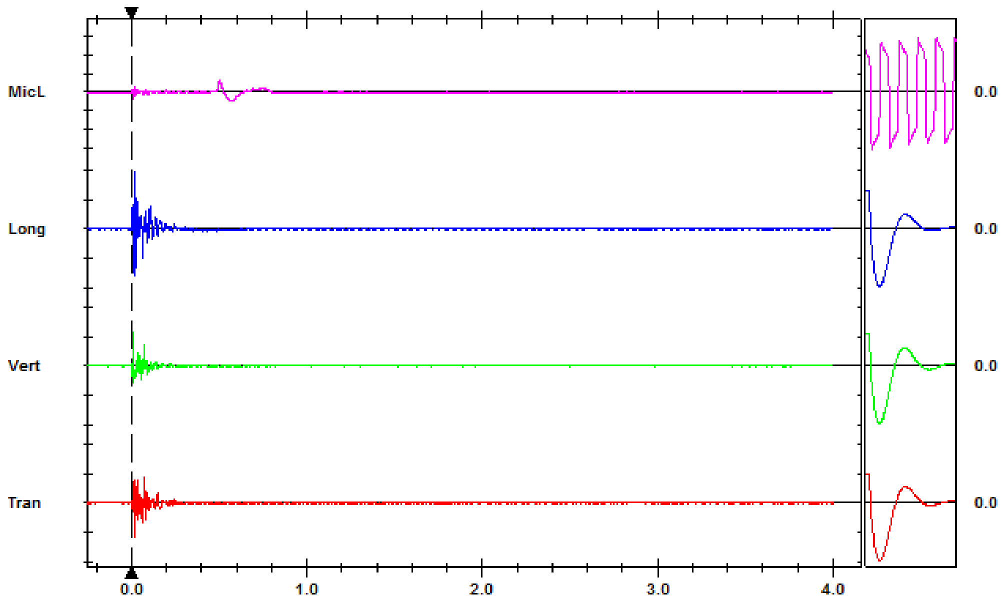
Post Event Notes

Microphone	Linear Weighting
PSPL	109.5 dB(L) at 0.502 sec
ZC Freq	11 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 674 mv)

	Tran	Vert	Long	
PPV	5.75	5.81	9.81	mm/s
ZC Freq	>100	64	>100	Hz
Time (Rel. to Trig)	0.017	0.011	0.022	sec
Peak Acceleration	0.439	0.384	0.653	g
Peak Displacement	0.00905	0.00964	0.0138	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.3	Hz
Overswing Ratio	4.0	3.6	4.5	

Peak Vector Sum 9.91 mm/s at 0.022 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

Trigger = ▶— — ◀

0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

Trigger = ▶— — ◀

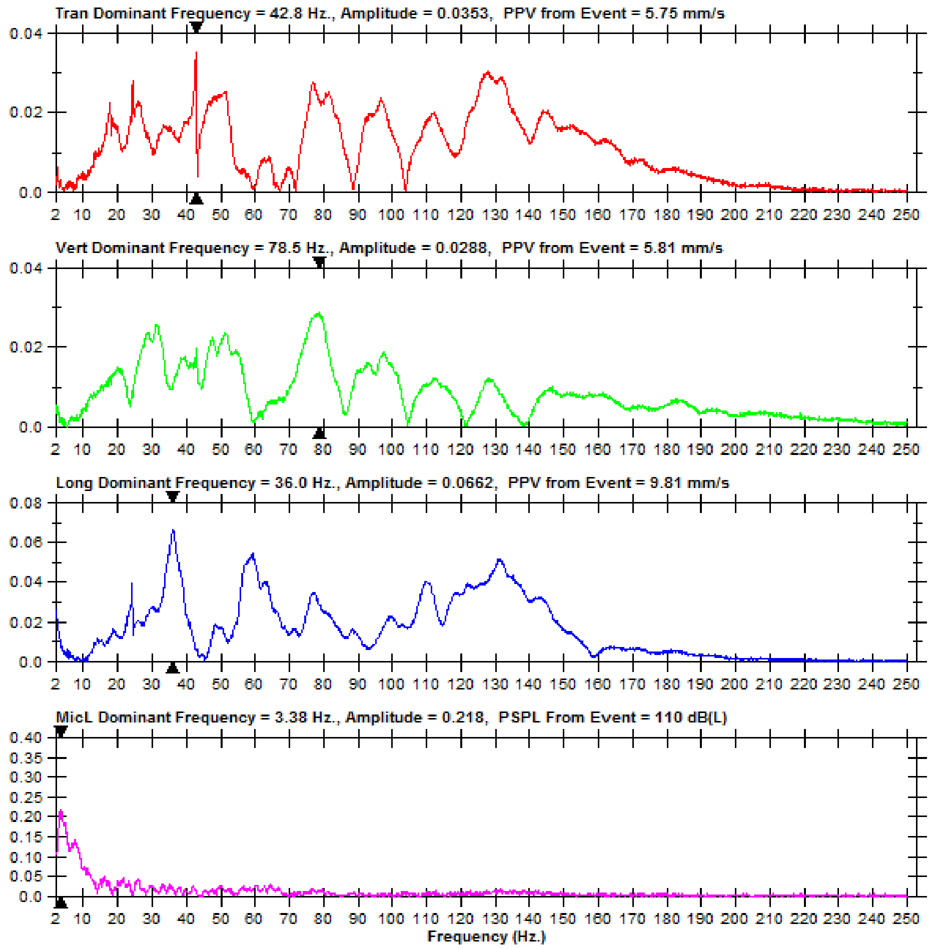
Figure A. 32 No:5a Seismograph record of production blasts

FFT Report

Date/Time	Vert at 15:47:01 January 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	5.9 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5EJ.UD0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)   Format © 1995-2013 Xmark Corporation

Figure A. 33 No:5b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 13:59:23 January 17, 2014
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

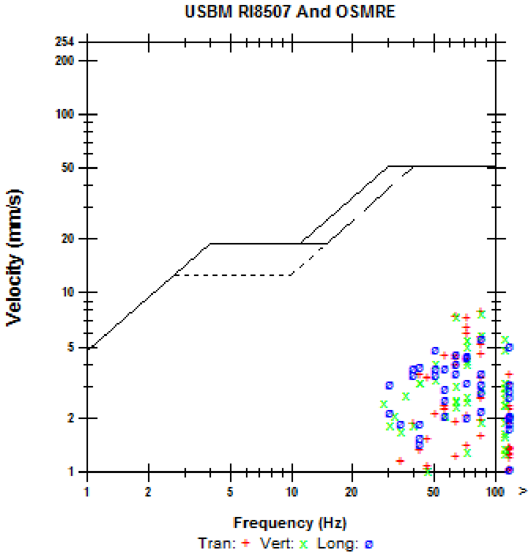
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.2 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F5PI.UZ0

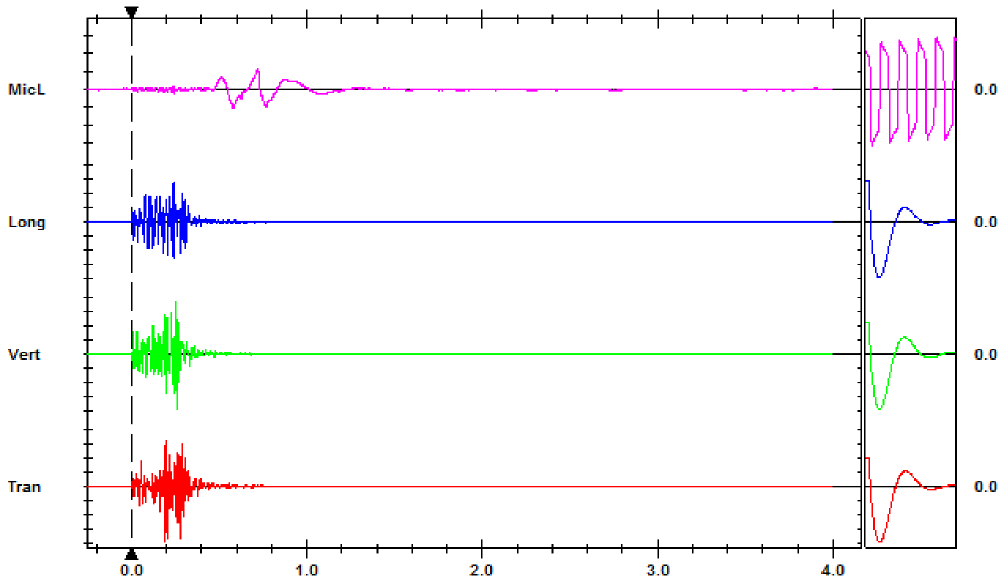
Post Event Notes

Microphone	Linear Weighting
PSPL	114.8 dB(L) at 0.718 sec
ZC Freq	7.1 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 609 mv)

	Tran	Vert	Long	
PPV	7.87	7.78	5.56	mm/s
ZC Freq	85	85	85	Hz
Time (Rel. to Trig)	0.193	0.261	0.240	sec
Peak Acceleration	0.418	0.439	0.326	g
Peak Displacement	0.0173	0.0170	0.0147	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.4	Hz
Overswing Ratio	3.9	3.5	4.3	

Peak Vector Sum 10.0 mm/s at 0.208 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 34 No:6a Seismograph record of production blasts

Instantel FFT Report

Date/Time	Vert at 13:59:23 January 17, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5PI.UZ0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes

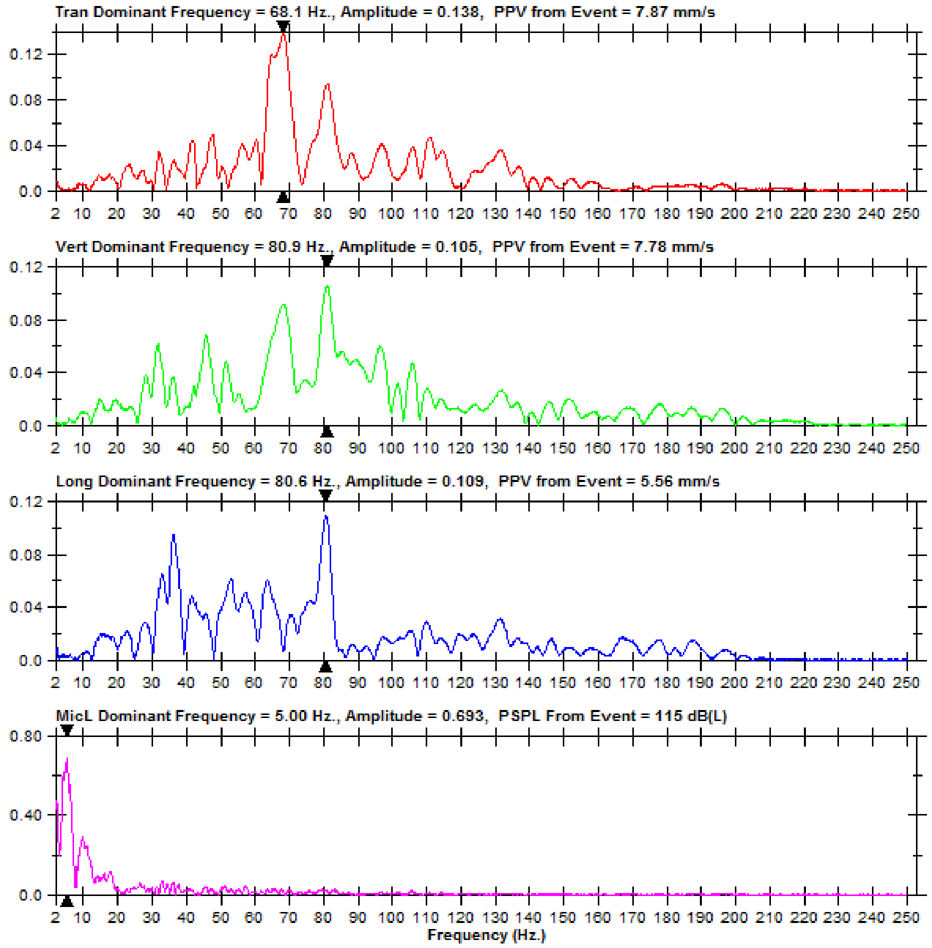


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Figure A. 35 No:6b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 14:18:32 January 17, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5PJ.QW0
Job Number:	1		

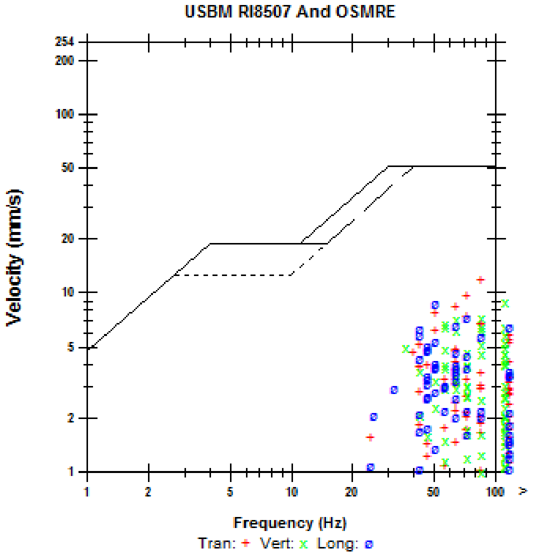
Notes
Location:
Client:
User Name:
General:

Post Event Notes

Microphone	Linear Weighting
PSPL	117.2 dB(L) at 0.727 sec
ZC Freq	5.3 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 602 mv)

	Tran	Vert	Long	
PPV	12.0	8.86	8.70	mm/s
ZC Freq	85	>100	51	Hz
Time (Rel. to Trig)	0.204	0.198	0.211	sec
Peak Acceleration	0.608	0.570	0.490	g
Peak Displacement	0.0224	0.0209	0.0187	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.4	Hz
Overswing Ratio	3.9	3.6	4.3	

Peak Vector Sum 13.0 mm/s at 0.204 sec



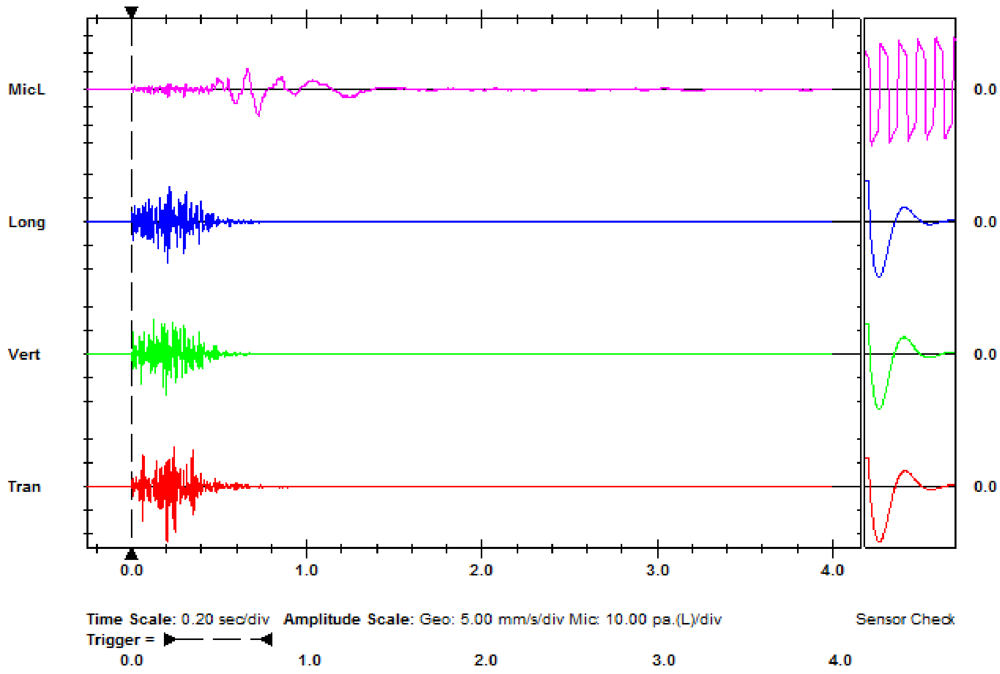


Figure A. 36 No:7a Seismograph record of production blasts

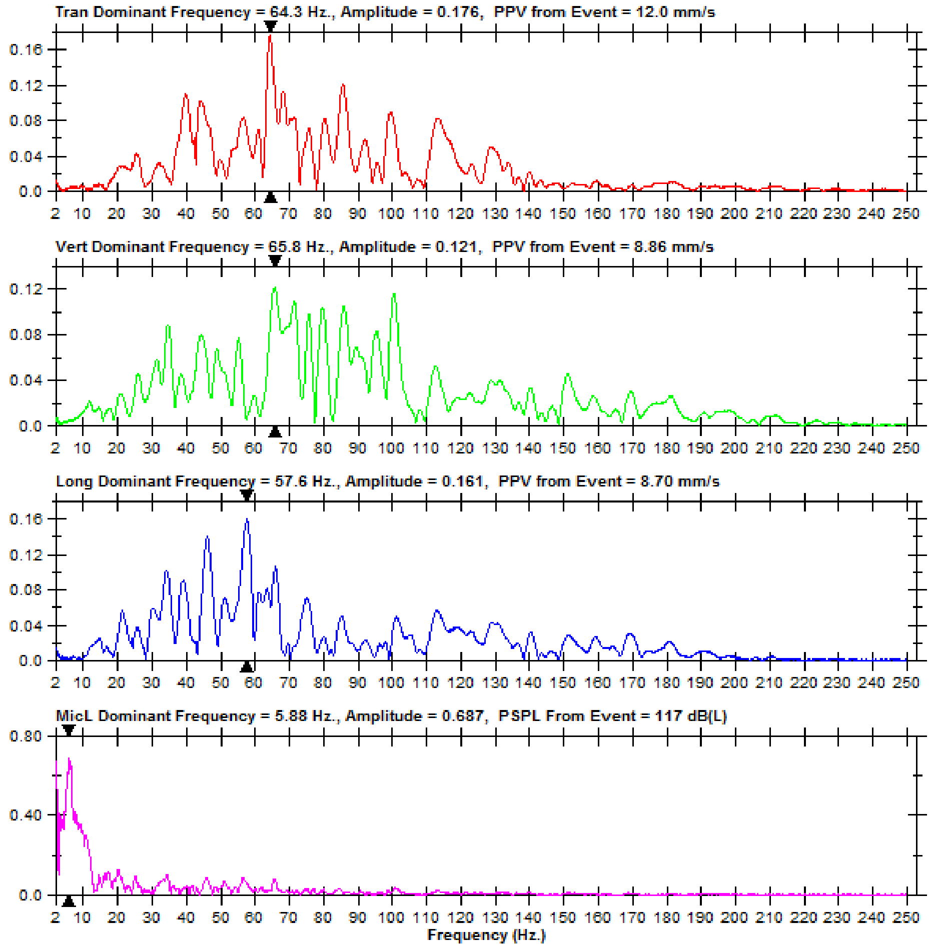
Instantel

FFT Report

Date/Time	Vert at 14:18:32 January 17, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5PJ.QW0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 37 No:7b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 14:38:31 January 17, 2014
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

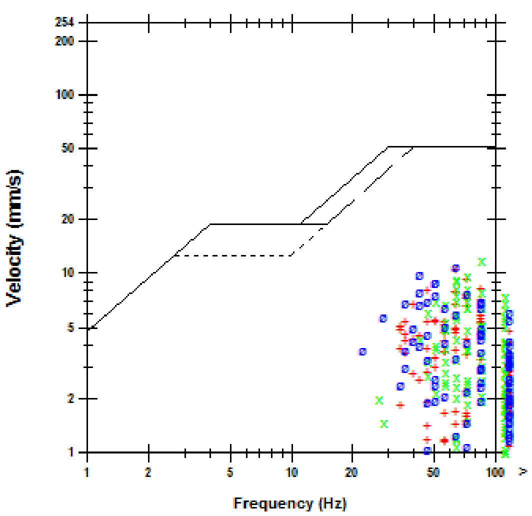
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.2 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F5PK.O70

