INVESTIGATION ON TECHNIQUES TO CONTROL STRUCTURAL DAMAGE DUE TO BLASTING ACTIVITIES

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Abstract

During a blasting process, velocities of the particles in the path of wave propagation are risen, as a result, the energy left over from a blasting process transmits to the surrounding. However, damage that could occur to structures depends on the received structural vibration and may vary with soil type, soil structure-interaction and characteristics of a structure. It is necessary to investigate possible techniques that can be used to reduce the blasting effect on structures.

This paper presents an investigation on structural performance and effective techniques to control ground vibration and damage to structures. In the current study, quarry blasting vibration was considered. Two brick walls having the size of 800 mm x 600 mm were cast in a selected quarry site. One of them was with a control technique; the foundation of the wall was protected by a trench (filled with pure rubber) nearby the wall. The other one was used as the reference wall. Bricks used for wall construction were scaled down to the 4: 1. Ground vibration at the structure was monitored for both test wall and reference wall by using a seismograph. Effectiveness of the control technique to control the damage to structure due to blast vibration is discussed in this paper.

Key words: blast vibration, control techniques, FFT report, seismograph

1. Introduction

In Sri Lanka, blasting is common in the quarry industry, where rock breaking process is mainly done by detonating explosives charged in holes drilled in rock. Carbon, sulfur and sodium nitrate in black powder are used as detonating explosives. The blast holes are usually detonated in sequence and a portion of the energy released is converted to wave energy with compression (*P*) waves (also called as primary waves), shear (*S*) waves (also called as secondary waves) and surface Rayleigh (*R*) waves. These waves transmit in all directions from the source of blasting. Surface Rayleigh waves receive the most energy and cause the most damage to structures since they travel along the surface of the ground, with particles moving in an elliptical path.

Blasting procedures and the chemicals used for blasting are different from site to site. For example, rock excavation on both small-scale and large-scale projects can be done either by “production blasting” or “controlled blasting”. With the changes in blasting procedures, vibration effects also vary. Production blasting uses large explosive charges at wide spacing that are designed to fragment a large amount of burden (i.e., the rock that lies between the existing slope face and the blast hole). Controlled blasting is used for removing material along the final slope face. In some cases, controlled blasting is also used before production blasting, in order to create an artificial fracture along the final cut slope, which will prevent the radial cracks caused by production blasting from penetrating back into the finished face. Production blasting is the most efficient way to remove large rock burdens. However, the controlled blasting reduces the ground vibration than the production blasting.

The ground vibration and the air blast produced by blasting are often felt by residents surrounding the mines and quarries. The ground vibrations generated by mining, quarry blasting operation, earthquake even cause structural damage to very close buildings. These ground vibration are associated with different types of elastic waves (i.e., Compression (*P*) waves, shear (*S*) waves and surface Rayleigh (*R*) waves) propagating through the ground.

The faster wave is called the primary or P waves, which are felt first. The effect of this wave is similar to a sonic boom that bumps and rattles windows. Some seconds later, the S waves arrive with their up-and-down and side-to-side motion, shaking the ground surface vertically and horizontally. This is the wave motion that is so damaging to structures. However, it has been reported that there could be a greater contribution of surface waves to quarry blasts due to the shallowness of their source depth (Su et al , 1991).

Typical frequency range of environmental ground vibrations is 1 - 200 Hz (Alejandro et al, 2007) .Magnitudes of ground vibrations are usually described in terms of particle vibration velocity (in mm/s or m/s). However, vibrations are often defined by Peak Particle Velocity (PPV). The motion of the ground particles usually occurs in three directions: horizontal, vertical, transverse. When vibration occurs, each particle has a velocity. The maximum velocity of this motion is referred to as the PPV. The motion is usually captured by using a seismograph and maximum velocities of all three directions are given. PPV value is considered as the standards for measuring the intensity of ground vibration. Peak vector sum (PVS) is the square root of the summed squares of all three velocity components at a particular time. In most blasting the PVS occurs at about the same time as the maximum of one of the velocity components, but is usually a little greater. Since one peak component normally does not occur at a time when there is no motion in the other two directions, the PVS reflects the addition of two other ground motions at the same time and therefore is a little larger. In most cases, the PPV is closely linked to the potential to damage structures rather than the acceleration or displacement (Wickramasighe et al, 2011).

