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Consideration on setting of detonation time interval of control blast

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ABSTRACT: In NATM tunnel construction, Noise, low frequency sound, vibration propagates to the surroundings by blasting excavation. Although these are instantaneous phenomena of several seconds a day, they have a large influence on neighboring houses, therefore, countermeasures are often used. In the problem of blasting vibrations, countermeasures are taken by control blasting to change that increase the number of detonations, but it is known that a high reduction effect can be exerted particularly by using an electronic delay detonator. Normally excavation is carried out by detonation of about 100 holes per 10 steps using an electric detonator. In the case of using an electronic delay detonator excellent in accuracy of control of time intervals, since it detonates in one hole per step, the influence of ground vibration can be suppressed by reducing the amount of explosive per step. In recent years, electronic delay detonators that can set and change the explosion time interval have been developed according to site geology such as ground geology and rock quality of vibration propagation routes. In this report, test blasting using an electronic delay detonator capable of changing the detonation time interval at the site was carried out, and the effect and control blasting utilization method were examined. From the results of test blasting, it has been shown that more effective vibration reduction is possible by setting the detonation time interval of the electronic detonator according to the ground surface hardness in the vicinity of the maintenance target and the geological condition of the propagation route. Furthermore, in order to improve the vibration reduction effect, we grasp that it is important to grasp the dominant frequency in the maintenance target and the propagation route. Therefore, we examined the method of grasping the dominant frequency and discussed the method of determining the detonation time interval and the method of determining the optimum range of application of control blast.

1 INTRODUCTION

Tunnel construction by drilling and blasting based on the New Australian Tunneling Method (NATM) generates instantaneous noise, low frequency sound, and repeated vibrations that can last for several seconds. Although this is instantaneous and occurs only several times per day, a significant sonic influence will be exerted on the neighboring inhabitants. Therefore, countermeasures are considered in several scenarios (Japan Explosives Industry Association 2002).

The blasting vibration can be reduced using controlled blasting based on an appropriate detonation method. For instance, if hole-by-hole detonation is possible, the amount of explosives that are required per blast can be reduced through the application of an electronic detonator (Tanaka 1992) over approximately ten precise detonation intervals. Recently, electronic detonators that can set and change the on-site detonation interval (Iwano 2014) have been developed, enabling the duration of blasting to be easily altered in response to the site conditions.

In this study, we assess the usage of controlled blasting based on the analysis of the results of test blasting in which an electronic detonator was used to alter the on-site detonation interval.

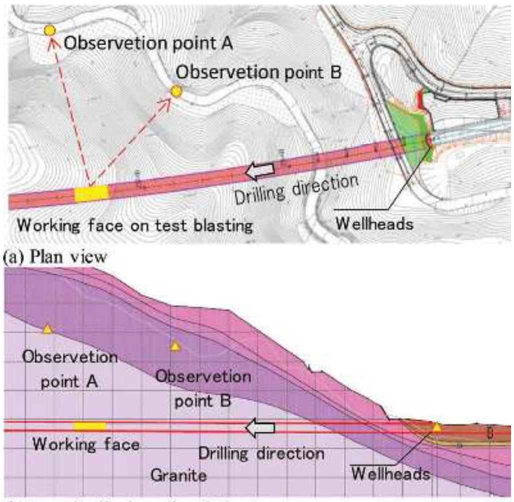
2 TEST BLASTING USING ELELCRONIC DELAY DETONATORS

2.1 *Site situation*

Test blasting was conducted during tunnel construction in the Fukuoka Prefecture. Although the sediment-like decomposed granite soil and severely weathered granite are distributed near the mouth of the tunnel, fresh granite (CM to CH class) is observed to fill the inner part of the tunnel. This tunnel exhibits several cracks with weathering in some parts; however, hard rocks that do not require steel support account for approximately 85% of the total volume. The tunnel face that was used for performing test blasting comprised fresh and hard granite and appeared to be tightly closed with only small cracks.