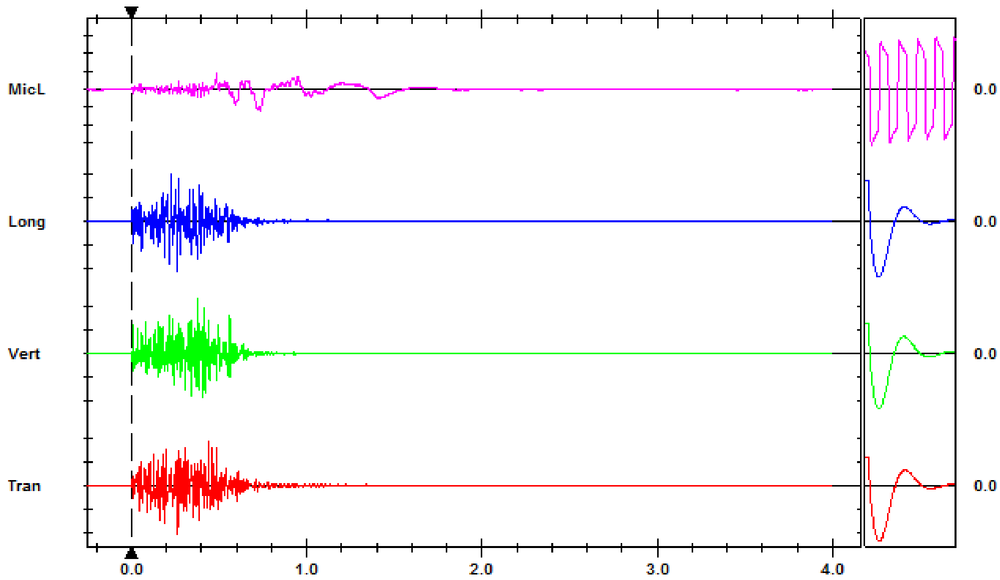
Post Event Notes

Microphone	Linear Weighting
PSPL	115.6 dB(L) at 0.734 sec
ZC Freq	5.9 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 627 mv)

	Tran	Vert	Long	
PPV	10.5	11.8	10.8	mm/s
ZC Freq	64	85	64	Hz
Time (Rel. to Trig)	0.266	0.377	0.264	sec
Peak Acceleration	0.494	0.577	0.409	g
Peak Displacement	0.0273	0.0209	0.0313	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.4	Hz
Overswing Ratio	3.9	3.6	4.3	

Peak Vector Sum 14.9 mm/s at 0.377 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div   Sensor Check

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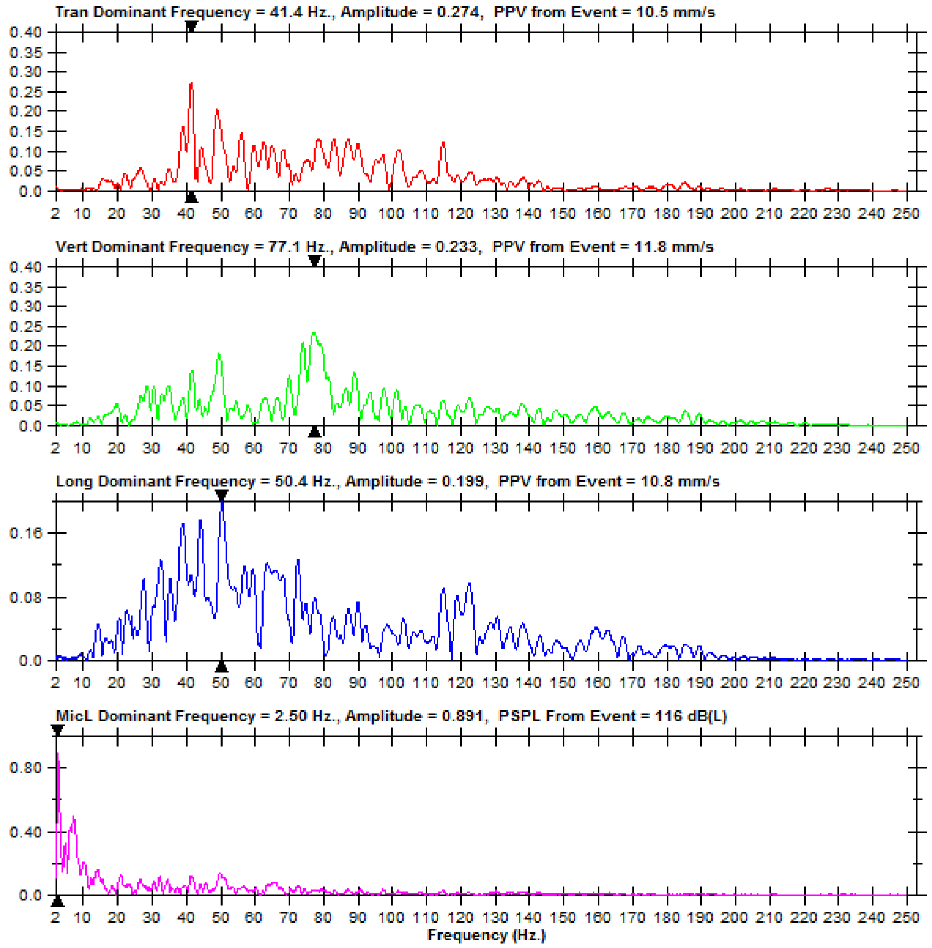
Figure A. 38 No:8a Seismograph record of production blasts

Instantel **FFT Report**

Date/Time	Vert at 14:38:31 January 17, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5PK.O70
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 39 No:8b Seismograph record of production blasts

Event Report

Date/Time	Tran at 14:57:14 January 17, 2014
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

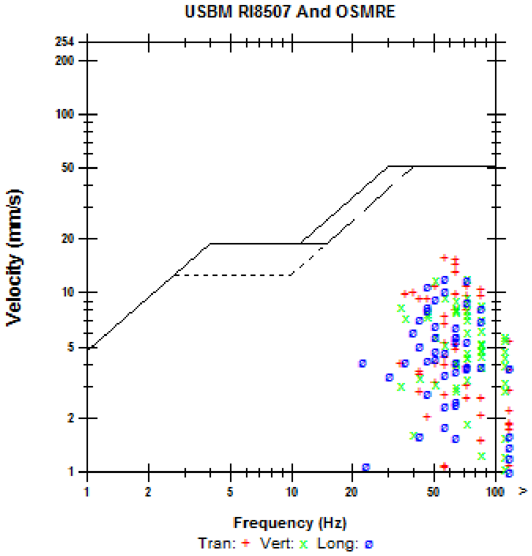
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F5PL.JE0

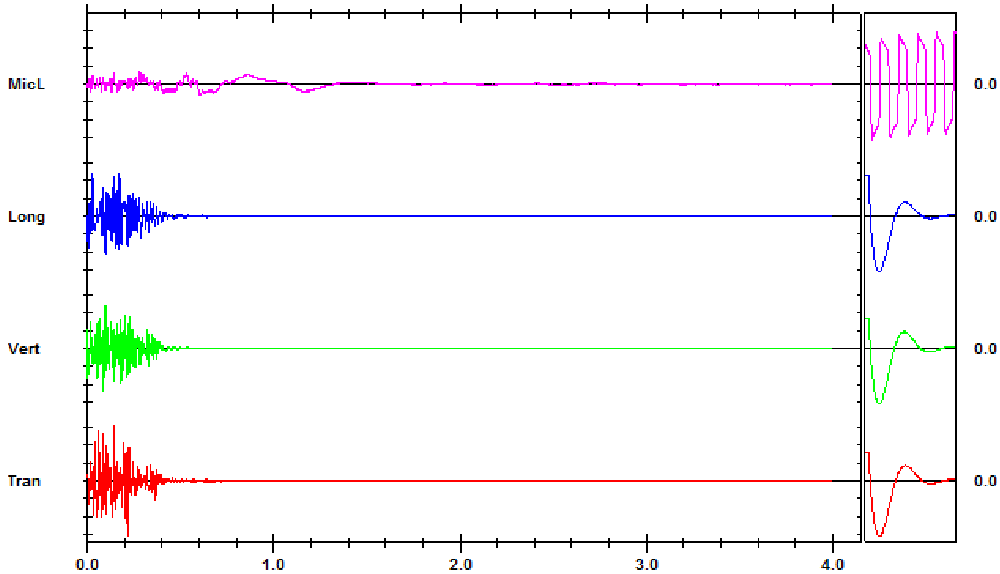
Post Event Notes

Microphone	Linear Weighting
PSPL	110.9 dB(L) at 0.280 sec
ZC Freq	9.0 Hz
Channel Test	Passed (Freq = 20.5 Hz Amp = 670 mv)

	Tran	Vert	Long	
PPV	15.7	12.0	12.1	mm/s
ZC Freq	57	73	57	Hz
Time (Rel. to Trig)	0.145	0.098	0.028	sec
Peak Acceleration	0.666	0.557	0.539	g
Peak Displacement	0.0413	0.0264	0.0336	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.4	Hz
Overswing Ratio	4.0	3.6	4.4	

Peak Vector Sum 18.7 mm/s at 0.086 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

Figure A. 40 No:9a Seismograph record of production blasts

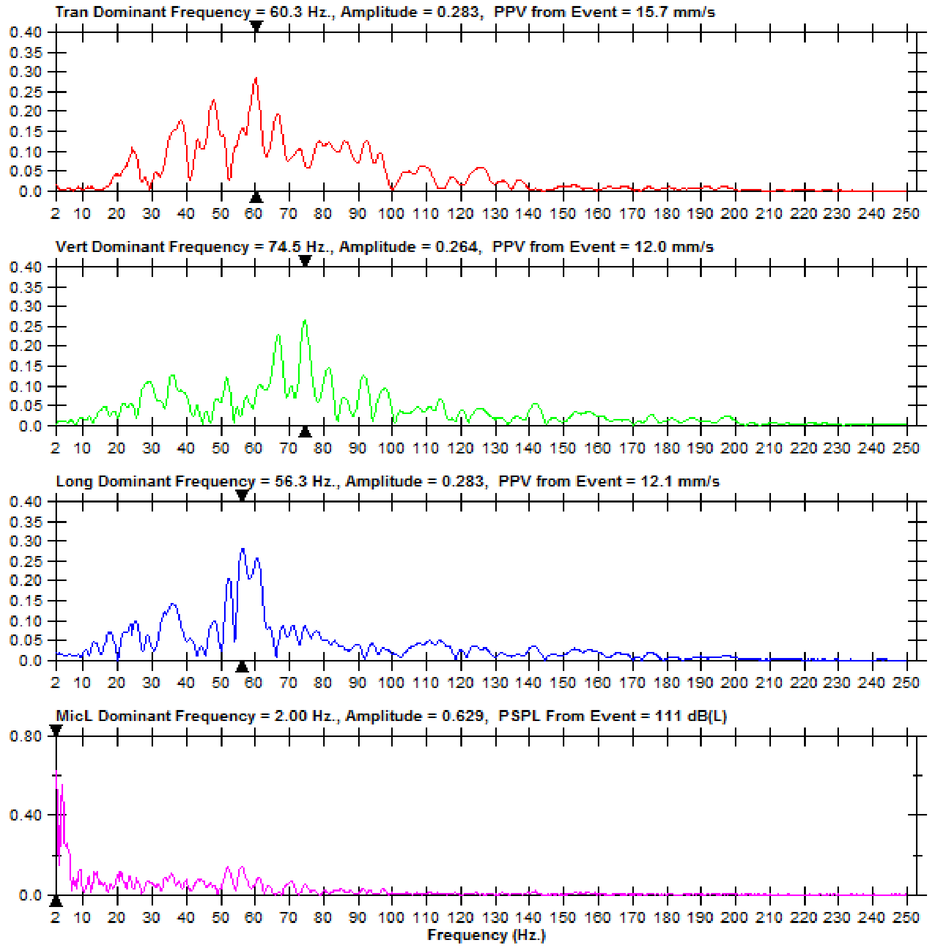
Instantel

FFT Report

Date/Time	Tran at 14:57:14 January 17, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 0.254 mm/s, Mic: 100 dB(L)	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F5PL.JE0
Job Number:	1		

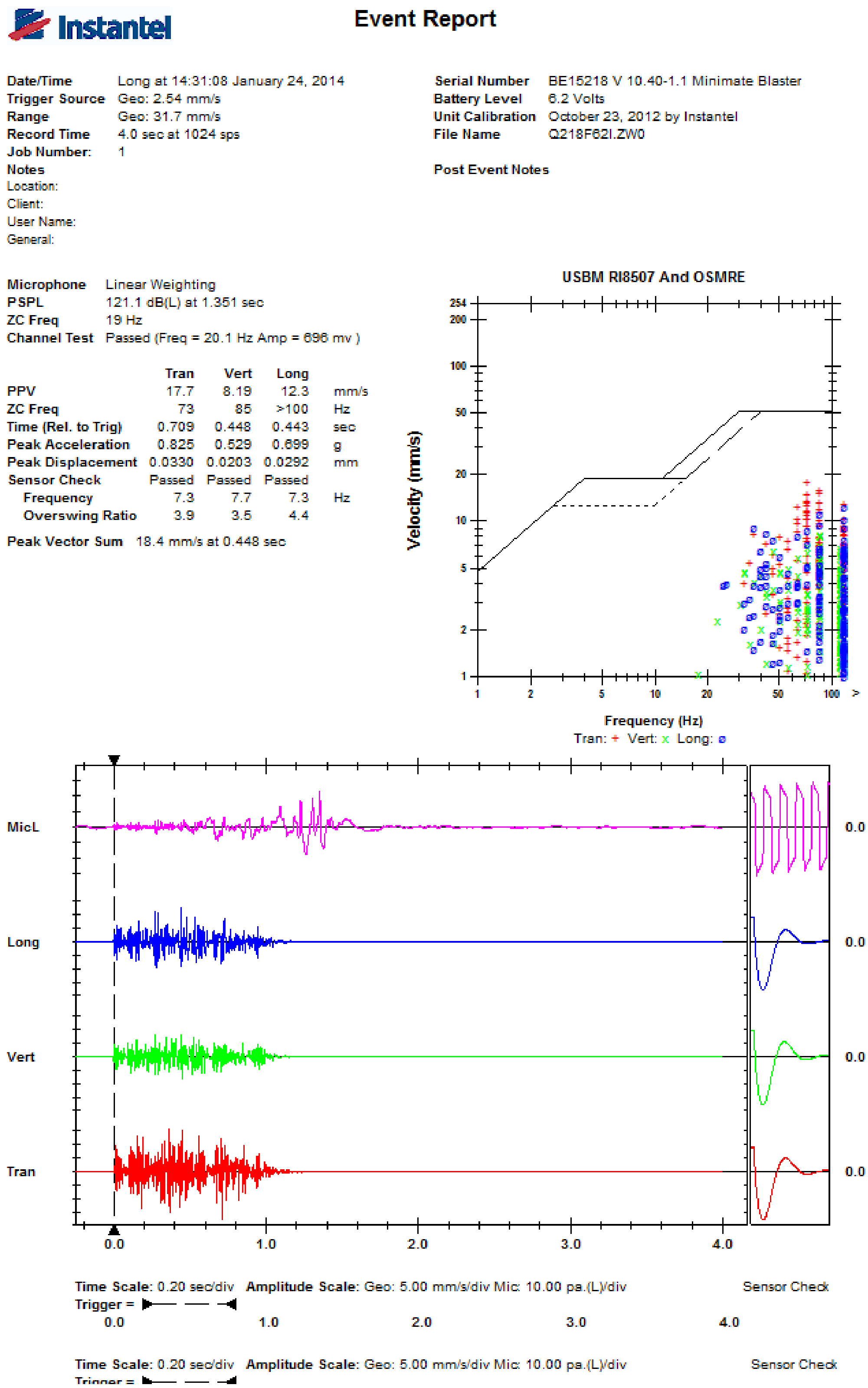
Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 41 No:9b Seismograph record of production blasts



Instantel **Event Report**

Date/Time	Long at 14:31:08 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62I.ZW0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes

Microphone Linear Weighting
PSPL 121.1 dB(L) at 1.351 sec
ZC Freq 19 Hz
Channel Test Passed (Freq = 20.1 Hz Amp = 696 mv)

	Tran	Vert	Long	
PPV	17.7	8.19	12.3	mm/s
ZC Freq	73	85	>100	Hz
Time (Rel. to Trig)	0.709	0.448	0.443	sec
Peak Acceleration	0.825	0.529	0.699	g
Peak Displacement	0.0330	0.0203	0.0292	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.3	Hz
Overswing Ratio	3.9	3.5	4.4	

Peak Vector Sum 18.4 mm/s at 0.448 sec

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 42 No:10a Seismograph record of production blasts

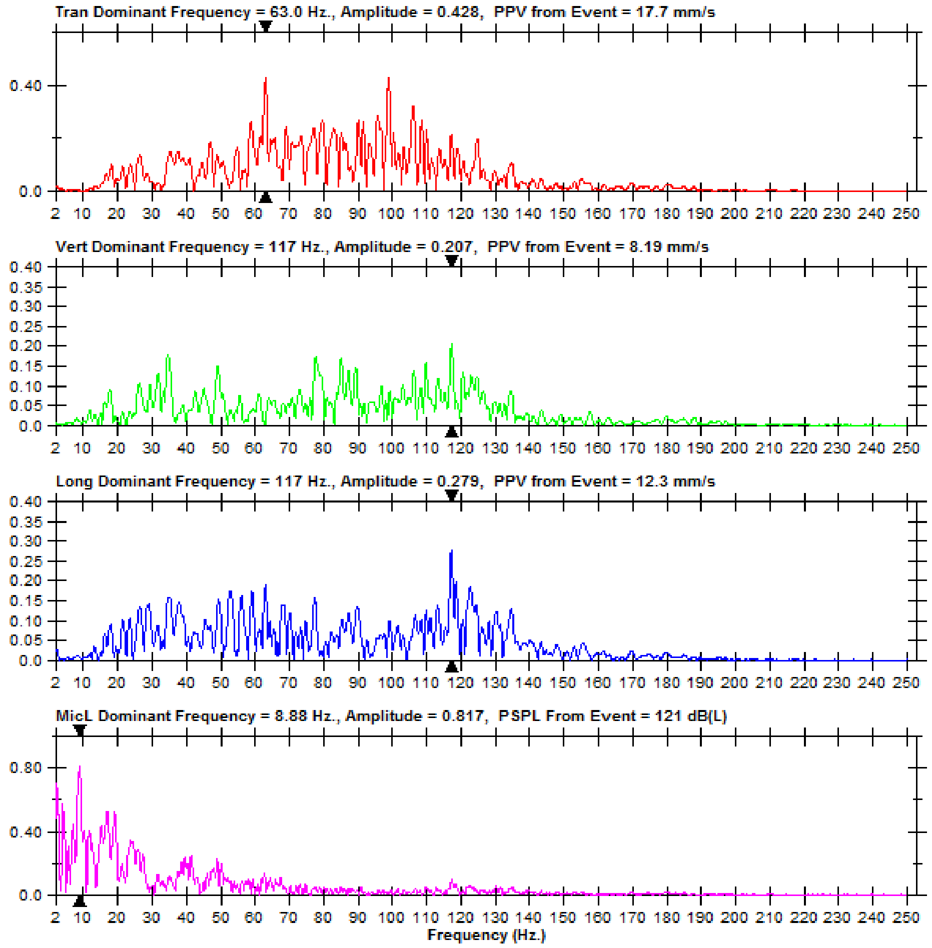
Instantel

FFT Report

Date/Time	Long at 14:31:08 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62I.ZW0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 43 No:10b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 14:46:55 January 24, 2014
Trigger Source	Geo: 2.54 mm/s
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1
Notes	
Location:	
Client:	
User Name:	
General:	