Blast induced ground vibration can potentially cause damage to structures such as partial collapsing, cracking, damage. Under certain vibration situations the structures subjected to cracking, local fatigue, non serviceability and sever stresses on the structure. For examples, in a previous study by Wickramasighe et al (2011) investigated performance of a cantilever type masonry wall for blast induced vibration. They have observed a significant crack at the inter-phase of a brick masonry wall and a rubble foundation at the vibration magnitude of 30.2 mm/s of PPV at a frequency of 50 Hz. Another research had been carried out by the Australian Coal Association Research Program to investigate whether a particular coal mine was operating within regulatory air and ground vibration requirements (Gad et al, 2005). Three houses had been selected as typical representative houses and ground and structural vibration had been measured with geophones along with crack record and growth monitoring. Their results show that the stresses resulting from blasting were well below damage levels, providing that blasting impacts remain within regulatory limits. Also they have found that natural factors such as ground movement and rainfall played an important role in the formation and propagation of cracks in the houses.

As expected, in Sri Lanka, there were many public complaints on rock blasting in a project area for construction. It was reported that many complaints have been raised on rock blasting activity in Hambantota harbor project (The Nation, 2009) and Southern Transport Development project (Environmental Impact Monitoring Report , 2011). Due to rapid development in the country, mega infrastructures are being constructed. Most of them are accompanying with rock blasting, pile driving, although they are being constructed in residential areas. As a result, the structures near the construction sites receive vibration that are possibly induced by rock blasting and pile driving. Therefore, investigation on possible techniques to control the effect of ground vibration on structures is an urgent requirement in the construction industry.

There has been a trend for regulatory authorities, especially those concerned with the environment, to impose low limits on blast vibration levels in response to community pressure, based on human perception and response to vibration. The effects of vibration can vary according to a number of factors including the magnitude of the vibration source, the particular ground conditions between the source and receiver, the foundation-to-footing interaction and the large range of structures that exist in terms of design (e.g. dimensions, materials, type and quality of construction, and footing conditions). The intensity, duration, frequency and number of occurrences of a vibration contribute to both the annoyance levels caused and the strains induced in structures.

For sustainable developments, vibration control methods should be cost effective with low environmental impact. In Sri Lanka, rubber is one of the main productions and it is easy to obtain this material for any level of people. In this study, an attempt has been made to investigate possibility of controlling the impact of ground vibration on structures by utilizing rubber material, which is wasted from manufacturing of rubber products. Effective techniques to control structural damage and vibration received to structure are investigated using an experimental study.

1.1 Objectives

Objectives of the current study are to determine performance of a wall panel exposed to ground vibration and to investigate effectiveness of control techniques to control the ground vibration received to the wall.

2. Methodology

To determine the performance of a wall panel due to blast vibrations, and the effectiveness of the control techniques, an experimental investigation was performed.

Hapugala quarry site, which was used in a previous study (Wickramasighe et al, 2011), was selected for the current study**.** In this site, blasting activities carried out are medium scale: blast holes, which are used for detonation of an explosive charge, are in the range of 5ft **-** 8ft. As frequent blasting activities were carried out at the site, experimental investigation was continued with the blasting schedule.

Two wall panels having the size of 800 mm x 600 mm were constructed at a selected location in the site. The location was selected by considering the magnitude of vibration received to the location and the site safety to conduct experimental measurements. Information published in the previous investigation (e.g. Wickramasighe et al, 2011) were used for the selection of location. For the wall panels, burnt clay bricks that were scaled down to 4:1, were used. Prepared brick units, having the size of 100mm (length) x 50mm (width) x60mm (height), were bonded using 1:5 cement: sand mortar mixture with 5mm thickness. Mortar thickness was limited to 5mm, in order to make it compatible with the size of brick units. Constructed wall was plastered using 1:1:8 cement: lime: sand mixture. Plastering thickness was also selected as 5mm.

One wall panel was considered as the reference wall, for that no any vibration control technique was applied. The other wall was considered as a wall with vibration control technique (test wall): wall foundation was shielded by a trench filled with rubber around the wall. The size of this trench was 200mm depth and 150mm width. This was located at 800mm away from the foundation. Rubber pieces, which are waste materials from the production of rubber items, collected from D.

Samson Industries (Pvt) Ltd, were used in this study (Figure 1). These rubber pieces were packed into the trench while pressing moderately by using hands.

Figure 1: Rubber sample used to fill the trench

Experimental walls were exposed to ground vibration induced by the quarry blast. A four channel seismograph was used to measure ground vibrations in three directions: transverse, vertical and longitudinal directions. Figures 2 and 3 show the reference wall and the wall with trench filled with rubber, respectively. Geophone of the seismograph was fixed to the ground close to the experimental wall (Figures 2 and 3). Geophone trigger level was set to 0.300 mm/s while Microphone trigger level was set to 2.00 Pa. (L). When blasting occurs, geophone of the seismograph was automatically triggered and all three vibration signals, at each blasting, were recorded.

