

An Analysis of the Results of Trial Blasting of Site Development Project in the Volcanic Island

Dong Wook Lee, Seung Hyun Kim

Abstract—Trial blasting is conducted to identify the characteristics of the blasting of the applicable ground before production blasting and to investigate various problems posed by blasting. The methods and pattern of production blasting are determined based on an analysis of the results of trial blasting. The bedrock in Jeju Island, South Korea is formed through the volcanic activities unlike the inland areas, composed of porous basalt. Trial blasting showed that the blast vibration frequency of sedimentary and metamorphic rocks in the inland areas is in a high frequency band of about 80 Hz while the blast vibration frequency of Jeju Island is in a low frequency band of 10~25 Hz. The frequency band is analyzed to be low due to the large cycle of blasting pattern as blast vibration passes through the layered structured ground layer where the rock formation and clickers irregularly repeat. In addition, the blast vibration equation derived from trial blasting was $R: 0.885$, $S.E.: 0.216$ when applying the square root scaled distance (SRSD) relatively suitable for long distance, estimated at the confidence level of 95%.

Keywords—Attenuation index, basaltic ground, blasting vibration constant, blast vibration equation, clinker layer.

I. INTRODUCTION

BLASTING entails the occurrence of public nuisances such as noise, vibration and flying of cataclastic rocks. So, blasting has been the target of many studies [1]-[8], which have been making technological advances in blasting mechanism and computer modelling technologies, explosive performance evaluation technologies, and measurement technologies.

Blasting has been planned and carried out to concurrently satisfy the economic feasibility and efficiency of rock disposal inevitably accompanying large-scale construction projects. However, the polymorphic ground of Jeju island, a volcanic island in Korea, is characterized by the layer structure where scoria layers and clinkers, or basaltic layers and the layers of pyroclastic deposits, were irregularly repeated because of dozens of volcanic eruptions. The absence of adequate reviews about the characteristics of blasting in this layer-structured ground is causing many problems.

There are some studies conducted about blast vibration in this polymorphic ground [1], [2]. According to the results of a study among them, the efficiency of blasting is low because of irregular distribution of clinker layers and porous basalt, so the specific charge should be increased to minimum 0.40 kg/m^3 for effective blasting and blast design should differ depending on

the presence or absence of a clinker layer within the excavation depth [1]. The results of another study showed in detail the polymorphic characteristics of the ground with layer structure where basaltic layers and clinker layers were irregularly repeated because of the origin of the formation, and compared the results of 24 occasions of Trial Blasting with a designed blast vibration estimation formula presented in the guidelines for designing open pit blasting in Korea [2].

The factors to determine amplitude and frequency, which are the key characteristics of the ground vibration related to blasting, largely include the characteristics of explosive source and the characteristics of rocks [3]. The characteristics of explosive source, which is controllable, are determined by explosive types, charging locations and hangfire time, and controlled through an application of blast patterns depending on the engineer's capacity. The characteristics of rocks, which are uncontrollable, are determined by the type and condition of a rock and the discontinuous face on propagation channels. It is difficult to predict them before identifying the characteristics of the ground vibration produced by actual test blast.

This study used the results of 8 occasions of test blast carried out in the ground of a volcanic island. This study also identified the characteristics of strata influencing the ground vibration using a diagram of strata cross section and data about the ground investigation in test blast area. Further, this study derived a blast vibration estimation formula using SRSD and CRSD to identify the characteristics of ground vibrations produced by blast in the ground of irregular layer structure, and analyzed the blast vibration and frequency according to the magnitude of explosive source.

II. CHARACTERISTICS OF THE STRATA OF VOLCANIC ISLAND

In Jeju island, which is a volcanic island, tholoides were formed by the eruption of trachyte with low liquidity in the initial phase through volcanic eruptions on dozens of occasions in the late 3rd period to the early 4th period of the Cenozoic era, whereas, in the late period, aspites or lava plateau was formed by the eruption of basalt with high liquidity [9]. As the formation was not very long ago and the dissection is not at a high level, the original volcanic landform is well preserved.