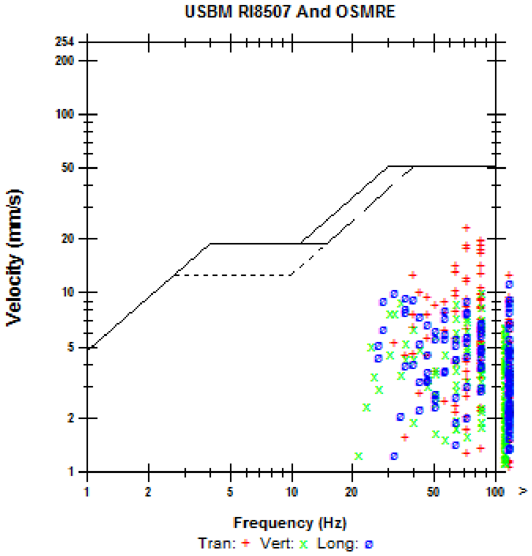
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.2 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F62J.Q70

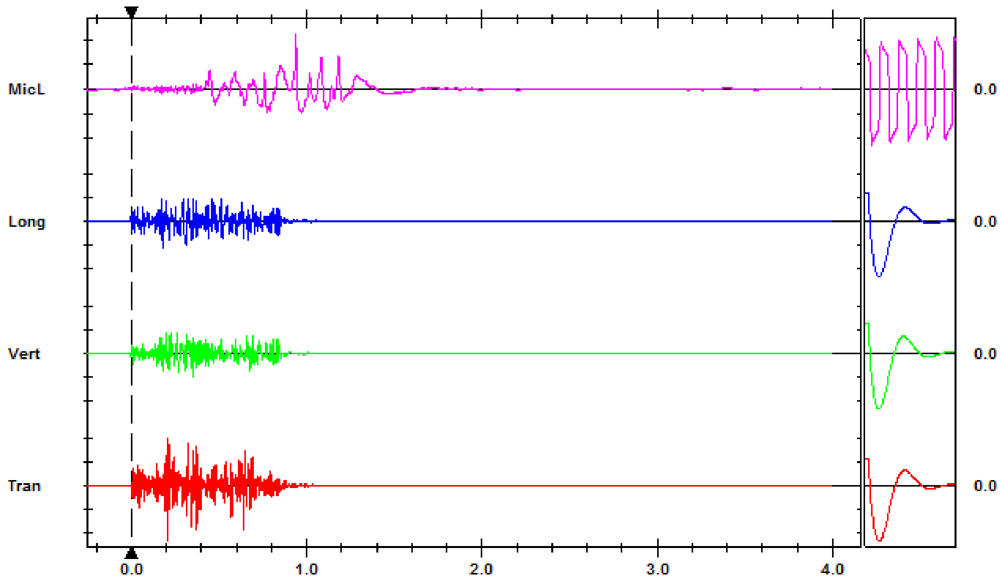
Post Event Notes

Microphone	Linear Weighting
PSPL	127.1 dB(L) at 0.938 sec
ZC Freq	15 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 704 mv)

	Tran	Vert	Long	
PPV	23.3	10.1	11.5	mm/s
ZC Freq	73	85	>100	Hz
Time (Rel. to Trig)	0.206	0.351	0.180	sec
Peak Acceleration	1.28	0.502	0.767	g
Peak Displacement	0.0422	0.0303	0.0522	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.3	Hz
Overswing Ratio	3.9	3.5	4.4	

Peak Vector Sum 23.4 mm/s at 0.206 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 10.00 mm/s/div Mic: 20.0 pa.(L)/div Sensor Check

Trigger =

0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 10.00 mm/s/div Mic: 20.0 pa.(L)/div Sensor Check

Trigger =

Figure A. 44 No:11a Seismograph record of production blasts

FFT Report

Date/Time	Vert at 14:46:55 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62J.Q70
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes

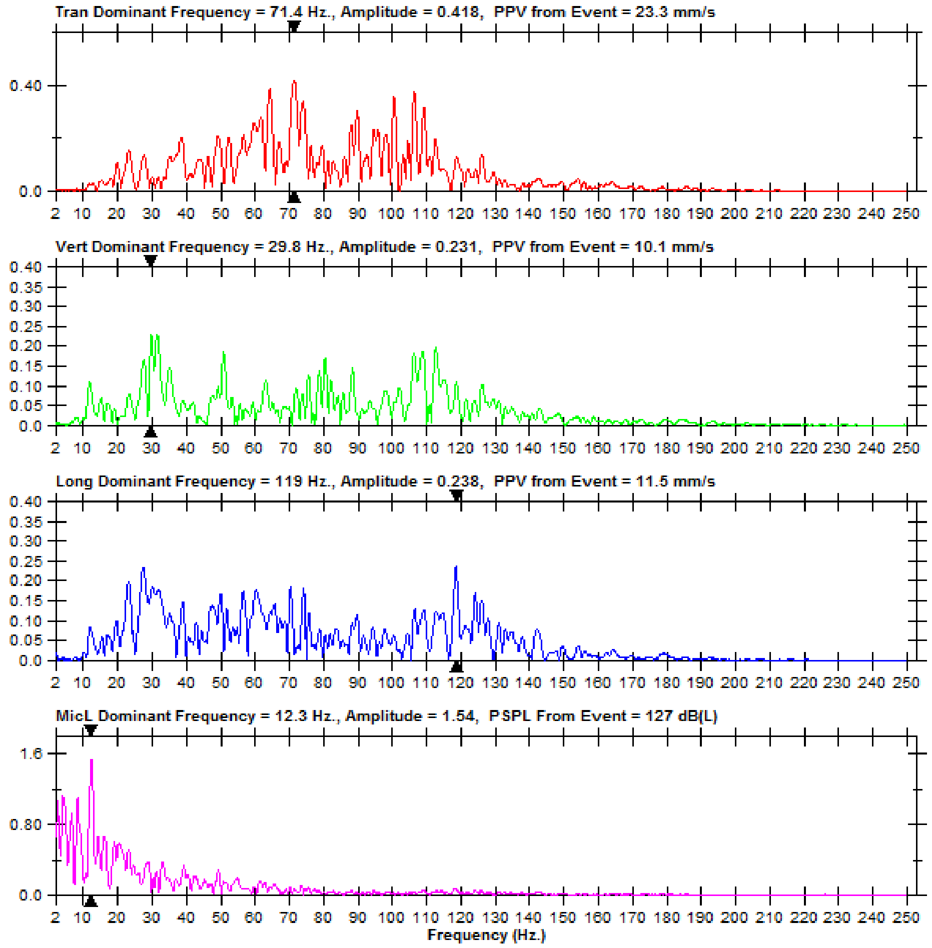


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Figure A. 45 No:11b Seismograph record of production blasts

Instantel **Event Report**

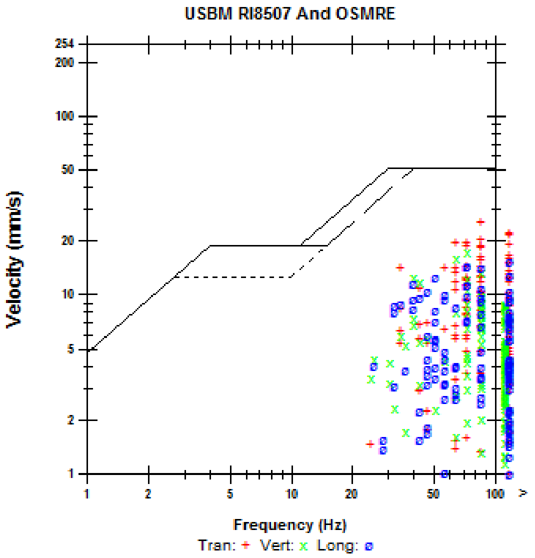
Date/Time	Vert at 15:01:23 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62K.EB0
Job Number:	1		
Notes		**Post Event Notes**	

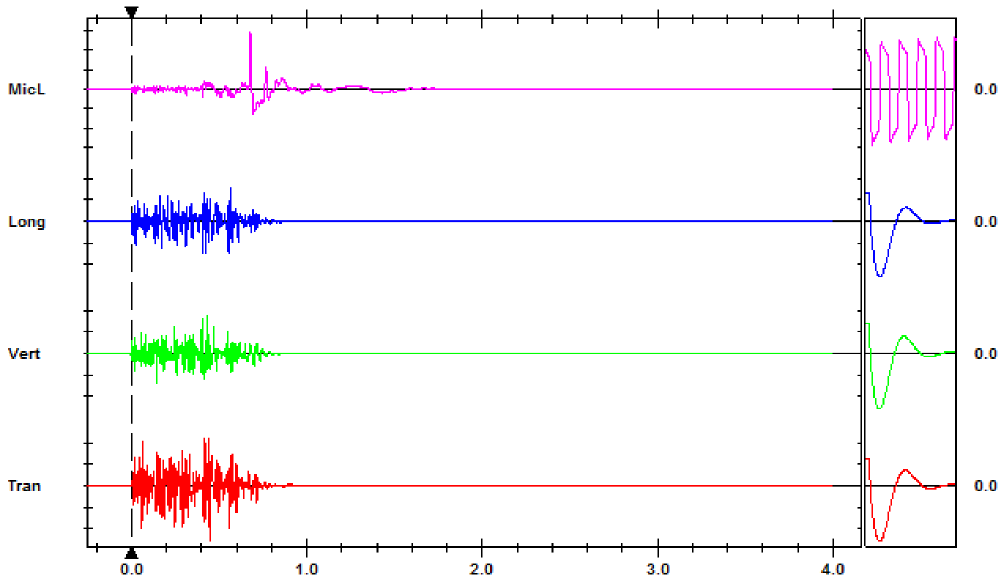
Location:
Client:
User Name:
General:

Microphone	Linear Weighting
PSPL	129.1 dB(L) at 0.680 sec
ZC Freq	7.5 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 705 mv)

	Tran	Vert	Long	
PPV	25.9	17.4	15.3	mm/s
ZC Freq	85	73	>100	Hz
Time (Rel. to Trig)	0.450	0.431	0.567	sec
Peak Acceleration	1.41	0.807	0.870	g
Peak Displacement	0.0491	0.0373	0.0422	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.3	Hz
Overswing Ratio	3.9	3.5	4.4	

Peak Vector Sum 28.1 mm/s at 0.450 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 10.00 mm/s/div Mic: 20.0 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 10.00 mm/s/div Mic: 20.0 pa.(L)/div Sensor Check
Trigger =

Figure A. 46 No:12a Seismograph record of production blasts

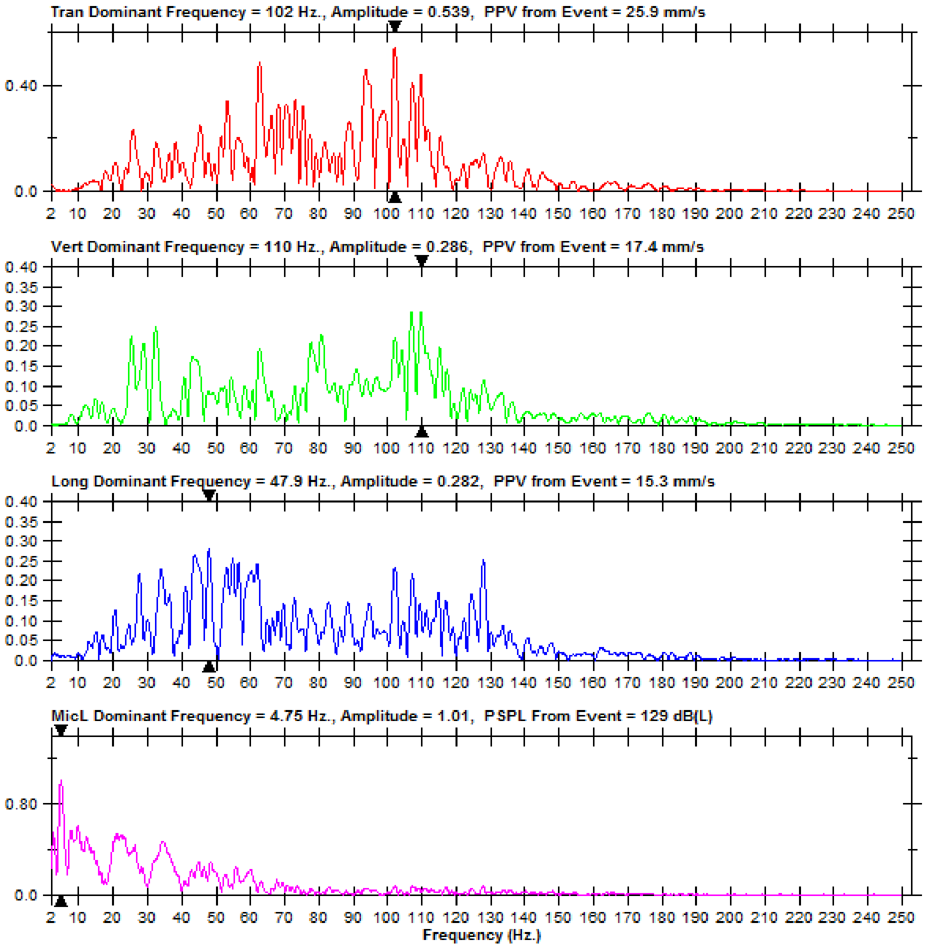
Instantel

FFT Report

Date/Time	Vert at 15:01:23 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62K.EB0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 47 No:12b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Long at 15:15:43 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62L.270
Job Number:	1		

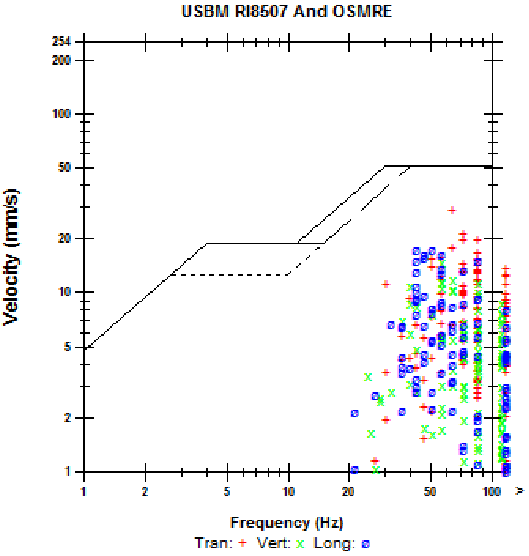
Notes
Location:
Client:
User Name:
General:

Post Event Notes

Microphone	Linear Weighting
PSPL	113.5 dB(L) at 0.480 sec
ZC Freq	7.0 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 706 mv)

	Tran	Vert	Long	
PPV	29.1	14.7	17.6	mm/s
ZC Freq	64	57	43	Hz
Time (Rel. to Trig)	0.420	0.324	0.274	sec
Peak Acceleration	1.04	0.708	0.711	g
Peak Displacement	0.0664	0.0329	0.0552	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.2	Hz
Overswing Ratio	4.0	3.5	4.4	

Peak Vector Sum 31.0 mm/s at 0.420 sec



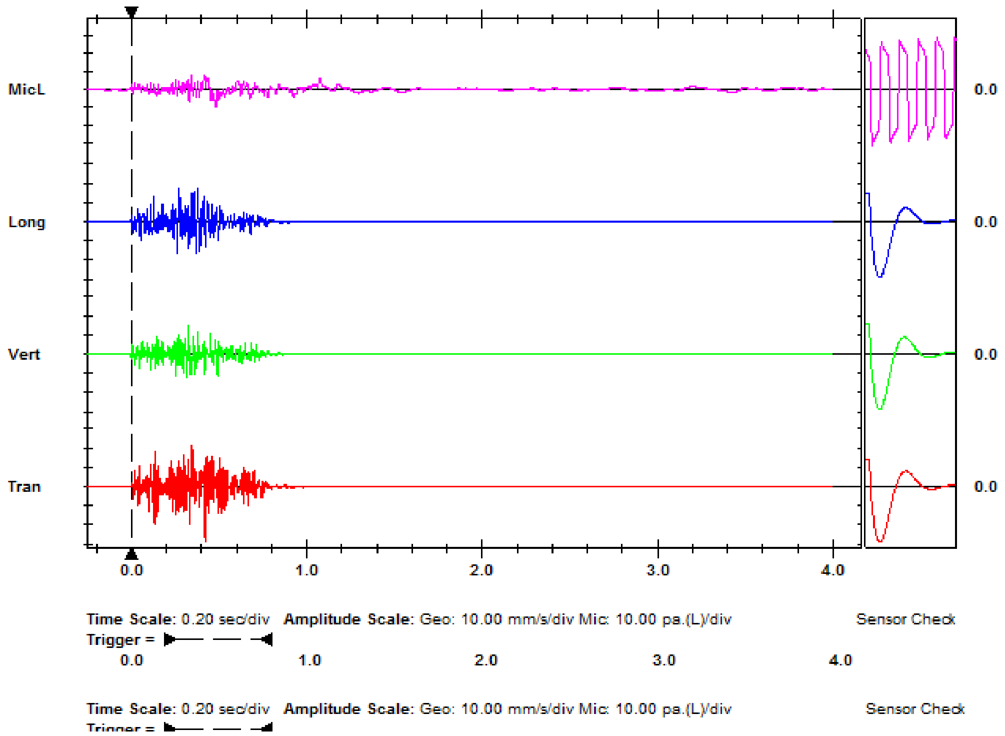


Figure A. 48 No:13a Seismograph record of production blasts

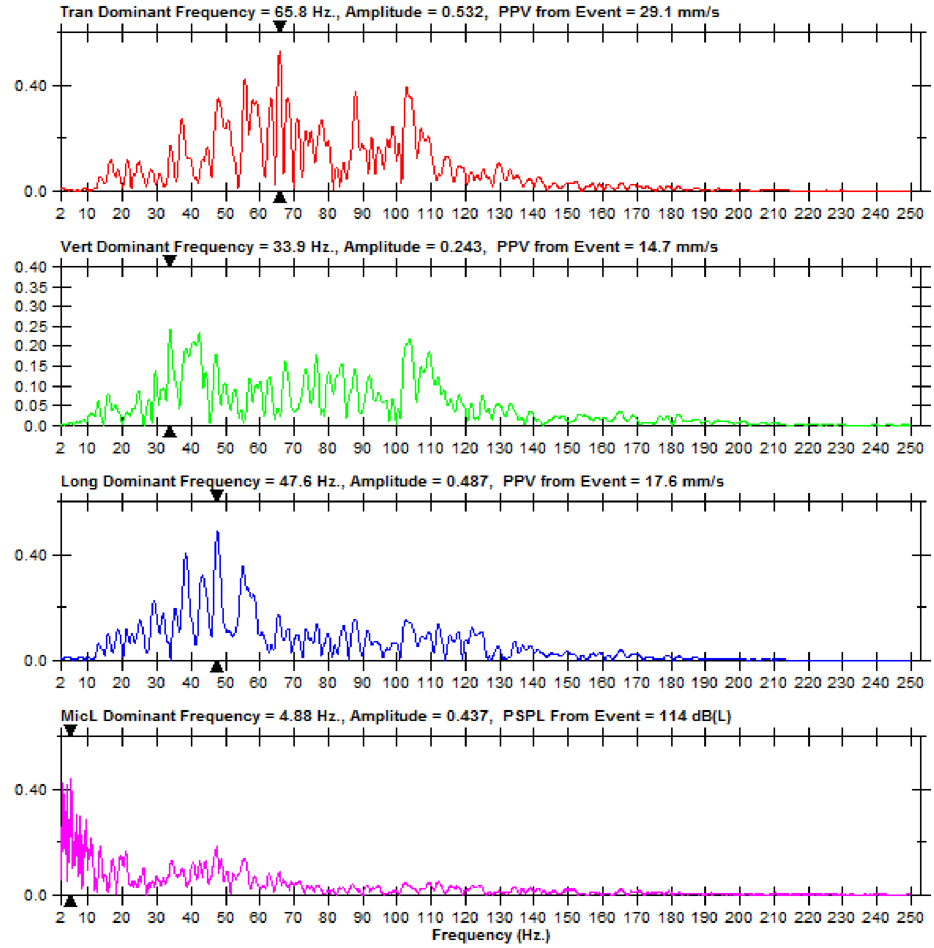
Instantel

FFT Report

Date/Time	Long at 15:15:43 January 24, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.2 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F62L.270
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60) Format © 1995-2013 Xmark Corporation