For the same size of blast hole (i.e., equal depths), at approximately equal distances, vibrations were measured for two consecutive blasting: one set of measurement at the reference wall while the other set of measurement at the wall with rubber trench. This was necessary because the same condition should be provided for both wall panels, as the measurements were done by using a single seismograph. It was assumed that the same size of blast hole at the same distance would induce the same ground motion. The same procedure was repeated for 5 ft depth blast hole and 7.5 ft depth blast hole and ground vibrations were measured. Table 1shows the details of the blasting which was carried in the quarry site.

Table 1: Details of the blasting

	Depth of blast hole (ft)	*Distance to walls from blast hole (m)*
Reference wall	*5*	*4.5*
Wall with rubber trench		*5.7*
Reference wall	*7.5*	*4.3*
Wall with rubber trench		*6.1*

Fast Fourier Transformation (FFT) of the measured ground vibration was obtained by using Blastmate III software (Blastmate ííí operator manual).

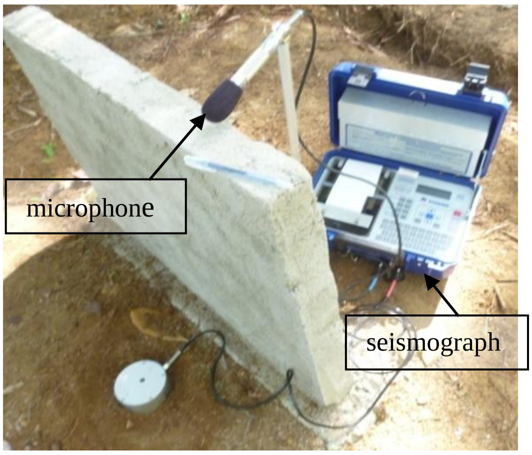

Figure 2: Reference wall

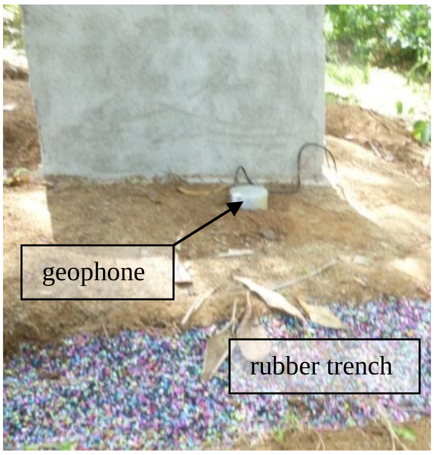

Figure 3: Wall with rubber trench

3. RESULTS

Table 2 summarizes the magnitude of vibration in PPV values measured at two different walls for two different blasting. For the depth of blast hole 5 ft, maximum PPV at the reference wall is 5.71 mm/s and at the wall with rubber trench it is 1.41 mm/s in the transverse direction. This trend in reduction in vibration can also be seen in other two directions. In the vertical direction, maximum PPV at the reference wall is 5.21 mm/s while that at the wall with rubber trench is 1.46 mm/s. For longitudinal direction, maximum PPV are 4.18 mm/s and 1.87 mm/s at the reference wall and the wall with rubber trench, respectively. PVS of the blast event is 7.18 mm/s for reference wall and it reduced to 2.06 mm/s at the wall with rubber trench. For the depth of blast hole 7.5 ft, at the reference wall the maximum PPV is 19.9 mm/s and it reduced to 13.4mm/s when the rubber trench was used.

This reduction in vibration are more clear in vertical and longitudinal directions: in these directions, maximum PPV was greater than 31.7 mm/s at the reference wall and it reduced to 13.2 mm/s and 12 mm/s for vertical direction and longitudinal direction, respectively. With the control techniques, the reduction in vibration received to wall for blast hole of 5 ft is also clear in PVS for the blast hole of 7.5 (table 2).