The geological features of Jeju island, unlike inland regions, are characterized by layer structure where depositions such as pyroclastic deposit from volcanic activities are distributed between rock layers. In other words, depositions such as pyroclastic deposits accumulated over long period on the layer of volcanic rock formed by magma released by volcanic eruptions, and again another layer of volcanic rock was formed on depositions produced by volcanic eruptions. This shows

Dong Wook Lee is Associate Professor, Dept. of Civil Engineering at Jeju National University, Jeju, 63243, Republic of Korea (phone: +82 64-754-3458; fax: +82 64-725-2519; e-mail: dwlee@jejunu.ac.kr).

Seung Hyun Kim is Ph.D. Student, Dept. of Civil Engineering at Jeju National University, Jeju, 63243, Republic of Korea (e-mail: ksh@jejunu.ac.kr).

layer structure where deposit layer is placed between rock layers [9]. As shown in Fig. 1, these layers of pyroclastic deposit are irregularly and repeatedly arranged between rocks, which form different types of layer structures. So, even within the same region, it is difficult to predict the change in strata, and also its geotechnical features are different from those of the ground of inland regions.

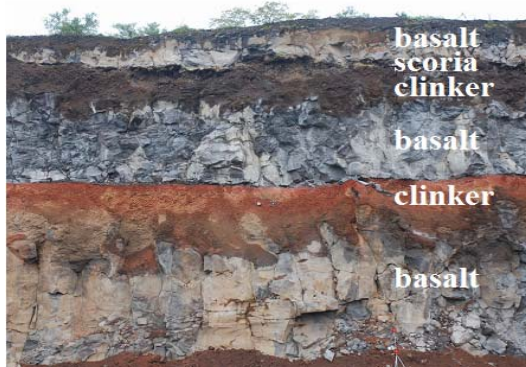


Fig. 1 Layer structure in Jeju

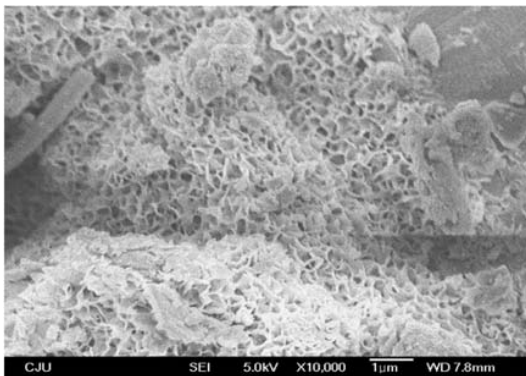


Fig. 2 FE-SEM observation ($\times 10,000$)

While lava released by volcanic eruption is flowing, it consolidates and forms a rock on the ground, the top and bottom of the rock exposed to air is rapidly cooled and becomes cataclastic, which is referred to as clinker in geological terms. Clinker appears mostly while it comes into contact with rock layers, and it is generally brown-tinted by being oxidized. Besides, clinker appears in the form of gravel in sections in severe cataclasm, forms a continuum with rock layers partially, and shows mechanical characteristics similar to those of weathered rocks.

Scoria is a type of pyroclastic deposit, which is material released in a solid state at the time of volcanic eruptions. While magma is released into the air, it loses volatile compounds and instead has porosity. This is referred to as scoria. Scoria is also slightly heavier than pumice, and stems from basic or neutral magma [2]. Fig. 2 shows the results of photographing the surface of scoria with a magnifying power of 10,000 using Field emission scanning electron microscope; FE-SEM. The surface is very rough and sharp, and has a large number of

pores ranging from very small to relatively large sizes.

III. GROUND CHARACTERISTICS OF TRIAL BLASTING AREA

Trial Blasting was carried out in Seoguipo city, Jeju Special Self-Governing Province, Korea. The results of a ground survey for Trial Blasting area are as follows: Clinker is distributed across the island; each layer has a thickness of 0.5 to 13.4 m and mostly has colors ranging from dark grey to brown; each layer is mixed with scoria and its boundary is difficult to identify; and the result of a standard penetration test shows a wide variety of N values within the range of 5/300 to 50/40 occasions/mm.