Figure A. 49 No:13b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Tran at 16:20:53 February 11, 2014
Trigger Source	Geo: 2.54 mm/s
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

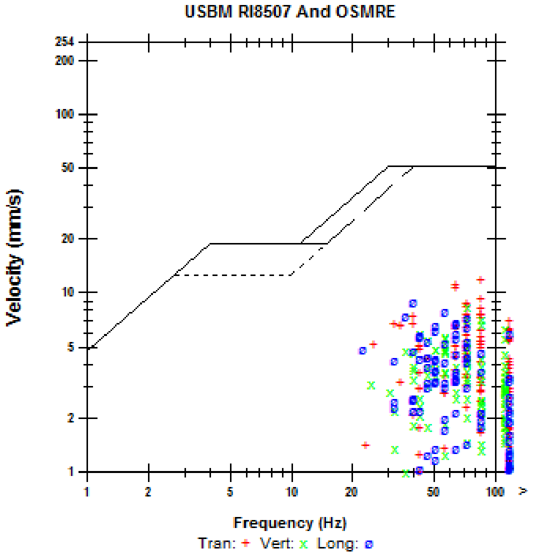
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F700.2T0

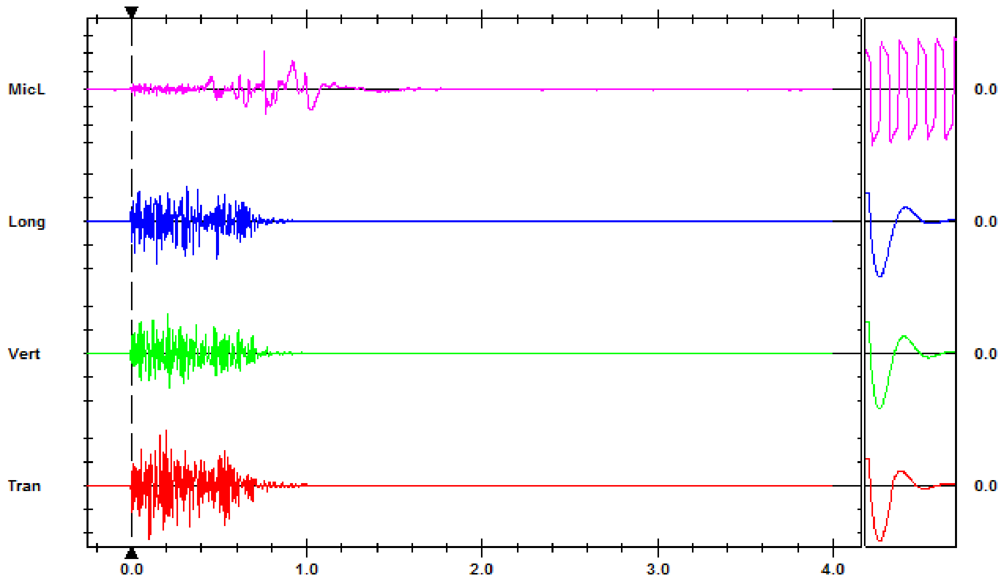
Post Event Notes

Microphone	Linear Weighting
PSPL	120.5 dB(L) at 0.756 sec
ZC Freq	43 Hz
Channel Test	Passed (Freq = 20.5 Hz Amp = 629 mv)

	Tran	Vert	Long	
PPV	11.8	8.35	8.97	mm/s
ZC Freq	85	73	39	Hz
Time (Rel. to Trig)	0.196	0.211	0.146	sec
Peak Acceleration	0.562	0.446	0.393	g
Peak Displacement	0.0289	0.0206	0.0338	mm
Sensor Check	Passed	Passed	Passed	
Frequency	8.5	7.7	7.3	Hz
Overswing Ratio	4.1	3.5	4.4	

Peak Vector Sum 12.3 mm/s at 0.163 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

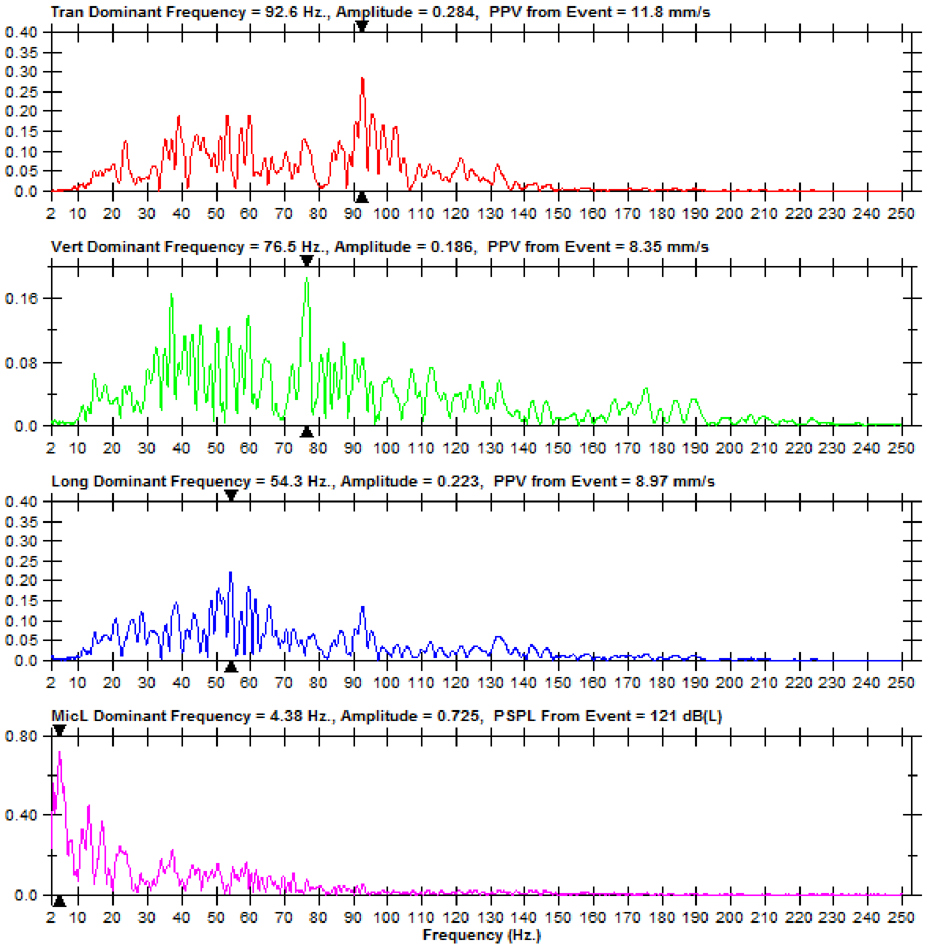
Figure A. 50 No:14a Seismograph record of production blasts

FFT Report

Date/Time	Tran at 16:20:53 February 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F700.2T0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 51 No:14b Seismograph record of production blasts

Event Report

Date/Time	Long at 16:45:56 February 11, 2014
Trigger Source	Geo: 2.54 mm/s
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F701.8K0

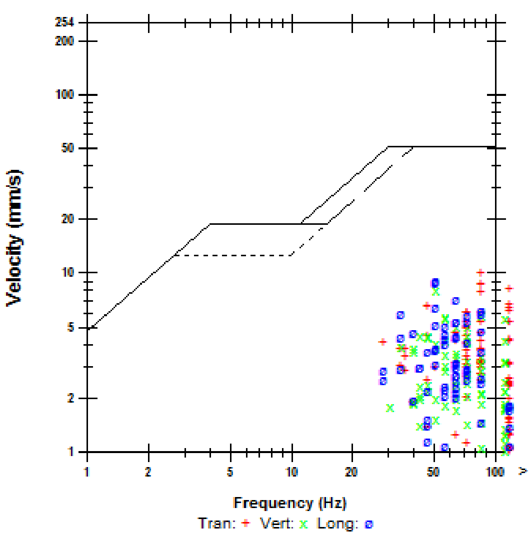
Notes
Location:
Client:
User Name:
General:

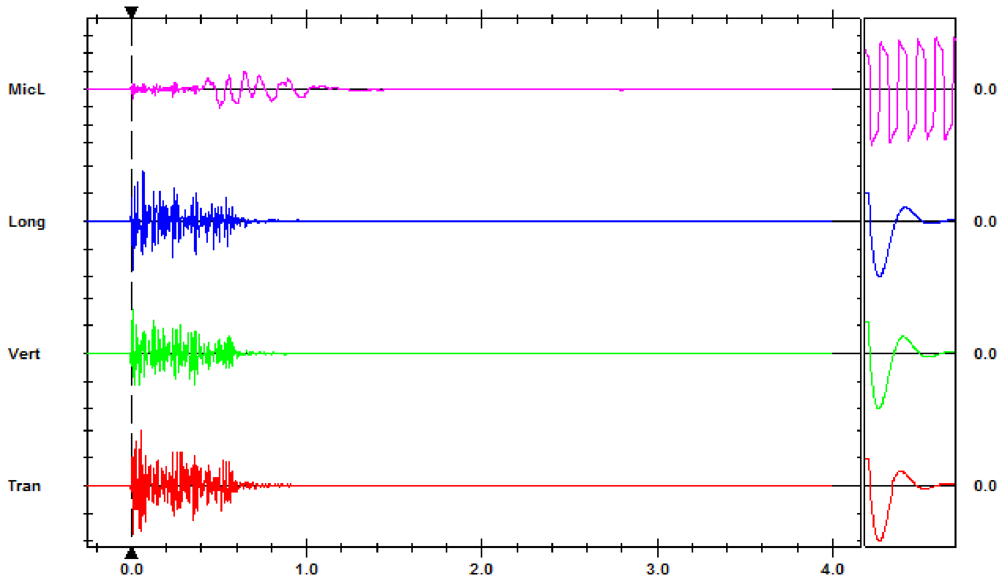
Post Event Notes

Microphone	Linear Weighting
PSPL	114.4 dB(L) at 0.505 sec
ZC Freq	9.1 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 632 mv)

	Tran	Vert	Long	
PPV	10.1	8.06	9.10	mm/s
ZC Freq	85	51	51	Hz
Time (Rel. to Trig)	0.057	0.008	0.068	sec
Peak Acceleration	0.585	0.389	0.366	g
Peak Displacement	0.0220	0.0183	0.0254	mm
Sensor Check	Passed	Passed	Passed	
Frequency	8.5	7.7	7.2	Hz
Overswing Ratio	4.1	3.6	4.4	

Peak Vector Sum 11.7 mm/s at 0.009 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger = ▶— —◀
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger = ▶— —◀

Figure A. 52 No:15a Seismograph record of production blasts

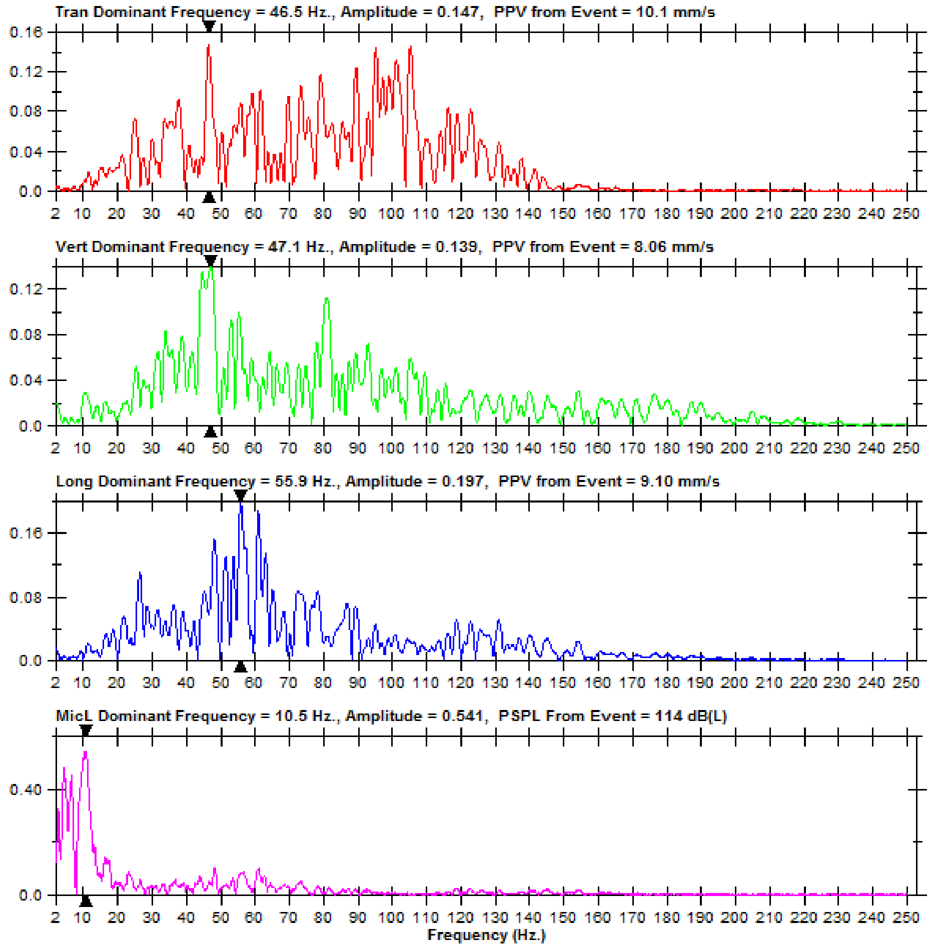
Instantel

FFT Report

Date/Time	Long at 16:45:56 February 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F701.8K0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 53 No:15b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Long at 17:09:46 February 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F702.CA0
Job Number:	1		

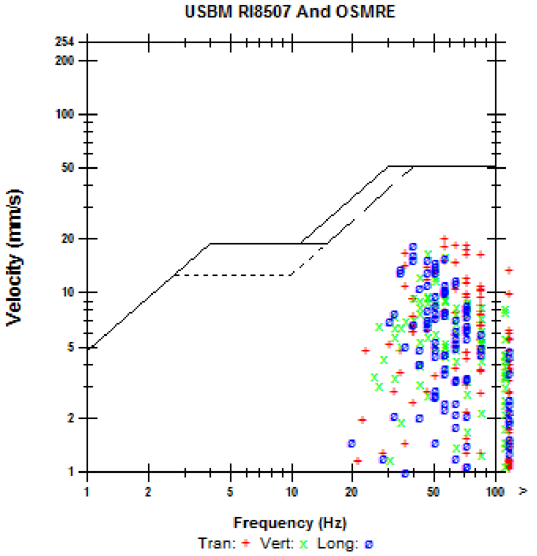
Notes
Location:
Client:
User Name:
General:

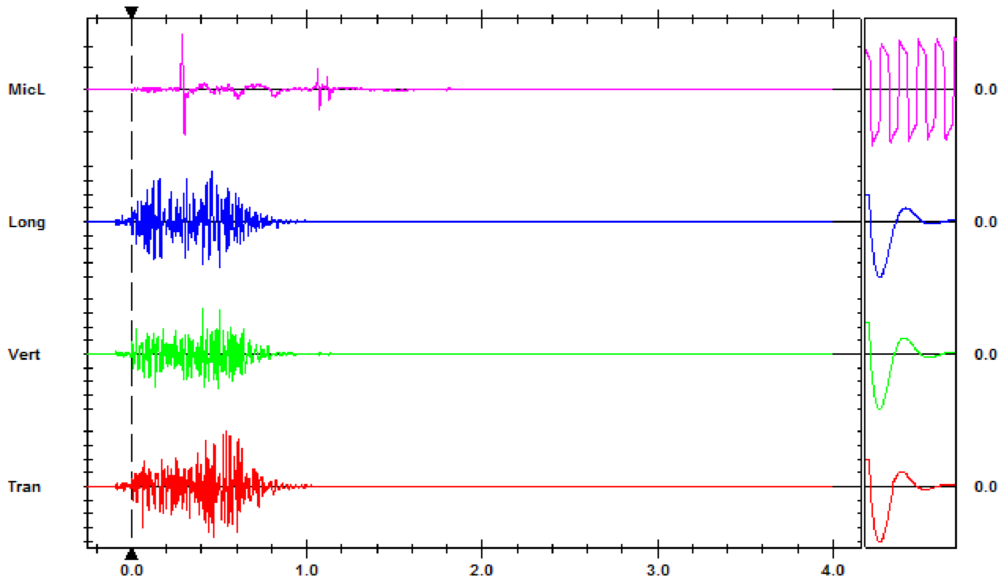
Post Event Notes

Microphone Linear Weighting
PSPL 136.2 dB(L) at 0.289 sec
ZC Freq 21 Hz
Channel Test Passed (Freq = 20.5 Hz Amp = 670 mv)

	Tran	Vert	Long	
PPV	20.3	16.7	18.4	mm/s
ZC Freq	57	47	39	Hz
Time (Rel. to Trig)	0.542	0.406	0.457	sec
Peak Acceleration	0.860	0.650	0.626	g
Peak Displacement	0.0588	0.0483	0.0629	mm
Sensor Check	Passed	Passed	Passed	
Frequency	8.3	7.6	7.2	Hz
Overswing Ratio	4.1	3.6	4.5	

Peak Vector Sum 23.1 mm/s at 0.503 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 50.0 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 50.0 pa.(L)/div Sensor Check
Trigger =

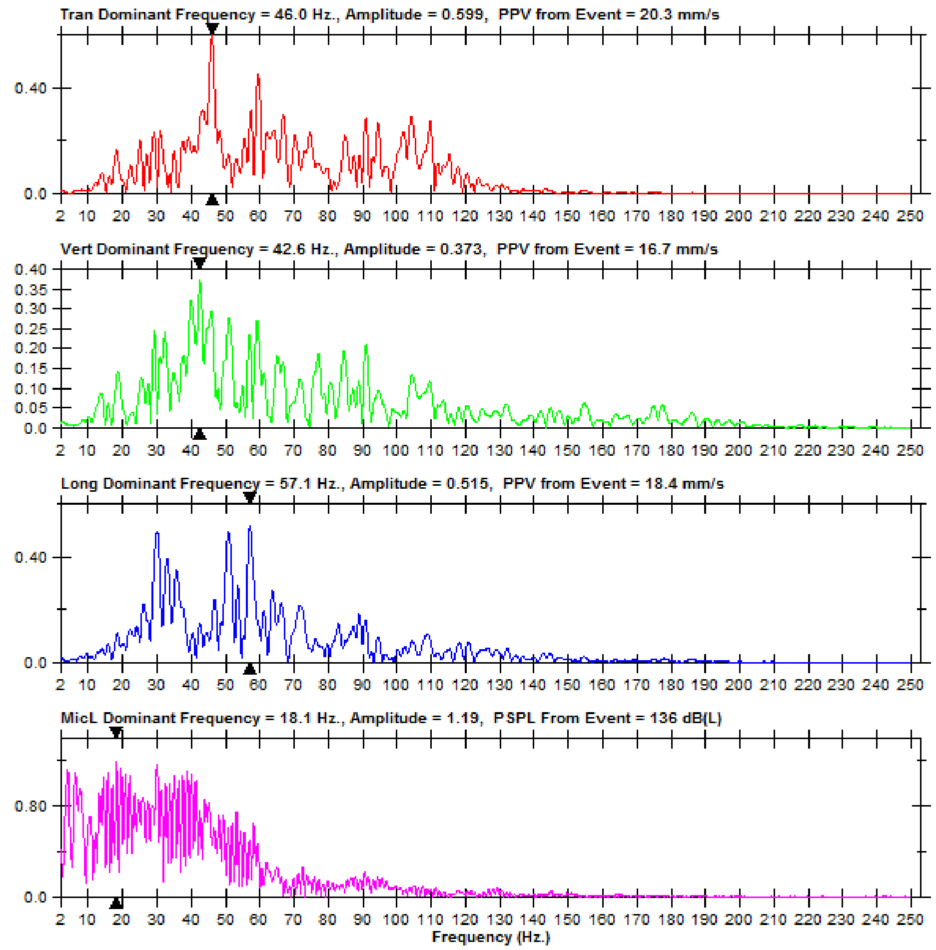
Figure A. 54 No:16a Seismograph record of production blasts