Table 2: Magnitude of ground motion in PPV and PVS

	Depth of blast hole (ft)	*Maximum PPV (mm/s)*			*Peak vector sum(mm/s)*
		transverse	*vertical*	*longitudinal*	
Reference wall	*5*	*5.71*	*5.21*	*4.18*	*7.18*
Wall with rubber trench		*1.41*	*1.46*	*1.87*	*2.06*
Reference wall	*7.5*	*19.9*	*>31.7*	*>31.7*	*>31.7*

Wall with rubber trench		*13.4*	*13.2*	*12*	*19.6*

The ground velocities at the reference wall and the wall with rubber trench for blast hole depth of 7.5 ft are shown in Figures 4(a) and(b), respectively. For blast hole depth of 5 ft, the ground velocity at the reference wall and the wall with rubber trench are shown in Figures 5(a) and (b), respectively. It can be seen from the figures that magnitude of amplitude of vibration varies with the direction of vibration. It seems that the most influenced direction of ground motion is longitudinal direction.

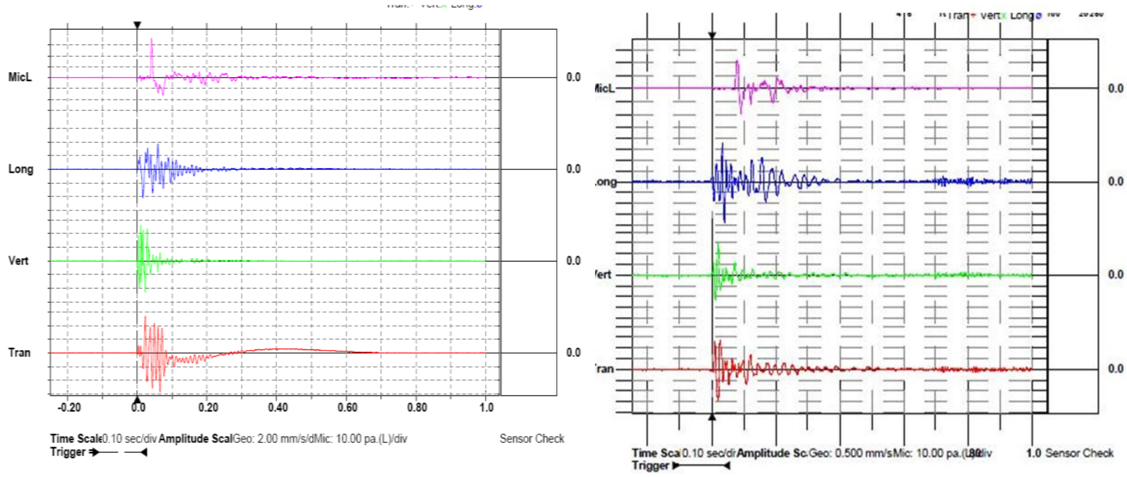

Figure 4: Ground velocity for blasting hole depth of 5 ft (a) at the reference wall (b) at the wall with rubber trench

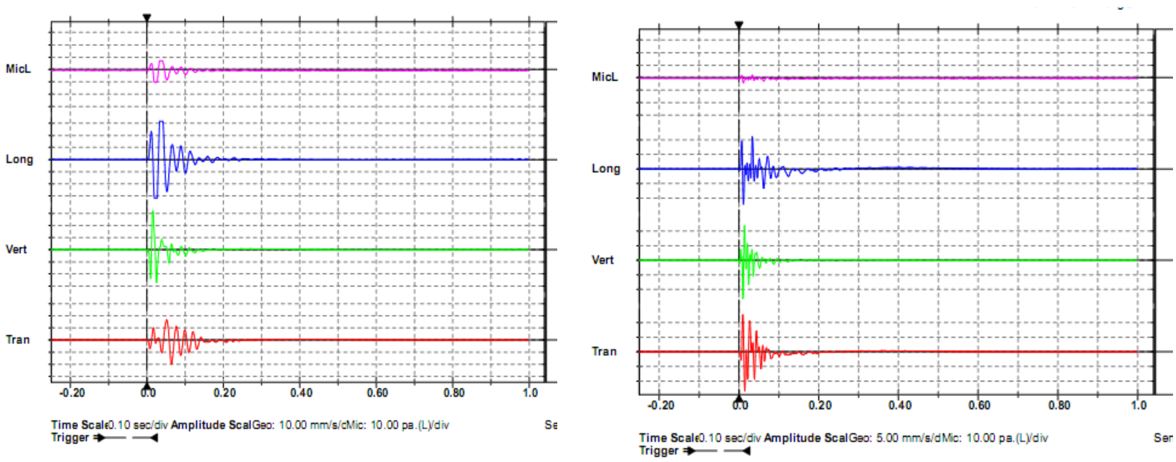

Figure 5: Ground velocity for blasting hole depth of 7.5 ft (a) at the reference wall (b) at the wall with rubber trench

Figures 6(a) and (b) show Fast Fourier Transformation (FFT) reports generated for vibration measurements in three directions (i.e., transverse, vertical and longitudinal) of ground vibration at the reference wall and at the wall with rubber trench, respectively. FFT reports generated for vibration induced by blasting depth of 7.5 ft in three directions at the reference wall and at the wall with rubber trench are shown in Figures 7(a) and (b), respectively. These measurements were reported for ground vibration induced at two consecutive blasting by detonating explosives charged 5 ft and 7.5 ft depth holes at approximately equal distances from the wall panels.