In Korea, rocks are classified into Si Oreum-trachy basalt; QSTB based on Korea's geological feature report [10]. Petrography targets grey or dark grey rocks, where 1 to 10 mm pores account for 20% of all pores. The content of a pore differs greatly according to the condition of outcrop, and it can be elaborately calculated without pores. The chemical composition is as follows: SiO_2 ranges from 48.6 to 50.47 wt%; Na_2O ranges from 3.24 to 3.89 wt%; K_2O ranges from 0.97 to 1.98 wt%; $Na_2O + K_2O$ ranges from 4.21 to 5.72 wt%. Based on the extent of labeling [11] of volcanic rocks using the composition ratio of SiO_2 and $Na_2O + K_2O$, Fig. 4 illustrates the areal coverage of basalt and trachy-basalt, and the areal coverage of trachy-basalt has a slight advantage. Also, the results of an indoor test of rocks in Trial Blasting area are as follows: The specific gravity was 1.79 to 2.72; the absorption ratio was 1.51 to 12.46 %; the unconfined compressive strength was 11.4 to 128.5 MPa; in the velocity of elastic waves, P-wave velocity was 1,452 to 3,999 m/sec and S-wave velocity was 889 to 2,077 m/sec; Poisson's ratio was 0.24 to 0.34; the modulus of elasticity was 0.78 to 27.0 GPa. Overall, the result of an indoor test is of a wide range, and so it is difficult to evaluate rocks fragmentarily.

To identify the characteristics of the ground that are the influencing factors of ground vibration produced by blasting, a Trial Blasting site was surveyed with the naked eye in the first place; an exposed clinker layer was checked as shown in Fig. 5; a ground survey report was reviewed. The ground characteristics were reviewed after setting a diagram of strata cross section in Fig. 6 as the typical strata section of Trial Blasting route. The results are as follows: In borehole BH-9, a soft rock layer is exposed to the surface layer and the thickness is 0.8 m (TCR: 82%, RQD: 70%); beneath it, there is a gravel-shaped clinker layer with a thickness of 1.6 m and a soft rock layer with developed pores and a thickness of 1.3 m (TCR: 88%, RQD: 76%); and also, there was another soft rock layer with a thickness of 5.5 m (TCR: 87%, RQD: 83%) beneath another gravel-shaped clinker layer with a thickness of 0.8 m. In borehole BH-11, there was a layer of pyroclastic deposit with a thickness of 1.7 m and with a mixture of silt, sand and gravels on the surface ground; beneath the layer of pyroclastic deposit, there was a layer of soft and dense rock with a thickness of 1.6 m (TCR: 99%, RQD: 97%); beneath the layer of soft and dense rock, there was a gravel-shaped clinker layer with a thickness of 1.4 m, a soft rock layer with developed pores and a thickness of

1.6 m (TCR: 82%, RQD: 71%), and another soft rock layer with developed pores and a thickness of 2.0 m (TCR: 85%, RQD: 73%) beneath another gravel-shaped clinker layer with a thickness of 3.2 m. In borehole BH-15, there was a layer of pyroclastic deposit mixed with scoria on the surface ground and with a thickness of 2.8 m, a gravel-shaped clinker layer with a thickness of 1.7 m, and a dense moderate rock layer with a thickness of 5.5 m (TCR: 100%, RQD: 100%).