2.2 *Measurement conditions*

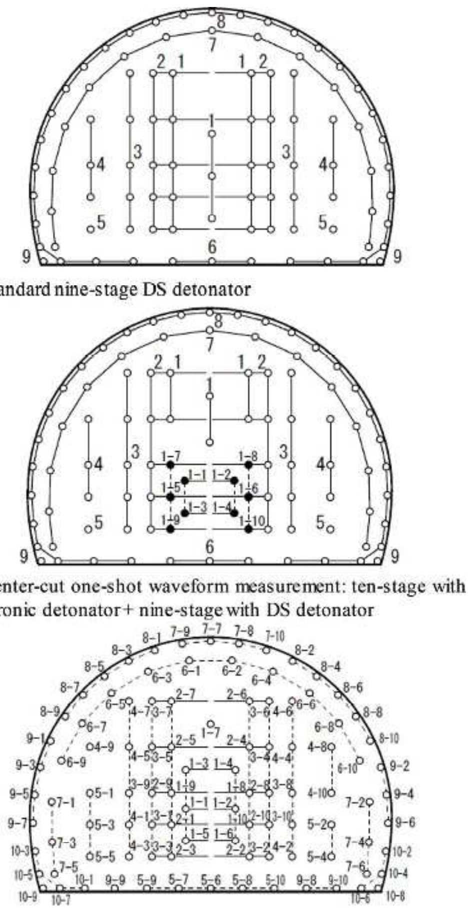
The vibration velocity was measured at the two locations (A and B) that are depicted in Fig. 1. Test blasting was conducted in the standard CI-pattern section depicted in Fig. 2 and involved the detonation of an electric detonator that was commonly used in the



(a) Plan view

(b) Longitudinal sectional view

Figure 1. Vibration measurement positions



a) Standard nine-stage DS detonator

b) Center-cut one-shot waveform measurement: ten-stage with electronic detonator+ nine-stage with DS detonator

c) Hole-by-hole detonation using an electronic detonator

Figure 2. Blast pattern diagram

field (hereafter referred to as the nine-stage DS detonator), single-shot detonations for evaluating the resulting waveforms, and hole-by-hole detonation using an electronic detonator. The detonations were applied in the pattern and positional relations that are depicted in Tables 1 and 2, respectively. As will be detailed in Section 2.4, the detonation interval of the electronic detonator was determined based on the vibration prediction results that were obtained from the single-shot detonation waveform.

2.3 *Single-shot detonation test results*

The single-shot detonations were conducted in four stages (0.6kg/hole) in an auxiliary center cut that was followed by detonations that were conducted in six stages (1.0kg/hole) in a deep center cut at 300ms intervals. Further, the vibration velocity waveforms that are obtained at observation points A and B are depicted in Fig. 3. The fourth stage vibrations are not recorded in Fig. 3 owing to the cutoff at which rocks were blown off around the blast holes. Detailed waveforms with large velocity amplitudes and frequency characteristics that are produced by the fifth and seventh stages are depicted in Figs. 4 and 5, respectively.

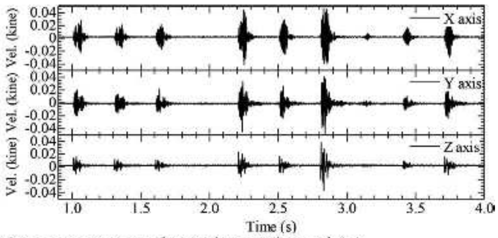
Although the velocity amplitudes that are received from the center-cut single shots vary significantly, the waveform properties at each measurement point are observed to be considerably consistent; further, the frequency characteristics also follow a similar trend. This demonstrated that the coincident measurement points and propagation paths resulted in high reproducibility of the waveform even though the velocity amplitudes that were produced at each