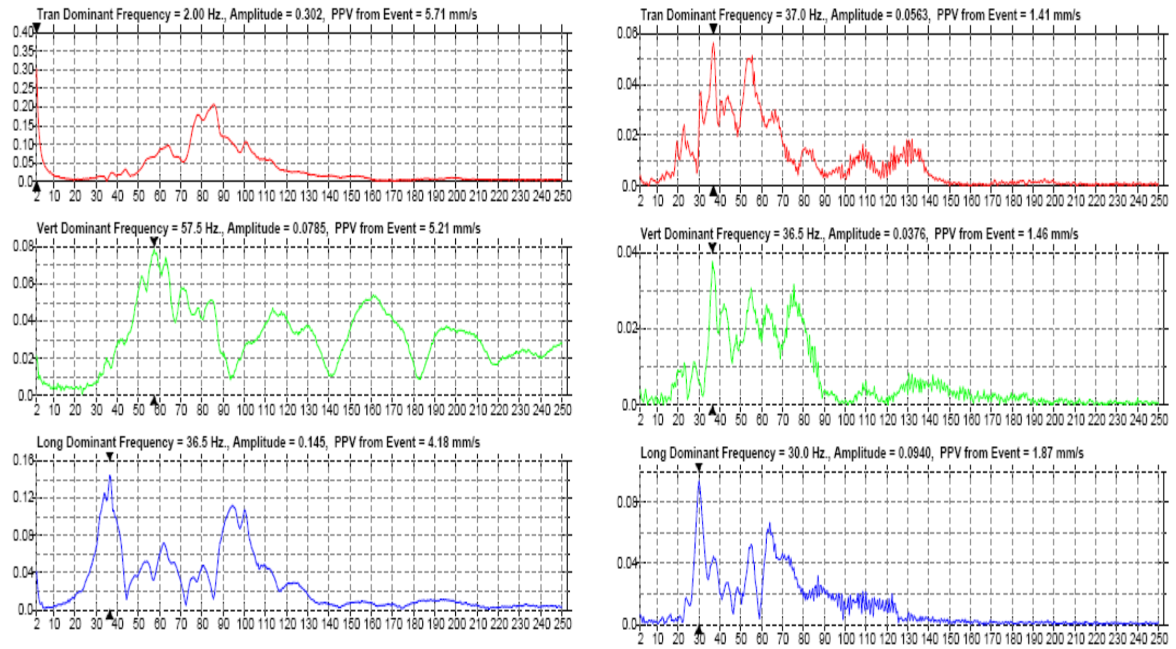

Figure 6:FFT of ground vibration for blast hole depth of 5 ft

(a) at the reference wall ***(b) at the wall with rubber trench***

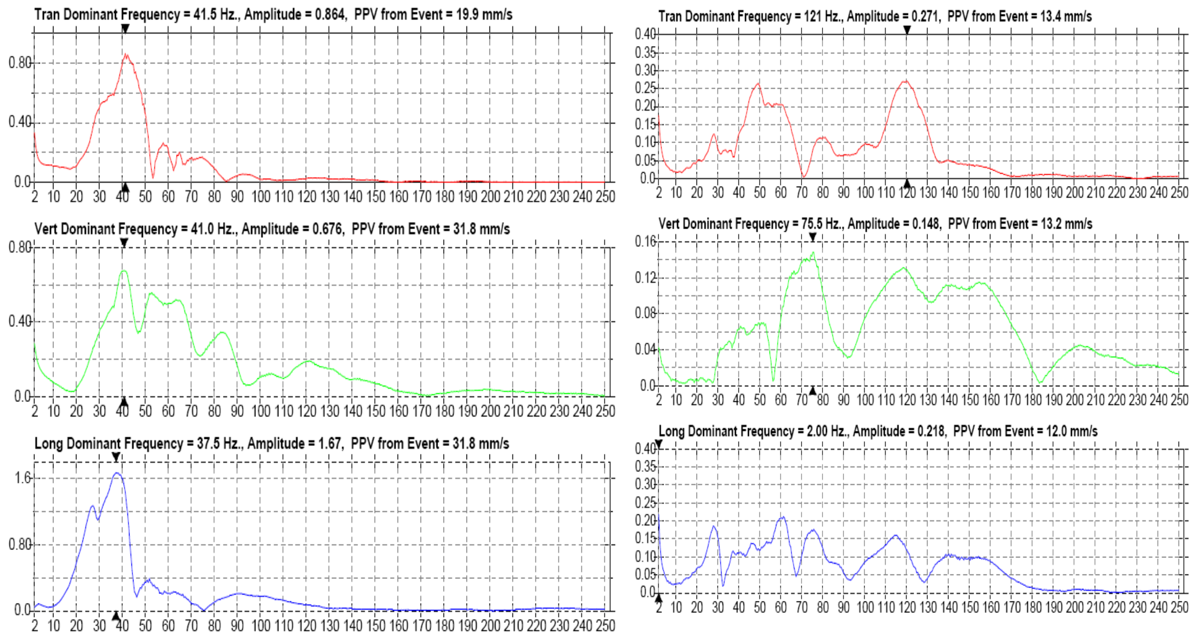

Figure 7 : FFT of ground vibration for blast hole depth of 7.5 ft
(a) at the reference wall ***(b) at the wall with rubber trench***

It can be seen from Figure 6 for blasting depth of 5 ft, the maximum amplitude (i.e., energy) of longitudinal ground vibration received to the reference wall was 0.145. For the wall with control technique, the maximum amplitude of ground vibration received was 0.094. For the blasting depth of 7.5 ft, the maximum amplitude of longitudinal ground vibration received to the reference wall was 1.67. For the wall with control technique, the maximum amplitude of ground vibration received is 0.218.

A comparison between Figures 6 and 7 clearly indicates that the trench filled with rubber contributes to a reduction in vibration between two walls. For the longitudinal vibration measured with blasting depth of 5 ft, the reduction in PPV was around 55.26% compared with the reference wall. For this blasting depth, the reduction in transverse vibration was 75.31% while the reduction in vertical vibration, was 71.97%. For the blasting depth of 7.5 ft, the reduction was around 62.26% for longitudinal vibration, 32.66% for transverse vibration and 58.49% for vertical vibration.

By considering the maximum amplitude of FFT reports of ground vibration at the reference wall and the wall with rubber trench, a significant reduction in the magnitude of FFT can be found for the wall with rubber trench. These results clearly indicate that the trench filled with rubber contributes to a reduction in vibration received to the wall. In addition, there were no cracks or any damage on the both walls.

4. Discussion

Experimental investigation showed that a reduction in blast induced ground vibration due to the rubber trench. In the current study, less ground motion at the walls with control technique implies that the rubber, although it is a waste material, can absorb the energy due to blasting and contributed to receive smaller ground motion, compared to the ground motion received at the wall without a trench with rubber.

