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Development of Blast Vibration Equation Considering the Polymorphic Characteristics of Basaltic Ground

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***Abstract*—**Geological structure formed by volcanic activities shows polymorphic characteristics due to repeated cooling and hardening of lava. The Jeju region is showing polymorphic characteristics in which clinker layers are irregularly distributed along with vesicular basalt due to volcanic activities. Accordingly, resident damages and environmental disputes occur frequently in the Jeju region due to blasting. The purpose of this study is to develop a blast vibration equation considering the polymorphic characteristics of basaltic ground in Jeju. The blast vibration equation consists of a functional formula of the blasting vibration constant K that changes according to ground characteristics, and attenuation index n. The case study results in Jeju showed that if there are clinker layers, attenuation index n showed a distribution of -1.32~-1.81, whereas if there are no clinker layers, n was -2.79. Moreover, if there are no clinker layers, the frequency of blast vibration showed a high frequency band from 30Hz to 100Hz, while in rocks with clinker layers it showed a low frequency band from 10Hz to 20Hz.

***Keywords*—**Blast vibration equation, basaltic ground, clinker layer, blasting vibration constant, attenuation index.

I. Introduction

JEJU Island consists of volcanic products that have been formed between the Quaternary period in the Cenozoic and the historical era. Accordingly, the water system, mountain system, and coastal topography of Jeju have various characteristics in relation to the period and pattern of the volcanic activities that formed Jeju, and the overall topography is broadly divided into the lava plateau developed on coastal lowlands, the Hallasan shield volcano at the center part, and the monogenetic volcanoes developed on top of it. As mentioned above, polymorphic strata were made in the Jeju area due to repeated cooling and hardening of lava during the formation by a number of volcanic activities. Among the strata, clinker and scoria layers are characteristic of a volcanic island, and are difficult to interpret in terms of engineering. Due to the nature of a volcanic island, bedrock is extensively distributed, and thus excavation through a blasting method depending on construction work is frequently performed.

The problem is that the effect of blasting is very irregular and inefficient unlike inland areas due to the clinker and scoria layers that show irregularity along with vesicular basalt because of the ground characteristics of the Jeju area, and there are frequent damages to residents and environmental disputes from blasting. The clinker and scoria layers, which are extensively and irregularly distributed on the ground of the Jeju area, have engineering characteristics that are distinctly different from those of general weathered granite and sandy soil. Thus, a difficult problem occurs when relevant layers are found on construction sites.

In the Jeju area, large-scale construction work is recently active due to the explosive introduction of population and capital based on political support such as the Real Estate Investment Immigration System, but the area is experiencing expected difficulties during civil engineering work due to the polymorphic ground characteristics having the layer structure of basalt layer and clinker or scoria layer (i.e., pyroclastic deposit). To resolve this problem, a blasting vibration prediction equation for Jeju needs to be developed considering the polymorphic ground characteristics of the Jeju area. For this purpose, in this study, the result of the test blasting that had been conducted 24 times at three locations within a large-scale site renovation field in Andeok-myeon, Seogwipo, Jeju Island was compared with the blasting result of general bedrock, and was also compared with the result of the test blasting that had been performed in the past in the Jeju area.

II. Ground Characteristics of the Jeju Area

The ground of the Jeju area consists of various forms of layer structures, and thus it is difficult to predict the change in the strata even at the same region. The layer structure of basalt layer and clinker or scoria layer (i.e., pyroclastic deposit) is the result of a number of volcanic activities; and to understand the ground characteristics of the Jeju area, the characteristics of the clinker and scoria (i.e., pyroclastic deposit) need to be understood. Fig. 1 shows the polymorphic ground characteristics of the Jeju area that has a layer structure, and Fig. 2 shows the box in which the drill core of the test blasting site has been collected where the clinker layer and the rock layer are repeatedly or non-repeatedly observed.

In the case of clinker, lava erupted during volcanic eruption forms bedrock as it slowly cools and solidifies, and the upper and lower boundaries that are in contact with cold air or the ground surface rapidly cool and break. This breakage zone is called clinker. Thus, clinker mostly occurs in contact with a rock layer and has very poor condition compared to a rock layer, but it is different from weathered rock that is formed by the weathering of bedrock over a long time. A clinker layer could be found along with pyroclastic material, could have a height of several meters, and could form a number of layers between relatively hard bedrock layers due to repeated volcanic

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activities. In Fig. 3, the N value of the clinker layer shows a range of 2 times; 30cm~50 times; 5cm based on the standard penetration test (SPT) at the test blasting site. For the section consisting of rock, a test was not carried out; and the measured N value showed an abruptly high value, or showed a very low value due to the pores between rock fragments. Thus, it is very difficult to estimate the mechanical property depending on the N value.