Table 1. Relation between the detonator type and charge dosage

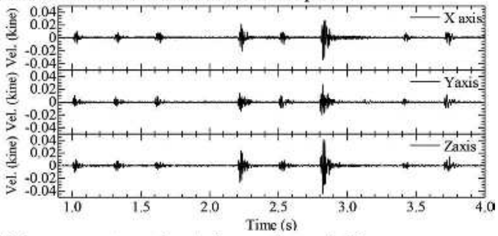
Standard DS electric detonaor			Electronic detonator									
			Center cut		32-ms intervals		8-ms intervals		20-ms intervals		13-ms intervals	
Number of detonators	Number of holes	Amount of charge (kg)	Number of holes	Amount of charge (kg)	Number of holes	Amount of charge (kg)	Number of holes	Amount of charge (kg)	Number of holes	Amount of charge (kg)	Number of holes	Amount of charge (kg)
DS1	13	13	4	2.4	10	8.8	9	8.4	10	8.8	9	7.8
DS2	10	10	6	6	10	12	10	10.4	10	10	10	10
DS3	10	10			10	10	10	10	10	10	10	10
DS4	7	5.6			10	10	10	10	9	9	10	10
DS5	1	0.8			10	10	10	10	10	10	10	10
DS6	4	3.2			10	10	10	10	10	10	10	10
DS7	17	13.6			10	10	10	10	10	10	10	10
DS8	31	29.8			10	10	10	10	10	8.6	10	9.8
DS9	2	2			10	10	10	10	10	10	10	10
					10	10	10	10	10	10	10	10
Total	95	88	10	8.4	100	100.8	99	98.8	99	96.4	99	97.6

Table 2. Distance between the observation point and the working face

Blasting method	Tunnel distance (m)	Distance of observation point A	Distance of observation point B
Standard DS electric detonator	211.4	126.2	94.0
Center cut by the electronic detonator	218.9	124.9	98.8
Electronic detonator; 32ms, 8ms interval	224.9	124.1	102.9
Electronic detonator; 20ms, 13ms interval	232.4	123.5	108.3

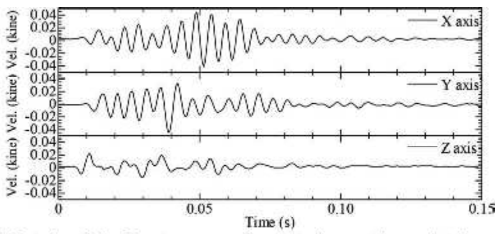


a) Measurement results at observation point A

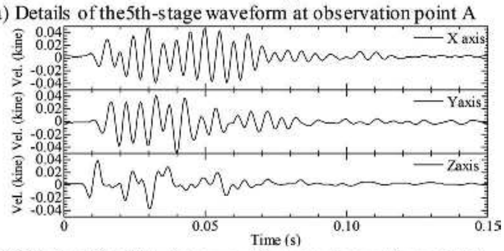


b) Measurement results at observation point B

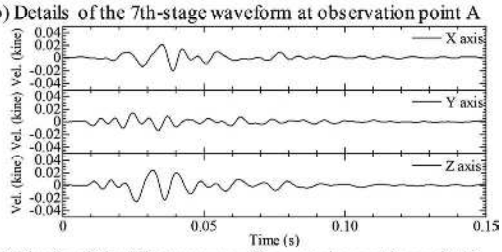
Figure 3. A time-series single-shot blasting waveform with ten-stage center cut



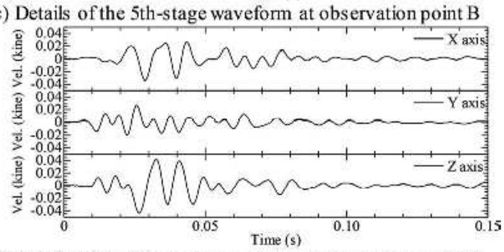
a) Details of the5th-stage waveform at observation point A