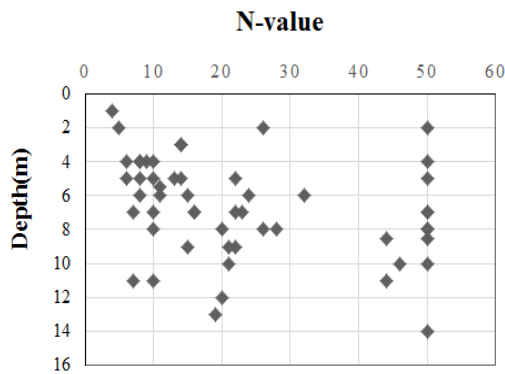


Fig. 3 Clinkers N-value by the SPT

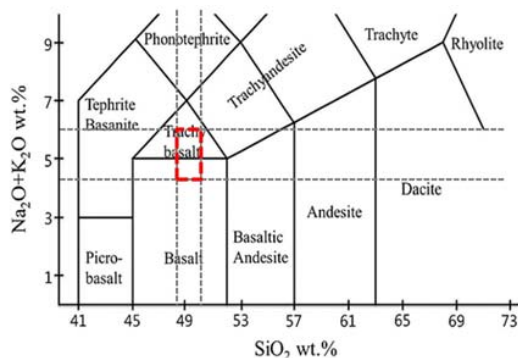


Fig. 4 Classification of the basalt according to TAS diagram

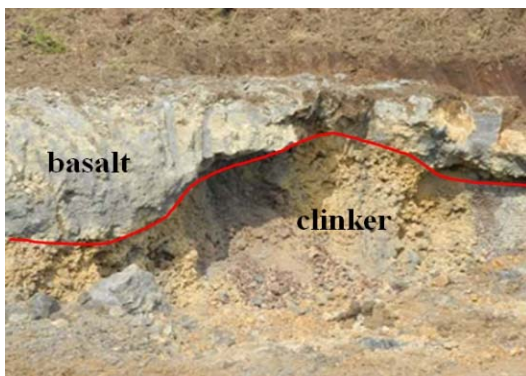


Fig. 5 Clinker layer exposed in a testing area

Clinker layers were found in all boreholes reviewed. Cataclastic rock fragments appeared in the form of gravels once or twice within a depth of about 10 m, and a small amount of rock fragment core was collected. Clinker layers ranged from

0.8 to 3.2 m in thickness, and showed a very irregular distribution in a stratigraphic sequence.

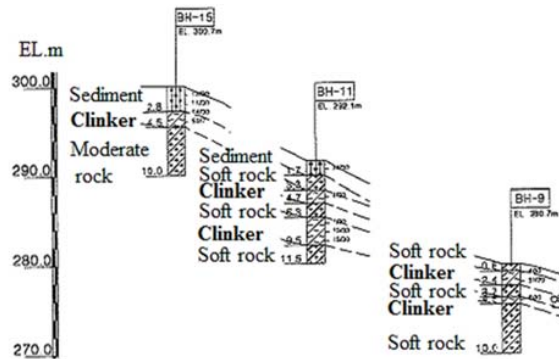


Fig. 6 Geological profile

IV. DESIGN OF TRIAL BLASTING AND ANALYSIS OF BLAST VIBRATION

Trial Blasting was carried out on 8 occasions and in a total of 70 holes. The blasting was carried out in the order of precise vibration-control blasting on each 2 occasion in 4 holes and 6 holes, small-scale vibration control blasting on 2 occasions in 10 holes, and then medium-scale vibration control blasting on 4 occasions in 10 holes. Emulsion explosives of 143.75 kg in total were used for them. Table I shows the test conditions, and Fig. 7 shows the rock-drilling patterns. To measure blast vibration, 11 units of measuring instrument were installed. Among them, 8 units were installed at regular intervals of 20 m with the distance of minimum 53 m to maximum 638 m kept between the explosive source of Trial Blasting and each measuring instrument and 3 units were installed in safety things.