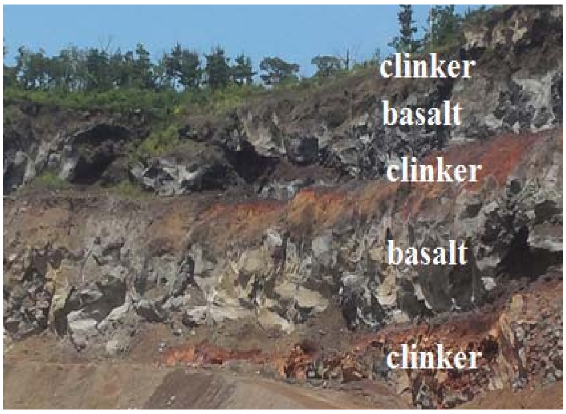

Fig. 1 Ground structures in Jeju

Fig. 2 Core drilling box of polymorphic ground

Scoria is a kind of pyroclastic material which erupts in a solid state during volcanic eruption, and it has many vesicles as volatile components escape during the release of magma into the atmosphere. It is rather heavier than pumice, and originates from basic or intermediate magma. The major composition is SiO_2+Al_2O_3+Fe_2O_3(70~80%), and it forms a topography with an angle of 30~40° due to the large angle of repose of the material. The size is less than about 6cm, and it is called ‘Song-E’ in Jeju. In addition, scoria shows a slight difference depending on the region, and is broadly classified into four types (reddish brown, yellowish brown, black, and gray) depending on the color. They show a difference in terms of chemical analysis and engineering characteristics. According to a recent study on scoria, the internal friction angle decreased as the content of Fe_2O_3 and Al_2O_3 increased among the major components of scoria, and the internal friction angles obtained from the triaxial compression test varied depending on the specimen but they were mostly between 25°~35° [1].

III. Test Blasting Data Processing and Analysis

The analysis of 177 vibration data obtained from the test blasting performed for 24 times at three locations within the site indicated that the blasting vibration prediction equation for the site was estimated to be $V_{95\%}=161.13(SD)^{-1.324}$(correlation coefficient 0.917, standard error 0.197) when the square root scaled distance(SRSD) was applied, as summarized in Table I. Also, the same site was estimated to be $V_{95\%}=326.73(SD)^{-1.446}$ (correlation coefficient 0.927, standard error 0.188) when the cube root scaled distance (CRSD). Figs. 4 and 5 show the result of the processing of vibration data using SRSD and CRSD.

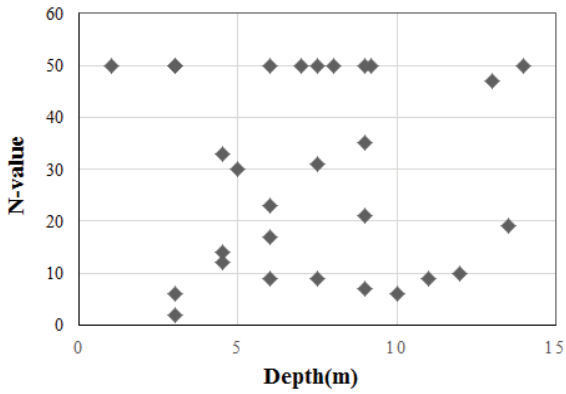

Fig. 3 Clinkers N-value by the SPT

TABLE I
Vibration Predictive Equations per Blast Sites
(SRSD, 95% Reliability)

Site	Vibration predictive equations	R	S.E	events
All	$V_{95\%}=161.13(SD)^{-1.324}$	0.917	0.197	177
Site. 1	$V_{95\%}=29.13(SD)^{-0.931}$	0.809	0.240	58
Site. 2	$V_{95\%}=471.17(SD)^{-1.584}$	0.964	0.148	66
Site. 3	$V_{95\%}=129.36(SD)^{-1.355}$	0.976	0.116	55