b) Details of the 7th-stage waveform at observation point A

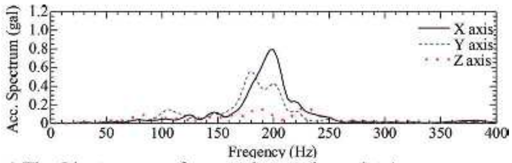


c) Details of the 5th-stage waveform at observation point B

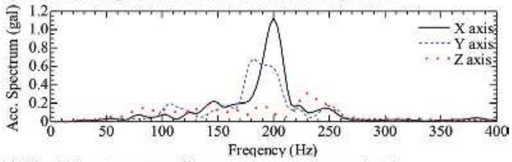


d) Details of the 7th-stage waveform at observation point B

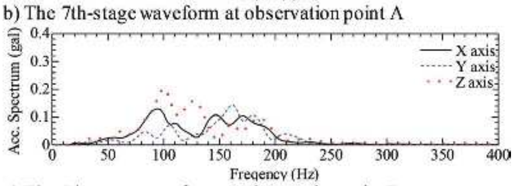
Figure 4. A time-series single-shot blasting waveform



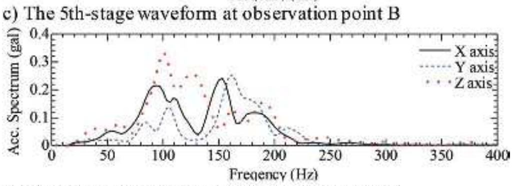
a) The 5th-stage waveform at observation point A



b) The 7th-stage waveform at observation point A



c) The 5th-stage waveform at observation point B



d) The 7th-stage waveform at observation point B

Figure 5. Frequency characteristics of the single-shot waveform

stage changed significantly de-pending on the rock conditions, such as hardness, cracking, and distance from the free surface.

2.4 *Prediction method using the result of single-shot blasting measurement*

Based on the results that were obtained from the consecutive blasting of cross sections in the single-shot tests, vibrations were predicted by superimposing the blasting waveforms that were measured in arbitrary time intervals over the entire course of the blasting.

For example, to predict the result of a case in which the fifth-stage blasting waveform obtained at observation point A was produced over 100 stages of blasting based on time intervals of 20ms, a time history waveform was created by overlaying the measured single-speed velocity waveforms over 100 stages with a delay of 20ms. Acceleration was further obtained by differentiating the resulting velocity waveform with respect to time, and, finally, a sensory correction based on the JIS (Japan Industrial Standard 2014) was added to obtain the predicted vibration level.

Figure 6 depicts the results of the predictive effort at each time interval. In the prediction process, the maximum value of the velocity, which is assumed to be a composite vector, and the maximum vibrational level in the vertical direction are extracted and organized over each time interval.

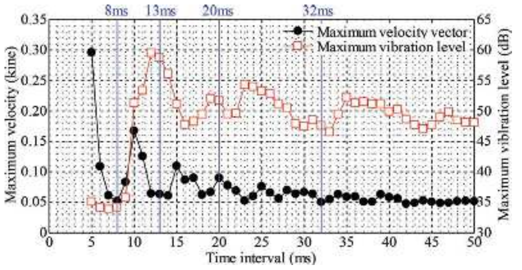


Figure 6. Prediction results for the 5th-stage waveform at observation point A

It can be observed from Fig. 6 that the maximum velocity and vibration level change significantly with the time interval and that the relations between the magnitudes of these factors are inconsistent because the frequency characteristics of the vibrational level are rectified based on the human sensory characteristics (sensory rectification).

This method can result in errors in the prediction of actual blasting results owing to the vibrational amplitude differences between the blast holes based on bedrock and other characteristics as well as the phase differences (differences between the transmission time) that are caused by the separation (propagation distance) between the working face and the maintenance target; the separation is observed to be a maximum of approximately 10m depending on the position of the blast hole. These prediction errors are described in the section related to the measurement results.

Based on the results of Fig. 6 and by focusing on the time intervals, we examined the following cases: (1) when the maximum velocity decreased over time intervals of 32ms, which was close to the time interval (30ms) of a conventional electronic detonator; (2) when the interval was as small as 8ms, which was when the maximum velocity decreased; and (3) 13ms or 20ms intervals in which the vibration level was characteristically predicted to be either small or large, respectively.