TABLE I
APPLIED DESIGN PARAMETER FOR TRIAL BLASTING

Control blasting	Precise vibration	small-scale vibration	medium-scale vibration
Specifications			
Diameter (mm)	51		76
Drilling length (m)	2.0	2.7	3.4
Bench height (m)	1.7	2.4	3.0
Burden (m)	0.7	1.0	1.5
Spacing (m)	0.7	1.0	1.6
Charge per hole (kg)	0.375	1.0	3.0
Charge per delay (kg)	0.375	1.0	3.0, 6.0
Powder factor (kg/m ³)	0.450	0.417	0.417
Explosive		Emulsion	
Explosive diameter (mm)	32		50
Detonator	MS electric detonator		

70 data sets of blast vibration acquired from Trial Blasting were computer-processed. The results are as follows: As shown in Table II, in the case of an application of SRSD, $V_{95\%} = 667.28(SD)^{-1.30}$ (correlation coefficient R: 0.885, standard error S.E: 0.216) was estimated at the 95% confidence level; in the case of an application of cubic root scaled distance (CRSD), $V_{95\%} = 1986.96(SD)^{-1.54}$ (R: 0.926, S.E: 0.175) was

estimated at the 95% confidence level. Figs. 8 (a) and (b) show the results of processing vibration data using SRSD and CRSD.

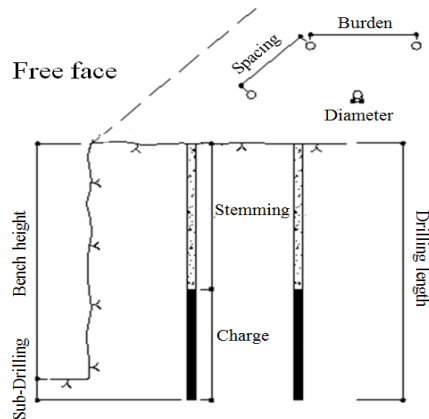
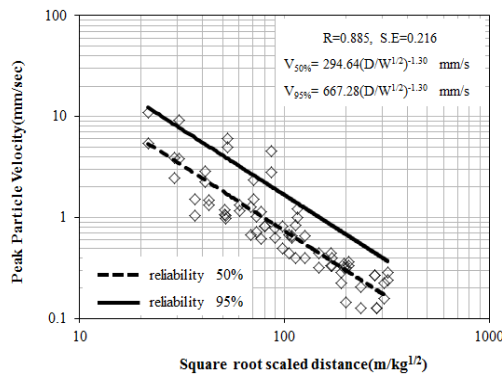
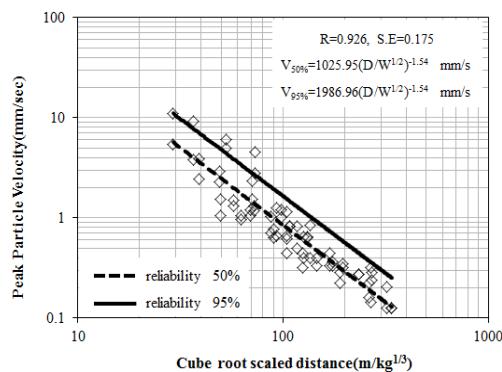


Fig. 7 Schematic diagram of blasting pattern



(a) SRSD



(b) CRSD

Fig. 8 Blast vibration data processing results

TABLE II
VIBRATION PREDICTIVE EQUATIONS (RELIABILITY 95%)

Scaled distance	Vibration Predictive Equations	R	S.E	Events
SRSD	$V_{95\%} = 667.28(SD)^{-1.30}$	0.885	0.216	70
CRSD	$V_{95\%} = 1986.96(SD)^{-1.54}$	0.926	0.175	70

As regards the selection of SRSD and CRSD in the blast

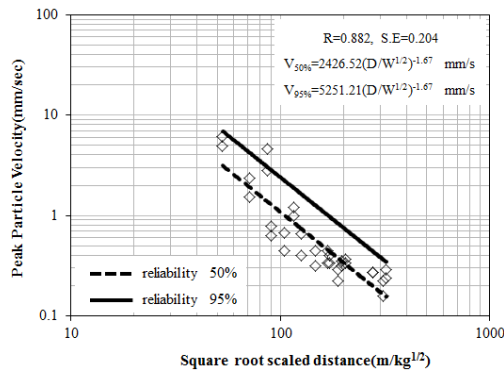
vibration estimation formula, previous study [4] suggests that both SRSD and CRSD can be used to predict the level of blast vibrations from a practical perspective. So, the problem of predicting the level of blast vibrations using the formula depends on the goodness of fit, or the degree of scattering of the results from a use of the given formula rather than any type of estimation formula.