The regression analysis of the test blasting data showed that the correlation coefficient of the blasting vibration prediction equation for the site at a confidence level of 95% was R=0.917, indicating a relatively high correlation. To examine the response characteristics of the bedrock from the site in relation to blasting vibration, the blasting vibration prediction equation for the site was compared with the design blasting vibration prediction equation ($V_{95\%}=200(SD)^{-1.6}$) suggested by Ministry of construction and transportation (2006) [2], which is a domestic design standard. The absolute value of the n value of the blasting vibration prediction equation for the site was 1.324, which was smaller than 1.6. This indicates that blasting vibration propagates farther and the attenuation is smaller compared to inland ground. Also, when the absolute value of n is identical and the design is the same, vibration propagates farther as the location constant K increases. And, the propagation characteristics of blasting vibration was identified by comparing a blasting vibration prediction equation by site shown on Table I and a blasting vibration prediction equation according to design guideline [2] as shown on Fig. 6. Under the same condition of blasting, blasting vibration by site occurred in the order of magnitude of Site 2 > Site 3 > Site 1 at a short distance, and in the order of magnitude of Site 1 > Site 3 > Site 2 at a long distance. Although Site 1 in particular showed the lowest magnitude of blasting vibration at a short distance, it showed the smallest attenuation of blasting vibration at a long distance compared to the other two sites and a remarkably small attenuation of blasting vibration at a long distance compared to design guideline. The values of location constants of Site 1 are all low with K value of 29.13 and n value of –0.931 compared to the other two sites and design guideline. The reason seems to be that blasting energy failed to affect the failure of rocks around the blast source and was propagated to a long distance. It is thought that, without reviewing ground characteristics, as normal blast design was applied to polymorphic ground where the layer structure of clinker layers and vesicular basalt layers are developed, blasting was inefficiently carried out.

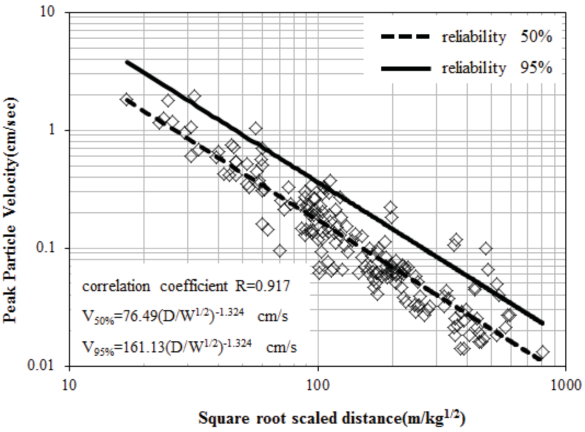

Fig. 4 Blast vibration data processing results (SRSD)

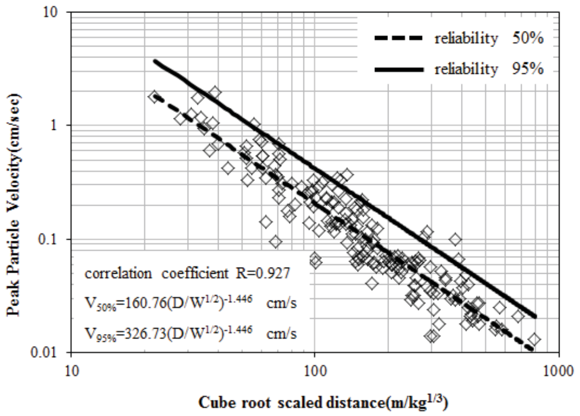

Fig. 5 Blast vibration data processing results (CRSD)

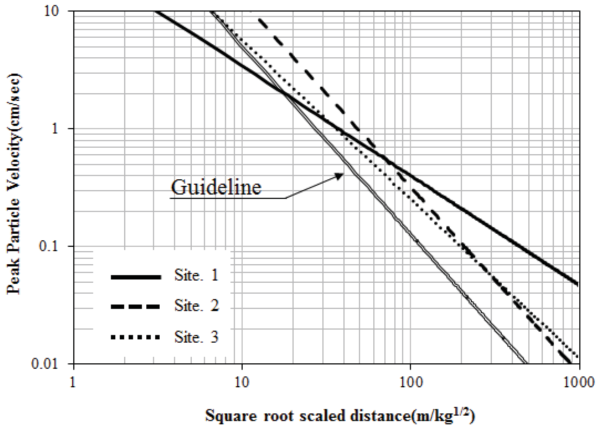

Fig. 6 Comparison of blasting vibration Characteristics

According to an analysis of the propagation characteristics of blasting vibration through comparison of design guideline and the blasting vibration prediction equations of Site 2 and Site 3 where blasting was relatively normally carried out, Site 2 seems to be the same ground with relatively little change because the difference in blasting vibration at a short distance was maintained with a slope similar to design guideline at a long distance as well; in the case of Site 3, as the distance was longer, the attenuation of blasting vibration was smaller compared with the design guideline. This seems to be the characteristics of polymorphic ground.

Frequency band of test blasting mostly ranged from 5Hz to 30Hz, centered on 10Hz to 20Hz. The blasting vibration frequency on a site with basalt and clinker layers including vesicles (e.g., the Jeju area) has a low frequency band of 10~20Hz; and to perform effective blasting, the specific charge needs to be adjusted [3].

IV. Comparison of the Blasting Vibration Prediction Equations

To examine the blasting characteristics of the polymorphic layer structure ground in the Jeju area, the test blasting analysis data in this study was compared with four test blasting data performed in the past in the Jeju area. Table II compares the blasting vibration prediction equations obtained in the Seogwipo area, Jeju Island.