2.5 *Results of test blasting*

The velocity waveform that is measured at observation point A is depicted in Fig. 7. Further, Fig. 8 depicts the same result that is converted to acceleration and the undergoing frequency analysis. This figure also depicts the second-round result of the nine-stage DS detonator in the upper row and the result of the electronic detonator with an interval of 20ms in the lower row. Furthermore, the plot in Fig. 9 compares the measurement results of test blasting with the predicted results for the time interval in Section 2.4 (Fig. 6).

The blasting of a DS detonator that exhibits a high vibrating velocity in the center cut, as depicted in Fig. 7, when compared with the hole-by-hole

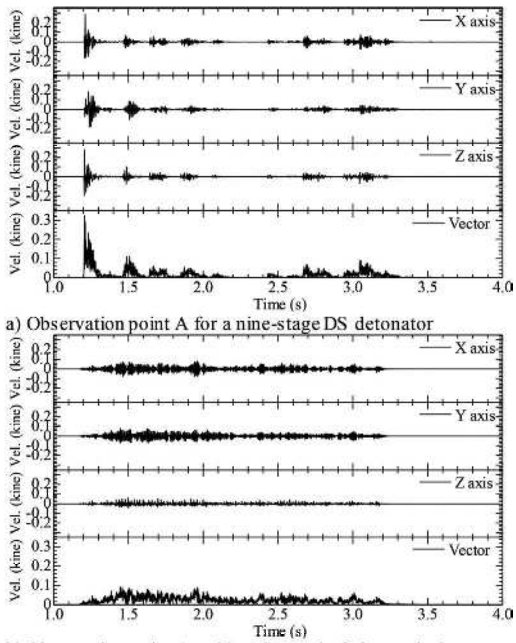


Figure 7. Time series of the vibration velocity waveform

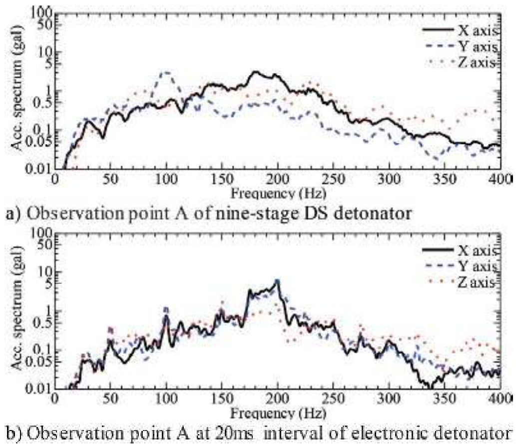


Figure 8. Frequency characteristics

deto-nation of an electronic detonator, including the effect of the decreased minimum resistance line by the auxiliary center cut, can considerably reduce the vibration. The frequency characteristics in Fig. 8 exhibit that the maximum values are generated at n times the fundamental frequency of 50Hz (50, 100, 150Hz), corresponding to a time interval of 20ms as described in the section related to the prediction methods. Further, it also exhibits that the components possessing a frequency of less than 50Hz, which human body feels easy, considerably influence the vibration level and are small as compared to the DS detonators. Furthermore, Fig. 9 depicts

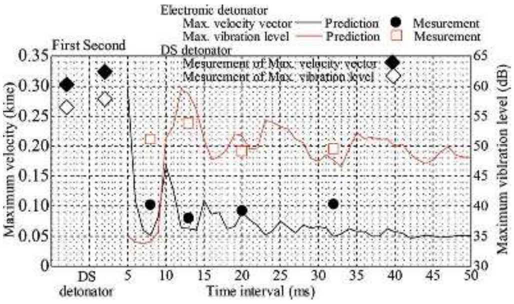


Figure 9. Comparison between the prediction and measurement for the fifth stage waveform at observation point A

that although there is a prediction error, it changes by up to twice at the maximum velocity and at approximately 5dB on the vibration level depending on the time interval of the electronic detonator. This confirms that it is necessary to set a detonation time interval depending on the conditions of the site.