Generally, each propagation formula is found by processing measurement data using SRSD and CRSD. Among the formulas, a formula with a high goodness of fit is commonly used as a formula for predicting the level of blast vibration in the target area. However, MOCT (2006) guideline [12] recommends SRSD method known to have a high correlation in open pit blasting with little elevation difference for practical conveniences. So, this study used the blast vibration estimation formula derived using SRSD method to make a comparison with MOCT's designed blast vibration estimation formula ($V = K(SD)^n = 200(D/\sqrt{W})^{-1.6} \text{ mm/s}$).

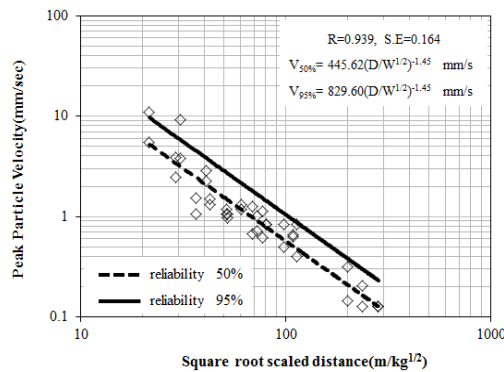
R^2 , which is the coefficient of determination in the blast vibration formula as an estimate of vibration data acquired from Trial Blasting using SRSD, is 0.783, and the absolute value of n , which is the damping factor of an onsite blast vibration estimation formula, is 1.30. This is less than 1.60, the absolute value of n under MOCT guideline, which means that blast vibration propagates far and its damping is small. Although the absolute value of the damping factor n was not the same, the value of blast vibration constant k was estimated at 667.28 below MOCT guideline. Rock-drilling (2.0 to 3.4 m) probably reached almost the boundary between a soft rock layer and a bottom clinker layer, and thus explosive gas pressure released into cataclastic rock fragments distributed in the form of gravels beneath a soft rock layer, decreasing the influence of the explosive source of blasting.

To identify the influence of the change in the blast magnitude of explosive source on blast vibration, vibration control blasting was classified into three categories based on the charge weight per delay of 1 kg: Precise vibration-control blasting (0.375 kg/delay) and small-scale vibration control blasting (1 kg/delay) were combined and then blast vibration estimation formulas for 32 vibration data sets were derived using SRSD; for medium-scale vibration control blasting (3, 6 kg/delay), blast vibration estimation formulas for 38 vibration data sets were derived using SRSD. Figs. 9 (a) and (b) show blast vibration estimation formulas derived after classifying blast magnitude based on the charge weight per delay of 1 kg.

Onsite blast vibration which combined blast vibration classified into precise & small-scale vibration control blasting and medium-scale vibration control blasting altogether including vibration data was compared with blast vibration under MOCT guideline using the blast vibration estimation formula, as shown in Fig. 10.