For the absolute value of the attenuation index(n) on the ground with a clinker layer, No. I suggested in this study was the smallest (1.324), followed by No. II (1.39), No. III (1.582), and No. IV (1.81). When the attenuation indices were compared, No. III and No. IV had a value of 1.582 and 1.81, respectively, showing relatively good attenuation indices, and No. I and No. II where the test blasting was performed at nearby regions had a value of 1.324 and 1.39, respectively, showing relatively low attenuation indices. Thus, it is thought that blasting vibration of the target area in this study would have low attenuation and propagate farther in the case of blasting based on the same design. This vibration attenuation characteristic seems to be because the frequency of the vibration produced by the test blasting was mostly low frequency (10Hz~20Hz).

TABLE II
VIBRATION PREDICTIVE EQUATIONS ON JEJU ISLAND (SRSD, 95% RELIABILITY)

No.	Clinker	Vibration predictive equations	R	events	Remark
Ⅰ	Y	$V_{95\%}=161.13(SD)^{-1.324}$	0.917	177	Test on
Ⅱ	Y	$V_{95\%}=295(SD)^{-1.39}$	0.880	128	
Ⅲ	Y	$V_{95\%}=268.58(SD)^{-1.582}$	0.963	48	
Ⅳ	Y	$V_{95\%}=1200.6(SD)^{-1.81}$	0.967	43	
Ⅴ	N	$V_{95\%}=41354.93(SD)^{-2.793}$	0.949	15	

The test blasting frequency of No. V where no clinker layer was reported in the project section showed a high frequency band of 30Hz~100Hz, and all the four test blastings performed when a clinker layer was present showed a low frequency band of 10~20Hz. Therefore, it is thought that the low frequency characteristic of the blasting vibration is related with the ground type having a layer structure of clinker layer and bedrock. and According to the result of a study on frequency conducted by the U. S. Bureau of Mines [4], the natural frequency of a structure is affected by the number of its stories. According to the result of an investigation on the characteristics of dynamic response of a structure, the natural frequency of a center wall ranged from 12 to 20Hz. Theoretically, when the frequency of ground vibration becomes the same as the natural frequency of a structure, responsive vibrations are amplified limitlessly [5]. This phenomenon is called resonance. General one or two story houses show a natural frequency of about 10 Hz [6], and they may not be greatly affected by ground vibration of more than 10 Hz frequency even if the amplitude is large [7]. Frequency band of Jeju area ranges mainly from 10H to 20Hz similar to the natural frequency of buildings. Therefore, it seems that a continuous occurrence of blasting vibration can affect the surrounding buildings. In addition, when there is a clinker layer within the drilling depth in the case of boring, collapse of the borehole wall occurs frequently. Blasting could be inefficient due to the lack of charge length or stemming column length as the boring depth cannot be sufficiently secured, and thus care needs to be taken.

In the case of blasting on the ground that is difficult to predict as rock layer and pyroclastic deposit (clinker or scoria) form a repeated or non-repeated layer structure (e.g., the Jeju area), it needs to be thoroughly examined if a clinker layer exists within the boring depth for blasting. If there is a clinker layer, a measure for securing the blasting drill-hole depth is required first. A number of problems relevant to blasting could be resolved when the application of blasting pattern and blasting method is carefully approached in order to secure the amount of rock breakage through blasting considering that the blasting vibration is low frequency.

V. CONCLUSION

To develop a blasting vibration equation considering the characteristics of polymorphic basalt ground, the layer structure of the ground in the Jeju area was analyzed, and a total of 177 test blasting data (24 times at three locations) obtained from a large-scale site renovation work were analyzed. The results of this study are as follows.

1) The ground in the Jeju area formed by volcanic activities had a layer structure where basalt layer and clinker layer are repeatedly or non-repeatedly observed. The N value of the clinker layer based on the standard penetration test (SPT) was in the range of 2 times; 30cm~50 times; 5cm, and thus it is very difficult to estimate the mechanical property.
2) The analysis of the 177 vibration data obtained from the test blasting indicated that the blasting vibration prediction equation for the site was estimated to be $V_{95\%}=161.13(SD)^{-1.324}$ (R=0.917, S.E=0.197) when SRSD was applied, showing a smaller attenuation index than the domestic standard.
3) The vibration frequency from blasting on the ground with porous basalt layer and clinker layer was distributed in a low frequency band of 10~20Hz, and it is thought that the clinker layer, whose mechanical properties are difficult to predict, affected the blasting vibration frequency.
4) Considering the occurrence pattern of each layer in the layer structure, a prediction model for the blasting vibration equation needs to be developed and applied from the planning stage. Also, continuous studies for resolving many problems relevant to blasting are required.

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