Here, as previously mentioned, the prediction error can be attributed to the phase difference (difference in the transmission time) between blast holes, which is caused by the difflerence in both the vibration amplitude and the separation distance (propagation distance) between the working face and maintenance target. The observation point A is located adjacent to the working face, and the propagation distance exhibits a difference of approximately 10m, which corresponds to the width of the tunnel. Assuming that the elastic wave velocity is 3.0km/s, the transmission duration will deviate by approximately 3ms (0.003 s) when the difference in distance becomes 10m. Therefore, a phase difference of 1–3ms is always observed depending on the position of the blast hole, and the prediction error, which is dependent on the difference in the propagation distance, becomes particularly large if the detonation time interval is set to be short. To verify the influence of the phase difference, Fig. 10 compares the predicted and measured results of velocity waveforms for the detonation at 32ms intervals. From the detailed diagram depicted in Fig. 10(b), although the waveform properties are similar, it can be confirmed that the distance between the sections at which various waveforms overlap varies and that the variation in vibration amplitude leads to prediction error.

3 CONTROLLED BLASTING WITH ELECTRONIC DETONATORS

3.1 *Points to be noted while setting the time interval*

To optimally predict the time interval for controlled blasting and while considering the soil properties of a maintenance target, it is necessary to grasp the maintenance objective and the dominant frequency

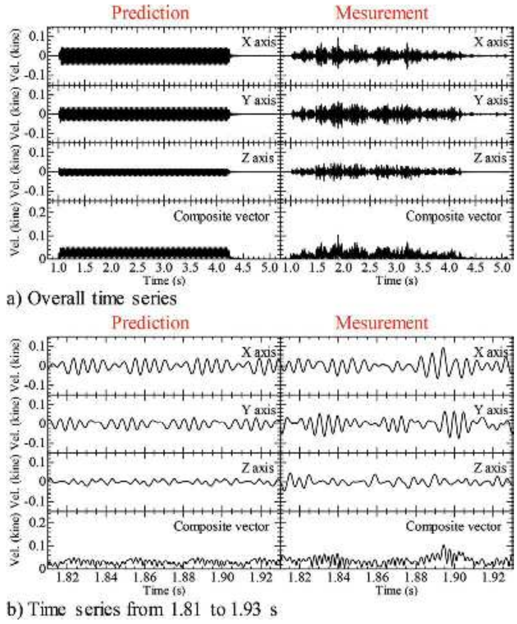


Figure 10. Comparison between the prediction and measurement of electronic detonator at a 32ms interval

of the maintenance target or propagation path. The maintenance objectives should be controlled by speed if the maintenance target is a structure, by the vibration level if it is a resident, and by displacement if it is a factory with precision equipment, including electron microscopes; thus, different setting methods should be used to maximize the reduction effect. Furthermore, because the vibration waveform of a single-shot explosion is highly reproducible, it is possible to reduce physical quantities, such as velocity, if the detonation time interval can be set, thereby ensuring that opposite phases can be observed between the overlapping vibration waveforms. To identify the detonation time interval between the points at which opposite phases are observed, the dominant frequency of the vibration must be known. However, if the vibration level has to be managed, it should be noted that the result that is expected from a physical quantity cannot be achieved while converting the acceleration to dB owing to the interference by changes in characteristics because of the time constant and sensory correction filter.

The factor that is used for setting the optimal time interval is basically the time interval between successive detonations that result in opposite phases with respect to the dominant frequency of the maintenance target or the propagation path. Further, assuming that the vibration waveforms of a single-shot explosion are similar, we can reduce the amplitude by making the waveforms of opposite phases to overlap with each other on a 1/2-wavelength interval of the vibration waveform, as depicted in Fig. 11. The interval that

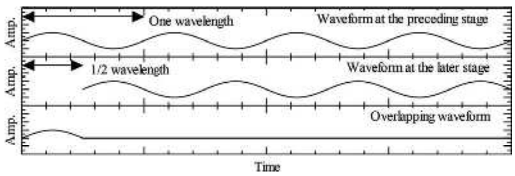


Figure 11. Conceptual diagram of the interval for creating an opposite phase

causes the opposite phase to be achieved is not only the 1/2-wavelength interval but also the 3/2-, 5/2-wavelength intervals, and so on. This indicates that the vibration waveforms are superimposed at intervals of 2/n (n = 1, 3, 5....) times the dominant frequency.