In this study, two assumptions were made. It was assumed that the same depth of blasting would produce the same vibration at the same distance from the source of vibration. With this assumption, vibrations at the reference wall and the wall with rubber trench were measured as two consecutive events by using the same seismograph. When considering the site, it was assumed that the soil is homogeneous for both walls. Although, actual condition might be slightly varied as there were tree roots in the site.

In the current study, it was found that ground vibrations induced by rock blasting can be reduced by applying the rubber trench surrounding the considered ground. This method can be applied for buildings close to the quarry site, in order to reduce the effect of ground vibration on structural damages. High ground vibrations are generated by operating heavy equipments at highway construction and piling site, disturbing surroundings. The method to reduce ground vibration found in the current study can be applied around the structure to reduce the damage, or surrounding the construction and piling site, so as to reduce the effect of ground vibration.

5. Conclusions

In this study, the ground vibrations due to blasting effects were investigated. With the current developments in the country, many construction projects are ongoing related to blasting. Therefore, it is useful to introduce techniques to control vibration so as to avoid the structural damages. In this study, two walls were constructed in the quarry site. One was with control technique and other one without vibration control technique. When blasting was ongoing, ground vibrations near the walls were measured. It was found that the control technique which is the trench around the wall filled with rubber could reduce the propagation of ground vibration to the wall. The method to reduce ground vibration found in the current study can be applied around the structure to reduce the damage, or surrounding the construction and piling site, so as to reduce the effect of ground vibration

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