(a) Precise & Small scale



(b) Medium scale

Fig. 9 Blast vibration estimation formula according to blast magnitude

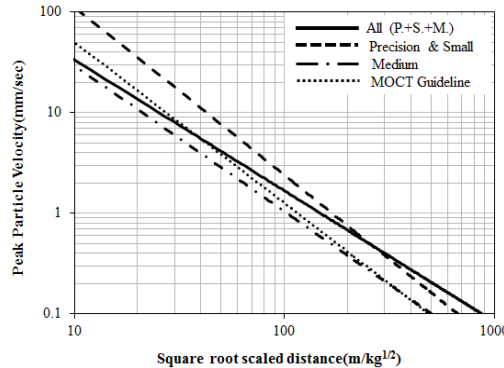


Fig. 10 Comparison of blasting vibration characteristics

When precise & small-scale vibration control blasting is compared with medium-scale vibration control blasting, the precise & small-scale blast vibration estimation formula with small charge weight per delay is above the medium-scale blast vibration estimation formula. There is a large difference in vibration propagation speed between them at a short distance. This difference is becoming narrowed with a longer distance, and medium-scale blasting with a relatively large explosive source shows a large energy reduction. In the case of onsite blast vibration formula, as precise & small-scale blast and medium-scale blast complement each other, vibration velocity at a short distance is similar to the case of precise & small-scale

blast. However, energy decrement becomes smaller at a longer distance, which makes vibration propagate farther. When compared with MOCT guideline, vibration velocity reverses around Scale Distance 35, which increases vibration velocity represented by an onsite blast vibration estimation formula. MOCT guideline predicts that vibration velocity becomes lower at a longer distance. This suggests that the charge weight under this MOCT guideline is heavier than optimal charge weight found using an onsite blast vibration estimation formula. For the polymorphic layer structure ground of Jeju island, it is necessary to apply a blast pattern design based on an onsite blast vibration estimation formula and a blasting method through an understanding of the distribution characteristics of a clinker layer that reduces blasting energy.

V. VIBRATION FREQUENCY ANALYSIS

Fig. 11 shows the results of analyzing the vibration frequency from a Trial Blasting. Onsite frequency band occurred between 5 Hz and 32 Hz, and focused on a low frequency band ranging from 10 Hz to 25 Hz.

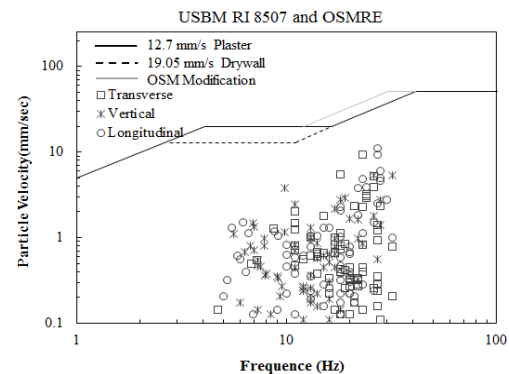


Fig. 11 Analysis of vibrations frequency

Generally, the vibration frequency from a Trial Blasting in a metamorphic or sedimentary rock ground ranges from 80 Hz to 100 Hz. On the other hand, the vibration frequency from a Trial Blasting in this study forms the main frequency band in a range from 10 Hz to 25 Hz and so has a relatively low frequency. This low frequency produced in the ground of a volcanic island is attributed to the extension of vibration cycle by blast, which is influenced by a gravel-shaped sparse clinker layer between rock layers, or porous basalt and layer structure ground.

According to the results of a study by USBM on frequency, the natural frequency of a structure is influenced by the number of layers. According to the results of investigating the dynamic response of a structure, the natural frequency in a central wall ranges from 12 Hz to 20 Hz [5]. Theoretically, when the frequency of the ground vibration is the same as the natural frequency of a structure, responsive vibrations are amplified infinitely [6]. This phenomenon is referred to as resonance, and a normal one-story or two-story house shows the natural frequency of approximately 10 Hz [7]. This house may not be greatly influenced by the ground frequency of a high frequency even if its amplitude is large. However, in the case of

large-scale slope, the ground vibration of low frequency (long wavelength) can trigger a material point movement of latent sloping block and increase the instability, which can eventually lead to slope failure [8].

Although the natural frequency of a structure varies according to the type of a security structure, the ground condition of a foundation, geometric layout around a structure, and the height of burst of a structure, the natural frequency of most structures is within a low frequency band lower than 20 Hz, according to the results of Fast Fourier Transform (FFT) analysis [1].

Frequency produced by a Trial Blasting occurs largely in a range from 10 Hz to 25 Hz similar to the natural frequency of a relatively low-rise structure, and so the continuous occurrence of blast vibration can influence the neighboring structures greatly.