If two or more dominant frequencies are to be maintained or if the dominant frequencies are dependent on the direction, the basic approach sets a dominant frequency based on the detonation time at a non-dominant frequency by considering the frequency characteristics in each direction.

However, it is necessary to consider that the blasting effect exhibits a considerable variation if the time interval is considerably short (Hiroo 1958). For example, as the time interval decreases, the amount of energy per unit time increases and the blasting effect improves; further, cleaning may require a considerable amount of time because a significant period of time will be required for the stones to move over an extensive scattering angle range. It may also be possible that blasting will occur in the subsequent stage before the formation of a clear space by the preceding blasting and that crushing is not obtained as planned. In addition, if the time interval is considerably short, the propagation distance of an easy shot varies by approximately several meters depending on the position of the blast hole. Therefore, it is possible that the state of the non-reverse phase continues and that the reduction effect is reduced. Thus, the basic approach would be to increase the detonation time interval by as much as possible.

3.2 *Applicable range of optimum-controlled blasting*

Compared with the normal blasting drilling, in controlled blasting by an electric detonator, it is assumed that the propagation path to the maintenance object alters because of the progress of tunnel face drilling and that the dominant frequency of the vibration waveform also changes. In this case, because the dominant frequency is dependent on the time interval and has been well understood, we can continue to conduct blasting by monitoring the change in the dominant frequency on the propagation route and by changing the time setting for every shift of 10 Hz.

When the dominant frequency of the maintenance target is high, there is a possibility that such a high frequency of the object cannot be detected because of the effect of the dominant frequency that originates from the time interval. In this case, it would be possible to perform four to ten stages of blasting at intervals of 300ms in the center cut (including auxiliary center cut) and the remaining easy shot at the current time interval. Further, the time interval can be reconsidered through predictive analysis by assuming one-shot waveform of the center-cut area. In addition, if we measure the vibration waveform of a single-shot detonation, we can also perform predictive analysis of approximately 10 stages of blasting using ordinary electric detonators and multistage blasting with MS + DS detonators; thus, we can proceed with construction while verifying (on an ongoing basis) the applicable range of the controlled blasting with an electronic detonator.

4 CONCLUSION

Based on the results of test blasting, we demonstrated that it was possible to effectively reduce the vibration by optimizing the detonation time interval of an electronic detonator by considering the site conditions. Further, we exhibited that it was important to confirm the dominant frequency in the maintenance target and the propagation path for obtaining the vibration-reduction effect. We also discussed a method for determining the detonation time interval and the optimal range of controlled blasting.

REFERENCES

Japan Explosives Industry Association. 2002.3. Blasting case collection, p. 80.

Yoshiharu Tanaka, Katsuzo Teramoto, Toshiyuki Ichijyo, Keiichi Sato, Masaaki Yamamoto, Kenichi Aiko. 1992.2. Discussion on blasting experiments using EDD, *Proceedings of the 24th symposium on rock dynamics, pp.* 390–394.

Keita Iwano, Toshiyuki Koshikawa, Kinya Kuriki, Takayuki Inukawa, Katsunori Fukui., 2014.12. Blasting for the reduction of environmental load under the residential area using high-precision electronic detonators, *Reports of Tunnel Engineering, Vol. 24, I-35.*

Japan Industrial Standard. JIS-C-1517 (2014). Vibration level meters: Measuring instruments used in transaction or certification.

Ito Hiroo. 1958.3. Blasting tests using electric detonators with various time intervals, *Journal of Mining Institute of Kyushu, Vol. 26, No. 3 , pp.* 133–136.