Instantel **FFT Report**

Date/Time	Long at 17:09:46 February 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F702.CA0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 55 No:16b Seismograph record of production blasts

Instantel **Event Report**

Date/Time	Tran at 17:34:47 February 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F703.HZ0
Job Number:	1		

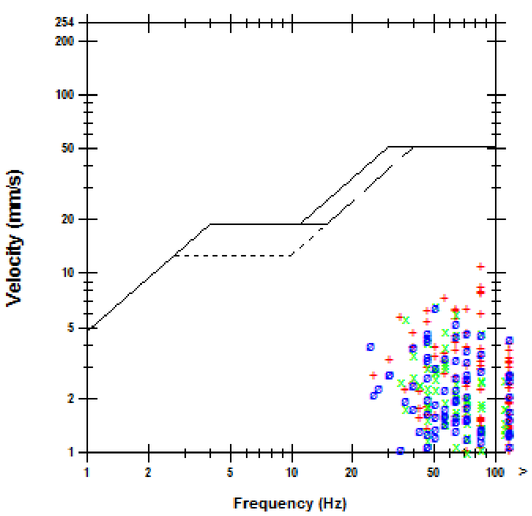
Notes
Location:
Client:
User Name:
General:

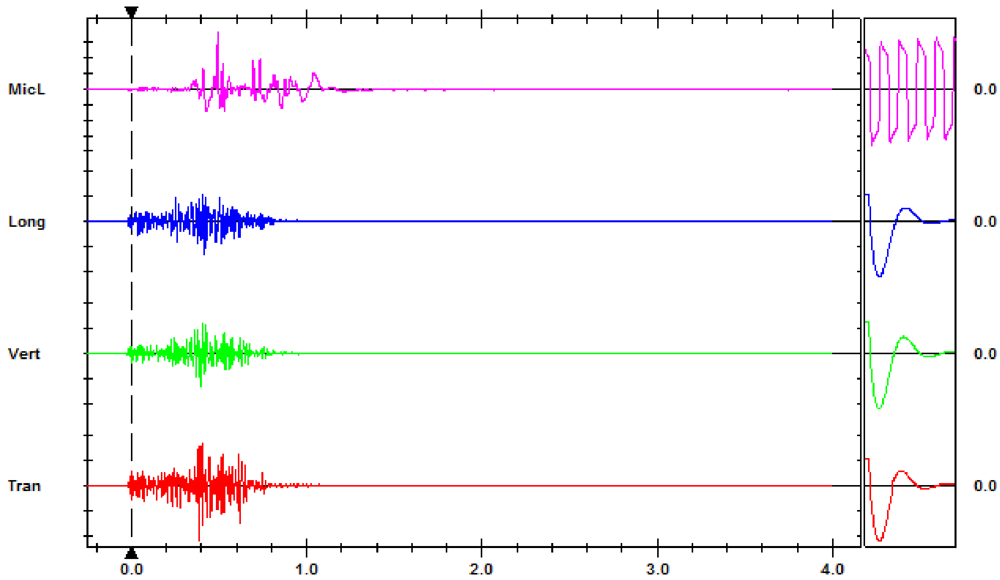
Post Event Notes

Microphone	Linear Weighting
PSPL	125.0 dB(L) at 0.493 sec
ZC Freq	34 Hz
Channel Test	Passed (Freq = 20.5 Hz Amp = 663 mv)

	Tran	Vert	Long	
PPV	11.0	6.64	6.51	mm/s
ZC Freq	85	51	51	Hz
Time (Rel. to Trig)	0.390	0.394	0.418	sec
Peak Acceleration	0.545	0.317	0.263	g
Peak Displacement	0.0231	0.0186	0.0187	mm
Sensor Check	Passed	Passed	Passed	
Frequency	8.2	7.6	7.2	Hz
Overswing Ratio	4.1	3.6	4.5	

Peak Vector Sum 12.0 mm/s at 0.390 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 56 No:17a Seismograph record of production blasts

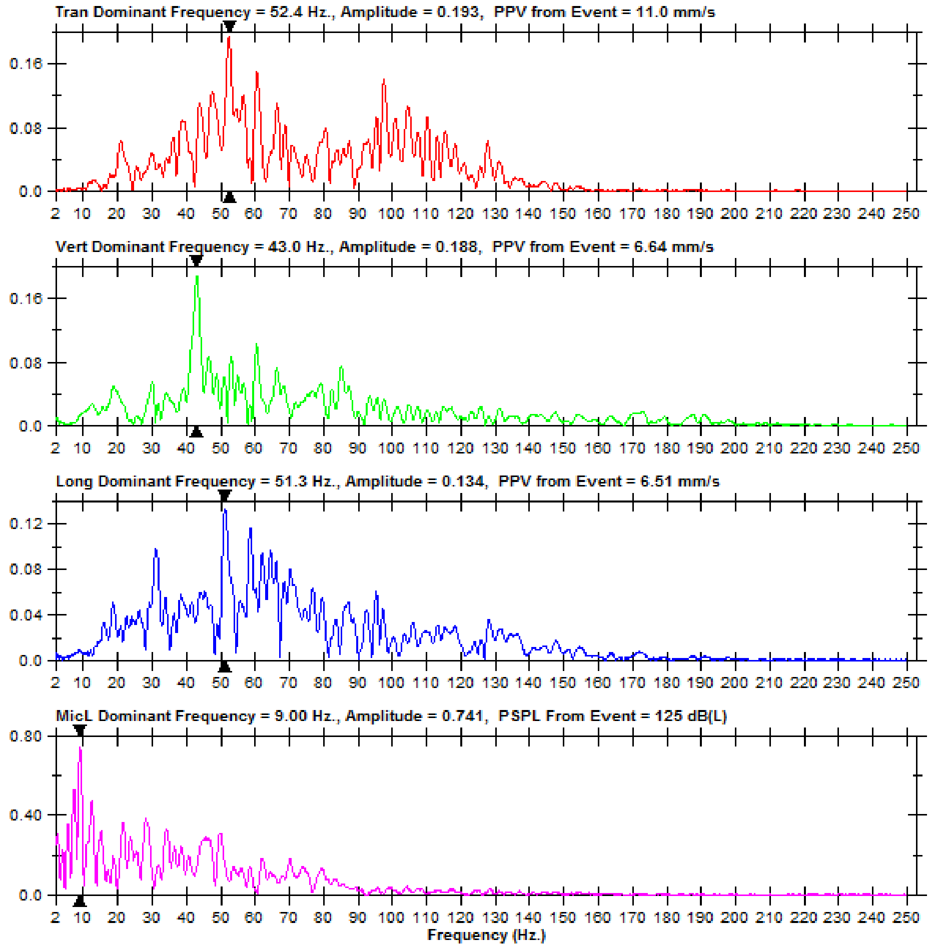
Instantel

FFT Report

Date/Time	Tran at 17:34:47 February 11, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F703.HZ0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 57 No:17b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 11:44:07 February 12, 2014
Trigger Source	Geo: 2.54 mm/s
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

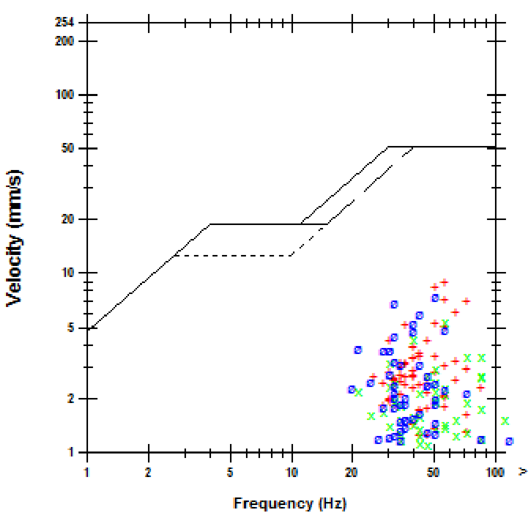
Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	6.1 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F71H.XJ0

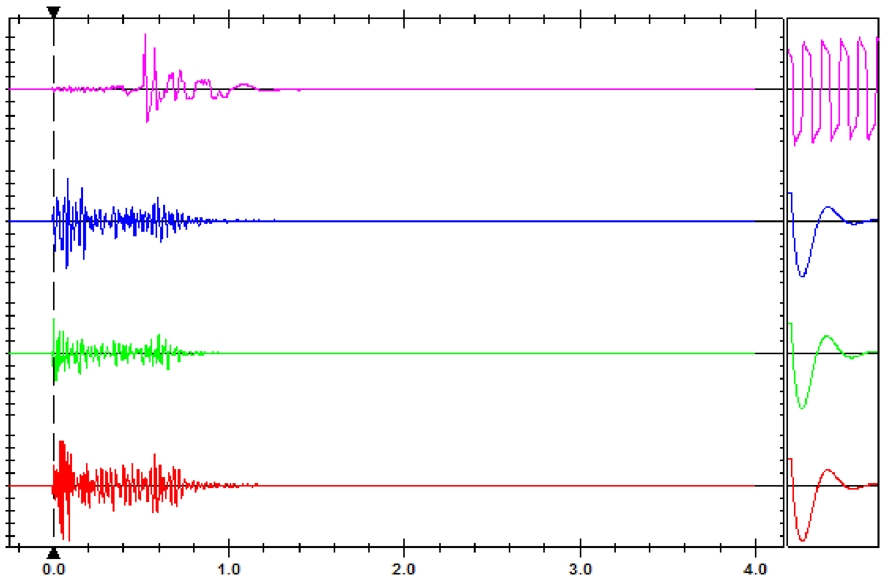
Post Event Notes

Microphone	Linear Weighting
PSPL	126.6 dB(L) at 0.521 sec
ZC Freq	12 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 647 mv)

	Tran	Vert	Long	
PPV	8.92	5.43	7.43	mm/s
ZC Freq	57	57	51	Hz
Time (Rel. to Trig)	0.091	0.003	0.077	sec
Peak Acceleration	0.370	0.245	0.321	g
Peak Displacement	0.0251	0.0167	0.0268	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.3	Hz
Overswing Ratio	3.9	3.5	4.3	

Peak Vector Sum 9.63 mm/s at 0.091 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 2.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

Figure A. 58 No:18a Seismograph record of production blasts

Instantel

FFT Report

Date/Time	Vert at 11:44:07 February 12, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F71H.XJ0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes

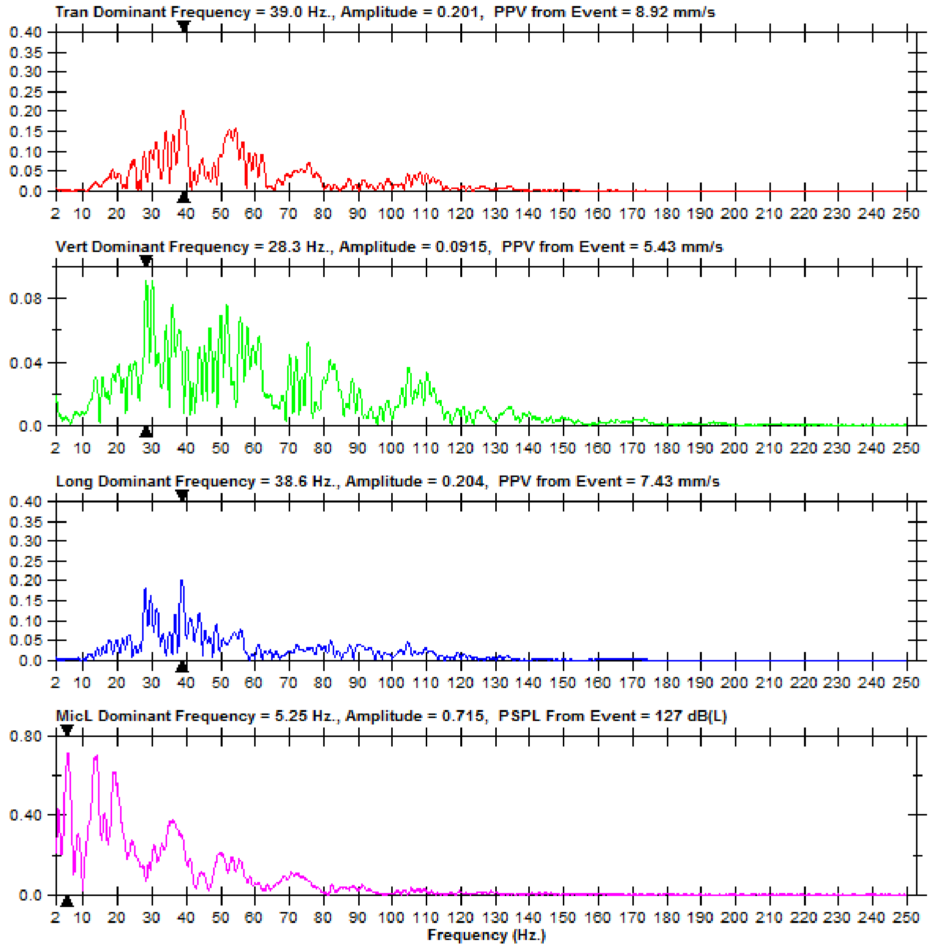


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Figure A. 59 No:18b Seismograph record of production blasts

Event Report

Date/Time	Vert at 12:11:07 February 12, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F71J.6J0
Job Number:	1		

Notes **Post Event Notes**

Location:

Client:

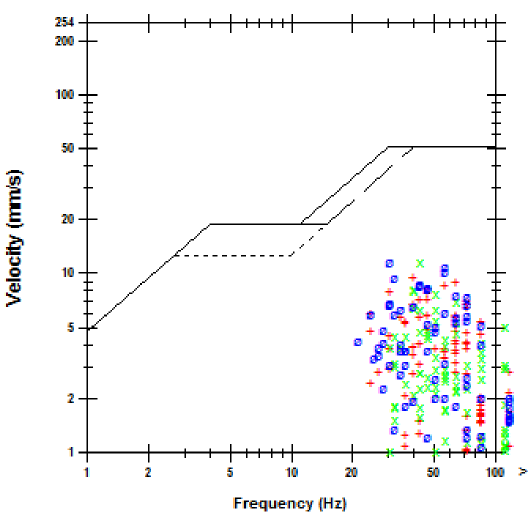
User Name:

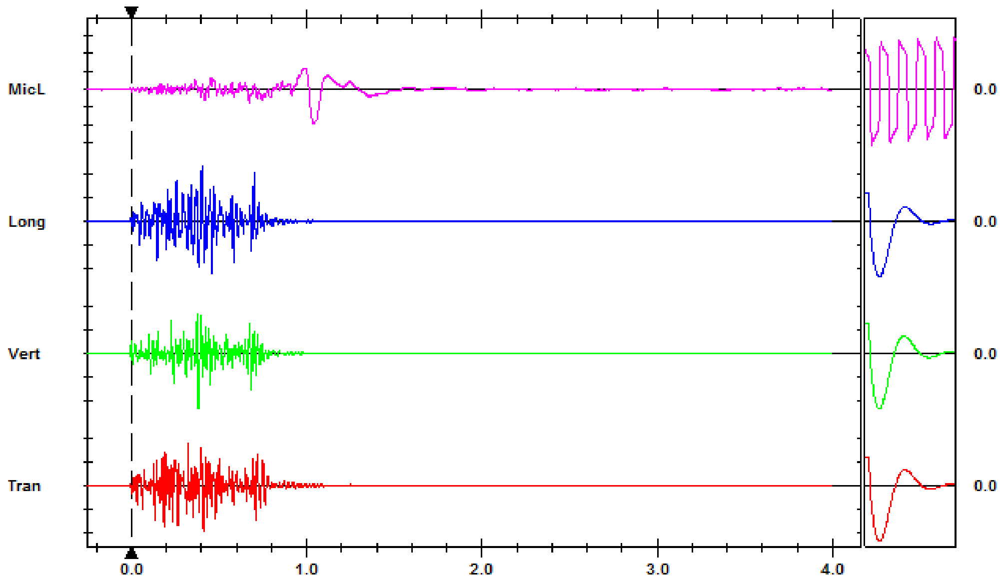
General:

Microphone	Linear Weighting
PSPL	119.7 dB(L) at 1.041 sec
ZC Freq	7.0 Hz
Channel Test	Passed (Freq = 20.5 Hz Amp = 599 mv)

	Tran	Vert	Long	
PPV	9.46	11.7	11.5	mm/s
ZC Freq	39	43	30	Hz
Time (Rel. to Trig)	0.412	0.384	0.403	sec
Peak Acceleration	0.383	0.592	0.423	g
Peak Displacement	0.0369	0.0447	0.0494	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.2	Hz
Overswing Ratio	3.8	3.5	4.3	

Peak Vector Sum 15.3 mm/s at 0.385 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

Trigger =

0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

Figure A. 60 No:19a Seismograph record of production blasts

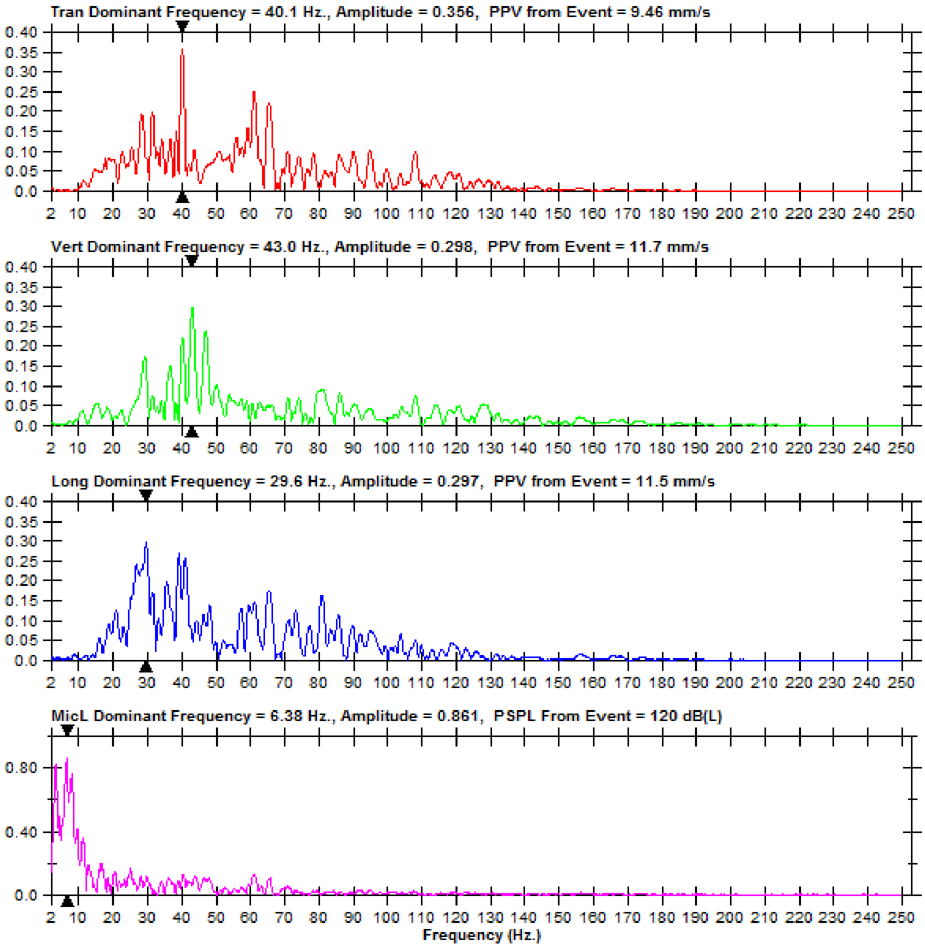
Instantel

FFT Report

Date/Time	Vert at 12:11:07 February 12, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.1 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F71J.6J0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 10, 2014 (V 10.60 - 10.60)