VI. CONCLUSION

To analyse the influences of blasting on the ground vibration under the condition of the ground of a volcanic island, a Trial Blasting was carried out on 8 occasions. That comes to the following conclusion.

- 1) According to the results of analyzing 70 vibration datasets acquired through a Trial Blasting, the blast vibration estimation formula adopting SRSD is estimated as $V_{95\%} = 667.28(SD)^{-1.30}$ (R: 0.885, S.E: 0.216), and so blast vibration constant and the absolute value of the damping factor are below MOCT guideline.
- 2) In the case that the magnitude of blast vibration is classified based on the charge weight per delay, vibration velocity is high in blasting with a small explosive source. The difference in vibration velocity is large at a short distance. At a longer distance, the difference in vibration velocity becomes smaller, and energy reduction occurs greatly in blasting with a relatively large explosive source.
- 3) In the layer structure ground where porous basalt and a clinker layer appeared on one or two occasions, blast vibration frequency occurred in a range from 5 Hz to 32 Hz, and concentrated on a low frequency band of 10 Hz to 25 Hz. It seems that the vibration cycle by blasting is extended under the influence of a sparse clinker layer where cataclastic rock fragments appear in the form of gravels.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014R1A1A4A01007087)

REFERENCES

- [1] H. S. Yang, N. S. Kim, H. D. Jang, W. B. Kim, Y. H. Ko, S. J. Kim, J. G. Kim, and H. S. Moon, "Study on optimization of blast design for improving fragmentation in Jeju basalt rock area," *J. of Korean Society of Explosives & Blasting Engineering*, Vol. 29, No. 2, pp. 89-99, Dec. 2011.
- [2] D. W. Lee, and S. H. Kim, "Development of Blast Vibration Equation Considering the Polymorphic Characteristics of Basaltic Ground," *World Academy of Science, Engineering and Technology, Proc. of 18th Int. Sci. Ac., Geo. and Env. Eng.*, London, U.K., pp. 979-982, 2016.
- [3] H. Robert, *Blasters Handbook 17th ed.*, ISEE, Cleveland, OH USA, pp. 594, 1998.
- [4] D. E. Siskind, *Vibrations from Blasting*, ISEE, Cleveland, OH USA, pp.14-15, pp. 17-28, 2000.
- [5] D. E. Siskind, M. S. Stagg, J. W. Kopp and C. H. Dowding, *Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting*, USBM RI 8507, 1980.
- [6] D. J. Inman, *Engineering vibration*, Prentice Hall Inc., Upper Saddle River, NJ, US, pp. 69-70, 1996.
- [7] C. H. Dowding, *Construction vibrations*, Prentice Hall Inc., Englewood Cliffs, NJ, US, pp. 620, 1996.
- [8] B. H. Choi, and C. H. Ryu, "Consideration on the Relation between Vibration Level and Peak Particle Velocity in Regulation of Ground Vibration", *J. of Korean Society of Explosives & Blasting Engineering*, Vol.30, No.2, pp. 1-8, Dec. 2012.
- [9] G. W. Koh, *Characteristics of the groundwater and hydrogeology implications of the Seogwipo formation in Cheju island*, Ph. D. dissertation, Pusan Na. Univ., Korea, pp. 39-61, 1997.
- [10] Park et al., *Geological Report of Seogwipo-Hahyori Sheet (1:50,000 Scale)*, Jeju-do and Korea Institute of Geology, Mining and Materials, Korea, pp. 50-51, 2000.
- [11] M. J. Le Bas, R. W. Lemaitre, A. Streckeisen and B. Zanettin, "A chemical classification of volcanic rocks based on the total alkali-silica diagram," *J. Petrol.*, Vol 27, pp. 745-750, 1986.
- [12] MOCT (Ministry of Construction and Transportation of Korea), *Blasting design and construction guidelines to road construction*. No. 11-1500000-001841-01, Dec. 2006.