Figure A. 61 No:19b Seismograph record of production blasts

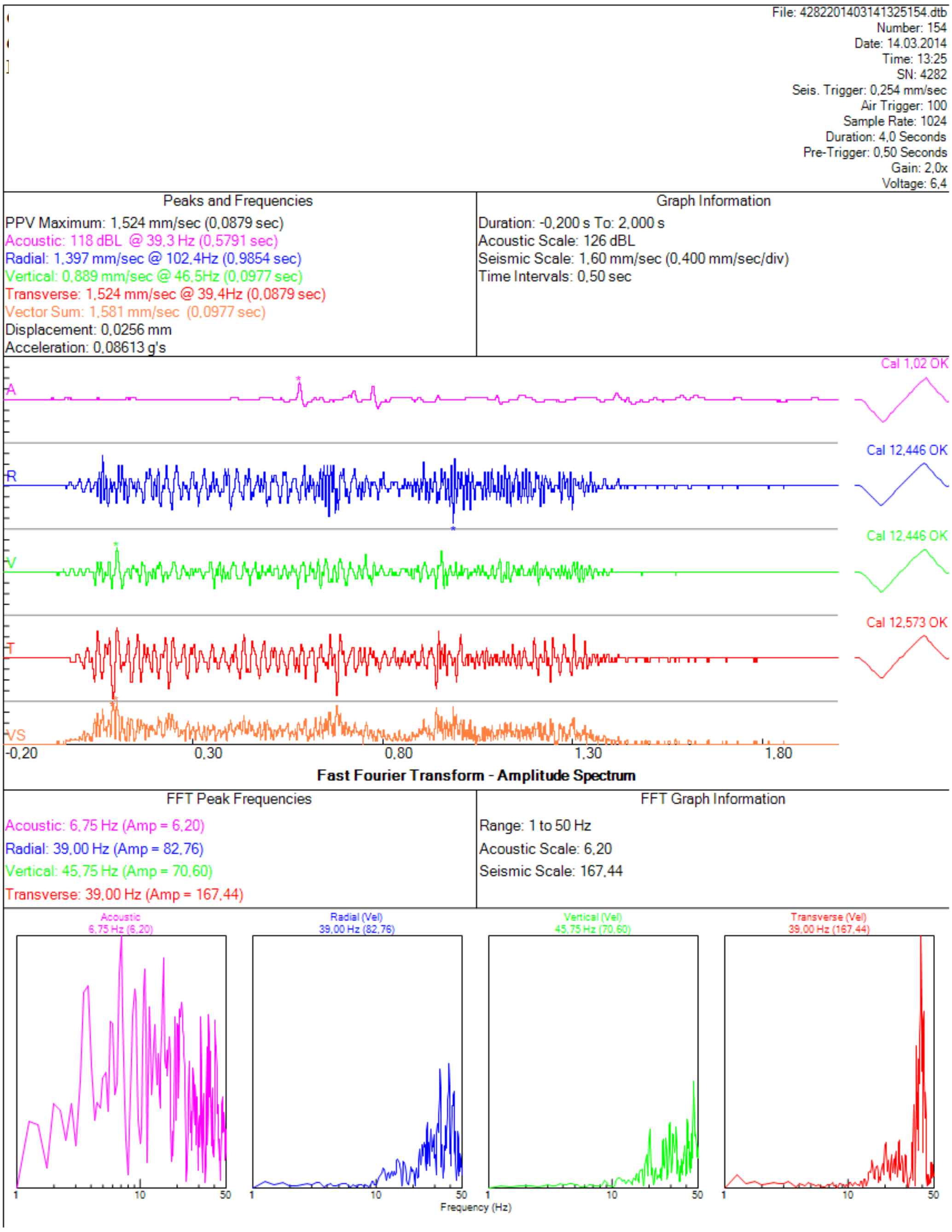


Figure A. 62 No:20 Seismograph record of production blasts

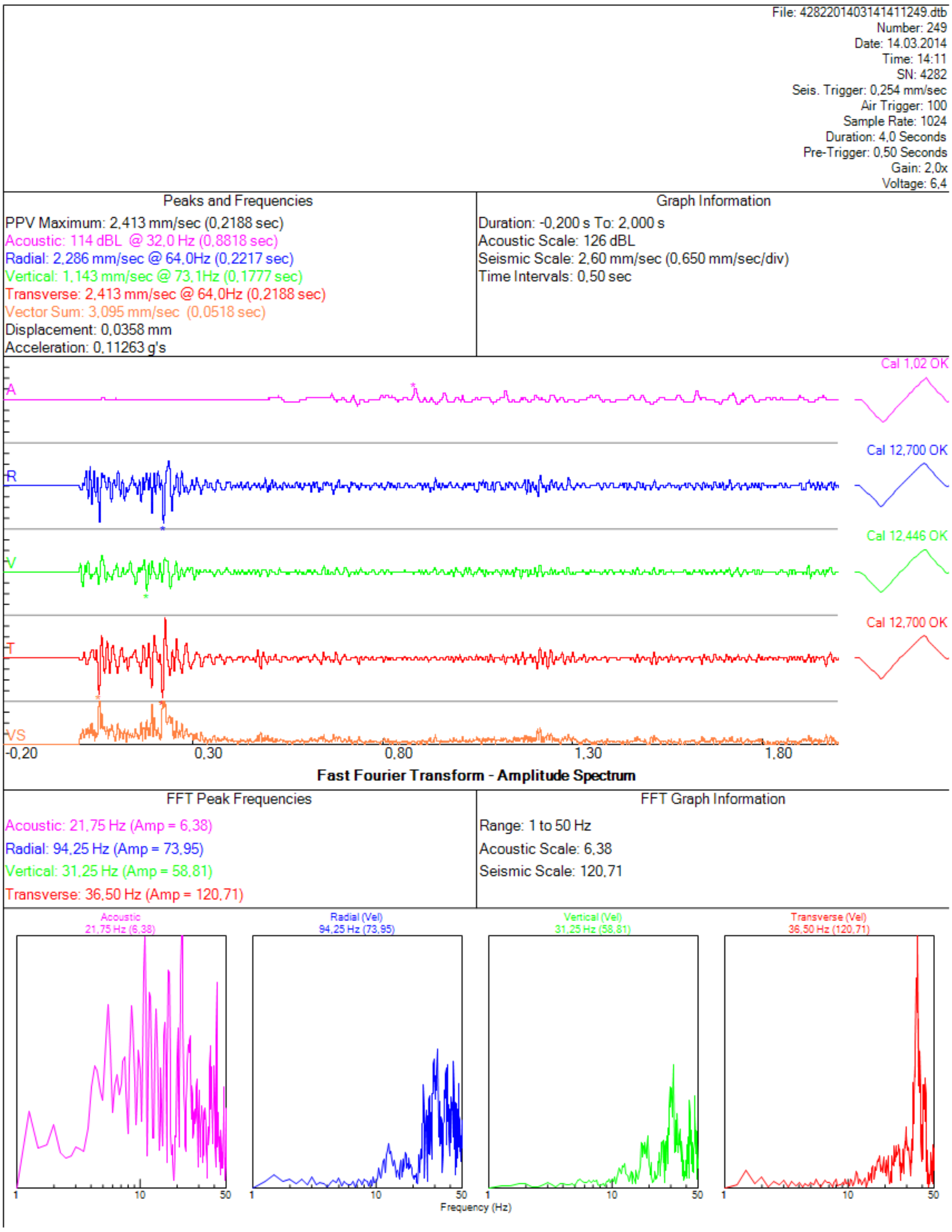


Figure A. 63 No:21 Seismograph record of production blasts

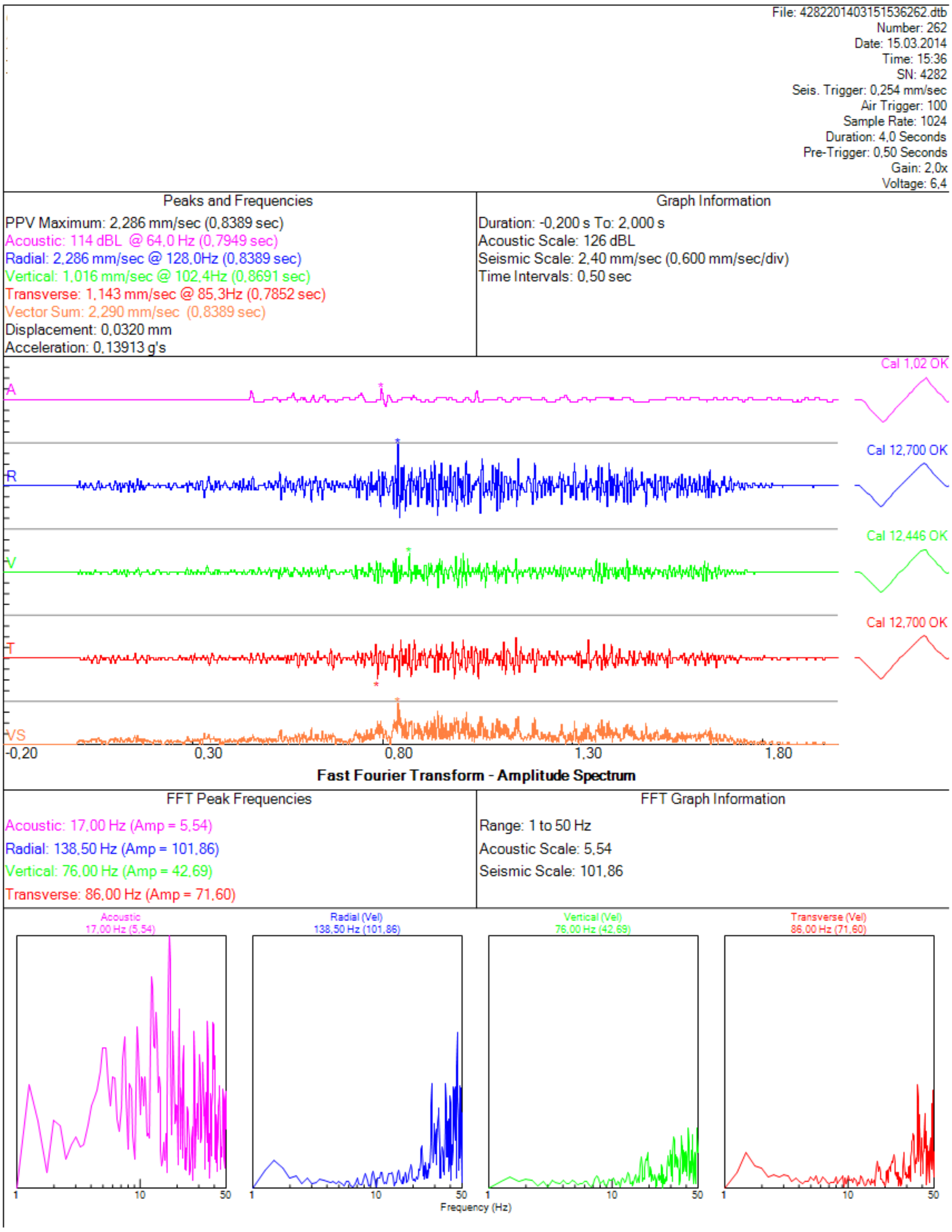


Figure A. 64 No:22 Seismograph record of production blasts

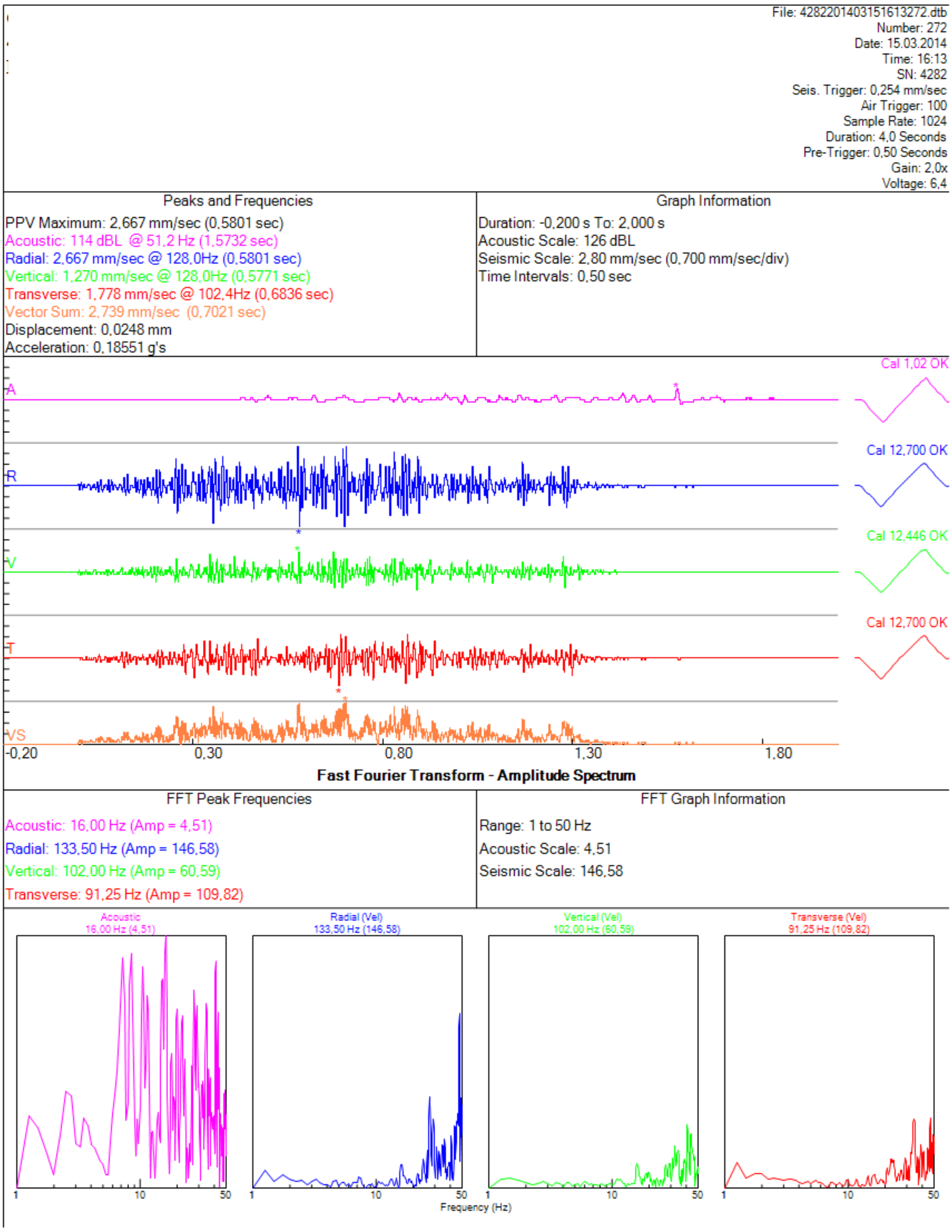


Figure A. 65 No:23 Seismograph record of production blasts

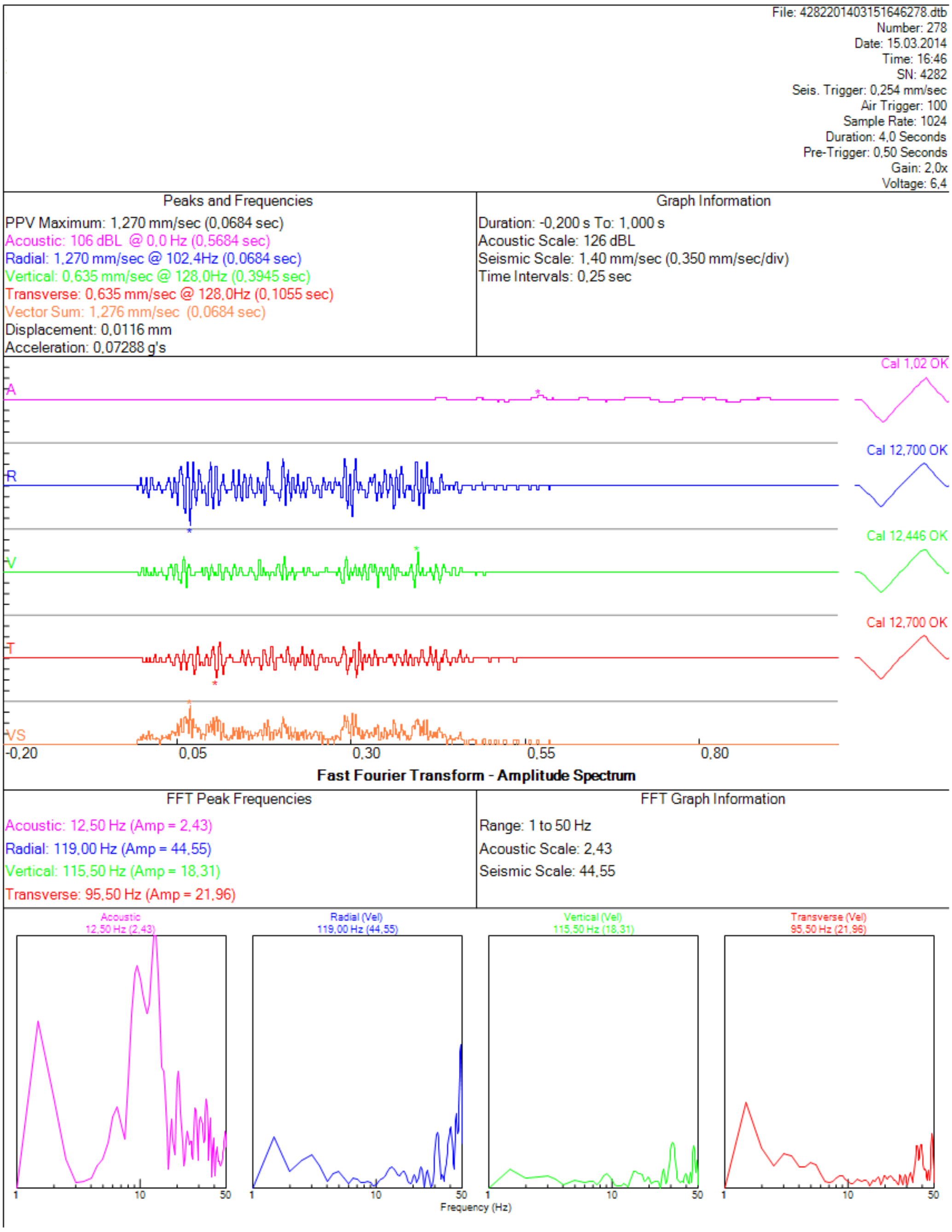


Figure A. 66 No:24 Seismograph record of production blasts

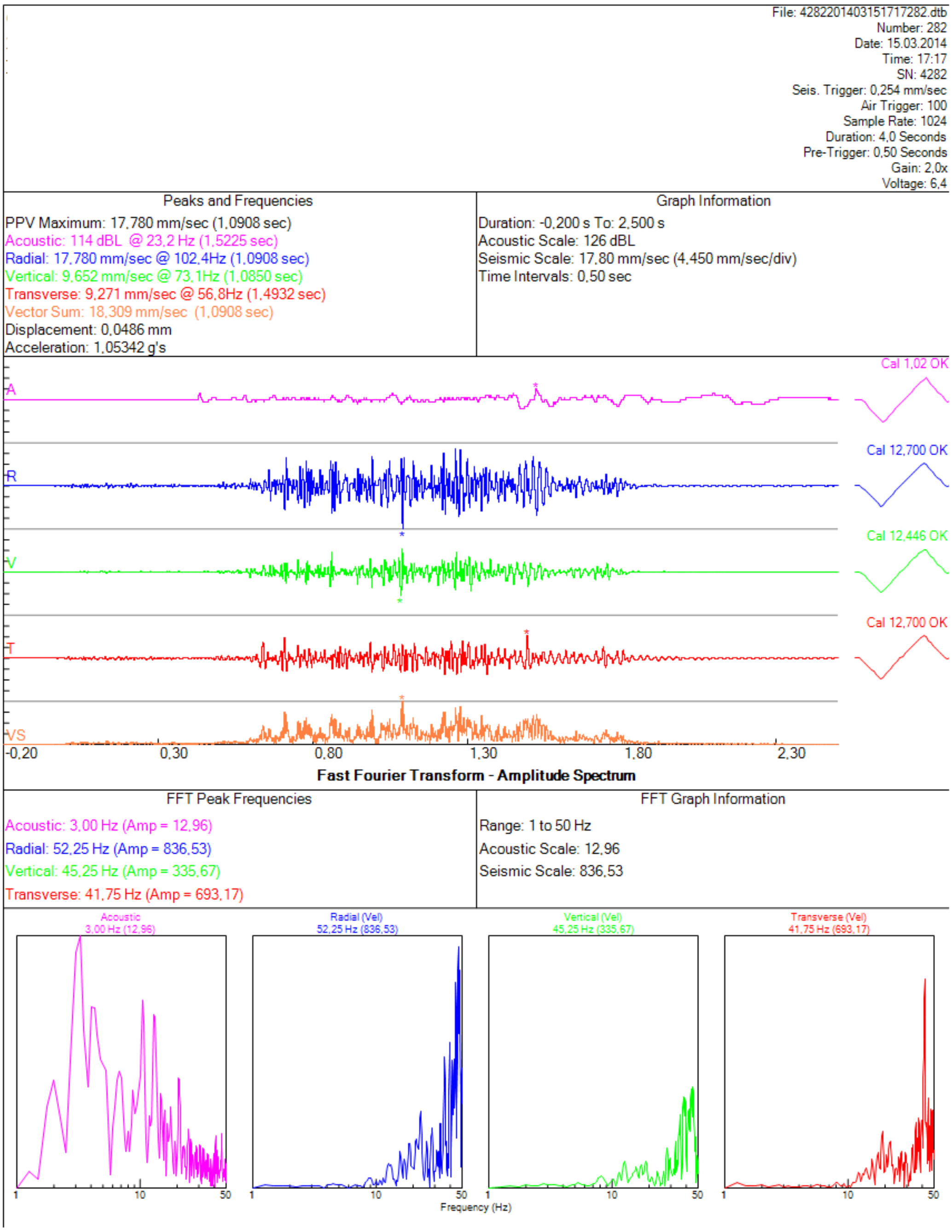


Figure A. 67 No:25 Seismograph record of production blasts

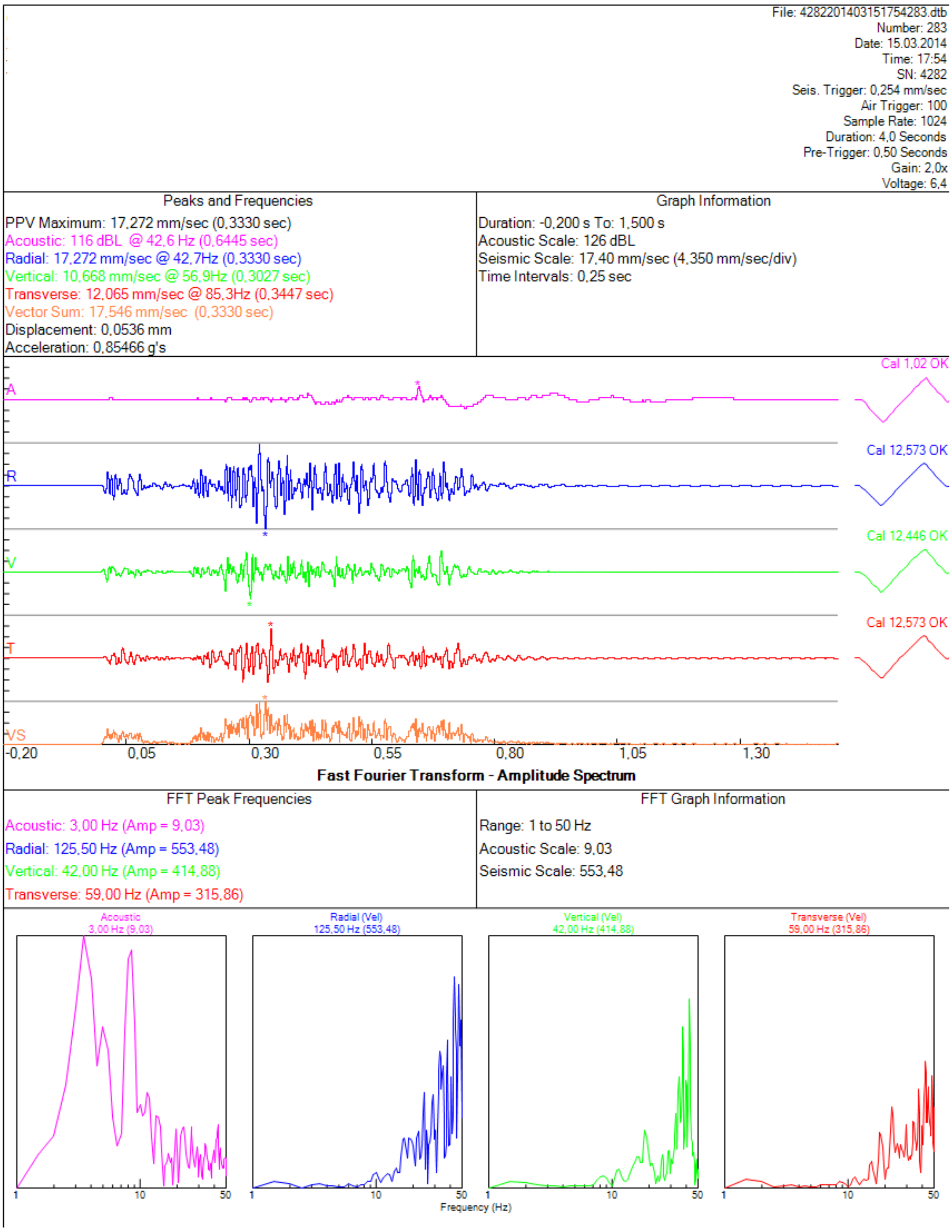


Figure A. 68 No:26 Seismograph record of production blasts

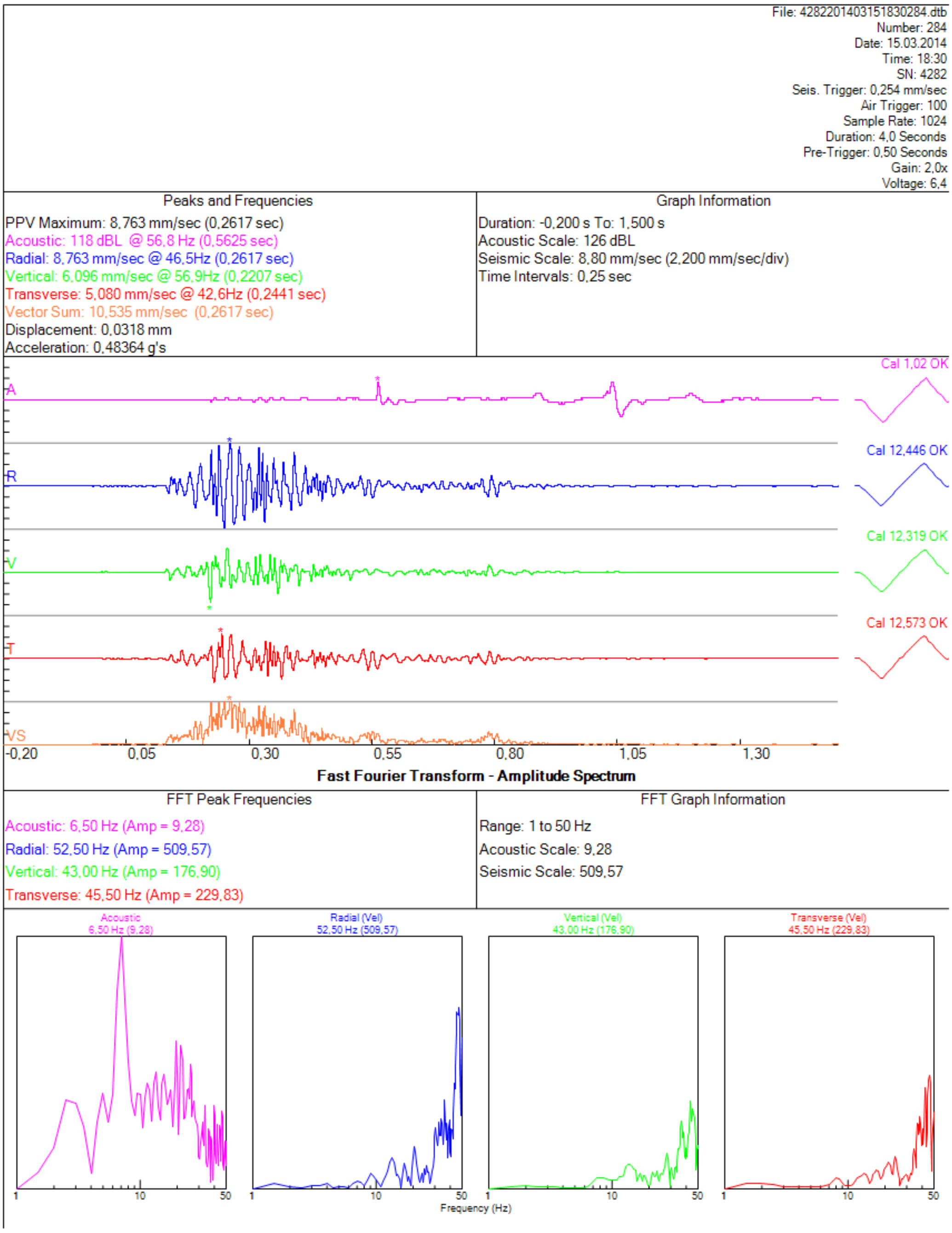


Figure A. 69 No:27 Seismograph record of production blasts

Instantel

Event Report

Date/Time	Vert at 14:11:35 March 19, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	5.9 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F8UI.3B0
Job Number:	1		

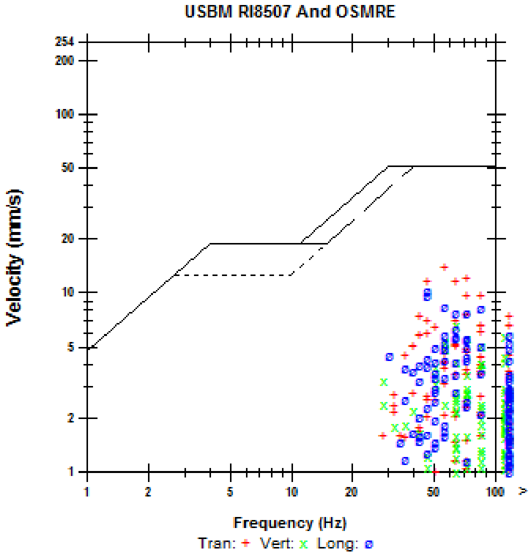
Notes
Location:
Client:
User Name:
General:

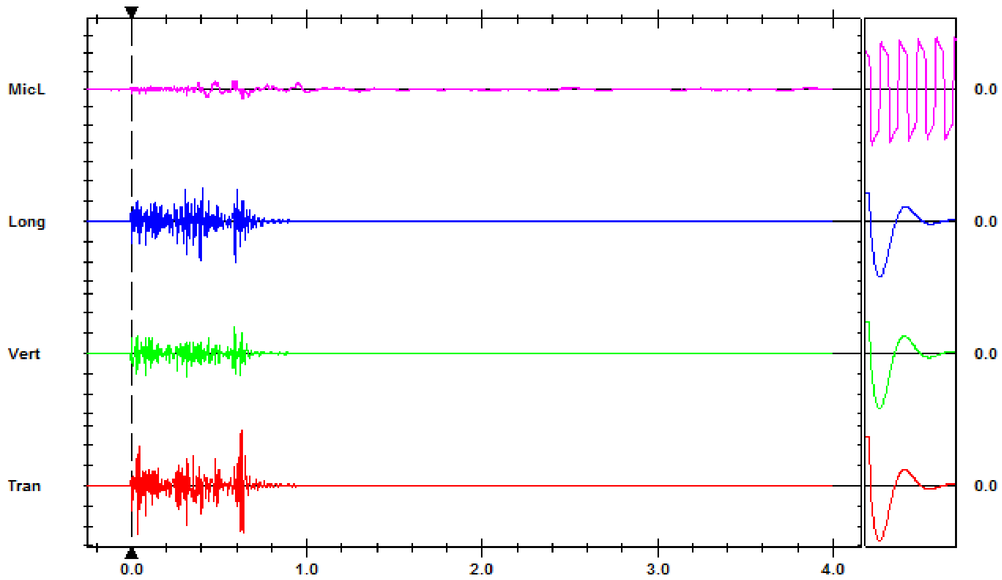
Post Event Notes

Microphone	Linear Weighting
PSPL	108.0 dB(L) at 0.634 sec
ZC Freq	39 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 578 mv)

	Tran	Vert	Long	
PPV	13.9	6.57	10.3	mm/s
ZC Freq	57	64	47	Hz
Time (Rel. to Trig)	0.627	0.589	0.592	sec
Peak Acceleration	0.621	0.356	0.484	g
Peak Displacement	0.0398	0.0163	0.0291	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.6	7.2	Hz
Overswing Ratio	3.8	3.5	4.2	

Peak Vector Sum 14.4 mm/s at 0.628 sec





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger =

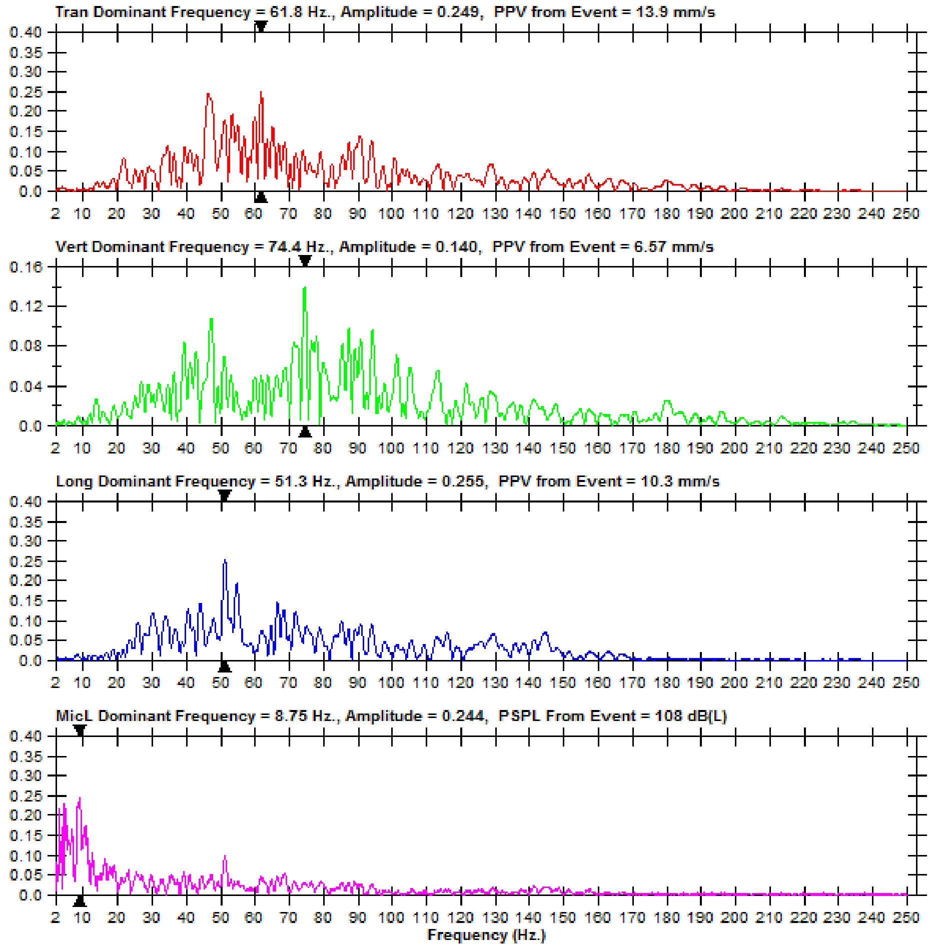
Figure A. 70 No:28a Seismograph record of production blasts

FFT Report

Date/Time	Vert at 14:11:35 March 19, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	5.9 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F8UI.3B0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: March 25, 2014 (V 10.60 - 10.60)

Figure A. 71 No:28b Seismograph record of production blasts

Event Report

Date/Time	Vert at 14:59:18 March 19, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F8UK.AU0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes

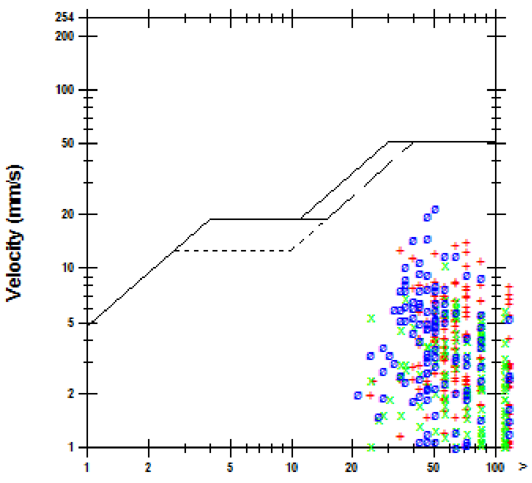
Extended Notes

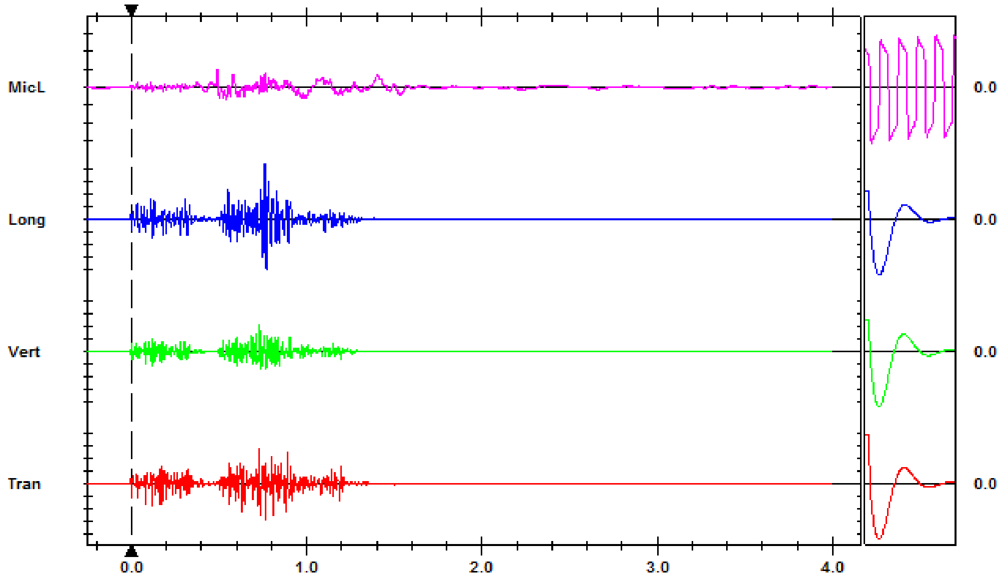
Microphone	Linear Weighting
PSPL	113.3 dB(L) at 0.491 sec
ZC Freq	8.8 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 559 mv)

	Tran	Vert	Long	
PPV	14.0	10.5	21.9	mm/s
ZC Freq	73	57	51	Hz
Time (Rel. to Trig)	0.768	0.732	0.761	sec
Peak Acceleration	0.713	0.404	0.769	g
Peak Displacement	0.0433	0.0264	0.0644	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.7	7.3	Hz
Overswing Ratio	3.8	3.5	4.2	

Peak Vector Sum 23.1 mm/s at 0.762 sec

USBM RI8507 And OSMRE





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check

Printed: March 25, 2014 (V 10.60 - 10.60) Format © 1995-2013 Xmark Corporation

Figure A. 72 No:29a Seismograph record of production blasts

Instantel

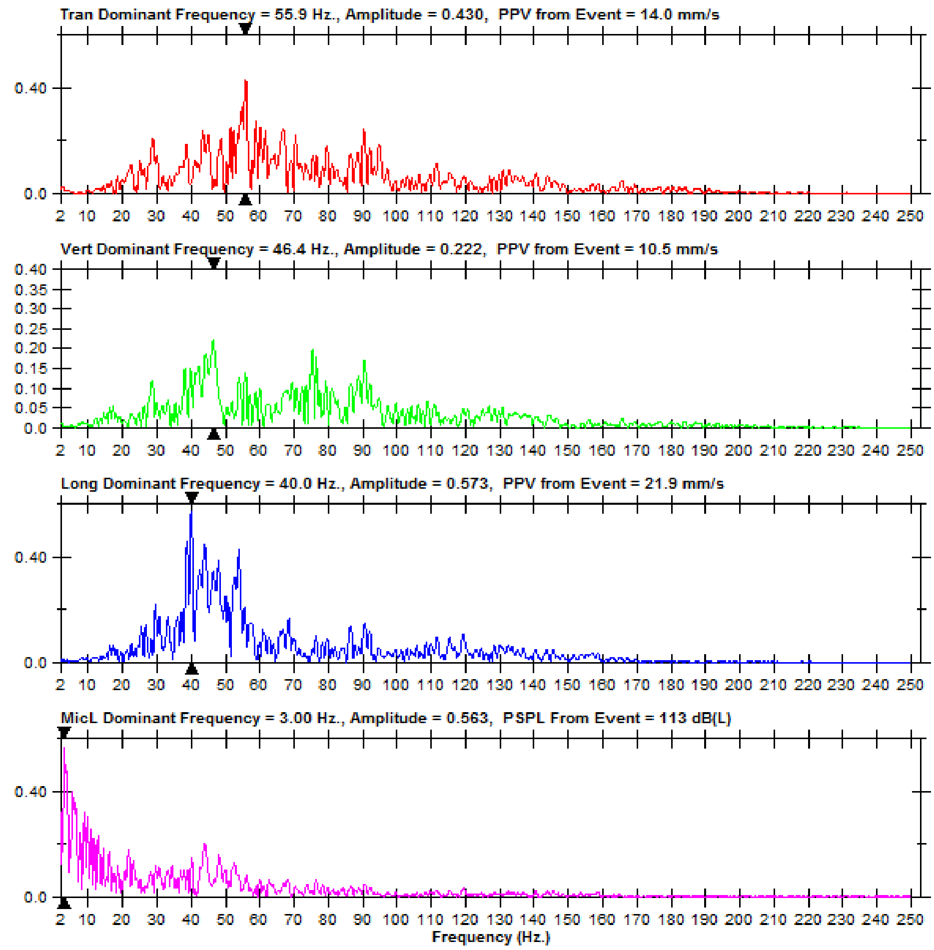
FFT Report

Date/Time	Vert at 14:59:18 March 19, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	6.0 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F8UK.AU0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Extended Notes

Post Event Notes



Printed: March 25, 2014 (V 10.60 - 10.60)

Format © 1995-2013 Xmark Corporation

Figure A. 73 No:29b Seismograph record of production blasts

Instantel

Event Report

Date/Time	Long at 14:40:06 April 4, 2014
Trigger Source	Geo: 2.54 mm/s
Range	Geo: 31.7 mm/s
Record Time	4.0 sec at 1024 sps
Job Number:	1

Notes
Location:
Client:
User Name:
General:

Serial Number	BE15218 V 10.40-1.1 Minimate Blaster
Battery Level	5.9 Volts
Unit Calibration	October 23, 2012 by Instantel
File Name	Q218F9O6.2U0

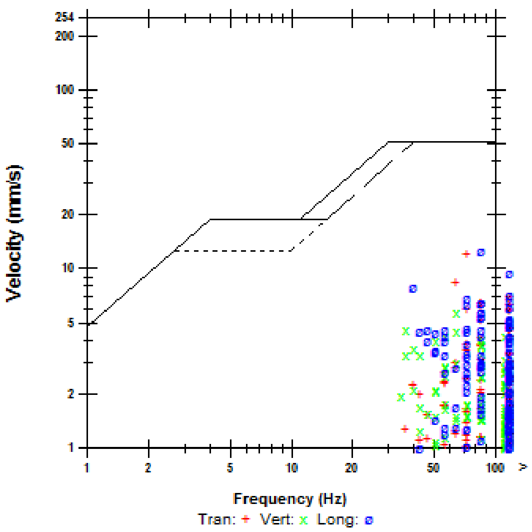
Post Event Notes

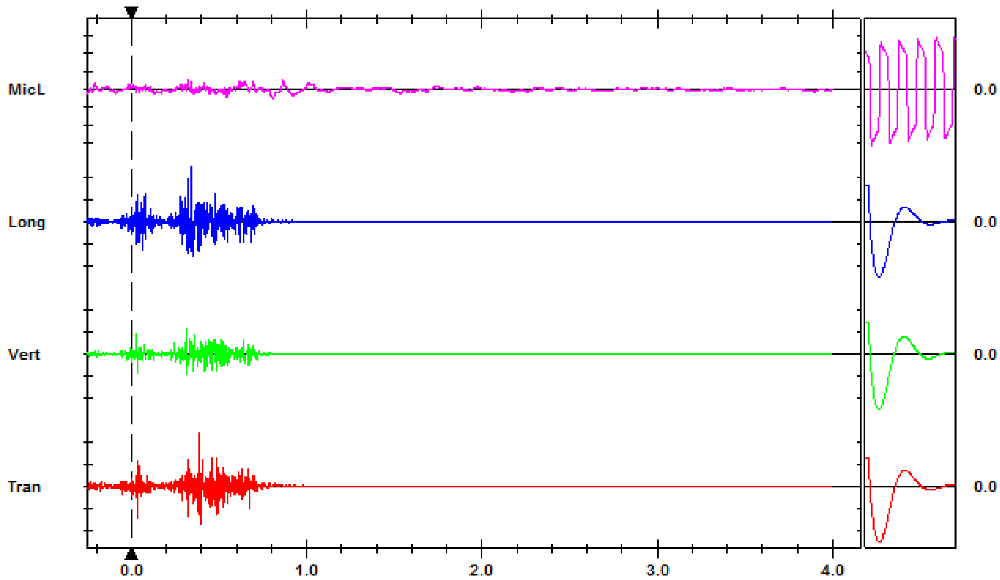
Microphone	Linear Weighting
PSPL	108.8 dB(L) at 0.326 sec
ZC Freq	39 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 609 mv)

	Tran	Vert	Long	
PPV	12.1	5.70	12.7	mm/s
ZC Freq	73	64	85	Hz
Time (Rel. to Trig)	0.390	0.315	0.343	sec
Peak Acceleration	0.583	0.437	0.663	g
Peak Displacement	0.0227	0.0144	0.0234	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.4	Hz
Overswing Ratio	3.8	3.4	4.2	

Peak Vector Sum 13.0 mm/s at 0.390 sec

USBM RI8507 And OSMRE





Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger = ▶— — ◀
0.0 1.0 2.0 3.0 4.0

Time Scale: 0.20 sec/div **Amplitude Scale:** Geo: 5.00 mm/s/div Mic: 10.00 pa.(L)/div Sensor Check
Trigger = ▶— — ◀

Figure A. 74 No:30a Seismograph record of production blasts

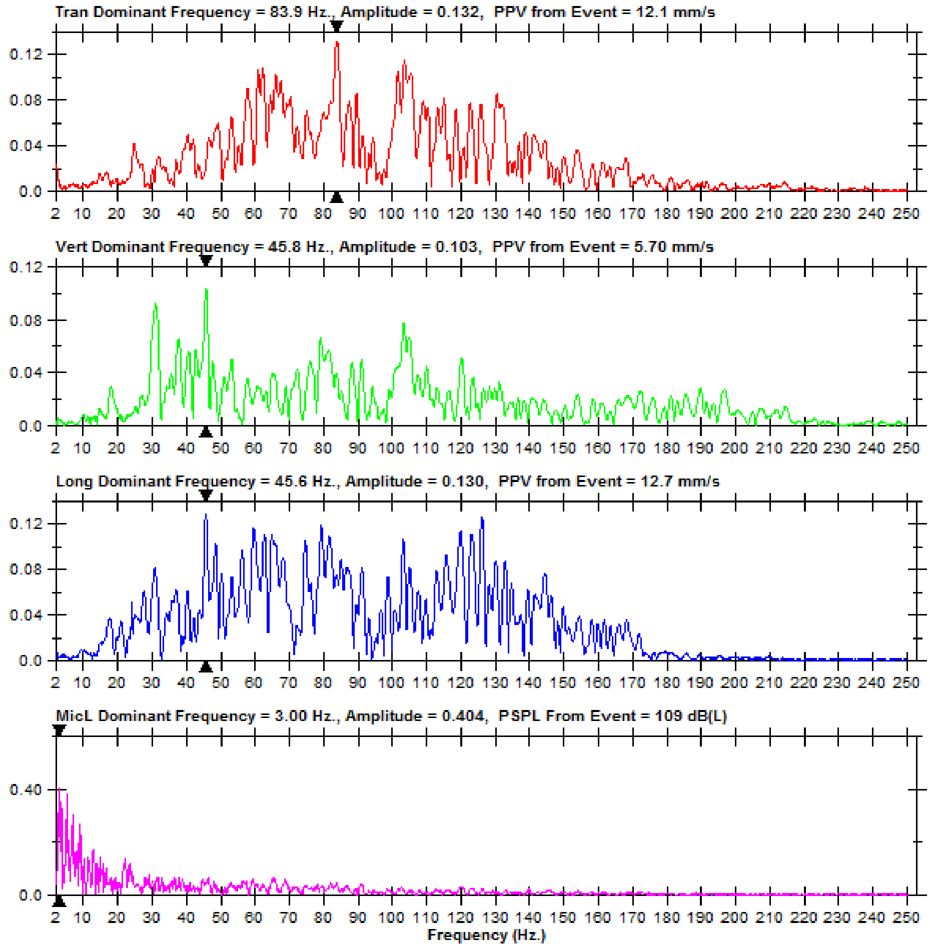
Instantel

FFT Report

Date/Time	Long at 14:40:06 April 4, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	5.9 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F9O6.2U0
Job Number:	1		

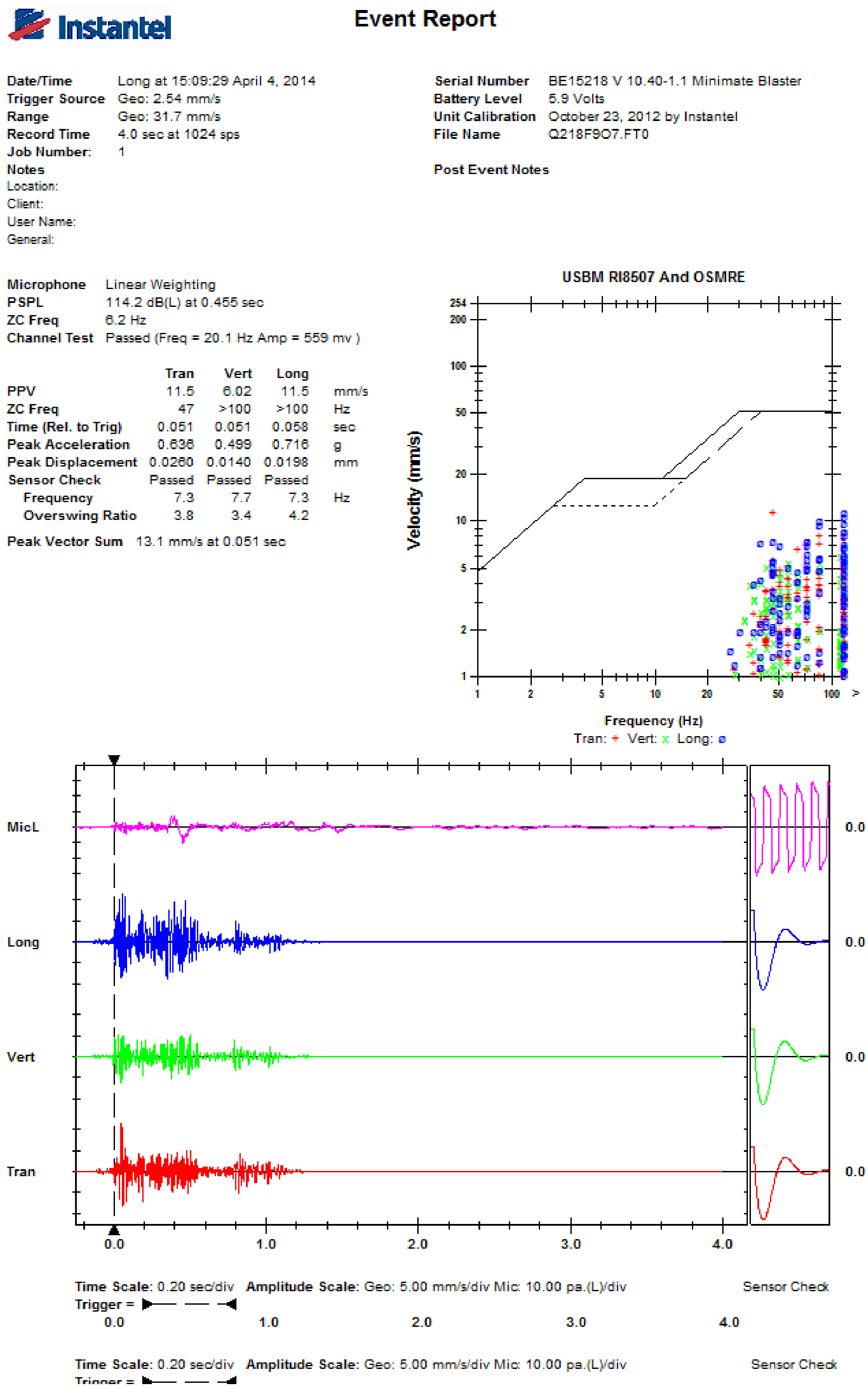
Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 7, 2014 (V 10.60 - 10.60)

Figure A. 75 No:30b Seismograph record of production blasts



Instantel **Event Report**

Date/Time	Long at 15:09:29 April 4, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	5.9 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F9O7.FT0
Job Number:	1		
Notes		**Post Event Notes**	

Location:
Client:
User Name:
General:

Microphone	Linear Weighting
PSPL	114.2 dB(L) at 0.455 sec
ZC Freq	6.2 Hz
Channel Test	Passed (Freq = 20.1 Hz Amp = 559 mv)

	Tran	Vert	Long	
PPV	11.5	6.02	11.5	mm/s
ZC Freq	47	>100	>100	Hz
Time (Rel. to Trig)	0.051	0.051	0.058	sec
Peak Acceleration	0.636	0.499	0.716	g
Peak Displacement	0.0260	0.0140	0.0198	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.3	Hz
Overswing Ratio	3.8	3.4	4.2	

Peak Vector Sum 13.1 mm/s at 0.051 sec

Figure A. 76 No:31a Seismograph record of production blasts

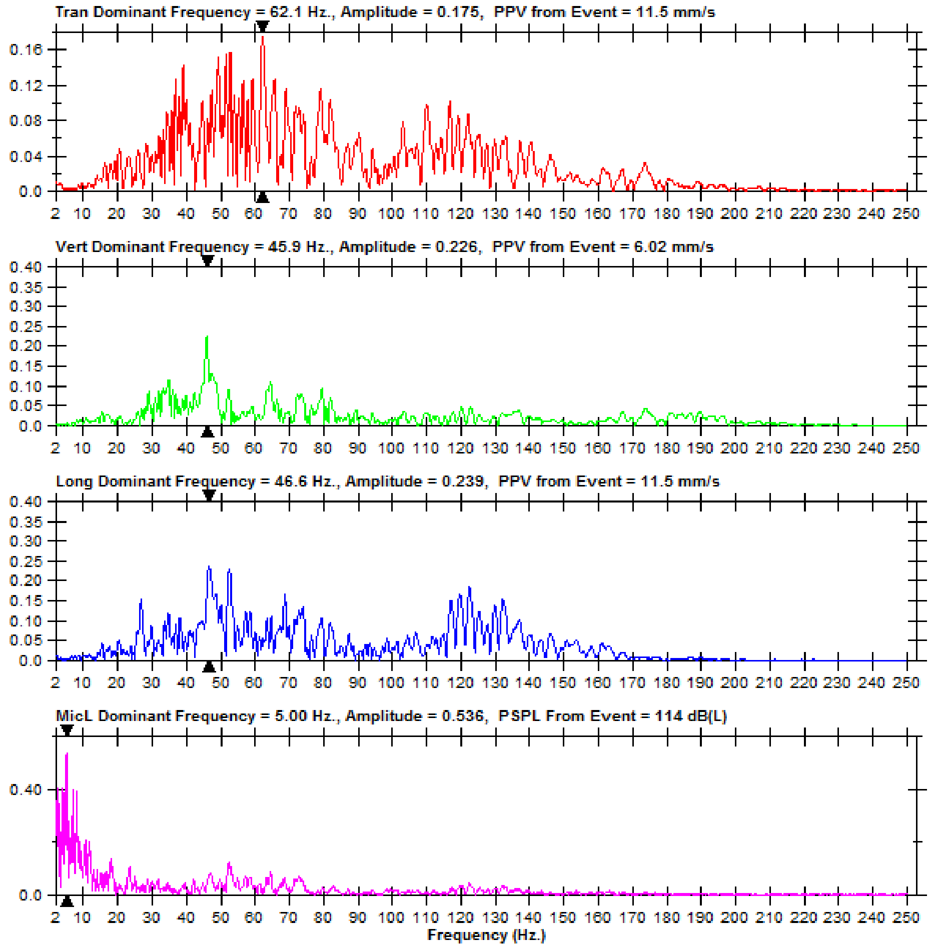
Instantel

FFT Report

Date/Time	Long at 15:09:29 April 4, 2014	**Serial Number**	BE15218 V 10.40-1.1 Minimate Blaster
Trigger Source	Geo: 2.54 mm/s	**Battery Level**	5.9 Volts
Range	Geo: 31.7 mm/s	**Unit Calibration**	October 23, 2012 by Instantel
Record Time	4.0 sec at 1024 sps	**File Name**	Q218F9O7.FT0
Job Number:	1		

Notes
Location:
Client:
User Name:
General:

Post Event Notes



Printed: April 7, 2014 (V 10.60 - 10.60)

Figure A. 77 No:31b Seismograph record of production blasts

B. SPECIFICATIONS OF BLAST SEISMOGRAPHS USED

- *Specifications of White Mini-Seis II Seismograph*

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

2- It can be used for a single shot or a continuous mode.

3- It basically consists of three geophones (transversal, vertical and longitudinal) positioned perpendicular to one another in a steel body and an external microphone.
4- A microphone rated to at least 100 dB can be connected to the seismograph.

5- Mini-Seis II can record frequencies from 2 to 250 Hz.

6- The full waveform signature is stored in solid state memory for up to 341 events.

7- Seismic recording range selected is from 0.250 to 64 mm/sec.

8- With a full charged battery, the instrument will operate from 7 to 10 days.

9- Maximum record duration is 9 seconds; accuracy is ± 1% at 15 Hz.

-Specifications of Instantel Minimate Blaster Seismograph

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

2. It basically consists of three geophones (transversal, vertical and longitudinal) positioned perpendicular to one another in a steel body and an external microphone.

3. There are three record modes; Manual, Single-shot, Continuous.

4. Seismic trigger range selected is from 0.25 to 127 mm/s (0.01 to 5 in/s)

5. Acoustic trigger range selected is from 106 to 148 dB

6. Record time ranges from 1 to 10 seconds (programmable in one-second steps)

7. Battery is rechargeable 6V sealed gel cell - capacity for 240 hours continuous monitoring.

8. Auto-record time is auto window programmable from 1 to 9 seconds, plus a 0.25 second pre-trigger. Event is recorded until activity remains below trigger level for duration of auto window, or until available memory is filled.

9. The full waveform signature is stored in solid state memory for up to 40 events.

10. Accuracy is ± 1% at 15 Hz whereas the resolution is 0.125 mm/s.